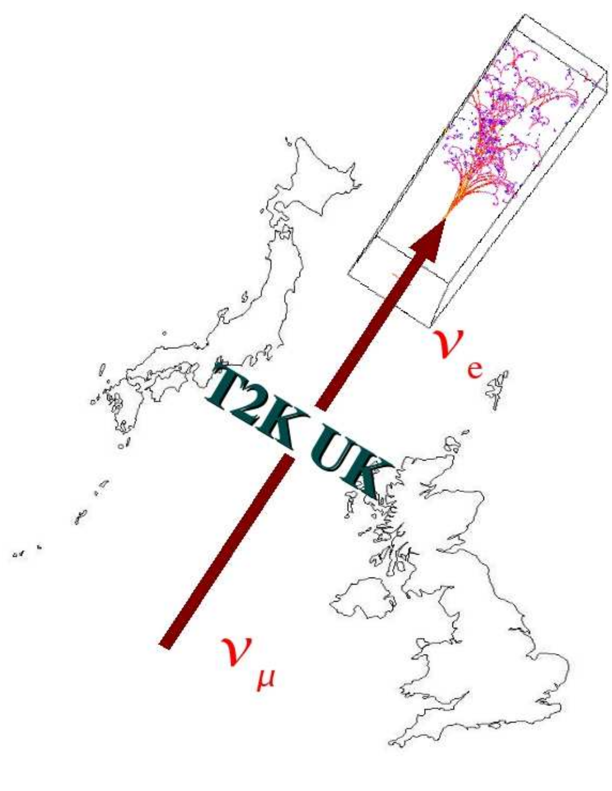
UK Contributions to the T2K Experiment: Case for Support

January 25, 2006



Abstract

The T2K experiment will study oscillations of an off-axis muon neutrino beam between the J-PARC accelerator complex and the Super-Kamiokande detector, with special emphasis on measuring the unknown mixing angle θ_{13} by observing the sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillation. The UK groups of the T2K collaboration propose to deliver a fully optimised electromagnetic calorimeter for the T2K near detector at 280m in addition to making major contributions to aspects of the J-PARC neutrino beam.

A. Grant, A. Muir
CCLRC, Daresbury Laboratory, Daresbury, WA4 4AD, UK

P. Dornan, G. Hall, M. Raymond, I. Taylor, Y. Uchida, A. Vacheret, F. van Schalkwyk,
J. Walding, D. Wark, M. Wascko
Imperial College London, London, UK

I. Bertram, A. Chilingarov, A. Finch, L. Kormos, P. Ratoff
Lancaster University, Lancaster LA1 4YB, UK

C. Chavez, J. Fry, N. McCauley, D. Payne, P. Sutcliffe, C. Touramanis
The University of Liverpool, Oliver Lodge Laboratory L69 7ZE, Liverpool, UK

A. Bevan, F.Di Lodovico, R.A. Owen
Queen Mary, University of London, London E1 4NS, UK

J. Butterworth, C.J. Densham, R. Edgecock, M. Fitton, V.B. Francis, R. Halsall, P. Loveridge,
T.C. Nicholls, G.F. Pearce, M. Rooney, A. Weber, M.L. Woodward
CCLRC - Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, UK

C.N. Booth, S.L. Cartwright, E.V. Korolkova, M.L. Navin, L.F. Thompson
University of Sheffield, Sheffield S3 7RH, UK

G.J. Barker, S. Boyd, R. Bridgland, T.J. Gershon, P.F. Harrison, A. Lovejoy, B. Morgan
Warwick University, Coventry, CV4 7AL,UK

Contents

Chapter 1

Executive Summary

A combination of experiments worldwide have now demonstrated that neutrinos have mass and oscillate, which is the first confirmed evidence for physics beyond the Standard Model. Critical questions remain to be answered, however, with the next major target: the measurement of the third mixing angle θ_{13}. A non-zero value for θ_{13} is a prerequisite for any terrestrial demonstration of CP violation in neutrino oscillations, which is the ultimate goal of oscillation physics (and the principle justification for building a Neutrino Factory). The T2K experiment will represent a very substantial step forward in our ability to probe neutrino oscillations. The most intense artificial neutrino beam ever constructed will be produced at the newly built JPARC facility on Japans east coast, and directed underground to the refurbished Super-Kamiokande detector 295 km away. Phase I of the experiment, with a proton beam now expected to exceed 0.75 MW and Super-Kamiokande, will extend our sensitivity to θ_{13} by a factor of about ten. A proposed second phase of the experiment, with a 4 MW beam and a possibility of building a 1 megaton Hyper-Kamiokande experiment, would extend this sensitivity even further, and also begin to have sensitivity to CP violation if θ_{13} is not far below the existing limit, by comparing running with neutrinos and anti-neutrinos. The T2K experiment has developed into a major international collaboration, with collaborators from at least 10 countries, fewer than half of whom are Japanese. The UK group is numerically the largest in Europe (where there are other groups in France, Spain, Italy, Switzerland, and interest in Germany). UK physicists have assumed roles in all the governing bodies of the collaboration, and the UK has already achieved high and growing visibility in the experiment.

The accuracy and reliability of the experiment depends crucially on near detectors which characterize the neutrino beam and its interactions before any oscillations take place. The UK group has obtained a major role in the specification, design, construction, and operation of the near detectors. We here propose that PPARC fund our work on the near detectors, which is centred on building a tracking electromagnetic calorimeter (ECAL), including the implementation of a relatively new type of photosensor (called here an AMPD to avoid confusion with its many proprietary names, the most familiar of which is the SiPM) and the associated electronics, DAQ, and engineering. Just as important to the experiment (and also of great strategic interest to the UK HEP programme as a whole) is our proposed involvement in designing and building the neutrino beamline, including a central role in the pion production target and beam dump.

The complete cost to PPARC under FEC, including manpower, equipment, travel and working allowance but not contingency, of the work proposed herein is £17.5M, of which £3.8M is for equipment, £4.4M is for non-PPD CCLRC manpower, £5.9M is for existing RG and PPD posts, and £1.5M is for new posts, and the rest is travel, Common Fund, and other costs. This significant sum has increased from the one discussed in our seedcorn proposal mostly because of changes in accounting that have come in under FEC and because this proposal is for four years (April 1, 2006 to March 31, 2010) rather than for the three years assumed in that proposal. A companion T2K Bridging Funding Proposal outlines what funds sought here would be necessary before the end of calendar 2006 to keep the UK group on schedule to provide its proposed deliverables to T2K while PPARC reviews this proposal. The rather complex interactions assumed between this grant and the current and future Rolling Grants are discussed in the Management Work Package.

Management - proposals and grants

The complicated relationship between this proposal, the associated bridging proposal, the current and new rolling grants and the CCLRC SLA merits some further description.

The academic and core research staff of the universities along with their core engineers and technicians will be funded via the PPARC experimental rolling grants. However, the project RAs at the universities will be funded through the T2K project grant. The CCLRC staff will be funded via the Service level agreement with PPARC.

The bridging proposal is necessary because the seed corn funding that we were awarded for the development of the full proposal will run out before the full proposal will have been processed by PPARC. A cessation of funding for the ongoing work on the beam, target and ECAL design which involves a significant amount of CCLRC engineering effort would have a serious detrimental effect on the overall project. The bridging proposal funding will allow this work to continue without interruption and enable us to maintain our construction schedule for the UK contributions to the T2K experiment.

A large part of the university staff expenditure (the core academic and research staff, engineers and technicians) will be incurred on the new experimental rolling grants that will commence on 1st October 2006. However, there are a small number of current rolling grant posts that are involved in the project (e.g. RAs at Imperial College and Lancaster) and these have already been rolled forward to 30th September 2008 (in the 2004 grants round). The remainder of the university staff (the project RAs in this proposal) will not be in rolling grant posts. The Rutherford and Daresbury Laboratory staff will be funded via the SLA between PPARC and CCLRC. Those engineers who are currently working on the project (mainly on the beam and target, but also some design effort for the ECAL) have been supported by the seed corn funding and it is intended that the bridging fund will enable them to continue to work on the project until the start of the T2K project grant.

Chapter 2

Introduction

2.1 Introduction - Neutrino Oscillations

The last 15 years have been an increasingly exciting time in the field of neutrino physics. Neutrino oscillations were shown to be the most likely explanation of the long-standing failure to observe the predicted flux of solar neutrinos when first the SAGE[1] and then the GALLEX[2] gallium radiochemical solar neutrino experiments reported a significant suppression of the observed flux of low-energy solar neutrinos. Neutrino flavour change was convincingly demonstrated by the SNO experiment[3], and then confirmed as oscillations by KamLAND[4]. Meanwhile observations of atmospheric neutrinos by Super-Kamiokande[5] (backed up by measurements by the Soudan II[6] and MACRO[7] experiments) showed a suppression of the atmospheric muon neutrino flux with zenith angle which was a perfect fit to oscillations, a finding confirmed by the K2K long-baseline experiment[8]. We thus have two confirmed observations of neutrino oscillations, thereby proving that neutrinos have mass. This is the first convincing demonstration of physics beyond the Standard Model, the implications of which are considerable. A third claim for neutrino oscillations by the LSND experiment[9] was not confirmed by the KARMEN experiment[10], which had similar sensitivity. In a minimal model with neutrino oscillations between the three known flavour states the LSND observation is inconsistent with the other experiments. It is currently being checked by the MiniBooNE experiment at Fermilab[11]. If against expectation the LSND result is confirmed by MiniBooNE, it would actually make the measurements planned in this proposal even more important, although we will not pursue this argument further here.

Neutrino oscillations may shed light on physics at scales far beyond the reach of terrestrial accelerators[12]. The mass they imply has implications for cosmology[13] and astrophysics[14], and the combination of these opens the exciting possibility of an explanation for the origin of the matter-anti-matter asymmetry in the universe[15]. A prerequisite for understanding these implications, however, is that we gain a thorough understanding of the phenomenon itself. A minimal neutrino oscillation model adds seven new parameters to the Standard Model; the masses of the three neutrino mass eigenstates, and the three mixing angles θ_{ij} and one CP violating phase δ of the MNSP mixing matrix[16]. The absolute masses have no effect on oscillations, as the actual observables are the differences of the squares of the masses Δm^2_{ij}. Vacuum oscillations do not depend on the sign of the mass differences, leaving an ambiguity in the ordering of the states which can only be resolved by observing matter effects (which do depend on the sign of the Δm^2_{ij}). Existing experiments have measured the angles θ_{12} and θ_{23}, the value of Δm^2_{23}, and the value and sign of

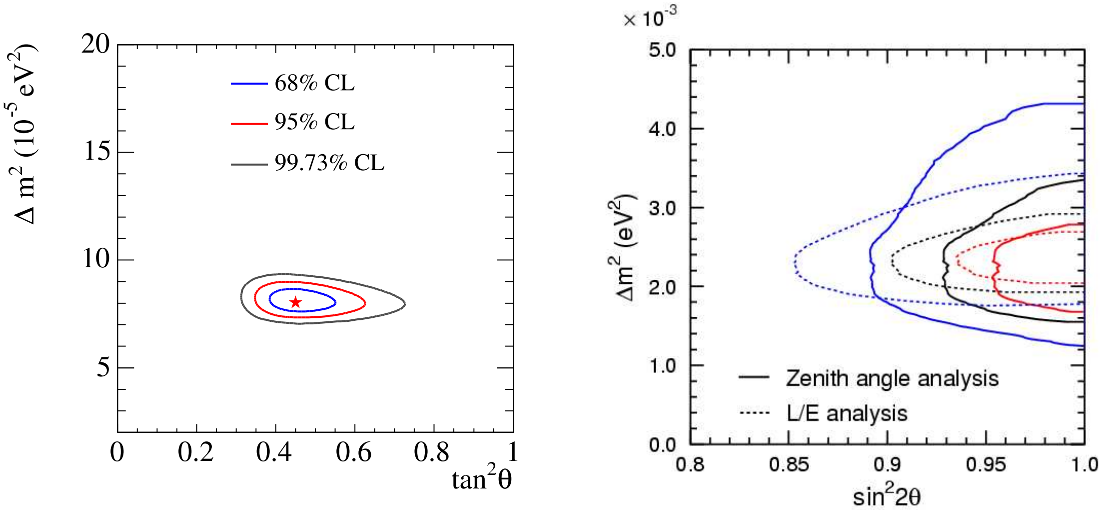


Figure 2.1: Allowed regions for 2-neutrino mixing parameters for solar+KamLAND (left figure) and from the latest Super-K analysis (right figure). Note that the oscillations in the right figure are vacuum oscillations, and hence a plot in $\tan^2\theta$ would be symmetric about 1 (i.e., the sign of Δm^2_{23} is not determined).

Δm^2_{12} (see Fig. 2.1). That leaves a number of unanswered questions still to be addressed[1]:

- What is the value of θ_{13}? So far we only have limits derived from the reactor experiments[17] at Chooz and Palo Verde, from solar neutrino experiments, and from Super-K — $\sin^2\theta_{13} < \sim 0.14$.
- Is $\theta_{23} = \frac{\pi}{4}$, i.e., is 2-3 mixing maximal? We currently know that $\sin^2\theta_{23} > \sim 0.9$, and more precision is crucial in constraining neutrino mass models.
- What is the sign of Δm^2_{23} (or Δm^2_{13}) , which is also of great interest to model builders?
- Is there CP violation in neutrino oscillations, i.e., is $\delta \neq 0$?

2.2 The T2K Experiment

A combination of existing and planned facilities in Japan offer an almost ideal fit to the needs of a next generation neutrino oscillation experiment looking for sub-dominant $\nu_\mu \to \nu_e$ oscillations. The J-PARC facility, being built at Tokai on Japan's east coast, is a joint project of the Japanese Atomic Energy Research Institute (JAERI) and KEK, originally intended primarily for neutron scattering and high-energy nuclear physics. The presence of a high-power proton synchrotron (PS) led to the idea of producing an intense ν_μ beam aimed at the Super-K detector by the conventional technique of producing charged pions by colliding the proton beam with a target and collecting and focusing the pions (selecting one charge, usually positive, in the process) into a decay volume. The resulting decays produce beams of ν_μ and muons, and the decay volume length is adjusted

[1]Of course there are other critical questions in neutrino physics (are neutrinos their own anti-particles, and what are the absolute neutrino masses?), but these cannot be addressed in oscillation experiments.

so that most of the pions but as few of the muons as possible decay before they reach the beam dump at the end. This experiment, called T2K, has a number of major advantages in the search for sub-leading oscillations:

- Any measurement of sub-leading oscillations needs the maximum possible flux to maximise the statistical sensitivity. To first order the neutrino flux depends on the beam power, and the J-PARC beam will be the highest-power pulsed proton beam ever built. In Phase I the design now calls for 1.34 MW of protons on target, while a Phase II upgrade is planned to 4 MW after $\sim$5 years.

- Given the known oscillations parameters and the distance from J-PARC to Super-K (295 km), the first oscillation maximum will be for neutrinos with energies of about 600–800 MeV, right at the maximum of the cross-section for the quasi-elastic reactions that permit accurate determination of the neutrino energy (needed for the precise measurement of θ_{23} and Δm^2_{23}).

- This advantage will be enhanced by using an off-axis beam geometry[18], which gives a higher flux at the oscillation maximum, a more sharply-peaked neutrino energy spectrum, and a smaller intrinsic beam ν_e contamination.

- The far detector, Super-K, is almost ideal for this measurement, which requires a large, well understood detector which can cleanly distinguish the signal ν_μ's, ν_e's, and background π^0's produced by neutral current interactions. Super-K is (and will be for some time) the world's largest underground detector, and has been the subject of intense study for many years and thus has very well understood energy resolution, and offers excellent and well-understood particle ID capabilities for the low-multiplicity events at these energies. Of course another major advantage is that the experiment already exists and will be fully operational (with the full complement of phototubes restored) well before the turn-on date for the T2K beam.

- An extensive set of near detectors will be used to fully characterise the beam in Tokai, thereby minimising the systematic uncertainties in measuring ν_μ disappearance and permitting very accurate determination of the oscillation parameters, while at the same time enabling an absolutely convincing quantification of the ν_e background expected at Super-K, allowing any excess seen to be confidently attributed to oscillations.

These advantages have lead to the formation of a major international collaboration to build the T2K experiment (for schedules of the major elements directly relevant to the UK bid see Annex C2.2). At the time of the last LoI for the entire T2K project the collaboration (see bibliography) had 145 signatories from 10 countries, 46 of these from Japan, and since then the foreign group has grown. The recent conceptual design report for the 280m detector (see bibliography) had 199 signatories from 10 countries, 34 of these from Japan, 83 from Europe and 60 from North America, with the 40 names from the UK making us the largest single country. The project has been approved in Japan, with a total budget of $\sim$\$165M which covers all civil construction costs and most of the capital costs of the beamline, target, decay volume and beam dump (see detailed description below). Foreign contributions are necessary to provide the near detector(s), and to supply additional engineering, design expertise, and some components in the beam complex if the experiment is to accomplish its ambitious sensitivity goals.

There are two main neutrino oscillations measurements to be made in T2K. The first is the disappearance of ν_μ from the original beam, the second is the appearance of ν_e. The disappearance measurement is a repeat of the observation which Super-K and other experiments have made using atmospheric neutrinos, and which K2K and (by the time T2K runs) MINOS will have made using accelerator neutrinos. The basic idea is just to compare the energy spectra of ν_μ derived from a measurement of the μ energy spectrum from quasi-elastic (QE) scattering events at a near detector and at Super-K, i.e., before and after oscillations. T2K, with its higher flux and better optimised energy, is intended to make a substantially better measurement of the "atmospheric" parameters θ_{23} and Δm^2_{23} which dominate this oscillation. These are interesting in themselves (an angle θ_{23} which is really maximal reveals some unexplained symmetry in the neutrino sector, while a large but not maximal angle could just be accidental), and they are needed to optimise the design of future neutrino oscillation experiments. The key experimental issues in this measurement are knowing the exact "unoscillated" beam spectrum (which requires a measurement of the beam spectrum at a near detector, and an accurate knowledge of any near/far corrections to this spectrum that arise from anything other than oscillations), an accurate understanding of the energy resolution for muons in both the near and far detectors, and knowledge of the non-QE contamination of the measured μ spectrum.

The even more important measurement, however, is the appearance measurement, as this is the measurement which is sensitive to θ_{13}. Electron neutrinos will be observed by looking for charged-current quasi-elastic (CCQE) production of electrons in the near and far detectors, and the oscillation signature is simply an excess of ν_e in the far detector with an energy distribution that matches the prediction based on the observed ν_μ disappearance. Here the experimental issues are primarily rate (for all but the largest currently allowed values of θ_{13} the experiment will be statistically limited for some time, see table of rates which will be discussed in chapter 4) and backgrounds. Given that Super-K is already built, the only way to improve the rate is to make sure that the beam achieves the maximum flux and duty factor, and for that the UK contributions to the beam, outlined in the next chapter and in Work Package 9, are absolutely vital. Backgrounds to ν_e divide into two categories, intrinsic contamination of the ν_μ beam by ν_e from the decay of kaons or muons, and "fake" ν_e events arising primarily from neutral-current (NC) events from higher-energy neutrinos (or neutrons) producing π^0s in the detector, the decay of which can sometimes be mistaken for electrons. The intrinsic contamination of the beam must be measured by the near detectors. The π^0 background is potentially trickier, because π^0 misidentification depends on detector response, and the near and far detectors are not identical, so there is not a simple cancellation in comparing the two. The near detectors are therefore required to make detailed measurements of the energy/angle distributions of NC events so that the fake event rate at the far detector can be accurately determined.

2.3 The Beam

In order to explain the UK contributions, more detail will be given about the beam in the next chapter and in Work Package 9. However a brief explanation is useful here in order to motivate the discussion of the near detectors and physics reach. Due to space constraints on the J-PARC site, the proton beamline for the T2K beam has to be bent in a tight radius inside the PS ring (see Fig. 2.2). This requires the use of dual-function (dipole and quadrupole) superconducting magnets that are currently under construction at KEK. The proton beam then passes through a high-power window, which separates the proton beamline from the target station, and collides with the pion production target, which is a He-gas cooled graphite rod. The resulting pions are collected and focused forward by a magnetic horn system. In order to maximise collection efficiency the target is actually located inside the first horn. The pions exit the horns into a $\sim$100 m long He-filled decay volume where the neutrinos are produced. At the end of this decay volume is the beam dump, where any undecayed pions as well as the remaining proton beam are stopped (this amounts to about $\frac{1}{4}$ of the total initial proton beam power, the remainder going mostly into the walls of the decay volume). Behind the beam dump is a set of position-sensitive muon monitors, which by measuring the direction of the muons also produced by the pion decays can determine on a spill-by-spill basis the direction of the beam.

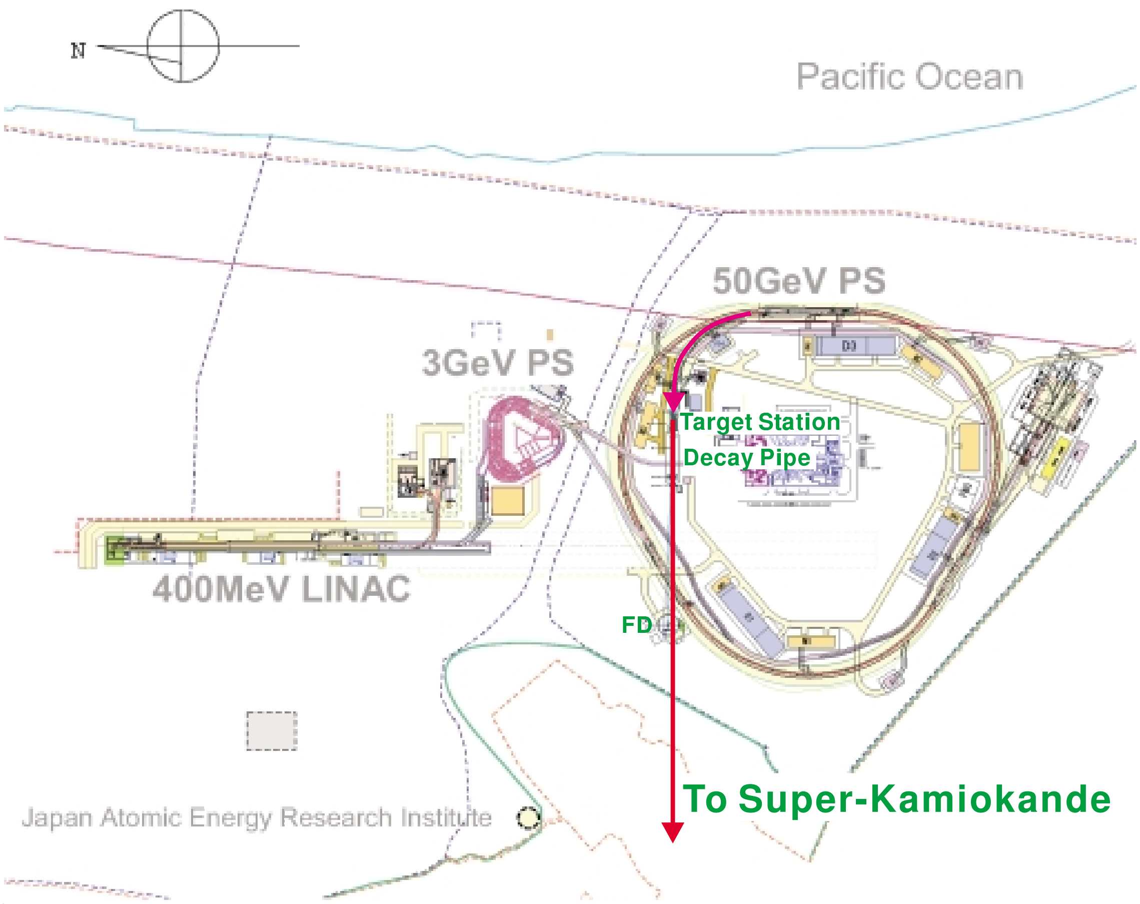


Figure 2.2: Overview of the J-PARC facility

This measurement of the beam direction is critical, because the entire beam setup is designed to produce a neutrino beam which is aimed several degrees away from the direct line to the Super-K detector. This, rather surprisingly, results in a substantial improvement in the quality of the beam. This arises from the kinematics of pion decay, which result in an enhancement of the neutrino flux over a very narrow energy range which depends on the exact off-axis angle (see Fig. 2.3). By selecting the angle, this peak can be tuned near the oscillation maximum at the far detector. This has three major advantages over a conventional on-axis beam. Firstly, the off-axis neutrino flux at the desired energy is actually higher than on axis. Secondly, there are fewer high-energy neutrinos, which do not contribute to the appearance signal but add to the NC backgrounds. Thirdly, the background due to the intrinsic contamination of the beam is less at the off-axis position owing

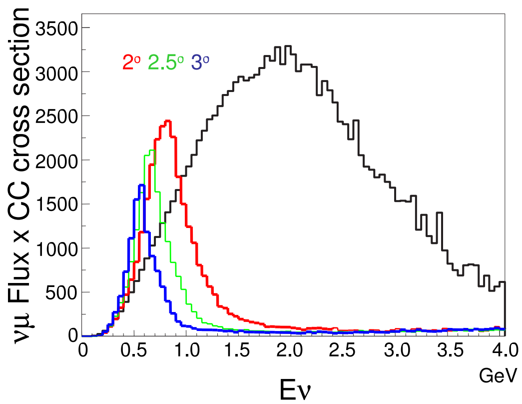


Figure 2.3: Energy spectra showing the on axis beam (black) and the 2, 2.5 and 3 degree off axis beams

to the different kinematics of muon and kaon decay. The very kinematics that produce the narrow peak, however, mean that the beam spectrum varies rapidly with off-axis angle. This means that the near detector, which sees the beam as an extended source, sees a different energy spectrum than the far detector. This produces a non-trivial near/far correction (see Fig. 2.4), the knowledge of which requires precise measurements at the near detector (and an excellent beam simulation, the implications of which will be mentioned in the next chapter).

The original plan for Phase I of T2K was to have 0.75 MW beam-on-target from the main ring at 50 GeV. For neutrino production all that really matters is the power, not the energy of the main ring. A number of optimization scenarios are currently under consideration and are shown in Figure 2.5. The original scenario was 0.75 MW, but this would have slipped back to the black curve, which is only at about 0.6 MW by April 2013. Various changes to accelerator operation are now thought feasible to push beam power to the orange curve which raises the beam power to 1.34 MW. However in order to avoid the possibilty that this would destroy the target for first beam, it was decided to retain the 0.75 MW target design at least for initial operation. In order to take full advantage of the power potentially available from the accelerator, however, we require ongoing development to improve the maximum power handling capabilities of the target.

2.4 The Detectors

2.4.1 The 280m Detectors — On-Axis

The 280m off-axis detector is the focus of the UK's primary involvement in T2K, and the next chapter will discuss it in detail. In addition to the muon monitors just downstream of the beam dump, there are two different near detector systems located in a circular hall excavated 280 m from the target. (And a proposed intermediate detector at 2 km, which will be discussed in section 3.4.2). The first of these is the on-axis detector, which is used to determine the precise beam direction relative to the far detectors (see Fig. 2.6). It consists of an array of iron-scintillator tracking detectors which track muons from CCQE events, producing a muon profile which gives the beam direction. The actual detection is done with scintillating bars, which will be discussed in more detail below.

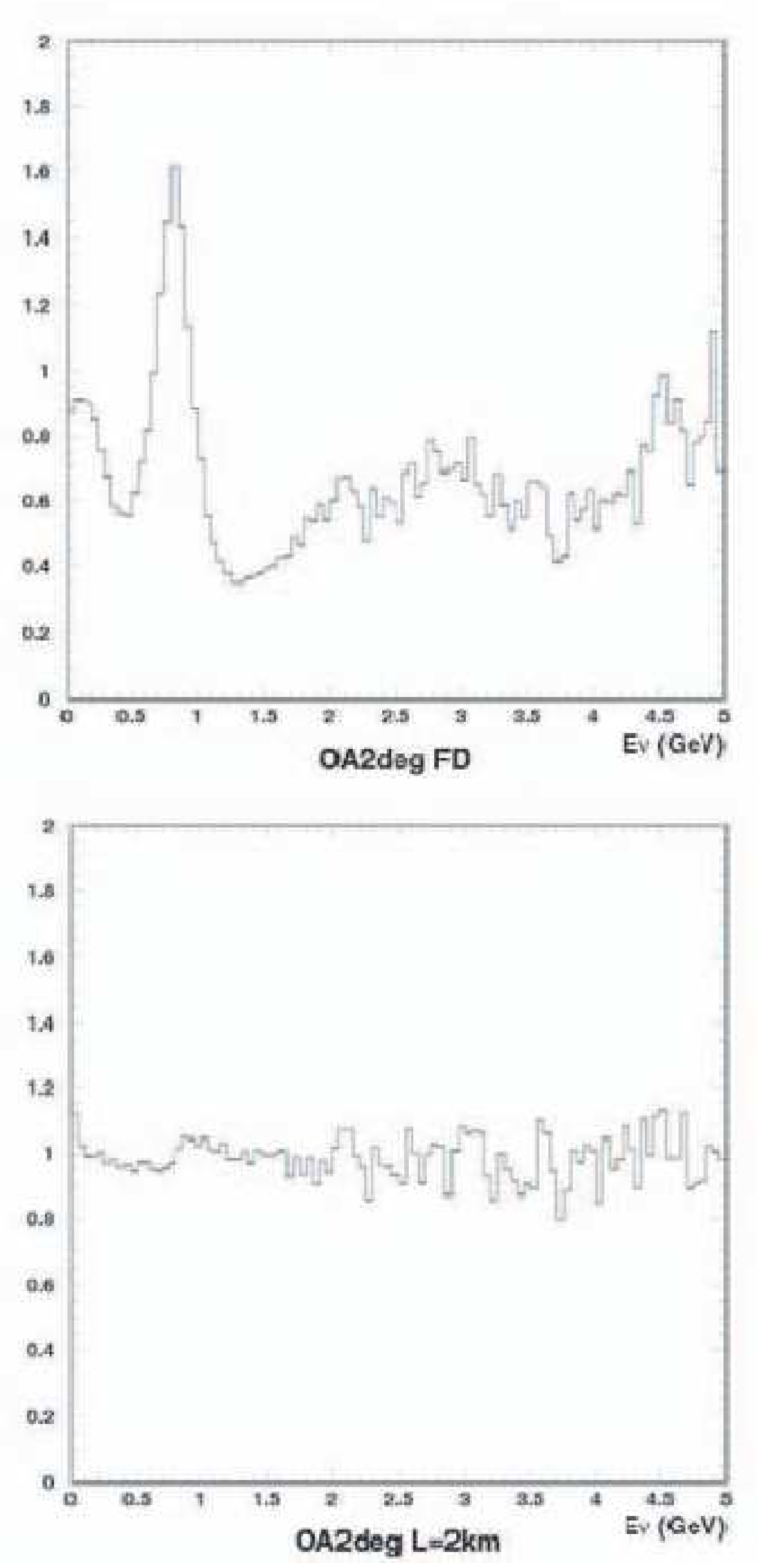


Figure 2.4: The ratio of the unoscillated neutrino energy spectra at the near and far detectors for a near detector at 280 m (left) and 2 km (right).

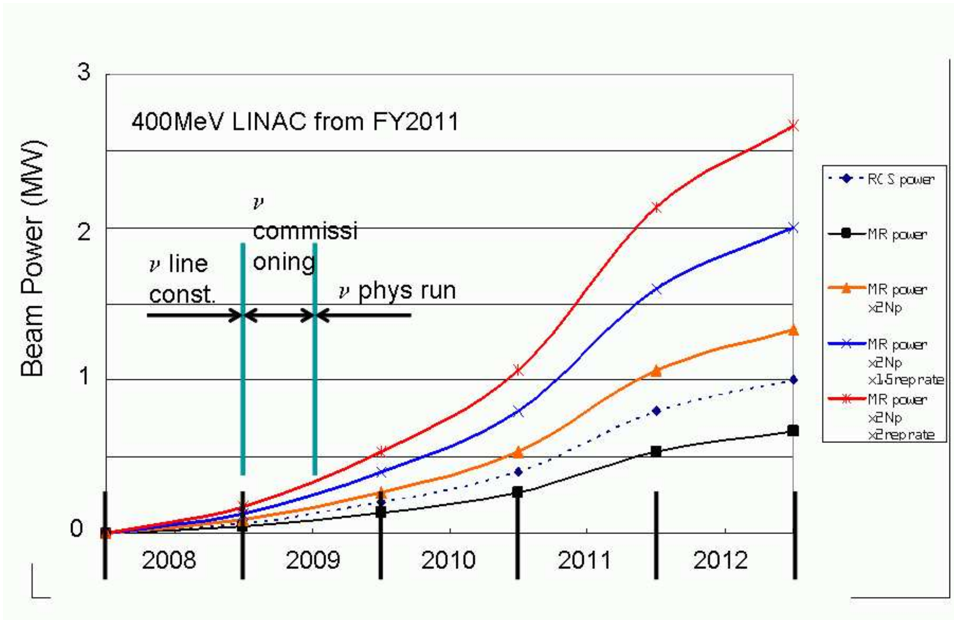


Figure 2.5: Beam power turnon for various changes to the accelerator operations.

2.4.2 The 280m Detectors — Off-Axis

The 280m off-axis detector sits in the direction to Super-K (although, due to the significant variation of the beam direction from different parts of the decay volume, it does not see exactly the same beam, as mentioned above). The purpose of this detector is to study the exact composition and spectrum of the beam, and to make studies of neutrino interaction properties relevant to the extraction of oscillation parameters from the far detector data. A schematic view of the detector is shown in Fig. 2.7.

The central part of the detector consists of two sections with different capabilities:

1. The Pi-Zero Detector or P0D sits at the upstream end of ND280m, and is optimised for measuring the rate of neutral current π^0 production. The P0D consists of tracking planes composed of scintillating bars alternating with lead foil. Inactive layers of passive water in sections of the P0D provide a water target for measuring interactions on oxygen.

2. Tracker: Downstream of the P0D is a tracking detector optimised for measuring the momenta of charged particles, particularly muons and pions produced by CC interactions, and for measuring the ν_e background in the beam. The tracker consists of two detector technologies: Time Projection Chambers (TPCs) and Fine Grained Detectors (FGDs):

   - TPCs: Three time projection chambers will measure the 3-momenta of muons produced by charged current interactions in the detector, and will provide the most accurate measurement of the neutrino energy spectrum. The 3D tracking and dE/dx measurements in the TPC will also determine the sign of charged particles and identify muons, pions, and electrons.
   - FGDs: Two FGD modules, placed after the first and second TPCs, consist of layers of finely segmented scintillating tracker bars. The FGDs provide the target mass for

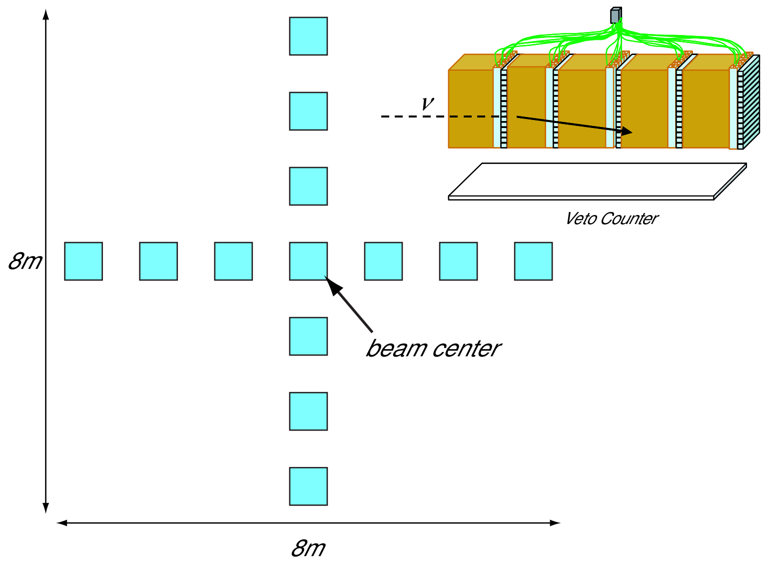


Figure 2.6: The 280m on-axis detector.

neutrino interactions that will be measured by the TPCs, and also measure the direction and ranges of recoil protons produced by CC interactions in the FGDs, giving clean identification of CC QE and CC non-QE interactions. One FGD module will consist entirely of plastic scintillator, while the second will consist of plastic scintillator and water to allow the separate determination of exclusive neutrino cross-sections on carbon and on water.

These detectors sit inside a structure termed The Basket, the purpose of which is to house and support all of the central scintillator and tracking sub-detectors. Surrounding the inner detectors on five sides is an electromagnetic calorimeter (ECAL) made up of alternating layers of Pb alloy sheets and plastic scintillator bars. The upstream end has a calorimeter section built into the P0D. The ECAL is a segmented Pb-scintillator detector whose main purpose is to measure those γ-rays produced in ND280m that do not convert in the inner detectors and is critical for the reconstruction of π^0 decays. The design, construction, installation and running of the ECAL is the primary contribution of the UK groups to the ND280m described in detail in Chapter 3.

In this document we refer to the section surrounding the inner detectors in the transverse direction as the "BARREL" and the section downstream of the tracker as the "DSECAL."

The ECAL is in turn surrounded by the old UA1-NOMAD magnet, which is used to generate a 0.2 T magnetic field to allow accurate measurement of charged-particle momenta in the tracker. The magnet (which was used as a hadronic calorimeter in UA1) will be partially instrumented with scintillator bars to detect sideways going muons, and is therefore also called the Side Muon-Range Detector, or SMRD. The SMRD also can provide a veto for events entering the detector from the outside and a trigger useful for calibration.

The ND280m detector will make a number of measurements which are critical to the oscillation analysis. As mentioned above, for the disappearance measurement the critical quantities are the flux and energy spectrum of ν_μ and the contamination of the CCQE muon sample by non-QE events. The first two are obviously important, as before one can make a precision determination of the effects of oscillation on a measured spectrum you have to know what the spectrum was in the

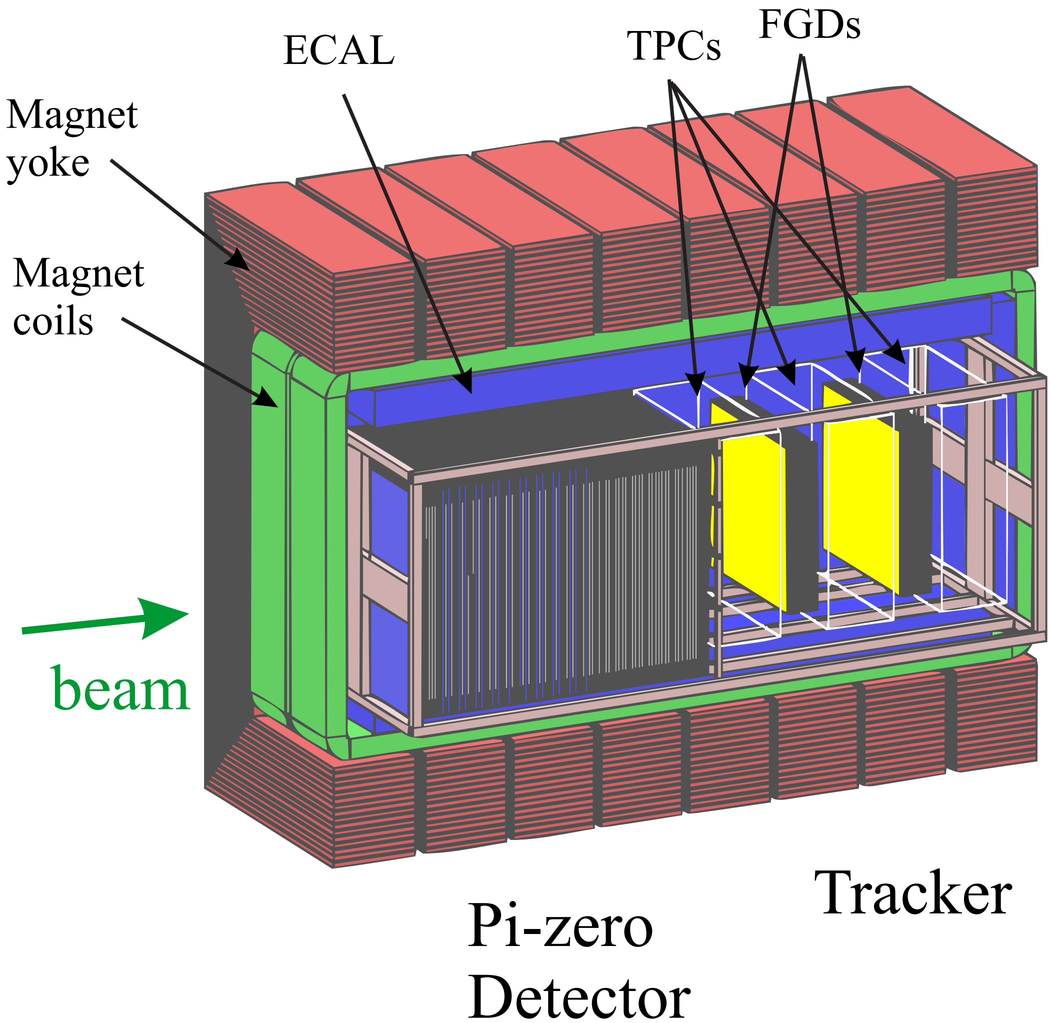
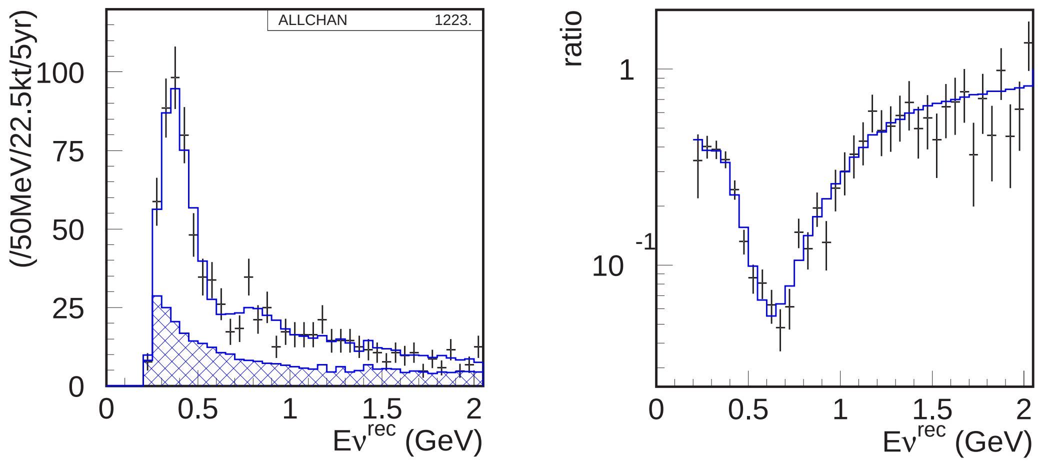


Figure 2.7: Cutaway view of the T2K 280 m near detector. The neutrino beam enters from the left.

first place (see Fig. 2.8(a)). The flux and spectrum will be determined from the muon momentum spectrum in the TPCs from CCQE events in the FGDs. The non-QE contamination of these events will also be determined by looking for other particles created in the same interactions in the FGD and TPCs and, crucially, in the ECAL. As can also be seen in Fig. 2.8(b), this non-QE contamination is a non-trivial fraction of the detected events, and its correction is critical to a measurement of the oscillation parameters. Of course the far detector is a water Cerenkov so we must measure the events in enough detail to be able to determine which would appear as single-ring events in Super-K and therefore be in the far detector CCQE sample. We must also determine the correction from the carbon of the scintillator target to the water in Super-K and for this reason one of the FGDs and the P0D both have sections of water target.

For the appearance measurement, the 280m detector must determine the ν_e contamination. Here the plan is also to look for CCQE events in the FGDs. The challenge of this measurement is to reject ν_μ events, which are $\sim$100 times as numerous. The ECAL will play a crucial role in this measurement by allowing muon/electron particle ID from an E/p measurement. The second essential quantity to measure for the appearance channel is the rate of π^0 production in NC events



(a)

(b)

Figure 2.8: (Left) The reconstructed neutrino energy distribution with the prediction of best fit oscillation parameters for input values of $(\sin^2 2\theta, \Delta m^2) = (1.0, 2.7\times 10^{-3}\mathrm{eV}^2)$. The hatched area show the non-QE component. (Right) The ratio of reconstructed neutrino energy distribution with oscillation to one without oscillation.

(or CC events where the charged particles would be below Cerenkov threshold in Super-K). The current world's data set for fixing the cross-section for this channel is shown in Fig. 2.9. Given the huge uncertainties this produces, and the fact that the background from this channel will become comparable to the signal for a value of θ_{13} only a factor of about 10 below the existing limit using the (very poorly measured) current value for the cross section, it is obvious that measurements at the near detector will be crucial for producing a useful appearance measurement. The 280m detector adopts two overlapping methods to perform this crucial measurement. A very detailed but rather poor statistics measurement of the single-π^0 production rate will be made by reconstructing π^0s in the ECAL which are produced by neutrino interactions in the FGDs. A higher statistics measurement but inclusive measurement will be made by the P0D and ECAL combination, but with a poorer reconstruction of the final state. Our current simulations indicated that the combination of these measurements should permit a precise enough extrapolation of the rate to Super-K to keep the systematic uncertainties in the ν_e appearance measurement below the statistical uncertainty for the entire T2K operation at lower beam power (before the 4 MW upgrade).

2.4.3 Super-Kamiokande

The Super-K detector has been successfully operated for atmospheric and solar neutrinos since 1996. In the energy range of interest the detector has a well-understood response to electrons, muons, and pions, and will be further studied and optimised as part of this programme. The chain-reaction implosion of several thousand of the phototubes in November 2001 has been widely reported, and resulted in the detector being rebuilt with the surviving tubes and correspondingly reduced sensitivity. New phototubes have now been built and are currently being installed. This installation will finish this year, meaning that Super-K will be fully operational and re-calibrated long before the beam becomes available. As was anticipated in our seedcorn proposal, UK T2K personnel have been participating in the rebuild as an essential part of our becoming fully involved in detector operations. All phototubes are now individually protected in acrylic/fibreglass

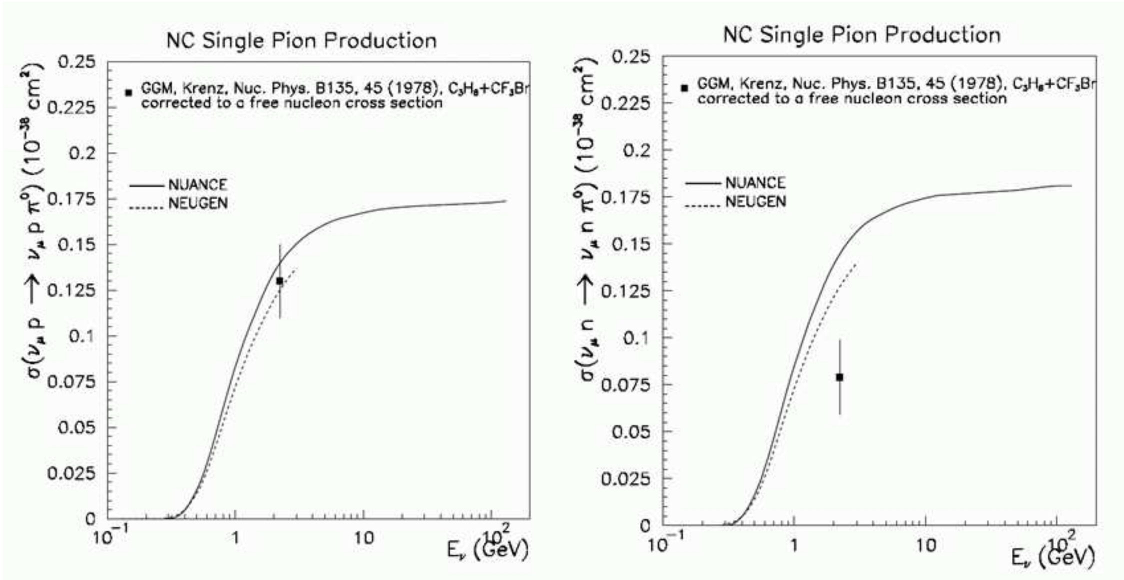


Figure 2.9: Cross-section for NC Single Pion production, with a single data point and predictions by the Nuance and NEUGEN simulations.

enclosures that will prevent any repeat of the chain reaction.

2.5 Expected Physics Sensitivity

Given that the T2K experiment is almost ideally suited for the study of $\nu_\mu \rightarrow \nu_e$ appearance, having the most intense beam, the proper energy and baseline, a large, well-understood far detector with excellent capability to differentiate signal from background, and the most extensive suite of near detectors for the detailed characterisation of the beam so far proposed, what sensitivity will it provide? As with any proposed experiment, this is not an easy question to answer, and has consumed much of the effort available over the seedcorn period. Analysis, which will be ongoing and is described in more detail below, is producing a better understanding of the precise impact of the near detector measurements on the systematic uncertainties in the measurements at Super-K. We no know that the project will, if it performs as designed, produce very significant advances on our current knowledge.

Fig. 2.10 shows again the expected measured muon energy spectrum in Super-K. The ν_μ disappearance measurement consists of looking for the dip in the spectrum caused by oscillations, as shown in the centre and right hand panels (note the very different vertical scales, showing that due to the optimal selection of energy and baseline, most of the neutrinos have oscillated away). In principle the measurement of the depth of the dip gives the value of $\sin^2 2\theta_{23}$, and its position gives Δm^2_{23}. As discussed before, both measurements are complicated by the presence of non-QE events from higher-energy neutrinos (shown in cross hatch in the plots). Our preliminary estimate is that we will have systematic uncertainties of 5% in the normalization and non-QE/QE ratio, 1% on the energy scale, 20% on the spectral shape and 5% on the spectral width. These would allow us a measurement accuracy of $\delta\left(\sin^2 2\theta_{23}\right) \sim 0.01$ (about an order of magnitude better than will be achieved by MINOS) and $\delta\left(\Delta m^2_{23}\right) < 1 \times 10^{-4}\ \mathrm{eV}^2$, which is also about an order of magnitude

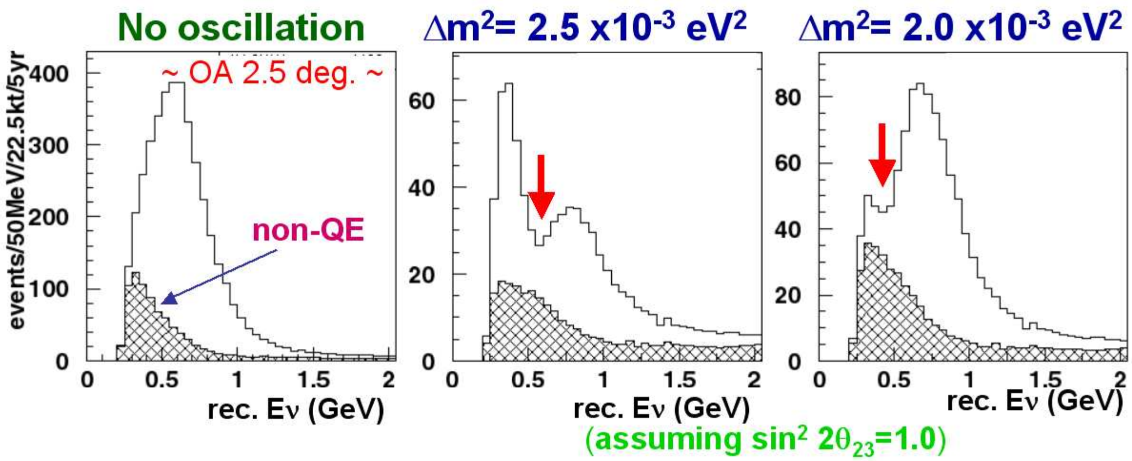


Figure 2.10: Muon neutrino spectra expected at Super-K for two different values of Δm^2.

improvement on what is expected from MINOS, in 5 years, assuming 10^7 seconds of running per year at nominal intensity.

For the $\nu_\mu \to \nu_e$ appearance search detailed studies continue of the ability to reject beam ν_e (which have a very different energy spectrum from signal ν_e) and π^0's in Super-K. What is less well known is the expected level of these backgrounds from our beam. The expected ν_e CCQE signal for the $\nu_\mu \to \nu_e$ appearance and the currently predicted backgrounds (based on a very poor knowledge of the relevant cross-sections) are shown in Table 2.1. For illustration, the signal and Backgrounds are shown in Fig. 2.11.

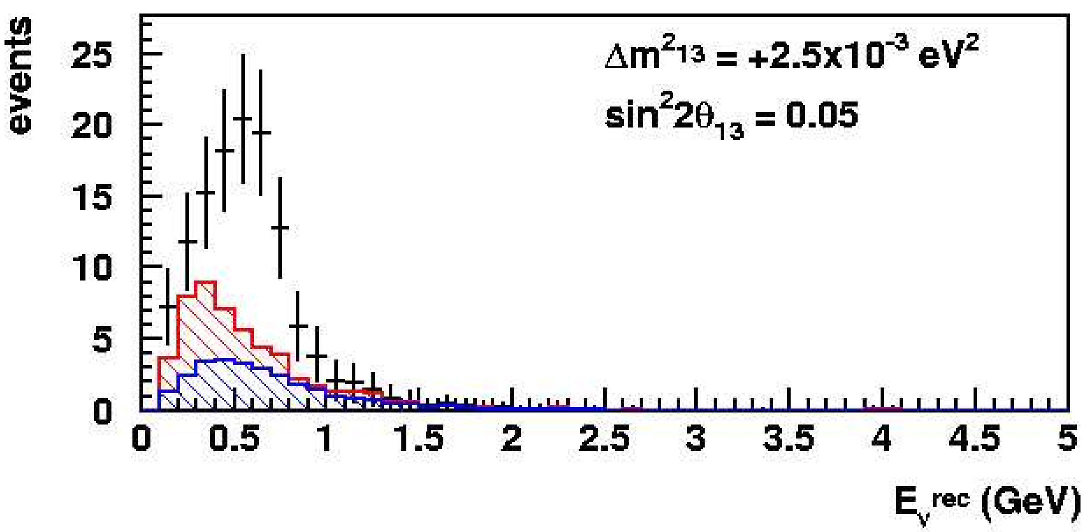


Figure 2.11: Observed ν_μ energy spectra at Super-Kamiokande. The red and blue hatched histograms in each figure show background contributions from ν_μ interactions and beam ν_e contamination. Statistics correspond to a 5 year run (10^21 POT).

Turning the expected sensitivity to the number of $\nu_\mu \to \nu_e$ appearance events into a sensitivity

	ν_μ CC BG	ν_μ NC BG	beam ν_e BG	ν_e CC signal
Fully contained $E_{\text{vis}} \geq 100$ MeV	2215	847	184	243
1 ring e-like, so decay-e	12	156	71	187
$0.35 \leq E_\nu^{\text{rec}} \leq 0.85$ GeV	1.8	47	21	146
e/π^0 separation	0.7	9	13	103

Table 2.1: The number of events selected by a ν_e appearance analysis, as predicted by the NEUT Monte Carlo for 5×10^{21} POT exposure. For the calculation of oscillated ν_e's, $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 and $\sin^2 2\theta_{13} = 0.1$ are assumed.

