The Status of the T2K Near Detectors

Neil McCauley

for the T2K Collaboration

The T2K Collaboration

59 Institutes, 12 countries

Canada

TRIUMF
U. Alberta
U. B. Columbia
U. Regina
U. Toronto
U. Victoria
York U.

France

CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germany

U. Aachen

Japan

ICRR Kamioka
ICRR RCCN
KEK
Kyoto U.
U. Kobe
U. Miyagi
U. Osaka City
U. Tokyo

Switzerland

U. Bern
U. Geneva
ETH Zurich

Poland

IPJ Warsaw
IFJ PAN, Cracow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroclaw

S. Korea

N. U. Chonnam
U. Dongshin
N. U. Seoul

Russia

INR

Spain

IFIC, Valencia
U. A. Barcelona

USA

Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

Italy

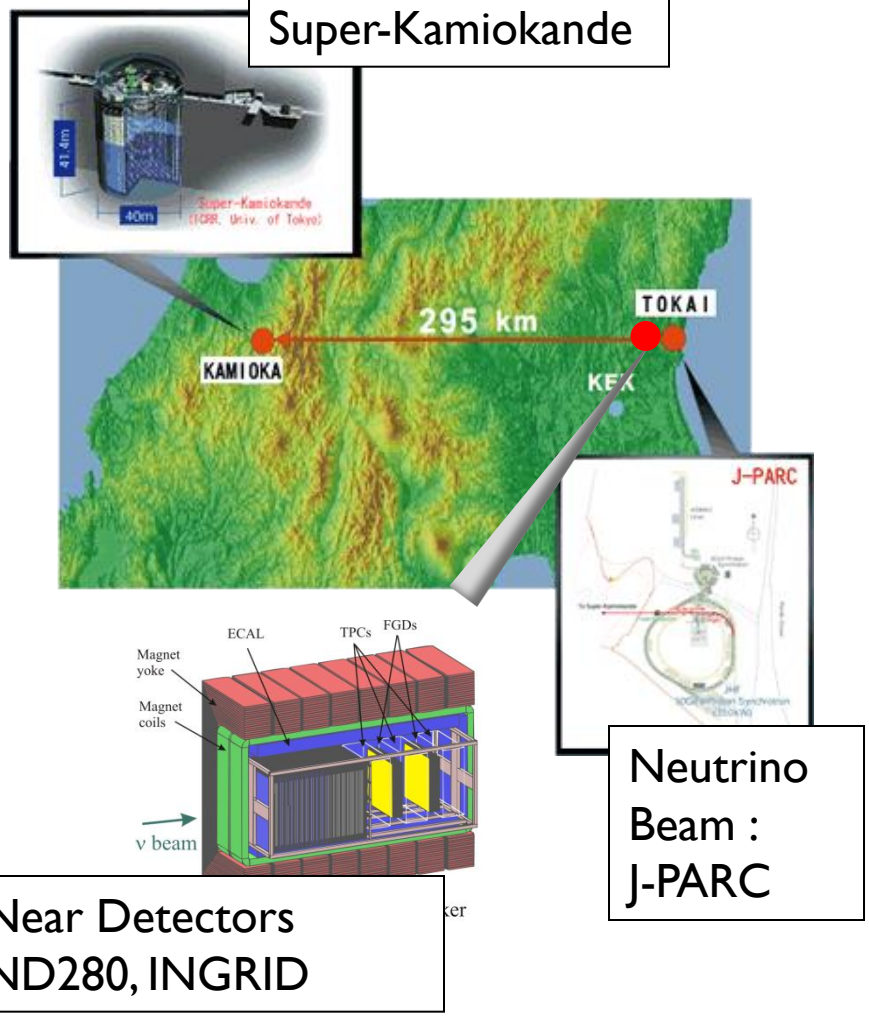
INFN, U. Bari
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova

United Kingdom

Imperial C. London
Queen Mary U. L.
Lancaster U.
Liverpool U.
Oxford U.
Sheffield U.
Warwick U.
STFC, RAL
STFC, Daresbury

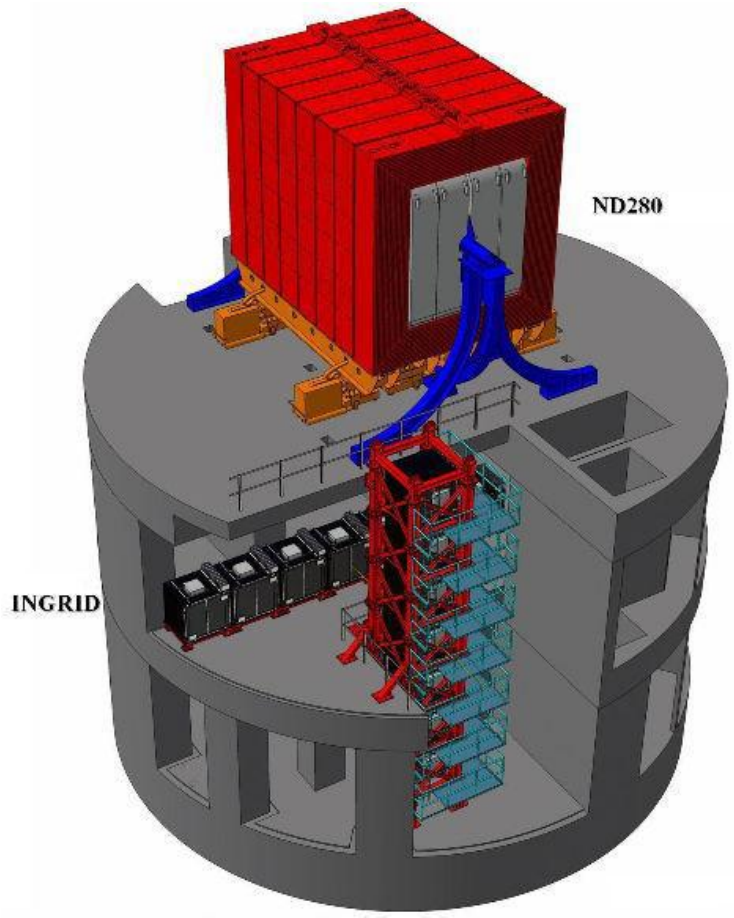
The T2K Experiment

- Long baseline neutrino experiment
  - Baseline 295km
  - First off axis neutrino experiment
- Search for/measure neutrino oscillations:
  - $\nu_\mu \rightarrow \nu_e$
  - $\nu_\mu \rightarrow \nu_\tau$
- Improve measurement of θ_{23}, Δm^2_{23}
  - Is θ_{23} maximal?
- First measurement of θ_{13}
  - How small is θ_{13}?



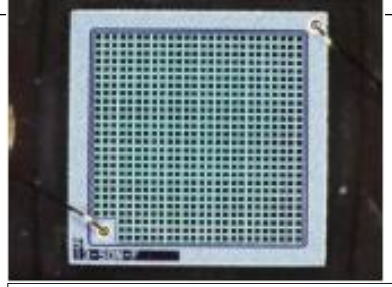
The Near Detector Complex

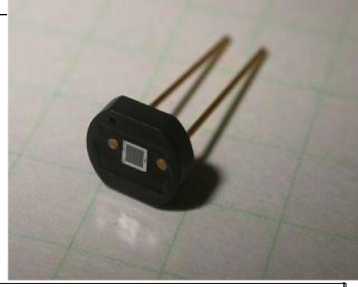
- INGRID
  - On Axis Detector
  - Beam Monitoring
    - Rate
    - Direction
    - Stability
- ND280
  - Off Axis Detector
  - Neutrino Flux and Spectra
  - Inputs into oscillation analyses
  - Neutrino Cross Section

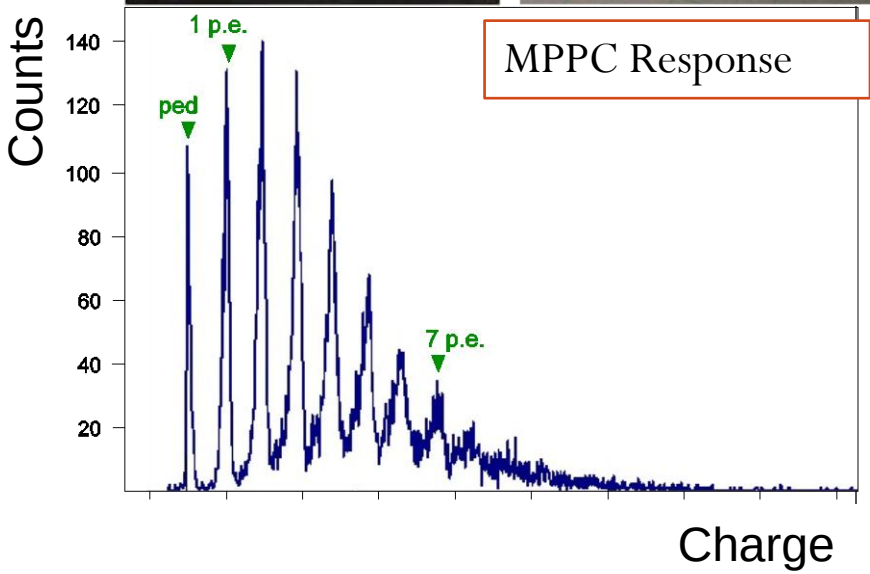


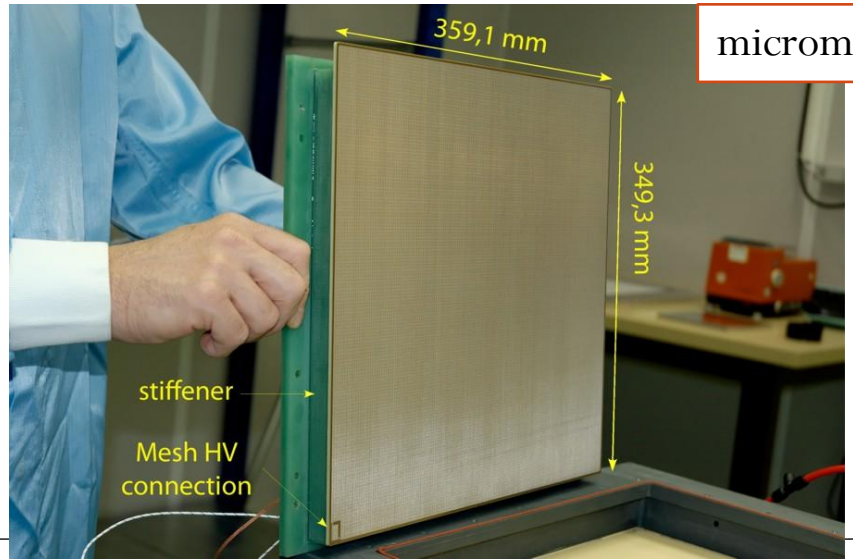
Technologies in ND280

- Scintillator Detectors
  - Plastic scintillator bars
  - Wavelength shifting fibres
    - Kuraray Y11, 1 mm diameter
  - MPPCs
    - Multi-Pixel Photon Counters.
    - 1.3x1.3mm
    - 667 pixels
    - First large scale deployment of MPPCs.
    - Readout via 2 electronics types
      - TRIPT (Ingrid, P0D, ECAL, SMRD)
      - AFTER (FGD)
- TPC
  - Readout via micromegas
    - 72 modules 34.2x35.9 cm^2
    - Pads : 7x9.8mm^2



