Neutrino Studies with the T2K P0D Detector

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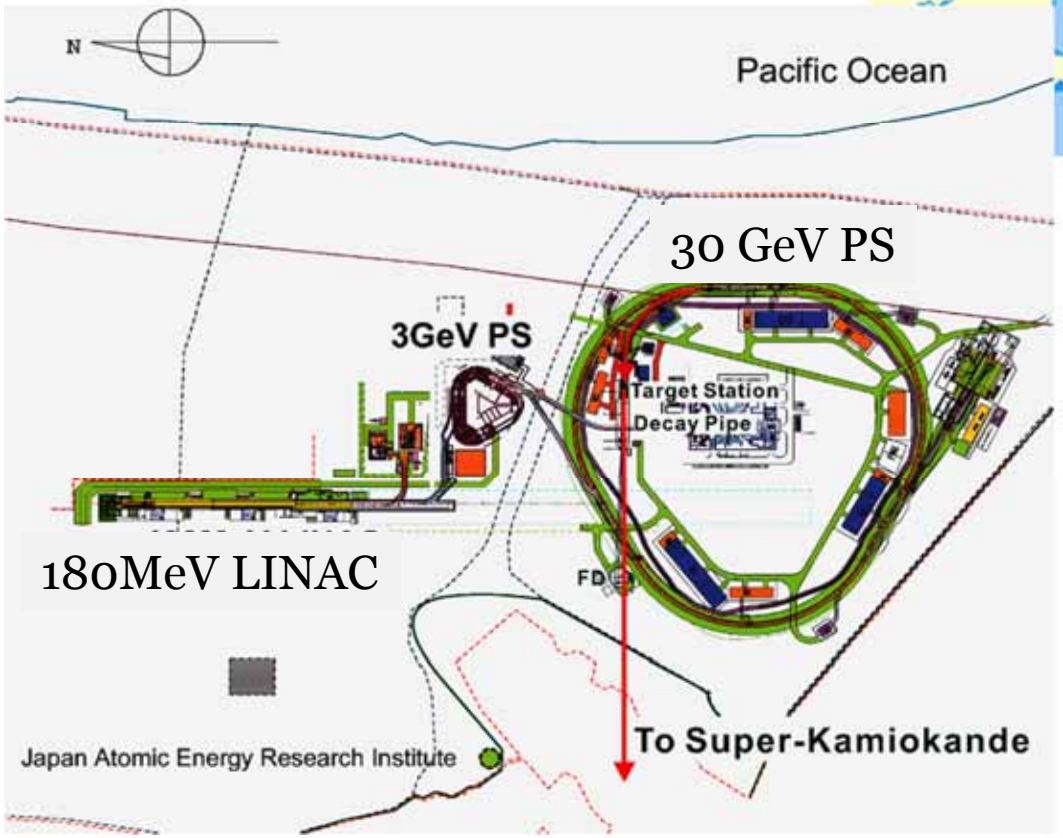
DPF2011

Outline

- T2K Overview
- ND280 Description
- PoD Detector
  - Physics goals
  - Design
  - MPPC photo detectors
  - Extruded Scintillator and WLS fiber
  - Cosmic ray tests, scanning tests
  - Calibration, efficiency
  - Analyses overview
- Summary

T2K Overview

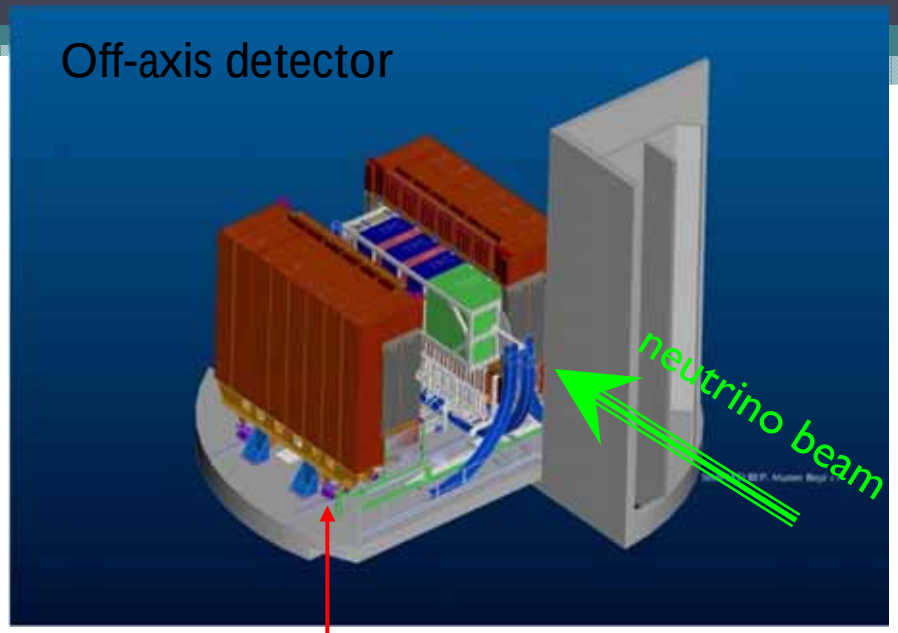
- T2K is Tokai to Kamioka long baseline neutrino oscillation experiment in Japan
- To measure θ_{13} by ν_e appearance from ν_μ beam

