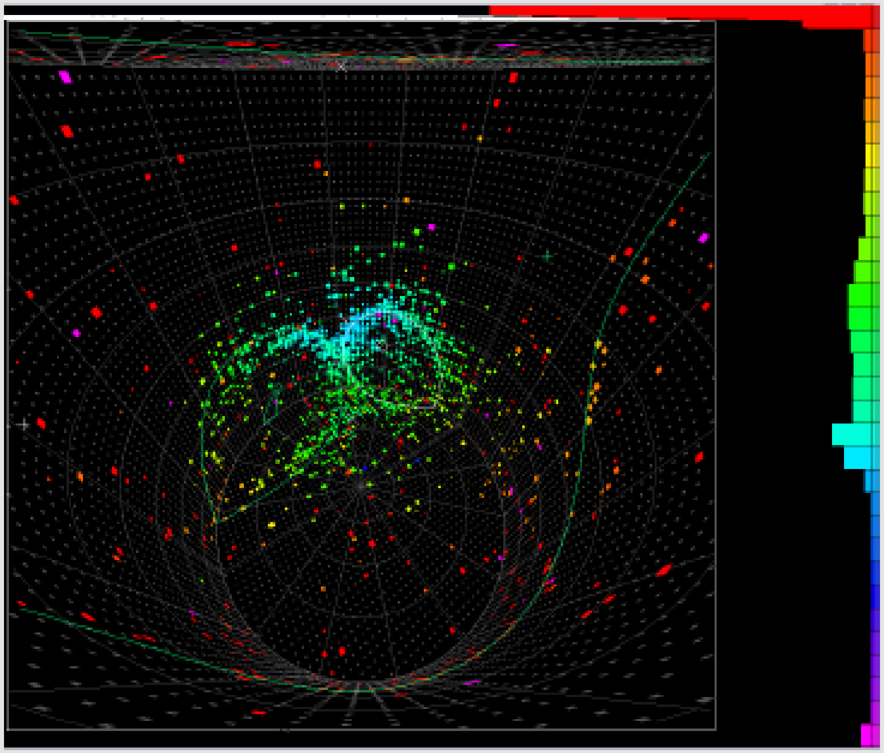
The Tokai to Kamioka Long Baseline Neutrino Oscillation Experiment



An image of the first beam neutrino event candidate seen at Super-Kamiokande

M Scott, Imperial College London

Overview

- Theory of neutrino oscillations
- Experiment outline and physics goals
- The experiment
  - The neutrino beam
  - INGRID
  - ND280
  - Super-Kamiokande
- Test beam data analysis

Neutrino Oscillations

Weak eigenstates are not mass eigenstates but instead are a superposition of the three mass states, given by:

$$|\nu_\alpha\rangle = \sum_{i=1}^{3} U_{\alpha i} |\nu_i\rangle$$

where $U_{\alpha i}$ is given by the Pontecorvo-Maki-Nakagawa-Sakata matrix:

$$U_{\alpha i} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

where $c_{ij} = \cos \Theta_{ij}$

Neutrino Oscillations - 2

Oscillation and survival probabilities for specific flavour states can be calculated:

Survival

$$P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \cos^4\theta_{13}\sin^2 2\theta_{23}\sin^2\left[\frac{1.27\Delta m_{23}^2 L}{E_\nu}\right]$$