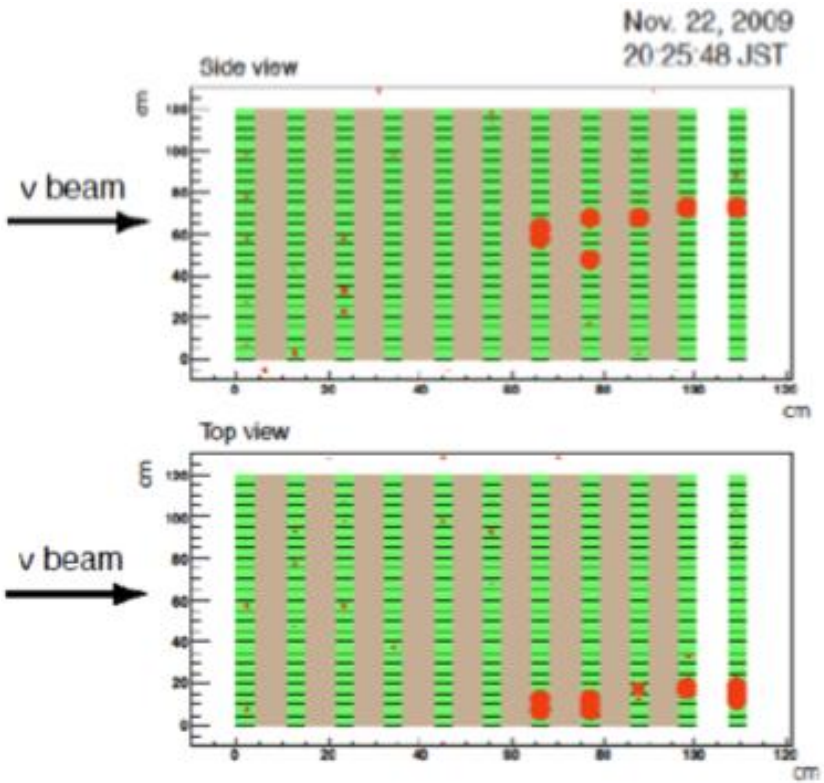


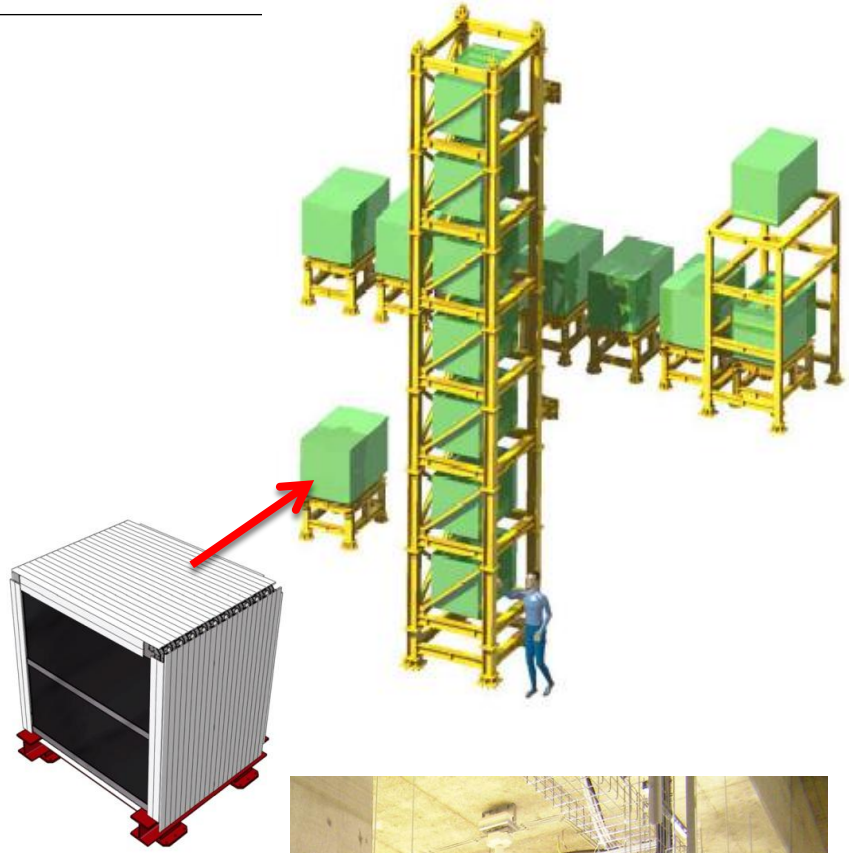


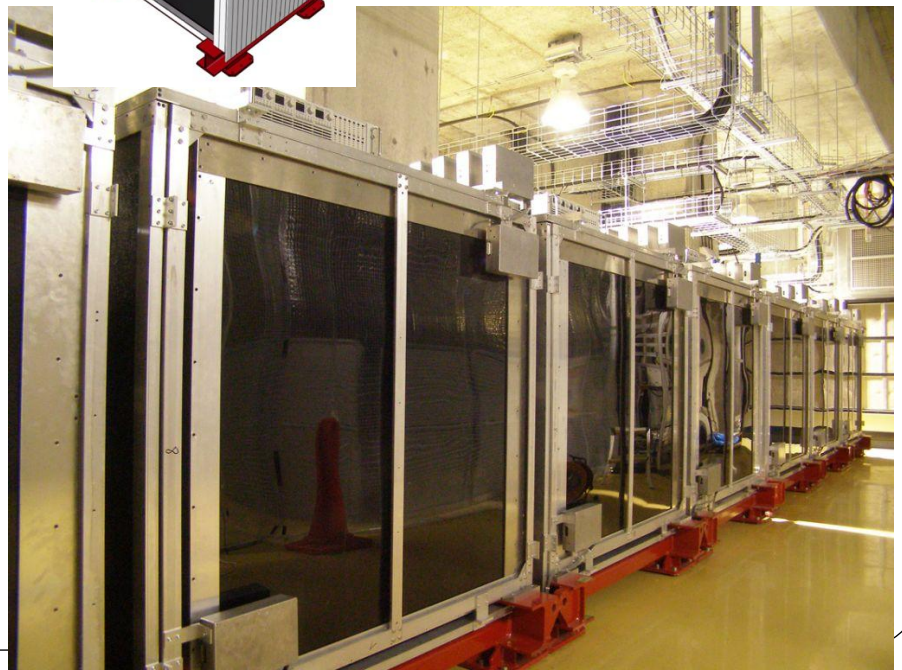


On Axis : INGRID

- Iron - Scintillator Detector
  - 16 Modules across the beam profile
- Monitor the beam intensity and direction
  - Use the interaction of the forward muon neutrinos.



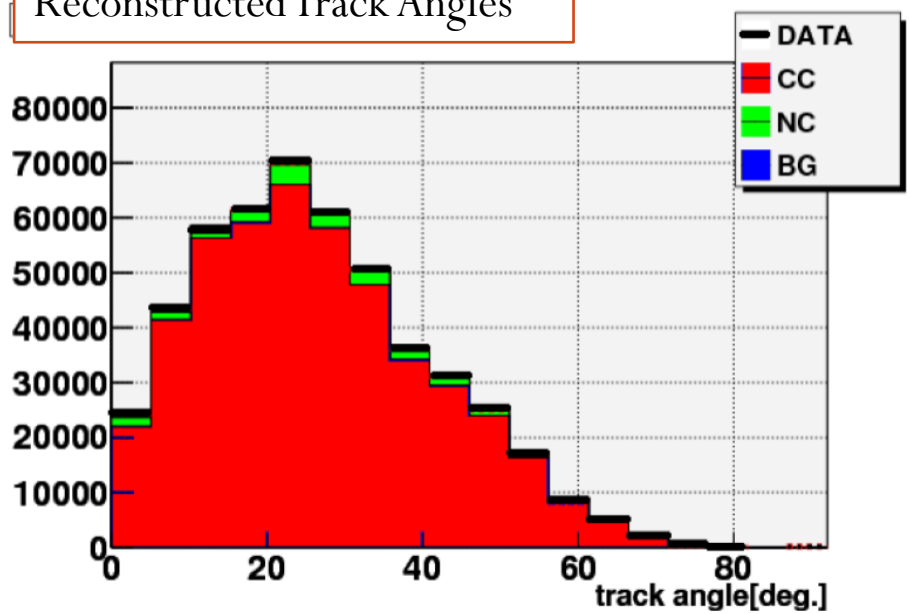




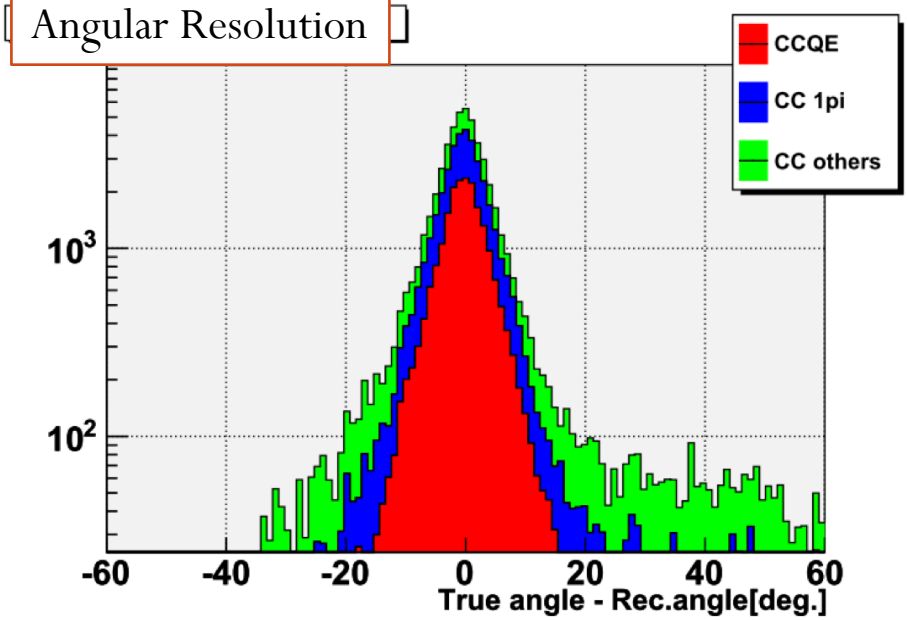
Analysis at Ingrid

- Select Events via:
  - Reconstructed Tracks.
  - Beam Timing
  - Fiducial Volume
    - Avoid entering events (sand muons)