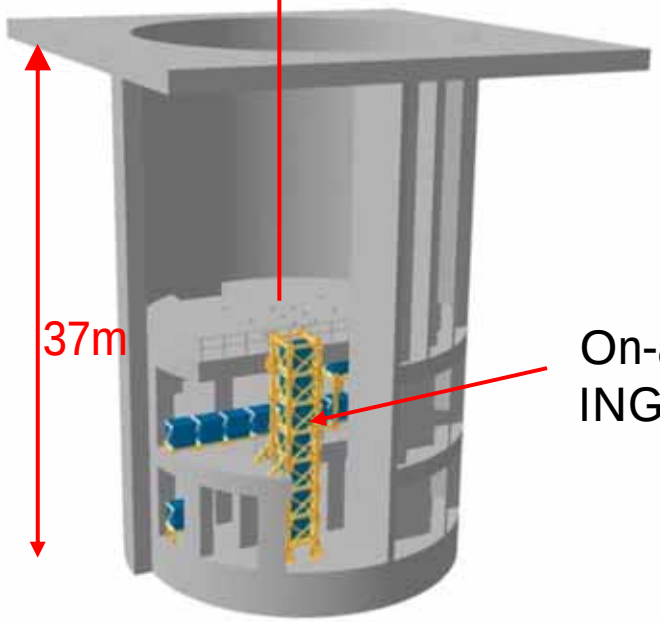


- Designed for up to 0.75 MW, 30 GeV proton beam
- ~0.6GeV off-axis neutrino beam
- Data taking started at the end of 2009
- A near detector (ND280) and far detector (SuperK)

T2K-ND280

- On – Axis Detector
  - Beam monitoring
  - Beam direction and profile
  - Beam Intensity
- Off – Axis Detector
  - Neutrino beam energy Spectrum
  - Beam flux
  - Backgrounds to ν_e appearance measurement:
    - Beam intrinsic ν_e
    - Cross Sections:
      - Primarily NCπ^0





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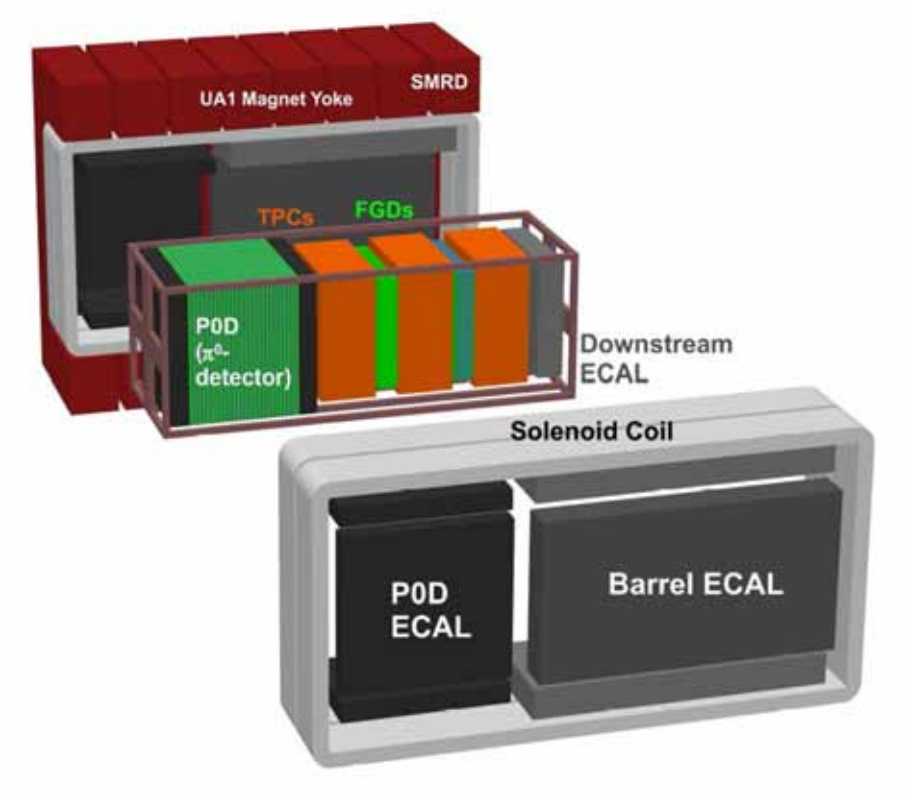
T2K ND280