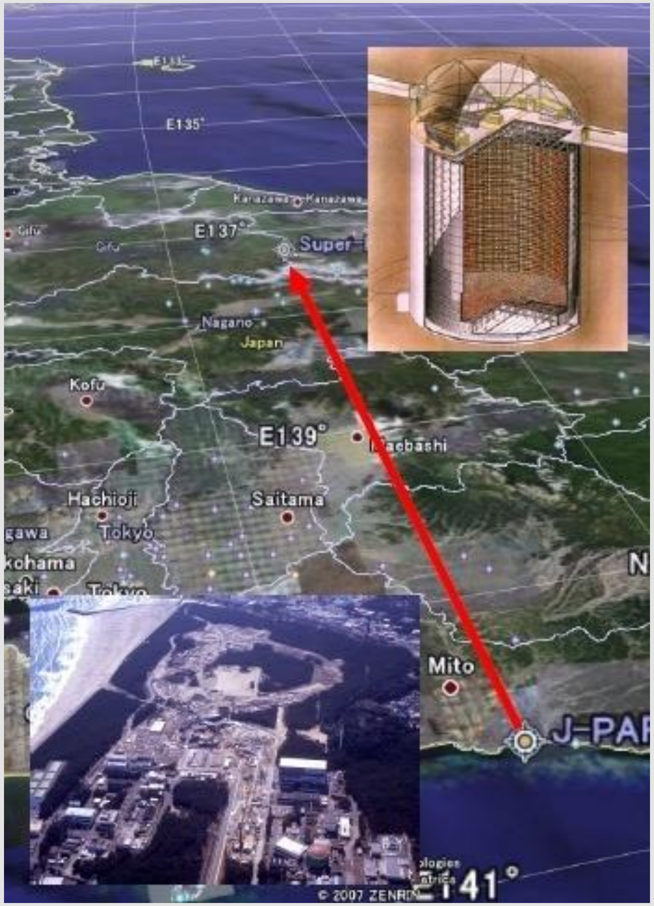
ν_e appearance

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13}\sin^2\theta_{23}\sin^2\left[\frac{1.27\Delta m_{13}^2 L}{E_\nu}\right]$$

where L is the distance the neutrino has travelled in km, E_ν is the neutrino energy in GeV, and $\Delta m^2_{ij} = m^2_i - m^2_j$.

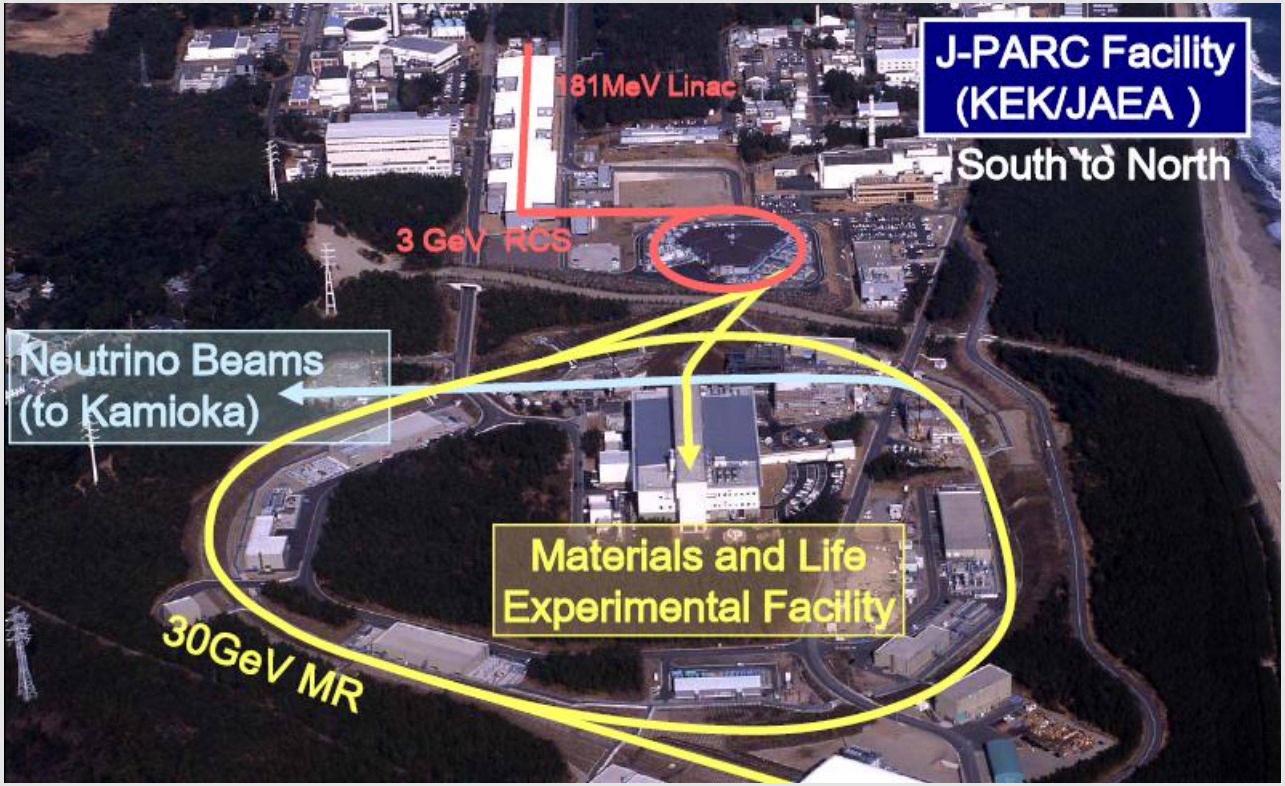
Experiment outline and physics goals

- 295km baseline neutrino beam experiment
- A suite of near detectors and a 50kton water Cherenkov detector.
- Physics goals:
  - Discovery of $\nu_\mu \rightarrow \nu_e$ oscillation
  - Precision measurements of oscillation parameters in ν_μ disappearance
  - Search for a sterile component of ν_μ