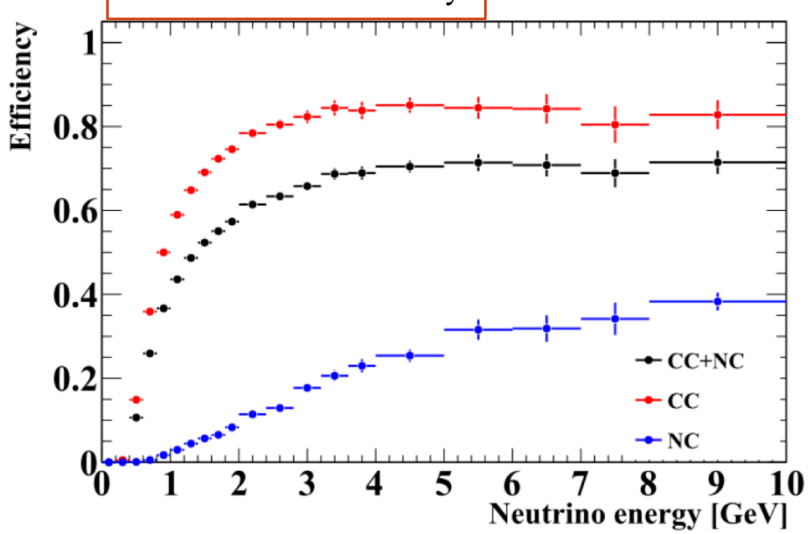
Reconstructed Track Angles



Angular Resolution

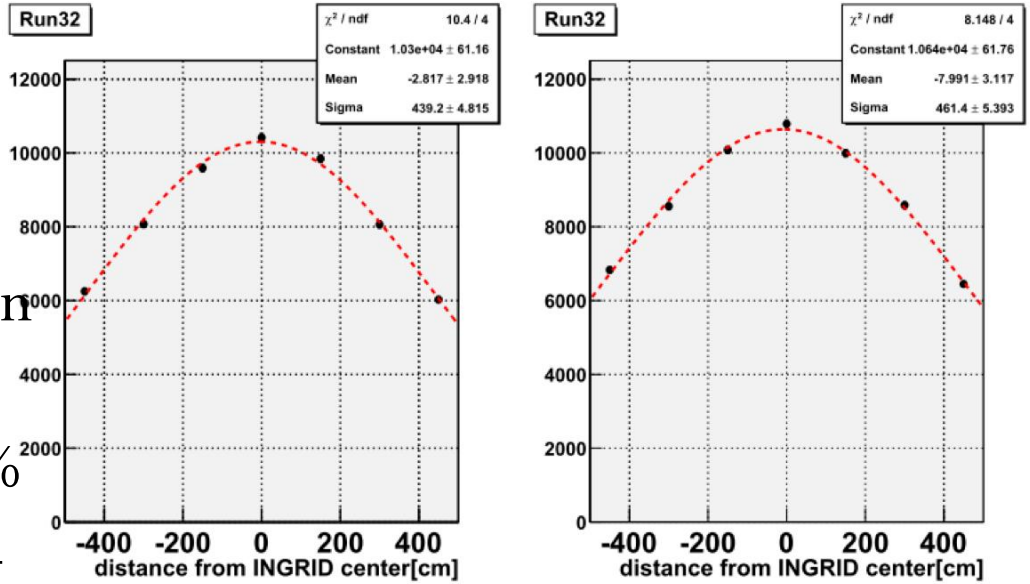


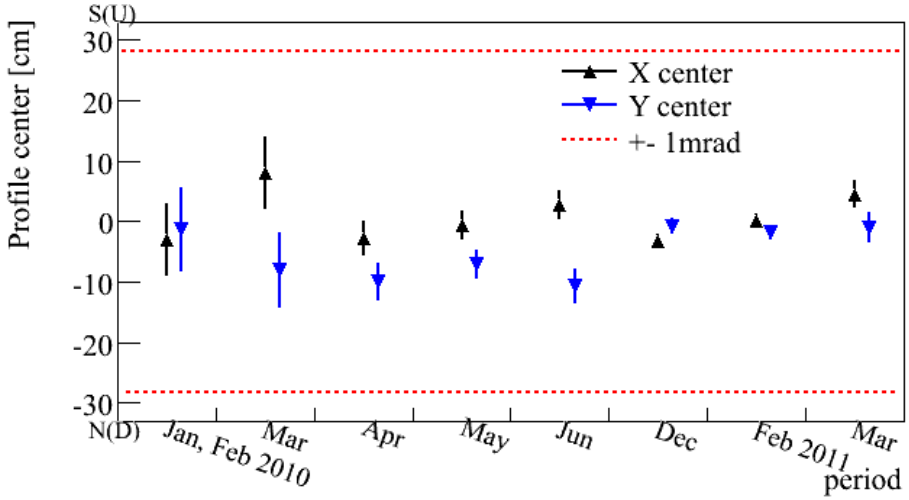
Selection Efficiency



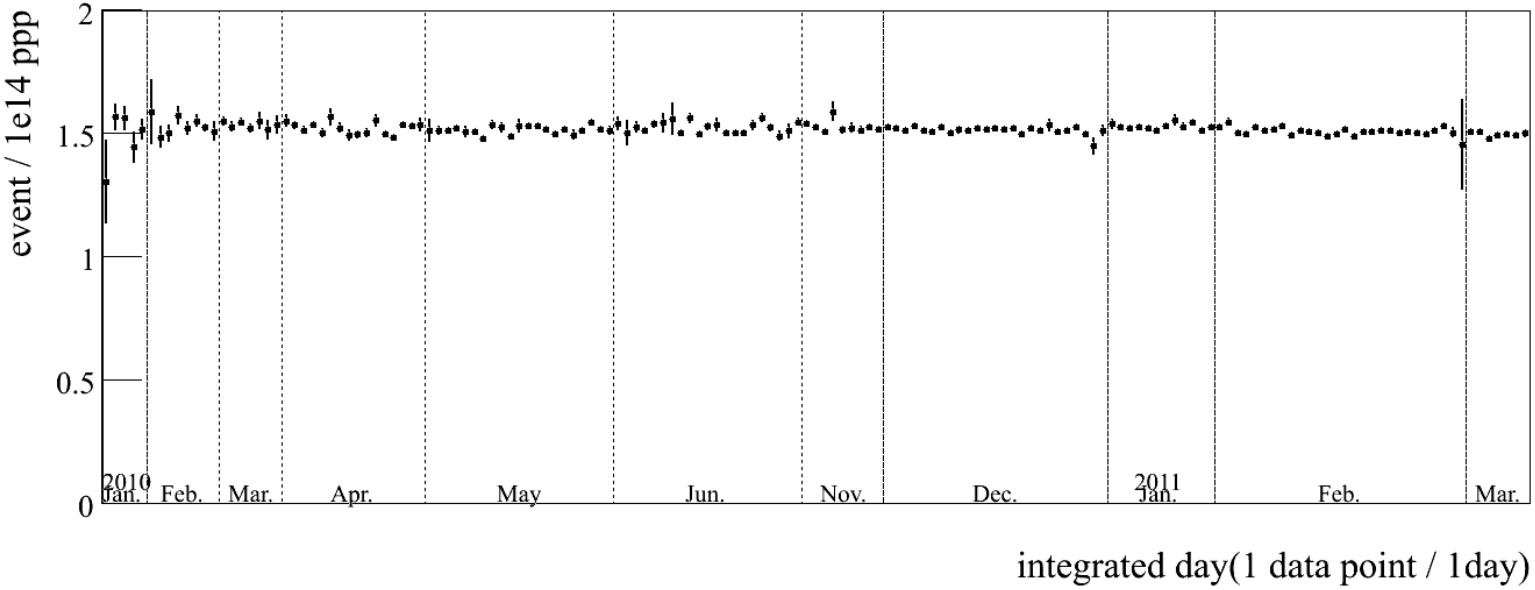
Beam Direction

- A change in the beam direction of 1 mrad corresponds to a variation of E_{peak} at SK of $\pm 2\%$
- The beam profile and steering are measured across INGRID.
- Horizontal
  - $-0.014 \pm 0.025(\text{stat}) \pm 0.33(\text{sys})$ mrad
- Vertical
  - $-0.107 \pm 0.025(\text{stat}) \pm 0.37(\text{sys})$ mrad





Beam Stability



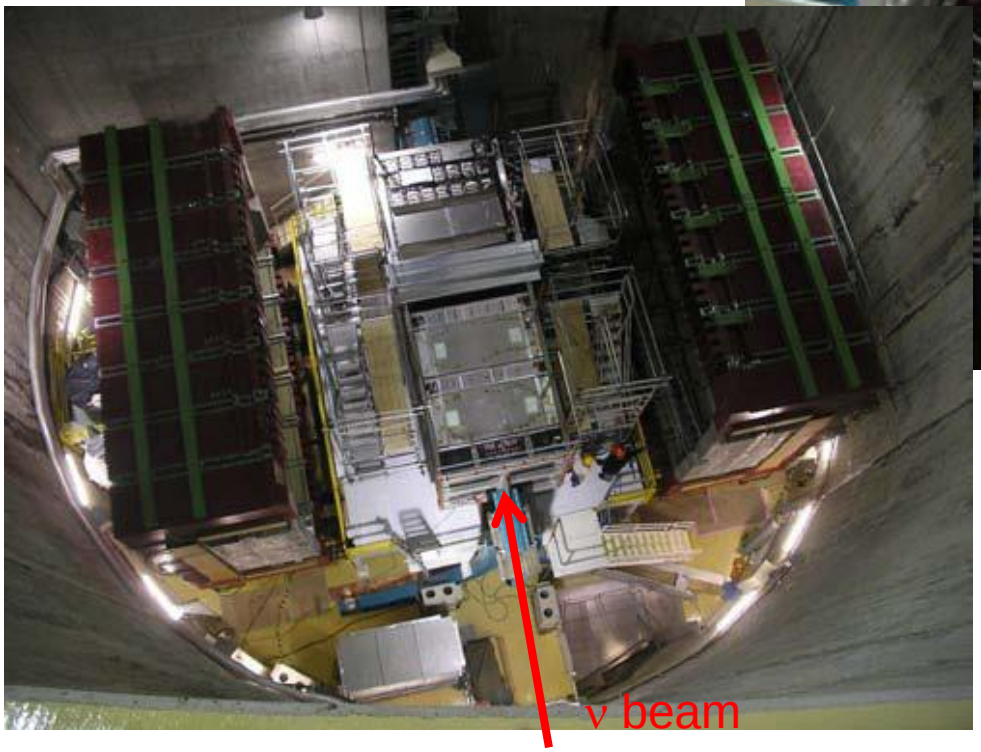
Beam Power Check:

$$\text{Rate: Data/MC} = 1.057 \pm 0.001(\text{stat}) \pm 0.040(\text{sys})$$

The ND280 Off-Axis Detector

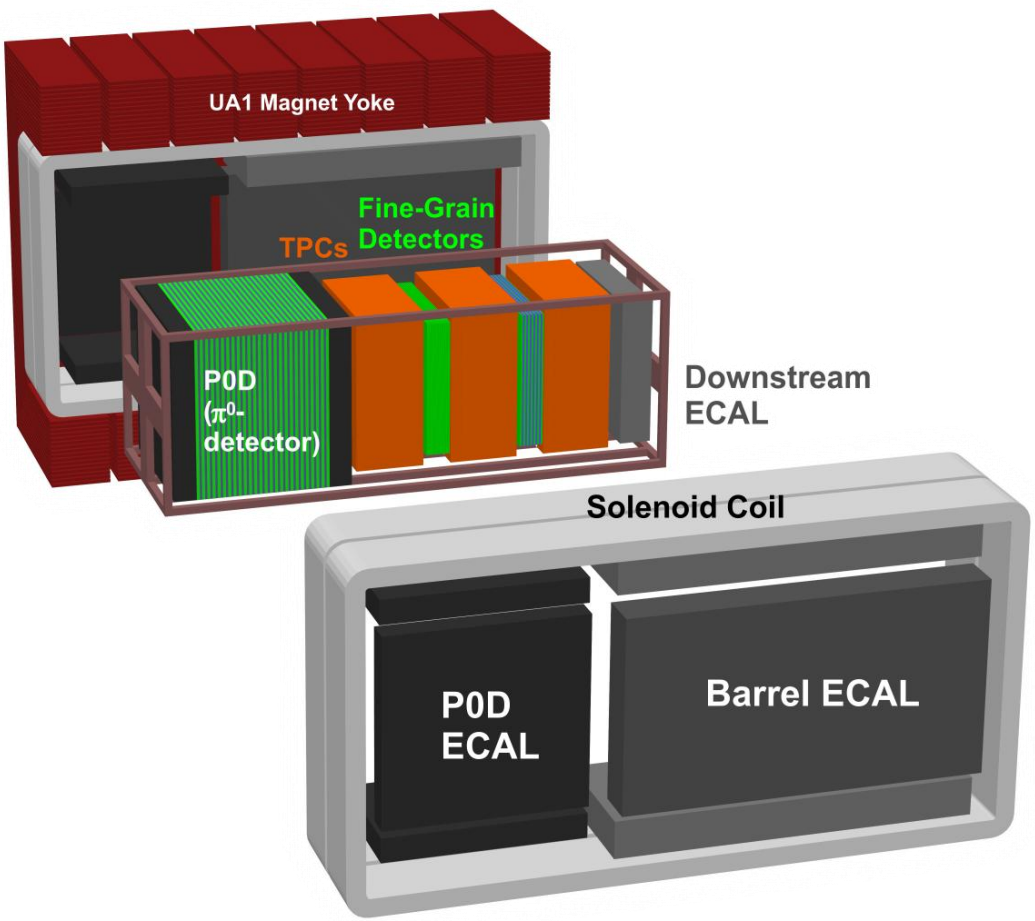
Understanding the beam

- ν_μ Flux and Spectrum
- ν_e Beam Contamination
- Neutrino Cross-Sections



Off-Axis Detector Design

- Refurbished UA1 Magnet 0.2T field
- Fine Grained Detectors (FGDs)
  - Neutrino target region for the tracker.
- TPCs
  - Particle Tracking
    - ν_μ, ν_e measurements
- P0D
  - Measure NC π^0 rate
- ECAL
  - Surrounds tracker and P0D.
  - Capture and measure EM energy
  - Only the DS ECAL in Run 1
- SMRD
  - Muon ranging instrumentation in the magnet yoke



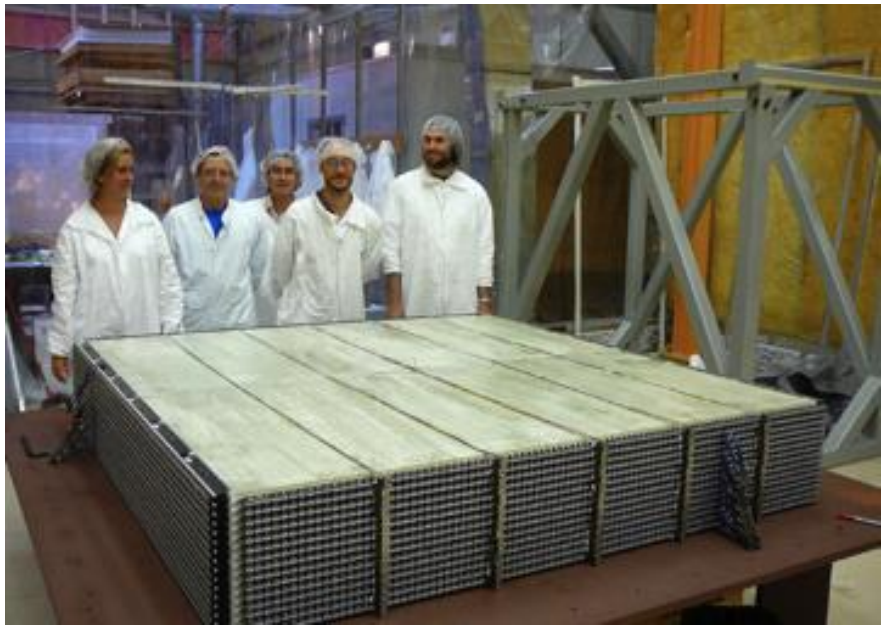
Key Features of the Off-Axis detector

- Tracker Region
  - High precision tracking with a magnetic field.
    - Provides excellent momentum resolution for charged particles.
  - Excellent particle identification
    - dE/dx in the TPC
    - Further particle ID in the ECAL and FGD
  - ECAL surrounding the tracker
    - Capture all the energy leaving the vertex.
- P0D
  - Specialised for the measurement of NC π^0s, a key T2K background.
- Water and Carbon targets for determination of cross sections on multiple materials.
  - Key point for T2K as SK target is water.