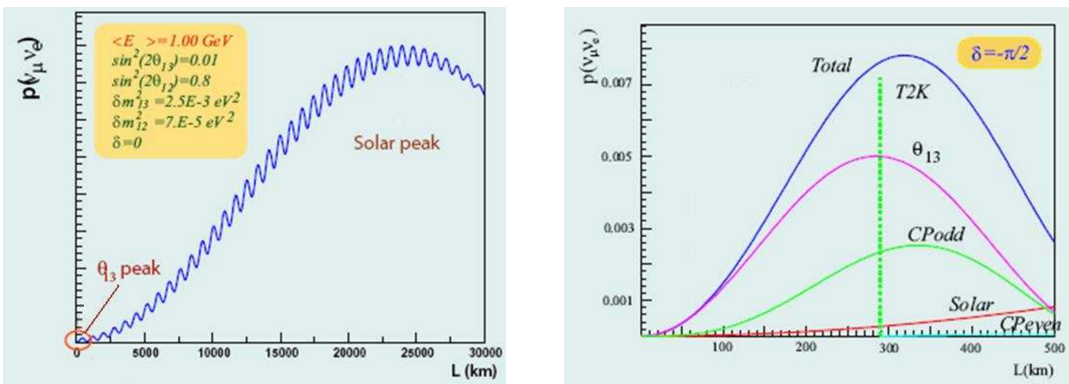


Figure 2.12: (Left) The probability of ν_e appearance in three-flavour oscillations. (Right) The contributions of the different terms of the equation given in the text.

to oscillation parameters is a highly non-trivial problem which has consumed much of the world's neutrino phenomenology community for the past several years. An approximate formula, ignoring matter effects, for the appearance probability is:

$$
\begin{aligned}
P\left(\nu_\mu \to \nu_e\right) &\approx \sin^2 2\theta_{13} \sin^2 2\theta_{23} \sin^2 \Delta \\
&\pm \alpha \sin 2\theta_{13} \sin\delta \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \sin^3 \Delta \\
&- \alpha \sin 2\theta_{13} \cos\delta \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \cos\Delta \sin 2\Delta \\
&+ \alpha^2 \cos^2 \theta_{23} \sin^2 2\theta_{12} \sin^2 \Delta
\end{aligned}
$$

where $\alpha \equiv \Delta m^2_{12}/\Delta m^2_{13}$ and $\Delta \equiv \Delta m^2_{13} L/4E$. α has been measured by existing experiments to be $\sim$0.3, and of course the value of δ is completely unknown. Fig. 2.12 shows the terms from the formula graphically. The last term (in α^2) is the solar-KamLAND oscillation: as shown in the left hand plot, it dominates the expression at long baselines. At T2K baselines, however, it is small, and the oscillation is dominated by the other three terms, which all depend on $\sin 2\theta_{13}$. The distance and energy for T2K has been chosen to maximise the effect of these θ_{13} driven oscillations, maximizing our sensitivity to θ_{13}. The observation of a non-zero θ_{13} would, of course, provide a key motivation for the Neutrino Factory programme. It does mean, however that an observation of $\nu_\mu \to \nu_e$ appearance from this single experiment would have an ambiguity in its interpretation (it could be a big θ_{13} and small CP odd term, or a smaller θ_{13} with a significant contribution from the CP odd term) which would require further experiments to resolve. If we do not see a signal for $\nu_\mu \rightarrow \nu_e$ appearance this ambiguity will also make the corresponding limit on θ_{13} dependent on the unknown value of δ, as shown in Fig. 2.13.

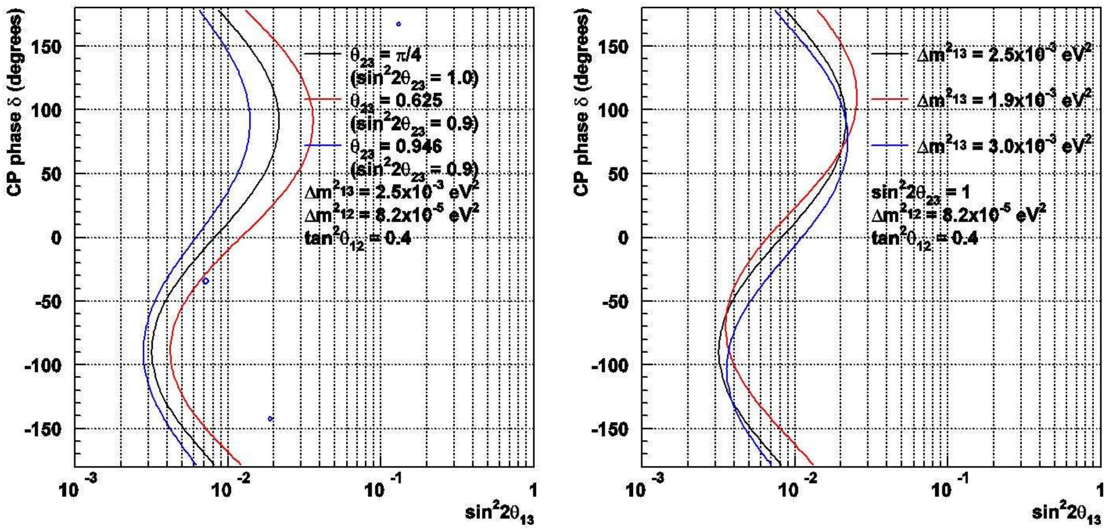


Figure 2.13: Sensitivity to $\sin^2 2\theta_{13}$ as a function of the CP phase δ.

Further Information

It is impossible to describe a $200M project in 10 pages. Additional information on T2K can be found at:

1. The T2K Homepage: http://neutrino.kek.jp/jhfnu/
2. The Near Detector Homepage: http://www.nd280.org/info
3. A somewhat dated but very complete technical report: http://jnusrv01.kek.jp/jnu/nu-TAC/jnuall-e.031029.pdf
4. Slides from the last collaboration meeting: http://jnusrv01.kek.jp/jhfnu/NP04nu/program.html

Chapter 3

Contributions from the UK to the T2K Project

3.1 Overview

When UK involvement in the T2K experiment was first suggested a few years ago the question was repeatedly asked whether the UK would be able to secure any significant role in a Japanese collaboration. We can say that this question has been decisively answered in the affirmative — the UK role in T2K has expanded to encompass several absolutely critical elements of the experiment, and without substantial UK involvement it is now difficult to see how the experiment could be delivered. Along with this has come corresponding growth in UK influence in the project, with the UK now providing members of all the main governing bodies of the experiment. The purpose of this chapter is to provide a summary description and justification of the elements which the UK T2K collaboration is proposing that PPARC fund as our contributions to T2K, and their importance to the experiment. The main elements of the package are contributions to the beam, in particular to the target, providing the entire ECAL for the 280m off-axis detector complete with electronics and photosensors, the reuse of our electronics solution for the P0D and SMRD detectors, some electronics elements for the other detectors as well (which can be provided at very low marginal cost to the UK but would be very expensive for others to re-engineer), the DAQ for the 280m detector, and some general "public service" contributions to the 280m off-axis detector as a whole. Each element will then be described in more detail in the individual work package chapters. We will also describe a number of other experimental opportunities which could follow in the future, but which are not being specifically requested as part of this proposal.

3.2 The Beamline

Any long-baseline neutrino experiment begins with producing the neutrino beam, and in fact this is probably the most technically challenging part of the experiment. The UK has already secured, through the excellent work of the RAL engineers provided by our successful T2K seedcorn bid, a central role in the beam design. UK engineering effort has value to the project disproportionate to its actual cost, as the Japanese lack substantial in-house engineering effort and must outsource design (even at a largely conceptual stage) to private firms. This produces wasted time tendering for preliminary designs which are rejected, and makes iterating an idea time consuming and (from our point of view) absurdly expensive. RAL engineers, by working closely with the Japanese physicists, have therefore been able to speed progress on critical components and gain a key role in the project. It is also worth pointing out that the $\nu_\mu \rightarrow \nu_e$ appearance measurement will be statistically limited for years, so the limiting factor in the rate at which we increase our sensitivity will be the total power delivered to the target, which depends not only on the accelerator, but also on the peak power tolerance, the reliability and lifetime of the target in what will be the highest power pulsed proton beam in the world. The major UK contribution will be design engineering. Those elements which are likely to need routine maintenance and replacement will certainly be built in Japan, however we are also bidding to supply the hardware for some elements. It is worth emphasizing at this point that this element of the T2K project has given and will give the UK a unique opportunity to build up our expertise in high-power proton targetry (a UK strategic priority). The beam components which the UK has undertaken to design and/or supply are as follows (see Fig. 3.1 and work package 9).

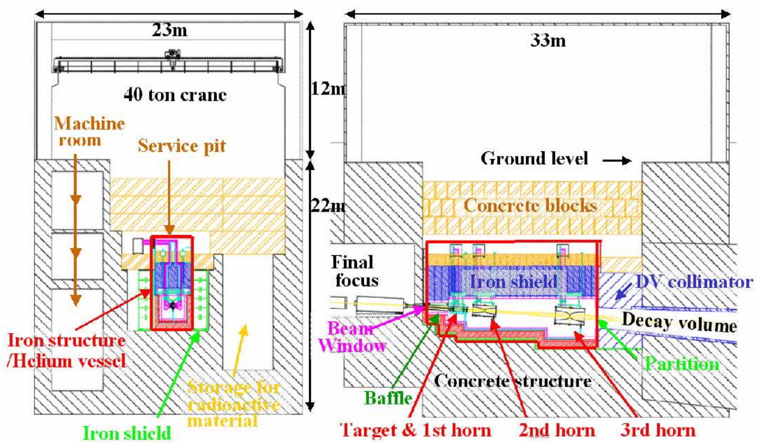


Figure 3.1: Cross–section of the target station.

3.2.1 The Beam Window

The proton beamline is separated from the target station by a high-power beam window. This window must withstand the whole power of the beam with a minimum of material while at a differential pressure of 1 bar. The UK will design the actual window, modifying where necessary the design of a ”pillow seal” demountable flange initially designed and developed at PSI. We are also bidding to produce this window in UK industry including the modified pillow seal, ship it to Japan and assist in its installation and commissioning.

3.2.2 The Baffle

After the window the beam passes through a baffle, the purpose of which is to prevent a mis-aimed spill from hitting and destroying the first horn. The baffle is expected to be a thick-walled graphite cylinder. The UK is bidding to design and supply the baffle.

3.2.3 The Target

The key element in the system is the pion production target (see Fig. 3.2). This target must withstand the maximum beam power possible (in order to maximize the rate), provide a minimum of

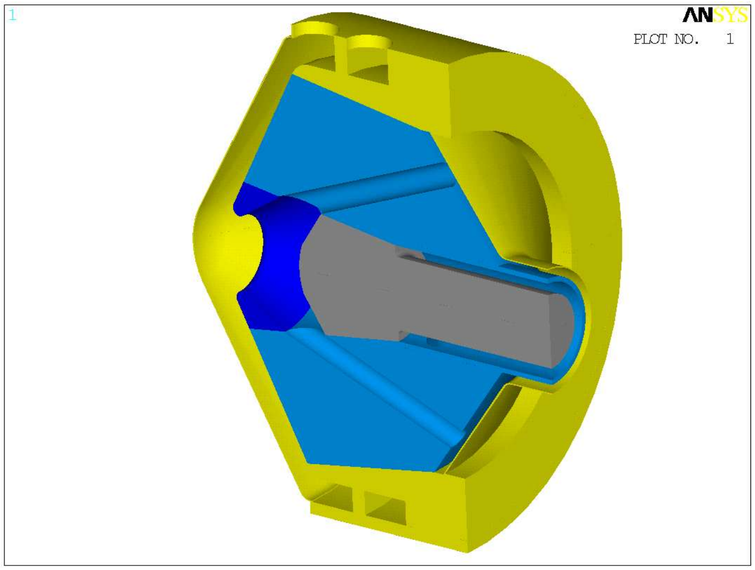


Figure 3.2: RAL design of upstream part of target showing He inlet and cooling path. Ti target enclosure shown in yellow.

material to absorb or scatter the produced pions, and be able to be physically located within and a minimum distance from the first horn (to maximize pion collection). It will be the highest-power pulsed proton target in the world. The UK is bidding to continue its role providing the actual design of the target, which will be built in Japan.

3.2.4 The Target Handling System

The speed and ease with which the target can be replaced will be a critical factor in keeping the beam running, given the inevitability of target failures at the design beam power. The UK, building on its expertise from the ISIS facility, is bidding to design and supply the system by which the target can be removed and replaced with a minimum of perturbation to the facility. This is an extremely challenging task which must be done right the first time, as modifications will be nearly impossible given the radiation levels in the target station after even minimal beam operation.

3.2.5 The Beam Dump

Any undecayed pions and the proton beam remnant are stopped at the end of the decay volume by a beam dump. This beam dump must withstand many years of operation at up to the highest foreseen beam power of 4 MW with a minimum of material (so as not to scatter and distort the angular distribution of the decay muons which are used to verify the beam direction). The UK wishes to continue its role designing the beam dump core, i.e., the part of the beam dump actually hit by the proton beam remnant.

3.3 The 280m Detector

Our main physics interest in T2K is the appearance experiment, and we have therefore tried to concentrate our efforts on those elements which are most critical for that measurement. As mentioned above, the most important measurements for the appearance measurement are the determination of the intrinsic ν_e contamination of the beam and the measurement of the rate of π^0 production in events which could mimic a ν_e CCQE event in Super-K (i.e., those lacking a charged particle over Cerenkov threshold). The ECAL plays a key role in both those measurements, so we are concentrating on it. The integrated photosensor - RO electronics - DAQ chain developed in the UK for the ECAL can be implemented without any modifications to a number of ND280 subsystems. We plan to take this opportunity to enhancing the UK role in the collaboration without any additional development cost.

3.3.1 The ECAL

The centrepiece of our detector involvement is the ECAL, which we wish to design, build, ship to Japan, install, commission, operate and maintain. The detector is a tracking calorimeter with layers of scintillating bars separated by thin layers of lead alloy. It consists of a barrel section "BARREL" and a downstream section "DSECAL."

This is also the cost driver for our activities, as the need to reconstruct π^0 events in the FGDs and electron/muon separation (for identifying ν_e in the beam) both drive one in the direction of a fairly fine-grained ECAL (the current design has 33k channels). See work packages 2 and 7.

3.3.2 The ECAL Photosensors

The scintillating bars are read out through wavelength-shifting fibers, as in MINOS, but unlike MINOS the 280 m detector is internally complex (a number of the subsystems use scintillator bars with fibers in different orientations and sizes) and is completely enclosed inside the UA1/NOMAD magnet. We therefore concluded that it would be impracticable to get all the fibers out through the magnet, and that our photosensors would therefore have to function in the 0.2 T magnetic field. This eliminated the usual solution (multi-anode photomultipliers). After considering and rejecting a number of alternatives we have settled on avalanche multipixel photodiodes (AMPDs, often referred to in the literature as *silicon photomultipliers*), a new type of photosensor of potential wide application in our field (and hence there is a strategic benefit to PPARC to be centrally involved in their first large-scale use). While no one has ever used these devices in the quantities which we anticipate for T2K, we are encouraged that at least three suppliers have appeared who would compete for our order, including Hamamatsu Photonics. The UK role would consist of the selection, purchase, QA acceptance testing, and installation in the ECAL of the selected photosensor. See work package 3.

3.3.3 Electronics

We propose to produce readout electronics with a front-end based on the Trip-t chip originally developed at Fermilab for the D0 experiment and a back-end based on FPGAs to be designed at RAL.

The ECAL cannot make the necessary measurements without the other detector subsystems, all of which except the TPCs are based on the same basic technologies. It therefore would make little sense for the T2K collaboration to spend its scarce manpower designing several electronics systems all to do the same job. For that reason T2K has therefore adopted a hybrid approach of trying to take advantage of commonality when it would be especially cost effective. The back-end will be used for all the scintillator based electronics, and therefore we propose to supply these for the entire 280m detector (the actual cost of the electronics is a small fraction of the design cost, so this adds very little to the UK cost). The front-end would be the same for the P0D and SMRD, and therefore we would like to supply those as well. The FGDs will use a slightly different layout, so they propose to build their own boards based on the same hardware and firmware. See work package 4.

3.3.4 The DAQ Hardware/Software

We must produce the DAQ system required to read out our electronics, and due to the large commonality between detector systems, we propose to extend this to do the DAQ for the entire 280m detector. See work package 5.

3.3.5 Mechanical/Thermal Integration and Support

All the subsystems in the 280m detector must be integrated together to form the complete system, which requires significant engineering to insure access, thermal control, and rapid assembly/disassembly for maintenance. The ECAL is the key to this, as it surrounds all the other detectors, and hence we wish to take responsibility for this activity. The downstream ECAL must also be supported, which requires the construction of the Basket, introduced in Section 2.4.2, and which will also support the other inner subdetectors. We have also included in this work package a financial contribution to the cost of refurbishing the UA1/NOMAD magnet and its shipment to Japan. The magnet and coils were donated by CERN, but the European collaboration must supply new power supplies and rails, refurbish the magnet and coils, and then ship all components to Japan. The agreed share of this cost for the UK is 260k Euro. See work package 6.

3.3.6 Calibration

Central to the understanding of any detector, obviously, is a comprehensive calibration plan, and our ECAL is no exception. The response of individual elements will be characterized with radioactive sources during construction, and this will be followed up (assuming this proposal is successful, of course) by a set of beam calibrations at CERN and at a tagged photon source (we are negotiating with Mainz, but other facilities are also being considered). See work package 7. (There are also ongoing electronics calibrations which come more under the electronics and DAQ work packages 4 and 5.)

3.3.7 Offline Software and Analysis

In the end we will have a working detector, and then it will be our job to derive the physics from it. For that we will need the usual suite of offline software tools. These are currently under development for T2K, with the UK taking a leading role in their production. This is planned to continue as we move through the construction phase, especially with respect to supporting the calibration efforts. In parallel the new tools are being used to optimize the design of the detector (many of these results will be given later in this proposal), an effort which will continue as we develop our final design. The analysis effort will then transfer its focus to calibration effort, leading on to the beginning of data taking during 09/10. See work packages 1 and 8.

3.3.8 Active Water R&D

The target mass for neutrino interactions in the 280 m detector is provided largely by the plastic scintillator. However, this introduces an additional near/far systematic error, since the bulk of the nucleons in plastic scintillator reside in carbon nuclei, as opposed to the oxygen nuclei in Super-K's water. The design of the 280m detector deals with this by including water target layers in part of the P0D and one FGD, so that the interactions of neutrinos on a water target can be determined by statistical subtraction.

Development of an active water-based scintillator would allow these passive water layers to be replaced by active material. A candidate water-miscible liquid scintillator has been identified and the UK group has been investigating its properties in collaboration with the Canadian group responsible for the FGD. This is an R&D project and is not scheduled for implementation in the first data-taking period of T2K. It is therefore not a work package of this proposal. The work being done is described in Appendix A: if a workable solution is found, it could be installed in the 280m detector as an upgrade during a suitable maintenance shutdown.

3.4 Future Developments

The work represented in this proposal, we believe, is a creditable output considering that with the exception of the beamline engineers, there is very little formal effort available for this project in the UK. While concentrating on putting ourselves in the position to make a credible technical proposal for the first phase of the T2K experiment, we have not had time to simultaneously pursue all other efforts which might benefit the T2K effort, or benefit from it. We therefore will put separate proposals to PPARC for any such projects we elect to pursue; however, we think it worthwhile here to alert the committees to the existence of these other efforts and the likelihood of future proposals for involvement in at least some of them.

3.4.1 T2K Phase 2

All measurements for which T2K is being built would benefit by more statistics, so the first priority for future work will be to increase the event rate. When originally proposed there was a clear distinction between T2K Phase I, with a 0.75 MW, 50 GeV proton beam producing a neutrino beam aimed at the existing Super-K detector, and a Phase II, where the beam power would be raised to 4 MW and Super-K replaced the a megatonne-scale Hyper Kamiokande detector. Recently the baseline plan has been revised, with discussions underway for beam power exceeding 0.75 in the initial (approved) stage of the project (but at lower beam energy, which has little effect on neutrino production). Plans for Phase II, with the 4 MW target and Hyper K, are still actively being developed. The UK group will want to remain closely involved in these improvements, in particular, each increase in beam power will have to be matched by upgrades in the design of the target. The UK group will no doubt seek ongoing support for target development, as will be discussed in work package 9.

3.4.2 The 2 km Detector(s)

The T2K experiment as initially proposed will make very significant advances in our understanding of neutrino oscillations, but just as plans exist to improve the statistical sensitivity of the experiment, there are also proposals to improve the systematic sensitivity. The first of these is the plan to add a second near detector complex two kilometres from the target. This would have two major advantages over the existing near detectors. Firstly, from two kilometres the decay volume appears essentially pointlike, so the observed spectrum is essentially the same as that seen at Kamioka, removing systematics associated with near/far corrections (see Fig. 2.4). The second advantage (or disadvantage, depending on what you are trying to measure) is that the flux is much lower. This will allow the use of a water Cerenkov detector at the 2 km site, which cannot be used at 280 m due to pileup. This will minimize any uncertainties in correcting for different detector technologies (and nuclear targets) at the near and far detectors. The low rate will also allow the use of inherently slow detection techniques: in particular, there is a plan to build a LAr calorimeter using technology derived from ICARUS. Given the great interest in LAr as a technology for Neutrino Factory detectors this would be an excellent opportunity for the UK to become more familiar with these detectors. Currently all available resources are focused on delivering the beam and ND280 systems for a timely start of the baseline T2K physics programme. When this is achieved, effort will be directed to the 2km detector, and at that point the UK will bid to become involved in the construction and operation of the 2km detectors.

3.4.3 T2K/NA49

Another way to decrease systematic uncertainties in T2K is to improve the beam simulation, which will reduce near/far uncertainties and provide a better normalization for cross-section measurements. The most important step in improving the simulation would be obtaining better data on hadron production in a T2K target by a proton beam of 30, 40, and 50 GeV. Just as the MINOS experiment required the MIPP hadron production experiment, and K2K required HARP, T2K would benefit greatly from a dedicated hadron production measurement as well. There is an experiment under consideration at CERN which would use a slightly upgraded version of the existing NA49 experiment to make such measurements. It is very much hoped that sufficient UK interest will exist to participate in this experiment, and discussions are underway right now.

3.4.4 Super-Kamiokande

This proposal is for UK involvement in the T2K experiment, and being a member of T2K does not automatically make one a member of the Super-K experiment. T2K members will have access to the beam-associated data from Super-K and some calibration data, but not to the full range of software tools, calibration data, and atmospheric and solar neutrino data. There would be considerable advantage to the UK group in having access to the full range of Super-K data, not least of which would be the ability of our students and postdocs over the next few years to train on real data. Preliminary discussions have taken place with Super-K concerning our joining, and the initial response has been positive, but there has not been time to reach an agreement on what hardware resources the UK would supply to enhance their programme (probably in the form of new calibration devices). We believe that joining Super-K would produce significant benefits to the UK at very minor cost, so we are very likely to propose that in the near future.

Chapter 4

Work Package 1: Physics Studies and ECAL Optimisation

4.1 Institutes Responsible

This work package will be provided by Imperial College, Lancaster, Liverpool, CCLRC Rutherford Appleton Laboratory, Queen Mary, Sheffield and Warwick. The work package managers are Y. Uchida (Imperial College) and S. Boyd (Warwick).

4.2 Introduction

The general design of the ECAL is of a system of lead and scintillator sampling calorimeters which surrounds the inner detectors in the downstream ("DSECAL") and perpendicular ("BARREL") directions to the neutrino beam. The details of the design, however, arise as a compromise between various different characteristics that the detector must possess. In this chapter, we discuss the requirements that the ECAL must meet and how design optimisation is being conducted. This optimisation work must happen in the context of the full ND280m detector and the entire experiment, and naturally resides together with the preparation for global physics analyses for all aspects of the T2K experiment.

4.2.1 ECAL Signal Particles

CCQE interactions

As mentioned in Section 2.4.2, charged-current quasi-elastic (CCQE) interactions make up the principal signal events in T2K. Fig. 4.1 is an event display of the inner detector with a simulated ν_μ CCQE event.

The distributions of signal particles from CCQE neutrino interactions in the FGDs which enter the ECALs are shown in Figs. 4.3 and 4.4. The incoming neutrino energy and neutrino flavour for these events can be reconstructed well in the far detector, and they provide the bulk of the neutrino oscillation information. Hence their spectra and interaction rates at the near detector must be measured to good precision.

Fig. 4.2 is a backgroud event to the ν_e CCQE signal, caused by a resonant pion production interaction, where the pion was absorbed in the nucleus. By making high-quality measurements

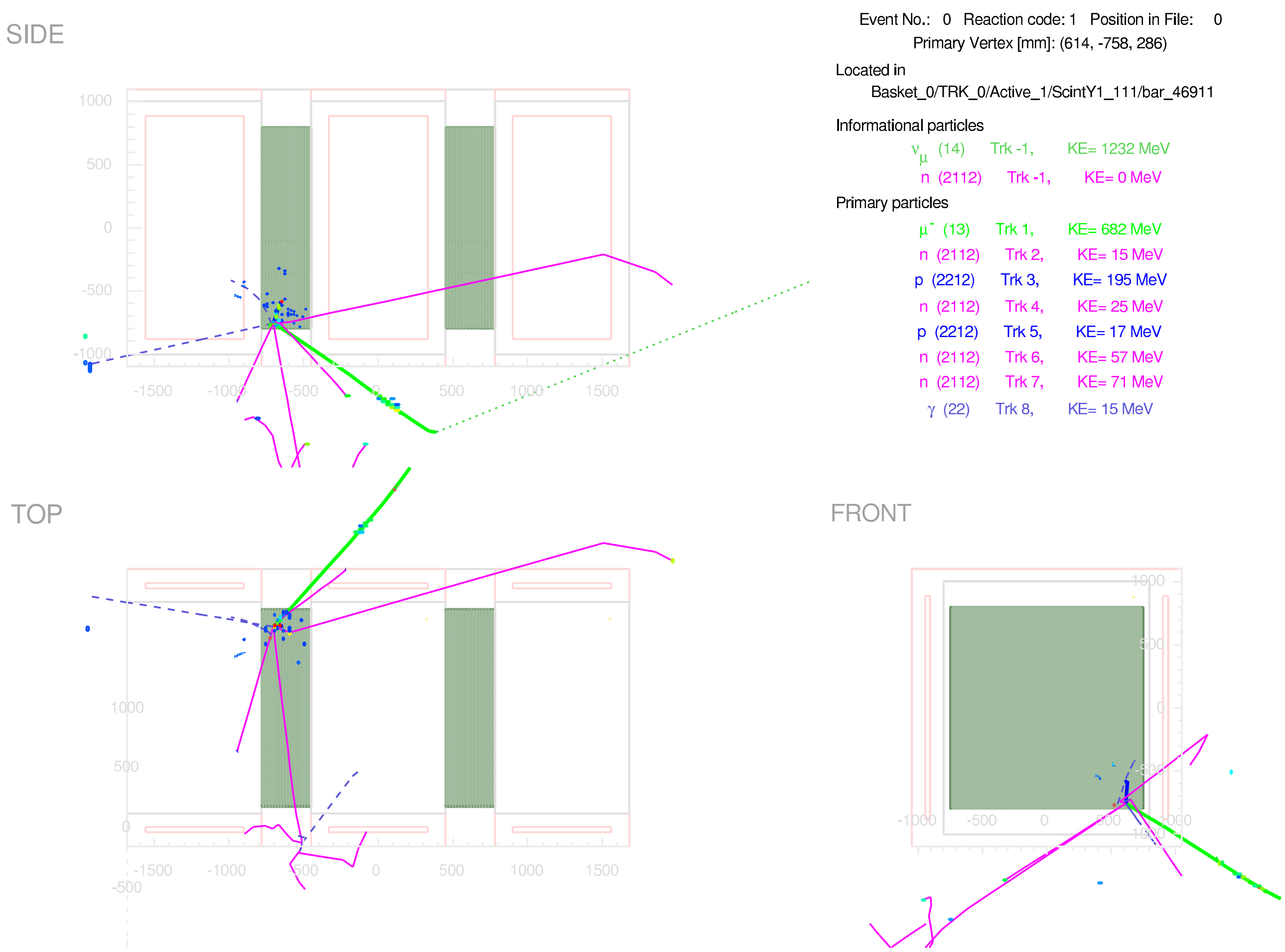


Figure 4.1: An event display of a simulated ν_μ CCQE interaction in FGD1. Lines indicate particle trajectories and detector hits are represented by colour-coded dots according to deposited charge. The incoming ν_μ has an energy of about 1.2 GeV, with a 680 MeV outgoing muon (green) which directly enters the BARREL and creates a minimum ionizing track. The accompanying proton stops in the FGD. Several soft neutrons (pink) can also be seen leaving the interaction point.

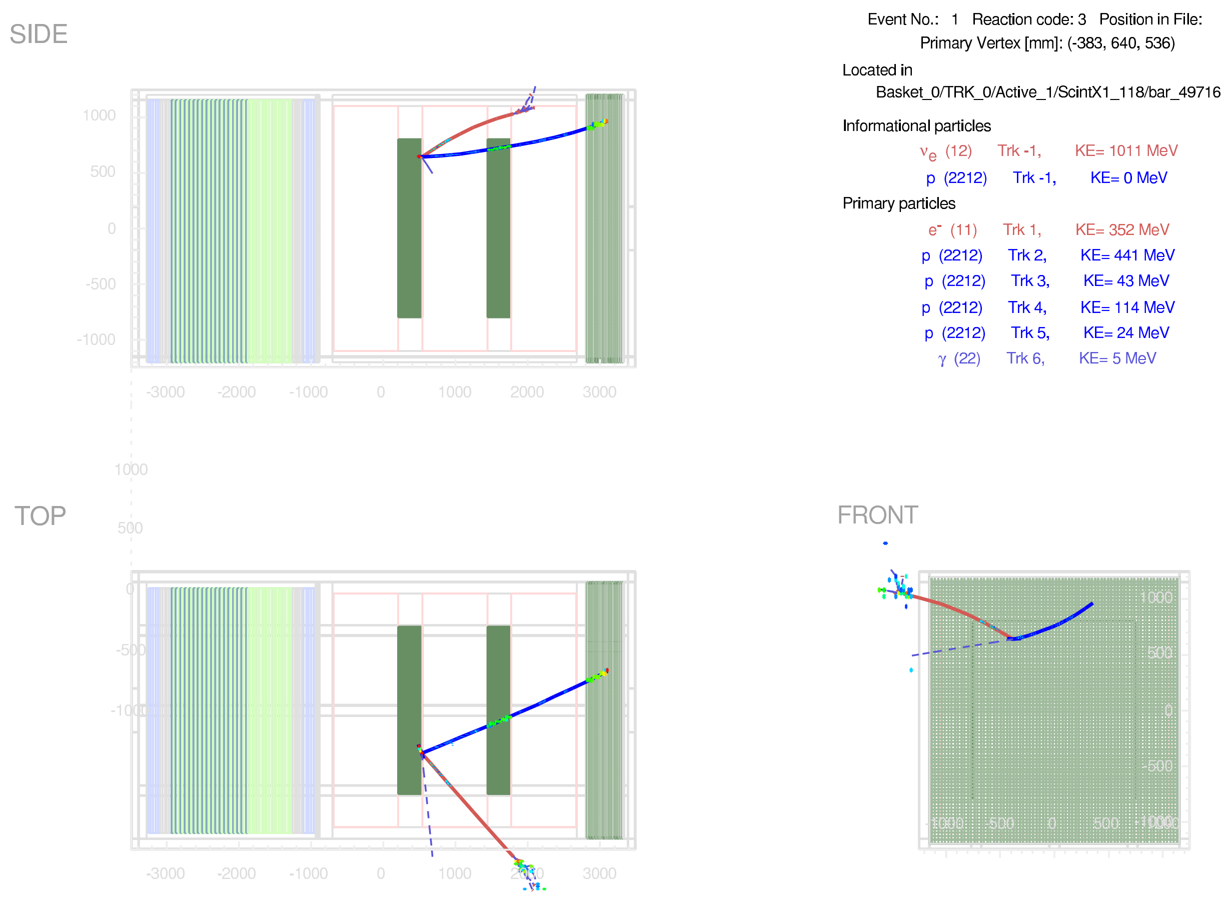


Figure 4.2: An event display of a simulated ν_e non-CCQE interaction in FGD1. The event topology resembles a CCQE interaction but the MC truth output shows that it was caused by a resonant pion production interaction. Lines indicate particle trajectories and detector hits are represented by colour-coded dots according to deposited charge. The incoming ν_e has an energy of about 1 GeV, with a 350 MeV outgoing electron (brown) which enters the BARREL and creates a small electromagnetic shower. In the BARREL, only the hits are shown in the interests of clarity. An proton (blue) penetrates FGD2 and stops in the DSECAL, leaving a large energy deposit at the end of its track. A good measurement of the electron and proton kinematics allows the classification of the event as not being consistent with a CCQE event caused by a beam neutrino.

of the kinematics of the electron and proton, the event can be classified as being unlikely to be due to a CCQE interaction caused by a neutrino travelling parallel to the beam.

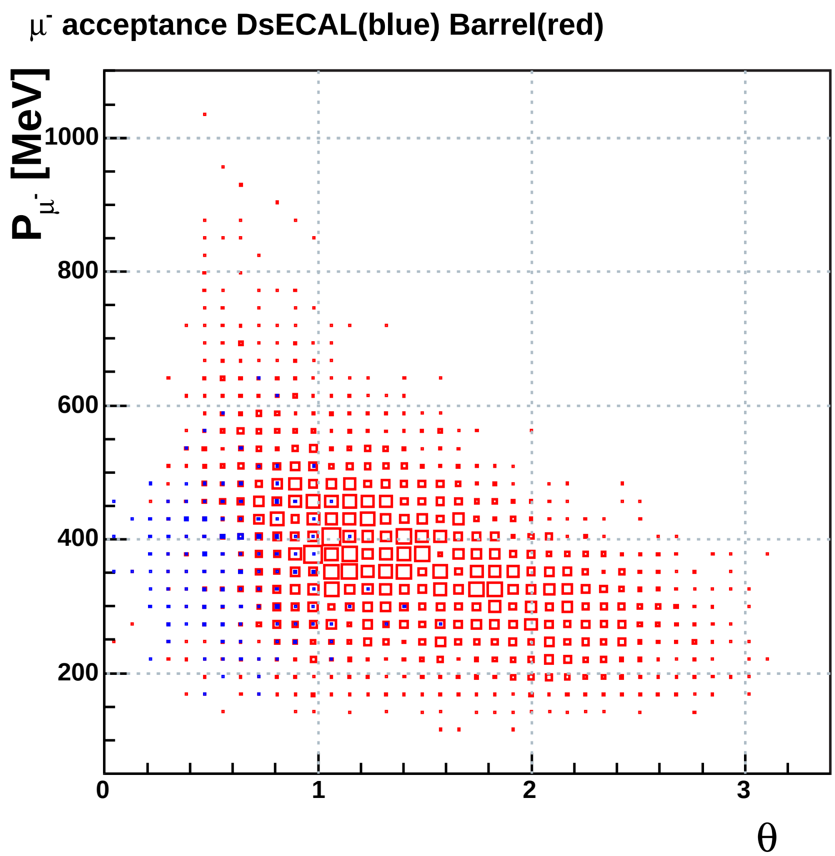


Figure 4.3: The true momentum spectrum and angular distribution of ν_μ CCQE muons originating in the FGDs, for the DsECAL (blue) and BARREL (red). About 65000 events per tonne of fiducial mass are expected in a year of running with 10^{21}p.o.t..

Electrons and protons can stop in subdetectors including the ECALs, as shown in Figs. 4.5 and 4.6. The figures demonstrate that the BARREL and DsECAL perform complementary tasks when measuring the signal interactions: particles from the two FGDs are observed in different ECAL sections, and the energy spectra of particles to be measured are different, especially for electrons.

CC-1π^+ interactions

The far detector, being a water Cerenkov detector, is able to make very good measurements of the leading lepton in a CCQE event. However, when a softer π^+ is emitted, this can be missed in the far detector reconstruction, skewing the energy reconstruction of the incoming neutrino, which depends on the quasi-elastic nature of the interaction. The near detector must be able to reconstruct these events with a much higher efficiency, so that their production cross section can be estimated. This will allow their contribution to the distortion of the energy spectrum to be disentangled from spectra observed at the far detector. The information from the ECAL can greatly aid the correct identification and reconstruction of these events.

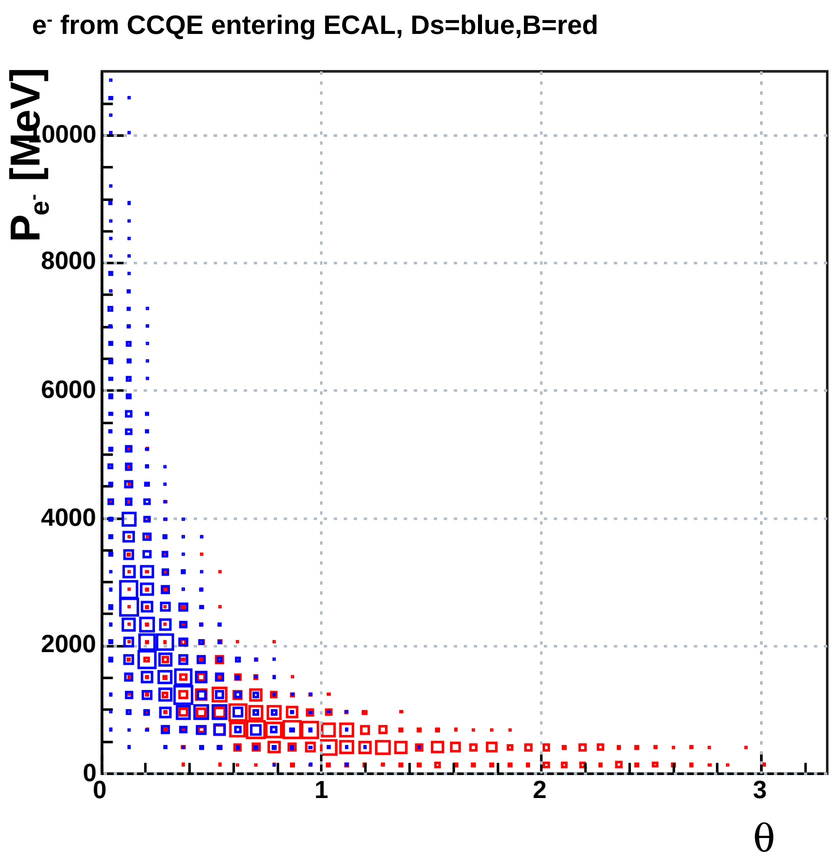
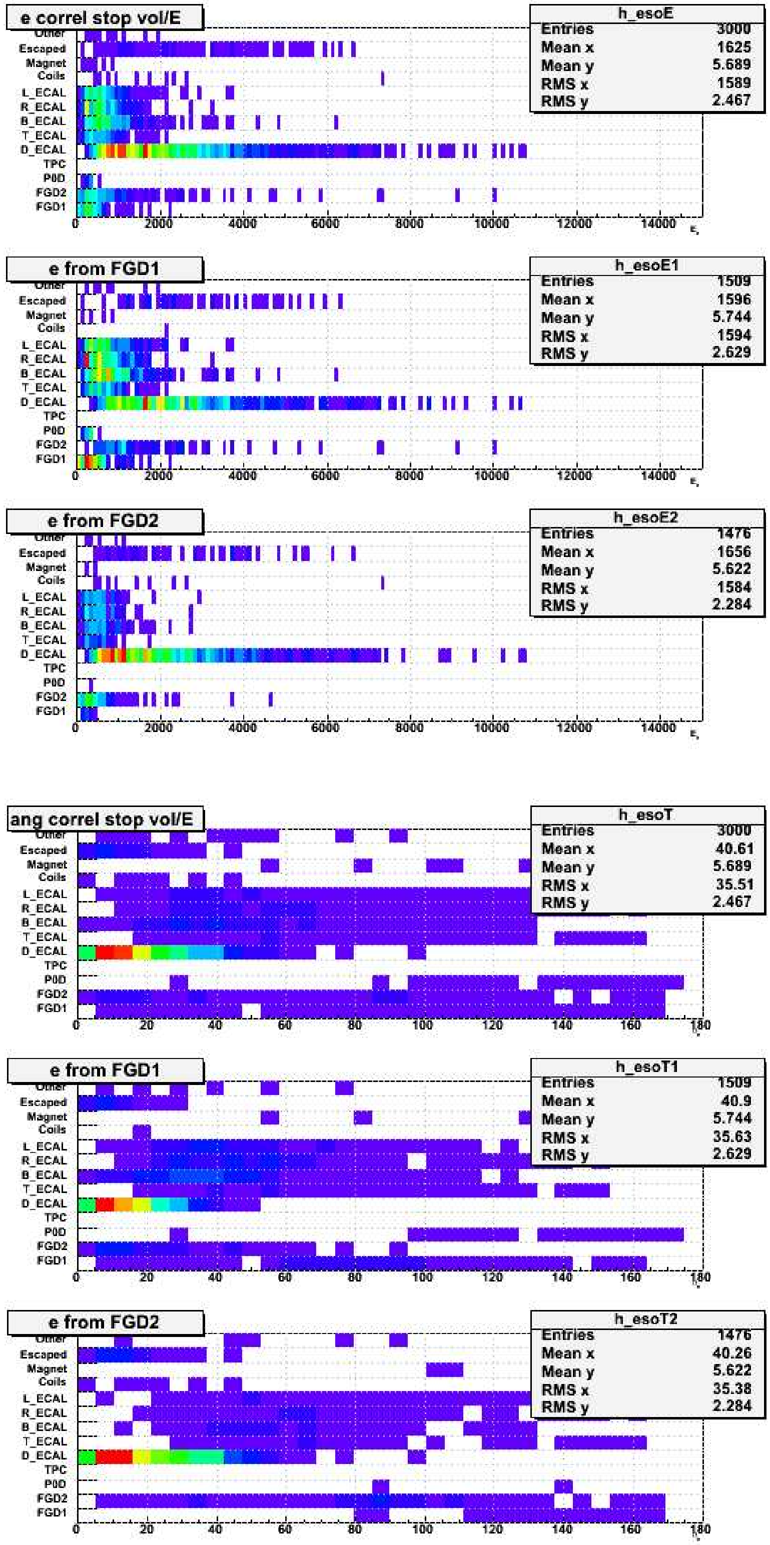


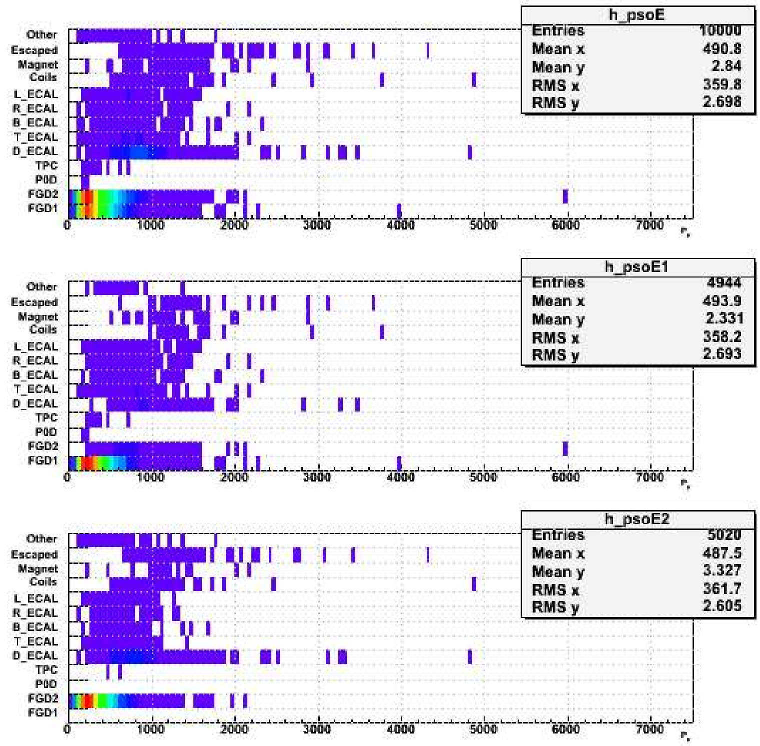
Figure 4.4: The true momentum spectrum and angular distribution of ν_e CCQE electrons originating in the FGDs, for the DsEcal (blue) and Barrel (red). About 400 events per tonne of fiducial mass are expected in a year of running with 10^{21}p.o.t..



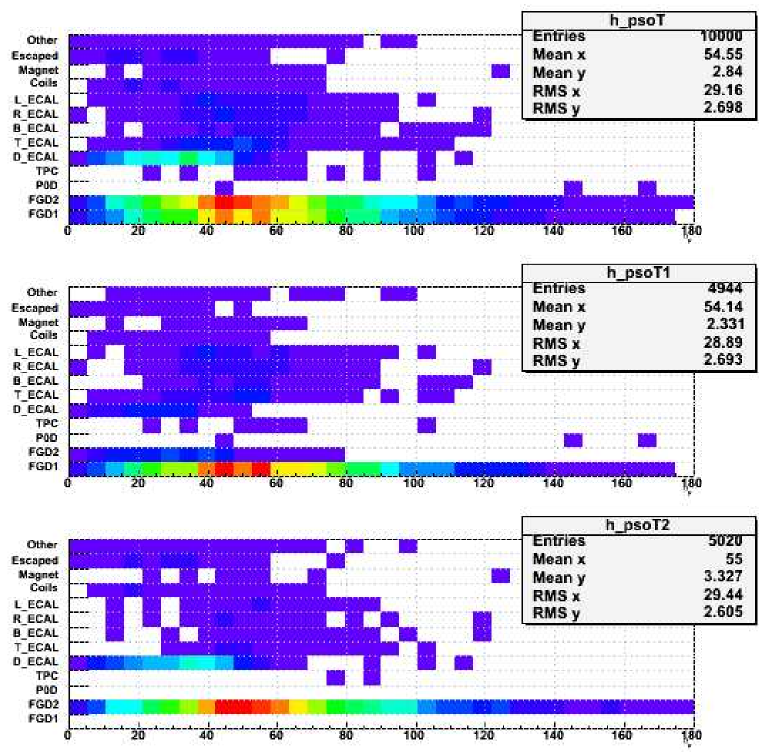
a)

b)

Figure 4.5: The a) energy [MeV] and b) angular [degrees] distributions of CCQE electrons from beam ν_e's, grouped by the detector component in which they stop.



a)



b)

Figure 4.6: The a) energy [MeV] and b) angular [degrees] distributions of CCQE protons from beam ν_μ's, grouped by the detector component in which they stop.

π^0 measurements

As discussed in section 2.4.2, one major goal of the ND280m detector is to allow the estimation of the rate of electron-faking π^0 interactions at Super-K. Therefore, this background channel to the ν_e appearance measurement is considered a "signal" for the near detector. Due to the extreme importance of this channel, two complementary ways of measuring these events are envisaged. The first is through the dedicated P0D, which should provide high statistics samples of π^0 events with its high reconstruction efficiency for forward-going photons. The second is by looking for interactions in the FGDs, using the ECAL as the principal detector for event reconstruction. An example of a π^0 that can be reconstructed in the ECAL is given in Fig. 4.7. The two methods of π^0 detection will have very different systematic uncertainties, with the latter method providing a powerful cross-check of the measurements made in the P0D.

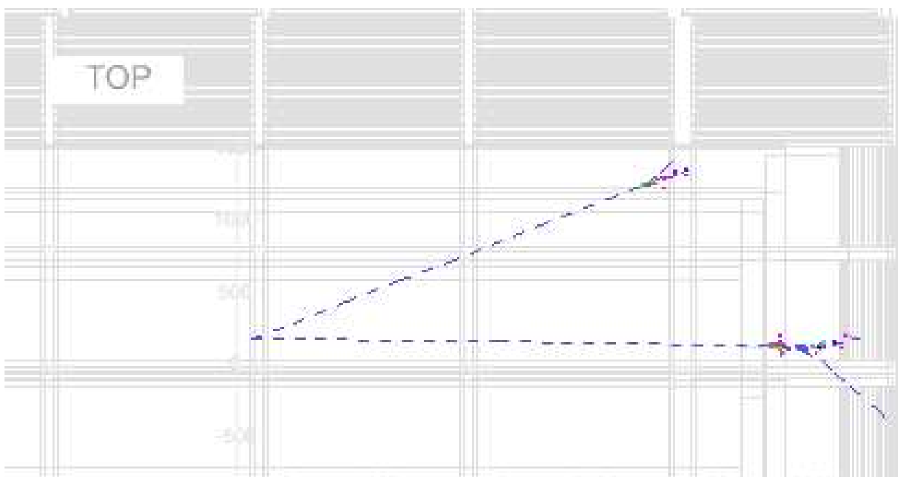


Figure 4.7: A π^0 decay event where the two photons shower in the ECAL. The dotted lines indicate the photon trajectories, and the hits in the ECAL are shown as coloured dots. It is possible to reconstruct the π^0 kinematics if the showers are sufficiently well-reconstructed.

4.2.2 Design Considerations

- The electromagnetic characteristics of the ECAL are driven by the radiation length (X_0) of lead, which is 5.6 mm. The interaction length, the characteristic length for hadronic interactions, is 171 mm for lead. Photons can travel appreciably in lead before interacting electromagnetically, and their mean free path in lead is $9/7\,X_0$, or 7.2 mm at 1 GeV, a figure which increases slightly at lower energies. These figures are for pure lead, and will change depending on the lead alloys chosen for reasons of engineering. The standard deviation of the barycentre position along the shower is 1.5 to $2\,X_0$ for photons, and about $1\,X_0$ for electrons.

- In contrast to many typical calorimeter designs, the ECAL must be able to handle signal interactions which can occur anywhere in the inner detector. Furthermore, the understanding of neutrino interactions on water and carbon rests on the reliable determination of the interaction origin of the particles in an event. Additionally, the ND280-OffAxis detector sits about 10 m away from the centre of the neutrino beam, and the inner detector and ECAL are surrounded by a magnet with a weight of several hundred tonnes. Hence the number of background interactions occurring in parts of the detector outside the fiducial volume is a few orders of magnitude greater than for the signal events. These considerations mean that the ECAL must be able to provide enough shape-based direction and pointing information to allow good event reconstruction and classification.

- The task of particle identification lies principally with the TPCs; the $\mathrm{d}E/\mathrm{d}x$, or energy deposited per unit length inside the TPC gas allows for very good discrimination between $e^{\pm}$, $\mu^{\pm}/\pi^{\pm}$, p for most of the momentum range of interest. However, for regions of phase space where the TPC is not able to make a good measurement, whether due to effects of geometry or momentum, the ECAL plays a crucial role in particle identification.

4.2.3 Design

The considerations outlined in the preceding section call for a detector with good pointing resolution but low dependence of performance on incoming particle direction, and good hermeticity while meeting constraints on both the outer and inner dimensions. This has lead us to settle on a highly-segmented sampling calorimeter design with plastic scintillator bars and lead absorber layers. A baseline ECAL has been specified as a representative design upon which further optimisation work will be conducted. The design and associated engineering studies are discussed in Chapter 5 – we concentrate here on our studies to optimise the ECAL design to understand the physics implications of any design decisions.

4.2.4 Design Optimisation

We define notation as follows for the Barrel (BARREL) and Downstream (DSECAL) detectors:

- Electromagnetic section (EM): the front part of the detectors, where the principal use is for actual energy measurement of EM showers.

  d^{EM} the thickness of the EM section.

  X_0^{EM} the number of radiation lengths in the EM section.

  N^{EM} the number of lead layers in the EM section.

  w^{EM} the width of the bars in the EM section

- Backing section (BK): the rear part, which facilitates background tagging, particle ID and extending the calorimetric energy range.

  d^{BK} the thickness of the BK section.

  X_0^{BK} the number of radiation lengths in the BK section.

  N^{BK} the number of lead layers in the BK section.

  w^{BK} the width of the bars in the BK section

In the baseline design, we have chosen not to include a backing layer, but this will be studied as an option during the optimisation stage. For all designs, the innermost and outermost layers are to be of scintillator to allow tagging of charged particles as they enter the detector.

Longitudinal and Transverse Segmentation

Initial studies have been based on 1 cm thick scintillator bars. Fig. 4.8 indicates the π^0 recon-

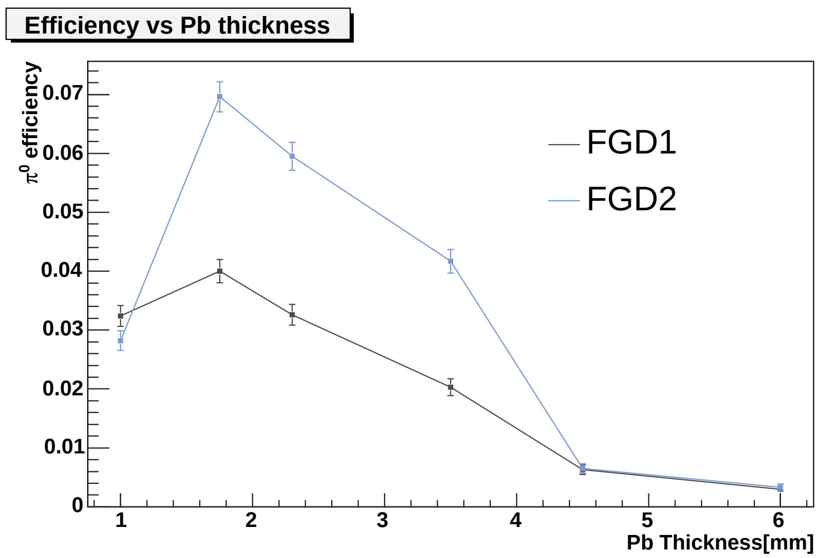


Figure 4.8: The effect of different lead layer thicknesses on π^0 detection efficiency, for 1 cm thick scintillator layers. The labels indicate the FGD from which the π^0 originated. Thicker lead layers lead to loss of information due to scattering and energy absorption, while layers which are too thin do not contain enough radiation lengths to convert the photons effectively.

struction efficiency as a function of lead layer thickness. For the baseline design we have chosen 1.75 mm for the thickness of the lead sheets, as a compromise between shower containment and good energy and shape reconstruction. Fig. 4.9 is of the π^0 reconstruction efficiency as a function of scintillator bar width w^{EM}. The ability to reconstruct π^0s is indicative of the detector's performance when observing electromagnetic showers.

Another reason to have good granularity is for the detector to be able to distinguish different types of particle. Particle identification between photons, electrons, protons, muons and pions requires the detector to recognise electromagnetic showers and their shape, $\mathrm{d}E/\mathrm{d}x$, tracks from minimum ionising particles, and more general properties of the energy deposits that particles leave.

In a detector with lead layer dimensions as above, electromagnetic showers have a transverse spread of about $w^{\mathrm{EM}} = 5$ cm. With a shape-based analysis to select electron showers in the nominal T2K neutrino beam flux, the fraction of misidentified muons worsens from about 10% to 35% as w^{EM} is increased from 2 cm to 4 cm.

We see that with a choice of 3 cm bars uniformly distributed through the detector, reasonable particle ID and energy reconstruction performance can be achieved. These bar sizes have been chosen for the baseline geometry.

More optimised scintillator bar geometries, including different combinations of w^{EM} and w^{BK} are to be studied as part of this work package.

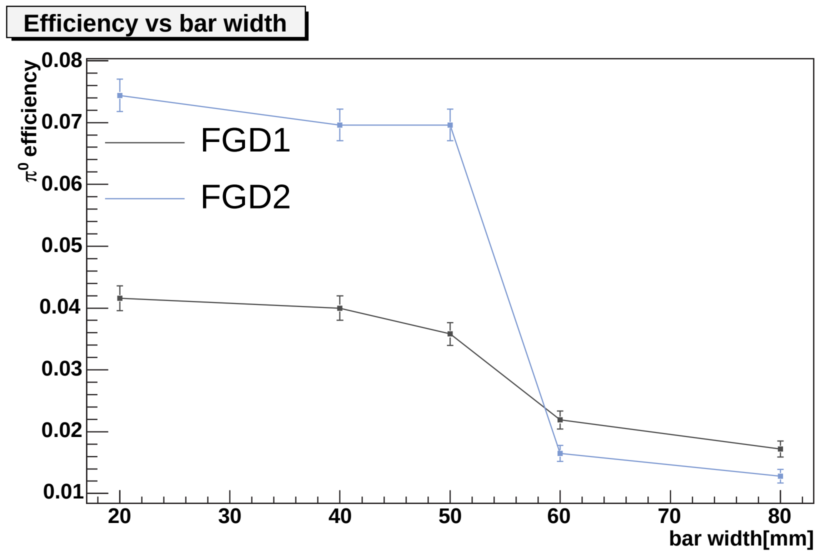


Figure 4.9: The effect of different scintillator bar widths w^{EM} on π^0 detection efficiency, for 1 cm thick scintillator layers. The labels indicate the FGD from which the π^0 originated. It can be seen that increasing detector granularity in the transverse direction by using narrower bars does not help electromagnetic shower reconstruction once the effect of the Molière radius starts to dominate.