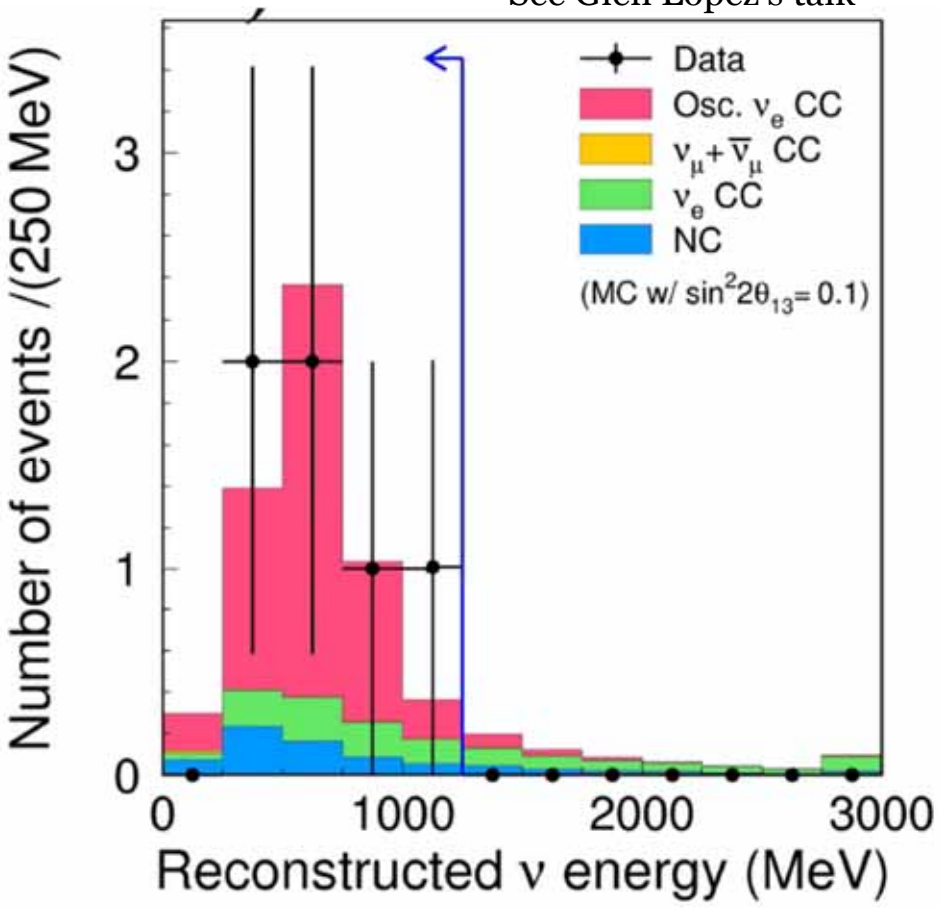


- Off-axis sub-detectors
  - P0D - Pi-Zero Detector
  - Tracker:
    - TPC - time projection chamber
    - FGD - fine grained detector
  - ECAL - electromagnetic calorimeter:
    - Downstream
    - PoD
    - Barrel
  - SMRD - Side Muon Range Detector (inside yoke)
  - UA1 magnet - ~0.2T

Physics Goals – P0D

- P0D is designed to measure:
  - Intrinsic beam ν_e
  - Cross-sections on H_2O (for systematics reduction at SuperK detector)
    - $NC\pi^0$
    - CC inclusive, including
      - CCQE
      - $CC1\pi$
- In this talk my analysis with one muon and one π^+ events are considered
  - $CCp\pi^+$ and $CCn\pi^+$ (as $CC1\pi^+$)
  - $CC1\pi^+$ resonant production isospin related to total $CC1\pi$ cross-section
  - $CC1\pi^+$/CCQE Data to MC prediction ratio is to be measured to remove beam flux uncertainties
  - To tune MC as input for oscillation analysis