The FGDs

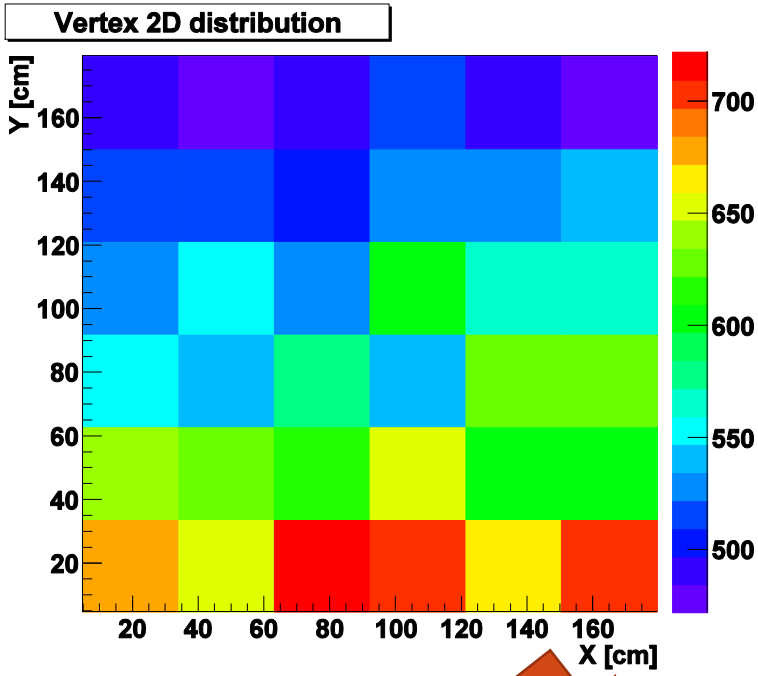
- Fine-Grained detectors
  - Alternating x-y planes of scintillator bars.
  - 9.6x9.6x1844 mm
  - 8448 channels
    - 0.24% bad channels
- Acts as the neutrino target for the tracker.
  - Good vertexing
  - Identification of short primary tracks.
- FGD1
  - Upstream
  - Scintillator Only
- FGD2
  - Downstream
  - Includes water target
- Extract rate on water by comparing both FGDs.

FGD water target

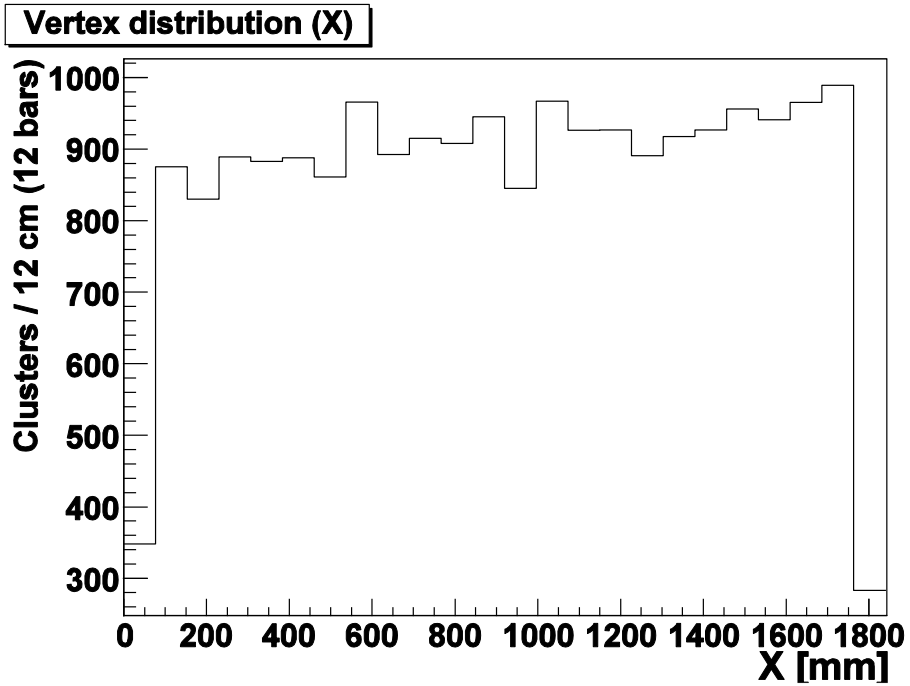


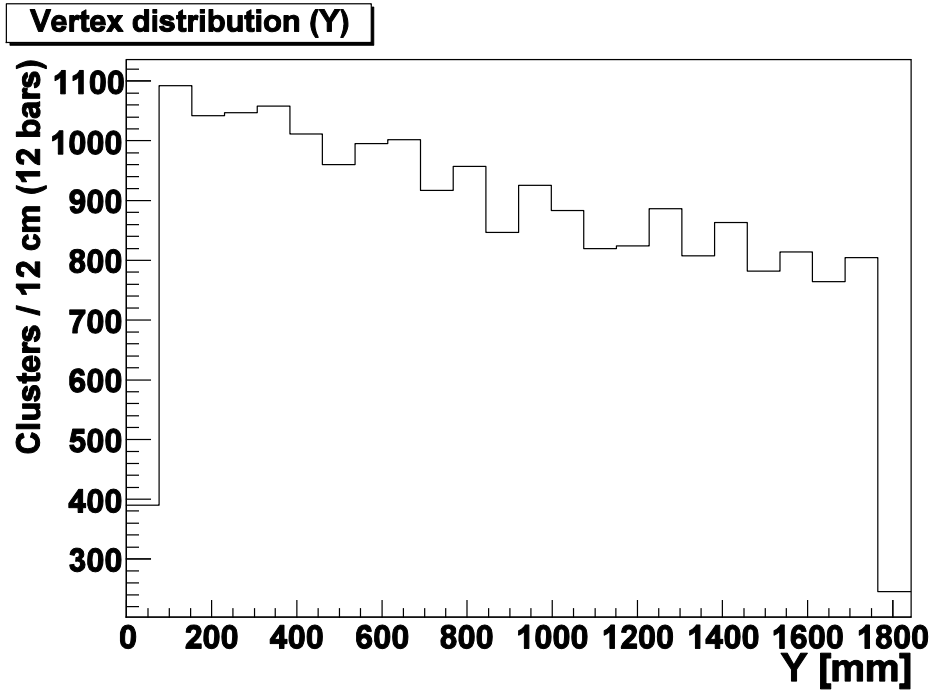
FGD Vertices

The FGD contains the primary vertex for tracker events.



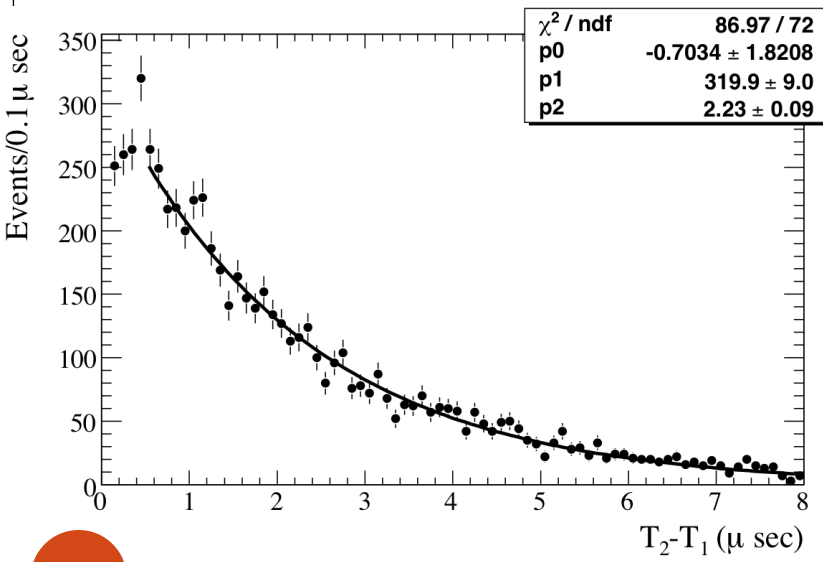
Beam Centre

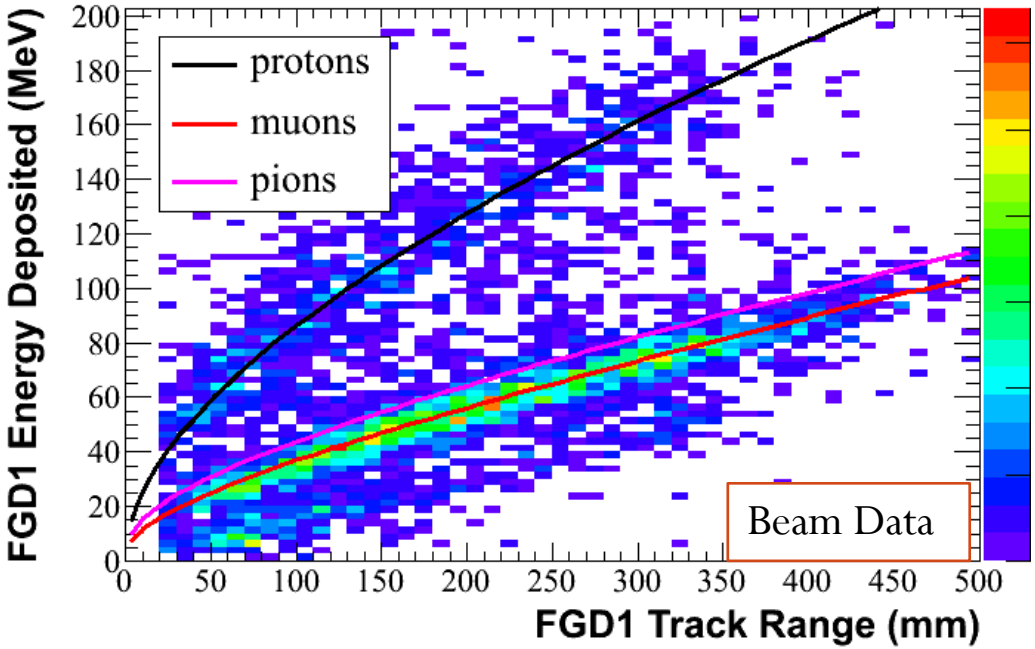


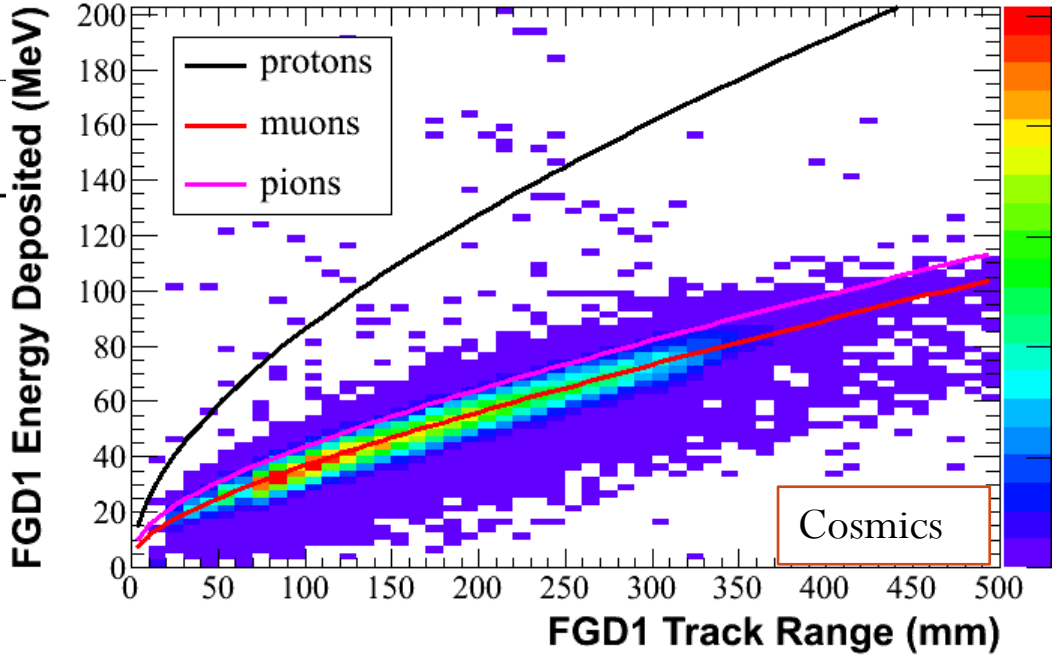


FGD Particle Identification

- PID in the FGD is crucial for identification of short tracks from the vertex.
- Use DE/DX information for PID.
  - Separate protons and muons.
  - Examine tracks that stop in the FGD
- Michel Electrons