Total Thickness

The outer dimensions of the ECAL are constrained by the size of the UA1 magnet and coil, which leave a space of about 3.5 m $\times$ 3.5 m $\times$ 7.2 m for the ECAL and inner detectors. Therefore the thickness of the ECAL sections has a direct impact on the space available for the inner detectors and their fiducial target volumes. We are working with an upper limit on the ECAL thickness of 50 cm. Fig. 4.10 shows the energy resolution as a function of incoming electron energy and the number of lead and scintillator layers. It can be seen that for thinner geometries, energy reconstruction starts to suffer at electron energies above 0.5 GeV.

For the baseline design, we have 33 lead layers N^{EM} in the BARREL, leading to $X_0^{\mathrm{EM}} = 1.75\mathrm{mm}/X_0^{\mathrm{Pb}} \times N^{\mathrm{EM}} \sim 10$. The DSECAL has 37 lead layers with $X_0^{\mathrm{EM}} \sim 12$.

4.3 Inputs

Inputs from other work packages within the proposal are :

- Provision of results from photosensor performance studies on the ECAL (WP3).
- Provision of electronics characteristics (WP4).
- Provision of results from engineering studies on the ECAL (WP6).
- Provision of results from calibration studies on the prototype (WP7).
- Provision of physics coding framework (WP8).
- Provision of information on the beam (WP9).

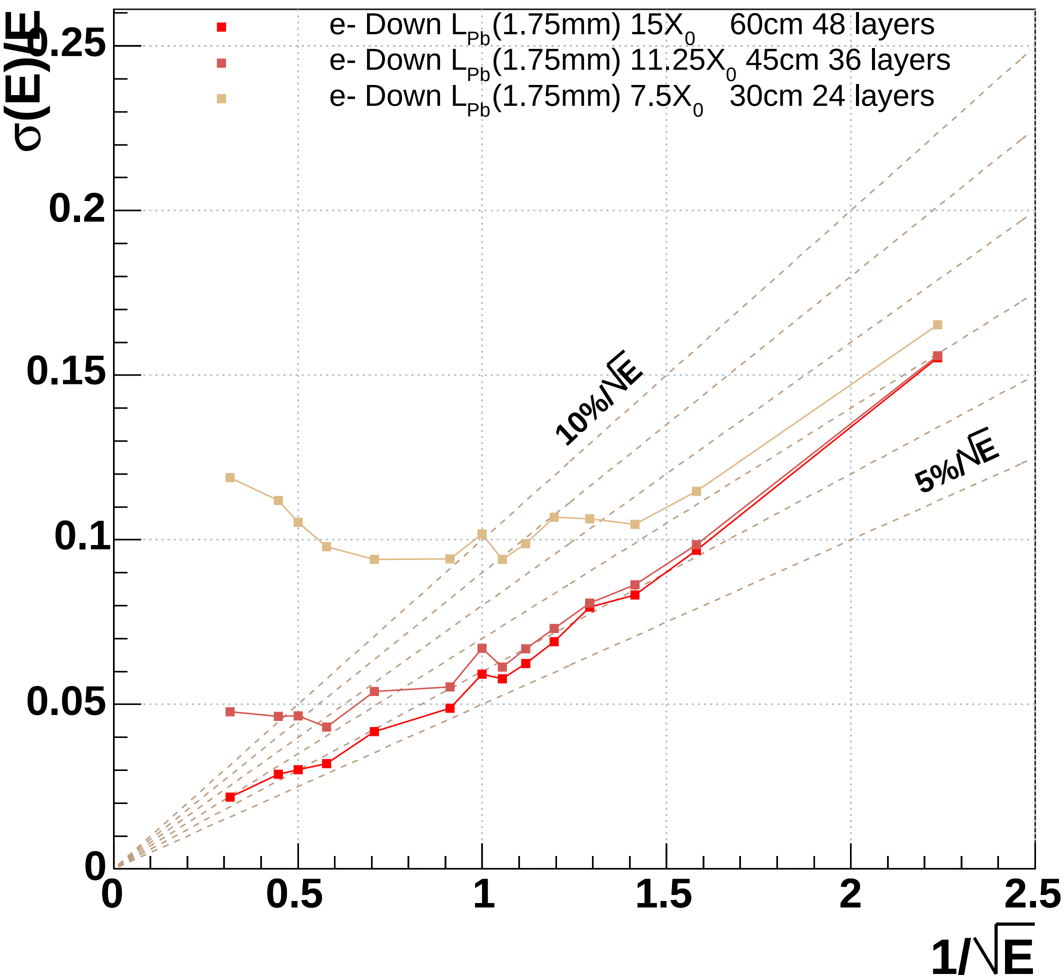


Figure 4.10: Electromagnetic energy reconstruction resolution of electrons in the DsECAL. The three data series correspond to different d^{EM}, the total thickness of the lead / scintillator sandwich section. The horizontal axis is $1/\sqrt{E}$ [GeV]. The baseline DsECAL has been chosen to contain 37 lead layers.

4.4 Objectives and Milestones

We describe in the following how work in this work package is to be conducted. Some of the items below are closely tied to work in the Offline Software Tools work package (Chapter 11). We make the distinction that the present work package covers software work that is an inherent part of the optimisation studies and event simulation and reconstruction, while more general software tasks (e.g. simulation and reconstruction framework building, photosensor / electronics modelling tools) would be included in the remit of the Software work package.

4.4.1 TASK I: Physics Studies and Optimisation Preparation

(Estimated FTEs/year: 2.0)
The first task in this work package is to ensure that all the tools and information necessary for design optimisation are made available. These include the following:

- Keeping track of developments in all other areas of ECAL and other subdetector design.
- Ensuring that the results of hardware studies and design choices are incorporated into the software framework.
- Performing the physics studies which are needed to allow design choices to be judged within the full physics context of the experiment.
- Developing the optimisation studies into a systematic procedure for making design decisions.
- Taking any issues raised by the optimisation studies and feeding them back into the ongoing hardware and engineering studies.

The physics studies will go beyond the ECAL and will involve all developments that affect the experiment. External influences such as a beam hadronisation experiment, and the SciBooNE[26] experiment, could offer rich material for incorporation into these studies which should be exploited in the work package.

The work described here will continue in the subsequent tasks in the work package, but a milestone can be defined as the time at which all of the components necessary for ECAL design optimisation have been made available.

This milestone should be reached by July 2006.

4.4.2 TASK II: Provisional Optimisation

(Estimated FTEs/year: 2.0)
After the work for the first milestone is completed, the optimisation group should provide a provisional optimised design to the ND280m collaboration.

The provisional optimisation milestone should be reached by September 2006.

4.4.3 TASK III: Final Optimisation

(Estimated FTEs/year: 2.0)
At the time that the specifications of the ECAL components and surrounding detectors are known, a final study will be performed to finalise the design and confirm that it performs adequately and is cost effective. These specifications include:

- the performance of the photosensors, scintillator bars and WLS fibres;
- the alloy chosen for the "lead" layers;
- the materials used in the engineering design;
- the properties of the inner detector and MRD designs.

The quality of the studies and knowledge of the detector at the provisional optimisation stage will determine the nature of the changes at this time. It would be highly desirable that any modifications at this stage are minimal. However, there may be some design choices that depend critically on external inputs which may have to be postponed until the final optimisation.

The final optimisation milestone should be reached by October 2006.

4.4.4 TASK IV: Continued Physics Studies

(Estimated FTEs/year: 4.0)
After the full specification of the ECAL, the construction work performed in the other work packages will come into full swing. From this point forwards, the emphasis of the present work package will move further towards working with the other work packages and collaborators around the world to understand the detector that is being built. For example, the Photosensors work package will be working on characterising the actual photosensors that are being delivered and built into the detector. This information will be propagated into the software for the near detector through cooperation with the Software work package. It will be the responsibility of the present work package to take this, and similar information regarding all aspects of the experiment, ensure that the physics tools are updated as necessary to reflect these, and feed back anything of significance to the other work package and groups in the collaboration. This will allow any ongoing optimisation of aspects such as calibration strategies and DAQ methods to be made with a good appreciation of their impact on the overall physics output of the detector.

At the same time, the physics tools will be managed in this work package to incorporate any new ideas and developments.

The work in this task is of an ongoing nature, with regular deadlines, typically coinciding with Physics or Collaboration meetings, which will arise as it is conducted in close cooperation with the rest of the collaboration.

At the time that the ND280m detector enters data-taking, the present work package must have a full set of tools to be ready for the incoming data. This milestone would therefore be set for early 2009.

4.4.5 TASK V: Commissioning

(Estimated FTEs/year: 7.0)
In April 2009, the off-axis inner detectors should be in place and the J-PARC neutrino beam will start running. From this time, real data will allow the physics algorithms to be tested and the signal and background rates in the detectors to be understood. Later in the year the ECAL will be installed and the beam luminosity will increase. The physics work package will combine the real data, and measurements from the beam and the slow controls, with the algorithms prepared in the preceding tasks and the *in situ* calibration data to ensure that the collaboration is fully prepared for the exploitation phase of the experiment. At the end of 2009, the work package will be able to deliver a set of tools for physics analysis and estimations of the sensitivity of the experiment given real detector and beam conditions.

4.5 Outputs

The present workpackage will provide a well-balanced final physics design for the ECAL, and a body of physics understanding of the entire experiment which will allow us to transition smoothly to the exploitation phase of T2K.

Chapter 5

Work Package 2: ECAL

5.1 Institutes Responsible

This work package will be provided by CCLRC Daresbury Laboratory, Lancaster University, Liverpool University, Queen Mary University London, Sheffield University and Warwick University. The work package managers are L. Kormos (Lancaster) and C. Touramanis (Liverpool).

5.2 Key Personnel

The work package managers have extensive experience in construction, commissioning, and exploitation of scintillator detector systems (C. Touramanis: CPLEAR PID and BABAR ECAL), and neutral particle reconstruction and neutrino experiments (L. Kormos: OPAL, SNO). Design engineering is covered by A. Muir (Daresbury Laboratory) and P. Sutcliffe (Liverpool University), who successfully designed the BABAR endcap ECAL. A. Grant (Daresbury Laboratory) is the ECAL project engineer. C. Touramanis and A. Grant are members of the T2K-ND280 Technical Board.

A number of highly skilled technical staff from the Rolling Grants and CCLRC/DL have been identified for production/assembly activities. A number of fixed-term technicians will be hired at Daresbury Laboratory to provide the significant effort required due to task complexity and tight timescale. A small number of project-funded RAs and technicians at University groups are requested to complete the total manpower for ECAL delivery.

The proposed ECAL has been designed in CAD. We have performed FEA studies to identify materials that will allow us to build an optimum detector (i.e. large active area and minimum material in the path of incoming photons) within the required mechanical specifications. We have also identified a large building at Daresbury Laboratory, with a 30-tonne crane and clean rooms, which will be available to us from early 2006 and for the duration of the planned activities (end 2009).

5.3 Introduction

As discussed in section 2.4.2, the Electromagnetic Calorimeter (ECAL) consists of two main regions: the BARREL region which surrounds the inner detectors; and the DSECAL (Downstream ECAL) region which forms a plane downstream of the inner detectors and occupies the last 50 cm of the basket. The entire ECAL, both BARREL and DSECAL regions, is constructed of alternating layers of lead and scintillating plastic with sufficient radiation lengths of material to contain electromagnetic showers of photons, electrons and positrons with energies up to 3 GeV. Fig. 5.1 shows that at least $10X_0$ of material are required to ensure that more than 50% of the energy resulting from photon showers initiated by π^0 decay is contained within the ECAL. Well contained showers are essential to obtaining good energy resolution, since the energy of an incident particle is linearly proportional to the total energy of the resulting shower.

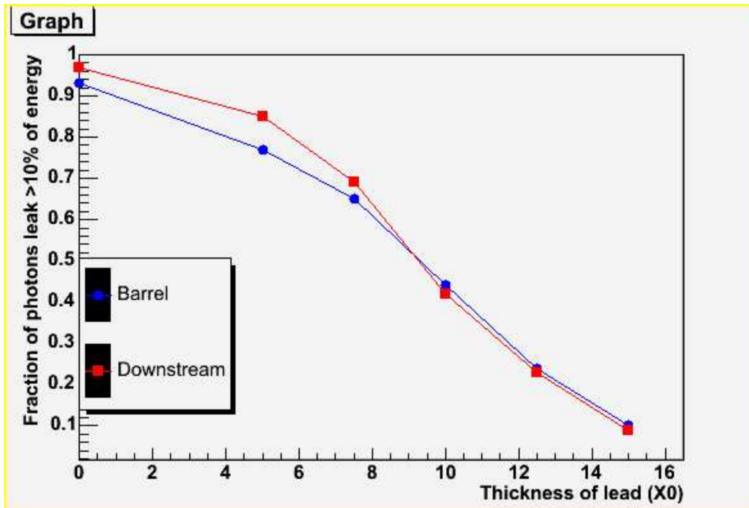


Figure 5.1: Electromagnetic shower containment versus lead thickness. Plotted is the fraction of photon energy lost versus the number of radiation lengths of material in the BARREL (blue) and DSECAL (red) regions, for photons produced by π^0 decay.

5.3.1 The Barrel Electromagnetic Calorimeter

The BARREL region sits inside the magnet coils but outside the basket and is attached at mounting points to the iron of the magnet yoke. The magnet yoke-and-coil assembly is designed to come apart into two C-shapes, as shown in Fig. 5.2, to allow for maintenance and repairs. The space inside the magnet yoke and coils that is available for the ECAL and all of the subdetectors within the basket is approximately 3.2 m (height) $\times$ 3.2 m (width) $\times$ 6.2 m (length). The space between the basket and the yoke-and-coil assembly must accomodate both the active region of the ECAL and the support, cooling and electronics requirements. The BARREL region is divided into six super-modules, two on the top, two on the bottom, and one on each side of the basket. Wherever possible, uniformity between the super-modules has been maintained for ease of design, construction, and calibration; hence, the BARREL super-modules differ only as necessitated by the routing of cooling pipes and electronics both from the ECAL and from the subdetectors inside the basket. Each of the super-modules is approximately 6.2 m(long) $\times$ 50 cm(deep); they vary only in width, with the exception that the ECAL surrounding the P0D is approximately 40 cm deep to allow for the routing of cables and cooling pipes into and out of the P0D. As a result, the longitudinal scintillator bars from which the super-modules are composed are either 620 cm or 420 cm long, with the latter corresponding to the 10 innermost layers, which are absent in the region surrounding the P0D. The perpendicular bars are either 150 cm, 140 cm, or 230 cm, corresponding to the top,

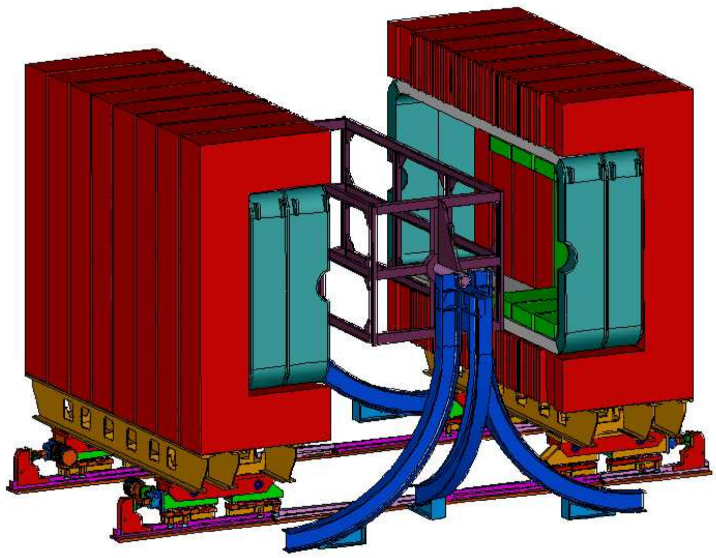


Figure 5.2: The basic structure of the magnet yoke (red), coils (blue), and the basket which holds the inner subdetectors. The ECAL fits inside the yokes and the coils, but outside the basket, as illustrated in green.

bottom, and side super-modules, respectively. The DSECAL bars are the same size as those of the side super-modules. The total number of bars is shown in Table 5.1.

Length of bars (cm)	Number of bars
620	4240
420	1767
150	6360
140	6360
230	9047
200	2913 (prototype)

Table 5.1: The number of plastic scintillator bars required for the ECAL.

Each super-module has 33 layers of 1.75 mm thick sheets of lead alternating with 34 layers of plastic scintillator bars, with the exception of the region surrounding the P0D, which has 23 layers of lead and 24 layers of plastic. The top super-modules are approximately 1.5 m wide, the bottom super-modules approximately 1.4 m, and the side super-modules approximately 2.3 m. In order to obtain good position information for track reconstruction and particle identification, a crossed geometry was chosen for the scintillator layers, such that alternating layers of scintillator run longitudinally (in the beam direction) and perpendicular to the beam direction. Each super-module begins with a scintillator layer of perpendicular bars, and ends with a longitudinal scintillator layer.

Each scintillator layer is composed of individual bars of extruded plastic scintillator which are glued onto the lead-alloy layer beneath. The scintillator bars have a rectangular cross-section of dimensions 1 cm (thick) $\times$ 3 cm (wide), and a central hole running down the length of the bar through which a wavelength-shifting (WLS) fibre is inserted in order to collect the light produced in the scintillator. The scintillator bar width of 3 cm was chosen as a compromise between detector channel cost and position resolution. For particle identification and tracking information, smaller widths are favoured as was discussed in Chapter 4. This is highlighted in Fig. 4.9, which shows that the π^0 reconstruction efficiency becomes seriously compromised for bar widths above 5 cm. The scintillator bar thickness of 1 cm was chosen to minimise the overall depth of the ECAL. Since it sits between the basket and the magnet, a thicker ECAL necessitates a smaller basket, and thus smaller inner subdetectors. A bar thickness of less than 1 cm does not provide sufficient light to produce a reliable signal.

The super-modules have masses ranging from approximately 11 tonnes to 15 tonnes. The crane at the detector facility in Tokai by which the modules will be lowered into the detector hall is rated to handle up to 10 tonnes; hence, each super-module is further divided radially into three modules, such that the inner layers form one module, the middle layers form another, and the outer layers form the last module. This yields 18 such modules, each of which is encased in a 2 mm thick light-tight carbon-fibre box for structural rigidity. The number of layers of lead-alloy for the inner, middle, and outer modules is 10, 11, and 12, respectively. For engineering purposes, the heaviest module is the outer module, which is directly attached to an aluminium strongback, of depth 5 cm, fastened to the magnet yoke at the mounting points. The middle module is attached to the outer module, and the inner module is attached to the middle module. The carbon-fibre box around each module is the carrying structure that can withstand and absorb all forces during transport, mounting, and normal operation in the magnet. Each box has all the appropriate mounting points to affix the ECAL to the magnet yoke, and is designed to include all of the necessary strengthening that will keep the modules within the specified maximum deformation envelope.

5.3.2 The Downstream Electromagnetic Calorimeter

The DSECAL sits inside the basket downstream from the other inner detectors and forms a plane perpendicular to the beam of dimensions 2.3 m $\times$ 2.3 m. It is constructed in the same way as the BARREL region, but with $12X_0$ of material rather than 10 in order to obtain reasonable data for the high numbers of particles which have a large forward momentum. This increased number of radiation lengths requires 37 layers of lead, and hence 38 layers of scintillator. Unlike the BARREL region, the mass of the entire DSECAL is small enough that the entire super-module can be placed *in situ* in Japan using the 10-tonne crane, negating the need to divide it into modules. The scintillator bars, each of which is 2.3 m long and 3 cm wide, have a crossed geometry, with alternate scintillator layers running in the x direction and in the y direction. One test module, based upon the DSECAL design, will be constructed for refining the construction procedure and testing the design, as well as for calibration and test-beam studies. This module will be 2.0 m $\times$ 2.0 m $\times$ 50 cm.

5.3.3 The Readout Channels

The light emitted from each WLS fibre will be collected by photosensors, each of which will be mounted into a specially-designed connector which holds both the photosensor and the WLS fibre, with an appropriate air gap between them. Fig. 5.3 is a cut-away view of the connector, showing the WLS fibre entering on the right, and the photosensor on the left with an air gap in between of a size chosen to maximise the light collection efficiency. Having the photosensors very near to the plastic bars eliminates the need to attempt to make a sharp bend in the WLS fibre, which has a large minimum radius of curvature. The fibres will be read out on each end of every longitudinal scintillator bar, which allows one to reduce background by requiring a coincidence between both ends of the bar, and also improves the uniformity of the signal by reducing the size of the attenuation correction needed. In order to minimise the channel count, the shorter (perpendicular) bars will be read out at one end only and mirrored at the other end. The total number of readout channels in the entire ECAL is 33,500. The total length of WLS fibre is approximately 70 km. The central 60 cm $\times$ 60 cm of the prototype will be instrumented with readout at both ends so that the effect of single-ended readout can be calibrated: hence, the prototype requires an additional 1520 channels, bringing the total to approximately 35,000 channels. Likewise, the prototype will also require approximately 6 km of WLS fibre, bringing the total to 76 km.

The photosensors are connected to the front-end boards (FEBs), which lie inside the carbon-fibre light-tight box enclosing each ECAL module. Each FEB services 64 readout channels, is approximately 10 cm $\times$ 15 cm in size, thus matching well the size of the light-tight box, and requires two cables to exit the box, as discussed in more detail in Chapter 7. In this way, the number of light-tight feedthroughs is greatly reduced compared with a scenario where the FEBs are outside the light-tight box. A carbon-fibre honeycomb structure prevents the lead and scintillator layers from crushing the electronics within the box. The mounting of the FEBs within a module is shown in Fig. 5.4.

5.4 Inputs

In order to meet the commitments of this work package, input is required from the following work packages:

- Provision of an optimised ECAL design (WP 1).
- Provision and support of the photosensors (WP 3).
- Provision and support of the electronics (WP 4).
- Provision and support of the data acquisition system (WP 5).
- Provision of prototype design specifications (WP 7).

5.5 Objectives and Milestones

The construction of the ECAL will be accomplished by sharing the work between several United Kingdom (UK) institutions. The main assembly will be done at Daresbury Laboratory. The fibre will be delivered by the supplier in "canes" of appropriate lengths, i.e. approximately 5–10 cm longer than the lengths of the scintillator bars, except for those longer than 500 cm, which will be delivered on spools. The mirroring of the WLS fibres will be contracted out to FNAL.

5.5.1 Task I: ECAL Design

A. Muir is providing the detailed ProE design of the BARREL. In addition, he is designing a specialised structure which attaches the horizontal section of the coil to the magnet yoke, including the mounting points for the ECAL modules. Together with A. Grant, he is designing the necessary

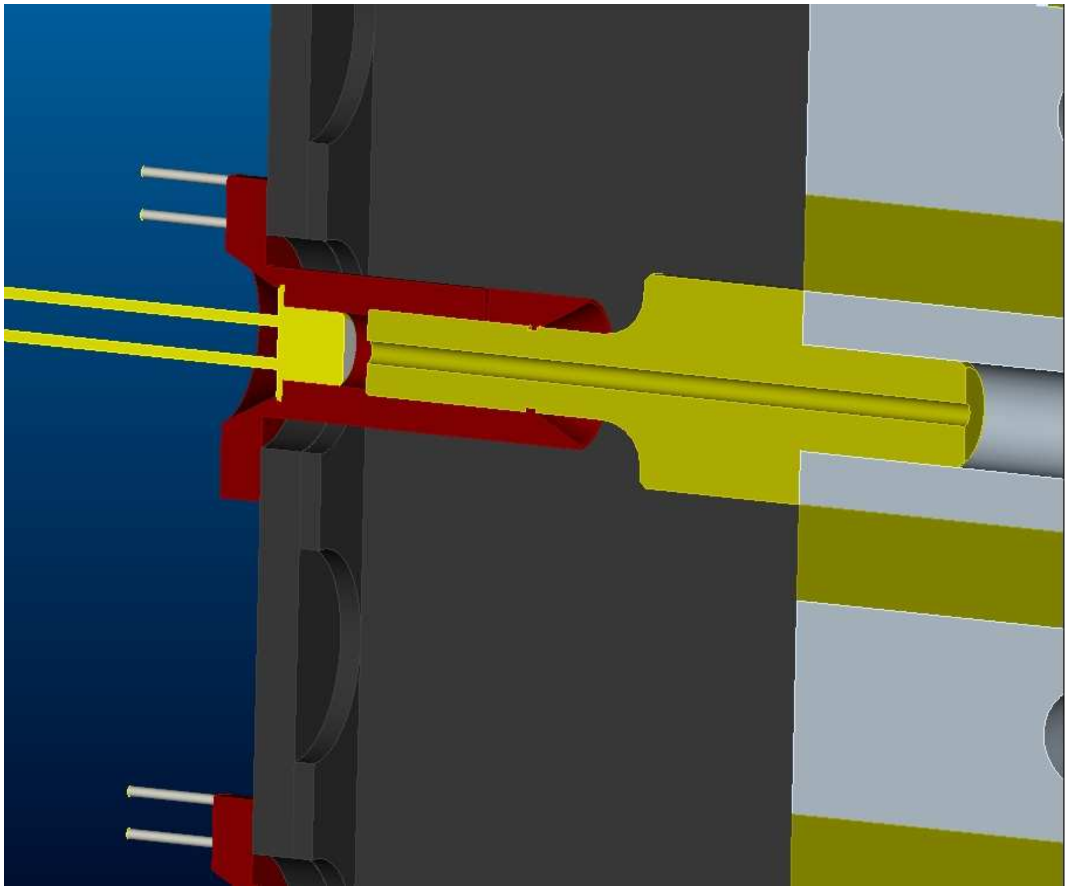


Figure 5.3: A cut-away view of the connector for the photosensor. The plastic scintillator bar is shown in light grey on the right, with the WLS fibre held in place within the central hole by a specially moulded grommet, shown in gold, inserted into the hole, which then supports the fibre and carries it to the photosensor connection, shown in red. The photosensor, shown in yellow, clicks into position inside the connector.

equipment for the installation of the ECAL into the magnet. P. Sutcliffe is providing the detailed ProE design of the DSECAL, and also doing the FEA studies for the entire ECAL. All of these duties must be finalised in a consistent manner by October 2006, allowing firm orders for the major components of the ECAL, such as the scintillator, to be made in good time.

5.5.2 Task II: Procurement

The following people are responsible for ensuring that all of the equipment and materials required to construct the ECAL arrive in time to allow adherence to the schedule: A. Grant, L. Kormos, P. Sutcliffe and C. Touramanis. Potential suppliers have already been contacted for the critical items, such as scintillator, WLS fibres, etc. The last phase of this task will be to ensure that adequate spares and service materials will be available for the commissioning and exploitation phases.

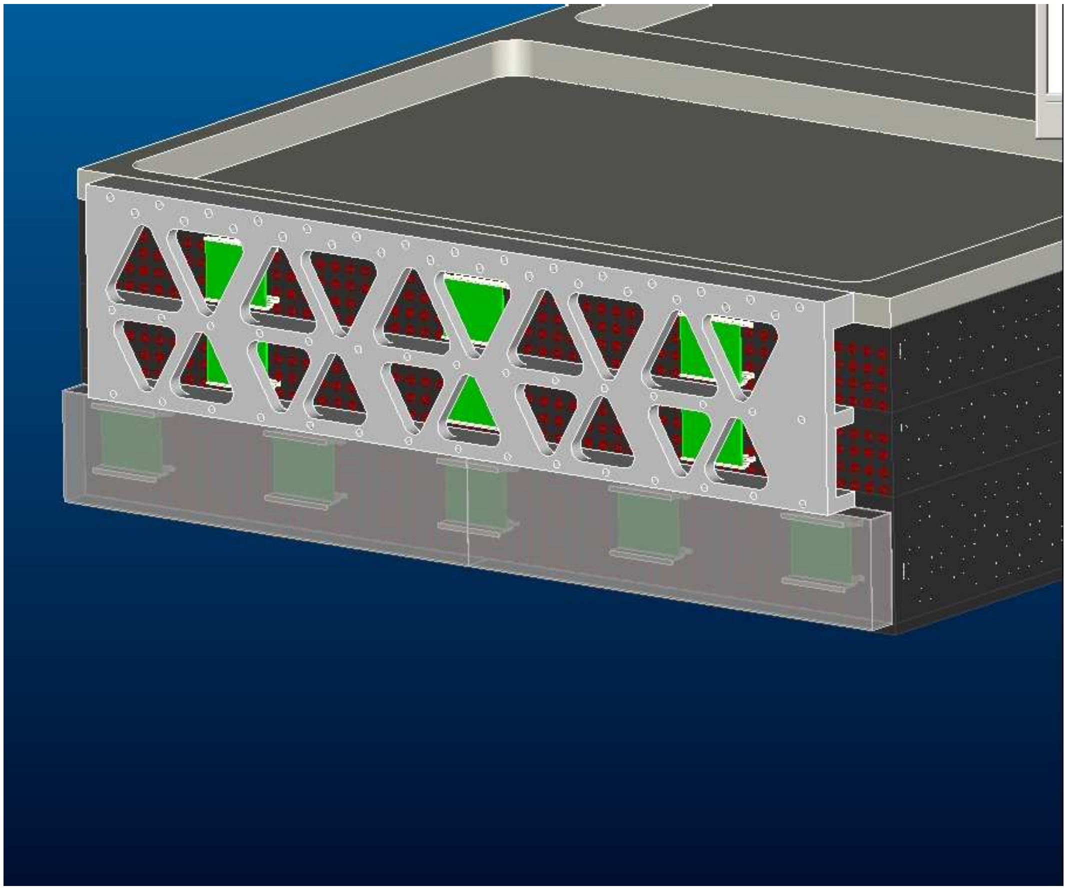


Figure 5.4: The FEBs (green) are shown mounted inside a module. The readout channels are shown as red dots, the supporting honeycomb structure is light grey.

5.5.3 Task III: Preparation of Production Facilities

Major preparation will be required at Daresbury Laboratory, including the construction of large tables, storage space, and the preparation of clean-room facilities, etc., before the ECAL can be built. In each of the 5 universities that are involved in the ECAL construction process, appropriate workspace must be prepared, such as assembly and storage space, and necessary infrastructure must be put in place. Dark boxes will need to be constructed in order to conduct the scanning of the scintillator/fibre assemblies that is discussed in Section 5.5.5. The corresponding scanners, which will be constructed under WP 7, will have to be installed together with their computing system, and the scanning system must be commissioned. The deadline for these preparations to be complete is Nov 2006 so that realistic tests with pre-production scintillator and fibre can be performed at all participating institutes in Dec 2006. The ECAL production manager at each location is responsible for organising this task using local manpower. These people are G. Barker, A. Bevan, A. Grant, L. Kormos, L. Thompson, and C. Touramanis.

5.5.4 Task IV: Production Co-ordination and Transportation

Shipments of the scintillator and WLS fibre will arrive at Daresbury Laboratory, and then have to be distributed among the universities for the initial stage of assembly as detailed in Section 5.5.5. Once this initial stage is complete, including the quality assurance (QA) checks described in Section 5.5.5, the fibre-equipped scintillator bars must be sent back to Daresbury for final module assembly and testing. A tracking database system will be implemented to trace the individual components throughout this procedure. This database will be updated at all production locations, allowing the co-ordination of transporation between Daresbury and the universities in a timely and efficient manner. This task will be carried out by the work package managers and the project engineer, along with technical support from rolling grant staff. In order to keep all groups on track, monthly meetings between the universities' ECAL production managers, the key technicians, the work package managers, and the project engineer are essential during the period from Jan 2007 until Sept 2009, or when the production phase has finished.

5.5.5 Task V: Stage 1 Assembly

Each of the institutions listed in Table 5.2 will be responsible for threading the WLS fibres through the central holes of the plastic scintillator bars, and affixing the fibre using a grommet at each end of the bar. The unmirrored end of the fibre then will be cut and polished, and inserted into a photosensor connector similar to the one shown in Fig. 5.3. The diamond cutter to be used at this stage polishes the fibre as it's cut. Each fibre-equipped bar will then be tested by scanning along the length of the bar with a low-rate radioactive source using the same readout electronics as will be used in the final detector (see Section 10.5.3). The bars will then be packaged and shipped to Daresbury. The amount of manpower months required at each institution for this task has been calculated by A. Grant and is consistent with the numbers in Table 5.2 and the manpower listed in Table A2.1. The responsibility for ensuring that the task is completed in a timely manner falls upon the ECAL production manager at each institution, and ultimately upon the work package managers. This task will be accomplished with the support of technical staff, RA staff and rolling grant staff.

5.5.6 Task VI: Stage 2 Assembly

Upon arrival of the fibre-equipped scintillator bars at Daresbury, the bars will be assembled into layers via the following procedure: each plane of prepared bars will be bonded onto sheets of lead-calcium-tin alloy, and tested using an *x*-*y* scanner; the assembly will be done during the day, and then the bonding adhesive will be allowed to dry overnight whilst the plane is being scanned in order to use time and manpower efficiently; subsequently, the planes will be assembled into modules. This part of the assembly relies on Daresbury Laboratory technical staff and fitters, under the supervision of the project engineer.

5.5.7 Task VII: Stage 3 Assembly

The photosensors will be shipped to Imperial College London, Sheffield University, and Warwick University, where quality assurance (QA) studies will be performed, as described in Section 6.5.6. The movement of the photosensors will be entered into the tracking database described in Section 5.5.4. As these studies are completed, the photosensors will be shipped to Daresbury, affixed to the connectors, and attached to the modules. Following this, the FEBs will be attached in place, and

Bars to be handled	Institution	Timescales
420 and 620 cm bars	Daresbury Laboratory	2006 - 2009
230 cm DsECAL bars	Queen Mary University London	2007 - 2009
230 cm side ECAL bars	Sheffield University	2007 - 2009
230 cm side ECAL bars	Warwick University	2007 - 2009
150 cm bars	Liverpool University	2007 - 2009
140 cm bars	Lancaster University	2007 - 2009
200 cm bars for prototype	Daresbury Laboratory	2007 - 2009

Table 5.2: The institutions which will be involved in ECAL construction.

the modules will be enclosed in the light-tight carbon-fibre boxes. Technical staff at Daresbury will provide the manpower for this task, with support if required from technical staff at other institutions.

5.5.8 Task VIII: Packaging and Shipping

Each complete module will be tested by technical staff at Daresbury before it is packaged and shipped to Japan, as described in WP 6.

5.5.9 Task IX: Commissioning

After installation of the ECAL detector (see WP 6), the commissioning phase of the detector begins, using both cosmic rays and beam interactions. It is expected that physicists will spend a significant amount of time *in situ* in Japan learning to understand the behaviour of the detector and solving start-up problems, whilst others in the home institutes will be working offline to assist in this. This task will last until the end of the Proposal grant period, after which the exploitation phase will begin. The commissioning phase will involve a large fraction of the physicists on the project.

The following milestones have been set:

- May 2007 to Sept 2009: Main construction phase for the ECAL begins. This will require the scintillator bars and WLS fibre to be shipped to the pertinent institutions by Spring 2007.
- Dec 2007: A full prototype to be built, consisting of a scaled-down DsECAL module, of dimensions 200 cm $\times$ 200 cm $\times$ 50 cm. This will require approximately 24 FEBs to be ready so that the electronic system can be tested along with the scintillator. The main purpose of this module is to test the Monte Carlo simulations, and ensure that the module plus electronics functions as expected.
- Summer/autumn 2008: Testing of the prototype (probably at CERN) using electron/pion particle beams (see 10.5.4).
- Spring/summer 2009: Testing of the prototype using a photon beam (probably at Mainz, see 10.5.4).
- Nov 2009: Packaging and shipment of ECAL Super Modules to Japan for integration with the rest of the ND280m detector.

The main milestones are shown in the Gantt Chart in Fig. 5.5.

5.6 Outputs

This work package will output a fully-functioning and tested electromagnetic calorimeter, complete with cooling system and primary electronics.

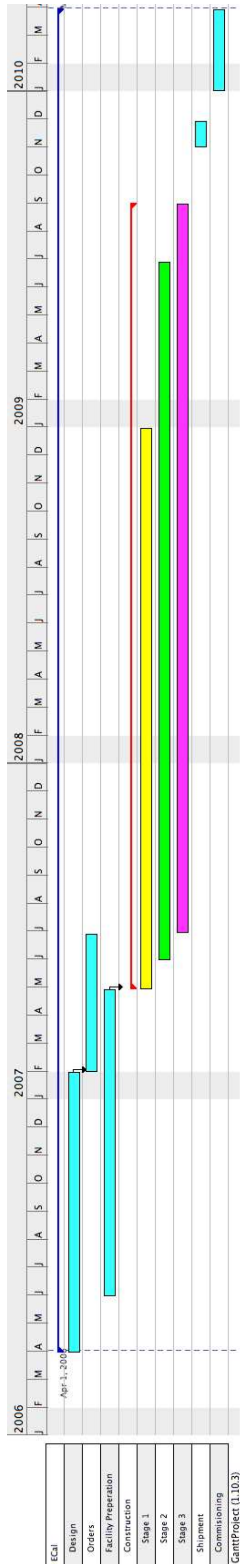


Figure 5.5: The main milestones for the ECAL work package.

Chapter 6

Work Package 3: Photosensors

6.1 Institutes Responsible

This work package will be provided by Imperial College London, Sheffield and Warwick. The work package managers are A. Vacheret (Imperial College) and G. Barker (Warwick).

6.2 Key Personnel

The key personnel are the staff primarily responsible for the running of the three UK testing sites. These are G. Barker (Warwick), L. Thompson (Sheffield) and A. Vacheret (Imperial College). Each has extensive experience with detector development and fabrication. G. Barker was for many years associated with the development of silicon microstrip detectors and was a key member of the DELPHI silicon microvertex upgrade. L. Thompson has a wealth of experience with scintillation detector techniques through e.g. his work on the Antares experiment and more recently through his investigations of water scintillator detectors. A. Vacheret was instrumental in the design, construction and implementation of the HAPPEX-II and E-158 Cerenkov calorimeters. Test benches are currently being developed at each of the three testing sites and contributions to evaluating photosensor performance, the readout electronics and the design of a suitable fibre-to-sensor connector have already been made.

6.3 Introduction

The specification of suitable photosensors is dictated by the environment in which they are required to function and the demands of the physics we want to measure.

6.3.1 Requirements

All active sub-systems of the ND280m are installed inside the magnet and must operate in a 0.2T magnetic field for a period of at least five years. The light yield expected for a minimum ionising particle depositing energy in a 1cm thick scintillator bar is about 10–15 photo-electrons at 30cm from the end of the WLS fibre. However, the typical attenuation length of WLS fibre is approximately 3.5m, with the result that signals at the level of only 2–4 photo-electrons are expected after light has traversed the longest scintillator bars of the ECAL. The ND280m design positions all photosensors *inside* the magnet volume rather than outside because of the following constraints :

- The number of channels for the scintillator based detectors is too large for the limited space that available for cables to be fed through the magnet.
- The low light yields and the attenuation length factor of the WLS fibres prevent us from running long distances of fibre across the detector.

The sensors will therefore be mounted as close as possible to the scintillator bars and must be able to function in a 0.2 T field and operate reliably and stably over many years. The large number of readout channels also dictates that the ideal sensor will have low power consumption and be available in large batches at a reasonable cost per unit. Furthermore, precise measurements of the energy of electrons and γ showers demands good linearity – within a range of up to a few hundred photo-electrons. From the J-PARC beam, neutrino interactions will occur inside a 58 ns window.Each of these beam buckets will be separated by hundreds of ns, so while the photosensor is required to be fast, the recovery time is not an major issue since the occupancy of neutrino events under normal running conditions is low.

Finally, it is important that the space occupied by the front-end readout electronics is kept to a minimum in order to leave the total fiducial volume of the target detectors like the P0Dand the hermeticity of the ECAL unaffected. The design of the electronics scheme is discussed in Chap. 7.

This defines the main requirements for a photosensor suitable for use at the ND280m detector. The current technologies available and the choice of photosensor are discussed in the next section.

6.3.2 Photosensor candidates

The technology available to detect green light from WLS fibre falls into two main categories :

- Vacuum devices: all devices derived from the classic vacuum photomultiplier principle such as the Multi-Anode PMT (MA-PMT), Micro-Channel Plate Photomultiplier (MCP-PMT) and Hybrid photodetector (HPD).
- Solid state devices : devices that uses p-n junction-type structures to amplify the photon signal. Candidates that have been tested are the standard Avalanche Photodiode (APD) and the Metal Resistor Semiconductor based APD or Avalanche Multipixel Photodiode (AMPD), also known as the Silicon Photomultiplier (SiPM).

Table 6.1 summarises the degree to which each of the main available photosensor technologies satisfies the ND280m photosensor requirements.

With reference to Table 6.1, some of the candidate sensors can be immediately ruled out as unsuitable: The MA-PMT cannot operate in high magnetic fields and would require additional shielding to function correctly in a field of 0.2T. With the significant number of devices required inside the magnet this extra shielding would adversely affect the uniformity of the dipole field.

Both HPDs and APDs are relatively low gain devices (of order 10^5). This is partially offset in the case of the APD by its excellent quantum efficiency (typically, 80%). Unfortunately the noise level of APDs operated at room temperatures is too high for our purposes, i.e. to resolve low light levels ($<$ 20photo-electron). They also require cooling to around -20 C, which effectively rules out their use.

There are MCP-PMT devices on the market which largely meet our requirements e.g. the Burle 85001 has been proven to work in a 0.2T field and has a typical gain of 6×10^5. A drawback to this

Requirements	MA-PMT	MCP-PMT	HPD	APD	AMPD
$B >= 0.2$T	×	✓	✓	✓	✓
Quantum efficiency	0.2	0.3	0.3	0.8	0.3
1 P detection	✓	✓	✓	×	✓
Gain $> 10^5$	✓	✓	low	low	✓
Linearity	✓	✓	✓	✓	limited
ENF	1.3	1.3	1.0	2	1.0
Fast response $<$ 10ns	✓	✓	✓	✓	✓
Recovery time	✓	✓	✓	✓	✓
Size	large	large	large	small	small
Longevity (5years)	✓	under tests	under tests	✓	under tests
Cost	average	average	high	low	low
Power consumption	high	high	high	average	low

Table 6.1: Summary table of various photosensor technologies compared to the ND280m photosensor specification. ENF stands for Excess Noise Factor and is related to the additional noise coming from the amplification process (an ideal amplifier has ENF = 1).

type of device is its size and the fact that fibres would need to be bundled before coupling (since they are 64-channel devices) which has obvious consequences for space allocation. In addition, some aspects of MCP-PMT operation still remain to be proven including the lifetime of the device.

From what is currently known of the photosensor candidates, AMPDs are the only devices that satisfy all requirements as listed above, and test results of prototype devices are presented below. For this reason the AMPD has been selected as the preferred option with which to instrument the P0D and ECAL, and the MCP-PMT is identified as a back-up solution which could provide a reasonable level of performance albeit with changes needed to detector engineering and electronics design.

Avalanche Multipixel Photodiode Devices

The Avalanche Multipixel Photodiode (AMPD) is an array of silicon p-n junction cells operated just above the breakdown voltage (i.e. in Geiger mode). The idea originated in Russia in the late 1990's and the first devices were developed by PULSAR (Moscow), CPTA Company (Moscow) and by Dubna electronic. The technology is therefore rather mature and in recent years other manufacturers have begun production programs for AMPDs, most noticeably, Hamamatsu Photonics (HPK) in Japan and several other companies in Europe e.g. SensL In Ireland and Photonique SA in Switzerland.

A detailed description of the avalanche photodiode method operating in the Geiger mode can be found in [29, 30, 31, 32]. The most advanced device for particle detection currently available places the avalanche photodiode on the base of a Metal-Resistor-Semiconductor (MRS) structure. This resistive layer acts to 'quench' the avalanche process by providing a opposing electric field in a type of negative-feedback mechanism. A schematic and the principle of operation of such a device is shown in Fig. 6.1. The typical bias voltage values are in the range of 25–100 V depending on the size and number of pixels. Each pixel operates as an independent Geiger micro-counter with a gain of the same order as a vacuum photomultiplier. The Geiger discharge is initiated by a photo-electron, a thermally released electron or from an area with a high electric field.

The pixel size can be in the range of 15–70 μm, and the total number of pixels is typically 100–

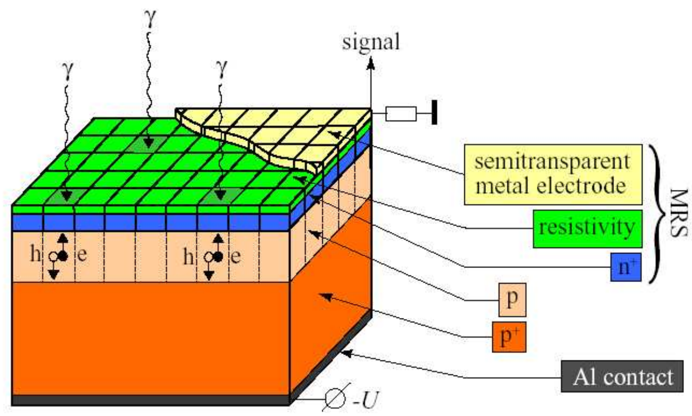


Figure 6.1: General layout of a AMPD photosensor. From [34].

4000 per mm^2. Fig. 6.2 shows a device made by CPTA (Moscow) which has a round sensitive area of 1 mm^2 containing 600 pixels. Each pixel operates as a binary device in such that a pixel signal

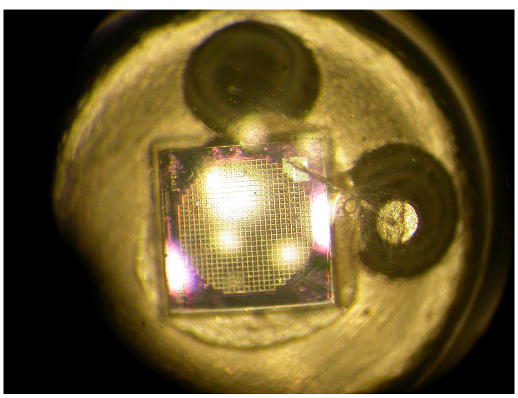
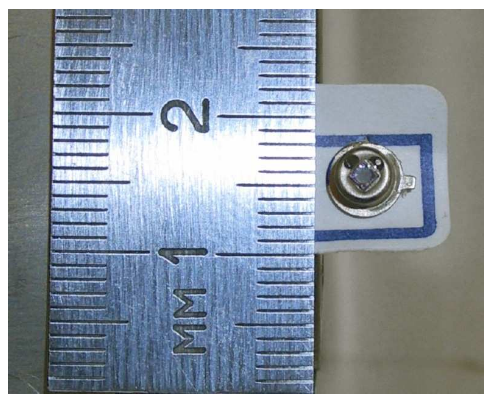
a)  b) 

Figure 6.2: a) The photosensitive face of a AMPD manufactured by CPTA. b) The AMPD in its cylindrical housing of diameter $\sim$ 4mm.

does not depend on the triggered number of carriers in that pixel. In this way, the AMPD signal is the sum of fired pixels and the detector acts as an analogue device with a dynamic range limited by the finite number of pixels. The nuclear counter effect for AMPDs is negligible.

The time response and ADC spectrum of an AMPD output is shown on figure 6.3 for a low intensity LED signal. The decay time of the signal is defined by the pixel size and the value of the quenching resistor. It varies between a few nanoseconds to hundreds of nanoseconds and the amplitude is of the order a few millivolts for 1 photo-electron.

The peak structure on top of a continuous distribution is the manifestation of the 'dual' behaviour of the device. The peak represents the discrete charge values for 1 to 3 pixels triggered by photo-electrons. The resolution on each peak is determined by a combination of the statistical fluctuation in the 1 photo-electron signal and the electronics noise generated in the front-end electronics and cables. Each pixel that contributes to the signal adds fluctuations to it and as the number of photo-electrons increases, so the peaks broaden. This clear structure of photo-electron

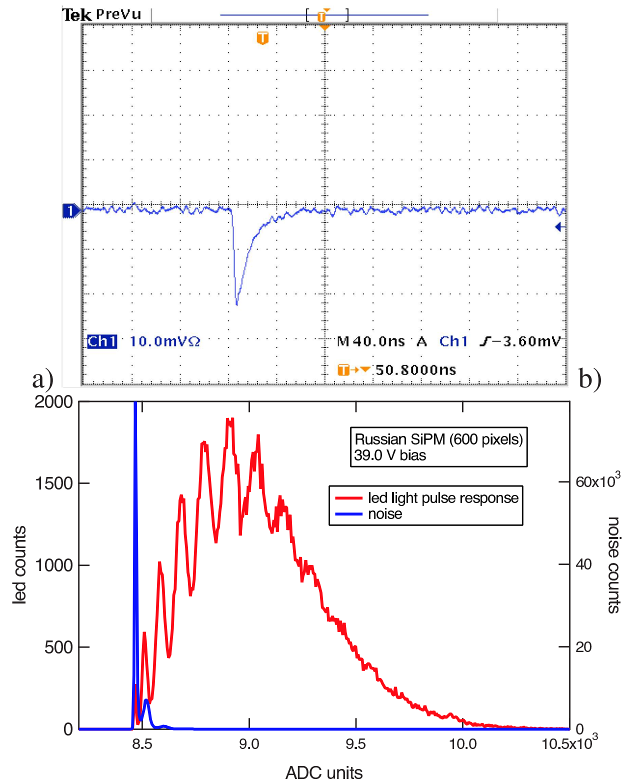


Figure 6.3: a) The photo-electron signal (10 times amplification) of a 400 pixel HPK prototype. The photo-electron raw signal amplitude is therefore of 1–2 mV and 10ns wide which corresponds to $\approx$ 0.2 pC of integrated charge. b) The integrated charge spectrum of a CPTA 42V in red for 200k LED pulses measured with a Trip-t front-end electronic chip (see Section 7.3.1). The blue curve shows the pedestal i.e. the signal with the LED off. Some dark rate counts can be seen at the one photo-electron level on the blue curve.

peaks at low light yields provides a possible mechanism with which to trace gain variations of the AMPD which could greatly simplify the task of calibrating each channel. If this can be achieved, it would represent one major advantage of using the AMPD, and this idea is explored further in the Calibration WP description (Chap. 10).

Parameters of the AMPD

- **Gain**

  The gain of an AMPD is determined by the charge accumulated in the pixel capacitance

  $$Q_{pixel} = C_{pixel} \cdot \Delta V \tag{6.1}$$

  where ΔV is the difference between the bias voltage and the breakdown voltage of the diode (i.e. the overvoltage). Since ΔV is a few volts, $C_{pixel} \simeq 50$ fF, corresponding to $Q_{pixel} \sim$ 150 fC or 10^6 electrons.

  Each pixel has a quenching resistor which controls the Geiger discharge fluctuations and therefore the pixel-to-pixel gain variations. The resulting photo-electron resolution is at the 5–10% level even at room temperature and is dominated by electronics noise.

The gain has a dependence on temperature and bias voltage changes. Typically, for the CPTA devices run at 42V bias, a 0.1 V variation in bias voltage corresponds to 2–3% change in gain and 5% change per 1°C. The absolute gain depends on the AMPD topology and bias voltage and typical values are in the range of 0.5–1.0 $\times 10^6$. Individual devices of the same type can have gains that vary by up to $\pm$25% at a fixed bias voltage.

- **Photon detection efficiency**
  The AMPD photon detection efficiency (PDE) can be approximated by product of 3 terms

$$\varepsilon \quad = \quad QE \cdot \varepsilon_{Geiger} \cdot \varepsilon_{pixel} \tag{6.2}$$

  where QE is the wavelength dependent quantum efficiency, ε_{Geiger} is the probability for a photo-electron to initiate the Geiger discharge, ε_{pixel} is a fraction of total active AMPD area occupied by sensitive pixels. All these terms depend on the sensitive silicon layer, size and configuration of the pixels. Currently, the PDE of AMPDs is in the range of 20–30% but much research effort is being put in by manufacturers to raise it above the 50% mark.

- **Dynamic range**
  The AMPD dynamic range is limited by the finite number of pixels m. Quantitatively, the response of an AMPD becomes non-linear at signal levels of about $N_{p.e.} > 0.2 \cdot m$.

- **Timing**
  The development of a Geiger discharge in the thin ($\sim 0.8\ \mu m$) depletion region takes a few hundred picoseconds. The typical rise time is 1 ns, whereas the decay time is determined by the pixel capacitance. The intrinsic time resolution measured with a very fast red-laser diode follows the Poisson law: $\sigma_t = 120ps/\sqrt{N_{p.e.}}$.

  Known problems of AMPDs :

- **Noise**
  The limiting factor of AMPD performance is the dark rate, which originates from carriers created thermally and the effect of high electric fields. At a 1 photo-electron threshold, the dark current is of the order 1–2 MHz/mm^2. This rate decreases exponentially with the threshold value and becomes negligible above a threshold of 2–3 photo-electrons. The dark rate can also be reduced by cooling and at 100°K, it drops to $\sim$1 kHz/mm^2. This parameter is the dominant limitation to the maximum size of the active area of an AMPD.

- **Crosstalk**
  A source of crosstalk between pixels in an AMPD comes from optical photons emitted during pixel discharge. Such photons have a significant probability of reaching the neighbouring pixel and causing an additional discharge. This optical crosstalk, if nothing is done to counter it, is at the level of 30 %. New technologies with trenches between pixels could reduce this crosstalk to 10%.

- **Recovery time**
  The recovery time of a pixel depends on its size and the electric field intensity. An AMPD pixel is able to trigger another discharge after a few μs. For low light levels, the recovery time decreases to tens of ns, partly due to the fact that only a small number of pixels have fired and a most of them are still available.

6.4 Inputs

The successful completion of the photosensor work package tasks is not dependent on the output of any other work package in this proposal.

6.5 Objectives and Milestones

AMPD photosensors designs have been evolving quite rapidly recently and significant improvements are foreseen in the near future. For example, as discussed earlier, HPK is committed to releasing a device that will meet our requirements by the mid-2007. Furthermore, the CPTA company has already made significant progress toward reducing optical crosstalk using new techniques and they are working closely with our Russian collaborators to optimise their devices. A test-bench at Imperial College has been in place for many months in order to allow us to learn about the devices and we are currently monitoring the performance of different prototypes from CPTA and HPK. Preliminary tests have also been made at Warwick and Sheffield.

We believe the technology to be mature enough for our purposes and only a few uncertainties remain about the longevity and product uniformity in mass production. However, AMPDs have not yet been used in a real experiment and so objectives and milestones concerning the photosensor candidate have to be assessed carefully in order to ensure that a final product with the requested specifications can be produced within the ND280m timeframe. An R&D phase with periodic reviews with manufacturers is required in order to finalise the development of the device. Pre-series testing and quality monitoring will be arranged with the manufacturers in order to start the production of a final device mid 2007.This should give enough time to supply photosensors for the start of scintillator bar module fabrication and allow for the construction of a full prototype at the end of 2007 (see Section 5.5). Reception of the batches, quality assurance tasks and book-keeping procedures will be conducted during the whole delivery period from 2007 to the end of 2008. The photosensors will gradually be integrated into the ECAL supermodules and calibration will performed *in situ* before shipping to Japan.

In summary, the milestones associated with this work package are :

- Definition of the technical specifications and quality assurance criteria prior to tender offer
- Complete design and testing of the AMPD connector prior to tender offer
- Complete development of the AMPD calibration method
- Complete pre-production tests

The schedule for each task in the work package is shown in Table 6.4.