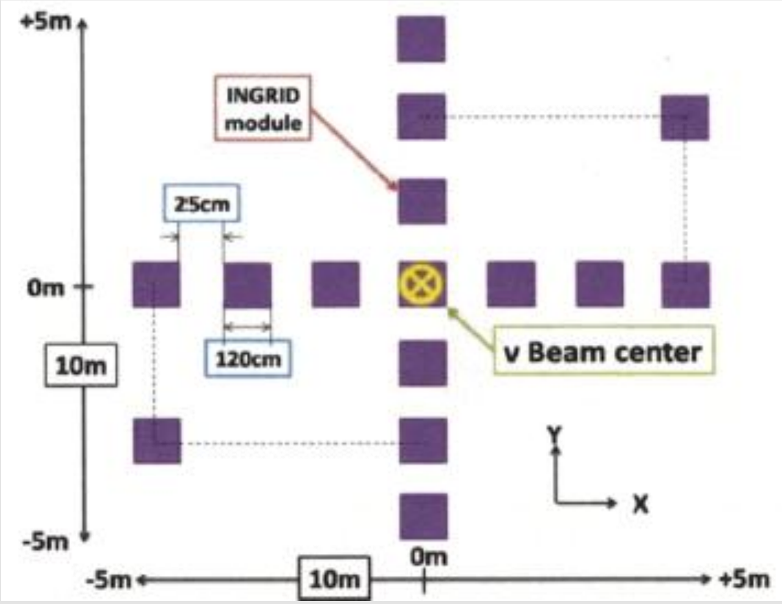


The T2K experiment – The neutrino beam

- 30GeV protons collide with a graphite target
- Magnetic horns focus mesons
- Mesons undergo 2-body decay, producing neutrinos
- Has an overall power of 0.75MW