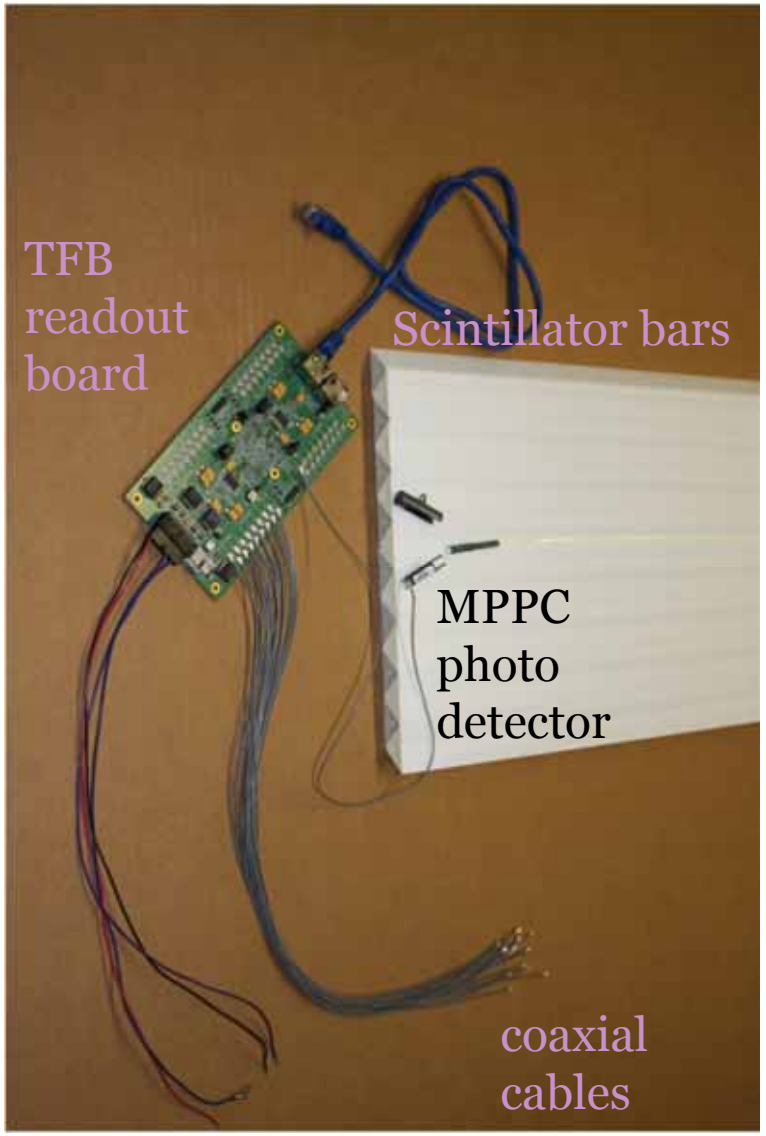
See Glen Lopez's talk



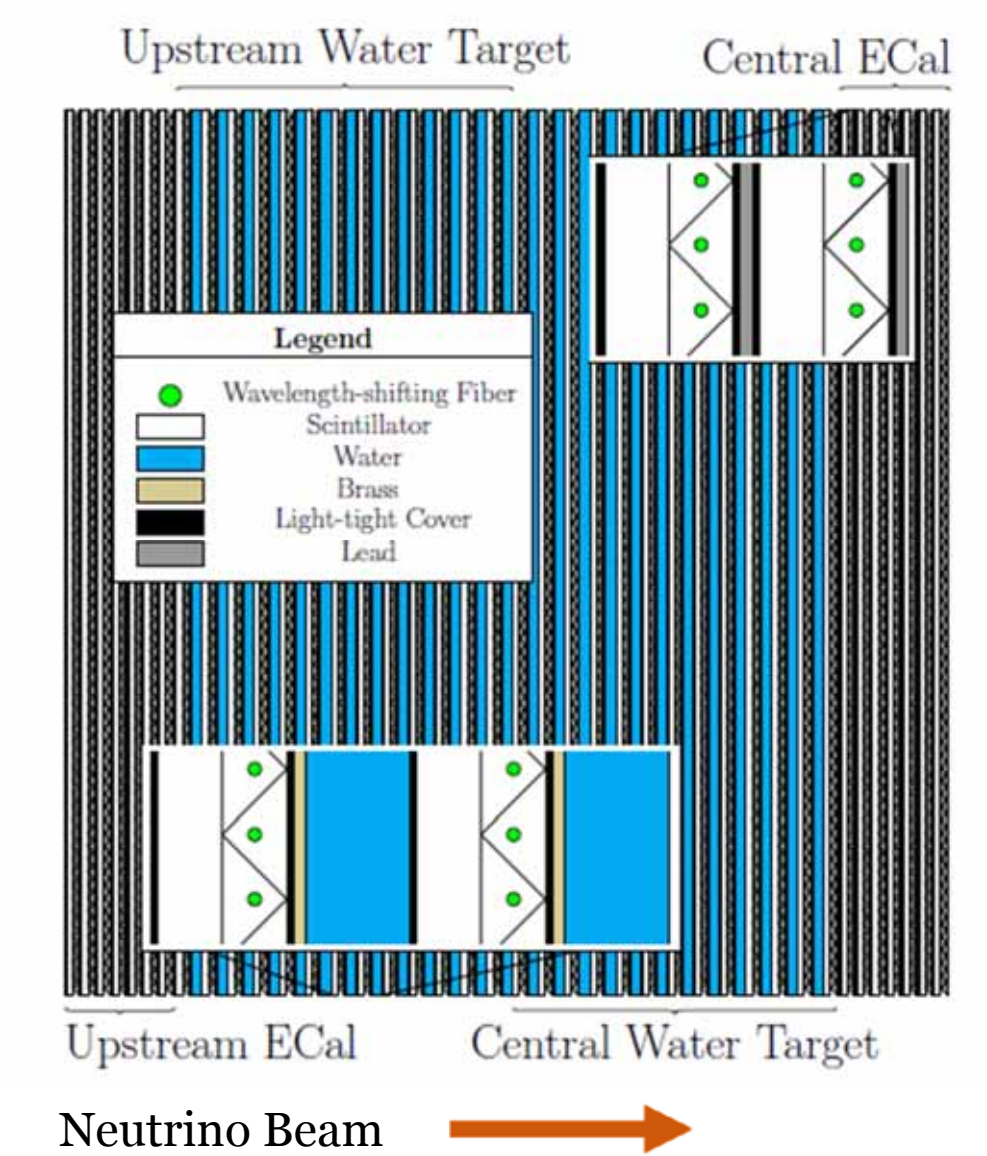
SK ν_e Event Selection

T2K – P0D

- P0Dule: two perpendicular arrays of triangular scintillator bars + Pb or brass/water radiator.
  - 134 vertical bars (Y, 2200 mm)
  - 126 horiz. bars (X, 2340 mm)
- Each bar:
  - Single coaxial hole
  - 1mm wavelength-shifting (WLS) fiber (Kuraray multi-clad, S-35, J-type, doped with Y-11 (175 ppm))
  - One end is mirrored