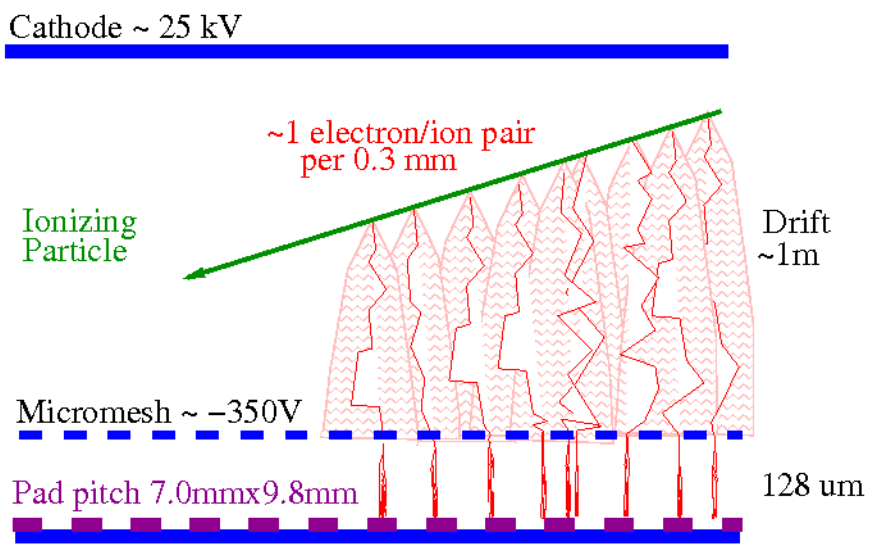


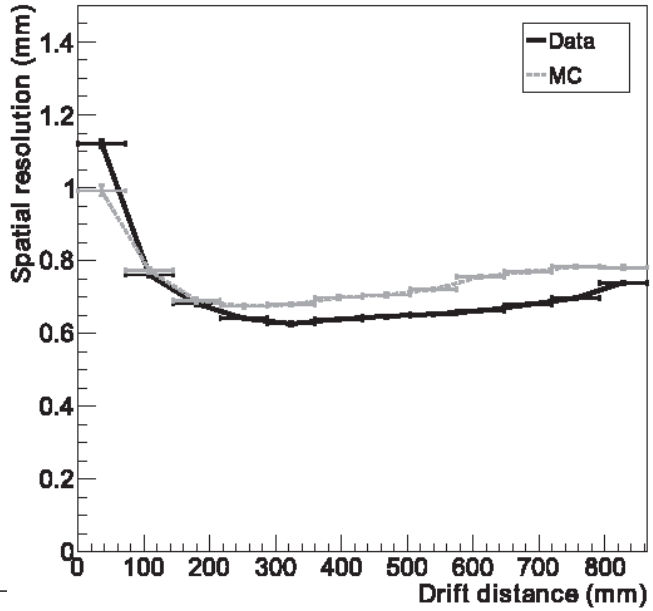




The TPC

- 3 TPCs interleaved with the 2 FGDs
- Readout via micromegas
  - 1726 pads per module
  - 124416 readout channels
  - 0.13% bad channels
- Provide detailed tracking information
  - 700 μm point resolution at full drift distance.
  - Momentum resolution 7% at 1GeV

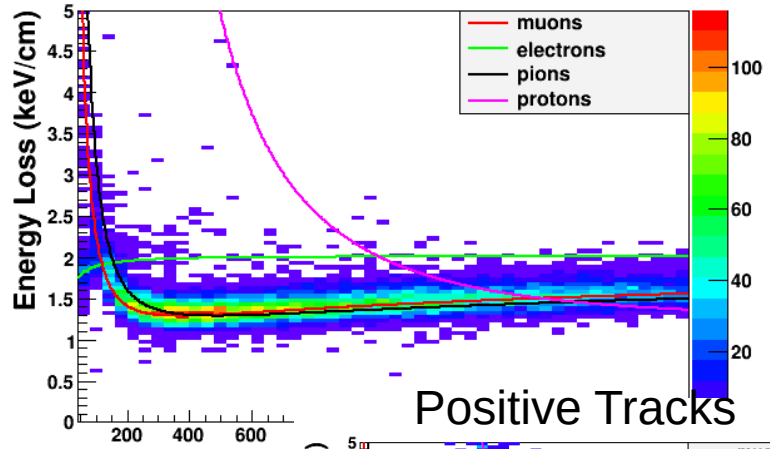




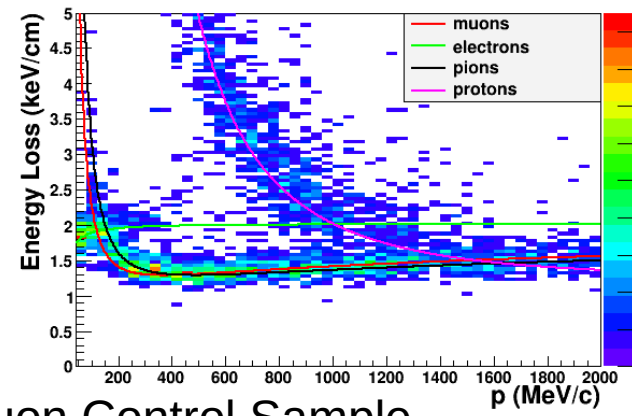
dE/dx in the TPC

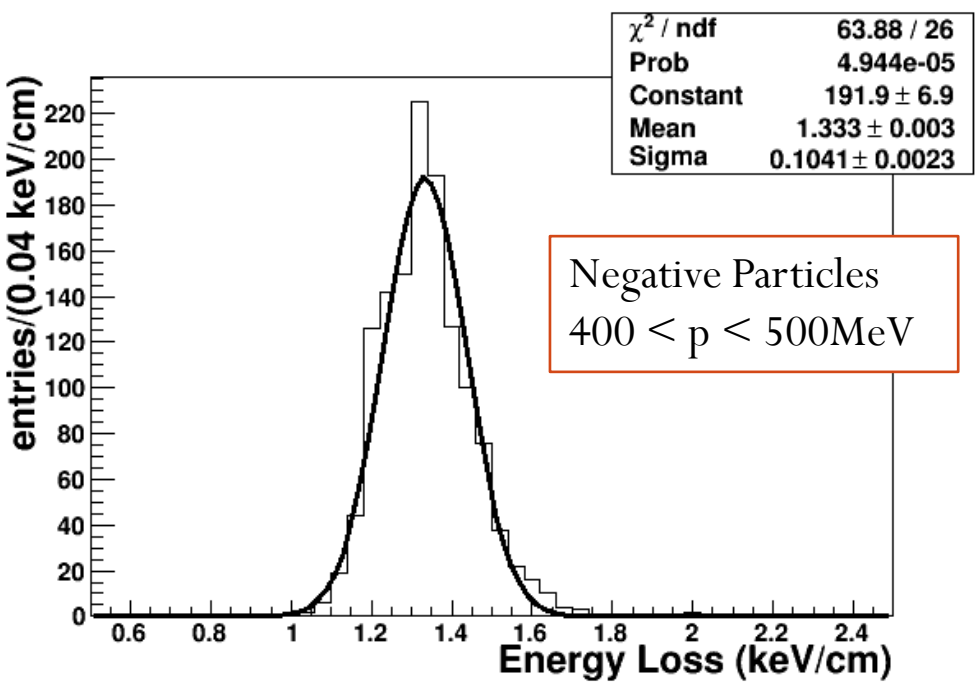
- dE/dx information in the TPC provides a very powerful PID tool.
- Can separate muons/pions from electrons and protons with high precision.
  - Crucial for ν_e analysis due to high muon rate from beam composition.

Negative Tracks

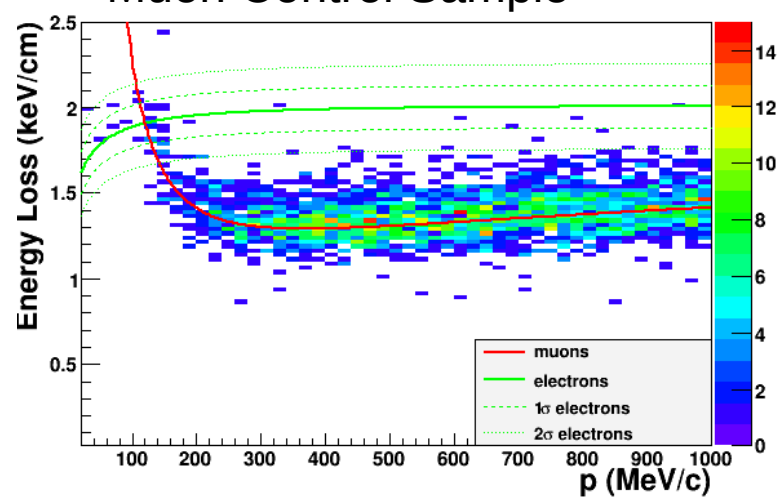


Positive Tracks



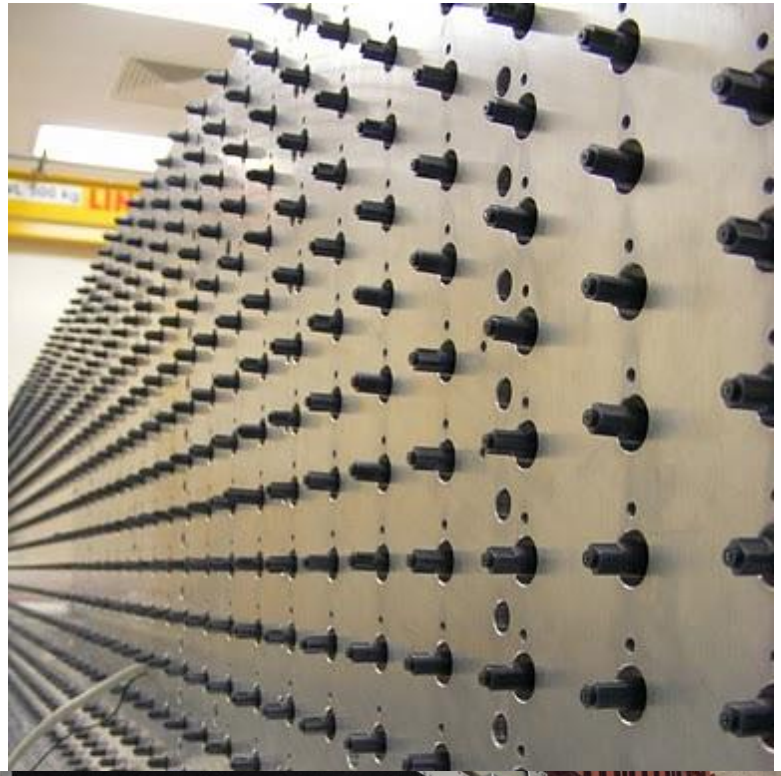


Muon Control Sample



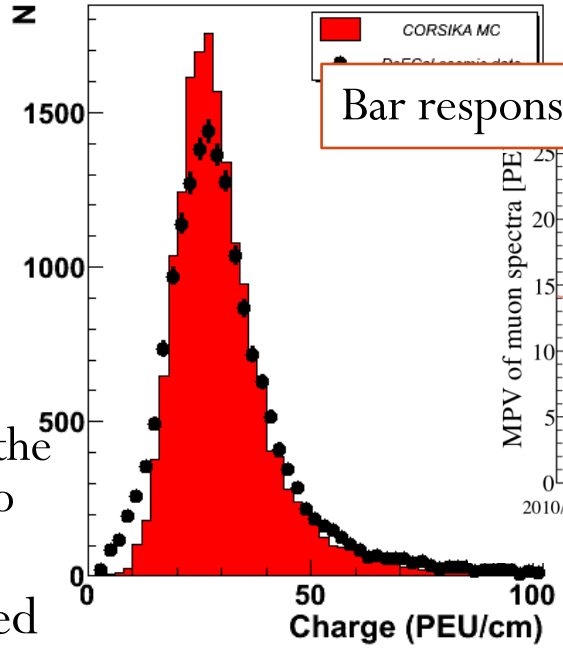
The ECAL

- Surrounds the tracker (FGD/TPC) and the P0D
  - Collects particles leaving those regions.
- Lead scintillator sandwich
  - 1x4 cm bar cross section
- Readout via wavelength shifting fibres and MPPCs.
- 22326 Channels on 336 TFBs in 13 modules
  - 35 (0.16%) bad channels.
- Downstream ECAL installed in 2009
  - Present in all data
  - Calibrated in testbeam at CERN
- Barrel ECAL and P0D ECAL installed in summer 2010.
  - Present only in run 2 data.