6.5.1 TASK I: Measurement of basic parameters and performance

This task comprises all the tests needed to characterise and compare performance of the various prototype devices. Feedback and discussion of the results with the manufacturers will play an important part in subsequent design iterations. This task is also crucial in developing and fine-tuning our AMPD response simulations. A series of tests will be conducted in order to evaluate the critical characteristics including the following:

1. Gain and photon detection efficiency

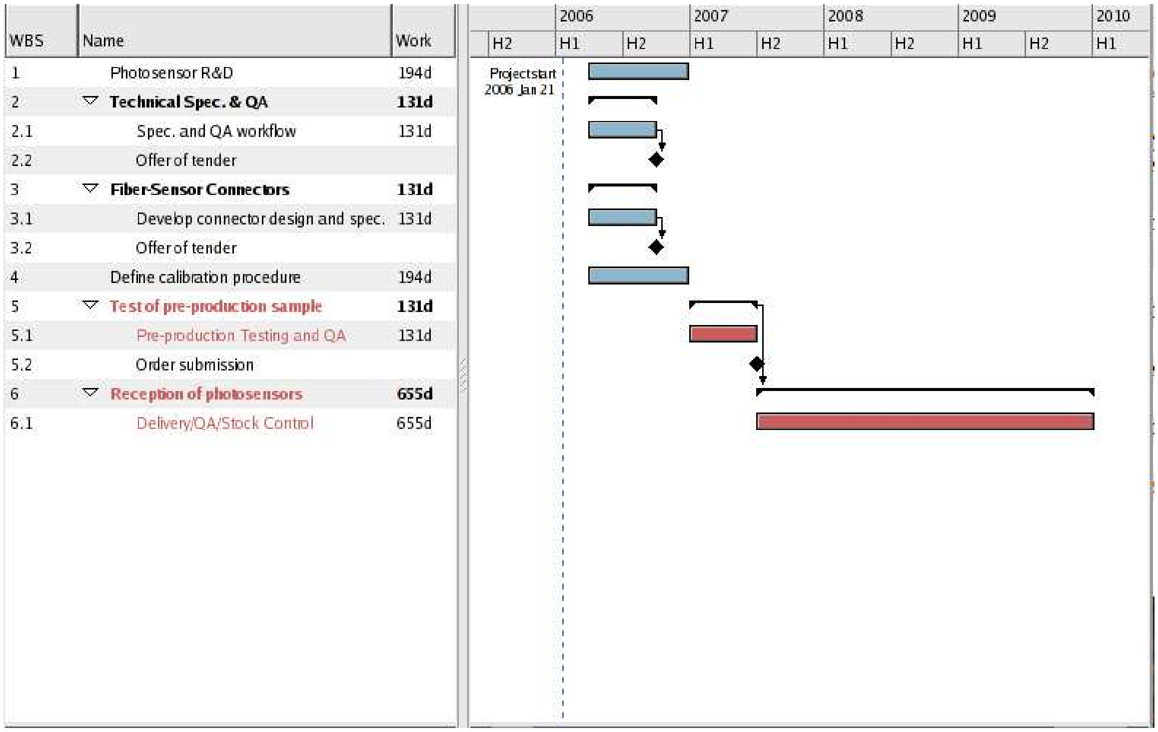


Figure 6.4: Schedule and important milestones for the photosensor development and production.

2. Linearity of response

3. Dark rate and crosstalk

4. Effect on gain of bias voltage and temperature fluctuations

5. Study of response with WLS fibres

6. Uniformity

7. Longevity

Because of the sensitivity of the device gain to temperature, tests will have to be made in a controlled temperature environment. The humidity will also be monitored closely for any correlation with the observed properties. Longevity and uniformity tests will require the simultaneous monitoring of a significant number of devices.

This work is scheduled to run from the start of the proposed period until the first quarter of 2007 in preparation for the placement of firm orders for devices (see below).

6.5.2 TASK II: Specification of production devices

After a period of AMPD prototype tests lasting three to six months, a list of specifications needs to be defined prior to opening contract negotiations with the potential photosensor manufacturers. Not only do the basic properties of the device need to be defined at that point but also all aspects of device acceptance criteria and agreements about the development and production schedules.

Technical specifications should be ready in time to open tendering from the second half of 2006. This will allow sufficient time for further developments and design reviews.

The batches of production devices will need testing for quality control before being passed for use in detector modules. For this a fast, computerised collection of device measurements based on the experience of the TASK I work will be developed. Of particular importance is knowledge of the linearity of response and stability of gain as a function of the operating conditions.

It is envisaged that the monitoring of representative samples from each delivered batch will be sufficient but we reserve the option to test every single AMPD device if the quality turns out not to be uniform enough (see Section A3.2.2). The quality assurance effort must continue until the end of the ECAL module construction phase in mid-2009.

6.5.3 TASK III: AMPD to WLS fibre optical connector development

The design of a connection between the photosensor and the WLS fibre is an important issue that drives the real light flux that will be read out by the photosensor. Since each subsystem using AMPDs contains tens of thousands of channels this work will have a major impact on the cost and time-scale of the project. Specific studies using photosensors and WLS fibre will be conducted in order to converge on a design that minimises the light loss at the junction while at the same time providing a simple design which is easy to fit and remove with good reproducibility. The connector design will be a key consideration in defining the packaging of the photosensor devices.

Concept designs exist and discussions with potential vendors have already begun. First prototype testing will begin in the first quarter of 2006. This task will overlap with the development phase needed to establish the sensor technology up to around mid 2007 and a final product should be available for the beginning of scintillator bar module construction.

6.5.4 TASK IV: Development of a AMPD calibration method

The objective of this task is to establish reliable methods of extracting AMPD parameters in a fully working ECAL. The key AMPD properties include:

- Gain
- Linearity of response
- Number of pixels fired
- Levels of crosstalk
- Dark noise

We plan to investigate monitoring the stability of the single photo-electron peak position (and width) as a way of calibrating the AMPD gain. In practise this technique will involve measuring the pulse spectra obtained from the passage of cosmic ray muons, whose single photo-electron peak position can be fit to and from which the corresponding AMPD gain can be computed. Measurements of the gain as a function of time and temperature can be used to correct it according to a reference value. In addition, combining the peak position information with momentum measurements of the muons from the tracking detectors (see Sect. 2.4.2), will allow the linearity of the AMPDs to be monitored. Note that the ND280m detector experiences a flux of high energy cosmic muons (based on an intensity of vertical muons above 1 GeV at sea level of $I \sim 1\text{cm}^{-2}\text{min}^{-1}$ [35]) of about 500,000 muons/min, given a detector surface of 760x560 cm^2. A significant part of these muons hits the calorimeter giving sufficient statistics to calibrate the AMPDs in the way outlined above. Work will be concentrated on studying the calibration algorithms, integrating the monitoring system into the data acquisition and defining the database fields for full scale calibration. Part of this work will involve the development of a realistic simulation of the device response which will play a vital role in the interpretation of the measurements. The timescale for an understanding of these calibration issues is by the end of 2007.

6.5.5 TASK V: Pre-production tests

Before the production phase begins in mid 2007, detailed tests of pre-series devices made under full production conditions need to be arranged with the manufacturer. The purpose is to ensure that all the specifications and quality criteria are met before a large scale production run begins. Test work will be spread between the three main test sites.

6.5.6 TASK VI: Reception and quality assurance

The production run photosensors will be received at each of the three testing centres, whereupon they will be electronically tagged and a series of quality assurance tests performed. Strict quality specifications will be agreed with the vendor so that only a random sample from each delivered batch should undergo full quality tests. We do however recognise the need for an option to test every device before its use in an ECAL module, and this contingency is listed in Section A3.2.2.

6.6 Output

The photosensor work package will deliver the $\sim$ 30k AMPD photosensor detectors and the WLS fibre couplers needed to instrument the ECAL for the ND280m detector, with full quality assurance crosschecks.

Chapter 7

Work Package 4: Electronics

7.1 Institutes Responsible

CCLRC/RAL, Imperial College and Queen Mary University of London are responsible for this work package. A. Weber (CCLRC/RAL) is the work package manager.

7.2 Key Personnel

Key people in the Electronics WP are

- **A. Weber** is very experienced in building electronics for neutrino detectors. During his time at Oxford, he was responsible for providing the front-end electronics as well as the GPS and timing system for the MINOS far detector and the near detector GPS and spill timing system. He has led the conceptional design of the electronics for the T2K/280m scintillator detectors and is on the board of conveners and the technical board for the 280m detector. He currently holds a joint appointment with the University of Oxford and will spend all his CCLRC/RAL time on the project.

- **M. Raymond** is experienced in a wide range of electronics and their applications. He is one of the most experienced analogue ASIC designers in the UK, and has made contributions of major importance to CMS in recent years. He has remarkable expertise constructing and evaluating circuits and systems, appraising them with a critical physicist's eye, frequently identifying crucial details whose neglect would have serious repercussions. He is the ideal person to evaluate the TRIP-t ASIC and to lead the design of the front-end boards.

7.3 Introduction

Providing front- and back-end electronics for the ECAL, the P0D the SMRD and the on-axis detector and back-end electronics only for the FGD falls under the remit of the Electronics WP.

The electronics for the scintillator detectors has several functions:

- Receive signals from photosensors
- Digitise (and zero) suppress the data from the photosensor
- Assemble the scintillator data and transmit it to the DAQ system

Detector	Granularity	Channels/unit	Channels
ECAL			35k
FGD	92 planes	192	18k
POD	60 planes	320	19k
SMRD	180 towers	48	9k
On-axis	14 modules	400	6k
Total			90k

Table 7.1: Channel and component count for the scintillator detectors.

- Generate and transmit cosmic triggers

It also controls the voltage of the photosensors and monitors the basic performance of all detectors. It obviously has to ensure that all the data during the 5μs neutrino spills is collected, but it should also be sensitive to through-going and stopping cosmic muon interactions out of spill.

The main features governing the design of the electronics are the following:

- Photonsensor gain of 10^5 to 10^6 per photon electron (PE)
- 1-1000 PE dynamic range
- 0.1 MHz noise rate at 1.5 PE thresholds
- Spill structure
  - 0.3 Hz
  - 15 bunches (length 60 ns, separated by around 280 ns)

There are approximately 90k channels to be read out (see table 7.1 for details).

The requirements for the different scintillator detectors are quite similar and the most cost effective choice is to use an identical electronics/DAQ system for all of them. This will also make the design, production, commissioning and maintenance of the system much easier and cheaper. We are therefore proposing to build functionally identical electronics for all the scintillator detectors as described below.

We have designed this electronics around an existing ASIC, which was developed by Fermilab to be used with VLPCs in DO. The MINERVA experiment[27] is also using this ASIC to read out MA-PMTs. Using this TRIP-t ASIC significantly reduces the cost, risk and development cycle. An overview of the proposed electronics is illustrated in figure 7.1.

7.3.1 TRIP-t ASIC

The TRIP-t ASIC is a 32 channel device that integrates and stores signals in a 48 channel deep analogue pipeline (well in excess of the number of bunches in the T2K spill). Simplified schematics taken from [36] can be seen in Figs. 7.2 and 7.3. Each channel has its own discriminator (with a global programmable threshold), but only the outputs from 16 channels (in parallel) can be selected for output at any one time. More details can be found in [36].

The gain of the TRIP-t ASIC is programmable, but the large range of photosensor input signals (up to 1000 PE) cannot be accommodated while simultaneously allowing a discriminator threshold of 1.5 PE. to be set with precision. We therefore intend to capacitively divide the photosensor

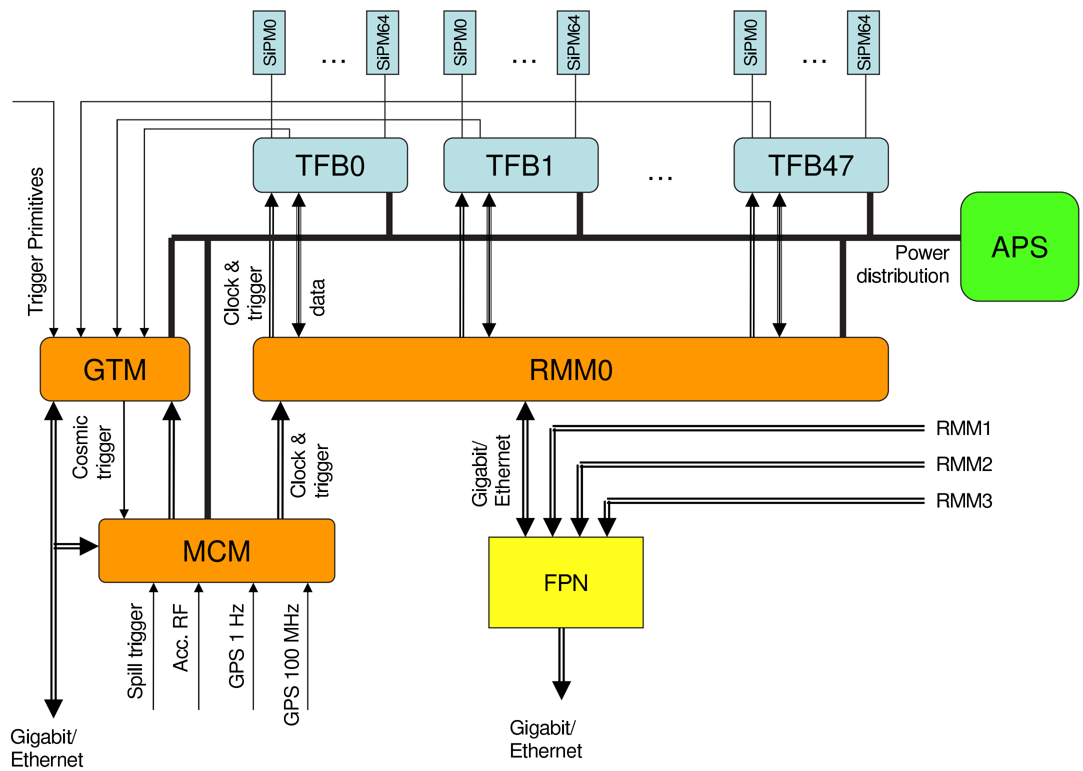


Figure 7.1: Schematic overview of the scintillator electronics

signals into low and high gain paths, using two TRIP-t channels per photosensor. The discriminator setting will apply to the 16 high gain channels, and the discriminator outputs of these will be the ones selected for output, and from which the precision time-stamps for the hits will be derived.

During the T2K spill period the TRIP-t preamplifiers are cycled between the integration and reset phases. At the end of each integration phase the integrated charge in all preamplifiers is stored in one of the pipeline time-slices, before the preamplifiers are reset. This operation will be synchronised to the accelerator clock which runs at approximately 3 MHz.

The TRIP-t ASIC also has a charge injection circuitry included. This will be used as a relative gain and linearity calibration for the different channels.

7.3.2 TRIP-t Front-end Board (TFB)

A total of 4 TRIP-t ASICs will be mounted on each front-end board. The TFB will thus read out 64 photosensors. We envisage that the photosensors will be connected with short (either miniature coax or twisted pair) cables to the TFB; this allows the maximum flexibility in connecting the scintillator/photosensors to the electronics. The maximum allowed cable length will depend on the readout chain noise, which depends on the final photosensor gain and cable capacitance. Preliminary studies indicate coaxial cable lengths of up to 100 cm are tolerable. The exact layout of the TFB may depend on the detector to be read-out as there are different geometrical constraints,

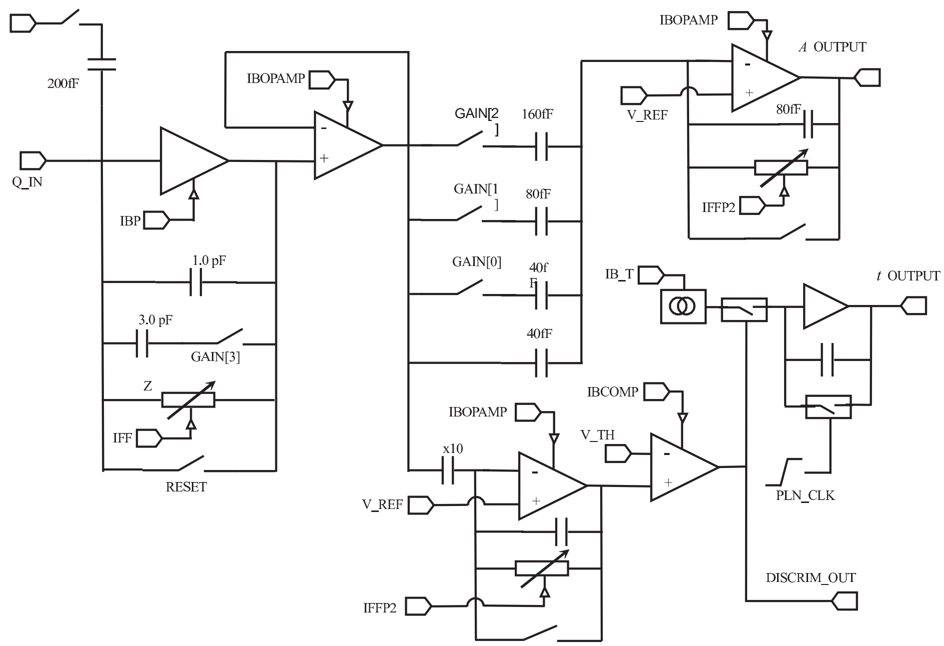


Figure 7.2: Schematics of the front end of the TRIP-t ASIC

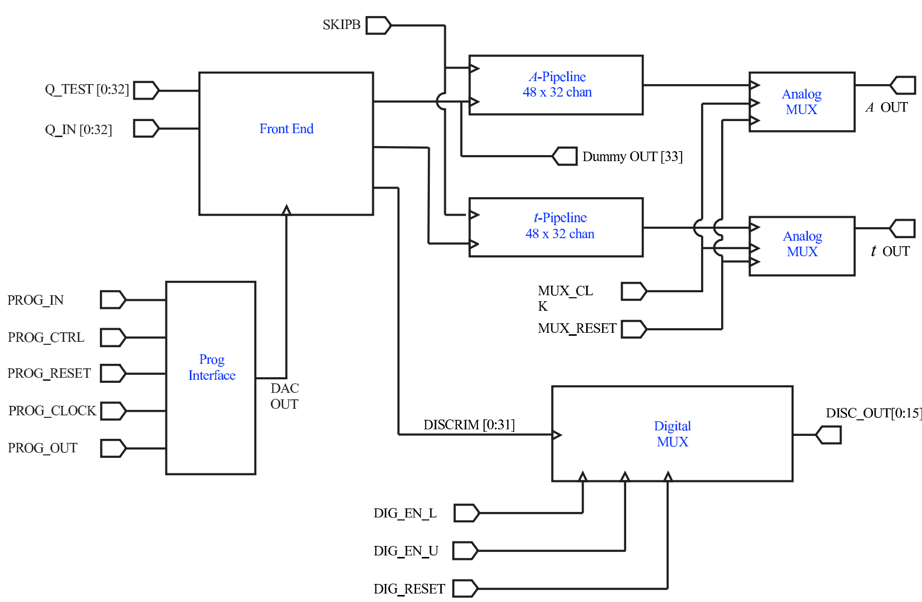


Figure 7.3: Block diagram of the basic functions of the TRIP-t ASIC

but they will be functionally identical[1].

The TRIP-t chips are controlled by a Field Programmable Gate Array (FPGA), which runs at a centrally synchronised 100 MHz clock. It will also receive a pulse-per-second signal to reset its internal clock counters, a signal synchronised to the accelerator clock and an external trigger signal.

Using its internal clock managers, the FPGA will be able to time stamp all TRIP-t discriminator signals with a 2.5 ns resolution. It will also control the TRIP-t to integrate the photosensor signals synchronised to the accelerator clock. At the end of the spill, the analogue pipeline is stopped and all integrated charges in the analogue pipeline will be multiplexed to a 10 bit ADC. All the charges above a programmable readout threshold coinciding with a discriminator signal will be stored and sent to the Readout Merger Module (RMM, see below). We foresee that all charges, independent of the discriminator signal, will be histogrammed in the downstream DAQ. This data can be used to study the photosensor dark spectrum and to monitor the photosensor and electronics gain.

The TFB has two other main functions. It will provide the bias voltages for the photosensors and generate trigger primitives for a cosmic trigger.

The HV for the photosensors will be somewhere between 30 and 70 V, depending on the device chosen. However, individual devices will have slightly different gains, which can be equalised by individually adjusting the HV of that channel. Using the TFB a general HV can be set in the appropriate range, allowing each channel to be individually adjusted by $\pm$ 5V.

The TFB can also be used to generate triggers primitives. However, we only foresee this function to be used in the TFBs connected to the SMRD. Each SMRD will read out one or 1.5 towers in the SMRD. By looking for patterns in the discriminated photosensor signals one can determine whether there was a track or track segment in each of the towers. This information can easily be used to determine whether a cosmic muon traversed the detector, as the towers cylindrically surround the entire detector. The FPGA would look for these patterns and transmit a signal on a separate LVDS link to the Global Trigger Module (GTM, see below) to indicate whether there was a track segment in a tower. These trigger primitives can later be used to calculate a global trigger decision.

7.3.3 Readout Merger Module (RMM)

The RMM controls the TFB. It will transmit, set-up and run specific parameters to the TFB and will also be able to re-program the firmware of the TFB FPGA. It receives the timing and trigger signal from the Master Clock Module (MCM, see below) and redistributes these signals to the TFB. After each trigger the TFB will send its data to the RMM. The RMM will collect the data from up to 48 TFBs and send them to the DAQ via a commercial optical Gigabit/Ethernet link. The RMM is not much more than a massive I/O module, which is implemented with a high end FPGA. It will have 48 times 4 LVDS links to the TFB and two high speed optical links, one for data transfer to a DAQ PC and another to receive the clock and trigger signals. Control of the RMM and TFB will be via the Gigabit/Ethernet interface on the RMM.

7.3.4 Global Trigger Module (GTM) and Master Clock Module (MCM)

The hardware of these two modules is largely identical to the RMM. Their functions, however, are quite different. The Global Trigger Module will receive the trigger primitives from all SMRD

[1] The TFB for the FGD will be laid out, produced and paid for by our collaborators from TRIUMF

TFBs modulated on a 100 MHz LVDS link (see above). It will look for coincidences between different SMRD towers and generate a cosmic trigger. As this system is implemented in an FPGA it is quite flexible and trigger conditions and pre-scaling factors can easily be changed. The trigger will be transmitted to the MCM. The MCM is the heart of the front-end electronics. It generates a 100 MHz clock signal, which is synchronised to the 10 MHz GPS signal. This clock is fanned out to all RMMs via identical optical links operating at 1 GHz. Modulated onto the same link are the 1 Hz signal used to reset the time-stamping circuitry in the TFB, the spill and cosmic trigger and the phase of the accelerator RF with respect to the 100 MHz clock. The RMM decodes these signals and transmits them via several LVDS links to the TFBs. This scheme ensures that all TFBs are synchronised to each other. The same timing signals will also be sent to the GTM. Both the GTM and the MCM will have an Ethernet connection and will be controlled and programmed via the network.

7.3.5 A TRIP-t Power Supply (APS)

The final design of the power distribution system is currently undefined. We assume we can use commercial units that supply all the voltages necessary to operate the TFB, RMM, GTM and MCM in several central locations outside the detector. Due to space constraints it is unpractical to supply each TFB with its individual power line. The power shall therefore be fed via a multi-core power-bus to the different detector components. Special care will be taken to avoid ground loops and minimise the total cabling.

The total power requirements are moderate. Each TRIP-t ASIC consumes 480 mW, and two TRIP-t chips require a single dual channel ADC consuming 215 mW, so the total power due to these components is 588 mW. A 4 TRIP-t TFB will thus consume 2.35 W. The front-end FPGA power consumption is harder to predict, but an assumed total individual TFB power consumption of less than 10 Watts, leads to a total TFB power consumption (90k photosensor channels) of less than 14 kW.

7.4 Inputs

This WP depends on inputs from a number of sources, both within and outside the scope of this proposal. Inputs from other WPs within the proposal are:

- Specification, design and delivery of the DAQ (WP 5)
- Physics studies to determine the electronics requirements for the ECAL(WP 1)
- Calibration requirements for scintillator detectors (WP 8)
- Properties of the photon detectors (WP 3)

The external inputs to this WP arising from activities taking place outside the scope of this proposal are:

- Experimental facility and infrastructure design
- Operational requirements
- Performance requirements from other scintillator detectors

- Specification of the accelerator interface

The schedule of the WP and design of the electronics has been defined to take into account these inputs.

7.5 Objectives and Milestones

We are proposing to build the entire system as described above. The different steps needed are listed below. The schedule for these tasks are shown as a Gantt chart in figure 7.4. The front-end boards have to be available during the construction of most of the scintillator detectors. Smaller, but complete readout systems will have to be available for different test beam activities before the final installation. These requirements lead to the milestones summarised in table 7.2.

7.5.1 Task I: TFB

We will design and manufacture the 1st TFB prototype during the first six months of the project, in parallel with the required firmware development to allow programming of the TRIP-t chips and the critical discriminator outputs time-stamping functionality. After testing the 1st prototype will be available for use in the vertical slice test at the end of 2006.

After reviewing requirements, the final version of the TFB and its associated firmware will be developed during 2007, becoming available, after testing, at the end of 2007.

Preparations for the TFB volume production (any market survey/call for tender required) will be carried out during the second half of 2007, allowing a pre-production series to be launched early in 2008. Following acceptance tests the full production will commence July 2008.

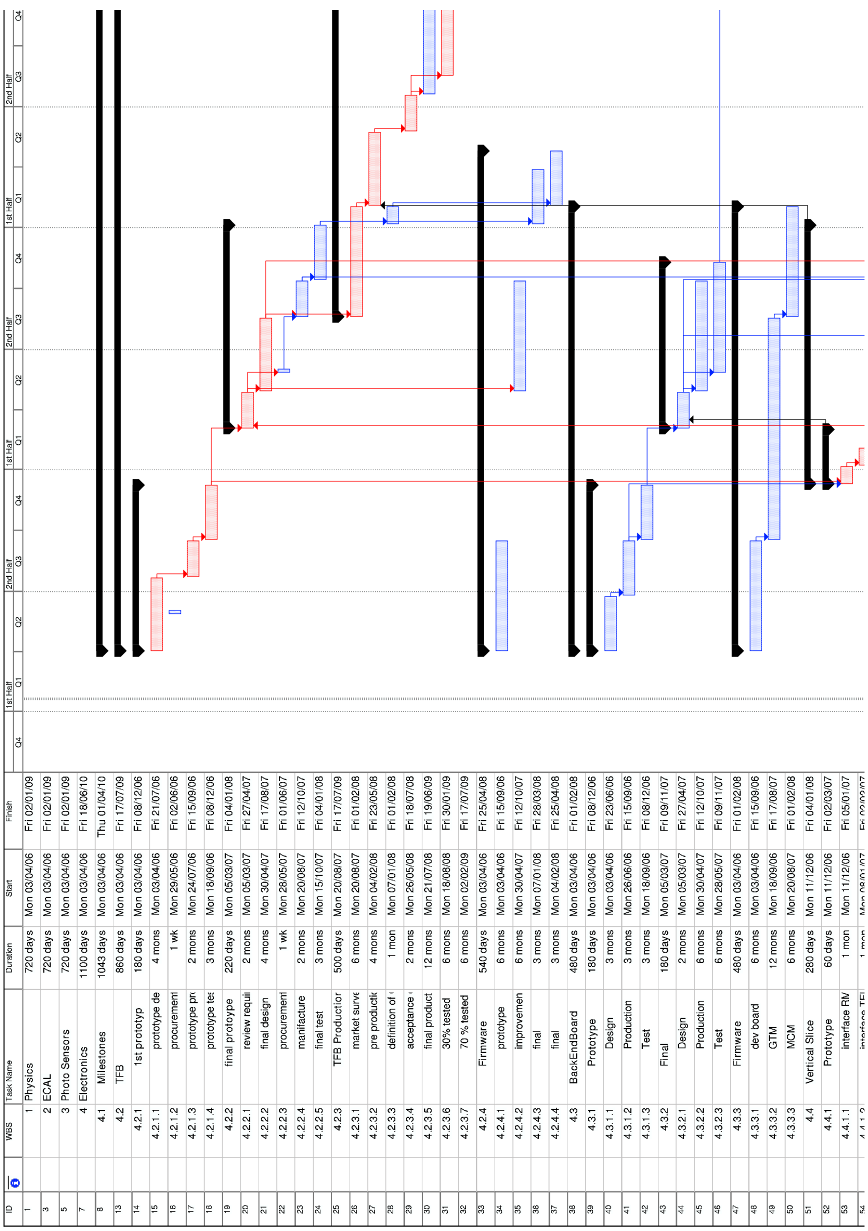
A 12 month production period is foreseen, finishing June 2009. Detailed QA and burn-in testing will be performed, keeping pace with production.

Because of the relatively large numbers of TFBs involved the volume testing needs special consideration. It is envisaged that two systems will be required. One will be installed at the manufacturer (to be operated by them) to allow identification of faulty boards as soon as they come off the production line, localising faults to particular regions or components on the board. This allows rapid rework/repair giving high level of confidence that boards delivered to us will subsequently be fault free. We have used this approach successfully in a previous large-scale manufacturing task. The second system will be used in-house for the detailed production acceptance and TFB characterisation, QA and burn-in (prolonged operation under power) tests. This system would accept multiple boards to keep up with production. It is likely (and desirable) that the manufacturer's system would simply be a cut-down version of the in-house system (simplified operation, less detailed and hence quicker testing).

Preliminary planning for the production test systems will be undertaken in the last quarter of 2006. The detailed hardware, firmware and software developments required for the test systems will occur during a 12 month period beginning April 2007, to enable both systems to be in place before the TFB volume production begins in July 2008.

7.5.2 Task II: The Back-end boards (BEB): RMM, GTM, MCM

All the BEB are, as described earlier, variants of a single opto-electrical I/O board, which is controlled by a high-end FPGA. CCLRC/RAL has delivered similar boards for ATLAS and the requirements and methods employed are quite similar to those.


ID | WBS | Task Name | Duration | Start | Finish
1st Half | 2nd Half | Q1 | Q2 | Q3 | Q4
1 | 1 | Physics | 720 days | Mon 03/04/06 | Fri 02/01/09
3 | 2 | ECAL | 720 days | Mon 03/04/06 | Fri 02/01/09
5 | 3 | Photo Sensors | 720 days | Mon 03/04/06 | Fri 02/01/09
7 | 4 | Electronics | 1100 days | Mon 03/04/06 | Fri 18/06/10
8 | 4.1 | Milestones | 1043 days | Mon 03/04/06 | Thu 01/04/10
13 | 4.2 | TFB | 860 days | Mon 03/04/06 | Fri 17/07/09
14 | 4.2.1 | 1st prototyp | 180 days | Mon 03/04/06 | Fri 08/12/06
15 | 4.2.1.1 | prototype de | 4 mons | Mon 03/04/06 | Fri 21/07/06
16 | 4.2.1.2 | procurement | 1 wk | Mon 29/05/06 | Fri 02/06/06
17 | 4.2.1.3 | prototype pr | 2 mons | Mon 24/07/06 | Fri 15/09/06
18 | 4.2.1.4 | prototype te | 3 mons | Mon 18/09/06 | Fri 08/12/06
19 | 4.2.2 | final protoype | 220 days | Mon 05/03/07 | Fri 04/01/08
20 | 4.2.2.1 | review requi | 2 mons | Mon 05/03/07 | Fri 27/04/07
21 | 4.2.2.2 | final design | 4 mons | Mon 30/04/07 | Fri 17/08/07
22 | 4.2.2.3 | procurement | 1 wk | Mon 28/05/07 | Fri 01/06/07
23 | 4.2.2.4 | manifacture | 2 mons | Mon 20/08/07 | Fri 12/10/07
24 | 4.2.2.5 | final test | 3 mons | Mon 15/10/07 | Fri 04/01/08
25 | 4.2.3 | TFB Productior | 500 days | Mon 20/08/07 | Fri 17/07/09
26 | 4.2.3.1 | market surve | 6 mons | Mon 20/08/07 | Fri 01/02/08
27 | 4.2.3.2 | pre productio | 4 mons | Mon 04/02/08 | Fri 23/05/08
28 | 4.2.3.3 | definition of | 1 mon | Mon 07/01/08 | Fri 01/02/08
29 | 4.2.3.4 | acceptance | 2 mons | Mon 26/05/08 | Fri 18/07/08
30 | 4.2.3.5 | final product | 12 mons | Mon 21/07/08 | Fri 19/06/09
31 | 4.2.3.6 | 30% tested | 6 mons | Mon 18/08/08 | Fri 30/01/09
32 | 4.2.3.7 | 70 % tested | 6 mons | Mon 02/02/09 | Fri 17/07/09
33 | 4.2.4 | Firmware | 540 days | Mon 03/04/06 | Fri 25/04/08
34 | 4.2.4.1 | prototype | 6 mons | Mon 03/04/06 | Fri 15/09/06
35 | 4.2.4.2 | improvemen | 6 mons | Mon 30/04/07 | Fri 12/10/07
36 | 4.2.4.3 | final | 3 mons | Mon 07/01/08 | Fri 28/03/08
37 | 4.2.4.4 | final | 3 mons | Mon 04/02/08 | Fri 25/04/08
38 | 4.3 | BackEndBoard | 480 days | Mon 03/04/06 | Fri 01/02/08
39 | 4.3.1 | Prototype | 180 days | Mon 03/04/06 | Fri 08/12/06
40 | 4.3.1.1 | Design | 3 mons | Mon 03/04/06 | Fri 23/06/06
41 | 4.3.1.2 | Production | 3 mons | Mon 26/06/06 | Fri 15/09/06
42 | 4.3.1.3 | Test | 3 mons | Mon 18/09/06 | Fri 08/12/06
43 | 4.3.2 | Final | 180 days | Mon 05/03/07 | Fri 09/11/07
44 | 4.3.2.1 | Design | 2 mons | Mon 05/03/07 | Fri 27/04/07
45 | 4.3.2.2 | Production | 6 mons | Mon 30/04/07 | Fri 12/10/07
46 | 4.3.2.3 | Test | 6 mons | Mon 28/05/07 | Fri 09/11/07
47 | 4.3.3 | Firmware | 480 days | Mon 03/04/06 | Fri 01/02/08
48 | 4.3.3.1 | dev board | 6 mons | Mon 03/04/06 | Fri 15/09/06
49 | 4.3.3.2 | GTM | 12 mons | Mon 18/09/06 | Fri 17/08/07
50 | 4.3.3.3 | MCM | 6 mons | Mon 20/08/07 | Fri 01/02/08
51 | 4.4 | Vertical Slice | 280 days | Mon 11/12/06 | Fri 04/01/08
52 | 4.4.1 | Prototype | 60 days | Mon 11/12/06 | Fri 02/03/07
53 | 4.4.1.1 | interface RM | 1 mon | Mon 11/12/06 | Fri 05/01/07

We will first use off-the-shelf development boards to develop the firmware for the RMM, GTM and MCM. By April 2007 we will be able to build a system to readout a sufficient number of TFBs to form a vertical slice test (see below). We will also produce a small simple PCB to adapt this development board connectors to the connectors that will be used in the final system. This work will be contracted out and is included in the equipment costs for this WP along with the development boards required.

The Lead Design Engineer will be responsible for all aspects of the project management, design, testing and commissioning of the system.

In the following year we will design and produce all the common BEB modules with the correct number of channels required for the system. There will be one FPGA based PCB design which has three functions in the system; RMM, GTM and MCM. Three separate sets of FPGA firmware will be required for this design.

The lead Design Engineer will be responsible for the Project Management, PCB design of the Common Module, production of the module as well as some aspects of the firmware design. The Firmware Design Engineer will be responsible for designing the initial versions of most of the FPGA firmware for all three versions of the firmware required to run on the module. The PCB Design Engineer will carry out the PCB design including any minor iteration. The Test Engineer will carry out JTAG and other post manufacturing testing of the Boards once they have returned from Manufacture.

The Lead Design Engineer and the Firmware Design Engineer will also cover aspects of the test software required for verification of the system.

From April 2008 we will carry out the main commissioning phase with the Design Engineer providing support for this process. This will include supporting installation, system tests and any Firmware improvements required. We expect most of this work to be finished by April 2009 and will finish the commissioning phase soon after ECALinstallation.

7.5.3 Task III: APS

After the power requirements are defined, we will design the APS to supply all the required voltages to the TFB. The engineer at QM will work with the TFB lead engineer and a technician/engineer at CCLRC/PPD to layout the APS and its associated power bus. This work will be done by the end of 2007. After sourcing and customising commercial power supplies in 2008, they will install and commission them during 2009/10.

7.5.4 Task IV: Vertical Slice Test

We plan that all the prototypes will be brought together for a first test at the end of 2006. This vertical slice will include photosensors, TFB prototype, RMM and MCM prototype, and the DAQ. It will verify the basic functions of the entire readout system as described in this proposal. We estimate that it will take 3 months to make all the systems work together.

This test will be repeated with the final TFB, photosensor and BEB before any large scale production of the TFBs.

7.5.5 Task V: Electronics Software and Simulations

We will first simulate the cosmic ray muons through the detector to determine the optimal strategy to generate a trigger from the SMRD hit pattern. This has direct implications for the design of the GTM and is the highest priority task. The trigger algorithms will later be optimised to

	milestone	date
1.	BEB and TFB prototype ready	12/06
2.	1st vertical slice finished	06/07
3.	Start BEB production	06/07
4.	Finished BEB production	12/07
5.	2nd vertical slice finished	06/08
6.	Start of TFB production	07/08
7.	Finished TFB production	06/09
8.	Finished TFB testing	08/09
9.	Electronics commissioned	09/10

Table 7.2: Milestones for WP4

Detector	TFBs	BEBs
ECAL	620	20 (4)
FGD		6 (2)
POD	300	8 (2)
SMRD	180	4 (1)
On-Axis	112	4 (1)
GTM		2 (2)
MCM		2 (2)
Total	1450	60

Table 7.3: Component count for the scintillator detectors. The total includes spares needed for the TFBs (20%) and BEBs (number in brackets).

account for the yet unknown calibration requirements of the different detectors. This work will take around one year. There is also a substantial amount of software to be written to analyse the gain calibration for the TRIP-t and the tuning of the photosensor HV to equalise the gain or the noise rate. Understanding the mechanics of this and the physics implications will be part of this task.

7.6 Outputs

The Output of this WP is functional, installed and commissioned electronics for the ECAL, the P0D and the SMRD. We are also providing RMMs for the FGD. The delivery date for this output is consistent with the milestones listed above and the end of the construction phase in the fourth quarter of FY2009/10. The components count for the different sub-detectors is summarised in table 7.3 and also includs the components needed for the on-axis detector. We are not supplying the TFBs for the FGD. Due to mechanical constraints it does need a different physical layout. This layout and the production will be done by our collaborators from TRIUMF.

Chapter 8

Work Package 5: Data Acquisition

8.1 Institutes Responsible

This work package will be provided by the CCLRC Rutherford Appleton Laboratory. The work package managers are G.F. Pearce (CCLRC RAL) and T.C. Nicholls (CCLRC RAL).

8.2 Key Personnel

The work package managers both have extensive experience in particle physics experiments, instrumentation systems and project management.

G.F. Pearce is a senior physicist in PPD at CCLRC-RAL. He has considerable experience across a broad range of particle physics experiments (LAMP-II, JADE, SOUDAN-2, MINOS). He is the RAL group leader and UK spokesperson for MINOS. He was the MINOS WBS co-level 2 manager for electronics, data acquisition and detector control systems, the online software coordinator and the data acquisition group leader with responsibility for delivery and support of all MINOS DAQ systems.

T.C. Nicholls is a senior instrumentation systems engineer in Technology Division at CCLRC-RAL. He has considerable experience with data acquisition and triggering systems in particle physics experiments (including H1 and MINOS). He is the CCLRC programme manager for delivery of instrumentation for the Diamond Light Source and is involved in a number of other international strategic activities in light-source based instrumentation, including the DESY XFEL. He was a core designer, developer and provider of the MINOS data acquisition systems.

Additional expert technical staff for the provision of the DAQ will come from PPD and EID at CCLRC, both of whom have a proven track record in particle physics experiments and instrumentation systems across a broad range of applications. The core PPD staff required to deliver the DAQ will also provide the necessary continuity of expertise into the operational phase of T2K.

8.3 Introduction

The data acquisition (DAQ) system of the T2K 280m detector will be required to collect raw data from all subdetectors and log formatted event data to persistent storage media for later analysis. Provision of run control and interfaces to online monitoring and detector control systems to facilitate effective operation of the experiment will also be necessary. We propose to implement a scalable, flexible system that will realise these needs.

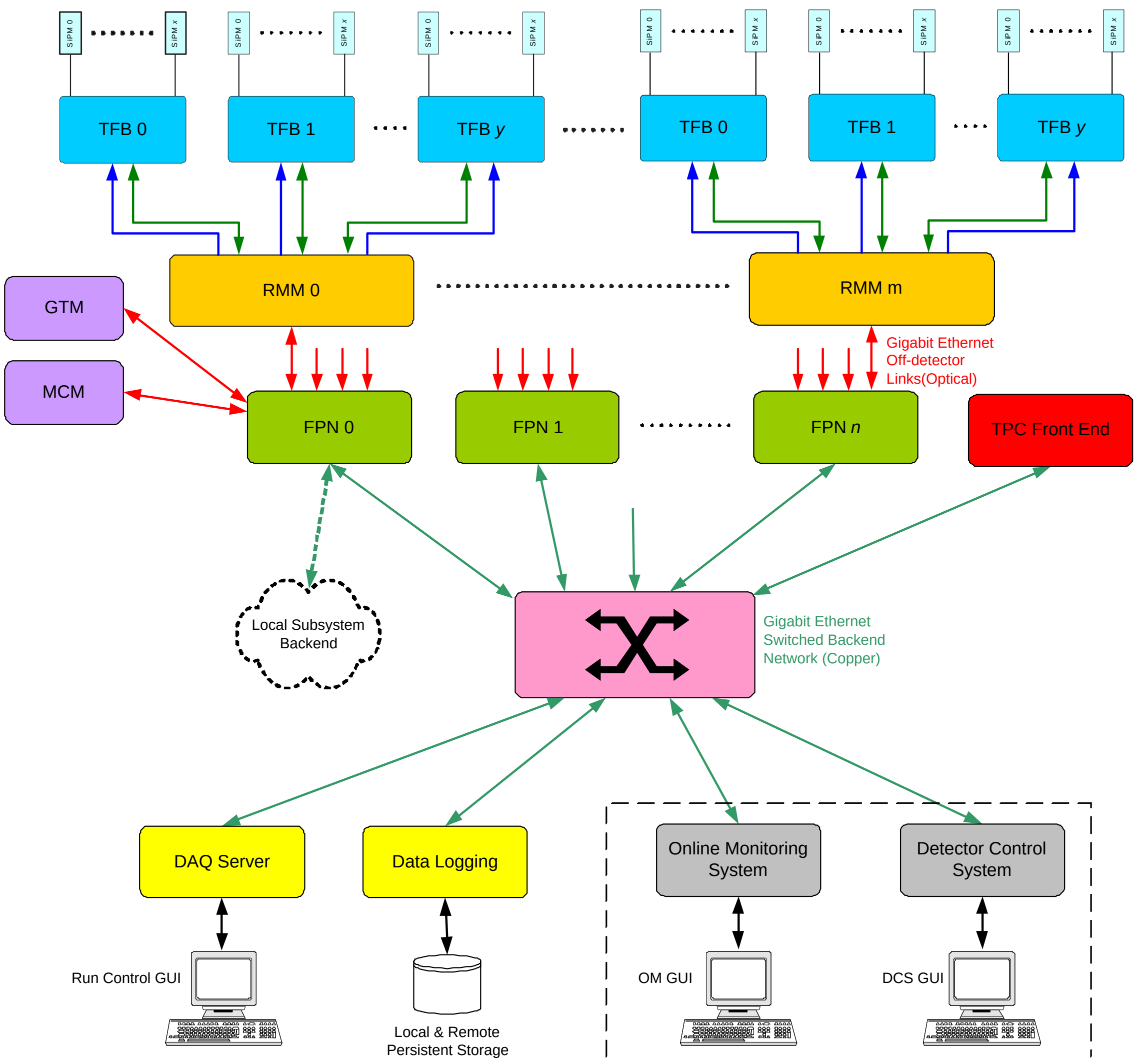


Figure 8.1: Conceptual design of the data acquisition system, showing its relationship to the front-end electronics of all subdetectors and the detector control and online monitoring systems. The acronyms are explained in the text.

8.3.1 DAQ System Requirements

The proposed readout electronics for the scintillator-based detectors, as described in Chapter 7, present data from those detectors on a Gigabit Ethernet physical layer. The TPC readout system also implements this interface; it is therefore a natural requirement that the DAQ system be able to make use of Gigabit Ethernet as the primary medium for data transfer.

The detailed requirements for the specific functionality that the DAQ will be required to provide will necessarily be developed during the initial phase of the project. However, there are a number of general requirements for the system:

- Interface to, and acquire data, from multiple subdetector systems
- Support a sustained data transfer and logging rate consistent with the scientific demands of the experiment
- De-randomise, build and format full event data for logging to persistent storage
- Allow sufficient operational flexibility such that subdetectors can be included and excluded from data-taking on a run by run basis
- Support the ability to readily implement local DAQ instances to support standalone debugging and commissioning of various subdetectors and subsystems
- Provide a high-level user interface to allow data-taking operation of the experiment
- Implement an interface to the detector control system to allow slow control and monitoring of the sensors and front-end electronics
- Provide an interface and access to data for online processes, such as online monitoring, to allow the quality of the data being obtained from the experiment to be monitored in near-real time.

The exact data transfer rate that the DAQ system will be required to support is highly dependent on a number of factors: the noise rate of the sensor finally selected for the scintillator-based detectors; the cosmic event triggering scheme implemented in the front-end electronics; and the cosmic trigger rate required to generate sufficient data to calibrate the detector in a timely fashion. The dominant contribution to the data rate from these detectors will arise from uncorrelated noise hits below approximately 1.5 photo-electrons present in cosmic triggers.

A worst-case scenario of 1 MHz noise rate per sensor and a 20 Hz cosmic trigger rate using the scheme described in Chapter 7 would yield a total raw data rate of 12 MB/s from the scintillator detectors. Triggering the TPC at this rate would yield a raw data rate from that system of approximately 2 MB/s. Assuming that no subsequent filtering or reduction (e.g. higher level triggering) is applied to the data, this would lead to a total logged data rate of 14 MB/s. This is well within the ability of a system based upon Gigabit Ethernet and modern commodity computers, which could log data to persistent storage at a rate of several tens of megabytes per second. However, this would place an unacceptable burden on the computing infrastructure required for the experiment. The DAQ system will therefore be required to implement some form of data processing and reduction to reduce the rate generated by the scintillator-based subdetectors. The flexibility to acquire and store the “raw” data from the subdetectors to allow for commissioning, monitoring and diagnostics will of course be preserved, albeit at a reduced rate.

8.3.2 The Proposed DAQ Implementation

In order to minimise the cost, effort and risk associated with this work package, it is proposed to base the system on an existing DAQ software framework. There are a number of these freely-available, which have been successfully deployed on a range of small and medium scale high energy and nuclear physics experiments and are supported by their authors and the community at large. The currently favoured choice is MIDAS [37], which is used extensively at a number of laboratories around the world. However, a final decision will be made on the basis of a careful evaluation of the possibilities once the detailed requirements for the DAQ system have been established.

Fig. 8.1 shows the current conceptual design for the DAQ system and its relationship to the front-end electronics and other online systems, such as detector control and online monitoring. The interfacing to the front-end electronics for the scintillator-based subdetectors, as described in the Section 7, will be developed within this work package. It is anticipated that the interface to the TPC will be provided by the relevant institutions. Here, the proposed use of a software framework, with an existing, well-defined programming interface for integrating custom systems, will provide a significant advantage.

The architecture shown is driven by the considerations outlined above and the working assumption that the MIDAS framework will be employed. However, the basic components and functionality will remain largely unchanged should another framework be selected. The function of each component is described in the following sections.

The Front-end Processing Node

The Front-end Processing Node (FPN) is responsible for receiving raw data streamed over optical Gigabit Ethernet links from the Readout Merger Modules (RMMs) of the scintillator subdetector front-end electronics. The FPN will conform to the application programming interface (API) supported by the streaming firmware present on the RMMs and will provide the primary interface to the functionality of the front-end electronics. The FPN will consist of a commercially available PC running the GNU/Linux operating system, offering an excellent price-to-performance ratio. Fig. 8.2 shows the functional blocks implemented in the FPN.

Using the cosmic readout and triggering scheme described earlier at a trigger rate of 20 Hz, the per-link rate is approximately 480 kB/s. It is anticipated that a two-to-one multiplexing of the RMM links into each FPN can be achieved, yielding a total of 14 FPNs required. In order to substantially reduce the data logging rate, the FPN will perform histogramming of data for calibration purposes. All hits from cosmic triggers will be histogrammed on a channel-by-channel basis in local memory. The histograms will then be inserted into the data stream for readout and storage at a significantly lower rate, for instance once every few minutes. This rate can be flexibly tuned to optimise data storage constraints against the calibration requirements for the detector. The local processing and storage requirements (approximately 10 MB per FPN) are not significant.

In order to match the event output for cosmic ray events to the offline needs, a programmable threshold will be applied to all hits read out for these triggers, for example passing only hits above 1.5 photo-electrons. In order to further tighten the selection of hits associated with cosmics triggers, which will have a well-known timing, a simple time cut (e.g. all hits within 200 ns of the trigger) could readily be applied. Note that the processing applied here is on a trivial, hit-by-hit basis and does not require any reconstruction of event topology. All hits passing these cuts will be written to buffers for subsequent readout by the DAQ backend. This will greatly reduce the raw

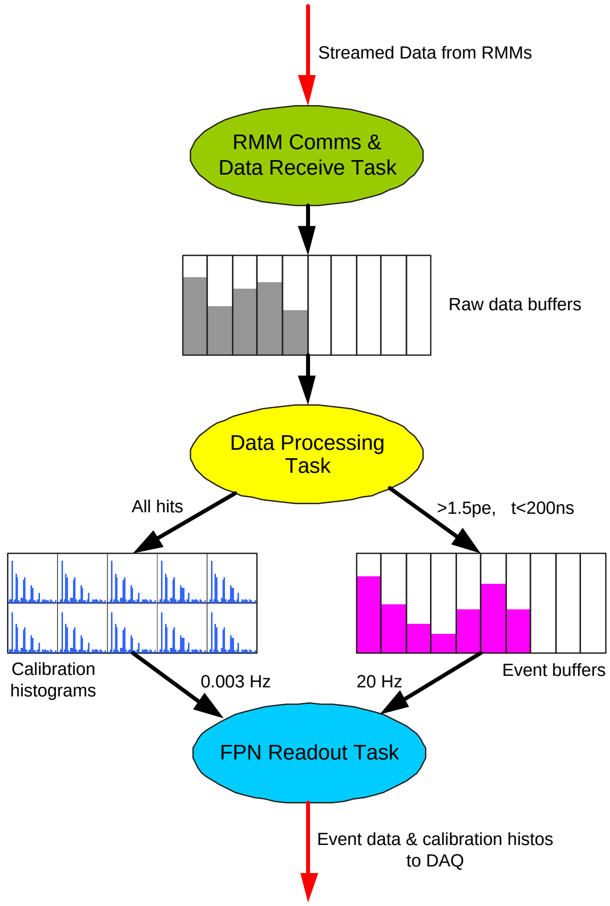


Figure 8.2: A schematic representation of the functionality of the DAQ Front-end Processing Node (FPN).

data rate to less than 1 MB/s. Hits from triggers associated with the 0.3 Hz beam spill rate could be buffered for readout with or without out such cuts being applied, according to need.

The Back-end Network

The FPNs communicate with the downstream components of the DAQ via the back-end network. Given the modest data rates expected in the scheme proposed here, this network will consist of a single, commercially-available Gigabit Ethernet network switch. Additional capacity and flexibility could however be readily achieving adding further switches if required.

The backend network provides the physical interface between the DAQ and the TPC subsystem front-end node. The latter also implements a Gigabit Ethernet interface and will participate in the DAQ on an equal basis with the other subsystems.

The Data Logging Node

This component is responsible for collecting the full data streams from all front-end subsystems, assembling them into full events and logging them to persistent storage. A likely scenario for providing a robust data logging scheme is for this node to write data files to local disk. These are then copied to the ultimate destination (e.g. a tape robot at a remote laboratory) by an archival task that runs asynchronously from the DAQ; this scheme provides a solution that is robust against external problems such as transient off-site network failures.

This node would again be implemented using a standard PC of similar specification to those used for the FPNs. The logging node could also provide other local storage media, such as high-capacity tape drives, according to the needs of the experiment.

The DAQ Server and Run Control

The DAQ server controls the state and operating mode of the DAQ, coordinating data acquisition activities. The precise nature of the server and its realisation in software will be dependent on the framework selected for the project. However, it will be required to provide a number of elements: maintain the global state machine representing the current state of data acquisition; control and store configuration data allowing components in the front-end systems and DAQ to be flexibly set-up and included or excluded from the data taking on demand; and a graphical user interface (GUI) to allow users to control the DAQ.

Since the facilities in proximity to the detector are limited, remote operation of the DAQ is foreseen as a requirement. A natural mechanism for delivering the run control interface is the World Wide Web; appropriate authentication mechanisms to prevent uncontrolled access to the system will be provided.

Interfaces to Online Monitoring and Detector Control Systems

The DAQ will be required to provide interfaces to these systems. The nature of those interfaces will be determined as the design of all three evolve. Note that the provision of the online monitoring and detector control systems themselves fall outside the scope of this work package.

Local Subsystem Backends

In order to provide flexibility for independent development, commissioning and debugging of detector subsystems, it is foreseen to provide the backend functionality of the DAQ on a local basis as necessary. Since the scope and performance requirements of these local systems is limited, the full backend could easily be provided by a single node. A number of the DAQ frameworks available allow for flexible configuration in this way.

Local DAQ systems will clearly be required during the development, testing, commissioning and integration of the various subdetectors and their electronics. The provision of local DAQ equipment for those subsystems, except for the ECAL, which is a UK responsibility, falls outside the scope of this proposal. Provision of support for the setup and initial use of such systems at other sites has however been factored into the manpower resources requested here.

8.4 Inputs

This work package depends on inputs from a number of sources, both internal and external to the scope of this proposal. Inputs from other work packages within the proposal are:

- Specification, design and delivery of the front-end electronics (WP 4)

- Physics studies and simulations for triggering and data requirements (WP 1)
- Calibration requirements for scintillator detectors (WP 7)

The external inputs to this work package arising from activities taking place outside the scope of this proposal are:

- Specification and design of the TPC front-end electronics
- Experiment operational requirements
- Design and interfaces to other online systems
- Experimental facility and infrastructure design

The structure and schedule for this work package has been defined to take into account these inputs.

8.5 Objectives and Milestones

The objectives for this work package are broken down into a number of tasks, which are described below. The schedule for these tasks is shown as a Gantt chart in Fig. 8.3.

8.5.1 TASK I: DAQ System Specification and Design

The first task in this work package is to undertake the detailed specification and design of the DAQ system, which requires the following activities:

- Capture and develop the detailed requirements for the functionality and performance of the system, as determined by the scientific needs of the experiment.
- Evaluate possible DAQ software frameworks and select the most appropriate for the needs of T2K.
- Undertake the detailed design of the system based on the requirements and capabilities of the selected framework.
- Prepare a Technical Design Report describing the design and functionality of the system. This will be particularly important in order to ensure that all communication between the DAQ and other subsystems is appropriate and to agreed standard interfaces.

The milestone for completion of this task is the end of the second quarter of FY 2006/07.

8.5.2 TASK II: DAQ Software Development

This task encompasses the main software development effort for the DAQ system and includes the following items:

- Develop the FPN task software (including calibration processing) and interface to the DAQ framework. There will be several phases of development here as the various demonstrator systems, described below, are integrated with the front-end electronics and evaluated.