  - The other end is optically coupled to a Hamamatsu MPPC for readout.
- Total of 10,400 channels

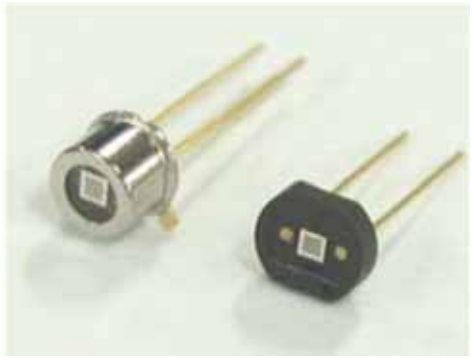


T2K-P0D Schematic Drawing



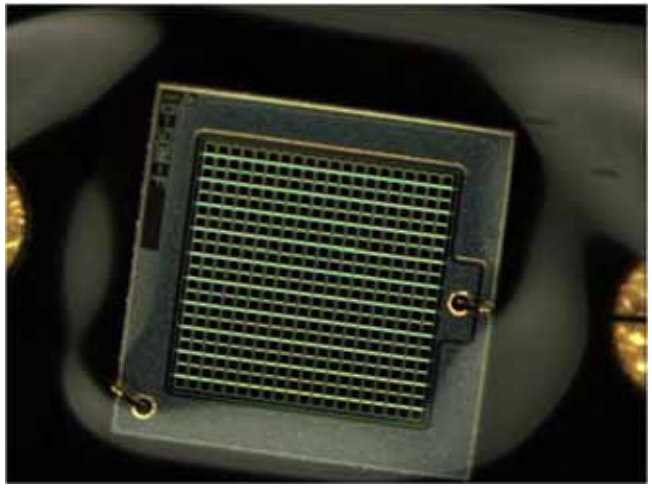
- A total of 40 P0Dules were used for P0D
- Total length of all P0Dules & targets assembled ~2.4m
- Ecals –7 P0Dules each, with 4mm Pb radiator
- Both Water Targets– 26 P0Dules, 25 water layers with 1.6mm brass sheets
- Fillable water bags for water-in and water-out measurements