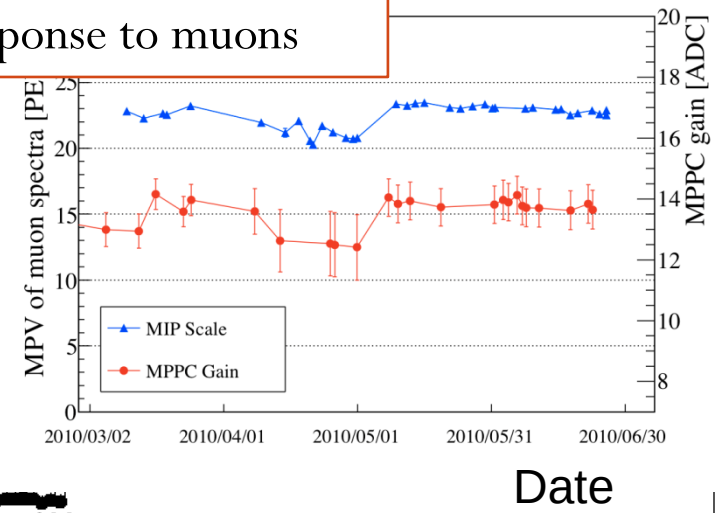


ECAL Energy

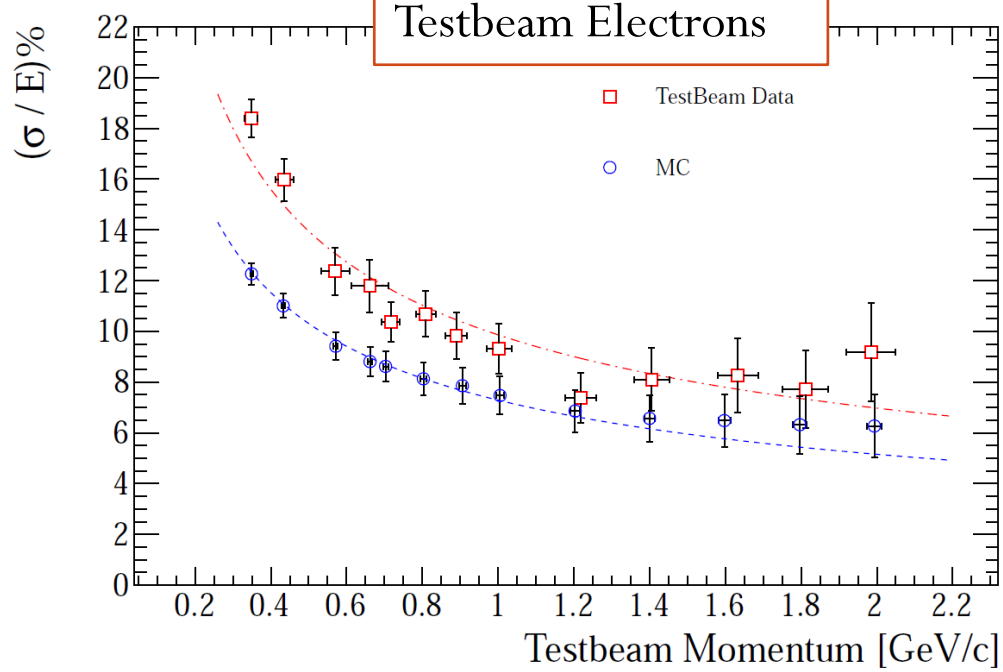
- Determine photon and electron energy.
  - Needed to reconstruct all the energy leaving the neutrino interaction.
- Detector response calibrated via muons.
  - Normalise to minimum ionising particle at normal incidence.
  - Correcting for attenuation in the fibre.
- EM Energy proportional to total charge collected.
  - $$\frac{\sigma_E}{E} = \frac{9.8\%}{\sqrt{E}(GeV)}$$



Bar response to muons

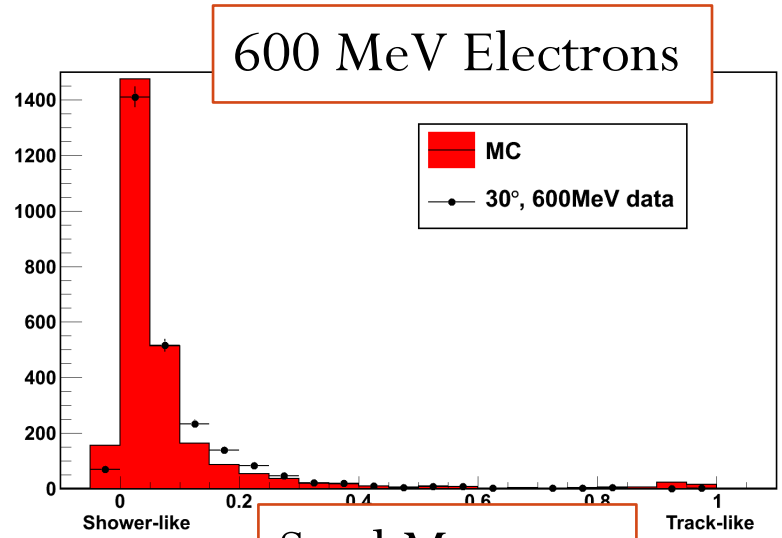


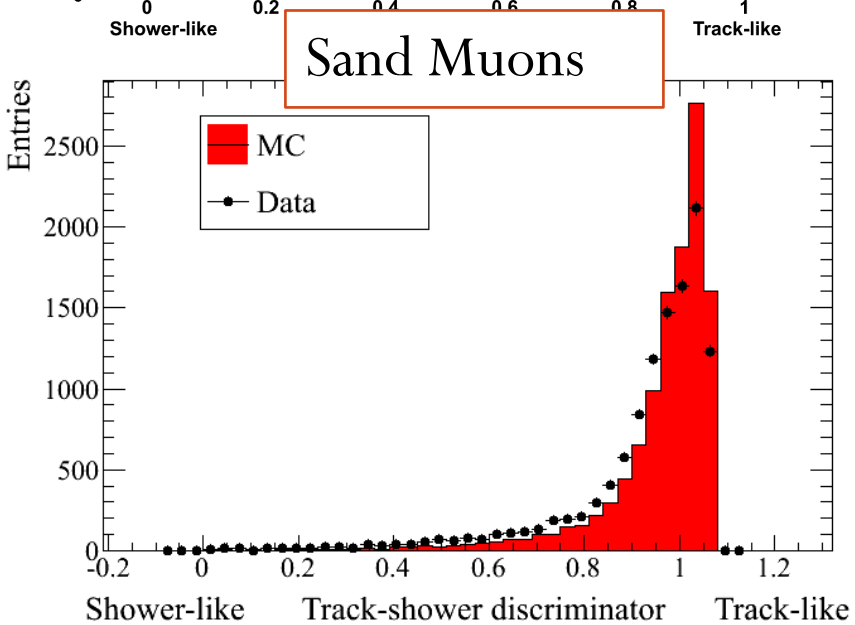
Testbeam Electrons



Particle Identification in the ECAL

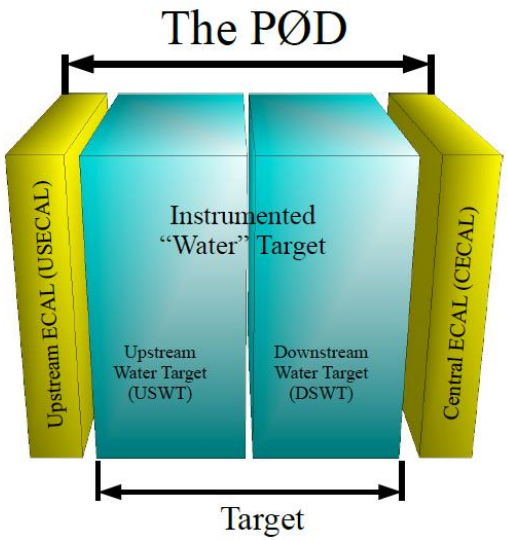
- Provides an independent PID to DE/DX in the TPC.
  - Improved purity
    - Further reduction to muon backgrounds.
  - Cross checks.
- Use a neural net based on the shape and charge distribution of a cluster.
- Verified with:
  - Testbeam data
  - Cosmic events
  - Beam induced muons