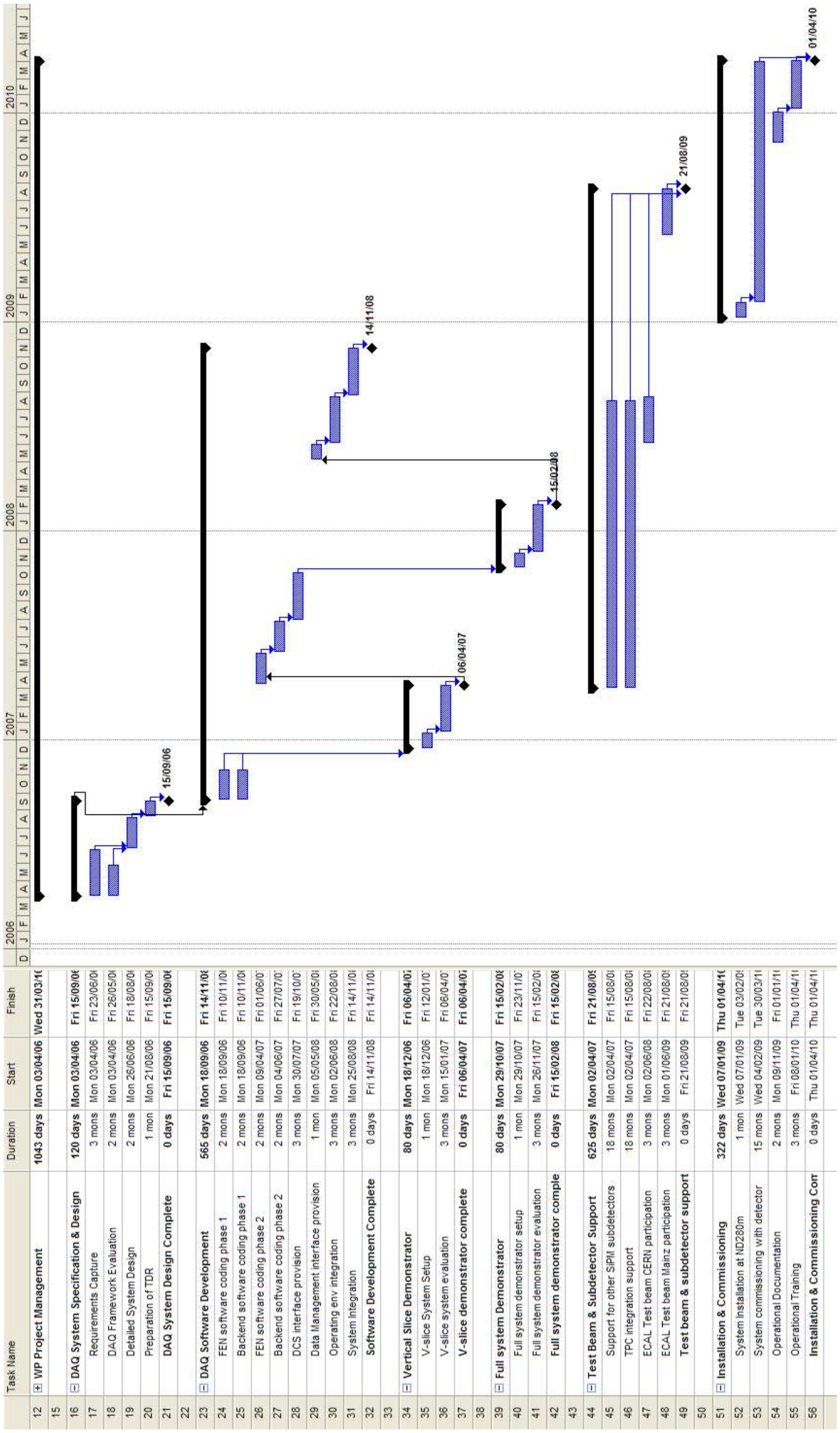


Figure 8.3: Schedule and main milestones for DAQ work package.

- Provide any customisation of the backend software. This will cover any additional functionality needed for the DAQ backend nodes (DAQ server, run control GUI, data logging node etc.) which may be required. Again, this will be phased around the demonstrator system tasks.

- Provide the Detector Control System interface. This will be developed according to the choice of implementation of that system. Since the DAQ provides the primary connection to the front-end electronics via the off-detector links, this interface will be used to control and monitor the electronics (bias voltages, temperatures, etc.).

- Integrate the DAQ into the experimental operating environment. This will include any work necessary to allow the DAQ to operate within the experimental computing infrastructure, for instance provision of data archiving scripts.

- Develop a fully integrated DAQ system. This covers the development and deployment of the software necessary to fully manage and operate the DAQ from a system perspective, including expert management scripts, software update tools etc.

The milestone for the completion of of all DAQ software development falls during the third quarter of FY 2008/09.

8.5.3 TASK III: Vertical Slice Demonstrator

The purpose of this task is to assemble and demonstrate a fully-working vertical slice of the photosensor, front-end electronics (or prototypes thereof) and data acquisition system and evaluate its performance. A period of system setup and debugging prior to system evaluation is scheduled.

The milestone for the successful demonstration and evaluation of a DAQ vertical slice is the end of the fourth quarter of FY 2006/07.

8.5.4 TASK IV: Full System Demonstrator

The objective of this task is to demonstrate a full prototype DAQ system that incorporates sufficient elements of the final system to adequately characterise the likely final performance. Again, a period of system setup and debugging is scheduled prior to the full system evaluation.

The milestone for the demonstration of the full DAQ system is scheduled for the beginning of the first quarter of FY 2007/08.

8.5.5 TASK V: Test Beam and Subdetector Support

This purpose of this task is to provide support for the use of the DAQ system during test beam campaigns for UK-provided subdetectors (i.e. the ECAL). Since basic DAQ systems will be required during the commissioning of front-end electronics for other subdetectors, support for these activities has been programmed. Finally, support for the integration of the TPC into the DAQ environment is foreseen.

The milestone for the completion of test beam and subdetector support task is the beginning of the second quarter of FY 2008/09.

8.5.6 TASK VI: Installation and Commissioning

The objective of the final task is to install and commission the final DAQ system at the experiment and cover the commissioning of the full detector prior to data taking with the neutrino beam. The initial installation is scheduled prior to the first beam operation with the partially-completed detector (FGD and TPC only) and it is planned to provide support throughout the period until the construction phase is completed.

The milestone for completion of the installation and commissioning of the DAQ is the end of the fourth quarter of FY 2009/10.

8.6 Outputs

The output from this work package is a functional, installed and commissioned data acquisition system for the 280m detector. The delivery date for this output is, consistent with the milestones listed above and the end of the construction phase, the end of the fourth quarter of FY 2009/10.

Chapter 9

Work Package 6: Mechanical/Thermal Engineering and Integration

9.1 Institutes Responsible

This work package will be provided by CCLRC Daresbury Laboratory and Liverpool. The work package managers are Alan Grant (DL) and Peter Sutcliffe (Liverpool).

9.2 Key Personnel

A. Grant (CCLRC Daresbury) is the ECAL project engineer and member of the T2K-ND280 Technical Board. He has long experience in a variety of research projects, and he is familiar with project management, procurement procedures, etc. He is member of the ND280 Technical Board.

A. Muir (Daresbury Laboratory) and P. Sutcliffe (Liverpool University) provide the main design engineering effort in this workpackage. They have long experience in the design of particle physics detector systems, including the BABAR endcap ECAL, the ATLAS silicon endcap, and the LHCb VELO.

The three engineers, in close collaboration, have produced in the last six months a comprehensive set of designs for the ECAL module boxes, as well as mounting, lifting, and installation solutions. They have also produced the design for the Basket, which is currently the focus of the ND280 engineering effort, as it relates to all ND280 subsystems. All components are modelled in ProE and ANSYS FEA studies are in progress.

9.3 Introduction

In contrast to its conceptual simplicity, the ND280 ECAL is a complex mechanical object and its engineering is far from trivial. The size of the largest supermodule is 6.4m x 2.6m, it weighs 15 tons, and contains 5000 scintillator bars in 34 layers, as well as the corresponding photosensors, cooling, and other services. All Barrel supermodules are attached to the magnet yoke either directly (side modules) or via special mounting racks that are part of our responsibility (top and bottom ones). All ECAL modules must be be light-tight, easy to mount and dismount for repairs and upgrades, and rigid enough to obey the strict tolerances within the detector. The Downstream ECAL is mounted within the Basket, aft of the P0D, FGDs, and TPCs. The Basket itself needs to be thin (maximum active detector), strong (to hold 30 tons of very asymmetric load with very small deformations), and provide precise location of all subsystems, be able to preserve tolerances under partial load and through earthquakes, and allow fast and safe installation and removal of individual subsystems for servicing.

The whole project is complicated by the multiple tight installation windows (separate for magnet and coils, basket, and ECAL), a very tight schedule between approval of this proposal and first installation milestone (summer 2008), and last but not least the availability of only a very small crane (10t or less) in the ND280 Hall, which necessitates extra modularity and in situ assembly for the ECAL and some of its installation structures.

This WP covers all stages of design, co-ordination, and time management, as well as procurements and manufacturing (in house or in industry), testing, transport, and installation of detector components.

Some manufacturing will take place at Daresbury and Liverpool, but it is anticipated that most of the larger structural components will be sub- contracted. Final assembly and testing will take place at DL. Daresbury has a large assembly hall, recently refurbished, which has a 30T crane and a suite of internal clean rooms with measurement facilities. Liverpool also has a clean room area capable of housing a large structure and measurement facilities, but is limited to a 0.5T crane. Both DL and Liverpool have highly trained technical staff with long experience in all aspects of building and installation of large detector projects.

9.4 Inputs

- Provision of detailed ECAL layout (WP1, WP2)
- Provision of detailed electronic boards mechanical and thermal specifications (WP4)
- Provision of detailed input from all ND280 subsystems other than the ECAL (from the appropriate groups through the ND280 Technical Board)
- Provision of detailed magnet and magnet support (Italian ND280 group responsible for the magnet)

9.5 Objectives and Milestones

The objectives for this work package are broken down into a number of tasks, which are described below.

9.5.1 Preparation of assembly tools and jigs for ECAL construction

The special tooling, jigs, tables, etc necessary for ECAL assembly and handling, complicated by size and weight of components and modules, will be designed, constructed, and installed at DL and the other participating institutes by the January 2007, so that assembly can start as soon as materials (scintillator and fibers) start to be delivered.

9.5.2 Design of coil supports

The UA1 magnet and coils will be refurbished at CERN. During our recent on-site inspection we found that the original support structure which fixes the horizontal part of the coils to the yoke has not been recuperated. We will design a new one, which will incorporate special mounting rails for the top and bottom Barrel ECAL. This task will be concluded by September 2006.

9.5.3 Design of the Basket

We have designed the Basket which will hold the P0D, FGDs, TPCs, and the downstream ECAL. The basket must be constructed from non-magnetic material, must be strong enough so that its maximum deformations are kept within strict tolerances, and it must be compatible with all subsystem designs. The basket is modelled in ANSYS for FEA studies. We are currently iterating with subsystems to ensure that sizes, weights, attachment points, dimension envelopes, services routing, are all planned in a consistent and compatible way. A set of coherent designs will be prepared and presented at a special Technical Board meeting in the UK in late April 2006, with final approval by July 2006.

9.5.4 Detailed Design for ECAL integration

Our current designs assume that: (a) the side ECAL is attached to the magnet yoke by special mounting points on the ECAL strong-back and the yokes; (b) the top and bottom ECAL attaches to rails mounted to the strong-back and the coil-supporting brackets mentioned earlier; (c) the downstream ECAL is held within the basket through special load-bearing and location pins. As the design and specification of all systems and devices affecting the ECAL is ongoing, we will ensure within the ND280 Technical Board that our procedures and designs are compatible with those of all other subsystems. When this stage is completed, we will produce and validate the final ECAL module detailed design. This will happen by October 2006, allowing the exact specification (dimensions etc) for ECAL components (scintillator bars, fibers) to be frozen and allow timely start of procurement procedures as soon as funds are released.

9.5.5 Design of ECAL cooling

The ECAL electronics (photosensors and readout cards) produce heat which must be removed in order to keep the temperature at a low and precisely control level. In addition, the ECAL surrounds the other subsystems and separates them from the coil which produces significant amounts of heat. A central chiller system will provide cold water flow for all subsystems. The ECAL will have cooling loops running along the strongback to remove heat coming from the coils, while special loops will run within the modules to remove the heat generated by the electronics. The temperature of the ECAL will be monitored at a number of predefined positions. Due to the high humidity in the area, we will continuously flush the ECAL modules with fry nitrogen to avoid condensation. The design is coordinated through the ND280 Technical Board. The design of the cooling and nitrogen loops will be finalized in 2006 to the degree that this affect ECAL module design. Studies to determine the exact flux of water and gas needed will continue and conclude in 2007.

9.5.6 Design of ECAL installation method and devices

Side ECAL supermodules will be lowered onto a purpose-built installation structure comprising sufficient degrees of freedom, through the jacking and slide systems, to allow alignment to the magnet frame prior to be bolted into position. (Fig. 9.1). Bottom ECAL super modules will be lowered onto the same system (Fig. 9.2(a)) and then aligned and lowered into position (Fig. 9.2(b)).

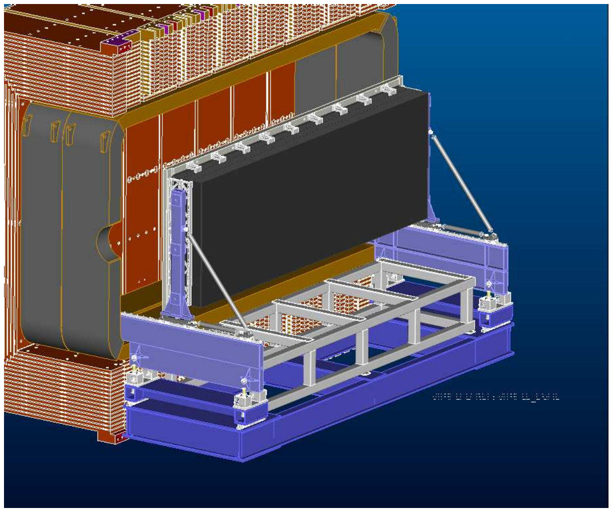


Figure 9.1: Side ECAL Super Module.

Top ECAL super modules will also be lowered onto the same installation system in an elevated

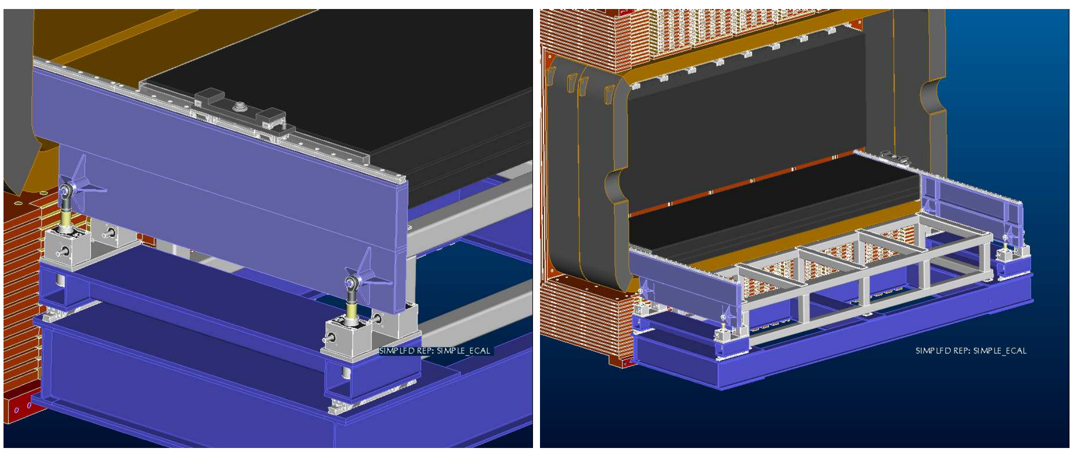


Figure 9.2: (a) Bottom ECAL supermodule lowered onto rail system. (b) Bottom ECAL positioned, lowered and fastened to magnet /coil assembly.

position (Fig. 9.3(a)). An additional steel structure is required for this operation. It will be aligned and jacked into position in a similar way to the bottom ECAL (Fig. 9.3(b)). The detailed design of all structures involved will be finalized by July 2007.

9.5.7 Construction and testing of large structures

Most of the large items mentioned so far (coil supports basket, installation frames) will be subcontracted to UK industry. We will plan, organize, and oversee this activities. All items will be delivered to DL for testing. We will plan and execute a series of load and operation tests as appropriate, to ensure that all devices will function as expected, and that they meet our specifications (e.g. maximum deformations under full or partial load). For this purpose we will construct dummy detectors with the appropriate dimensions, mounting points, and weight distribution. We

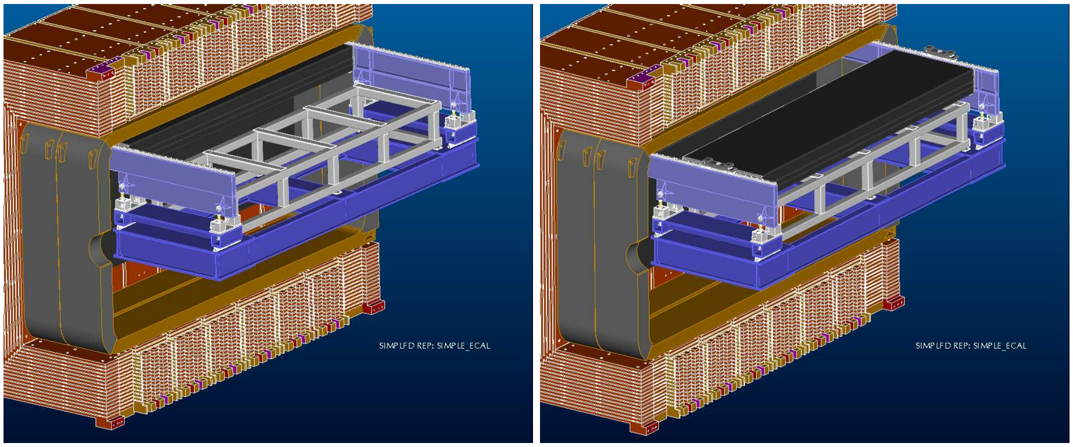


Figure 9.3: (a) Top ECAL supermodule lowered onto elevated rail system. (b) Top ECAL positioned, raised and fastened to magnet /coil assembly.

will survey all devices at key test stages using laser tracking systems at DL. As part of these test programme we will also validate our assembly and handling techniques and iron out any unforseen problems that could delay installation in Japan. This task will extend until July 2009, with the detailed schedule driven by the overall T2K progress and schedule.

9.5.8 Shipping to Japan

We will design and procure all the necessary packing materials and we will organize the transport of all structures and tools, as well as the ECAL modules themselves to Japan. The first parts to be shipped will be the coil supports (mid-2008) and the last will be the ECAL modules (end-2009).

9.5.9 Installation

Current plans define the magnet, coil, and all necessary structures in summer 2008. The basket will be installed in January 2009, immediately before the first subsystems (FGD, TPC) are installed in it. ECAL installation is planned for December 2009 - February 2010. All UK-built items will be installed in the experimental Hall by UK technicians overseen by our engineers. This task will go on until the last ECAL module is installed in early 2010.

9.5.10 Project management

The management and coordination of all other tasks in the WP is complicated and crucial for the successful integration of the whole ND280, and this the subject of this task, which has already started, and will be ongoing until the end of the construction period covered by this proposal.

9.5.11 Milestones

The following key milestones have been set:

- Completion of all preparatory work for ECAL construction: January 2007
- Completion of major design work (Coil supports, Basket, ECAL integration): October 2006

- Completion of detailed designs for cooling and installation: July 2007
- Fully tested coil support shipping to Japan: May 2008
- Fully tested Basket shipping to Japan: May 2008
- ECAL modules and installation structures and tools shipping to Japan: November 2009

  A Gantt chart summarising the work package milestones is shown in Fig. 9.4.

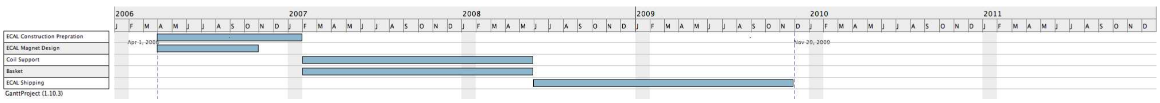


Figure 9.4: Schedule and main milestones of the integration work package.

9.6 Outputs

This Package will provide all engineering design, management, and oversight between now and completion of the ND280 detector with ECAL as a fully-functioning subsystem. Details about deliverables and timescales have been presented in the previous section of tasks.

Chapter 10

Work Package 7: Calibration

10.1 Institutes Responsible

This work package will be provided by Imperial College London, Liverpool, Queen Mary, Sheffield and Warwick. The work package managers are S. Boyd (Warwick) and F. di Lodovico (Queen Mary).

10.2 Key Personnel

The work package managers both have considerable experience in the calibration of an electromagnetic calorimeter:

- **Steve Boyd** is a lecturer at the University of Warwick. He has considerable experience with sampling calorimeters using scintillator as the active element. He played a prominent role for two years in the calibration and reconstruction group working on the NOMAD Front Calorimeter. He has worked on the analysis of calibration data from the NuTeV experiment, another sampling calorimeter, and was a member of the MINOS Calibration group which setup and operated a small calorimeter of MINOS design to test the MINOS system integration and calibration procedures.

- **Francesca Di Lodovico** is a lecturer at QMUL. She has worked on the calibration of the electromagnetic calorimeter and on the identification algorithms for the electromagnetic particles in BaBar. She was in charge of the neutral particles reconstruction and identification group in BaBar for two years. Corresponding results have been used by all the BaBar analyses. She was in charge of the operations of the data reconstruction production in BaBar for one year, becoming familiar with the needs and requirements for an efficient working software. She is currently the principal investigator of the QMUL BaBar group.

Additional support for the calibration group will come from academics who have experience in hardware and software calibration. RAs will be an indispensable part of the group for running the test–beams and implementing the software.

10.3 Introduction

The electromagnetic calorimeter in the T2K near detector must fulfil the requirements for a variety of tasks. The major tasks, such as the detection of photons from π^0 decay or the contribution of information to the particle identification capability of the detector, require that that the calorimeter be both well understood and monitored continuously.

The calibration of the ECAL is a multiple stage procedure with the goal of converting an observed ADC count in the front-end electronics into an energy deposition from a particle or shower passing through the ECAL. The process requires knowledge of the linearity of the electronics and photosensors, monitoring of the response of the scintillator and wavelength shifting fibre and conversion of energy observed in the ADC to energy of the initial particle.

In the following, each calibration stage will be discussed in detail, and the major calibration tasks are identified.

10.4 Inputs

Inputs from other work packages within the proposal are :

- Provision of the calibration module (WP 2).
- Provision and support of the photosensors (WP 3).
- Provision and support of the readout electronics (WP 4).
- Provision and support of the data acquisition system (WP 5).
- Provision and support of the reconstruction and analysis software (WP 8).

10.5 Objectives and Milestones

The objectives and milestones of the different aspects of the calorimeter calibration are described. The first two sections deal with the electronic and photosensor calibration and monitoring, although the actual implementation is part of the goals of the Electronics and Photosensor Work Packages, respectively. The other sections deal with the different aspects of the calibration of the scintillators.

10.5.1 Monitoring of the Electronics

The main goal of the electronics calibration is to linearise the response of the front–end electronics so the non–linearities in other components (e.g. photosensors) may be addressed. This will be done using a charge injection system that will inject known quantities of charge into each channel in the readout electronics chain. Scanning the amount of charge over the dynamic range of the ADC will allow the relation between input charge and channel to be determined and will provide monitoring of the performance of the electronics that is independent of the scintillator or photosensor response. Such a system is common and has been successfully incorporated into the electronics used in the MINOS experiment [38]. The development of the charge injection system is part of the electronics work package (WP4).

10.5.2 Photosensor Linearity and Monitoring

The aim of monitoring the gain and linearity of the photosensors, usually photomultipliers, has been traditionally fulfilled by a light injection (LI) system. A recent example of this calibration system is the light injection system for the MINOS calorimeter [39, 40]. An estimate of the cost of an identical system for the T2K ECAL based on MINOS costs and taking into account the ten–fold increase in the number of channels over MINOS, indicates that such a system would cost more than two million pounds. Further, as the ECAL is contained wholly within the magnet, design and construction of such a system would be far harder than it was in the case of MINOS, where the light can be easily transported to the readout fibres. The constrained situation makes a full LI system undesirable and the base design does not implement one.

The ND280m detector will use a new photosensor device, the AMPD, described in the photosensors work package (Chap. 6). The great advantage of an AMPD is that it is "self–calibrating" because of the excellent photo-electron resolution. The AMPD gain can in principle be monitored by observing the pulse spectra obtained from the passage of cosmic ray muons, whose single photo-electron peak position can be fitted, and the corresponding AMPD gain extracted (see Sect. 6.5.4) Using the information on the muon momentum coming from the internal tracking detectors, the linearity of the AMPD can be monitored. An LI system is not currently considered to be a requirement. However, the photosensor is novel and detailed studies of the photosensor properties are still being performed. The results of these studies may indicate that an LI system is required and we have allowed for the possibility of a system that is less complicated than MINOS in the contingency.

10.5.3 Task I : WLS Fibre and Scintillator Quality Control and Calibration

It is important to have quality control procedures in place during the bar production and after assembly of each layer in the modules. Once assembled, an understanding of the relative response of each scintillator bar, and an absolute calibration of the ECAL energy scales is required.

Scintillator characterisation and WLS fibre quality control

To control the quality of both the WLS fibre and check the result of the assembly procedure a fibre and bar scanner is required for each of the institutes participating in the bar production.

The scanners have two uses. The first is to scan the attenuation curve of a subset of the WLS fibres from each batch that is delivered. This sample must pass a quality control test before fibres from that batch are used in production. The scanner should be equipped with a light source and a PIN diode to readout the light collected by the fibre. Any damage to the fibre will immediately be observed as a unexpected change in the attenuation length profile of the fibre.

The second use of the scanner is to check the assembly procedure and to ensure that the insertion of the fibres into the scintillator bars does not cause damage. To do this a radioactive source will be scanned down the length of the bar and the light output of the scintillator is measured. It is especially important to do this at the start of production whilst errors in procedure are being found and fixed. As the assembly procedure is refined the frequency of scanning may be allowed to fall. However, it is vital that the assembly team at each institute is able to quickly and efficiently scan a subset of the bars that are being made before being shipped to the Daresbury Laboratory to ensure that they are not producing poor quality material.

A scanner capable of accommodating scintillator bars and WLS fibres between 1.5 m and 6 m long must be available at Daresbury and at every University which is participating in the scintillator assembly. It is envisaged that the design of the scanner system will be very similar to that used successfully in the MINOS experiment, pictured in Fig. 10.1, although the different sizes of the scintillator bars imply a somewhat different sized machine. In the MINOS device, the short axis moves using a lead screw, and the long axis using a rack and pinion system. However, since the current construction model assumes that a bar will be scanned individually before transport to Daresbury, there is no need for a servo-operated cross slide and associated frame. At time of scanning the MINOS scintillators are already packaged into modules. This will not be the case for the T2K ECAL scintillators, so a dark box will have to be incorporated into the design. It is expected that the one and two metre bars can be accommodated by machines of identical design. The 6 m long bars will, however, require a different sized machine.

The most crucial feature of the source is that it provides an absolutely known and stable photon energy deposit in a single strip. Examples of radioactive source systems to calibrate the scintillators can be found in BaBar [42], where a 6.13 MeV circulating photon source is used regularly, reaching a statistical precision of 0.35% in a 30 minute run, and MINOS [38], where a 3 mCi $^{137}C_s$ source was used to scan the bars before the final assembly of the modules. The precise nature of the source is currently being studied, with an emphasis placed on providing a safe working environment for those overseeing the assembly of the modules.

Once the scintillator bars have been assembled into modules at Daresbury, a larger scanner will be used to check the assembly and determine the attenuation lengths of each scintillator bar in the module by scanning the radioactive source across the entire module. This is part of work package 2.

The milestone for completion of the scanners is June, 2007, so the manpower working for the accomplishment of this task must be concentrated at the beginning of the project. A joint effort of engineers, technicians and physicists for a total of about 1.5 FTEs up to the completion of the scanners will be needed.

10.5.4 Task II/III : Test Beam Work

The electromagnetic calorimeter must perform a variety of tasks and there is a strong need for test beam data for the following objectives:

- **Determining the energy scale :** To fulfil the main function of calorimetry it is important that the conversion factor between deposited energy and ADC counts be known. The calibration tasks described in the previous sections have established the conversion from ADC counts to deposited energy measured in units of a m.i.p. The last part of the puzzle is to determine the conversion from these arbitrary units to units of GeV. This requires *a priori* knowledge of the energy of particles that enter the calorimeter.

- **Test the calibration methods :** A test beam is the only place (bar the actual experiment) in which a full test of the entire calibration scheme can be applied and tested.

- **Test of pattern recognition algorithms :** Another important function of this calorimeter is to contribute information to the algorithms which will be used, in conjunction with information from the other detectors, to identify particle types from neutrino interactions in the near detector, and hence classify interactions into their interaction modes. Again, although pattern recognition algorithms can be developed in simulation, experience (at MINOS and other neutrino experiments) has shown that a clean sample of different particle types at the relevant energies is invaluable in verifying the identification method and obtaining realistic estimates of particle identification efficiencies.

- **Comparison with simulation :** At the energies at which this experiment will run, it is well known that available hadronic Monte Carlo simulations do not reproduce data well. Since

Figure 10.1: Picture of the MINOS Module Scanner that was used for quality assurance before the scintillator modules were installed in the detector. Shown is a MINOS scintillator module being scanned. The lead pot in the center of the cross–frame contains the radioactive source which is scanned across and along the bars. The machine used for T2K will not require the cross–frame, but will require a dark box.

one of the tasks of the calorimeter is to provide information to aid in the identification of pions, relying completely on the simulation would be foolish.

- **System integration :** It is extremely important that the entire ECAL system, including the hardware, data acquisition and detector control subsystems, is tested and debugged before installation in ND280m detector. A test–beam represents the first and best chance to run the detector under standard operating conditions and will provide a valuable opportunity to test the system.

Test Beam requirements

The requirements of the beam test are clear. The calorimeter must be capable of studying electrons and hadrons with energies ranging from 200 MeV to 5 GeV. It must also be capable of studying photons with energies ranging from 50 MeV up to 300 MeV for the π^0 studies. The photon and electron response is expected to be the same for energies above approximately 150 MeV. Below this, the photon behaviour becomes increasingly affected by Compton scattering, which worsens the reconstruction of the photon direction resolution. The lower momentum bound of the electron beam that best fits our requirements is at 200 MeV (see Table 10.1) and so it would be advantageous to be able to insert the calorimeter in a photon beam with energies between 50 MeV and 200 MeV. There are, then, requirements for an electron beam, a pion beam and a photon beam. Since muons will be used extensively in the relative calibration, they should also be present. Clearly the beams must be able to be set to several intermediate energies as well in order to fully map the response function. Since the calorimeter will be used to study neutrino interactions, with particles entering from all angles, the capability of rotating the ECAL module to present different angles of incidence is necessary. The capability to trigger on particle type is also a requirement, if a mixed beam is used. It is not necessary that a fully instrumented ECAL module be used. In fact, given that angular scans are required, a full module would probably be too large for the test area. However,the instrumented region must be able to cover showers occurring with angles of incidence up to approximately 50 degrees. As the design of the barrel and downstream sections of the ECAL are somewhat different, it may be necessary to test both of them. The present expectation is that the final prototype modules will be used in the test beam work.

There are several locations that fulfil these requirements. It would be desirable to be able to perform all measurements at the one location. However, the requirement of the photon test beam implies that measurements may have to be taken at at least two locations at different times.

Work for any of these beam-tests may be summarised in the following tasks:

- Understand the properties of the beam; implement a realistic simulation of the beam.
- Understand and simulate the effects of the final electronics choice for better comparison with beam data.
- Implement the full calibration chain, which will involve interaction with the DAQ and electronics group, as well as significant software construction e.g. database systems, reconstruction schema.
- Understand the use of the particle identification systems available at the beamline.
- Commissioning of detector at the beamline and collection of data for different particle types, energies and incident angles.

Facility	Particles	Momentum Range	Availability
KEK LINAC End Station	μ,e,p,π	0.1 GeV - 5 GeV	After 2006
DESY	e	0.5 GeV - 7 GeV	No allocation yet
Frascati	e	50 - 750 MeV	No allocation yet
TRIUMF		$<$ 500 MeV	No allocation yet
CERN (PS)	μ, e, p, π	0.2 GeV - 10 GeV	No allocation yet

Table 10.1: Available beam lines which match, wholly or in part, the particle and momentum spectra required for the T2K ECAL .

- Perform detailed comparisons of data and simulation in order to understand the properties of the calorimeter.

Task II : Electron/Pion test-beam

Only a handful of beam lines fulfil the requirements for the electron/pion beam test. These are summarised in Table 10.1 showing the facility, available particles and their approximate momentum ranges, and availability post-2005.

Of the available options, the secondary beam lines in the CERN East area match the requirements most closely. These lines are equipped with sets of Cerenkov counters to aid in particle identification. However, experience with the MINOS Calibration Detector suggests that additional equipment is required to fully understand the incoming particles. Specifically, a small Time-Of-Flight (TOF) system will be needed to aid the particle identification. This TOF system will consist of three stations positioned at different places in the path of the test–beam. Each station will have several components. A small bar of fast scintillator, Bicron BC-404 or BC-420 scintillator material with a decay time of 1.5 ns and an attenuation length of 1.7m is ideal. This will be connected to a fast photomultiplier tube, the Philips XP2020 or equivalent, by a short light guide. The photomultipler tube will be protected from external magnetic fields by a mu-metal shield. Such a system can attain a time resolution of approximately 100 ps which easily fulfils the requirements for the test–beam.

The milestones for the electron test–beam are

- Design, fabricate and test TOF system for deployment at CERN (April, 2008).
- Complete electron/pion test-beam at CERN (Oct 2008).
- Complete analysis of test-beam data to finalise calibration and publish results (Dec 2009).

Preparatory work for the test–beam will start in 2006/2007 and proceed up to when the module will be transferred to CERN for the test–beam. About 3 FTEs of physicists are foreseen to work on it. Data analysis of the test–beam data will be predominantly performed by the research associates.

Task III : Photon beam

A key measurement that the ECAL will contribute towards is that of photons from π^0 decays. Photons with the energies of interest here behave substantially differently than electrons from an eCerenkovlectron test beam. At the energies of interest, there is a large amount of Compton scattering, which smears the direction reconstruction. Furthermore, photons tend to interact several layers within the calorimeter which, combined with different leakage properties, makes the energy

Facility	Beam Type	Photon Energy (MeV)
LEGS Brookhaven	Compton	110-300
ROKK Novosibirsk	Compton	100-1600
Max-Lab Lund	Brem	20-225
MAMI Mainz	Brem	50-800
ELSA Bonn	Brem	340-3100

Table 10.2: Available tagged photon beamlines which match, wholly or in part, the photon energy spectrum required for the T2K ECAL . All facilities in this table have an electron tagging system.

resolution different than that of electrons of the same energy. Photon test beam data would be invaluable in studying these effects in detail. However, the energy of the photons of interest is too high for most available light sources which are tuned to X-ray wavelengths.

We envisage the use of one of the tagged photon beam facilities in Europe. These facilities generate photons in the energy range of a few MeV to 1 GeV in one of two ways: using photons from Bremsstrahlung radiation and Compton backscattering of a laser beam off electrons in an electron storage ring. Bremsstrahlung beams are biased towards low energy photons and have large backgrounds. However, the use of a tagging system to identify the electron which underwent Bremsstrahlung effectively removes this background. The facility that is used must have such a tagging system.

A list of all available facilities with their main characteristics is reproduced from [43] in Table 10.2.

Of the available facilities, the MAMI microtron in Mainz, Germany, and the Max-Lab facility in Lund, Sweden, presents the best match to the required photon energy range. The Max-Lab facility is, however, a small operation and lacks the infrastructure and space required for the tests that the ECAL module will undergo. The Mainz facility is equipped with the required electron tagging system and infrastructure necessary for the deployment of the test module. Further enquiries into the capabilities of the Mainz system and the possibility of obtaining beamtime are underway.

The milestones for the photon test–beam are

- Complete photon test-beam at Mainz (Oct 2009).
- Complete analysis of test-beam data to finalise calibration and publish results (Dec 2010).

Preparatory work for the test–beam will start in 2007/2008. Some of the tools devised for Task II (TOF system, software etc) will be used also for Task III. About 3 FTEs are needed this task. The research associates will then work on the analysis of the test–beam data.

10.5.5 Task IV : Off–line Calibration

The aim of the off–line calibration is to apply the calibration constants obtained by the radioactive source measurement, the test–beams and the analysis of the cosmic muons, taken during data–taking, to the measured ADC counts, in order to translate them in measured energy.

The ADC counts will have already been corrected by the electronic and AMPD calibrations. The corresponding tasks in the Electronic and Photosensor Work Packages foresee the integration of these calibrations in the DAQ system.

Having calibrated the electronics and photosensors, corrected for non-linearities and attenuation effects, the light output of the scintillator and wavelength shifting fibres must be considered.

For a given energy deposition by a charged particle, the amount of light detected from different scintillator bars will be slightly different. Small variations in the concentration of fluor, in the optical coupling of the fibre to the scintillator and the fibre to the photosensor, in the photosensor gain and quantum efficiency and many more effects will give rise to a different response from each scintillator. The response also depends on environmental conditions and varies as the scintillators age.

All these effects can be compensated for by using cosmic ray muons and muons from neutrino interactions both in the detector and in the material surrounding the detector. Such muons provide a continuous, well-understood source that can be used to monitor the scintillator response over the life time of the experiment. The general procedure will be to collect a number of muon hits in each bar and then fit the energy deposition profile with a functional form based on known muon dE/dx behaviour. A standard energy deposition from a minimum ionising particle (m.i.p) is then defined to be some statistic based on this distribution, such as the position of the peak in the energy loss spectrum or the truncated mean of the distribution. The exact statistic that will be used will be determined by investigating the stability of different options in the working system. As explained above the rate of external muons going through the ECAL is of the order of 100Hz, whilst the rate of muons from interactions in the cavern walls is of the order of 1 Hz. This provides sufficient statistics to perform this procedure daily. The goal is to understand the relative response and time variation of that response to better than 5% per day.

Work required for the relative calibration involves development of the software and data analysis. Methods to correct for different path lengths of muons in the scintillator bar must be developed. Such work is, however, routine and has been performed in a variety of experiments [44].

The main requirement for the off–line calibration is for a system that supports multiple algorithms and is extendible in its functional dependence. The coefficients, i.e., the calibration constants, of the functions used for the energy correction must be decoupled from the code itself, which contains the functional forms of the functions, and stored separately in a relational database.

The off–line calibration design should also include the cosmic muons “rolling calibration”. Cosmic muons, taken when the detector will be *in situ* and taking data, are useful for monitoring the scintillator strip response over time and the gain and linearity of the AMPD. The corresponding strategy to adopt regarding the AMPD will be developed together with the Photosensor Work Package. Analysis of the cosmic muons and extraction of the calibration constants will be performed automatically, when a sufficient number of muons has been collected, and the corresponding calibration constants extracted from the analysis written into the database (or equivalent system).

Milestones for this task consist in designing the off–line software calibration system, developing the cosmic muons “rolling” calibration and finally writing and testing the code. Close interaction with the core software group, and especially the database management team, is forseen. This framework should be useable by June 2008 and fully integrated and tested by June 2009.

The requirements for the off–line calibration will be defined during 2006/2007 in collaboration with WP1 and WP8. About 3 FTEs are needed to implement and test the code up to 2009. Final commissioning will be performed in 2009/2010 together with the groups of people who have been working on the test–beams and the corresponding analysis data.

A software group will be created to coordinate the calibration software activities and interact with the Physics and Software work packages. About 2 FTEs will work on this task, joined, as the analysis phase ramps up, by the other members of the calibration group.

The schedule for each task in the work package is shown in Table 10.2.

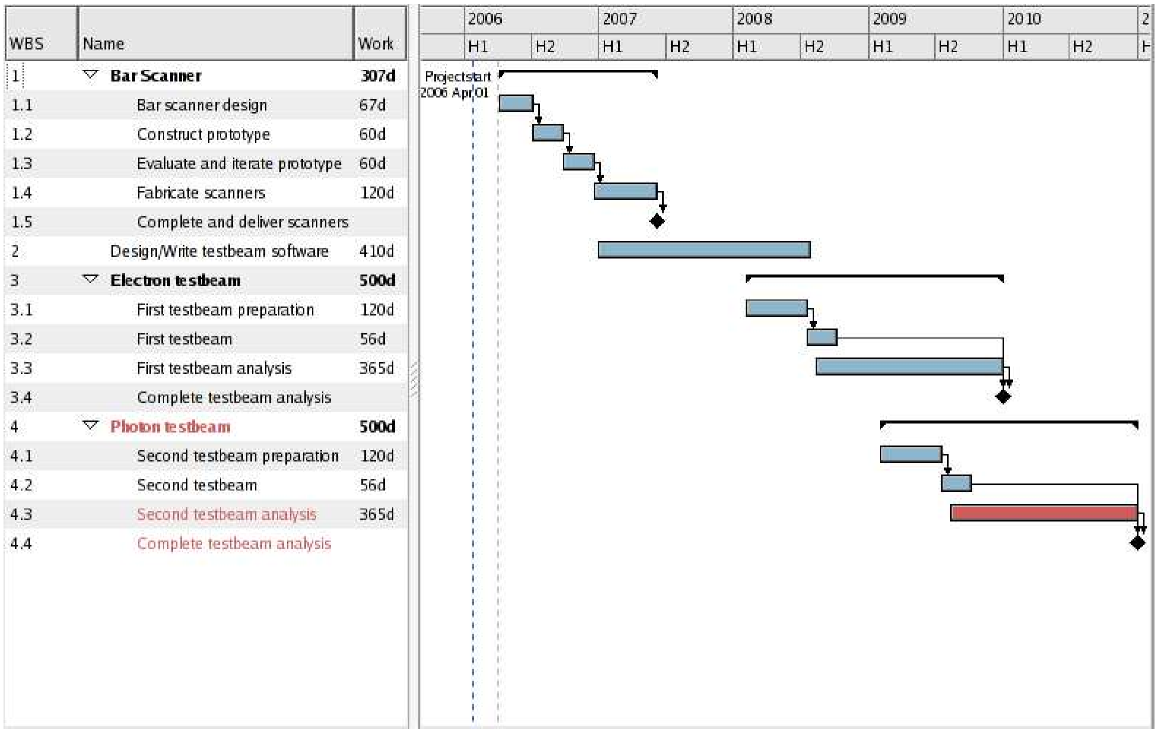


Figure 10.2: Schedule and main milestones of the calibration work package.

10.6 Outputs

The outputs from this work package comprise

- A fully debugged and tested calibration procedure.
- Publication of data on the response of the ND280m detector to test–beam electrons, pions and photons.

Chapter 11

Work Package 8: Offline Software Tools

11.1 Institutes Responsible

This work package will be provided by Imperial College London, Lancaster, Liverpool, Sheffield and Warwick. The work package managers are Y. Uchida (Imperial College) and A. Vacheret (Imperial College).

11.2 Introduction

In this work package, we will provide the software that will be necessary to help optimise, build and calibrate the ECAL, and will work with the collaboration to write a global set of tools that will be used to conduct physics studies before and after the start of data-taking.

We start by briefly describing the software that is currently being used, and then move on to that which we need to develop in the future.

11.2.1 Current Status of Offline Software

Many software packages, both externally sourced and newly written, are in use in the T2K collaboration at the time of this proposal. They include beam simulations and neutrino interaction code, both of which are crucial if the potential of the ND280m detector is to be fully realised. Currently, the well-established interaction MC codes NEUT, NUANCE and NEUGEN are being used.

In the time since the present form of the ND280-OffAxis detector was conceived, two generations of global detector simulations have been used to help understand and refine the designs. The first was a GEANT3-based MC which was adopted from that used by the MINERνA [27] collaboration, and the more recent simulation uses Geant4 [50]. The latter has been developed in conjunction with an I/O library, and in the UK we have written an event display library and application and an analysis framework to work together with these. The software that supports the offline code [51, 46, 45, 47] that is being written has been chosen from those that are widely used in the high-energy physics community.

11.2.2 Ongoing and Longer-Term Software Needs

The initial versions of the offline software have been developed in conjunction with the work on the conceptual design for the detector. Since the conceptual design is now fixed, a pressing need for the software group is the establishment of a full database to track all parameters related to the detector geometry, code and data processing. A well-designed, common database interface is a critical requirement for a detector system as complex as the ND280m. The physics, ECAL hardware, photosensor and calibration work packages will benefit greatly from the early adoption of a well considered database system.

The simulation software already has many of the required features, but many aspects of the geometry will need to be coded in much more detail. There are significant uncertainties in hadronic interactions at sub-GeV energies, and the simulation software will need to incorporate the latest developments in the understanding of these so that they can be reflected in the event simulations at the ND280-OffAxis detector.

Currently, the conversion between charged particle interactions in the detector components to the digitised signals seen in the DAQ is of an ad-hoc nature. As the knowledge accumulated in the photosensor, calibration, electronics and other work packages evolves, the offline software will be required to incorporate this in the form of full detailed simulations, and faster parametrised response algorithms if necessary. The present work package will need to provide a framework to allow this, and incorporation of the results from the other work packages and collaborators into the global database in order that they can be tracked with ease.

The provision of different neutrino interaction models and a well-defined tuning procedure will be essential if the data from the near detector is to be used effectively. At this time, a new interaction generation framework called GENIE [52] is being developed, and is rapidly approaching maturity as it is validated and used in the context of the MINOS experiment. We intend to work closely with the GENIE collaboration to take advantage of the many new features that its modern design allows.

The current analysis framework incorporates several reconstruction algorithms for the different subdetector components, but these will need much development which will be based on the results from the other work packages and collaborators. The software group will need to work on the programming interfaces for the analysis framework in order that non-experts be able to run it without too much learning overhead.

Since the event rates of the experiment are low, and the events themselves are of a sparsely populated nature, the computational resources required by the T2K experiments will be quite modest by modern standards in high-energy physics. However, some issues of global collaboration and data-sharing at T2K are common to those of LHC-scale experiments.

It is understood that the GRID could therefore provide a valuable framework upon which to base the infrastructure for our simulation and data-processing needs. In the UK, we are working with the GRID initiative to cater for smaller experiments, and will soon move our processing onto the GRID. The UK T2K group will be requesting a fair share of the UK tier-1 and tier-2 resources including both CPU and storage (to be negotiated via the GridPP Users Board).

11.3 Inputs

Inputs from other work packages within the proposal are :

- Provision of software requirements for physics studies (WP1).
- Provision of software requirements for photosensor simulations (WP3).
- Provision of software requirements for electronics simulations (WP4).
- Provision of software requirements for calibration studies (WP7).

11.4 Objectives and Milestones

11.4.1 TASK I: Global Database

(Estimated FTEs/year: 0.7)

In common with all complex detectors ND280m will require several databases to store and access many types of data including: calibration data, data file catalogues, trigger lists, geometry and alignment information, etc.

A set of use cases that accurately describe the requirements of the experiment will be required and will be collected from the various groups with an interest in databases. Simultaneously a review of the available database technologies (eg. `mysql, postgresql`) will be carried out. A choice of database will be made by the end of 2006.

A prototype database will be then be designed and implemented to allow the development of software interfaces to the software framework. Once a prototype database has been implemented it will be used for carrying out table design exercises, scaling tests, and tests of interfaces to the analysis code (June 2007).

On a similar time scale a provisional database will be required to store the calibration data that will be produced by the various test beam exercises being carried out by the other work packages.

On completion of the prototype database an ongoing series of database-table design, implementation, and testing will commence with the goal of providing a completed design of the required database tables over the next several years until the detector is completely installed and taking data. In particular we will require a data catalogue for storing information pertaining to simulation and calibration files by the beginning of 2008.

Each sub detector will be installed and commissioned over an extended period commencing in March 2009 when beam is delivered to ND280m and ending in 2010 once the complete detector has been assembled. The databases will have to be implemented on a rolling schedule as each sub-detector is completed.

Milestones

Oct 2006	Use cases completed
Dec 2006	Database technology choice made
Jun 2007	Prototype database testbed implemented
Oct 2007	Testbeam and calibration database tested and used
Apr 2008	Completion of data catalogue
Mar 2009	Production database complete
Mar 2010	Completion of production database for detector components

11.4.2 TASK II : Development of the Simulation and Analysis Framework

(Estimated FTEs/year: 1.5)

The work on the simulation and analysis framework should continue, and a complete chain of simulation and analysis be available to any collaborator with a reasonable commitment of learning effort. This will include building interfaces with external libraries such as GENIE. The physics content of the analysis algorithms will be expected to be provided by the physics work package and other collaborators. The present work package should provide a usable and fully documented framework by the end of 2006. This work will be conducted in conjunction with the ND280m software group.

Milestones

Aug 2006	Completion of I/O class design for reconstruction objects
Dec 2006	Implementation of full simulation / reconstruction flow
Dec 2007	Re-evaluation and improvement of framework design choices
Dec 2008	Delivery of full official framework for production runs

11.4.3 TASK III : Management of the Global ND280 Software

(Estimated FTEs/year: 0.7)
The software includes many different sub-packages which span all the offline-software needs of the experiment. The majority of these will be incorporated into a single standardised setup which can be installed, developed and used in a consistent way. Currently the CVS and CMT packages are used as tools to aid software management. Overseeing the development of this setup is an important task, the quality of which will affect the efficient deployment and use of the software. Adherence to agreed standards and completion of documentation must be required of all submissions that are to become part of the official code base.

Milestones

Oct 2006	Establishment of long-term software standards
Weekly	Certification of submitted code for adherence to standards including documentation
Every 6 months	Re-evaluation of external tool choices

11.4.4 TASK IV : Responsive Software Development and Support

(Estimated FTEs/year: 0.5)
In addition to the central software tasks that can be delineated at this time, the ND280m software group will provide software frameworks and assistance as required by the different groups within the collaboration. These will include the use of new external tools which appear, and the incorporation of new physics models. The bulk of the offline software will be integrated with the database and in many cases the simulation or reconstruction tools, and a common design philosophy is desirable across all of these. The coding of the new software content such as new algorithms and database content creation will reside outside of the present work package; the responsibility here is to ensure that the new software integrates well with the official setup. This will be an ongoing task which will continue as the experiment is being built and will be conducted in conjunction with the ND280m software group.

11.4.5 TASK V: Grid Computing

(Estimated FTEs/year: 0.2)

In the UK (as in many other countries) all of the major computer facilities will be integrated in to the GRID. As such, T2K, including ND280m program, will have to be able to run all of its software in a GRID environment. The global nature of the collaboration will require the support of several different GRIDs (LCG, OSG, etc) and an ability to inter-operate. As such the offline software must be developed in such a way as to be compatible with running over a wide area network (WAN).

The first step to running on the GRID is to ensure that the offline software can be distributed and run over the WAN. For this purpose the software release system (CMT [45]) has to be used in a way that ensures this. The first stage of the project will be to investigate the current methods for distributing software to the GRID using CMT and to implement a method of distributing software releases (Oct 2006).

In the early stage of the software development process it is assumed that we will use the `GridPP` portal [48] for job submission with software that requires no WAN network connections. As T2K will be using GRID resources we will have to set up a Virtual Organisation (VO) for the experiment and maintain and update the list over time to ensure that all users can participate (Dec 2006).

To simplify the use of the GRID a work-flow package will be developed based on the `Runjob` project [49] (which the Lancaster group has played a significant role in developing). This work-flow package will produce all of the required metadata and job descriptions required to monitor jobs submitted to the grid as well as a standard interface to the job submission system. A prototype work-flow system will be developed by Jun 2007 with a finalised product to be completed by the end of 2007.

Once the GRID infrastructure for the ND280m program has been implemented it will have to be maintained. The VO and jobflow software will have to be maintained and updated to support the continuing development of T2K.

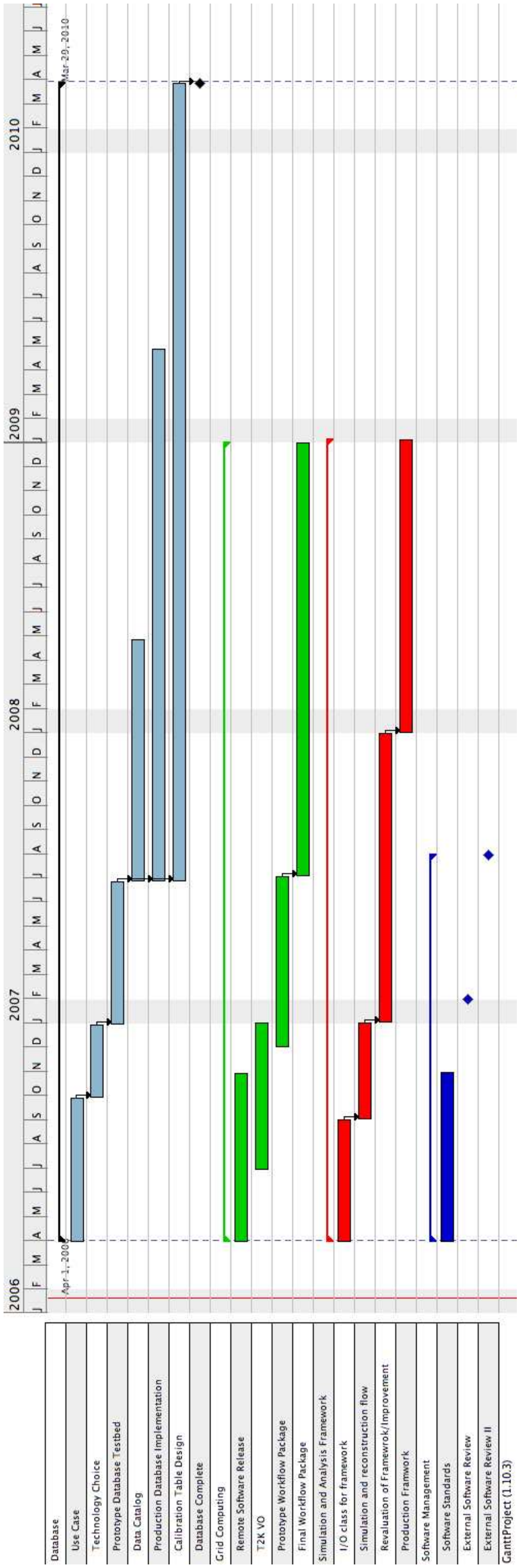
Milestones

Oct 2006	Remote Software releases
Dec 2006	ND280m VO created
Jun 2007	Prototype of workflow package released
Dec 2008	Workflow package released
2008 Ongoing	Maintenance of GRID products

The schedule for each task in the work package is shown in Table 11.4.5.

11.5 Outputs

The present workpackage will provide the software basis for the design and construction of the ECAL, and as a major contributor to the ND280m software group, will provide the software frameworks to be used across the collaboration.


2006
2007
2008
2009
2010
Apr 1, 2006
Mar 29, 2010
Database
Use Case
Technology Choice
Prototype Database Testbed
Data Catalog
Production Database Implementation
Calibration Table Design
Database Complete
Grid Computing
Remote Software Release
T2K VO
Prototype Workflow Package
Final Workflow Package
Simulation and Analysis Framework
I/O class for framework
Simulation and reconstruction flow
Revaluation of Framewrok/Improvement
Production Framwork
Software Management
Software Standards
External Software Review
External Software Review II
GanttProject (1.10.3)

Chapter 12

Work Package 9: Beam and Target

12.1 Institutes Responsible

This work package will be provided by the CCLRC Rutherford Appleton Laboratory. The work package manager is C. Densham (CCLRC RAL).

12.2 Key Personnel

Relevant experience of key personnel with contributions to Work Package items (Total SY).

C. Densham: Work Package manager and Engineering Analysis Group Leader at RAL. At RAL ISIS facility major project was to design and develop a high power radioactive beam target for intensities 100 times greater than currently available from the ISOLDE facility at CERN; Monte Carlo code on radioactive beam release processes from target was main part of Oxford University physics DPhil thesis. Expertise in Finite Element Analysis (FEA) techniques e.g. responsible for engineering analysis of Atlas End Cap Toroid magnets. Led UK team to design, manufacture and assemble LHCb RICH2 superstructure recently installed at CERN. Involved in UK shock wave studies programme for a future neutrino factory target.