The Interactive Neutrino GRID

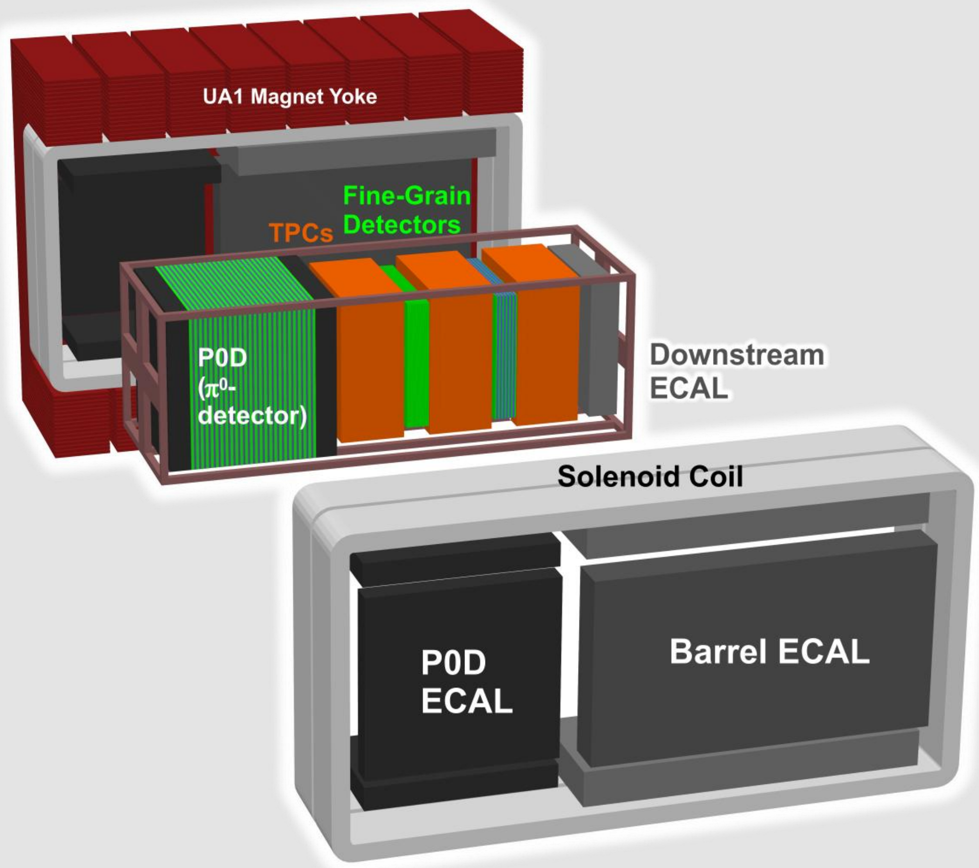


M. Otani *et al*. Nuclear Science Symposium Conference Record, 2008. Pages 2930 - 2933, Oct. 2008.

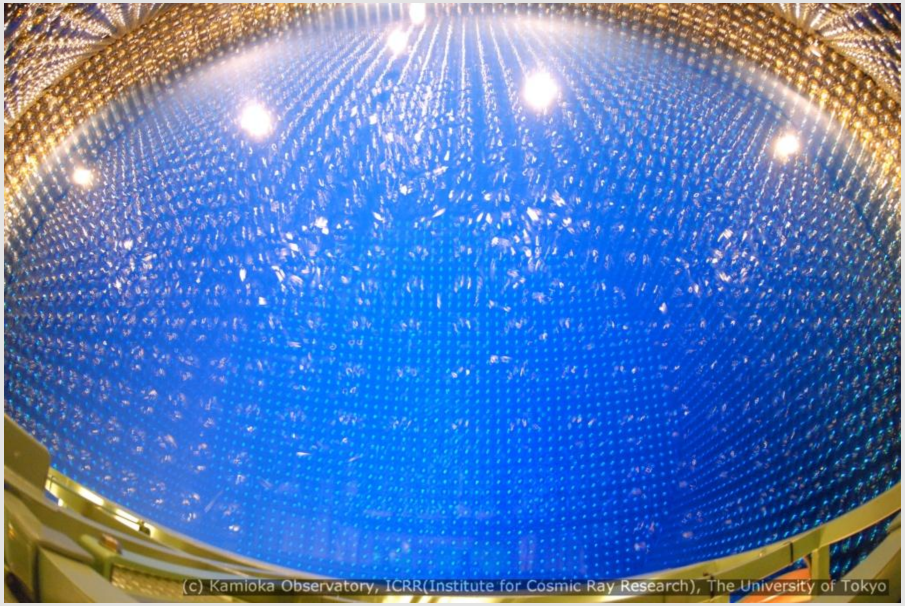
- Designed to measure the beam direction to 1mrad
- 16 identical modules
- 10 x 10m^2 cross
- 11 scintillator layers interspersed with 9 iron plates.

The ND280 detector

- Necessary to characterise the neutrino beam
- Three regions:
  - The π^0 detector (P0D)
  - The tracking detectors
  - The electromagnetic calorimeter (ECAL)
- Scintillator bars used throughout read by multi-pixel photon counters (MPPCs).