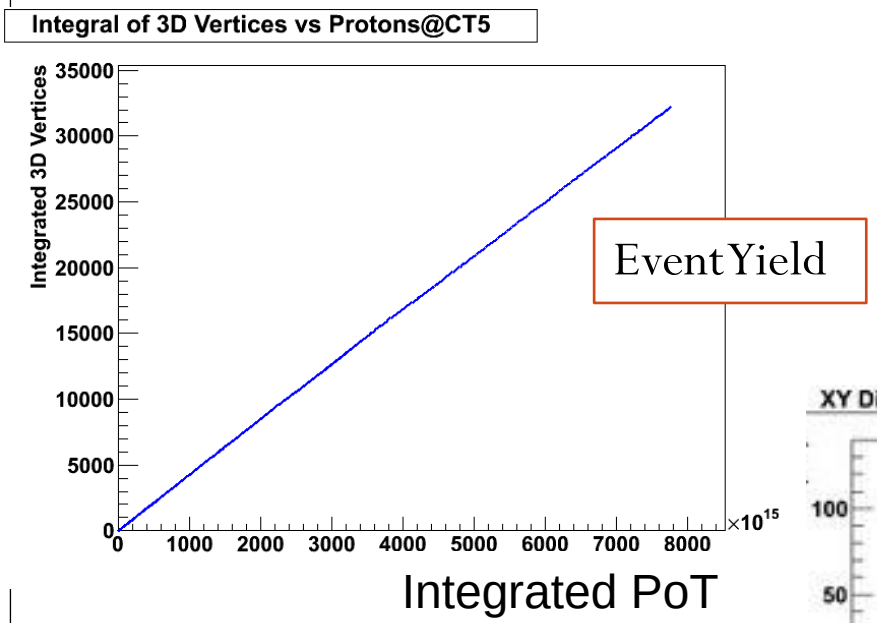


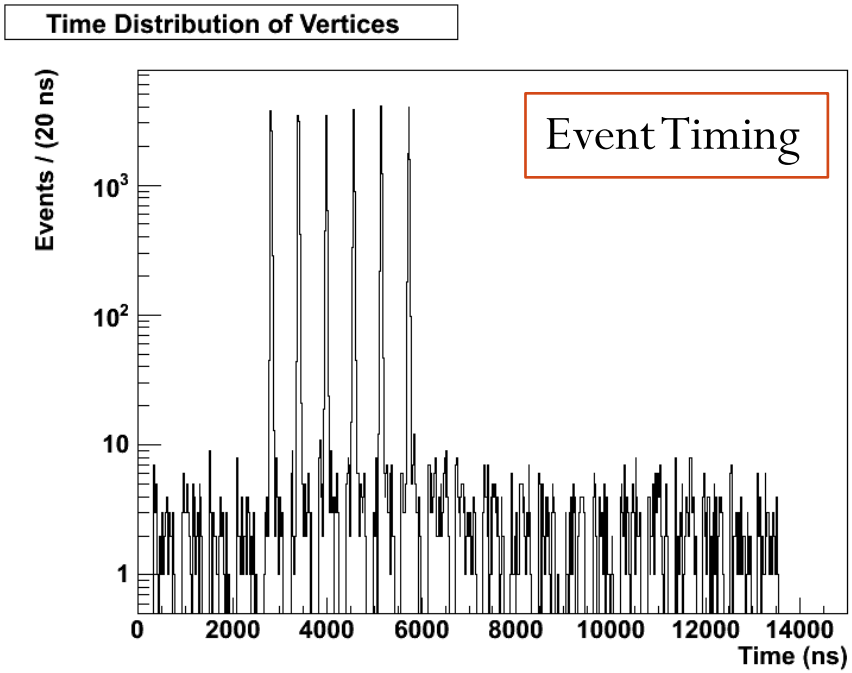
The P0D

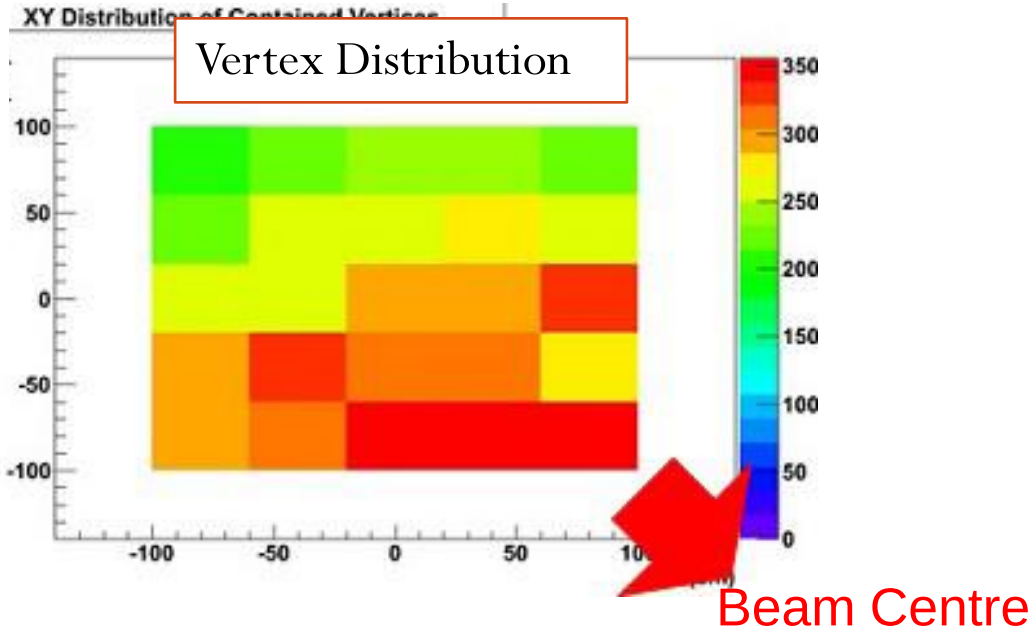
- Optimised to detect neutral current π^0s .
  - 33.5(B)x17.25(H) mm triangular bars
  - Lead and brass radiators
  - 10400 channels
    - 0.07% bad channels
- Water target designed for operation with water in/water out.
  - Determine rate on ^{16}O
  - Water in: all run 1 and 6.98×10^{19} pot in run 2
  - Water out: 3.03×10^{19} pot in run 2.



Events in the P0D

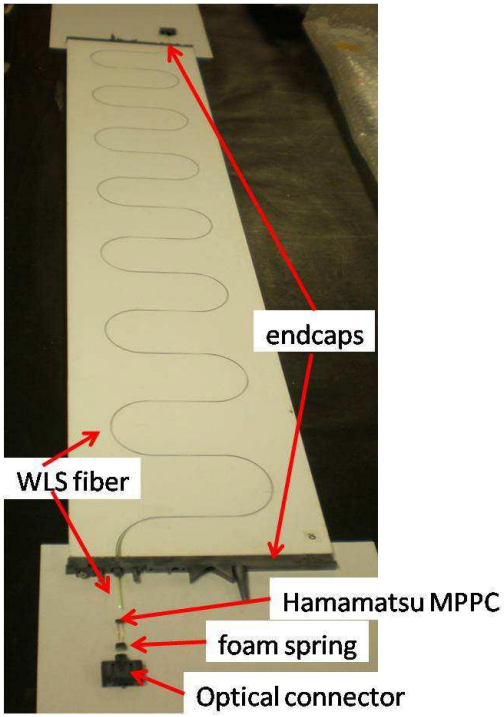


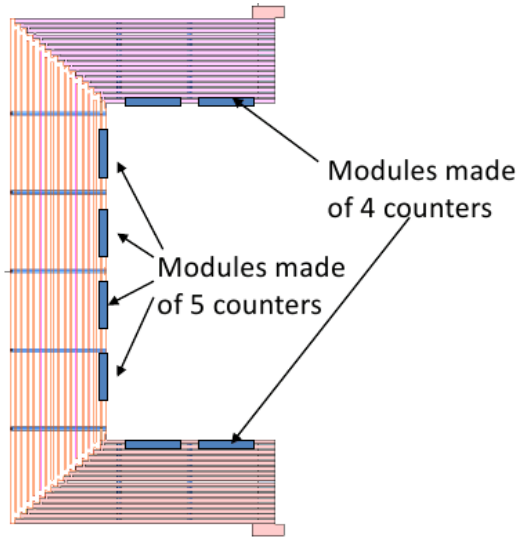




The SMRD

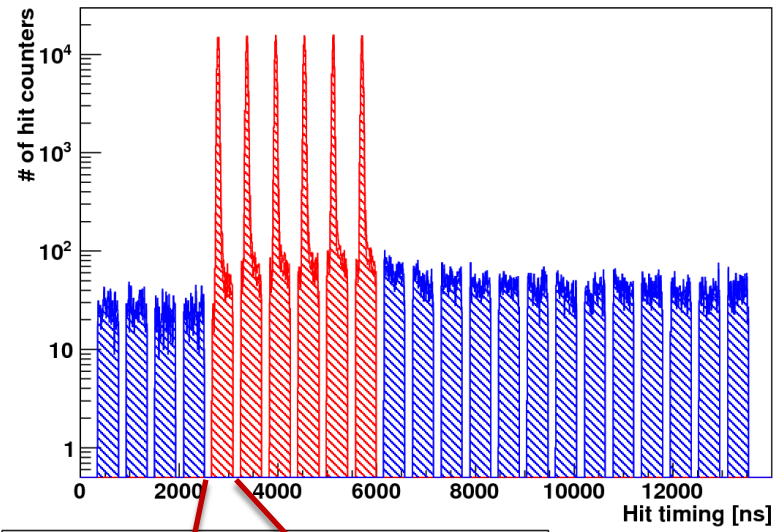
- Scintillator panels instrumenting the magnet
  - Measure the muon from neutrino interactions
  - Provide cosmic trigger
- Panels are:
  - 870x167x7 mm horizontal
  - 870x175x7 mm vertical
  - Unique wiggled grove for fibre.
- 4016 channels
  - 0.07% bad channels.



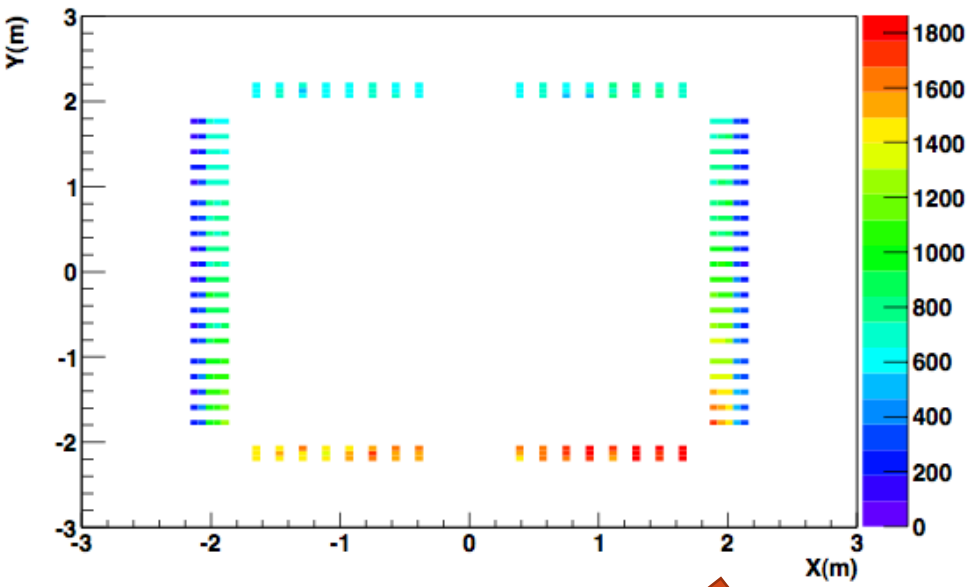


Events in the SMRD

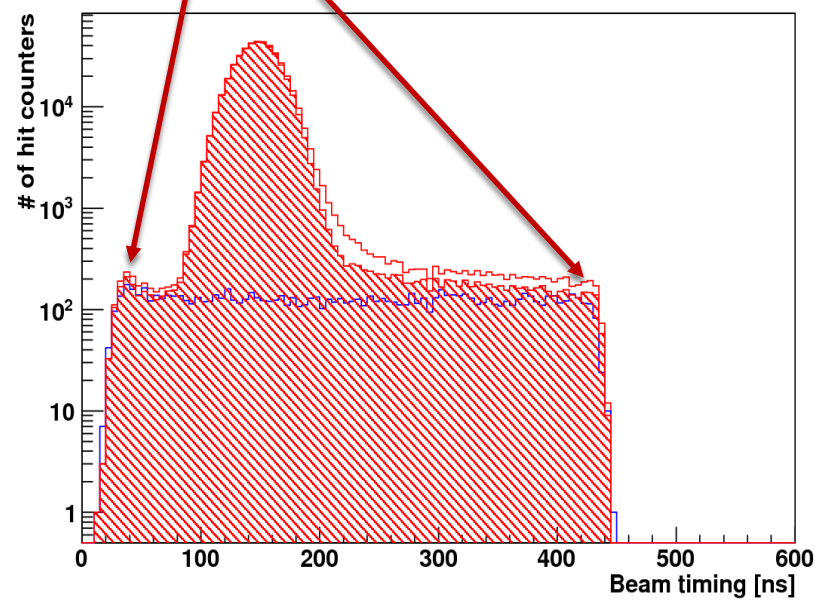
Beam Timing in the SMRD



SMRD Beam Event Hits



Time Distribution in integration window



Beam Centre

Impact of the Earthquake on ND280

- The Near Detector was running when the Earthquake struck in March
- The UPS maintained power and systems shut down as UPS power was used up.
  - UPS batteries have been replaced.

- Since the earthquake all near detector subsystems have been powered up and cosmic data has started to be collected.
  - Damage to the subsystems is minor.
  - Work will be carried out over the summer to recommission the detector.

- The near detector will be ready to start collecting data with the beam in December.