M. Woodward: Mechanical and Project Engineer and Design Group Leader at RAL. While at Harwell and Amersham designed and developed the first high level radioactive materials transport flask to be licensed in the UK in accordance with the international IAEA regulations . Set up and managed a Contract Design company. At RAL was responsible for design and engineering of LHCb RICH2 Superstructure.

P. Loveridge: Mechanical Engineer with expertise in FEA of superconducting magnets and composite materials. Carried out all engineering analysis of RICH2, in particular low mass optimisation of large entrance and exit windows, and of Be mirrors for the RICH1 project. Recently successfully integrated modelling of both magnetic fields and mechanics of a NbSn SC magnet for the Next European Dipole project.

M. Fitton: Recently completed PhD at Oxford Brookes University in adhesion and its analysis. Expertise in Computational Fluid Dynamics, modelled current ISIS target to solve non-uniform flow problems.

12.3 Introduction

12.3.1 Beamline and target components outline description

The proton beamline for the T2K facility will be extracted from the inside of the proton synchrotron and deflected in a tight radius towards the target station. (see Fig 12.1). After the final bending and focussing magnets, the beam will pass through a Beam Position Monitor followed by a beam window to separate the machine vacuum from the helium filled target station volume. In front of the target will be installed a collimator, or “baffle”, to protect the first magnetic horn in the event of a mis-steered beam pulse.

Following directly after the baffle will be the pion production target. Interaction of the proton beam with the graphite target is the first step in the generation of the neutrino beam. The resulting pions which have sufficient forward momentum will be collected and focussed into the decay region by a magnetic horn system. The target will be located inside the first of the three horns in order to maximize collection efficiency.

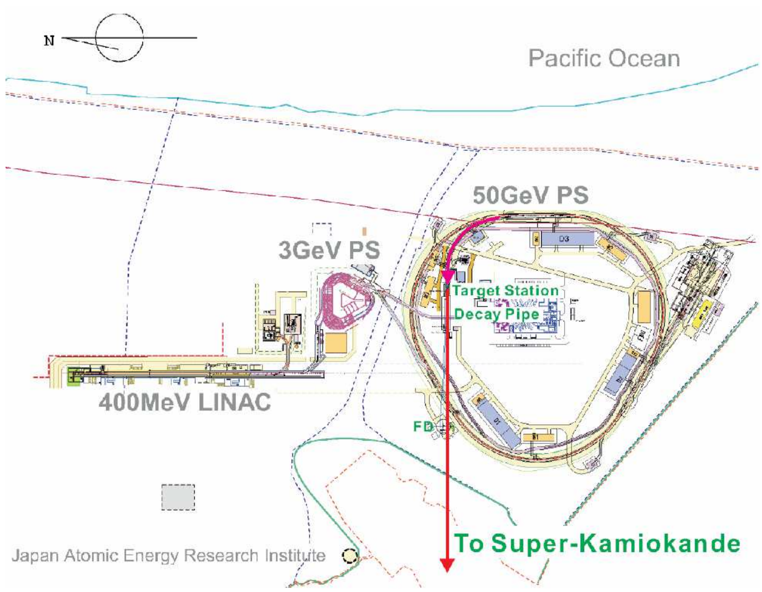


Figure 12.1: Overview of the JPARC facility.

The pions exit the horns into a decay volume, of which the first 50 m section has already been constructed since it passes beneath the 3 GeV proton beam leading to the neutron facility. The length of the decay volume has recently been proposed to be reduced from 110 m to 94 m in order to save civil construction costs. The neutrinos will be produced by decay of the pions to muons during the traverse of the decay volume. At the end of the decay volume will be the beam dump, where any undecayed pions as well as the remaining proton beam will be stopped, amounting to about one quarter of the total initial proton beam power. The beam dump will be followed by a metre of concrete to complete the biological shielding of the muon monitor room.

The beam window, the baffle and the target +horn system will each be mounted beneath separate shield plugs. These will be incorporated into the roof of the target station shielding and sealed into the helium vessel as indicated in Fig. 12.2. Replacement of components will be achieved by lifting out the individual shield plug and lowering it into a remote handling cell. The component in question can then be replaced, and the shield plug re-inserted and sealed into the target station and helium vessel complete with the new component. The decay volume and beam dump share the same helium atmosphere as the target station. After replacement of any of the components, the entire target station and decay volume will be evacuated prior to back-filling with helium.

One of the most challenging aspects of the project is the timescale. The Japanese major funding profile dictates that the facility be ready to receive a proton beam by April 2009. The UK collaboration must achieve the milestones leading up to this deadline for the beam and target work. A considerable amount of design, prototype development, manufacturing and installation work has to be achieved in this highly compressed timescale.

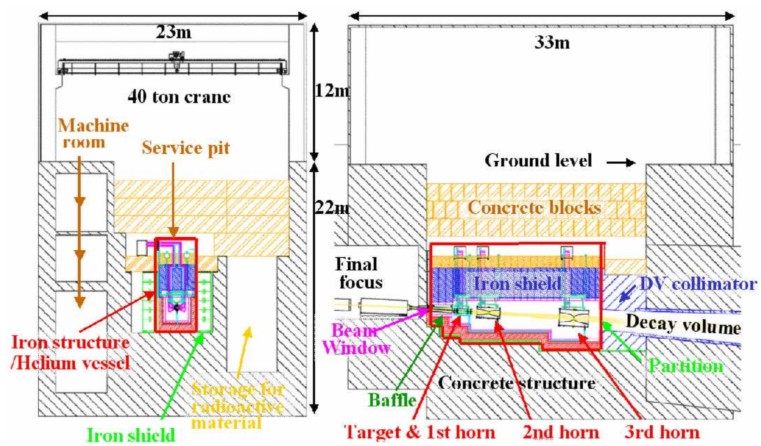


Figure 12.2: Cross–section of the target station.

12.3.2 Outline of UK responsibilities

During the PPARC seedcorn funded period[53], the T2K collaboration has developed to the stage where the UK is well placed to take on the responsibilities negotiated with KEK. Principally these involve all the components that the proton beam directly interacts with from the Beam Window to the Beam Dump. A detailed list of the proposed responsibilities is given later; in summary these are:

- 1. Complete design, engineering analysis, specification, manufacture and supply of the Beam Window, the Baffle, and a remote handling system for the target.
- 2. Design, analysis and specification of the Target and the Beam Dump core. The target is expected to be replaced relatively often during the lifetime of the facility, and so it is desirable that the manufacturing technology be developed in Japan. The Beam Dump manufacture will be carried out by Japanese industry since it will have a large material cost with little technical complexity.

The beam dump must be designed to last the full 25 year lifetime of the facility, and withstand the full 4 MW beam power envisaged for the future upgrade. This is because the dump will be sealed into the He vessel and will not be maintainable after it has been activated. However, in common with the horn and the proton beam itself, the specification of the beam window, baffle and target is that they should be designed and constructed for maximum lifetime at the initial 750 kW beam operation. It is considered too difficult to design these for higher beam powers, certainly in time for the initial start-up. To get a feel for the difficulties in the design of the Beam Window and Target in particular, note that if a single pulse of the 750 kW beam hit a solid iron block it would raise the internal temperature of the block to 1100° C and produce stresses exceeding the tensile strength of the material. These components must have useful lifetimes, e.g. 1/3 year, withstanding such pulses every 3.64 seconds.

The UK engineers who will have designed and developed these components will be in the best position to lead the development of higher power versions. Consequently, as effort becomes available after the initial construction has been completed, it is proposed to begin design, development and materials research for a higher power target and beam window.

The engineering expertise available at KEK is limited. Consequently, in the event of a target failure the initial KEK proposal was that the entire horn and target system be replaced with a complete new assembly. However, the lifetime of a target may be considerably less than that of the horn. Due to the high cost and difficulty of manufacture of the magnetic horn system, KEK has accepted the UK suggestion that this course of action carries a high degree of risk in terms of the reliable and cost effective operation of the facility. Thus the UK is proposing to design the target so that in the event of failure it can be replaced remotely. This can only be done by lifting the complete target and horn assembly out and placing it in a separate active handling area to be incorporated into the target station. RAL expertise in remote handling systems has been acquired through experience on ISIS, while the Japanese are critically short of design capability in this area. If failed targets are to be replaced it is agreed that the UK group will design, manufacture, test and install the remote handling system required to do this difficult operation.

RAL will not be responsible for the design of the shield plugs, the active handling area nor the magnetic horn and its support system; TRIUMF will be responsible for the window installation and support. However since the design of these will have an impact on the design of the components that the UK is expecting to take responsibility for, RAL maintains a dialogue and is negotiating with KEK and TRIUMF staff over their design and implementation. Finally, RAL will not be responsible for carrying out simulations using particle tracking codes; it will remain the responsibility of KEK staff to carry out such simulations and provide RAL with the necessary data.

12.4 Inputs

Most of the inputs required for the UK deliverables have been supplied by KEK in the form of schedule, outline envelopes and power deposition data calculated using MARS. There are no inputs required from other UK Work Packages.

12.5 Objectives and Milestones

12.5.1 Task I : Beam Window

The beam window separates the proton machine vacuum from the atmospheric pressure helium filling the target station and decay volume. A high strength titanium alloy is one of very few candidate materials. Ti-6Al-4V has a good combination of low density to minimise the power deposited by the beam, a sufficiently low thermal expansion coefficient, high strength at a realistically achievable operating temperature, and sufficient ductility. Ti alloys can be difficult to fabricate and weld and so manufacturing prototyping will have to proceed alongside the design process. Samples of the material that have received doses up to 0.29 DPA have been shown[54, 55] to retain these properties. This compares however with a dose of 4.3 DPA/year calculated for 0.75 MW operation at 50 GeV, or 7.2 DPA/year at 30GeV. The only other candidate material is a high strength Be alloy.

The beam window is critical to the safety of the facility, as its failure could damage upstream machine elements. Consequently it will be designed to be easily replaced. It will be fastened to the end flange of the Beam Profile Monitor vessel immediately upstream by a remotely dismountable vacuum connection. Downstream it will be sealed to the target station helium vessel. An inflatable pillow seal will be incorporated into the window to achieve this, based on a design developed at PSI.

RAL will take full responsibility for the design, specification, manufacture and supply of one prototype and one complete window and pillow seal, and will specify the necessary helium cooling supply, vacuum and air lines. The group at TRIUMF will be responsible for the installation and support of the window, the installation of services and the remotely dismountable vacuum connection to the Beam Profile Monitor vessel.

The thinner the window material, the lower will be the beam power deposited in it; however it needs a minimum thickness to withstand the vacuum-to-He pressure load. The power deposited in the window requires that it be directly cooled; it will comprise two skins cooled by helium flowing in between them. To minimise the active area of the window and thus the thickness, a window will be designed to accommodate only one off-axis angle. If the off-axis angle is changed at some point in the future, then the window will be removed and a new one installed to suit the new angle. The entrance and exit flange dimensions will suit the full range of possible off-axis angles of the machine.

In addition to the pressure and thermal stresses, the window will also be subjected to thermal shock from the 5 ms beam spill length. RAL is currently studying this in order to optimise the window thickness and shape to minimise the combined stresses. Studies carried out during the seedcorn phase indicate that the stress in the window is dominated by shockwave issues. The thickness range of the window is such that the eight 58ns bunch structure can cause shock waves to interfere with one another, thus choice of the correct thickness is critical. Even with careful choice of window thickness, see Fig. 12.3, the minimum shockwave stress is sufficient to cause concern regarding fatigue life of the material.

With the window thickness and consequently the heat load determined, the next stage will be to design the helium cooling path and optimise it using CFD to minimise the helium pressure and flow rate while also minimising the temperatures in the material.

12.5.2 Task II : Baffle

The enigmatically named baffle is a collimator intended to protect the first horn surrounding the target. In the event of a mis-steered beam, the baffle is required to scatter a single pulse sufficiently to reduce the likelihood of damage to the horn, before the beam can be tripped for the next pulse. In addition, the baffle will protect the beam dump since it has not proved possible to design the dump to withstand even a single errant pulse that has not first been scattered by the target.

In outline, the baffle needs to be a 1.7 m long thick-walled graphite tube with an internal diameter of 32 mm. Preliminary calculations show that under normal operating conditions the baffle will experience a heat load of 1.2 kW from beam halo and another 1 kW from pions back-scattered from the target.

As for the window, RAL is proposing to take full responsibility for the design, manufacture

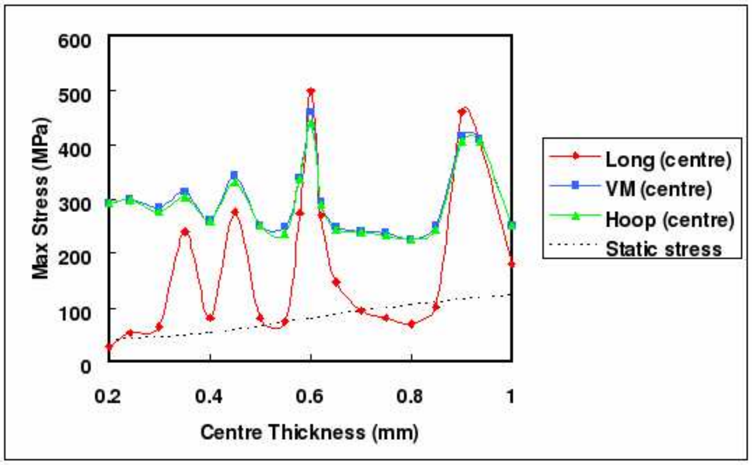


Figure 12.3: Maximum shock wave stress generated in Ti-6Al-4V window as a function of thickness.

and supply of the baffle, including the specification of the necessary services and support.

12.5.3 Task III : Target

The target/horn system is almost certainly the most demanding part of the project. This is not immediately apparent, as the target is in essence simple: a metre-long bar of graphite. However, this 30 mm diameter bar of graphite must dissipate the power and the shock waves deposited in it by a proton beam carrying 2.7 MJ of energy in a 5 ms pulse every 3.6 s. Cantilevered from the upstream end, it must fit snugly inside but without touching i.e. shorting out the first horn, and it must have very little material surrounding it so that the pions can escape and be efficiently collected. The target will be cooled by high-velocity He gas contained within a thin-walled titanium can, complete with entrance and exit windows. Of course the target and first horn will become very heavily activated within a very short time of the beginning of operation, so any maintenance/repair activities will have to be conducted remotely, and any damaged/discarded targets will have to be stored as high- level waste. It is assumed that any failure of the target would be detectable by muon monitor measurements, by damage to the horn, or by a loss in helium coolant pressure. Since the clearance between the target and horn is negligible, it is also assumed that the 900 mm length of graphite would not be able to fail in such a way as to allow a beam pulse to pass without being scattered by the target material.

The target is an area where the lack of engineering effort at KEK is particularly serious. Significant conceptual and engineering analysis work has already been carried out by RAL during the seedcorn phase. Figs. 12.4-12.5 show a model of the RAL proposed design for the upstream target support end, with the graphite encased entirely within a Ti enclosure. In this design, helium first cools the entrance Ti window, then passes through angled holes in the target to flow between an intermediate graphite tube and the outer Ti can. At the far end of the target, it cools the downstream Ti window before returning to cool the target itself. The flow around the end of the target has itself taken a considerable amount of optimisation using a CFD code. The helium must flow around the end of the target so that it cools the Ti end window sufficiently, without generating large pressure drops or areas of recirculation before it returns cooling the surface of the target. Shock wave calculations using ANSYS and LS-Dyna have been performed to identify design issues and

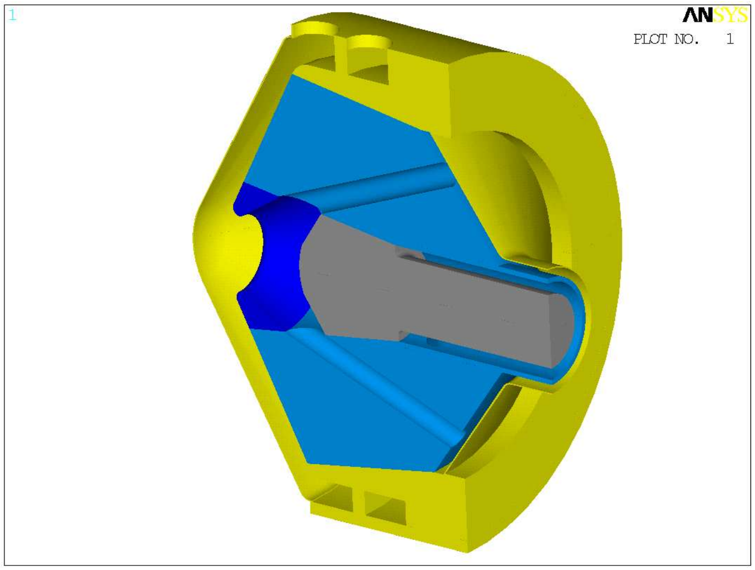


Figure 12.4: RAL design of upstream part of target showing He inlet and cooling path. Ti target enclosure shown in yellow.

problems as shown in Fig. 12.8.

Engineering with graphite is in itself difficult. It is a low strength material, and properties can be highly variable between batches. While specialised manufacturing techniques can improve properties such as thermal conductivity, such improvements tend to be reversed with even a small amount of radiation damage. Graphite is often used in industry as a non-stick table on which to perform welding or brazing of metals in vacuum. It is then no surprise that using such processes during the manufacture of graphite components is inherently problematic.

Much conceptual and detailed engineering work on the target system remains outstanding. This is a problem that goes far beyond T2K, as building a high-powered target is a necessary part of almost all future experiments with a proton driver, especially a Neutrino Factory

12.5.4 Task IV : Target Support and Handling System

The difficulty of supporting the target safely within the first magnetic horn cannot be overstated. Sufficiently reliable operation of the target and horn system for a useful lifetime is crucial to the operation of the facility. The current dimensions give a 1 mm radial clearance around the 900 mm long target. The target diameter has been optimised for maximum pion production, while the horn has been optimised to maximise capture. The mass flow of helium required to cool the target is such that, with the maximum annular space permitted for the coaxial helium flow, flow velocities in excess of 500 m/s result. Thus there is very little room for manoeuvre. The titanium enclosure will be coated with a ceramic insulation layer to prevent a short in the event of the target touching the inner conductor. This ceramic coating will exist in a demanding environment. In addition to the radiation damage, every time the horn is pulsed, a shock wave is generated in the material analogous to the proton beam induced shock wave generated in the target. With the inner conductor 3 mm thick compared with the 0.3 mm Ti target enclosure wall thickness, this source of shock and vibration is unlikely to enhance the lifetime of either the target or the horn.

RAL is planning to design the target together with a system to support the target within the first

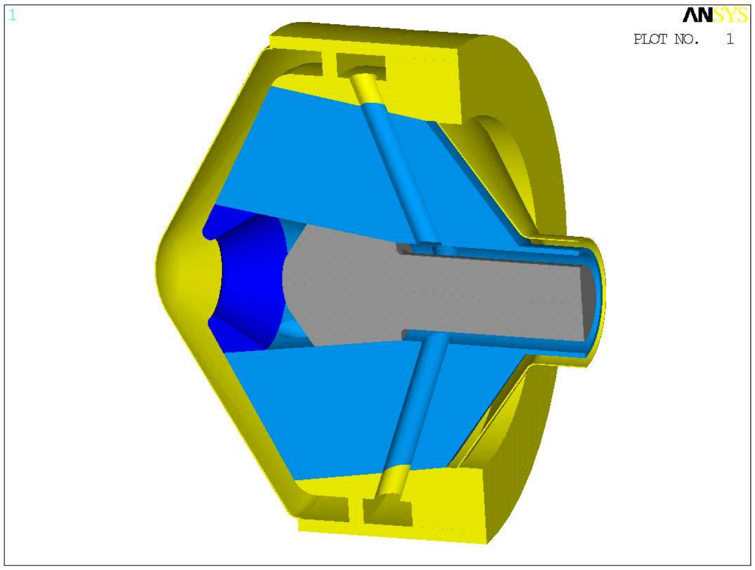


Figure 12.5: RAL design of upstream part of target showing He return path. Ti target enclosure is shown in yellow.

magnetic horn in such a way that failed targets can be replaced remotely in the T2K active handling cell. Given how challenging this task will be, RAL will press the collaboration to consider a smaller diameter target, as a slightly reduced pion yield may be compensated by significantly longer operation time.

12.5.5 Task V : High Power Material Studies

RAL staff are already involved in an experiment to simulate proton beam induced shock waves in targets by passing up to 8 kA currents in 100 ns pulses through small diameter tantalum wires as part of a separate PPARC funded project. This experiment is of direct relevance to the T2K project for both graphite target material and the Ti alloy for the target and beam window. Thus for negligible extra cost the scope of this project is being extended to cover the T2K parameters for both materials, showing synergy with the PPARC program for high power target studies. It is also proposed to continue this joined-up approach for experiments using high power lasers and the ISOLDE facility, CERN.

The problems are obvious no candidates exist for a beam window or target above 0.75 MW beam power within the parameters of the T2K facility. No solutions are expected during the lifetime of this grant, but it is hoped to identify future areas of research. For example, it is planned to investigate graphite extruded with holes incorporated into it to act both as a direct coolant path and to dissipate shock waves. These problems will not be solved in isolation, as they are common for many high power particle accelerator projects, e.g. targets and dumps for the FAIR facility, beam dumps for the ILC, and most significantly targets for a future neutrino factory.

Experience gained working on the T2K target will thus be of general use to the UK Nufact targetry programme.

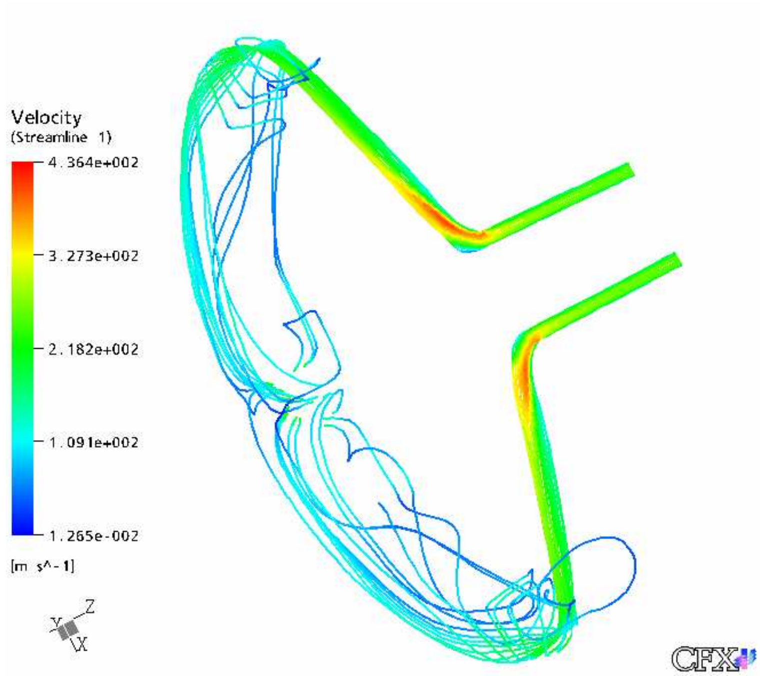


Figure 12.6: Helium velocity flow lines in section of return path.

12.5.6 Task VI: Beam Dump

The final resting place of the proton beam and any undecayed pions is the beam dump at the end of the decay region. It comprises a graphite front plug, followed by Cu and Fe to range out all the hadronic secondaries. To minimize expense the beam dump must be made as short as possible, and the thickness is also constrained by the need to keep the energy loss of muons traversing the beam dump as low as possible, so that the beam direction can be determined from monitoring the low-energy muons from pion decay. It is 3 m wide, 6 m high to cover the full range of off-axis angles from $2-3°$, and almost 6 m long.

Although it is not the most technically complex part of the facility, there are a number of factors that cause difficulty. It must be cooled from outside the active volume to minimise the activation of cooling water, and in order to present a uniform material cross-section for the muons passing through. Consequently high temperatures and thermal stresses will be generated at the centre of the core materials. Graphite is the only material suitable to scatter the proton beam before the majority of the energy is deposited in the copper; fortunately it is also relatively inexpensive. Fig. 12.9 shows a plot of temperatures in a half model of the graphite part of the core.

Although the beam has been scattered to some extent by the graphite target 110 m upstream, simulation work by RAL has discovered that for 50 GeV operation a minimum of 3.6 m graphite is required to reduce the power density generated in the copper to a level whereby its tensile strength is not exceeded at the elevated operating temperature. Copper is the only material with sufficient thermal conductivity to dissipate the power over the required distance. After 0.9 m Cu the final secondaries are stopped by 1.35 m of steel and 1 m concrete forming a biological shield for the muon detector pit behind the dump. The final and greatest difficulty comes from activation; even a short period of operation of the beam at low intensities will make hands-on access to any part of the dump impossible. It will also be sealed inside the same helium vessel as

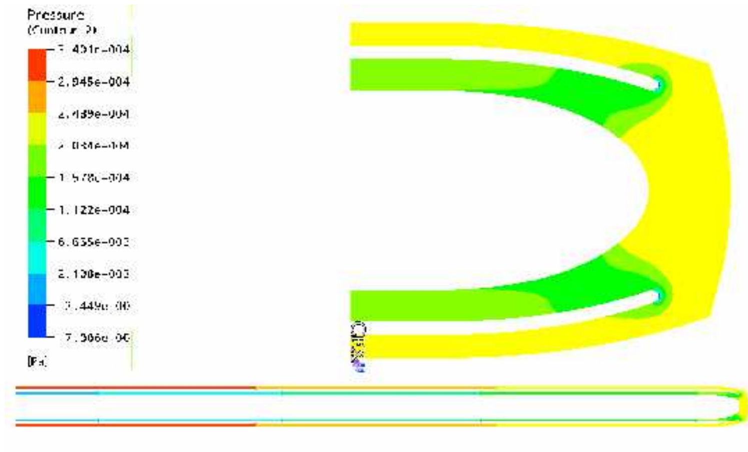


Figure 12.7: Pressures in He along target and downstream window.

the decay volume and target station, and is in a configuration where even remote maintenance is not possible. Consequently the beam dump must operate without maintenance for the lifetime of the facility and so it must be designed for the full 4 MW beam power.

RAL is proposing to continue its responsibility for the design of the beam dump core comprising the graphite, copper and iron. This will include the design of the modules cooling the graphite, and the design of the cooling for the copper. KEK also requested that RAL take responsibility for the design of the helium vessel surrounding the beam dump core; however the work involved is difficult to estimate and so we are not requesting for this to be funded.

12.5.7 Project Milestones

- Beam dump major dimensions and quantities specified. Graphite material ordered (May 2006)
- First complete target prototype specified and ready for manufacture to begin. Beam dump graphite core and cooling modules specified and ready for manufacture to begin (2 April 2007)
- DV and BD civil construction and helium vessel complete. Begin installation of Beam Dump. (December 2008)
- Beam window and baffle ready for installation. (1 September 2008)
- Target remote handling system installed, tested and ready for use. T2K facility scheduled to begin operation. (April 2009)

A Gantt chart summarising the main milestones of the beam work is shown in Fig. 12.10.

12.6 Outputs

12.6.1 Beam window

- Full engineering design and analysis of the window, including optimisation of the shape using CFD and FEA analysis, and shock wave damage studies.

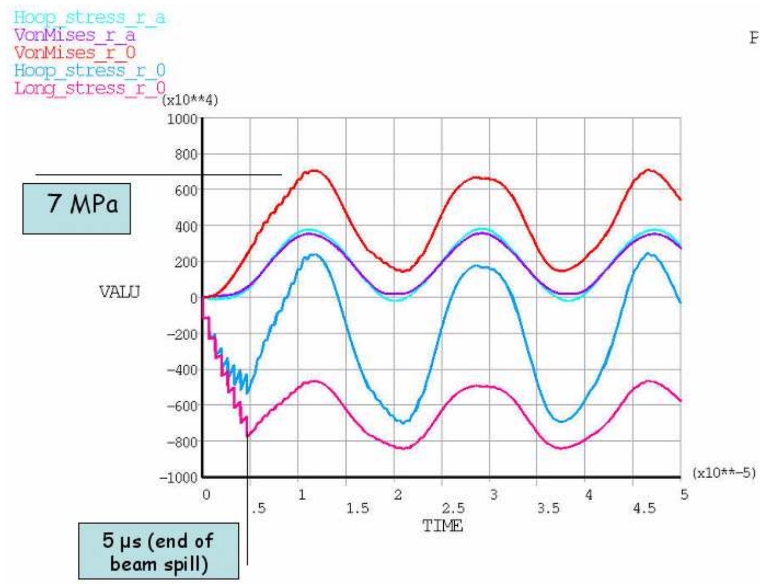


Figure 12.8: Shock wave oscillations in target over 50us after 5us beam spill.

- Incorporation of a remotely operated pillow seal connecting it to the downstream flange of the final Beam Profile Monitor vessel, so that it can be remotely replaced.
- Specification of all services required, namely helium flow rate, compressed air lines and vacuum ports.
- Manufacture and supply of a prototype and a final complete window and pillow seal assembly for a single specified off-axis angle.

12.6.2 Baffle

- Full engineering design and analysis of the baffle, including specification of cooling method (He or water) and flow rates.
- Specification of diagnostics required, ie thermocouples.
- Specification of attachment method of baffle to supporting shield plug.
- Manufacture and supply.

12.6.3 Target

- Full engineering design and analysis of the target; design of the helium cooling path using CFD codes; shape optimisation; thermal, stress and shock wave analysis using FEA codes; simulation of shock waves using high current pulsed power supply at RAL.
- Design of titanium target enclosure including entrance and exit windows.
- Identification of manufacturing methods and requirements for prototyping.

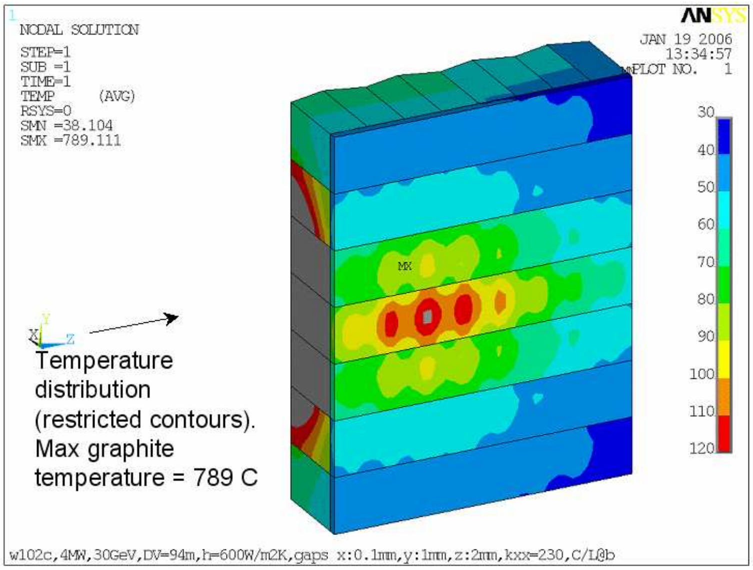


Figure 12.9: Temperature distribution in half model of graphite beam dump core, showing horizontal cooling modules along the beam dump length.

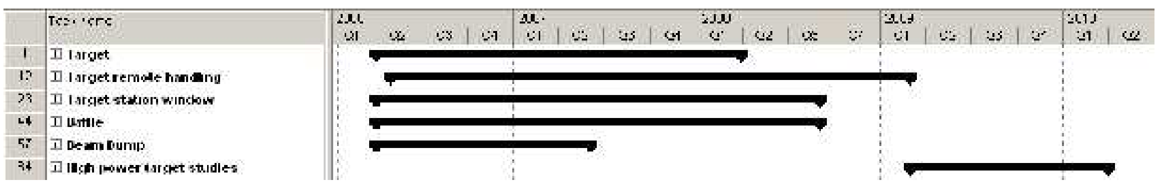


Figure 12.10: Schedule and main milestones of the beam and targetry work package.

12.6.4 Target Support and Handling System

Complete specification, design, development, manufacture, supply, installation and testing of target support and remote replacement system including remote helium connections.

12.6.5 Beam Dump

Complete design of beam dump core comprising the graphite and copper sections and the cooling modules. General Assembly drawings will be supplied to KEK in sufficient detail for manufacturing drawings to be prepared directly by Japanese industrial partners.

Chapter 13

Management Plan

13.1 Overall Structure of the UK Collaboration

The T2K-UK management structure consists of two committees:

- the Institutes Board;
- the Project Management Committee $\star$;

and two executive managers:

- the UK Spokesperson $\star$;
- the Project Manager $\star$.

The starred persons or bodies are required by PPARC policy.

13.2 The Institutes Board

This is the governing body of the UK collaboration. Its duties are:

- approval of all major decisions relating to the collaboration, e.g. submission of proposal, major changes to responsibilities, etc.;
- formal approval, generally twice per year, of budgets and schedules as presented by the Spokesperson;
- formal approval of collaboration reports to PPARC bodies such as the Oversight Committee, the Grants Panel, etc.;
- admission of new collaborating institutes (and, should this ever happen, acceptance of formal withdrawal of a collaborating institute);
- appointment of the executive management (and, in the unlikely event of this becoming necessary, formal revocation of such appointments).

The Institutes Board (IB) consists of one representative per collaborating institute. New collaborating institutes have the right to a representative as soon as their application to join has been formally approved by the Board. The Chair of the Institutes Board shall be appointed for a fixed term of 3 years without renewal. The position of Chair rotates round the collaborating institutes; nominations are made and, in the event of multiple nominations, voted upon by the members of the IB. The duties of the Chair are to convene and preside over IB meetings, to ensure that minutes of Board meetings are taken and circulated, and to act as Returning Officer for votes of the IB and the Collaboration. The IB shall meet as deemed necessary by the IB Chair, and in any case at least twice per year. Individual IB members and the UK Spokesperson may request an IB meeting through the IB Chair. The UK Spokesperson and the Project Manager are invited to all IB meetings ex officio, but are not themselves IB members and do not vote. Decisions of the IB may be taken by consensus or by formal majority vote of Institute representatives.

13.3 The Project Management Committee

The Project Management Committee consists of the T2K-UK Work Package Managers, along with the executive management (Project Manager and UK Spokesperson). Its duties are to monitor the progress of the project, ensure that milestones are met, and review the budget. It is chaired by the Project Manager and reports to the Spokesperson. The PMC meets as frequently as necessary.

13.4 The UK Spokesperson

The UK Spokesperson represents the Collaboration to external bodies such as PPARC and is the overall leader of the science team. He or she is responsible for the strategic management of the project as a whole: therefore s/he should not be a Work Package Manager nor an Institute representative on the IB. The Spokesperson reports to the Institutes Board.

13.4.1 Election of the Spokesperson

The Spokesperson is elected for a period of three years, renewable. Nominations for Spokesperson are made by IB members and an approved list of candidates is agreed by the IB. In the event of multiple candidates, the Spokesperson is elected by majority vote of all members of the UK Collaboration with a PhD, the IB Chair acting as Returning Officer. If the IB Chair is nominated, he or she must step down as IB Chair for the duration of the election process.

13.4.2 Removal of a Spokesperson

The IB has the power to remove the Spokesperson from office. In the event of a formal request by at least two IB members, the IB Chair is required to call a special meeting of the IB in the absence of the Spokesperson to consider this action. The decision on whether or not to ask the Spokesperson to stand down will be taken by majority vote at the end of this meeting.

13.4.3 Deputy Spokesperson

In the event of the Spokesperson's being temporarily unavailable, e.g. owing to illness, for a period which is too long to be covered by the Project Manager (or which includes a meeting at which the

Spokesperson's presence is formally required) a Deputy Spokesperson may be appointed by the IB.

13.5 The Project Manager

The Project Manager is responsible for day-to-day planning and execution of the project, within the budget and timescale agreed with PPARC. He or she assists the Spokesperson in interacting with PPARC; for example, both are expected to be present at Oversight Committee meetings. It is expected that the Project Manager will be a senior RAL-PPD physicist, and that he will also act as the Collaboration budget holder. The Project Manager reports to the UK Spokesperson. Candidates for the post of Project Manager are nominated by the UK Spokesperson and endorsed by the Institutes Board. This is not a fixed term position: ideally, the Project Manager will remain in post for the duration of the construction phase of the project.

13.5.1 Removal of the Project Manager

The Spokesperson has the power to request the resignation of the Project Manager. This action requires prior endorsement by the IB.

13.6 Interaction with PPARC

In addition to the internal management structure, PPARC will appoint

- a Project Sponsor, who is "the person within PPARC who essentially commissions the activity and who has delegated responsibility within PPARC for the project" (this is apparently "usually Director of Programmes or the Head of Astronomy or Particle Physics");
- an Oversight Committee, which will "normally meet every six months and will receive reports from the Project Manager and the Spokesperson." The Oversight Committee "provides independent scientific, technical and management advice" to the Project Sponsor.

"In addition to the above", PPA(03)09 says, "projects may be reviewed on a less regular but more in-depth basis as appropriate. This may include the PPRP as is currently the case for particle physics projects."

In general, such interactions with PPARC should be handled by the Spokesperson, with the assistance of the Project Manager. The IB should become involved only if PPARC requests substantive changes to the management, timing, scope or financing of the collaboration. However, in view of the potential implications for personnel and resource management within institutions, the Spokesperson's written submissions to such committees should be reviewed and endorsed by the IB prior to submission.

Annex A: Work Package Request for Resources

A description of the resources requested and the corresponding costs by each work package is given in the following sections, split into manpower, equipment and travel. The staff requirements per work package are given in fractions of FTEs with respect to the financial years.

Annex A1

Work Package 1: Physics Studies and ECAL Optimisation

A1.1 Resources requested

A1.1.1 Manpower

The effort per FY in units of FTE proposed for staff contributing to this work package is shown in Table A1.1.

A1.1.2 Equipment and Consumables

This work package is primarily an analysis oriented one. As such no equipment or consumables are being requested.

A1.1.3 Travel

The resources needed beyond staff costs will be kept as low as possible, by using modern remote conferencing methods and software tools, and restricting physical meetings to those that are organised outside of the software group at the collaboration or UK level. We are requesting funds to cover one trip to a UK institution bimonthly for 10 people in the first two years, and every four months during the construction phase. We also request two international trips of one week duration for 10 people to dedicated physics meetings.

A1.2 Cost Profile

A1.2.1 Overview

An overview of the total costs for this work package is shown in A1.2.

A1.2.2 Working Allowance and Contingency

This package does not request any explicit working allowance or contingency.

Staff	Funding	FY06/07	FY07/08	FY08/09	FY09/10	Total FTE
Imperial College						
Y. Uchida	Rolling Grant	0.2	0.2	0.2	0.2	0.8
A. Vacheret	Rolling Grant	0.2	0.2	0.3	0.3	1.0
M. Wascko	Rolling Grant	0.6	0.6	0.4	0.4	2.0
D. Wark	Rolling Grant	0.2	0.2	0.2	0.2	0.8
RA-Imp-1	Project	0.0	0.1	0.3	0.2	0.6
Subtotal		1.2	1.3	1.4	1.3	5.2
Lancaster						
I. Bertram	Rolling Grant	0.0	0.1	0.2	0.2	0.5
A. Finch	Rolling Grant	0.2	0.2	0.2	0.2	0.8
L. Kormos	Rolling Grant	0.2	0.2	0.2	0.2	0.8
P. Ratoff	Rolling Grant	0.0	0.1	0.2	0.2	0.5
RA-Lanc-1	Rolling Grant	0.1	0.2	0.2	0.2	0.7
New RA-Lanc-2	Project	0.0	0.2	0.2	0.2	0.6
Subtotal		0.5	1.0	1.2	1.2	3.9
Liverpool						
N. McCauley	Rolling Grant	0.3	0.3	0.3	0.3	1.2
D. Payne	Rolling Grant	0.0	0.2	0.2	0.5	0.9
C. Touramanis	Rolling Grant	0.0	0.0	0.1	0.1	0.2
Subtotal		0.3	0.5	0.6	0.9	2.3
Queen Mary						
A. Bevan	Rolling Grant	0.0	0.0	0.1	0.2	0.3
F. di Lodovico	Rolling Grant	0.0	0.1	0.2	0.2	0.5
W. Menges	Rolling Grant	0.0	0.0	0.2	0.5	0.7
New RA-QM-1	Rolling Grant	0.0	0.3	0.3	0.5	1.1
Subtotal		0.0	0.4	0.8	1.4	2.6
RAL PPD						
C. Andreopoulos	CCLRC SLA	0.0	0.2	0.3	0.3	0.8
RA-RAL-1	CCLRC SLA	0.0	0.5	0.5	0.5	1.5
RA-RAL-2	CCLRC SLA	0.0	0.5	0.5	0.5	1.5
Subtotal		0.0	1.2	1.3	1.3	3.8
Sheffield						
S. Cartwright	Rolling Grant	0.4	0.4	0.3	0.4	1.5
New RA-Shef-1	Project	0.0	0.0	0.0	0.4	0.4
Subtotal		0.4	0.4	0.3	0.8	1.9
Warwick						
G. Barker	Rolling Grant	0.0	0.0	0.0	0.3	0.3
S. Boyd	Rolling Grant	0.0	0.0	0.0	0.2	0.2
T. Gershon	Rolling Grant	0.0	0.0	0.2	0.2	0.4
P. Harrison	Rolling Grant	0.0	0.0	0.2	0.2	0.4
New RA-War-1	Project	0.0	0.0	0.0	0.3	0.3
New RA-War-2	Project	0.0	0.0	0.0	0.3	0.3
Subtotal		0.0	0.0	0.4	1.5	1.9
Total FTE		2.4	4.8	6.0	8.4	21.6

Table A1.1: Summary of work package staff requirements in units of FTE.

Work package 1	**Cost (£k)**
Staff Costs	
Imperial College	586
Lancaster	292
Liverpool	175
Queen Mary	169
RAL/PPD	321
Sheffield	201
Warwick	141
Total Staff costs	1885
Equipment	0
Consumables	0
Travel	30
Total Non-Staff Costs	30
Total	1915

Table A1.2: Summary of work package costs £*k*.

Annex A2

Work Package 2: ECAL

A2.1 Resources Requested

A2.1.1 Manpower

As mentioned in the Section 5.5, several institutions will participate in constructing the ECAL. In addition, Daresbury Laboratory and Liverpool University are sharing the engineering responsibilities. The expected manpower requirements are listed in Table A2.1.

Table A2.1: Summary of work package staff requirements in units of FTE.

Staff	**Funding**	**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total FTE**
Daresbury						
Staff	**Funding**	**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total FTE**
Daresbury						
A. Grant	CCLRC SLA	0.4	0.5	0.3	0.3	1.5
A. Muir	CCLRC SLA	0.8	0.0	0.0	0.0	0.8
TECH-DL-1	CCLRC SLA	0.1	1.0	0.8	0.5	2.4
TECH-DL-2	CCLRC SLA	0.0	1.0	0.8	0.0	1.8
Fitter-DL-1	CCLRC SLA	0.1	1.0	1.0	1.0	3.1
Fitter-DL-2	CCLRC SLA	0.0	1.0	1.0	0.4	2.4
Fitter-DL-3	CCLRC SLA	0.0	1.0	1.0	0.0	2.0
Fitter-DL-4	CCLRC SLA	0.0	1.0	0.4	0.0	1.4
Fitter-DL-5	CCLRC SLA	0.0	1.0	0.0	0.0	1.0
Fitter-DL-6	CCLRC SLA	0.0	1.0	0.0	0.0	1.0
Fitter-DL-7	CCLRC SLA	0.0	1.0	0.0	0.0	1.0
Fitter-DL-8	CCLRC SLA	0.0	0.3	0.0	0.0	0.3
Subtotal		1.4	9.8	5.3	2.2	18.7
Lancaster						
A. Chilingarov	Rolling Grant	0.2	0.2	0.2	0.0	0.6
L. Kormos	Rolling Grant	0.4	0.4	0.4	0.4	1.6
I. Mercer	Rolling Grant	0.4	1.0	1.0	0.0	2.4
						Continued on next page

Table A2.1 – continued from previous page						
Staff	**Funding**	**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total FTE**
Daresbury						
P. Ratoff	Rolling Grant	0.2	0.2	0.2	0.2	0.8
RA-Lanc-1	Rolling Grant	0.4	0.8	0.8	0.8	2.8
J. Statter	Rolling Grant	0.0	1.0	0.5	0.0	1.5
Subtotal		1.6	3.6	3.1	1.4	9.7
Liverpool						
J. Carrol	Rolling Grant	0.1	0.3	0.4	0.3	1.1
C. Chavez	Rolling Grant	0.0	0.2	0.3	0.2	0.7
N. McCauley	Rolling Grant	0.1	0.1	0.1	0.1	0.4
D. Payne	Rolling Grant	0.0	0.0	0.1	0.3	0.4
P. Sutcliffe	Rolling Grant	0.1	0.2	0.4	0.1	0.8
M. Thresher	Rolling Grant	0.1	0.7	1.0	1.0	2.8
C. Touramanis	Rolling Grant	0.3	0.3	0.3	0.4	1.3
M. Whitley	Rolling Grant	0.1	0.2	0.5	0.5	1.3
M. Wormald	Rolling Grant	0.1	0.4	0.4	0.4	1.3
New RA-Liver-1	Project	0.2	0.7	0.7	0.7	2.3
Subtotal		1.1	3.1	4.2	4.0	12.4
Queen Mary						
A. Bevan	Rolling Grant	0.1	0.2	0.2	0.2	0.7
G. Marshall	Rolling Grant	0.1	0.2	0.2	0.1	0.6
J. Mistry	Rolling Grant	0.2	0.3	0.3	0.2	1.0
J. Morin	Rolling Grant	0.2	0.2	0.2	0.2	0.8
J. Morris	Rolling Grant	0.3	0.2	0.2	0.2	0.9
Subtotal		0.9	1.1	1.1	0.9	4.0
Sheffield						
L. Thompson	Rolling Grant	0.1	0.1	0.1	0.0	0.3
New TECH-Shef-1	Project	0.5	1.0	0.5	0.0	2.0
New RA-Shef-1	Project	0.2	0.3	0.3	0.0	0.8
Subtotal		0.8	1.4	0.9	0.0	3.1
Warwick						
G. Barker	Rolling Grant	0.0	0.3	0.3	0.0	0.6
S. Boyd	Rolling Grant	0.0	0.3	0.2	0.0	0.5
A. Sheffield	Rolling Grant	0.1	0.1	0.0	0.0	0.2
New TECH-War-1	Project	0.2	1.0	1.0	1.0	3.2
New RA-War-1	Project	0.0	0.2	0.3	0.2	0.7
New RA-War-2	Project	0.0	0.3	0.5	0.3	1.1
Subtotal		0.3	2.2	2.3	1.5	6.3
Total FTE		6.1	21.2	16.9	10.0	54.2

A2.1.2 Equipment and Consumables

The plastic scintillator required for the ECAL is being costed by two suppliers: FNAL, and Itasca Plastics, both in the United States near Chicago. These suppliers provided the scintillator for SciBar, MINERνA, and Minos, and thus have experience in meeting the needs of experiments similar to T2K. SciBar, MINERνA, and Minos have all used polystyrene infused with PPO (1%) and POPOP (0.03%), which has been extensively tested and appears to be of sufficient quality for our use [27, 28]. According to a recent cost estimate from FNAL, we expect the cost of the scintillator bars to be approximately £205*k*. The price does not yet include crating and shipping.

The lead sheets and the aluminium for the strongback will be provided at competitive prices by UK suppliers.

The WLS fibres of the quantity and quality that we require could be supplied by Kuraray or Bicron. A recent quote from Kuraray for 1.2 mm-diametre Y11(200) Multiclad S-35J type Kuraray fibres indicates that the cost will be approximately £146*k*. The cost of mirroring of the fibres at FNAL is estimated to be less than the cost of doing the mirroring at the UK institutions. In addition, the considerable expertise of FNAL is important. An FNAL quote indicates that it will cost approximately £69*k* for this work. Information from Kuraray indicates that the cost of shipping the fibres from Kuraray to FNAL and FNAL to Daresbury Lab is £20*k*.

It is important to provide structural rigidity for the modules without impacting on the passage of particles through the material. However, the weight and length of the modules make this a formidable challenge, and impose very strict specifications for the material. A number of UK and US companies who specialise in carbon-fibre construction have been contacted. The cost of carbon-fibre is strongly dependent on the quality of the material; however, initial investigations indicate that £350*k* should provide an appropriate quality and quantity of carbon-fibre for the ECAL module boxes.

Based on enquires with various companies, the cost of the photosensor connectors is estimated at approximately £50*k*, of which £20*k* is tooling and £30*k* is the cost for the devices.

Due to the large variation in the photosensor gain with temperature, it is important to keep the temperature of the ECAL well-controlled. In addition, the ECAL acts as an effective thermal shield between the magnet coils, which will operate at temperatures up to 50°C, and the inner detectors, which also have strict temperature requirements. Consequently, we plan to have water cooling loops running along the aluminium strongback, and inside the module boxes containing the photosensors and electronics. The water will be cooled by a chiller located in the experimental hall. In order to avoid condensation, the inside of the ECAL module boxes will be continually flushed with dry nitrogen. The total cost of this cooling system is estimated to be £80*k*.

At each stage of construction, the ECAL components must be adequately tested. An *x*-*y* scanner allows each newly-constructed layer to be checked for fracturing in the WLS fibres and/or photosensor problems. The cost of this scanner is approximately £20*k*.

The equipment cost estimates for the ECAL are shown in Table A2.2. In addition to these costs, each of the six institutions constructing the ECAL will require consumables such as cleaning materials, paper, office supplies, etc. We estimate that each of the six institutions will require £2*k* per year; the total over all four years is £48*k*.

A2.1.3 Travel

We foresee that the engineers working on the design of the ECAL will require trips to vendors in order to ensure complete agreement between various components of the detector. We anticipate 4 one-week trips during the period FY2006/07 to FY2007/08 to the US.

Item	Cost (£k)
Scintillator	205
Lead sheet	50
WLS fibre	146
WLS fibre mirroring	69
WLS fibre shipping	20
Fasteners	5
Carbon-fibre	350
Aluminium	90
6 diamond cutters	18
Bonding adhesive	5
Electrical cables	15
Photosensor connectors	50
Ferrules	28
Aluminium support plates (sides)	62
FEB mounting plate	12
Cooling system	80
Dry nitrogen circulation pipes, valves, etc	10
x-*y* scanner for QA	20
Total	**1,235**

Table A2.2: Cost for ECAL materials in *£k*.

Meetings between the universities' ECAL production managers, key technicians, the work package managers, and the project engineer are essential during the period from Jan 2007 until Sept 2009, or when the production phase has finished. This involves travel within the UK for 10 people each month.

During the production phase, (Stages 1, 2 and 3 as described in Sections 5.5.5, 5.5.6, 5.5.7) it will be necessary to move components quickly between UK institutions, as described in Sections 5.5.4. The scintillator bars and WLS fibre will be transported on an average of once per week between Daresbury and each of the five universities involved in the construction. This requires the use of a van five days per week. One option is to lease an appropriate van, and hire a driver, for the period from May 1, 2007 until June 30, 2009.

Before the ECAL installation, as well as during the ECAL installation and commissioning phases, it will be important to have two RA's present in Japan, each on a six-month LTA. These RA's would assist in a myriad of ways, including helping the technicians with installation, cabling, writing software, diagnostics, and early data checking.

A2.2 Cost Profile

A2.2.1 Overview

The total cost for the ECAL is shown in Table A2.3. The equipment costs are for the items described in Section A2.1.2 and in Table A2.2.

Work package 2	**Cost (£k)**
Staff Costs	
CCLRC Daresbury	1496
Lancaster	478
Liverpool	1019
Queen Mary	240
Sheffield	134
Warwick	325
Total Staff costs	3692
Equipment	1235
Consumables	48
Travel	108
Total Non-Staff Costs	1381
Total	5073

Table A2.3: Summary of workpackage costs £*k*.

A2.2.2 Working Allowance and Contingency

Working Allowance

The carbon-fibre cost estimate shown in Section A2.1.2 and Table A2.2 is based upon the aggressive assumption that a particular grade of carbon-fibre will be suitable to our needs. If this is not the case and the carbon-fibre must be of higher quality, the cost of the carbon-fibre could double, adding another £350*k* to the overall costs.

It is imperative that the schedule agreed to with the T2K collaboration be adhered to; thus, any failure of a supplier such as FNAL or Kuraray to provide the material when promised would have to be compensated by extra manpower in the UK institutions when the materials did arrive. This could cause an additional 20% cost in manpower, or £731*k*.

The quotes obtained so far for the scintillator, WLS fibres and mirroring, lead sheet, aluminium, and the photosensor connectors are only known to a rough estimate at this time. A 20% increase in costs for these items once the detailed design is finalised is not unrealistic. The cost of these items amounts to £610*k*, so the possible increase is £122*k*.

Currency exchange prices could affect the prices of the scintillator, WLS fibre, mirroring, and the photosensor connectors. A fluctuation of 10% is realistic, and could add £47*k* to the cost.

Reason	Cost
Carbon-fibre cost change due to higher grade required.	£350*k*
Extra manpower required to maintain schedule.	£731*k*
Price increases on rough quotes from suppliers.	£122*k*
Currency exchange changes	£47*k*
Total	**£1250k**

Table A2.4: Summary of ECAL work package working allowance items

Contingency

Due to tight schedule constraints, schedule slippage at any of the universities in Stage 1 Assembly (Section 5.5.5) could result in a requirement to send technicians who are already familiar with the production process to Daresbury Laboratory from other institutions in order to ensure that Stage 2 and Stage 3 assembly schedules (Sections 5.5.6 and 5.5.7) are not compromised. Assuming that the requirement is for five technicians for one month, the cost would be approximately £20*k*.

Shipping the completed ECAL components to Japan will require special preparation. Even so, it is possible that one or more modules may become seriously damaged during transit. In that case, the modules would need to be either completely rebuilt, or else repaired. The estimated cost of this could be £500*k*.

During the production phase, the significant loss of staff time due to illness, strikes, etc. could cause unacceptable delays that must be compensated by extra shifts or manpower. An estimated cost for this is £20*k*.

Reason	Cost
Technicians travelling to DL	£20*k*
Damage during shipping to ECAL	£500*k*
Loss of staff due to illness, etc.	£20*k*
Total	**£540k**

Table A2.5: Summary of ECAL work package contingency items

Annex A3

Work Package 3: Photosensors

A3.1 Resources Requested

A3.1.1 Manpower

The manpower requirements of over all tasks, per institute and per financial year of the proposal are listed in Table A3.1.

Staff	Funding	FY06/07	FY07/08	FY08/09	FY09/10	Total FTE
Imperial College						
Y. Uchida	Rolling Grant	0.1	0.1	0.1	0.1	0.4
A. Vacheret	Rolling Grant	0.5	0.5	0.2	0.2	1.4
Subtotal		0.6	0.6	0.3	0.3	1.8
Sheffield						
L. Thompson	Rolling Grant	0.1	0.1	0.1	0.0	0.3
New RA-Shef-1	Project	0.0	0.1	0.1	0.0	0.2
Subtotal		0.1	0.2	0.2	0.0	0.5
Warwick						
G. Barker	Rolling Grant	0.4	0.2	0.1	0.1	0.8
A. Lovejoy	Rolling Grant	0.2	0.2	0.0	0.0	0.4
New RA-War-2	Project	0.2	0.4	0.0	0.0	0.6
Subtotal		0.8	0.8	0.1	0.1	1.8
Total FTE		1.5	1.6	0.6	0.4	4.1

Table A3.1: Summary of work package staff requirements in units of FTE.

A3.1.2 Equipment and Consumables

Testing labs able to fully evaluate and characterise AMPD devices are being set-up in three institutes: Imperial College, Sheffield and Warwick. They will have the capability of measuring the response of devices to pulsed LED's, radioative sources and cosmic muons. In addition to evaluating/characterising AMPD prototypes, these facilities will be used to develop suitable connection methods with wavelength shifting fibres, , for calibration studies, the pre-series tests that provide the final crosscheck before a production run of devices is ordered and on-going quality control checks during the module construction phase.