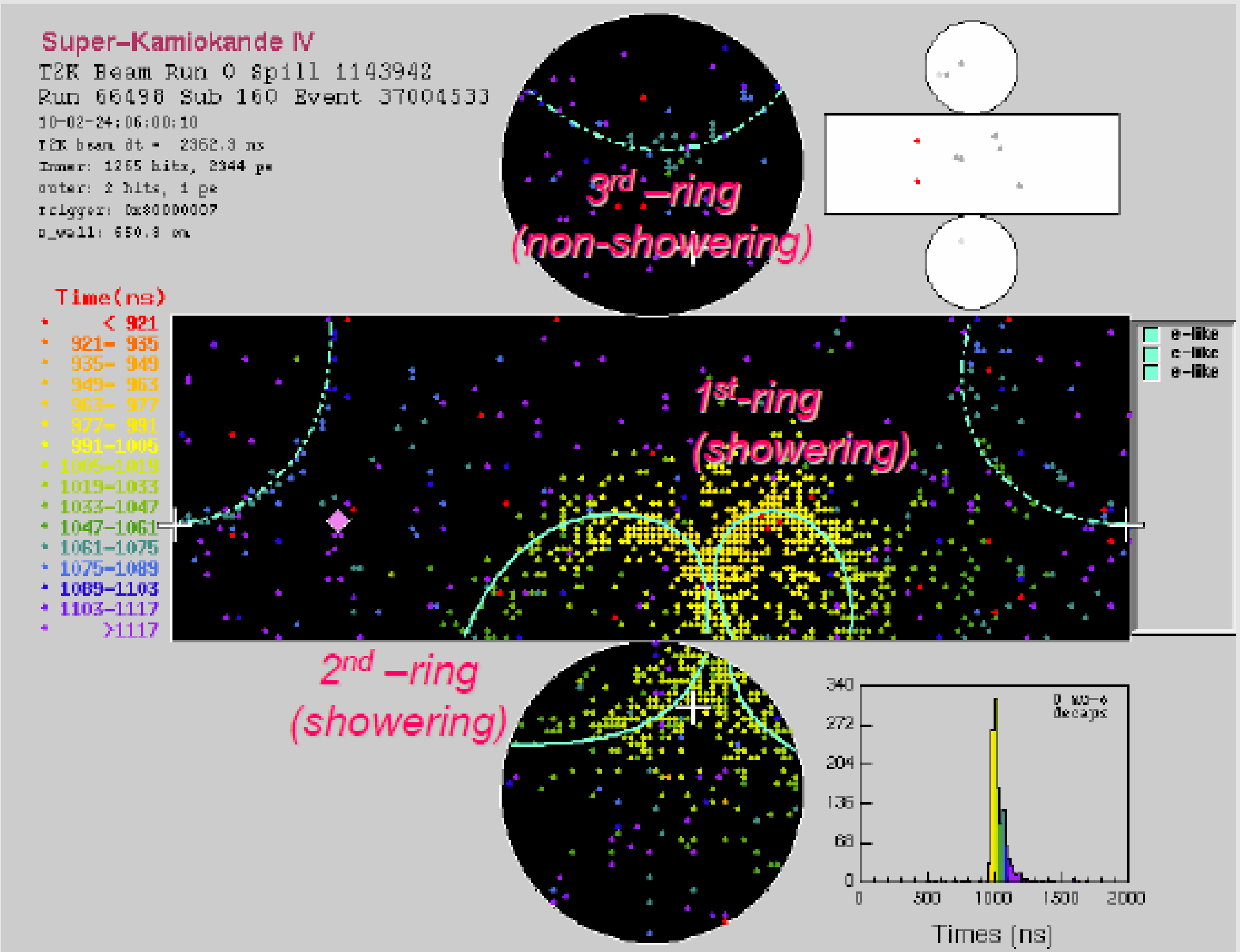
Super-Kamiokande



- 50kton water Cherenkov detector
- 1km underground, equivalent to 2.7km of water.
- Can separate muons from electrons with a rejection factor of about 100

- Reconstructs particle ID, energy and direction along with the interaction vertex
- Accepts events whose vertices > 2m from the sides of the tank giving a fiducial volume of 22.5ktons

First T2K neutrino event at SK!