MPPC Photosensor – Basic Characteristics



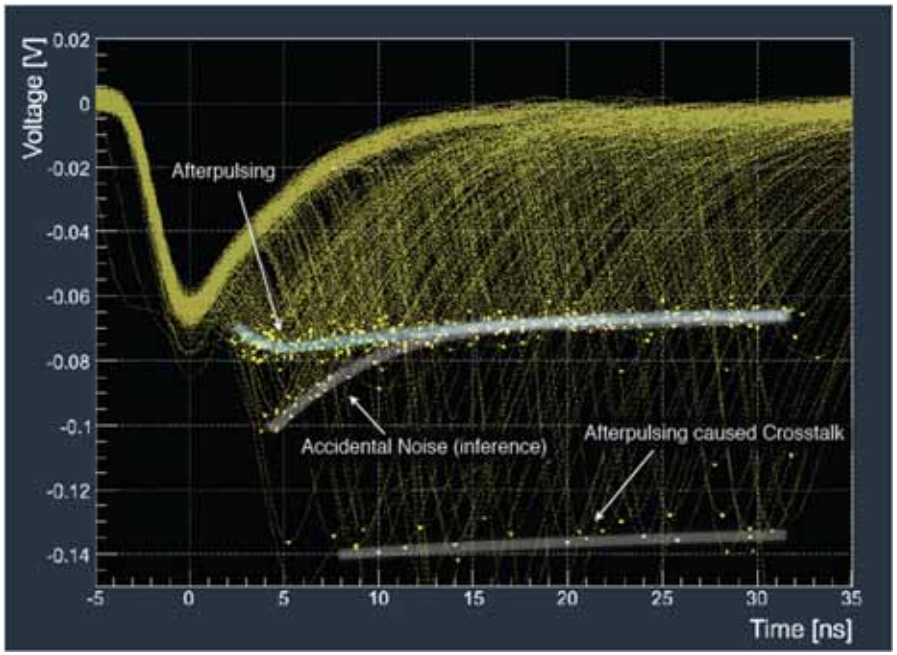
- For model S10361-050U
  - Chip size - 1.5 x 1.5 mm^2
  - Active area - 1 x 1 mm^2
  - Pixel size - 50 x 50 μm^2
  - Number of pixels – 400
    - (a sub-model S10363-050U for T2K ~667, non square)
  - Pixel effective size - 38.1×38.8 μm^2
  - Geometric efficiency - 61.5%
  - PDE typ. ~40%-50% (400nm)
  - Gain typ. $7*10^5$
  - Time resolution – 220 ps
  - Temp. coeff. of bias voltage – 50 mV/^oC
  - Dark count rate ~270 · 10^3/sec