Physics Analysis at ND280

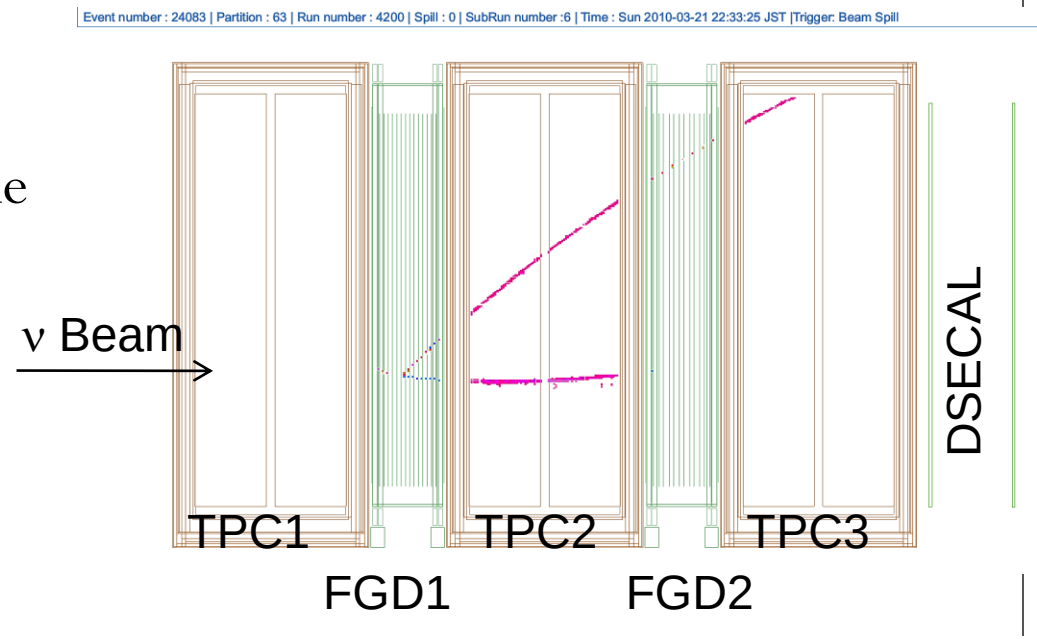
- Currently only available from T2K run 1 data.
  - Analysis of run 2 data is ongoing.

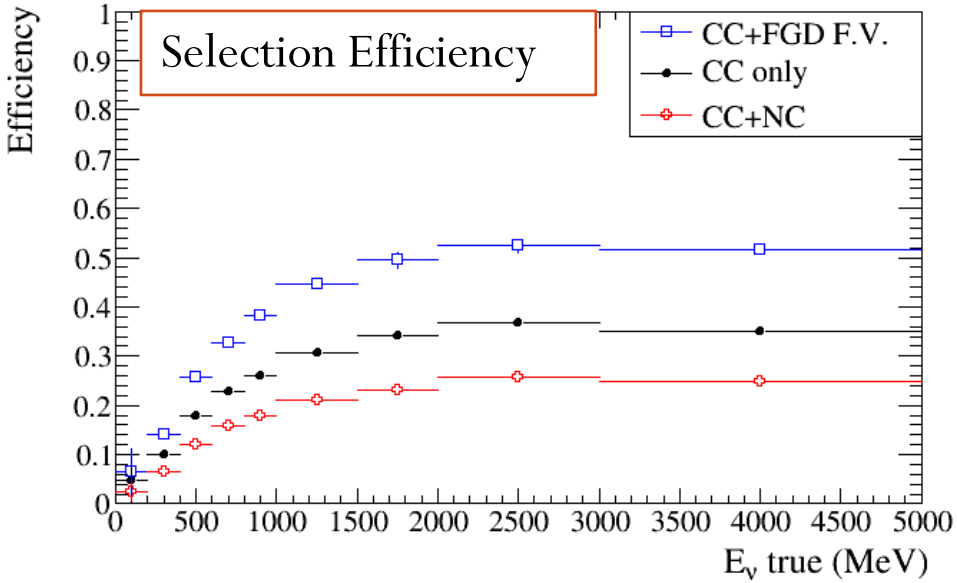
- First ND280 Analyses:
  - Inclusive ν_μ rate
    - Input to oscillation analysis via beam normalisation
    - FGD+TPC
  - Inclusive ν_e rate
    - Verification of beam prediction.
    - FGD+TPC
- ND280 has a rich physics program to come.

- For more details talk by D. Brook-Roberge on Thursday.

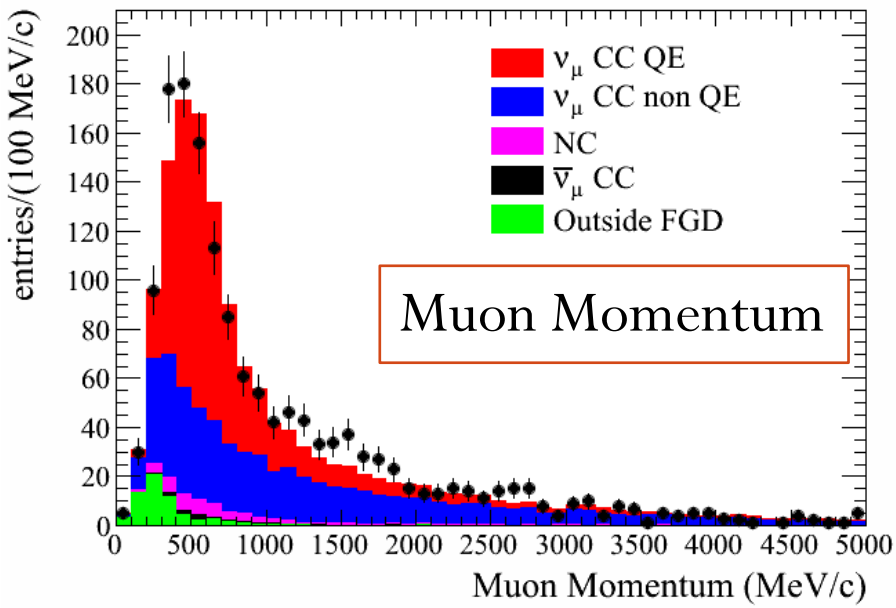
ν_μ CC Event Selection at ND280

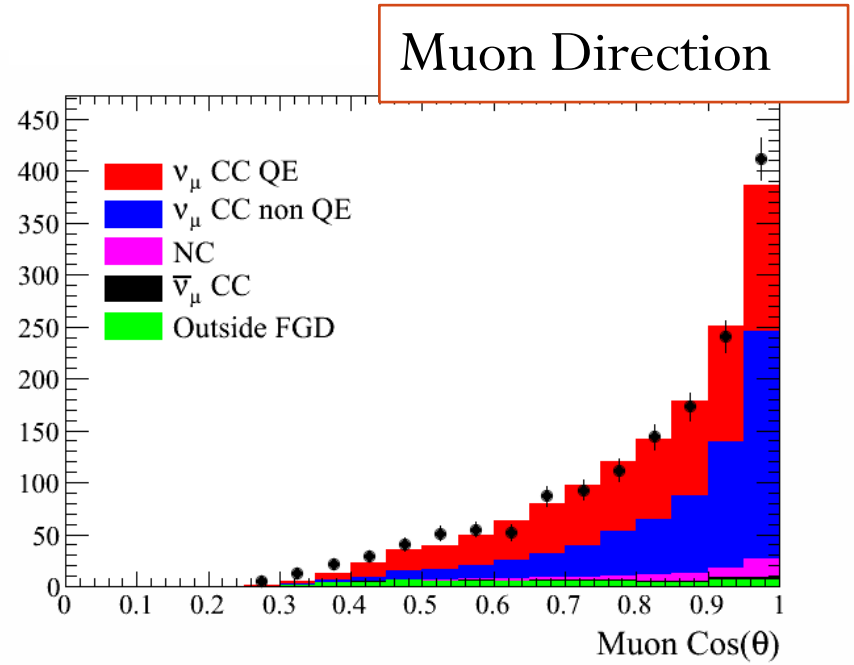
- Inclusive Analysis, just uses the muon.
  - CCQE analysis is more complex, will be used in the future.
- Require
  - No track in TPC1
  - Vertex in FGD1 and at least 1 track p>50MeV in TPC 2
  - Select highest momentum track
  - TPC dE/dx consistent with muon.
  - If no tracks in TPC2, repeat with FGD2/TPC3 combo





ν_μ CC Inclusive measurement





$$\frac{\text{Data}}{\text{MC}} = 1.036 \pm 0.028(\text{stat})^{+0.044}_{-0.037}(\text{det sys}) \pm 0.038(\text{physmodel})$$

- Systematics include
  - TPC Tracking efficiency, Detector matching
  - dE/dx distribution
  - Backgrounds

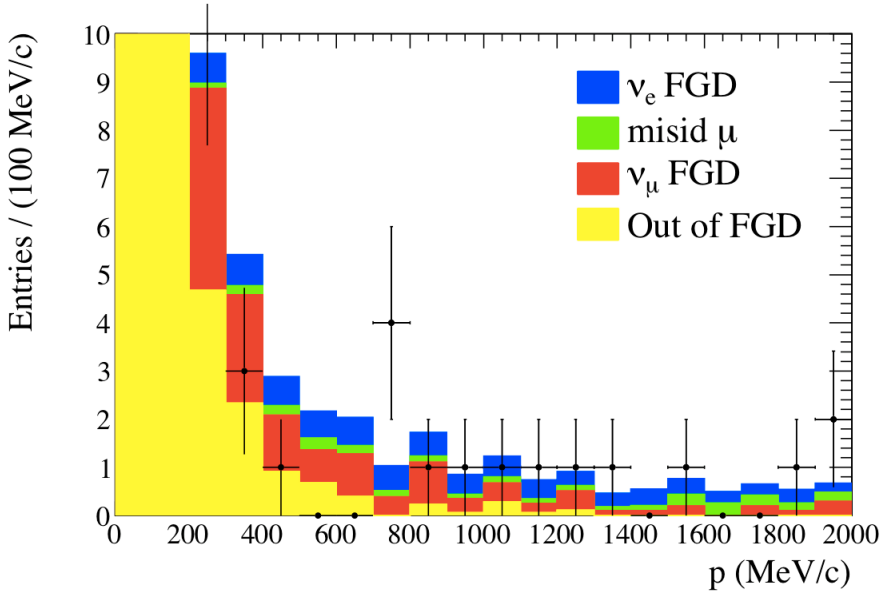
T2K Run 1 = 2.88×10^{19} pot

Measurement of the Beam ν_e component.

- Unlike ν_μ analysis there are significant backgrounds:
  - Muons
    - Need very good PID
  - Electrons
    - Interactions from ν_e are not the only source of electrons.
  - External Backgrounds
    - Beam induced gammas that shower in the FGD
- Run 1 analysis
  - Uses FGD+TPC combination
- Require
  - Vertex in FDG fiducial volume
  - No track in upstream TPC
  - Most energetic track is negative and electron like
    - TPC PID is crucial
  - $M_{inv} < 100$ MeV if 2 tracks
    - Photon rejection
  - $0 < p < 2000$ MeV

ν_e Inclusive Measurement

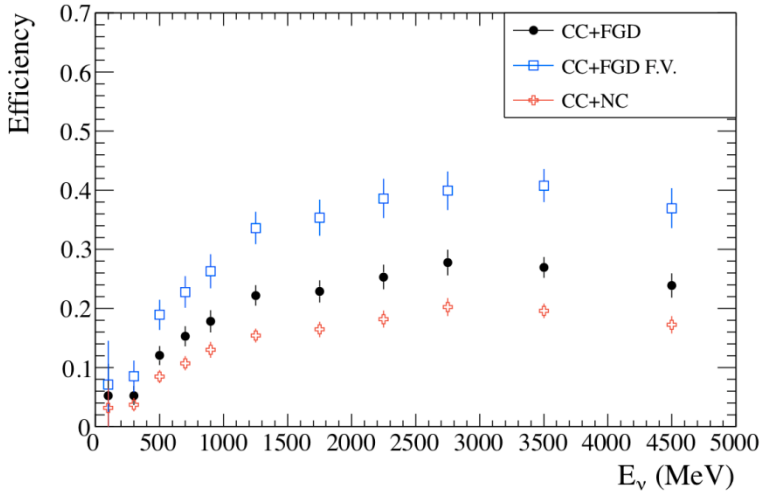
- We carry out a maximum likelihood fit to signal and background
  - Background dominated by real electrons



- Fit gives 8 beam ν_e events.

$$\frac{\nu_e}{\nu_\mu} = 0.010 \pm 0.007(\text{stat}) \pm 0.003(\text{sys})$$

$$\frac{(N_{\nu_\mu}/N_{\nu_e})\text{Data}}{(N_{\nu_\mu}/N_{\nu_e})\text{MC}} = 0.6 \pm 0.4(\text{stat}) \pm 0.2(\text{sys})$$



T2K Run 1 = 2.88×10^{19} pot

Conclusions

- The T2K near detector suite is working well
- The near detector survived the earthquake and will be ready for data taking when JPARC resumes operations in December
- First results from the near detector are available and are used in T2K oscillations analyses
  - In the future additional near detector information will be added to the oscillation analyses.
  - Neutrino cross section measurements will be produced.

Events at ND280