1st + 2nd ring

Invariant mass: 133.8 MeV/c^2

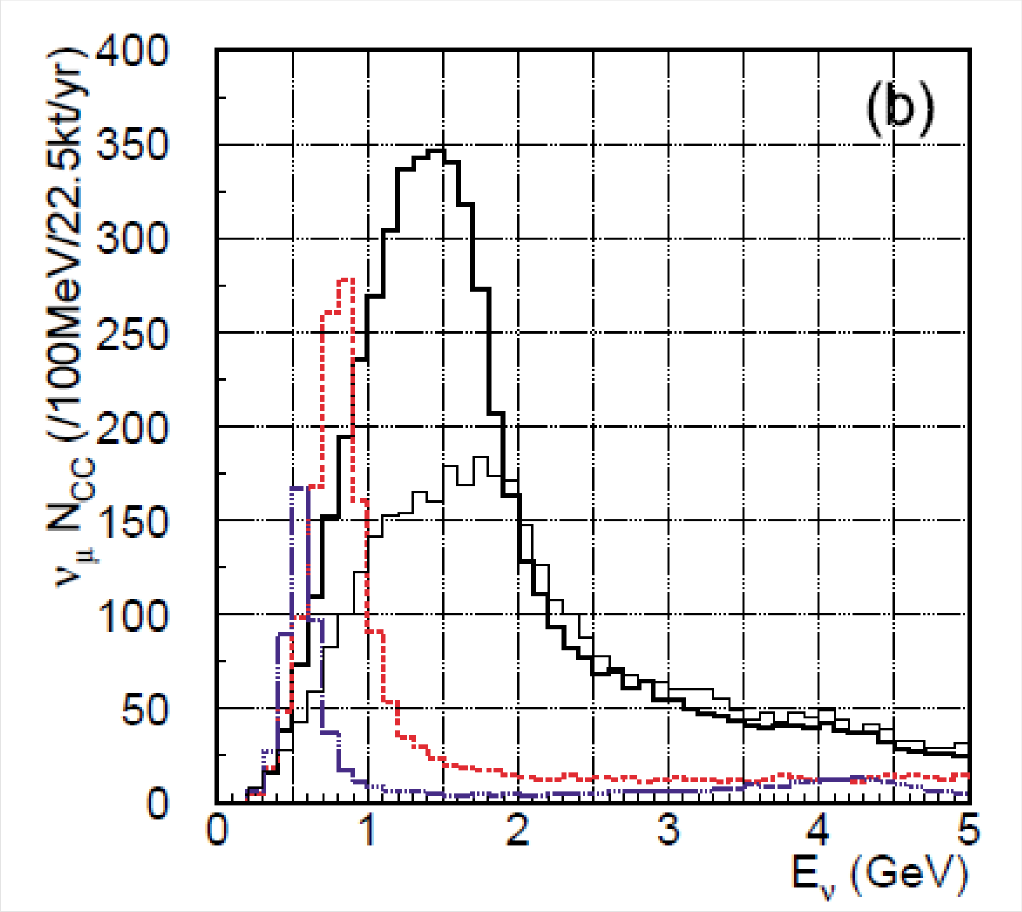
Momentum: 148.3 MeV/c

Test beam data analysis

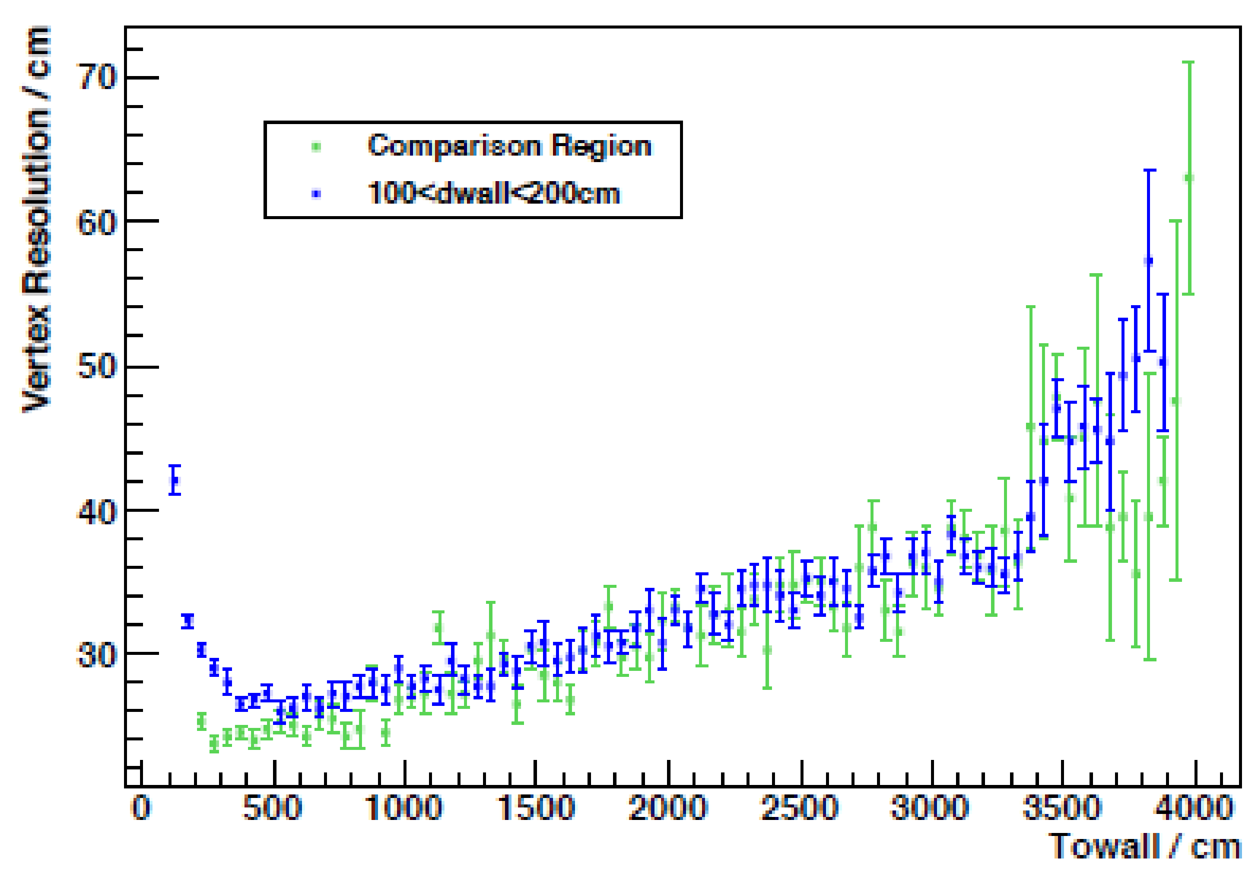
- T2K construction is nearing completion and the first beam event has been seen in SK.
- The Downstream ECAL was used to collect data from a test beam at CERN last year
- A number of calibration constants are being calculated with the aim of starting a data production run in about 1 month.