S10361-050U MPPC

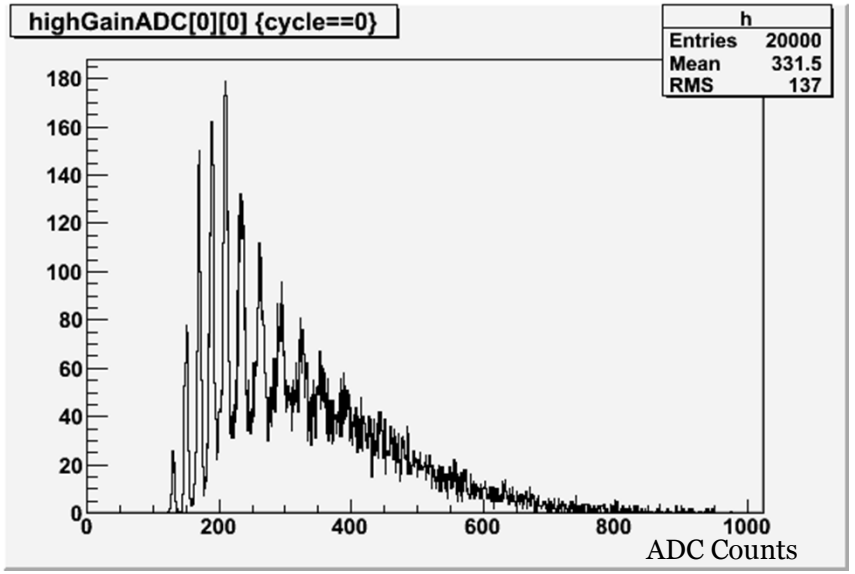


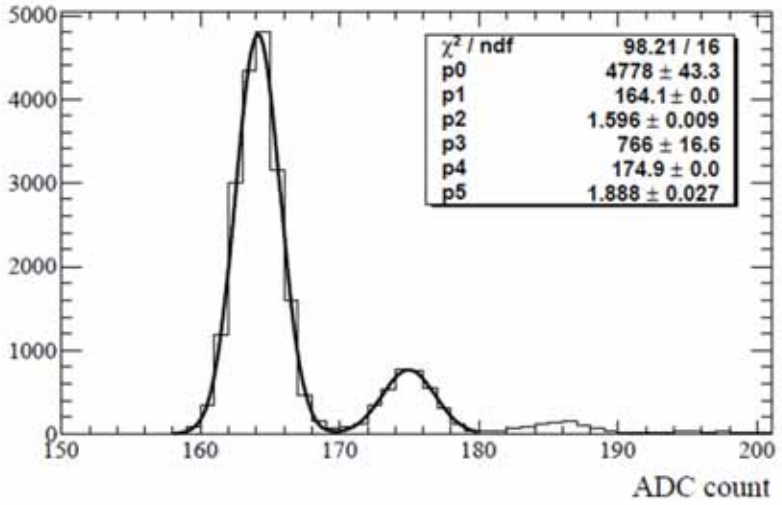
Performance Measurements

- Independent pixels – PE separation
- Complex noise – dark rate, afterpulse, crosstalk



* "Study of Afterpulsing of MPPC with Waveform Analysis", Hideyuki Oide et al.

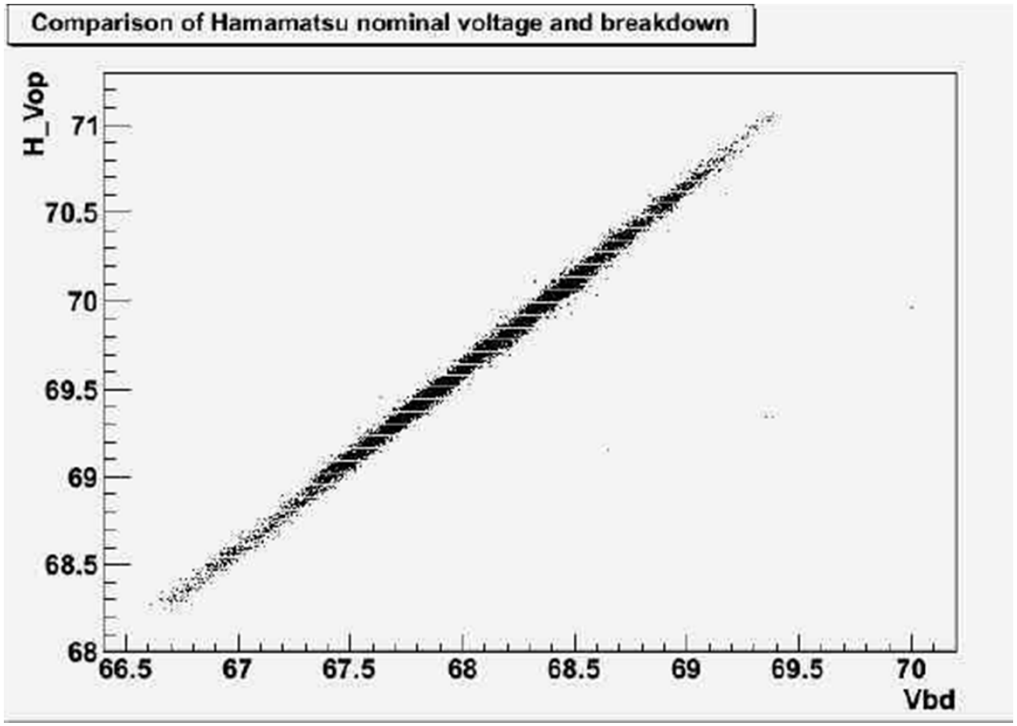




MPPC Large Scale Deployment

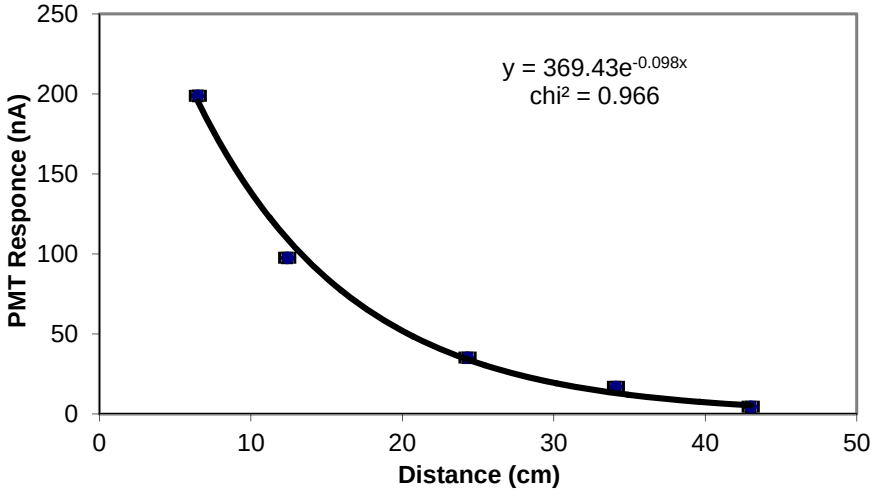
- Each sensor tested before installation
  - Found 83 'bad' (strongly deviated from expected characteristics) from ~11k shipment
- Additional testing after installation
  - Using dark noise
  - During scanning and after superpodule assembly
  - Found 14 inoperable
    - 2 had surface damage
- After transit to Japan
  - 2 more sensors bad
  - After 1.5 years of operation