TASK I

The following table lists outstanding items specific to the task of evaluating the AMPDs. Hardware is required to power the devices, amplify the signals and to monitor and log the data along with temperature and humidity measurements. Green extended photomultiplier tubes coupled to the same scintillator as AMPD devices, will provide an accurate measurement of the linearity and relative calibration of AMPD response.

Item	Cost Estimate
ADC (16bit)	£1000×3
PC + monitor to host DAQ	$(£600 + £300) \times 3$
Analogue card for p.c.	£150×3
AMPDs power supply modules	£250×6
AMPDs temperature ($\pm 0.1^{\circ}$) and humidity monitor	£800×3
Computerised datalogging of Voltage/current/temp./humidity (16-bit)	£200×3
Low-noise pre-amplifier(Ortec/Phillips)	£1000×3
50m WLS fibre	£100
(Green-extended) PMT modules	£600×4
Task I Total	£16150

Continuing communication and feedback of test results with the vendors is essential to the development of an AMPD for T2K. To support this effort, the following level of travel is required:

- 1×2(people) trips to Japan: Flight + 7 days subsistence
- 2×2(people) European trips: Flight + 7 days subsistence
- UK travel: 10×6(people) train fares between London/Warwick/Sheffield

TASK II

The requirements of this task are manpower and travel funds. Barker(Warwick) and Vacheret(Imperial) will be responsible for defining the device specification suitable for the ECAL and, in agreement with the wider collaboration, for participating in the placement of the final order for devices. Two additional trips to vendors are requested associated with finalising contract details at a cost of 1×2(people) flight to Japan + 7 days subsistence.

A level of physicist time to man the testing labs, is required up until the end of module production in mid 2009 in order to complete the AMPD quality assurance task. The AMPDs are expected to cost in the region of \$10 per device which is a number representative of feedback we have received while in discussion with the possible vendors. We are requesting funds to instrument the ECAL and the proposed prototype section: ECAL $35,000$ channels $\times \$10 = \$350,000 \sim £200,000$.

TASK III

Requires physicist and technical input to perform tests to optimise the WLS fibre/AMPDinterface connector. Some engineering effort will be needed to design and build prototypes and define a suitable connector mechanism before the final design is ordered from industry.

TASK IV

Requires physicist manpower to develop a method to extract basic parameters of the AMPD and to trace their variations.

TASK V

Requires physicists to coordinate and perfom the tests of a pre-series batch in collaboration with the suppliers.

TASK VI

This requires physicist effort to coordinate the task of large-scale quality assurance and the careful database-logging of the results.

A3.2 Cost Profile

A3.2.1 Overview

Table A3.2 summarises the total costs of the work package. Equipment costs represent the sum of the amount needed to equip the testing sites and the cost of providing $35,000$ channels of AMPDs. Consumables have been costed at the rate of £3000 per per year, per institute, plus and additional charge of £2000 during the two years of module construction to fund the transportation of AMPDs from the testing sites to Daresbury.

Work package 3	**Cost (£k)**
Staff Costs	
Imperial College	145
Sheffield	33
Warwick	152
Total Staff costs	330
Equipment	216
Consumables	32
Travel	18
Total Non-Staff Costs	266
Total	596

Table A3.2: Summary of work package costs *£k*.

A3.2.2 Working Allowance and Contingency

working allowance

Since the AMPD devices are at various stages of development depending on which vendor we consider, there is some likelihood that the cost estimate of \$10/device could rise. To cover this risk, which is evaluated in the table below, we propose to hold in the working allowance (and contingency, see below) enough funds to cover an increase in cost per device by \$5 (i.e. a total cost per device of \$15) corresponding to $35,000 \times \$5 = \$175,000 \simeq £100,000$.

As mentioned in the description of Task VI, Section 6.5.6, contracts will be made with vendors stipulating strict device specifications and we envisage making quality control tests on only a subset of the full production run of ECAL sensors. In the event of problems with the uniformity of device quality, a larger fraction of devices will need to be go through the quality assurance tests. Depending on the specific nature of the problem, this could impose a significant drain on our manpower resources and we request that a 20% increase on the total manpower budget be assigned as a working allowance to cover this eventuality. This translates into a cost of $20\% \times £455,000 = £91,000$.

Contingency

We request that a contingency funding contribution be assigned for this work package to cover the possibility that:

- The AMPD unit price rises to \$20 per device - a cost increase of \$5/device over and above that already allowed for in the working allowance and corresponding to $35,000 \times \$5 = \$175,000 \simeq £100,000$.

Annex A4

Work Package 4: Electronics

A4.1 Resources Requested

The effort required for the development of the electronics is shown in Table A4.1.

Staff	**Funding**	**FY06/07**	**FY07/08 FY08/09**	**FY09/10**	**Total FTE**	
Imperial College						
S. Greenwood	Rolling Grant	0.25	0.25	0.5	0.5	1.5
G. Hall	Rolling Grant	0.1	0.1	0.1	0.1	0.4
M. Khaleeq	Rolling Grant	0.25	0.25	0.5	0.5	1.5
M. Raymond	Rolling Grant	0.5	0.5	0.5	0.5	2.0
O. Zorba	Rolling Grant	0.35	0.25	0.25	0.0	0.85
New RA-Imp-1	Project	0.2	0.5	0.3	0.2	1.2
RG-RTP-Imp-1	Rolling Grant	0.35	0.25	0.25	0.0	0.85
Subtotal		2.0	2.1	2.4	1.8	8.3
Queen Mary						
New Eng-QM-1	Rolling Grant	0.3	0.6	0.6	0.2	1.7
Subtotal		0.3	0.6	0.6	0.2	1.7
RAL PPD						
T. Durkin	CCLRC SLA	0.1	0.3	0.3	0.5	1.2
A. Weber	CCLRC SLA	0.5	0.5	0.5	0.5	2.0
RA-RAL-1	CCLRC SLA	0.5	0.5	0.5	0.5	2.0
Subtotal		1.1	1.3	1.3	1.5	5.2
RAL TECH						
ENG-RAL-2	CCLRC SLA	1.0	1.0	1.0	0.5	3.5
ENG-RAL-3	CCLRC SLA	0.0	1.0	0.0	0.0	1.0
ENG-RAL-4	CCLRC SLA	0.0	0.25	0.0	0.0	0.5
ENG-RAL-5	CCLRC SLA	0.0	0.25	0.0	0.0	0.5
Subtotal		1.0	2.5	1.0	0.5	5.0
Total FTE		4.4	6.5	5.3	4.0	20.2

Table A4.1: Summary of work package staff requirements in units of FTE.

A4.1.1 Task I: TFB

The development and production of the TFB will be the undertaken by the Imperial College group. The staff resources are summarised in table A4.1.

To take overall responsibility for the task, defining, supervising and participating in the design and testing of prototype and production versions, we require 1 month per year of a senior academic and 6 months per year of an experienced Senior Electronic Engineer/Physicist.

The 1st TFB prototype will be developed by the end of 2006, and requires 4 months of Electronics Technician (PCB design) effort and 6 months of FPGA/Firmware Engineer effort.

The final prototype development takes place at the end of 06/07 and beginning of 07/08 and again requires 4 and 6 months of Electronics Technician and FPGA Engineer effort respectively (2 and 3 in each of the 06/07 and 07/08 periods).

We require a further 6 months of FPGA Engineer effort in 08/09 to finalise the firmware required for TFB operation in the experiment.

The specification and development of the production test systems (hardware, firmware and software) will be undertaken by an RA with support from the Firmware Engineer (we envisage that the production test systems will be based on commercial, inexpensive FPGA development boards). Preliminary planning and specification of the systems requires 3 months RA effort in 06/07. Hardware, firmware and software developments require 3, 6 and 4 months of RA, Firmware Engineer and Electronic Technician effort respectively in 07/08 and a final 3 months of RA effort in 08/09.

In 08/09 and 09/10 we require full time technician effort (24 staff months) to support and perform the volume production QA and burn-in testing.

There are 1450 TFBs (including 20% spares) to be built for the POD, the SMRD, the on-axis detector and the ECAL. The estimated cost for the components and industrial testing are summarised in table A4.2. PCB costs are based on manufacturers estimates and previous experience of large scale production testing costs. the TRIP-t costs are for packaged and tested chips supplied by Fermilab. Other electronic component costs are estimated or based on the cost of components which appear to meet the functional requirements. The cost for the industrial and burn in test systems are estimated to be £ 5k each.

A large fraction of the costs in table A4.2 are associated with the photon detector to TFB connection. We have chosen to cost this on the assumption that a coaxial connection will give us the best possible immunity to interference in the final system, and the miniature connectors and cables costed in the table are the cheapest commercial components we can identify at present.

A4.1.2 Task II: BEBs

In 2006/07 we will use off-the-shelf development boards to develop the firmware for the common Timing, Trigger and Merger Module. We will, by the end of the financial year, be able to build a system to readout a sufficient number of Front End Boards to form a vertical slice test. We will also need to produce a small simple PCB to adapt the Dev Board connectors to the connectors that will be used in the final system. This work will be contracted out and will need to be included in the equipment costs for this work package along with the development boards required. The Lead Design Engineer (1 FTE) will be responsible for all aspects of the project management, design, test and commissioning of the system.

In 2008/09 we will design and produce all the Common Timing, Trigger and Merger Module modules with the correct number of channels required for the system. There will be one FPGA based PCB design which has three functions in the system - Timing distribution, Data merger

Component	unit cost	units	total cost
PCB and assembly	40	1	40
Industrial tests	54	1	54
TRIP-t	10	4	40
ADC	5	2	10
HV-DAC	4	8	32
Div. digital	10	1	10
Calibration DAC	4	1	4
Power	10	1	10
Connectors	10	1	10
Passives	23	1	23
Micro controller	12	1	12
FPGA	60	1	60
Coax socket	0.6	64	40
Terminated miniature Coax cable	3.5	64	224
PD connector	0.6	64	40
Total		1	609

Table A4.2: Estimated board cost for the TFB in £ (excluding VAT).

module and the Trigger Module. 60 almost identical boards will have to be build. Three separate sets of FPGA firmware will be required for these designs. The lead Design Engineer (1 FTE) will be responsible for the Project Management, PCB design of the Common Module, production of the module as well as some aspects of the firmware design. The Firmware Design Engineer (1 FTE) will be responsible for designing the initial versions of most of the FPGA firmware for all three versions of the firmware required to run on the module. The PCB Design Engineer (0.25 FTE) will carry out the PCB design including any minor iteration. The Test Engineer (0.25 FTE) will carry out JTAG and other post manufacturing testing of the Boards once they have returned from Manufacture. The Lead Design Engineer and the Firmware Design Engineer will also cover aspects of the test software required for verification of the system.

In 2008/09 we will carry out the main commissioning phase with the Design Engineers (0.5 FTE) providing support for this process. This will include supporting installation, system tests and any Firmware improvements required (0.5 FTE).

In 2009/08 we will complete the commissioning phase with the Lead Engineer (0.25 FTE) and the Design Engineers (0.25 FTE) providing support for this process.

The development of the prototype boards needs a PC with special network cards, cables and optical splitters and a few server boxes together with especially developed connector board to interface with the TFBs. We estimate the total cost for these of these to be around £ 15k. Based on similar designs already done at CCLRC/RAL, the unit cost for the final BEBs is expected to be £2000.

A4.1.3 Task III: APS

The task requires an engineer to specify the requirements and work to implement a solutions. Some electro/mechanical effort is needed to understand the mechanical constraints. The later will be provide by RAL. We assume that we will be able to use customised industrial power supplies to build the system. The current estimate for the APS and the power distribution bus is £ 100k.

Some limited amount of money is needed to build prototypes and to support diverse test stands.

A4.1.4 Task IV: Vertical Slice Test

There is no specific hardware needed for this task. The work required is included in tasks I and II.

A4.1.5 Task V: Electronics Software and Simulations

There is no specific hardware needed for this task. The work requires 0.5 FTE over 4 years and is described in subsection 7.5.5.

A4.1.6 Travel

There is a substantial amount of travel required for the WP. This includes UK travel between CCLRC/RAL, Imperial College and the ECAL construction site to coordinate the construction of the different electronics component and support of the ECAL construction. There is also travel to the US, Japan and Canada support the construction of the different sub-detectors using our electronics. Some initial travel to Japan is necessary to discuss and define the interface to the accelerator timing signals. During the installation of the electronics, we expect to have one person permanently in Japan and additional expert trips of one month each to install and commission the electronics for the different detectors. See table A10 .2 for a breakdown of the required trips.

A4.2 Cost profile

A4.2.1 Overview

Table A4.3 summarises the total costs of the work package.

Work package 4	**Cost (£k)**
Staff Costs	
Imperial College	670
Queen Mary	190
RAL/PPD	432
RAL/TECH	534
Total Staff costs	1826
Equipment	1175
Consumables	16
Travel	104
Total Non-Staff Costs	1295
Total	3121

Table A4.3: Summary of work package costs *£k*.

Risk	Manpower in FTE	Equipment in £k	Total in £k
Trigger	2	100	282
ASIC	0.5	180	226
General mod.	1	200	291
Total			799

Table A4.4: Contingency for WP4 in £ k

A4.2.2 Working Allowance and Contingency

We have identified the following risks:

- The system as described above to trigger the electronics might actually be too slow and can't be implemented in a single board (GTM). We think that this is highly unlikely, but this can't be ruled out until a detailed FPGA design and a detector trigger simulation has been done. We assume that we would need an additional 2 FTE and £ 100k to develop a system to allow the detector to take cosmic calibration data.

- The TRIP-t ASIC was designed for VLPC readout at D0, and appears well suited to our application, but this is based on laboratory tests of the first version which are still at a relatively preliminary stage. If some feature of the chip turns out to be not adequate, and we cannot find a workaround, it may be necessary to ask FERMILAB to develop a revised version. The effect on the schedule could be minimised by continuing to prototype with the existing version. A revision of the chip would cost approximately £ 180k, based on estimates of \$150 k (mask), \$50 k(10 wafer run) and \$100 k (6 staff months design time). A re-evaluation and testing of the new ASIC, together with the necessary firmware modification will require 6 month of staff effort.

- Although we have been careful in the design of the system, building on the specific experiences of the group, it can always happen that we have overlooked a certain aspect of the electronics necessary to properly operate the electronics. This is especially true, as the design of the scintillator detectors, which are not a UK responsibility is likely to undergo minor modifications. We don't expect any of those modification to have an impact on the electronics, but it might for example require changes in the mechanical layout of the boards. We also currently foresee no direct cooling of our electronics as the power consumption is quite moderate. To cover those risk, we assume that we would need 1 FTE and £ 200k.

Any additional manpower required to cover these risk will probably only be available from the technical devision at CCLRC. We therefor used the average CCLRC/ID staff cost of £ 91k to estimate the associated cost. The working allowance is summarised in table A4.4.

We went through a detailed conceptual design process for the entire electronics. It was unrealistic to get detailed technical designs or precise quotes for any of the equipment we are trying to build with the manpower available. However, there is considerable experience with in the collaboration institutes (Imperial College, CCLRC/RAL), which allowed us to get reasonable cost estimate for most of the equipment. Based on this experience and the details of the design, we propose the cost and working allowance listed above. For further as yet unspecified risk we assume that we will need a contingency of 10% of the total WP cost. This amounts to £ 300k.

Annex A5

Work Package 5: Data Acquisition

A5.1 Resources Requested

A5.1.1 Manpower

Manpower effort for the delivery of the DAQ work package will be provided by the CCLRC Rutherford Appleton Laboratory. The projected manpower requirements are listed in Table A5.1.

Staff	Funding	FY06/07	FY07/08	FY08/09	FY09/10	Total FTE
RAL PPD						
G. F. Pearce	CCLRC SLA	0.2	0.3	0.4	0.5	1.4
PP-RAL-1	CCLRC SLA	0.5	1.0	1.0	1.0	3.5
RA-RAL-2	CCLRC SLA	0.2	0.5	0.5	0.5	1.7
Subtotal		0.9	1.8	1.9	2.0	6.6
RAL TECH						
T. C. Nicholls	CCLRC SLA	0.2	0.3	0.3	0.2	1.0
ENG-RAL-1	CCLRC SLA	0.5	0.5	0.5	0.2	1.7
Subtotal		0.7	0.8	0.8	0.4	2.7
Total FTE		1.6	2.6	2.7	2.4	9.3

Table A5.1: Summary of work package staff requirements in units of FTE.

A5.1.2 Equipment and Consumables

A cost breakdown for the equipment required for this work package is shown in Table A5.2. This includes provision of the final DAQ system for the off-axis and on-axis detectors at the 280m near detector site, a local system to allow for software development, testing and the vertical slice task and a system to be provided for the ECALtest beam campaign.

A5.1.3 Travel

The travel needs specific to the DAQ work package have been estimated as follow:

- Technical meetings in the UK for discussion and liason with other work package personnel. We estimate this as 6 visits per year for each of 3 people in 06/07, 07/08 and 08/09. The

Item	**Count**	**Spares**	**Unit Cost**	**Total**
Production System				
FPN nodes	17	2	2200	41800
BE Gigabit Ethernet Switch	3	1	2000	8000
BE nodes (Server etc.)	12	2	2200	30800
Disk RAID Array	2	1	2500	7500
Tape Handler	2	1	1000	3000
Console Server	2	1	1600	4800
Uninterruptible Power Supply	3	1	1000	4000
Monitors	4	0	500	2000
19 inch racks	3	0	400	1200
Cables	60	6	5	330
Shipping	1	-	5000	5000
Vertical Slice/Test Stand				
DAQ Nodes	5	0	2200	11000
Gigabit Ethernet Switch	1	0	1000	1000
Monitors	2	0	500	1000
Miscellaneous Items	1	0	500	500
Development hosts	4	0	1800	7200
ECAL Test Beam				
DAQ Nodes	3	0	2200	6600
Gigabit Ethernet Switch	1	0	1000	1000
Monitors	2	0	500	1000
Miscellaneous Items	1	0	500	500
Shipping	1	-	2000	2000
			Total	£140230

Table A5.2: Costing of Equipment Requested

duration of each visit would be 1 day.

- Technical meetings abroad (Japan, N.America, Europe) for discussion and liason with other sub-detector and sub-system groups. We estimate this as 2 visits per year for each of 3 people in 06/07, 07/08 and 08/09. The duration of each visit is 1 week.

- Visits to non-UK sub detector groups to provide DAQ support and training on detector test stands. We estimate this as 1 visit for each of 2 people to each sub-detector group, a total of 4 visits. The duration of each visit is 2 weeks.

- Visits to test beam sites to provide DAQ and DAQ support for calibration detector campaigns. We estimate this as requiring 1 trip for each of 3 people to each test beam site. The duration of each visit is 8 weeks.

- Installation, commissioning and support of the DAQ on the 280m detector at JAERI. We estimate this will require 1 person on LTA from January 2009 with 3 other DAQ group members making 2 visits each from January 2009 to end of construction. The duration of each short term visit would be 8 weeks.

It is assumed in these estimates that the vertical slice demonstrators will take place at CCLRC-RAL. Costings for the above DAQ visits are included in work package 10.

A5.2 Cost Profile

A5.2.1 Overview

Work package 5	**Cost (£k)**
Staff Costs	
RAL/PPD	552
RAL/TECH	244
Total Staff costs	796
Equipment	140
Consumables	4
Travel	113
Total Non-Staff Costs	257
Total	1053

Table A5.3: Summary of workpackage costs £*k*.

A breakdown of the total work package costs including staff effort, equipment and a nominal figure for consumable items, is presented in Table A5.3. The staff effort costs for CCLRC PPD and Technology departments are presented seperately.

A5.2.2 Working Allowance and Contingency

Summaries of working allowance and contingency items are presented in Tables A5.2.2 and A5.2.2 respectively. Where working allowance or contingency items require staff effort, this has been costed on the basis of requiring CCLRC Technology staff in FY07/08, which is when the significant engineering would most likely be incurred for the DAQ work package. The contingency item for additional equipment is derived from the expectation that a significant change to the scope of the DAQ would require additional processing layers (e.g. higher-level triggering).

Reason	**Percentage**	**Cost**
Engineering effort for limited scope changes	1 FTE (= 10%)	£101*k*
Price fluctuations in commodity items	10%	£12*k*
	Total	£123*k*

Table A5.4: Summary of DAQ work package working allowance items

Reason	**Percentage**	**Cost**
Engineering effort for significant scope changes	2 FTEs (= 20%)	£202*k*
Additional DAQ equipment for signficant scope changes	25%	£31*k*
	Total	£233*k*

Table A5.5: Summary of DAQ work package contingency items

Annex A6

Work Package 6: Mechanical/Thermal Engineering and Integration

A6.1 Resources Requested

A6.1.1 Manpower

Liverpool will provide engineering design expertise to design the Basket. All the Finite-Element work required for the Basket and any other sub components that may be highly stressed. This may also include thermal analysis. Engineering assistance during the design and construction of the Basket through to installation.

Daresbury will provide: (i) engineering design for the installation equipment required to install the ECAL.(ii) All the assembly and technical effort necessary for installation of the Basket and the ECAL. (iii) Organise the shipping of all the integration equipment to Japan including the packing crates.

Manpower resources requested are summarised in the following table:

Staff	**Funding**	**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total FTE**
Daresbury						
A. Grant	CCLRC SLA	0.4	0.4	0.3	0.0	1.1
A. Muir	CCLRC SLA	0.2	0.8	0.0	0.0	1.0
TECH-DL-1	CCLRC SLA	0.1	0.2	0.1	0.0	0.4
TECH-DL-2	CCLRC SLA	0.3	0.5	0.1	0.0	0.9
Subtotal		1.1	1.9	0.5	0.0	3.5
Liverpool						
P. Sutcliffe	Rolling Grant	0.1	0.4	0.4	0.4	1.3
J. Carroll	Rolling Grant	0.2	0.2	0.2	0.2	0.8
Subtotal		0.3	0.6	0.6	0.6	2.1
Total FTE		1.4	2.5	1.1	0.6	5.6

Table A6.1: Summary of work package staff requirements in units of FTE.

A6.1.2 Equipment and Consumables

Capital costs for the work package are detailed in the following table. The entry for the magnet represents the UK's contribution (of 260,000 Euros) to the task of supplying the magnet system discussed in Section 3.3.5.

Item Description	Cost (K£)
Magnet	
UK share of refurbishment and shipping costs (260000 Euros)	178.571
Sub total	178.571
Basket	
Basket frame	47.8
Support structure	47.8
Sub total	95.6
Installation Equipment	
Base frame 1 (lower level working)	12.0
Base frame 2 (higher level working)	12.0
Base frame 3 (top/bottom insitu assy frame)	8.0
Jacks (10Ton) x 8	4.0
Base rail system and support	12.0
Magnet slide carriges x 4	2.0
Vertical support system x 2	5.0
Lifting frame rated for 10T	6.0
Fasteners	1.0
Lifting equipment - slings/chains etc	1
Sub total	67.0
Integration Equipment	
POD support system and brackets	1.5
TPC support system and brackets	1.5
FGD support system and brackets	1.5
Sub total	4.5
Dummy Detectors	
POD	3.5
TPC x 3	4.5
FGD x 2	3.0
Sub total	11.0
Test and Assembly Equipment	
Lifting jigs/fixtures for basket assembly	10.0
Timber magnet model for dummy installation test	10.0
Sub total	20.0
Shipping containers	
Timber cases for shipping basket	20.0
Shipping Basket	15.0
Timber cases for shipping ECAL	23.0
Shipping ECAL	20.0
Sub total	78.0
Grand total	454.6

It is assumed that there will be several visits to Europe for collaboration/integration meetings. There will also be visits to Japan, Canada and the USA for integration detector meetings to learn from MINERVA experiences and factory acceptance tests for contractual items:

	2006/07	2007/08	2008/09	2009/10
Coil installation: 3 trips to Japan of 4 weeks	-	-	£10,500	-
Basket installation: 3 trips to Japan of 3 weeks	-	-	£8,400	-
Basket installation: one, 3-month LTA	-	-	£10,000	-
ECAL installation: 3 trips to Japan of 8 weeks	-	-	-	£21,000
3 visits to collaborators in Canada/US	-	£3,600	£3,600	£3,600

A6.2 Cost Profile

A6.2.1 Overview

Work package 6	**Cost (£k)**
Staff Costs	
CCLRC Daresbury	360
Liverpool	192
Total Staff costs	552
Equipment	455
Consumables	0
Travel	61
Total Non-Staff Costs	516
Total	1068

Table A6.2: Summary of work package costs *£k*.

A6.2.2 Working Allowance and Contingency

Working Allowance

There are several areas which should be considered for working allowance. Shipping costs may be more expensive when we are ready to transport the basket and the ECAL to Tokai. It is possible that these could increase by as much as 20% or $\sim$ £15,600.

Staff cost during installation in Tokai. Staff are currently claiming accommodation plus £30 per day. However individuals are allowed to claim accommodation plus £70 per day. At the agreed rate this will increase staff costs by £20,000.

Contingency

The main area of concern for this work package is the requirements of each of the detector systems which need to be installed and supported by the basket. At this point in time drawings exist for the magnet and coils, but there are no drawings as yet for the P0D, TPC's, FGD's and the DsEcal.

In addition it is not known just how much space is required around these detectors for access, both electrical and mechanical services and any associated electronics hardware. Space within the basket is for the detectors is a major concern and we may have as is the thickness of the structural elements of the basket. The basket is currently being costed as a stainless steel structure, but this cost could easily be increased by 20% or £20,000 depending on the complexity of the design.

Annex A7

Work Package 7: Calibration

A7.1 Resources Requested

Resources requested for performing the different calibration techniques described are listed in the following. A total of 4 tasks have been identified corresponding to the scintillator characterization (see Section 10.5.3), electron/pion test–beam (see Section 10.5.4) and the photon test-beam (see Section 10.5.4) and off–line calibration (see Section 10.5.5).

A7.1.1 Manpower

The manpower estimated for the calibration is shown in Table A7.1.

A7.1.2 Equipment and Consumables

The total equipment costs are outlined in Table A7.2. Unless otherwise stated, costs for shipping have been based on quotes from the commercial freight carrier DaviesTurner plc. Estimates for the costs of electronics are based on quotes from Canberra Harwell Ltd. Estimates of costs for photomultiplier tubes are based on quotes from the Photonis Group. Costs for the bar scanners are based on realised MINOS costs. Costs for the radioactive source are given by Eckert & Ziegler, Isotope Products Europe GmbH. The estimate of the scintillator cost was provided by Bicron.

Task I

Due to the short schedule the scanners should, as much as possible, be constructed from off the shelf components that are easily obtained and easy to replace if necessary. The costs reflect this.

The cost of design and construction of a bar scanner is estimated, based on known costings from the the construction of a similar machine used in the MINOS experiment, to be £11k. This does not include a provision for an automated cross frame, as the construction model assumes that each bar will be scanned individually as part of the quality assurance program. The possible addition of a cross-frame is allowed for in the working allowance. The scanner requires a DAQ computer and control software, estimated at £4k, and the radioactive source, costed at £1k. Light from the bar will be read out using a photomultiplier tube. The cost of the tube and associated electronics (amplifier, ADC and interface to the DAQ computer) is estimated to be £9k. Construction consumables (e.g. metal for dark box construction) are estimated to be £5k per machine. As discussed in work package 2, the construction of the scintillator bars will proceed in parallel at

Staff	Funding	FY06/07	FY07/08	FY08/09	FY09/10	Total FTE
Imperial College						
Y. Uchida	Rolling Grant	0.1	0.1	0.1	0.1	0.4
A. Vacheret	Rolling Grant	0.1	0.1	0.2	0.2	0.6
M. Wascko	Rolling Grant	0.1	0.1	0.3	0.3	0.8
New RA-Imp-1	Project	0.0	0.4	0.4	0.6	1.4
Subtotal		0.3	0.7	1.0	1.2	3.2
Liverpool						
J. Fry	Rolling Grant	0.0	0.0	0.1	0.2	0.3
M. Thresher	Rolling Grant	0.1	0.3	0.0	0.0	0.4
Subtotal		0.1	0.3	0.1	0.2	0.7
Queen Mary						
F. di Lodovico	Rolling Grant	0.2	0.3	0.3	0.3	1.1
Wolfgang Menges	Rolling Grant	0.0	0.0	0.3	0.5	0.8
Alex Owen	Rolling Grant	0.2	0.5	0.4	0.4	1.5
New RA-QM-1	Project	0.2	0.7	0.7	0.5	2.1
Subtotal		0.6	1.5	1.7	1.7	5.5
Sheffield						
S. Cartwright	Rolling Grant	0.1	0.1	0.2	0.1	0.5
L. Thompson	Rolling Grant	0.1	0.1	0.1	0.3	0.6
New RA-Shef-1	Project	0.0	0.3	0.2	0.2	0.7
Subtotal		0.2	0.5	0.5	0.6	1.8
Warwick						
S. Boyd	Rolling Grant	0.3	0.3	0.3	0.3	1.2
A. Lovejoy	Rolling Grant	0.1	0.2	0.1	0.0	0.4
A. Sheffield	Rolling Grant	0.1	0.1	0.1	0.0	0.3
New RA-War-1	Project	0.2	0.6	0.5	0.5	1.8
New RA-War-2	Project	0.0	0.3	0.3	0.3	0.9
Subtotal		0.6	1.6	1.3	1.1	4.6
Total FTE		1.6	3.7	4.1	4.2	15.9

Table A7.1: Summary of work package staff requirements in units of FTE.

six institutes, each with its own bar scanner. Shipping of each machine to a specific University has been costed at £1k. CCLRC Daresbury has a scanning machine that can be adapted for this purpose. The PIN diodes and associated electronics are estimated to to cost £1k.

Design of the scanning system and construction of the data acquisition system will be carried out by A. Lovejoy, A. Sheffield and RA-War-1. Construction and assembly of the scanners will be carried out by A. Sheffield and M. Thresher and the mechanical workshops of the Universities of Warwick and Liverpool.

Tasks II,III and IV

Each test-beam will require at least four months preparation within the UK to ensure that the module and data acquisition are operational before being inserted into the beam. The test-beam effort itself, and subsequent analysis also require significant dedicated effort. As the test-beam

	Item	Number (£k)	Unit Cost (£k)	Cost (£k)
Equipment	Bar scanner	6	11	66
	Radioactive source	6	1	6
	PIN Photodiode and amplifier	6	1	6
	DAQ computer and software	6	4	24
	Scanner Photomultiplier tube	6	1	6
	ADC	6	3	18
	Gate generators, logic units, discriminators, scalers	6	5	30
	VME Crate, HV system	7	3	21
	TOF Photomultiplier tubes	3	1	3
	Fast Scintillator (BC-404 or BC-420) and light guides	3	1	3
	TDC	1	4	4
	CFD	3	3	9
Subtotal				196
Consumables	Machining costs for scanners			30
	Shipping of scanners			6
	Shipping to and from test-beams			16
	Sundry			20
Subtotal				72
Total				268

Table A7.2: Total work package costs *£k*.

scheduling is influenced by the demands of other work at test–beam facilities that are beyond our control, the precise scheduling and duration of tasks is not accurately known. It is estimated that each test-beam will be eight weeks in duration, with two weeks reserved at the beginning for setting up and debugging systems, and one week at the end reserved for packing the module for return to the UK, shipping smaller equipment, and general cleaning up.

Crating and shipping of the test module from the UK to each of the test-beam sites and back has been costed to be £16k.

A Time-Of-Flight system is required for particle identification at the CERN test-beam. A system similar to that used for MINOS requires three fast photomultiplier tubes (e.g. Philips XP2020), a TDC module, three constant fraction discriminators (CFD) , and three logic units. The final design depends on the data acquisition, readout and trigger systems and has not yet been developed. An indicative cost is shown in Table A7.2.

Experience has shown that the cost of consumables for a test–beam can easily be as high as £10k. This is for small equipment costs, hire and replacement of electronics modules from the laboratory electronics pools, the construction of individual electronics cards, transport of bulky items and other incidental costs required for a successful test–beam. Total consumables for the test–beam are £20k.

S. Boyd and F. di Lodovico will coordinate the test-beams. Each test–beam will require the presence of experts in each of the subsystems. Data acquisition system development and support during the runs will be provided by G. Pearce and T. Nicholls as part of work package 5. The manpower and costs required for this are outlined in that work package. Support for the readout electronics will be provided by RA-Imp-1 and A. Vacheret. A. Weber will also provide expertise as part of work package 4. L.Thompson, A. Vacheret, RA-Imp-1 and RA-War-2 will provide experience with operation and understanding of the photosensors. F. di Lodovico, Alex Owen and RA-QM-1 will oversee the implementation and maintenance of the detector control system. The test–beams will require staff to sit shifts, monitor the detector operation, understand the particle identification information and perform preliminary analyses of the data. All staff in Table A7.1 will take part in these duties.

Significant software development will be required in order to be able to analyse the test–beam data. Development of this software will take place in conjunction with work package 8 and in consultation with the wider ND280m software core group. The software framework must contain all the functionality needed by the beginning of data–taking at the first test–beam. S. Boyd, F. di Lodovico, RA-War-1, Wolfgang Menges, Alex Owen, RA-QM-1, and RA-War-1 will all work in setting up the software for taking data at the test–beams. Analysis of the data from these test–beams will be a lengthy process. All RAs referenced in Table A7.1 will be take part in understanding the detector and the extraction of physics from the test–beam data. S. Boyd, F. di Lodovico, M. Wascko, S. Cartwright, L.Thompson and J. Fry have experience at test–beams and in analysis and will all contribute to the analysis effort.

In parallel to the test–beams, the design and implementation of the off-line calibration software will be perfomed. S. Cartwright, RA-Shef-1 will work with Y. Ushida and A. Vacheret, who already have extensive experience in the current software development and are members of ND280m software core group. RAs and staff members who have been working on the test–beams will partecipate at the discussion for the design of the off–line calibration and will join more actively the software group once the test–beams are finished.

A7.1.3 Travel

We envisage the following travel needs for the calibration work package tasks:

- Task I: One meeting per month for five people over a period of six months to organize and commission the scanner development and construction.

- Task II and III:

  - Testing of the calibration module at Daresbury Lab will be performed between January and Summer 2008. Ten people will participate in the commissioning of the calibration module at Daresbury Lab, each staying for two weeks.
  - Preparatory work at CERN and Mainz to finalize all the details for the test–beam: It is foreseen that two people will travel to CERN and Mainz for two weeks for this purpose.
  - Test–beams: data–taking at CERN and Mainz will involve 5 people for 8 weeks. Moreover, 3 people are foreseen to be travelling to CERN (Mainz) for 1 week twice during the test–beam. Travel for DAQ support is already foreseen in DAQ work package (WP 5).
  - Regular test–beam organizational meetings and analysis of data: Ten people will be meeting regularly once per month at a UK location. After the run it is expected that meetings will evolve to remote conferencing.

- Task IV: Regular monthly calibration software meetings in the year before the test–beams at a UK location are foreseen. It is envisaged that ten people will attend this meeting which will last for one day.

A7.2 Cost Profile

A7.2.1 Overview

An overview of the total costs for this work package is shown in A7.3. Additional consumables over and above those discussed above have been added for each institute participating in the work package. This was costed at a flat rate of £ 2k per year is for the purchase of small laboratory items such as cleaning equipment, alcohol and other material. The added cost is

Work package 7	**Cost (£k)**
Staff Costs	
Imperial College	282
Liverpool	14
Queen Mary	435
Sheffield	143
Warwick	373
Total Staff costs	1247
Equipment	196
Consumables	80
Travel	79
Total Non-Staff Costs	355
Total	1602

Table A7.3: Summary of work package costs *£k*.

A7.2.2 Working Allowance and Contingency

Working Allowance

The main specific contribution to the working allowance from Task I is the possible extension of the bar scanner to be able to scan transversely across a number of scintillator bars. Based on MINOS experience, the more complicated design and construction is expected to add £7k to the cost of each bar scanner. A furthur contribution to the working allowance arises from a possible delay, from internal or external reasons, in the construction of the bar scanners. This would set back the project schedule as bars would then have to be shipped to institutes with working scanners. In this case it would be necessary to increase effort by reallocating manpower. The cost of 0.3 FTE Grade G technician (£10k) has been assigned to the working allowance to temporarily speed up the effort whilst other personnel reallocations are being made. The working allowance for the travel and shipping costs for the test–beams is estimated to be £5k to allow for possible increases in the cost of shipping. We have assigned a contribution to the working allowance of 10% (£20k) to cover any M&O above the allocated amount for equipment.

Reason	**Cost**
Inclusion of automated cross slide	£ 42k
Extra technician effort	£ 10k
Fluctuation in cost of shipping	£ 5k
Price fluctuations in equipment price	£ 20k
Total	£ 77k

Table A7.4: Summary of working allowance for calibration work package.

Contingency

There are two main contributions to the contingency. The first is the possible need to monitor the gain and linearity of the photosensors using a light-injection (LI) system. The decision will depend on the studies which will be perfomed in Task IV of WP 3. The results of further photosensor testing will determine whether or not an LI system is required. Until then, the design of such a system remains at the conceptual stage, and hence the cost cannot be precisely determined. However, it is anticipated that the following relatively simple system will suffice: Light emitted by LEDs placed within the carbon-fibre boxes of the ECAL modules is injected on to the WLS fibres, to be then read out by the photosensors. In this case, a few cm of fibres between the scintillator and the photosensor must be exposed. The LEDs would be monitored by a robust and well understood photosensor. We are currently considering simple photomultiplier tubes installed within the outer ECAL container. Light injection would then occur during magnet off-periods. We estimate a possible cost for such a device of £ 100k for the equipment and 4 FTE of effort (£ 200k) fully involved with the design and construction path.

The other main contribution to the contingency is a delay, from external factors, to the test–beam schedule. Depending on the nature of the delay (e.g. an important component of the beam fails and requires several months to cool down and repair) the test–beam may have to be abandoned or re-scheduled. The contingency here is the cost of re-starting the test–beam program at some later stage. This is costed at one extra full eight week long test–beam for eight people (£32k) added to an extra shipping step, or £8k, for a total of £40k.

Reason	**Cost**
Extra manpower for the LI	£ 200k
Equipment for the LI	£ 100k
Provision for extra test–beam	£ 40k
Total	£ 340k

Table A7.5: Summary of contingency for calibration work package.

A7.2.3 Milestones

The milestones associated with this work package are

- Complete design and fabrication of bar scanners for university construction groups.
- Complete electron/pion test-beam.

- Complete photon test-beam.

A7.2.4 Deliverables

The main deliverables from this work package are

- Operational bar scanners for each of the university construction groups
- Publication of results from the test-beam showing the performance of the ECAL in electron, pion and photon beams.

Annex A8

Work Package 8: Offline Software Tools

A8.1 Resources Requested

A8.1.1 Manpower

The effort per FY in units of FTE proposed for staff contributing to this work package is shown in Table A1.1.

A8.1.2 Equipment and Consumables

The software development work will require some modest hardware resources, which will increase as the detector approaches data-taking. Much of this will be made available by using the resources on the GRID.

The UK Offline software effort is also taking on the responsibility of developing the T2K database's and providing support for various software efforts of all work-packages. As such we require a 5 TB raid server, based at one of the collaborating institutes to provide a platform for the following tasks: database testing (in particular scalability which will require test data bases with at least a TB of content), test-beam data storage, etc. We request the purchase of 1 5 TB raid array at a cost of £8k.

A8.1.3 Travel

It is foreseen that most of the contact between the software group members will be via remote conferencing methods. However there will be dedicated software working weeks in which the core members meet at the same physical location for one week to allow them to efficiently produce the required software framework. In order to support this travel, we request funding for two such trips per annum. Each trip would last for one week, with six people from the software core group attending at £500 per week. The cost for this is £ 6k per annum.

A8.2 Cost Profile

A8.2.1 Overview

An overview of the total costs for this work package is shown in A8.2.

Staff	Funding	FY06/07	FY07/08	FY08/09	FY09/10	Total FTE
Imperial College						
Y. Uchida	Rolling Grant	0.2	0.2	0.2	0.2	0.8
A. Vacheret	Rolling Grant	0.2	0.2	0.3	0.3	1.0
M. Wascko	Rolling Grant	0.2	0.2	0.2	0.2	0.8
Subtotal		0.6	0.6	0.7	0.7	2.6
Lancaster						
I. Bertram	Rolling Grant	0.3	0.2	0.2	0.2	0.9
A. Finch	Rolling Grant	0.2	0.2	0.2	0.2	0.8
New RA-Lanc-2	Project	0.2	0.8	0.8	0.8	2.6
Subtotal		0.7	1.2	1.2	1.2	4.3
Liverpool						
C. Chavez	Rolling Grant	0.0	0.1	0.2	0.4	0.7
N. McCauley	Rolling Grant	0.2	0.2	0.2	0.2	0.8
D. Payne	Rolling Grant	0.3	0.3	0.2	0.2	1.0
Subtotal		0.5	0.6	0.6	0.8	2.5
Sheffield						
New RA-Shef-1	Project	0.0	0.3	0.4	0.4	1.1
Subtotal		0.0	0.3	0.4	0.4	1.1
Warwick						
S. Boyd	Rolling Grant	0.1	0.2	0.1	0.0	0.4
B. Morgan	Rolling Grant	0.1	0.2	0.2	0.2	0.7
New RA-War-1	Project	0.0	0.2	0.2	0.0	0.4
Subtotal		0.2	0.6	0.5	0.2	1.5
Total FTE		2.0	3.3	3.4	3.3	12.0

Table A8.1: Summary of work package staff requirements in units of FTE.

A8.2.2 Working Allowance and Contingency

The construction of an efficient and useable software framework is a large task. For a large experiment like T2K much effort will be put into this work, not only by the software group in the UK, but also in conjunection with the software groups from other collaborators. It cannot be ruled out that the software contribution outlined here cannot be delivered or fails to meet the requirements of the experiments due to external factors. In this case, an additional dedicated programmer for the software group will be required for a period of at least one year before the experiment starts data–taking, to ensure that all the software is ready in time. The working allowance for this work package consists of the salary of a full–time programmer for one year and is costed at £70k.

Work package 8	**Cost (£k)**
Staff Costs	
Imperial College	254
Lancaster	286
Liverpool	215
RAL/PPD	51
Sheffield	56
Warwick	120
Total Staff costs	982
Equipment	8
Consumables	0
Travel	48
Total Non-Staff Costs	56
Total	1038

Table A8.2: Summary of work package costs £*k*.

Annex A9

Work Package 9: Beam and Target

A9.1 Resources Requested

A9.1.1 Manpower

The manpower requirements of over all tasks, per institute and per financial year of the proposal are listed in Table A9.1.

Staff	Funding	FY06/07	FY07/08	FY08/09	FY09/10	Total FTE
RAL PPD						
R. Edgecock	CCLRC SLA	0.1	0.1	0.0	0.0	0.2
Subtotal		0.1	0.1	0.0	0.0	0.2
RAL TECH						
S. Canfer	CCLRC SLA	0.1	0.1	0.1	0.1	0.4
R. Day	CCLRC SLA	0.1	0.1	0.1	0.0	0.3
C. Densham	CCLRC SLA	0.8	0.8	0.8	0.8	3.2
M. Fitton	CCLRC SLA	0.5	0.5	0.5	0.5	2.0
V. Francis	CCLRC SLA	1.0	1.0	0.5	0.5	3.0
P. Loveridge	CCLRC SLA	0.6	0.6	0.6	0.6	2.4
M. Rooney	CCLRC SLA	1.0	1.0	1.0	0.5	3.5
M. Woodward	CCLRC SLA	0.4	0.2	0.2	0.2	1.0
Subtotal		4.4	4.3	3.8	3.2	15.8
Sheffield						
C. Booth	Rolling Grant	0.1	0.1	0.1	0.1	0.4
Subtotal		0.1	0.1	0.1	0.1	0.4
Total FTE		4.7	4.5	3.9	3.3	16.4

Table A9.1: Summary of work package staff requirements in units of FTE.

A9.1.2 Equipment and Consumables

An itemised summary of equipment costs for the beam project is shown in Table A9.2.

	Item	Cost (£k)
Beam Window	Flow/heating test rig	5
	Pillow seal prototype	10
	Window prototype	50
	Window manufacture	60
Subtotal		125
Baffle	Prototype manufacture of graphite bonding system	20
	Final manufacture	30
	Installation and Support	10
Subtotal		60
Target support and remote handling	Support system, He coupling and prototype testing	110
	Remote target insertion and replacement system	90
Subtotal		200
Shock wave studies	Material and supports	2
High power studies	High power materials development	30
Total		417

Table A9.2: Total work package costs £*k*.

A9.2 Cost Profile

A9.2.1 Overview

A summary of the costs associated with this workpackage is given in Table A9.3.

A9.2.2 Working Allowance and Contingency

Working Allowance

The working allowance requested for this work package is outlined in Table A9.4.

Contingency

In the event of failure to meet the specification after manufacture, or premature failure of any of the UK supplied components, or change of specification after manufacture, then it may be necessary to supply replacements. The only exception to this is the target remote handling system. If this proves unusable for any reason the default option is that there will be no replacement of failed targets: the complete target and horn system will be replaced as a unit. Thus we have:

Work package 1	**Cost (£k)**
Staff Costs	
RAL/PPD	17
RAL/TECH	1379
Sheffield	39
Total Staff costs	1435
Equipment	417
Consumables	0
Travel	159
Total Non-Staff Costs	576
Total	2011

Table A9.3: Summary of workpackage costs £*k*.

Reason	**Cost** (£k)	
	Staff	Equipment
Manufacturing or design error of target station vessel or TRIUMF remote clamp requires re-design or modification of beam window.	10	25
Failure of window prototype requires modification to design or extra development	10	25
Failure of graphite bonding system requires re–design and extra prototyping	29	9
Increase in target/horn clearances requires re–optimisation of target	66	0
Change in beam or facility parameters requires re–design of beam dump	51	0
Subtotals	166	59
Total		255

Table A9.4: Summary of working allowance for beam and targetry work package.

Contingency Item	**Cost** (£k)
Beam window	60
Baffle	30
Total	90

Table A9.5: Summary of contingency for beam and targetry work package.

Annex A10

Work Package 10: Project Management, Travel and Common Fund

A10 .1 Project Management

The T2K-UK detector construction project will be managed by a Project Management Committee (PMC) led by a Project Manager. The function of the PMC and the main duties and appointment procedure for the Project Manager are described in Chap. 13. The manpower requirements of the project management aspects of the proposal per financial year are listed in Table A10 .1.

Staff	**Funding**	**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total FTE**
D. Wark	CCLRC SLA	0.25	0.25	0.25	0.25	1.0
New Proj. Man. post		1.0	1.0	1.0	1.0	4.0
Total FTE		1.25	1.25	1.25	1.25	5.0

Table A10 .1: Summary of work package staff requirements in units of FTE.

A10 .2 Travel

The T2K-UK travel requirements are substantial and may be divided into the following categories:

- T2K collaboration meetings at KEK (typically 2 per year);
- ND280 meetings in Europe, North America or Japan (typically 3 or 4 per year, with the meetings in Japan coinciding with the full T2K collaboration meetings);
- T2K-UK meetings at one of the UK collaborating institutes (2 IB meetings per year, monthly PMC meetings and several full T2K-UK collaboration meetings per year);
- T2K convenor meetings at KEK (typically 4 per year);
- Construction work at the CCLRC Daresbury and Rutherford laboratories and construction related visits to overseas laboratories;

- Integration work visits;
- Beamline visits to KEK;
- Test-beam work at overseas accelerator laboratories;
- Installation and commissioning work for the ECAL, electronics, DAQ, Slow Controls and Beamline at Tokai from 2008 onwards.

The number of people attending the various meetings will vary quite significantly from roughly one per institution at the IB to the entire UK collaboration in the case of T2K-UK collaboration meetings. Most academic and research staff at each institution will attend the full T2K and ND280 collaboration meetings. The PMC meetings will be attended by the Work Package Managers, the Project Manager and the UK spokesperson (about 20 people). Numerous visits to component vendors are anticipated in the first couple of years of the project. University technical staff will frequently visit Daresbury and Rutherford laboratories to participate in construction and testing work. In the later years of the project there will be about 4-5 staff LTA years in Japan for the installation and commissioning phase along with a significant number of shorter visits. Test beam work in 2007/8 and 2008/9 will involve about 8 people for up to 8 weeks per year. In parallel with the ECAL activity, the beamline related work will involve 6 people visiting Tokai for about 8 weeks in 2008/9.

The travel requirements for each financial year are summarised in in table A10 .2. The unit cost of each type of trip has been obtained using a set of simple assumptions. For UK meetings we assume an average of £50 per day. One week trips to European sites are costed at £500. Trips to North America are estimated to cost £1200 for the first week (including travel) and £700 for subsequent weeks. Trips to Japan are estimated to cost £1500 for the first week (including travel) and £700 for subsequent weeks. Some rounding and approximation has been used to obtain the actual numbers quoted in the travel summary table. The total travel requirement for the 4 year construction phase is £1,520,200.

Table A10 .2: Requested Travel Funds

Travel Funds									
		2006/7		2007/8		2008/9		2009/10	
Purpose	Unit (£)	Visits	Cost (£)	Visits	Cost (£)	Visits	Cost (£)	Visits	Cost (£)
General Mtgs									
2 T2K Mtgs	1500	60	90000	60	90000	60	90000	60	90000
2 ND280 Mtgs	1200	60	72000	60	72000	60	72000	60	72000
4 T2K Convnrs	1500	12	18000	12	18000	12	18000	12	18000
4 T2K-UK Mtgs	50	120	6000	120	6000	120	6000	120	6000
Monthly PMC	50	240	12000	240	12000	240	12000	240	12000
2 UK IB Mtgs	50	16	800	16	800	16	800	16	800
WP1(Physics)									
Bimonthly UK Mtgs	50	60	3000	60	3000	30	1500	30	1500
Physics Work Mtgs	5000	1	5000	1	5000	1	5000	5	5000
WP2(ECAL)									
Monthly Mtgs	50	120	6000	120	6000	120	6000	120	6000
Vendor visits	1200	4	4800	4	4800	0	0	0	0
Transport	25000	0	0	1	25000	1	25000	0	0
Inst/Com LTA	12500	0	0	0	0	0	0	2	25000
WP3(Sensors)									
Vendor visits	1500	2	3000	2	3000	0	0	0	0
Vendor visits	500	4	2000	4	2000	0	0	0	0
Monthly Mtgs	50	72	3600	72	3600	0	0	0	0
WP4(Electr.)									
Monthly Mtgs	50	40	2000	40	2000	20	1000	10	500
Collab-US/Can	1200	4	4800	4	4800	8	9600	0	0
Collab-Japan	1500	2	3000	2	3000	0	0	0	0
ECAL support	400	0	0	2	800	4	1600	0	0

Continued on next page

Table A10 .2 – continued from previous page

Travel Funds									
		2006/7		2007/8		2008/9		2009/10	
Purpose	Unit (£)	Visits	Cost (£)	Visits	Cost (£)	Visits	Cost (£)	Visits	Cost (£)
General Mtgs									
Test Beam	2000	0	0	0	0	2	4000	0	0
Instal'n/Sup.	3500	0	0	0	0	6	21000	6	21000
Inst./Sup. LTA	25000	0	0	0	0	0	0	1	25000
WP5(DAQ)									
Technical(UK)	50	18	900	18	900	18	900	0	0
Tech.(Overseas)	1000	6	6000	6	6000	0	0	0	0
Support	1000	0	0	6	6000	6	6000	0	0
Test Beam	4000	0	0	3	12000	3	12000	0	0
Instal'n/Comm.	6500	0	0	0	0	0	0	6	39000
Inst./Com. LTA	25000	0	0	0	0	0	0	1	25000
WP6(Eng/Integ)									
Collaboration	1200	0	0	3	3600	3	3600	3	3600
Coil Instal'n	3500	0	0	0	0	3	10500	0	0
Basket Inst'n	2800	0	0	0	0	3	8400	0	0
Basket Inst'n	10000	0	0	0	0	1	10000	0	0
ECAL Instal'n	7000	0	0	0	0	0	0	3	21000
WP7(Calibr'n)									
Monthly Mtgs	50	120	6000	120	6000	120	6000	120	6000
Scanner Mtgs	50	30	1500	0	0	0	0	0	0
Daresbury	600	0	0	0	0	10	6000	0	0
Testbeam short	500	0	0	8	4000	8	4000	0	0
Testbeam long	4000	0	0	5	20000	5	20000	0	0
WP8(Software)									
Monthly Mtgs	50	120	6000	120	6000	120	6000	120	6000

Continued on next page

Table A10 .2 – continued from previous page

Travel Funds									
		2006/7		2007/8		2008/9		2009/10	
Purpose	Unit (£)	Visits	Cost (£)	Visits	Cost (£)	Visits	Cost (£)	Visits	Cost (£)
General Mtgs									
S'ware Work Mtgs	3000	2	6000	2	6000	2	6000	2	6000
WP9(Beam/Targ)									
KEK/J-PARC	1500	20	30000	20	30000	20	30000	20	30000
Instal'n/Comm.	6400	0	0	0	0	6	38400	0	0
Active Water									
TRIUMF visits	1200	4	4800	0	0	0	0	0	0
Totals			297200		362300		441300		419400

A10 .3 Common Fund Contributions

The T2K collaboration will operate a ‘common fund’ system to finance aspects of the project not naturally covered by the remit of any of the sub-detector groups. It has been agreed by the collaboration that each country will contribute $\$5,000$ to the Common Fund per PhD appearing in the author list, to start in financial year 2007/08. The following table lists the number of PhD’s contributing as a function of institute and year.

Institute	FY07/08	FY08/09	FY09/10	Total
Daresbury	0	0	0	0
Imperial	7	7	7	21
Lancaster	7	7	7	21
Liverpool	6	7	7	20
RAL(PPD)	8	7	7	22
RAL(TECH)	3	3	3	9
Sheffield	4	4	4	12
QMCL	4	5	5	14
Warwick	5	7	7	19
Total	44	47	47	138

Summed over all contributing institutes in the UK, this ammounts to a Common Fund contribution for the duration of the proposal of, $(138 \times \$5,000) = \$690,000$ or $£393,000$.

Annex B: Overview of resources Requested

An overview of the resources requested in the proposal and the corresponding costs are given in the following sections, first describing the total staff effort per institute, then the total costs for PPARC, the PPARC supported contributions to the different work packages by institute and finally the working allowance and contingency costs. The years and the corresponding fractions of FTEs which appear in the following tables refer to the financial years.

Annex B1

Staff Effort Overview Per Institute

Table B1 summarises the total effort required for the project, including projected new posts. It should be noted that the CCLRC PPD posts RA-RAL-1, RA-RAL-2 and PP-RAL-1 are unidentified. The goal of CCLRC RAL is to support these posts through redeployment of existing positions and/or advanced replacements for retirements, so that there is no long term increase in the staffing level at RAL. The extent to which this goal can be met will be clarified on the time-scale of the PPGP submission.