Backup slides

Neutrino energy spectrum for 1, 2 and 3 degrees off axis

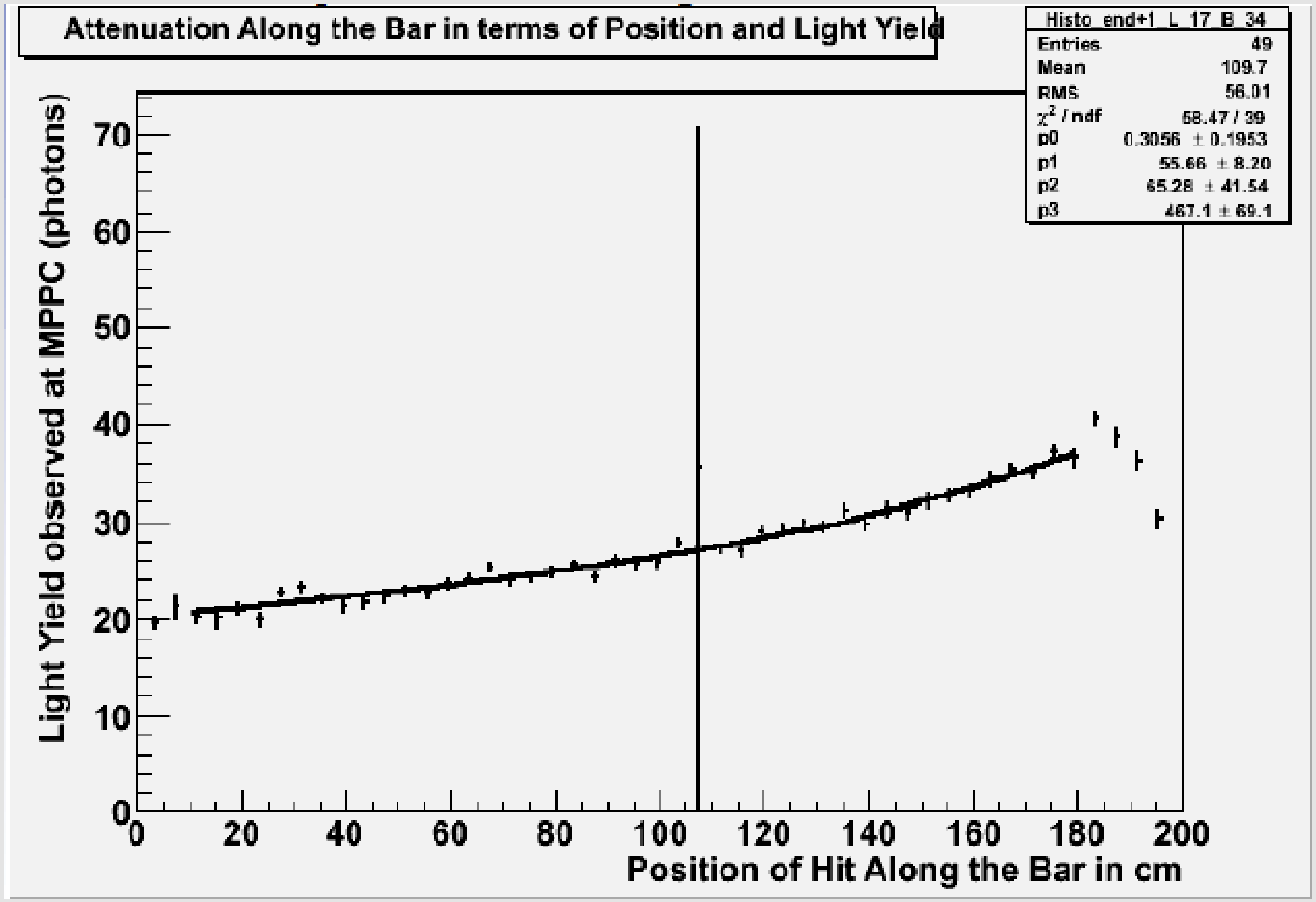


EFV at SK



- Work by G. Kogan, S. Dipper

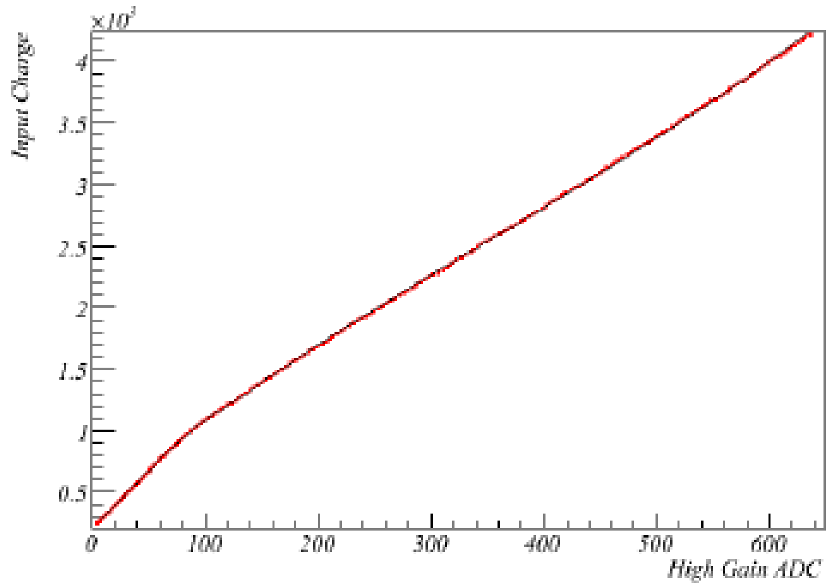
Light attenuation along scintillator bars

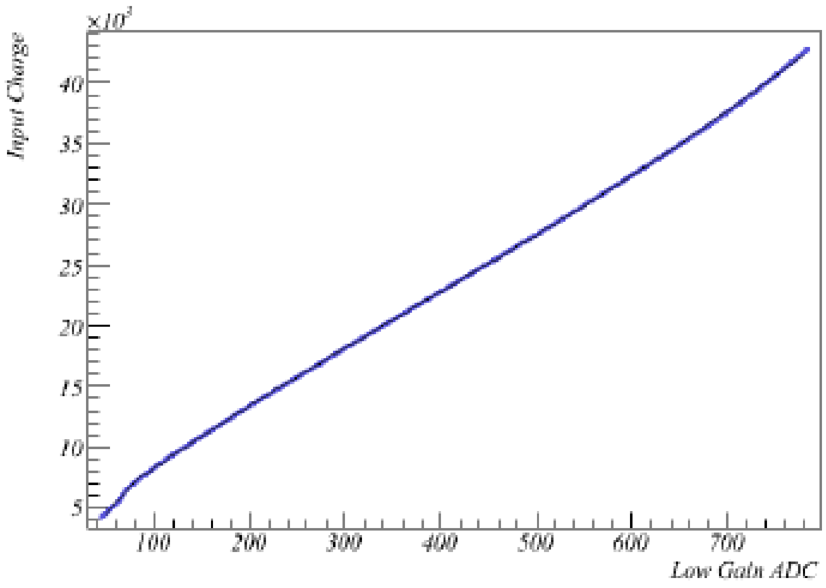


- Particles deposit energy in the bar
- Scintillation is collected by wavelength shifting fibres
- Carried to MPPCs to be collected and readout

Work done by M. George (QMUL) and G. Davies (Lancs.)

Charge injection calibration





- Measuring the ratio of the charge output from the MPPC readout electronics to that input from the MPPCs.
- This is fitted with a cubic polynomial, allowing the input charge to be calculated from the measured output

Work done by A. Waldron (Oxford)