Table B1.1: Staff Effort Overview per Institute

Daresbury Laboratory					**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total**
Staff Name	Grade	Start Date	End Date	Incr. Date	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)
A. Grant	Engineer	Apr 06	Mar 10	1st Jul	0.8	0.9	0.6	0.7	3.0
A. Muir	Engineer	Apr 06	Mar 10	1st Jul	1.0	0.8	0.0	0.0	1.8
Tech-DL-1	Technician	Oct 06	Mar 10	1st Jul	0.1	1.0	0.8	0.5	2.4
Tech-DL-2	Technician	Oct 06	Mar 10	1st Jul	0.1	1.2	0.9	0.8	3.0
Fitter-DL-1	Technician	Oct 06	Mar 10	1st Jul	0.1	1.0	1.0	1.0	3.1
Fitter-DL-2	Technician	Oct 06	Mar 10	1st Jul	0.0	1.0	1.0	0.4	2.4
Fitter-DL-3	Technician	Oct 06	Mar 10	1st Jul	0.0	1.0	1.0	0.0	2.0
Fitter-DL-4	Technician	Oct 06	Mar 10	1st Jul	0.0	1.0	0.4	0.0	1.4
Fitter-DL-5	Technician	Oct 06	Mar 10	1st Jul	0.0	1.0	0.0	0.0	1.0
Fitter-DL-6	Technician	Oct 06	Mar 10	1st Jul	0.0	1.0	0.0	0.0	1.0
Fitter-DL-7	Technician	Oct 06	Mar 10	1st Jul	0.0	1.0	0.0	0.0	1.0
Fitter-DL-8	Technician	Oct 06	Mar 10	1st Jul	0.0	0.3	0.0	0.0	0.3
Fitter-DL-9	Technician	Oct 06	Mar 10	1st Jul	0.3	0.5	0.1	0.8	1.7
Imperial College London					**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total**
Staff Name	Grade	Start Date	End Date	Incr. Date	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)
P .Dornan	Physicist	Oct 06	Mar 10	1st Oct	0.1	0.1	0.1	0.1	0.4
S .Greenwood	Technician	Oct 06	Mar 10	1st Oct	0.25	0.25	0.5	0.5	1.5
G. Hall	Physicist	Oct 06	Mar 10	1st Oct	0.1	0.1	0.1	0.1	0.4
M .Khaleeq	Technician	Oct 06	Mar 10	1st Oct	0.25	0.25	0.5	0.5	1.5
M. Raymond	Researcher	Oct 06	Mar 10	1st Oct	0.5	0.5	0.5	0.5	2.0
Y. Uchida	Physicist	Oct 06	Mar 10	1st Oct	0.6	0.6	0.6	0.6	2.4
A. Vacheret	RA	Oct 06	Mar 10	1st Oct	1.0	1.0	1.0	1.0	4.0

Continued on next page

Table B1.1 – continued from previous page

M. Wascko	Physicist	Oct 06	Mar 10	1st Oct	0.9	0.9	0.9	0.9	3.6
D. Wark	Physicist	Oct 06	Mar 10	1st Oct	0.3	0.3	0.3	0.3	1.2
O. Zorba	Engineer	Oct 06	Mar 10	1st Oct	0.35	0.25	0.25	0.0	0.85
RG-RTP-Imp-1	Engineer	Oct 06	Mar 10	1st Oct	0.35	0.25	0.25	0.0	0.85
New RA-Imp-1	RA	Jan 07	Mar 10	1st Oct	0.2	1.0	1.0	1.0	3.2
Lancaster					**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total**
Staff Name	Grade	Start Date	End Date	Incr. Date	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)
I. Bertram	Physicist	Oct 06	Mar 10	1st Aug	0.3	0.3	0.4	0.4	1.4
A. Chilingarov	Applied Physicist	Oct 06	Mar 10	1st Aug	0.2	0.2	0.2	0.0	0.6
L. Kormos	Physicist	Oct 06	Mar 10	1st Mar	0.6	0.6	0.6	0.6	2.4
A. Finch	Physicist Programmer	Oct 06	Mar 10	1st Aug	0.4	0.4	0.4	0.4	1.6
I. Mercer	Technician	Oct 06	Mar 10	1st Aug	0.2	1.0	1.0	0.0	2.2
P. Ratoff	Physicist	Oct 06	Mar 10	1st Aug	0.2	0.3	0.4	0.4	1.3
RA-Lanc-1	RA	Jul 06	Mar 10	1st Jul	0.5	1.0	1.0	1.0	3.5
New RA-Lanc-2	RA	Jan 07	Mar 10	1st Jan	0.2	1.0	1.0	1.0	3.2
J. Statter	Technician	Apr 07	Mar 10	1st Aug	0.0	1.0	0.5	0.0	1.5
Liverpool					**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total**
Staff Name	Grade	Start Date	End Date	Incr. Date	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)
J. Carrol	Technician	Oct 06	Mar 10	1st Oct	0.3	0.5	0.6	0.5	1.9
C. Chavez	RA	Oct 06	Mar 10	1st Aug	0.0	0.3	0.5	0.6	1.4
J. Fry	Physicist	Oct 06	Mar 10	1st Aug	0.0	0.0	0.1	0.2	0.3

Continued on next page

Table B1.1 – continued from previous page

N. McCauley	Physicist	Oct 06	Mar 10	1st Jun	0.6	0.6	0.6	0.6	2.4
D. Payne	RA	Oct 06	Mar 10	1st Aug	0.3	0.5	0.5	1.0	2.3
P. Sutcliffe	Engineer	Oct 06	Mar 10	1st Aug	0.3	0.6	0.8	0.5	2.2
M. Thresher	RA	Oct 06	Mar 10		0.2	1.0	1.0	1.0	3.2
C. Touramanis	Physicist	Oct 06	Mar 10	1st Aug	0.3	0.3	0.4	0.5	1.5
M. Whitley	Technician	Oct 06	Mar 10	1st Aug	0.1	0.2	0.5	0.5	1.3
M. Wormald	Technician	Oct 06	Mar 10	1st Aug	0.1	0.4	0.4	0.4	1.3
New RA-Liver-1	RA	Oct 06	Mar 10	1st Aug	0.2	1.0	1.0	1.0	3.2
RAL PPD					**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total**
Staff Name	Grade	Start Date	End Date	Incr. Date	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)
C. Andreopoulos	RA	Apr 06	Mar 10	1st Jul	0.0	0.4	0.5	0.5	1.4
T. Durkin	Technician	Apr 06	Mar 10	1st Jul	0.1	0.3	0.3	0.5	1.2
R. Edgecock	Physicist	Apr 06	Mar 10	1st Jul	0.1	0.1	0.0	0.0	0.2
G. F. Pearce	Physicist	Apr 06	Mar 10	1st Jul	0.3	0.4	0.5	0.5	1.7
D. Wark	Physicist	Apr 06	Mar 10	1st Jul	0.25	0.25	0.25	0.25	1.0
A. Weber	Physicist	Apr 06	Mar 10	1st Jul	0.5	0.5	0.5	0.5	2.0
RA-RAL-1[1]	RA	Oct 06	Mar 10	1st Jul	0.5	1.0	1.0	1.0	3.5
RA-RAL-2	RA	Jan 07	Mar 10	1st Jul	0.2	1.0	1.0	1.0	3.2
PP-RAL-1	Physicist Programmer	Oct 06	Mar 10	1st Jul	0.5	1.0	1.0	1.0	3.5

Continued on next page

[1] The positions RA-RAL-1, RA-RAL-2 and PP-RAL-1 are existing unidentifed positions. The goal of CCLRC RAL is to support these posts through redeployment of existing positions and/or advanced replacements for retirements, so that there is no long term increase in the staffing level at RAL. The extent to which this goal can be met will be clarified on the time-scale of the PPGP Grant Submiision.

Table B1.1 – continued from previous page

RAL TECH					**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total**
PM-RAL-1	Engineer TECH	Apr 06	Mar 10	1st Jul	1.0	1.0	1.0	1.0	4.0
S. Canfer	Technician TECH	Apr 06	Mar 10	1st Jul	0.2	0.2	0.2	0.2	0.8
R. Day	Technician TECH	Apr 06	Mar 10	1st Jul	0.1	0.1	0.1	0.0	0.3
C. Densham	Engineer TECH	Apr 06	Mar 10	1st Jul	0.8	0.8	0.8	0.5	2.9
M. Fitton	Engineer TECH	Apr 06	Mar 10	1st Jul	0.5	0.5	0.5	0.5	2.0
V. Francis	Engineer TECH	Apr 06	Mar 10	1st Jul	1.0	1.0	0.5	0.5	3.0
P. Loveridge	Engineer TECH	Apr 06	Mar 10	1st Jul	0.5	0.5	0.5	0.5	2.0
T. C. Nicholls	Engineer TECH	Apr 06	Mar 10	1st Jul	0.2	0.3	0.3	0.2	1.0
M. Rooney	Engineer TECH	Oct 06	Mar 10	1st Jul	1.0	1.0	1.0	0.5	3.5
M. Woodward	Engineer TECH	Oct 06	Mar 10	1st Jul	0.4	0.2	0.2	0.2	1.0
ENG-RAL-1	Engineer TECH	Apr 06	Mar 10	1st Jul	0.5	0.5	0.5	0.2	1.7
ENG-RAL-2	Engineer TECH	Apr 06	Mar 10	1st Jul	1.0	1.0	1.0	0.5	3.5
ENG-RAL-3	Engineer TECH	Apr 06	Mar 10	1st Jul	0.0	1.0	0.0	0.0	1.0
ENG-RAL-4	Engineer TECH	Apr 06	Mar 10	1st Jul	0.0	0.25	0.0	0.0	0.25
ENG-RAL-5	Engineer TECH	Apr 06	Mar 10	1st Jul	0.0	0.25	0.0	0.0	0.25
Sheffield					**FY06/07**	**FY07/08**	**FY08/09**	**FY09/10**	**Total**
Staff Name	Grade	Start Date	End Date	Incr. Date	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)	Effort (FTE)
C. Booth	Physicist	Oct 06	Mar 10	1st Jan	0.1	0.1	0.1	0.1	0.4
S. Cartwright	Physicist	Oct 06	Mar 10	1st Jan	0.5	0.5	0.5	0.5	2.0
L. Thompson	Physicist	Oct 06	Mar 10	1st Jan	0.3	0.3	0.3	0.3	1.2
New TECH-Shef-1	Technician	Oct 06	Mar 10	1st Jan	0.5	1.0	0.5	0.0	2.0
New RA-Shef-1	RA	Oct 06	Mar 10	1st Jan	0.2	1.0	1.0	1.0	3.2

Continued on next page

Table B1.1 – continued from previous page

Staff Name	Grade	Start Date	End Date	Incr. Date	FY06/07 Effort (FTE)	FY07/08 Effort (FTE)	FY08/09 Effort (FTE)	FY09/10 Effort (FTE)	Total Effort (FTE)
Queen Mary College London									
A. Bevan	Physicist	Oct 06	Mar 10	1st Oct	0.1	0.2	0.3	0.4	1.0
F. di Lodovico	Physicist	Oct 06	Mar 10	1st Oct	0.2	0.4	0.5	0.5	1.6
G. Marshall	Technician	Oct 06	Mar 10	1st Oct	0.1	0.2	0.2	0.1	0.6
W. Menges	RA	Oct 06	Mar 10	1st Oct	0.0	0.0	0.5	1.0	1.5
J. Morin	Engineer	Oct 06	Mar 10	1st Oct	0.2	0.2	0.2	0.2	0.8
J. Morris	Engineer	Oct 06	Mar 10	1st Oct	0.3	0.2	0.2	0.2	0.9
J. Mistry	Technician	Oct 06	Mar 10	1st Oct	0.3	0.2	0.2	0.2	0.9
A. Owen	Physicist Programmer	Oct 06	Mar 10	1st Oct	0.2	0.5	0.4	0.4	1.5
New ENG-QM-1	Engineer	Oct 06	Mar 10	1st Oct	0.3	0.6	0.6	0.6	2.1
New RA-QM-1	RA	Jan 07	Mar 10	1st Jan	0.2	1.0	1.0	1.0	3.2
Warwick									
G. Barker	Physicist	Oct 06	Mar 10	1st Aug	0.4	0.5	0.4	0.4	1.7
S. Boyd	Physicist	Oct 06	Mar 10	1st Oct	0.4	0.8	0.6	0.5	2.3
T. Gershon	Physicist	Oct 06	Mar 10	1st Oct	0.0	0.0	0.2	0.2	0.4
P. Harrison	Physicist	Oct 06	Mar 10	1st Aug	0.0	0.0	0.2	0.2	0.4
A. Lovejoy	Technician	Oct 06	Mar 10	1st Aug	0.3	0.4	0.2	0.0	0.9
B. Morgan	Physicist Programmer	Oct 06	Mar 10	1st Aug	0.1	0.2	0.2	0.2	0.7

Continued on next page

Table B1.1 – continued from previous page

A. Sheffield	Technician	Oct 06	Mar 10	29th Nov	0.2	0.2	0.1	0.0	0.5
New RA-War-1	RA	Jan 07	Mar 10	1st Jan	0.2	1.0	1.0	1.0	3.2
New RA-War-2	RA	Jan 07	Mar 10	1st Jan	0.2	1.0	1.0	1.0	3.2
New TECH-War-1	Technician	Jan 07	Mar 10	1st Aug	0.2	1.0	1.0	1.0	3.2

Annex B2

Overview of Costs to PPARC

Table B2 summarises the staff, capital and travel costs of the project in £ k. A description of the costs requested by each work package can be found in the Annex of that work package. In the table the costs of CCLRC staff and University staff are listed separately. The cost of University staff to PPARC is estimated to be the total cost of University staff multiplied by 0.8. The CCLRC staff costs added to the cost of University staff to PPARC is then added to capital costs, consumables and travel costs to arrive at an estimate of the total cost of the project.

Table B2 summarises the total staff costs to PPARC. Costs are spilt into existing and new posts at Universities, CCLRC PPD, CCLRC Daresbury and CCLRC TECH.

	FY 06/07	FY 07/08	FY 08/09	FY 09/10	Total
Staff Effort					
CCLRC Daresbury	120	936	464	336	1856
Imperial College	379	540	561	514	1994
Lancaster	123	325	332	276	1056
Liverpool	191	427	489	508	1615
CCLRC RAL PPD	186	394	417	457	1454
CCLRC RAL TECH	656	814	609	442	2521
Sheffield	66	182	182	176	606
Queen Mary	160	307	366	201	1034
Warwick	128	326	335	322	1111
Equipment					
WP 1	0	0	0	0	0
WP 2	533	612	90	0	1235
WP 3	16	100	100	0	216
WP 4	35	185	766	189	1175
WP 5	21	11	108	0	140
WP 6	0	310	0	145	455
WP 7	174	11	11	0	196
WP 8	8	0	0	0	8
WP 9	7	170	220	20	417
WP 10	0	0	0	0	0
Travel					
WP 1	8	8	7	7	30
WP 2	11	35	31	31	108
WP 3	9	9	0	0	18
WP 4	10	11	37	46	104
WP 5	7	25	18	63	113
WP 6	0	3	33	25	61
WP 7	8	30	35	6	79
WP 8	12	12	12	12	48
WP 9	30	30	69	30	159
WP 10	48	0	0	0	0
Common Travel	199	199	199	199	796
Indirect Costs					
Consumables	44	46	46	44	180
Exceptional Items					
Common Fund	0	44	47	47	138
Totals					
CCLRC Staff Cost	962	2144	1490	1235	5831
University Staff Cost	1047	2107	2265	1997	7416
Costs to PPARC of University Staff	838	1686	1812	1597	5933
Total Staff Costs to PPARC	1800	3830	3302	2832	11764
Equipment	794	1399	1295	354	3842
Consumables	44	46	46	44	180
Travel	342	362	441	419	1564
Common Fund	0	44	47	47	138
Total Costs to PPARC	2980	5681	5131	3696	17488

Category of Staff cost	2006/07	2007/08	2008/09	2009/10	Total
Total University staff	838	1686	1812	1597	5933
Cost of old posts	713	1191	1316	1217	4437
Cost of new posts	125	495	496	380	1496
Total CCLRC PPD existing posts	186	394	417	457	5871
Total CCLRC PPD new posts	0	0	0	0	0
Staff costs for new posts	125	495	496	380	1496
Staff costs for old posts	899	1585	1733	1674	5891
Staff costs CCLRC Daresbury+TECH	776	1750	1073	778	4377
Total	1800	3830	3302	2832	11764

Table B2.1: Staff costs to PPARC showing the total staff cost for all University staff, the total for existing and new University posts, the total staff cost for CCLRC PPD old and new posts and the total staff cost for CCLRC Daresbury and TECH. All costs are in units of £ k

Annex B3

PPARC Supported Contributions to Work Packages by Institute

Table B3.1 summarises the cost requested by each work package in £ k. Shown are staff costs for each institute contributing to the work package and the combined travel and equipment costs.

WP	DL/TECH	Imperial	Lancaster	Liverpool	QMUL	RAL/PPD	RAL/TECH	Sheffield	Warwick	Equip/Travel	Total
WP1	0	586	292	175	169	321	0	201	141	30	1915
WP2	1496	0	478	1019	240	0	0	134	325	1391	5083
WP3	0	145	0	0	0	0	0	33	152	266	596
WP4	0	670	0	0	190	432	534	0	0	1295	3121
WP5	0	0	0	0	0	552	244	0	0	257	1053
WP6	360	0	0	192	0	0	0	0	0	516	1068
WP7	0	282	0	14	435	0	0	143	373	355	1602
WP8	0	254	286	215	0	51	0	56	120	56	1038
WP9	0	0	0	0	0	17	1379	39	0	576	2011
WP10	0	57	0	0	0	81	364	0	0	48	502
Tota	1856	1994	1056	1615	1034	1454	2521	606	1111	4790	18037

Table B3.1: PPARC supported contributions to work packages by institute.

Annex B4

Summary of Working Allowance and Contingency

Table B4.1 presents the additional costs in k£ requested for working allowance and contingency for each work package in the project.

Work package	**Working Allowance (£ k)**	**Contingency (£ k)**
WP1	0	0
WP2	1250	540
WP3	191	100
WP4	799	300
WP5	123	233
WP6	36	20
WP7	77	340
WP8	70	0
WP9	255	90
Total	2801	1623

Table B4.1: Requested working allowance and contingency by work package.

Annex C: Risk Analysis and Schedule

Annex C1

Risk Analysis

Risk	Effect	Risk Factor			Level	Mitigation
		L	I	LxI		
General						
Natural disaster	End of Project	1	5	5	Medium	Design equipment to meet strict Japanese building specifications designed to cope with natural events.
Damage of major components in transport, shipping, installation	Delay of schedule and added FTEs	2	2	4	Medium	Packing, handling and contingency
Loss of key staff	Delay of schedule and added FTEs	2	3	6	Medium	Shared responsibilities
Loss of workforce (eg. illness, inability to recruit or retain staff, delays in RA appointments etc.)	Delay of schedule and added FTEs	2	2	4	Medium	Flexibility and contingency
Loss of supplier	Delay to schedule and added FTEs	1	3	3	Medium	Identifying alternative suppliers
Major price fluctuations	Higher cost; de-scope project	2	2	4	Medium	Factor into working allowance; plan for descoping
External schedule delays (eg. delay in vendor delivery schedule, test–beam scheduling etc.)	Schedule push-back; manpower reallocation	2	2	4	Medium	Possible storage plans; plan for minor schedule slippage
Schedule slippage or unable to meet major WP milestones	Unable to deliver systems for prototyping and commissioning, test–beams, final experiment	2	3	6	Medium	Iterative development process with early design phase. Adequate project management, monitoring and reporting to ensure WP remains on schedule
WP1 (Physics Studies and ECAL Optimisation)						
Software tools not being provided in timely manner	Inability to perform optimisation / physics tasks	2	1	2	Low	Improve coordination with WP8 and ND280m software group.
WP3 (Photosensors)						
AMPD technology deemed unsuitable for use	Increase in project budget and time scale: alternative devices (Burle MCP-PMT 85011-501) cost over 4 times the AMPD price per channel plus some engineering and electronics changes would need to be made.	1	3	3	Medium	Fully investigate the Burle MCP-PMT 85011-501 devices (work in progress by our American collaborators)
Compromise in one or more desired specifications of the AMPD production devices	Degraded physics potential	2	2	4	Medium	Collaborate with a number of AMPD vendors

Continued on next page

Table C1.1 – continued from previous page

Risk	Effect	Risk Factor			Level	Mitigation
		L	I	LxI		
WP4 (Electronics)						
ASIC not adequate	modify ASIC	2	2	4	Medium	
Trigger more complicated	complex trigger hardware	2	2	4	Medium	try to simplify trigger requirements
Industrial testing more expensive	increase cost	1	3	3	Medium	work early with industry to optimise overall cost
External design constraints	increase cost	1	2	3	Medium	work with detector groups to verify design early
WP5 (DAQ)						
Significant changes to scope of DAQ requirements (e.g. rate) during project lifetime	DAQ severely limits experimental capability	2	3	6	Medium	Full engagement of collaboration during requirements capture and design phase, clear definition of design capabilities of DAQ, flexible and scalable system design, factor additional engineering and capital expenditure of system into contingency
Minor changes to scope of DAQ requirements	DAQ limits experimental capability	2	3	6	Medium	Flexible, scalable system design, factor additional engineering and capital expenditure into working allowance
DAQ system design inadequate for experimental needs	DAQ limits experimental capability	2	3	6	Medium	Effective engagement of collaboration with DAQ requirements and design, technical design reviews at critical phases
Changes to other subsystem interfaces to DAQ	Additional engineering effort required to deliver new interface	2	3	6	Medium	Specify, design and publish interface standards early in the project lifecycle
Unable to identify DAQ software framework appropriate for requirements	Significant additional engineering effort required to complete system	2	3	6	Medium	Careful analysis of requirements and evaluation of available frameworks, factor additional effort into contingency
Operational failure of DAQ system	Experiment unable to acquire data	2	3	6	Medium	Adequate spares for lifetime of experiment, provision of expert support for system, continuity of expertise between construction and exploitation phases.
Accidental or malicious damage to system hardware or software	DAQ system failure	2	3	6	Medium	Robust physical design, robust and secure system architecture, ensure adequate security of location and infrastructure, routine monitoring and maintenance, hold "live spares" for critical items
WP7 (Calibration)						

Continued on next page

Table C1.1 – continued from previous page

Risk	Effect	Risk Factor			Level	Mitigation
		L	I	LxI		
Construction of bar scanners delayed	Construction of scintillator bars delayed	2	2	4	Medium	Design of scanners begun early; Scanners constructed mostly from off the shelf components; Concurrent construction at several institutes.
Extended or delayed test-beam required due to problems with calibration module or beam	Higher travel costs; Possible rescheduling	2	2	4	Medium	Thorough testing of equipment before transport; Commissioning stage before beam insertion; Close contact with beam delivery organisation; Presence of sub-system experts at test-beam
Require more calibration data	Degrade physics resolutions	3	1	3	Medium	Consider possibility in design of calibration system
Light injection required to monitor linearity	Calibration more complicated; Higher cost and added FTEs, potential delay	2	3	6	Medium	Exploit all the AMPDs properties and devise alternative ways of calibration. Possible design for the LI system and cost foreseen in contingency
WP8 (Offline Software Tools)						
Unable to process data quickly enough	Infrastructure overwhelmed	1	2	2	Low	Design system to cope with excessive data rates
WP9 (Beam and Target)						
Manufacturing or design error of target station vessel	Modification of beam window required	2	2	4	Medium	Incorporate adjustment into window design
TRIUMF remote clamp or handling design fails	Redesign of beam window required	2	2	4	Medium	Negotiate sufficient z-space for modifications
Window prototype failure	Redesign of beam window required	3	2	6	Medium	
Failure of beam window during operation due to fatigue/ radiation damage	T2K halted until window replaced	4	3	12	High	Supply spare; ensure window easily replaceable
Failure of graphite bonding system for baffle	Redesign, repeat prototype	3	1	3	Medium	Working allowance
Failure of KEK to manufacture target prototype	Redesign target	3	2	6	Medium	Investigate alternative manufacturing methods
Insufficient clearance between target and/or magnetic horn; or handling cell proves unusable	Target remote handling system inoperable	3	3	9	High	Horn must be replaced in event of target failure; increase clearances

Continued on next page

Table C1.1 – continued from previous page

Risk	Effect	Risk Factor			Level	Mitigation
		L	I	LxI		
Failure of target and horn system during operation	T2K halted until target and horn replaced	4	3	12	High	Instigate critical review into complete target and horn system, clearances and handling; press for spares to be manufactured
Undetected failure of target/horn causes full intensity pulse on beam dump	Failure of beam dump; T2K inoperable	1	5	5	Medium	Review diagnostics
Leak in decay volume	Oxidation of Beam Dump limits T2K to low power operation	3	2	6	Medium	Only a problem for ¿ 1 MW operation
Leak in beam dump plumbing	Only half cooling circuit functioning - limits T2K to low power operation	2	2	4	Medium	Twin cooling circuits; make installation simple to minimise leak risk; specify QA on welds
Change in beam parameters	Redesign of components	2	2	4	Medium	Working allowance in staff costs
Failure to meet milestones due to design/parameter changes	T2K schedule not met	3	2	6	Medium	Delay in facility start date
Failure to achieve continuity funding from April 06	T2K beam and target work halted; T2K deadlines unachievable	2	3	6	Medium	Default on Work Package

Annex C2

Overview Gantt Charts

C2.1 T2K Project Schedule

A summary of the milestones and schedule of the JPARC neutrino project is shown in C2.1.

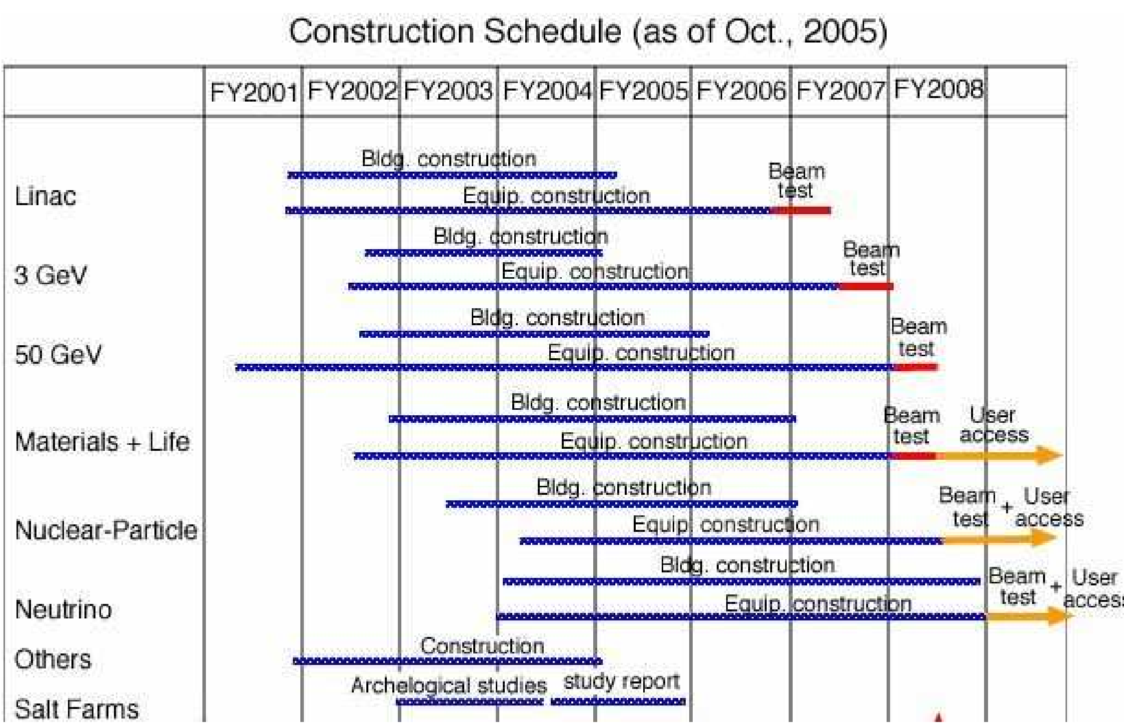


Figure C2.1: A summary of the overall project milestones.

C2.2 T2K ND280m Detector Schedule

The schedule and milestones for the construction and installation of the T2K ND280m near detector is presented in C2.2.

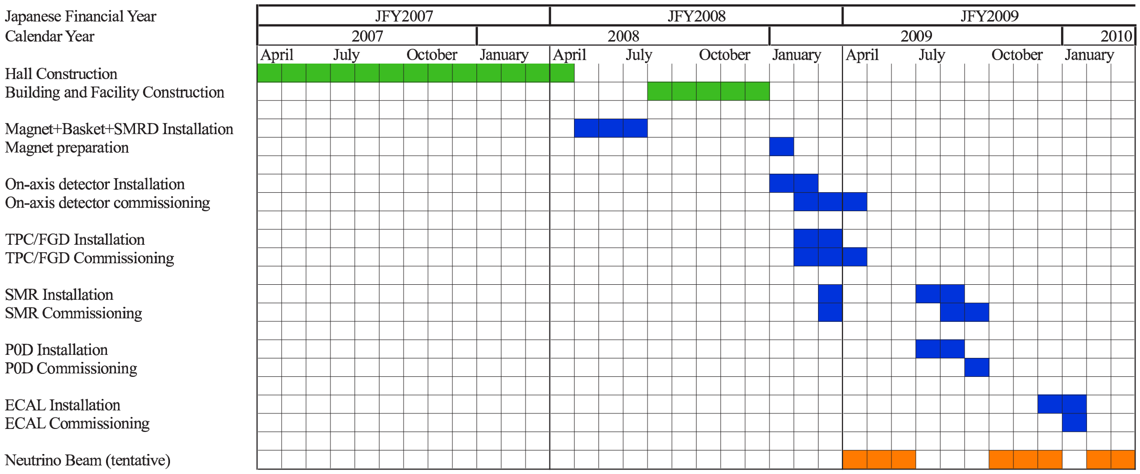


Figure C2.2: A summary of major T2K 280m Milestones.

C2.3 JPARC Neutrino Beamline Construction Schedule

The beamline construction schedule is shown in C2.3.

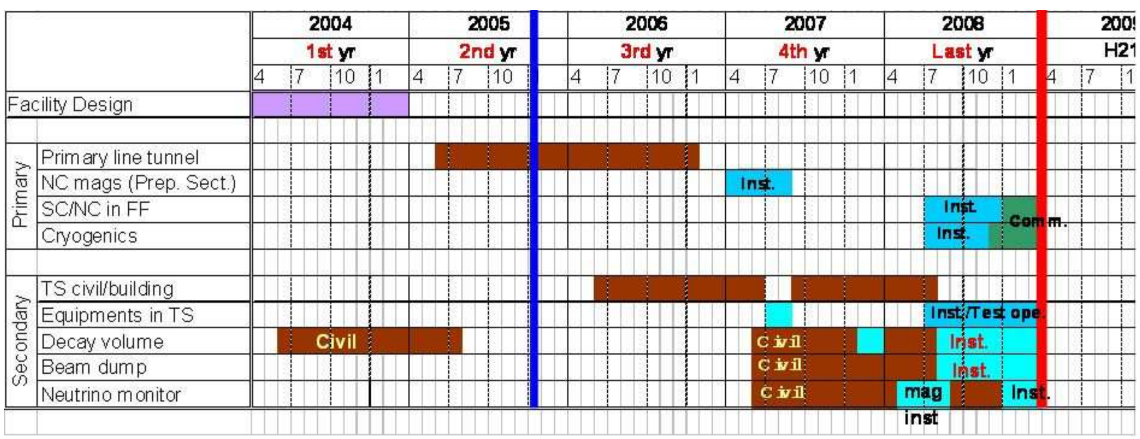


Figure C2.3: A summary of the JPARC beamline construction schedules.

C2.4 T2K UK Contributions

The Gantt chart summarising the UK contributions is shown in Fig. C2.4. The major milestones are recorded in Table C2.1.

Table C2.1: Summary of the major projecct deliverables

Task/Milestone	**Start Date**	**End Date**
WP1: Physics Studies		
WP1-T1: Software Preperation	Apr 1, 2006	Aug 1, 2006
WP1-T2-3: Detector Optimisation	Apr 1, 2006	Dec 31, 2006
WP1-T4: Algorithm Development	Jan 1, 2007	Jan 1, 2009
WP1-T5: Physics Commisioning	Jan 1, 2009	Dec 31, 2009
WP2: ECal		
WP2:Full Prototype	Oct 31, 2006	Dec 31, 2007
WP2: Electron Testbeam	Jun 1, 2008	Nov 4, 2008
WP2: Photon Testbeam	Jun 1, 2009	Oct 31, 2009
WP2: Construction of ECAL	Jun 1, 2007	Aug 31, 2009
WP2: Shipment to Japan	Nov 1, 2009	Nov 30, 2009
WP3: Photosensors		
WP3: Photosensor R&D	Apr 1, 2006	Dec 31, 2006
WP3: Optical Connector	Apr 1, 2006	Oct 1, 2007
WP3: Testing and Evaluation	Jan 1, 2007	Jul 2, 2007
WP3: Calibration and Quality Assurance	Jul 1, 2007	Sep 30, 2009
WP4: Electronics		
WP4: Protype Boards (TFB, BEB)	Apr 1, 2006	Dec 31, 2006
WP4: Vertical Slice 1	Dec 31, 2006	Jun 30, 2007
WP4: BEB production	Jun 30, 2007	Dec 31, 2007
WP4: Vertical Slice II	Dec 31, 2007	Jun 30, 2008
WP4: TFB Production	Jun 30, 2008	Jun 30, 2009
WP4: TFB Testing	Jun 30, 2009	Aug 31, 2009
WP4: Commisioning	Aug 31, 2009	Sep 30, 2010
WP5: DAQ		
WP5-T1: Specification and Design	Apr 1, 2006	Sep 30, 2006
WP5-T2: Software Development	Sep 30, 2006	Dec 31, 2007
WP5-T3: Vertical Slice 1	Sep 30, 2006	Mar 31, 2007
WP5-T4: Full System Demonstrator	Mar 31, 2007	Jun 30, 2007
WP5-T5: Testbeam Support	Jun 30, 2007	Sep 30, 2008
WP5-T6: Installation and Commisioning	Apr 1, 2008	Mar 31, 2010
WP6: Mech/Therm Engineering		
WP6: Install Fixtures for ECAL	Jul 1. 2008	Aug 1, 2008
WP6: Install support for inner detector	Jan 1. 2009	Mar 1, 2009
WP6: Installation of ECAL	Nov 1, 2009	Feb 28, 2010
WP7: Calibration		
WP7: Design/Construction Scanners	Apr 1, 2006	Jun 2, 2007
WP7: Testbeam Software	Jan 1, 2007	Jul 31, 2008
WP7: Electron Testbeam	Feb 1, 2008	Jan 1, 2010
WP7: Preperation	Feb 1, 2008	Jul 17, 2008
WP7: Beam	Jul 17, 2008	Oct 6, 2008
WP7: Analysis	Aug 1, 2008	Jan 1, 2010

Continued on next page

Table C2.1 – continued from previous page

Task/Milestone	**Start Date**	**End Date**
WP7: Photon Testbeam	Feb 2, 2009	Dec 31, 2011
WP7: Photon Preperation	Feb 2, 2009	Jul 17, 2009
WP7: Beam	Jul 17, 2009	Oct 5, 2009
WP7: Analysis	Aug 10, 2009	Dec 31, 2011
WP7: Offline Calibration	Oct 1, 2006	Mar 31, 2009
WP7: Design	Oct 1, 2006	Sep 30, 2007
WP7: Implementation	Sep 30, 2007	Mar 31, 2009
WP8: Offline Software		
WP8-T1: Database	Apr 1, 2006	Mar 31, 2009
WP8-T1: Technology Evaluation	Apr 1, 2006	Dec 31, 2006
WP8-T1: Prototype/Testbeam	Dec 31, 2006	Oct 31, 2007
WP8-T1: Production Database	Oct 31, 2007	Mar 31, 2009
WP8-T2: Framework	Apr 1, 2006	Dec 31, 2008
WP8-T2: Development Framework	Apr 1, 2006	Dec 31, 2006
WP8-T2: Reevaluation and Upgrade	Jun 30, 2007	Dec 31, 2007
WP8-T2: Production Framework	Apr 1, 2008	Dec 31, 2008
WP8: Grid Computing	Apr 1, 2006	Dec 31, 2008
WP8: Remote Software Distribuution	Apr 1, 2006	Oct 31, 2006
WP8: Prototype Workflow	Jan 1, 2007	Jun 30, 2007
WP8: Production Workflow	Jan 1, 2008	Dec 31, 2008
WP9: Beam and Target		
WP9: Beamdump Design	Apr 1, 2006	May 1, 2006
WP9: Prototype Target	Apr 1, 2006	Apr 30, 2007
WP9: Civil Construction	Apr 1, 2006	Dec 31, 2008
WP9: Remote Handling	Apr 1, 2006	Apr 30, 2009

Annex D

Public Outreach

D.1 Outreach Activities

The importance of fostering interest in and understanding of PPARC science among the general public and in schools is recognized by all UK particle physicists, and the T2K-UK group is fully committed to playing a part in this. Outreach activities carried out by T2K-UK members which are not specific to T2K include the following:

- National Particle Physics Masterclasses for sixth-form (Y12/13) school students, hosted by Imperial College, Lancaster, Liverpool, QMUL and Sheffield.
- Public webcasts: Y. Uchida and D. Wark helped to organise, and participated in, Imperial College's contribution to the CERN world-wide webcast arranged as part of the World Year of Physics. Uchida and Wark answered questions on neutrino physics in general and T2K in particular.
- Media events: members of the collaboration have appeared in a number of radio and television programmes in recent years. Some recent examples include D. Wark's appearance in the Melvin Bragg show on Radio 4, speaking on the Higgs boson, and in the National Geographic TV programme "Hitler's Sunken Secret".
- Talks to the public through the Café Scientifique system, local astronomical societies, etc.
- Talks to undergraduate students and the public through the Institute of Physics lecture programme.
- Work/research experience placements for school students and undergraduates.

Neutrinos are a source of particular fascination for scientifically oriented members of the public, as evidenced by John Updike's well-known poem "Cosmic Gall" and the media interest shown in both the SNO experiment (led in the UK by D. Wark) and the ANTARES project (UK participants including L. Thompson and S. Cartwright). A 2004 BBC Horizon programme on solar neutrinos, which featured David Wark and was made at his instigation, won the Grierson Award for best science documentary in the UK.

The T2K experiment, with both novel science and an exotic location, therefore has good potential for developing public interest. We propose to build on the generic outreach work undertaken by UK particle physicists in the following areas.

- The T2K-UK website will include a section designed for outreach and educational use, in which the properties of neutrinos, the aims of the T2K experiment, and the UK contributions are explained at an appropriately pedagogical level.
- We will develop educational resources associated with T2K, in particular
  - an interactive exercise on neutrino oscillation for use in Masterclasses;
  - a set of posters on neutrino physics for schools, colleges and unveristies, along the lines of the successful Royal Holloway poster set on particle physics in general.
- Working with PPARC and university press offices, we will ensure that significant milestones in the T2K project are publicised by appropriate press releases and provide any necessary media contacts.
- Popular books: David Wark has had discussions about writing a popular book on neutrino physics, based on the award-winning documentary programme mentioned above.

We plan to coordinate our outreach activities with other UK neutrino physicists (e.g., UK participants in MINOS, COBRA and SuperNEMO), with the aim of developing a high public profile for the whole UK neutrino programme.

Appendices

Appendix A

Active Water

A.1 Introduction and Motivation

The target mass for neutrino interactions in the ND280 will be provided by segmented scintillator bars, read out by wavelength-shifting fibres. For neutrinos near ~ 700 MeV, the dominant reaction is charged current quasi-elastic ($\nu_\mu n \to \mu^- p$). Fine-grained segmentation allows tracking of both outgoing particles giving a strong kinematic constraint to reject backgrounds. Using a scintillator rather than a Cerenkov detector allows the detection of the recoil proton, which is below the Cerenkov threshold.

Unfortunately in this design the target mass is mostly carbon, whereas the bulk of the mass of the far detector Super-Kamiokande is water (therefore oxygen rich). Systematic effects caused by the use of different nuclear targets will unavoidably arise. In particular the current theoretical understanding of the corrections for the cross section differences from different nuclei (especially the modifications for pion absorption in the nuclear medium which can make 30-50% corrections to the cross-sections) is poor. Furthermore the scattering reaction at Super-K is nucleus specific and the scattering off carbon rather than oxygen could produce background reactions with different signatures at each detector. In particular neutral current single pion production may be more prolific on carbon atoms than oxygen atoms; this is the largest source of background for the ν_e appearance search. Additionally resonance production in oxygen is affected differently than in carbon due to long-range nuclear correlations.

The development of a water-based scintillating mixture as an alternative to plastic scintillator extrusions will provide an oxygen rich target material at the near detector that will minimise cross-section uncertainties.

A.2 Scintillator Mixture

The chosen water tolerant liquid scintillator is “Quicksafe A” (QSA) manufactured by Zinsser Analytic [56].The active scintillation ingredient is di-isopropylnapthalene. It is non-hazardous with a flashpoint greater than 150°C and is biodegradable. QSA also contains primary and secondary fluors to “shift” the wavelength of the scintillator light to match the absorption spectra of the wavelength-shifting fibres that will transmit the light to the photodetectors. The scintillator is mixed with water and the miscibility with water improved with the addition of a surfactant. The default scintillating mixture is 70% water, 25% QSA and 5% Triton X-100 surfactant.

A.3 Mechanical Design

The mechanical design for the water scintillator layers is based on a successful prototype designed for the OPERA and MINOS experiments and also adopted by the NOνA neutrino experiment. In this design the detector will consist of planes of liquid scintillator built from layers of extruded plastic. The presently chosen plastic is cellular extruded twin-wall polypropylene sheets, manufactured as Correx [60] or Matraplast [59]. This plastic is favoured as it is inexpensive and easily available off the shelf. Alternating x and y layers will be glued together for strength. This concept is shown diagrammatically in figure A.1.

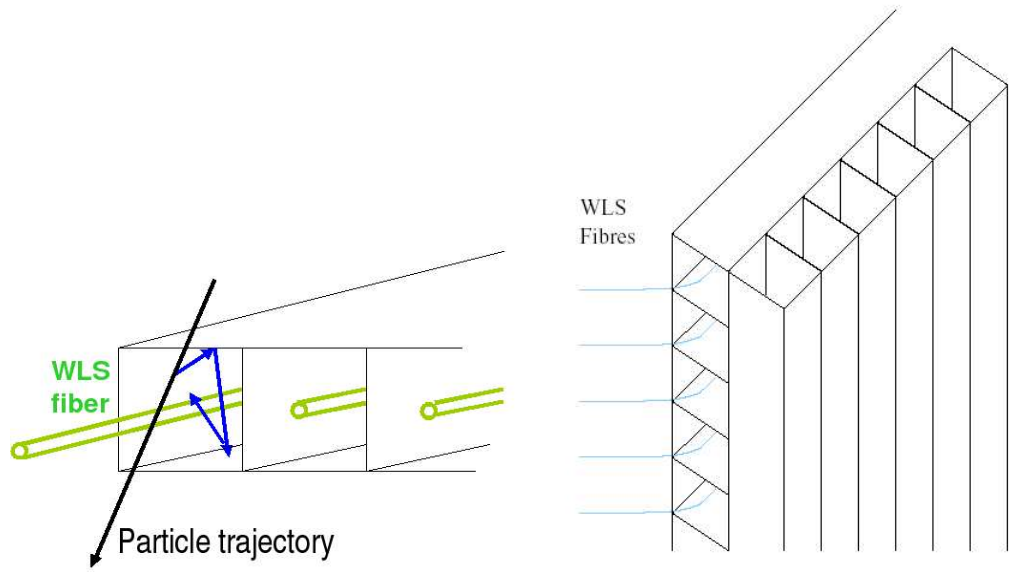


Figure A.1: The principle of the detector (left) [57] and side view of an x-y layer of extruded cells, showing WLS fibres for the x layer (right) [58]

Scintillation light produced by the passage of a charged particle through the scintillator will be reflected inside the cell and hit the WLS fibre which will act as a light guide to transmit the trapped light to a photodetector. The reflectivity of the cell walls will be a critical factor in maximising the light collection from the passage of a charged particle through the scintillator. Therefore the inside of the detector walls will be painted with reflective paint Eljen-520 [61], which will also serve to protect the plastic from chemical aggression of the QSA.

A.4 Prototype and Beam Test Results

Tests of prototype scintillators have been carried out at the M11 test beam at TRIUMF which delivers low-intensity beams of electrons, pions, muons and protons of variable momentum. Beam tests have been performed with a single cell prototype consisting of a corrugated plastic panel, about 170 cm long, with a single 1.5 mm WLS fiber running along the length of the cell. This prototype uses ”single-ended” readout with a Phillips XP2262 photomultiplier, and the other end is cut at a 45 degree angle and blackened to minimize reflections. The light yield as a function of the distance of the beam from the photomultiplier is shown in A.2.

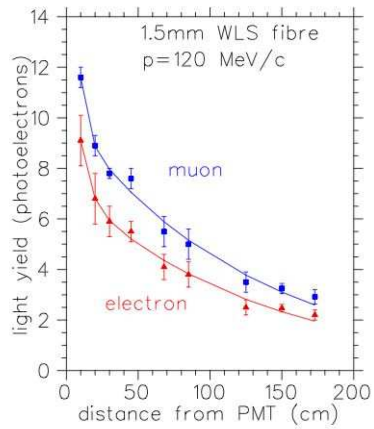


Figure A.2: Light yield for 120 MeV/c muons (top set of points) and electrons (bottom set) for single-cell prototype with 1.5 mm diameter fiber and XP2262 PMT.

At a distance of 1.2 m from the PMT, the light yield is about 2.5 photo-electrons for a minimum ionizing particle. This is small, but with the superior quantum efficiency of a AMPD as a photon detector, and double-ended readout, it is possible that a minimum-ionizing particle may produce up to 6 or 7 photo-electrons per channel. By contrast, protons of momentum 270 MeV/c produced 33 photo-electrons in the same test configuration, about twice what we would expect by scaling the light yield observed for muons and electrons by dE/dx. Importantly, this indicates that the foremost purpose of the water scintillator, namely, as a tracker for the recoil proton from CC quasi-elastic events, the light yield is adequate.

Despite the fact that prototype tests indicate an adequate light yield for low energy protons, improvements are certainly desirable which necessitate further investigations, the focus of this work package. Recent beam tests designed to address this problem have been undertaken, also at the M11 beam line. Scintillator mixtures were tested in a 1cm $\times$ 1cm $\times$ 50cm Matraplast cell through which a 1.5mm diameter Kuraray Y11(200) wavelength shifting fibre passed through. A mixture of 70% water, 25% QSA and 5% Triton X-100 was tested. Thereafter the 25% scintillating portion of this nominal mixture was altered by either dilution with water or addition of extra fluors, in an attempt to improve upon the light output. Additionally a "home brew" of QSA was made with the raw ingredients. The results (from muons) are illustrated in figure A.3.

As can be seen from figure A.3 a scintillating mixture of 70% water, 25% QSA and 5% Triton X-100 gave the highest value of the average number of photo-electrons (Npe) per beam particle for that sample significant above experimental errors. Therefore further work is required, for example to change the types of fluors involved.

A.5 Proposed Programme of Work

The Sheffield group already has appreciable experience in this area and has worked closely with other T2K collaborators in recent M11 beam tests. In order to fully develop water based active scintillator a number of improvements are desirable and a programme of work is envisaged, including:

- Determination of characteristics (such as ageing, reactivity and transmissivity) of various

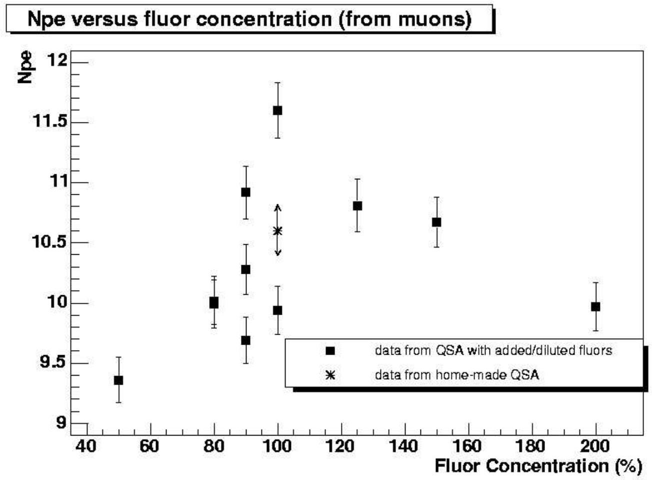


Figure A.3: Results from testing scintillator samples with TRIUMF beam: Npe versus fluor concentration (from muons)

scintillator cocktails as a function of temperature;

- Optimisation of ”base scintillator” mixture (i.e. primary fluor, surfactant and water), in particular relative concentrations and determination of most efficient fluor and surfactant;
- Study of light yield of scintillator cocktail as a function of various secondary fluor mixtures and concentrations;
- Testing of biological inhibitors which may be needed to avert mould growth in the water/scintillator mixtures and assessing any impact on overall scintilltor performance;
- Measurements of the mechanical stability of the proposed cell wall material;
- Reflectivity studies of proposed cell wall materials with and without protective and reflective paint coverings;
- Design, develop and assess endplugs to seal individual cells and act as a mechanical guide for WLS fibres.

Much of this work can be carried out in Sheffield with existing infrastructure which includes a cosmic ray muon telescope purchased with seedcorn money, a spectrophotomter and a reflectometer. Full testing of the scintillator however is best done in a test beam. To date the best facility is the M11 beam line at TRIUMF since it delivers multiple particle types at a relevant (and selectable) energies and with low intensities. Furthermore, test beam visits to TRIUMF involve collaborating with other T2K experts in this field based at TRIUMF and UBC. Costs for 2 visits to TRIUMF for Navin (non-PPARC student) and Thompson/or new Sheffield RA have thus been incorporated into the request for travel detailed in Annex. A10 .

Bibliography

[1] SAGE collaboration, recent results in arXiv:astro-ph/0204245.

[2] The GALLEX collaboration, Phys. Lett. **B447**,127-133 (1999).

[3] Q.R. Ahmad *et al.*, Phys. Rev. Lett. **89** 011301 and 011302 (2001).

[4] For the latest KamLAND results see arXiv:hep-ex/0406035.

[5] Y. Fukuda *et al.*, Phys. Rev. Lett. **81**,1562 (1998).

[6] See M. Goodman, talk at Neutrinos ’02, arXiv:hep-ex/0210055.

[7] See M. Goodman, talk at Neutrinos ’02, arXiv:hep-ex/0210055.

[8] K2K Collaboration, arXiv:hep-ex/0406055.

[9] A. Aguilar *et al.*, Phys. Rev. **D 64**,112007 (2002).

[10] G.J. Drexlin, Prog. Part. Nucl. Phys. **48**, 73 (2002).

[11] The MiniBooNE collaboration, arXiv:hep-ex/0408074

[12] S.F. King, Rept. Prog. Phys. **67**,107-158 (2004).

[13] Many papers, for instance W. Hu, D.J. Eisenstein, M. Tegmark, Phys. Rev. Lett. **80** 5255 (1998).

[14] Many papers, for example arXiv:astro-ph/0212/0212195.pdf

[15] T. Yanagida, Nucl. Phys. Proc. Suppl. **118**,323-326 (2003).

[16] For a review see the PDG, http://pdg.lbl.gov/2004/reviews/numixrpp.pdf

[17] M. Apollonio *et al.*, Phys. Lett. **B466** 415 (1999), A. Piepke *et al.*, Prog. Part. Nucl. Phys. **48**, 113 (2002).

[18] R. Helmer, see http://www-jhf.kek.jp/NP02/Sep28/helmer.pdf

[19] E. Aliu *et al.*, Phys. Rev. Lett. **94**, 081802 (2005).

[20] P. Astier*et al.*, Nucl. Phys. **B611**, 3-39 (2001).

[21] T. Araki *et al.*, Phys. Rev. Lett. **94**, 081801 (2005).

[22] S. Brice *et al.*, Nucl. Phys. Proc. Suppl. **143**, 115-120 (2005).

[23] N.McCauley *et al.*, Nucl. Phys. Proc. Suppl. **149**, 128-130 (2005).

[24] B. Aubert *et al.*, Phys. Rev. Lett.**95**, 142001 (2005).

[25] K.A. Aniol *et al.*, Phys. Rev. **C69**, 065501 (2004).

[26] "Bringing the SciBar Detector to Fermilab", SciBooNE Collaboration. FERMILAB-PROPOSAL-0954, Jan 2006 arXiv:hep-ex/0601022.

[27] "Proposal to perform a high-statistics neutrino scattering experiment using a fine-grained detector in the NUMI beam", Minerva Collaboration (D. Drakoulakos *et al*), FERMILAB-PROPOSAL-0938, Feb 2004 hep-ex/0405002.

[28] "The K2K SciBar Detector", K2K Collaboration (K. Nitta *et al*), hep-ex/0406023, Jun 2004.

[29] G.Bondarenko *et al.*, Nucl. Phys. Proc. Suppl. **61B**,347 (1998).

[30] A. Akindinov *et al.*, Nucl. Inst. Meth **A494**, 474 (2002).

[31] G.Bondarenko *et al.*, Nucl. Inst. Meth **A442**, 187 (2000).

[32] V.Golovin and V.Saveliev, Nucl. Inst. Meth **A518**, 560 (2004).

[33] V. Andreev *et al.*, Nucl. Inst. Meth **A549**, 368 (2005).

[34] A. Akindinov *et al.*, Nucl. Inst. Meth **A539**, 172 (2005).

[35] Particle Data Group, S. Eidelman *et al.*, Phys. Lett. **B592**, 1 (2004).

[36] Details of the TRIP-t ASIC can be found at https://plone4.fnal.gov/P1/AFEIIUpgrade/AFEIIProto/AFEIIdocs/

[37] S. Ritt, P-A. Amaudruz, *et al.*, The MIDAS Data Acquisition System, http://midas.psi.ch.

[38] P. Adamson *et al.*, "The MINOS Scintillator Calorimeter System", IEEE Trans.Nucl.Sci.49:861-863,2002.

[39] P. Adamson *et al.*, "The MINOS light-injection calibration system", NIM A 492 (2002) 325-343, 21-Oct-02.

[40] P. Adamson *et al.*, "On the Linearity of the MINOS Light-Injection Calibration System", NIM A 521 (2004) 361-366.

[41] P. Buzhan *et al*, "An Advanced Study of Silicon Photomultiplier", published in ICFA Instrum.Bull.23:28-41,2001.

[42] B. Aubert *et al.*, "The BaBar Detector", Nucl.Instrum.Meth.A479:1-116,2002.

[43] J. L. Tain *et al*, "Proposal for the Construction of a Gamma-Ray Beam Line at Spanish Synchrotron ALBA" [www.ause.uma.es/ALBA/Anteproyectos_lineas/Gamma%20rays_31_04.pdf] (Dec, 2004)

[44] P. Adamson *et al.*, "The MINOS Calibration Detector", to be published in Nucl. Inst. Meth. **A**.

[45] C. Arnault, CMT, `http://www.cmtsite.org/`

[46] CVS, `http://www.nongnu.org/cvs/`

[47] ELOG, `http://midas.psi.ch/elog/`

[48] GridPP, `https://www.gridpp.ac.uk/portal/`

[49] Runjob, `http://projects.fnal.gov/runjob/`

[50] V. N. Ivanchenko [Geant4 Collaboration], Nucl. Instrum. Meth. A **502** (2003) 666.

[51] R. Brun & F. Rademakers, *ROOT - An Object Oriented Data Analysis Framework*, **Proceedings AIHENP'96 Workshop, Lausanne**, Sep. 1996, Nucl. Inst. & Meth. in Phys. Res. A **389** (1997) 81-86. `http://root.cern.ch/`

[52] C.Andreopoulos and H.Gallagher, *"Tools for Neutrino Interaction Model Validation"*, Proceedings of the **3rd Intl. Workshop on vN interactions (NuINT-04), 26-29/09/2005, Gran Sasso, Italy**. Nucl. Phys. B **139** (2005) 247-252.

[53] T2K UK Seedcorn proposal to PPARC, 2005.

[54] "Material Studies for Pulsed, High Intensity Proton Beam Targets", N. Simos, H. Kirk, P. Thieberger *et. al.*, Nucl.Phys B Proceedings Supplements, Volume 149, p. 259-261

[55] "Solid Target Studies for Muon Colliders and Neutrino Beams", N. Simos, H. Kirk, H. Ludewig *et al.*, Nuclear Physics (in review)

[56] http://www.zinsser-analytic.com/137.asp

[57] P. Border *et al.*,Nucl. Inst. Meth. **A463**,194 (2001).

[58] S. Oser *et al.*, 'Feasibility Studies for a Finely Segmented Water Scintillator Detector Version 1.0: November 26, 2004'

[59] http://www.matraplast.com

[60] http://www.cordek.co.uk/correx/products

[61] http://www.eljentechnology.com/