~17 bad channels total (~0.16%)
~12 damaged during installation

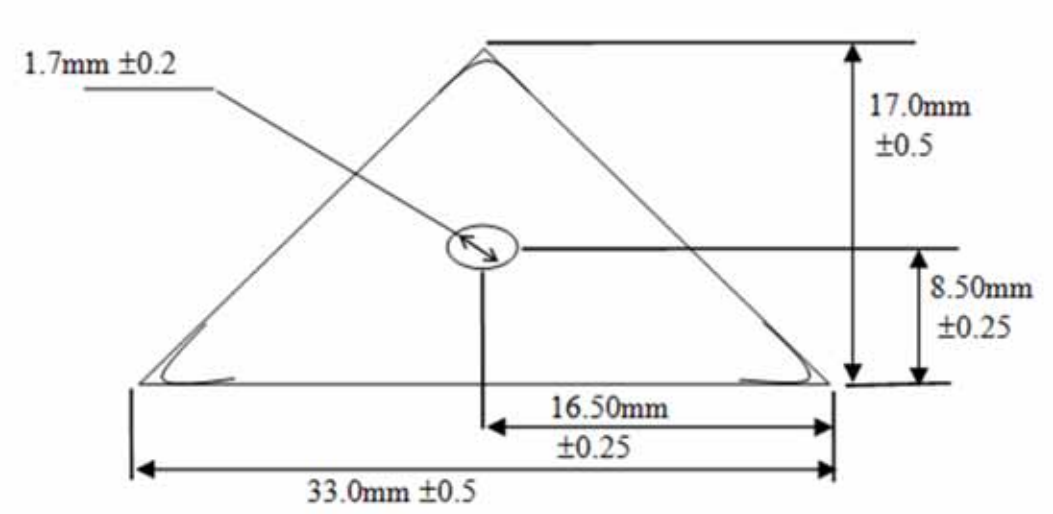


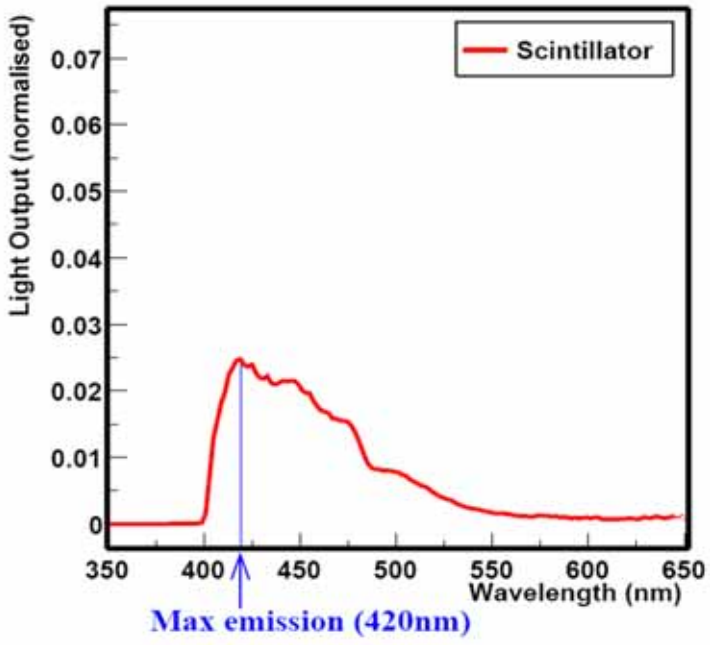
- Bias spread between sensors
  - Manuf. supplied biasing voltage values vs. breakdown voltage

Extruded Scintillator Bars



PMT response radioactive source position along the bulk triangular shape scintillator without WLS fiber, yielding attenuation lengths of ~10.2.

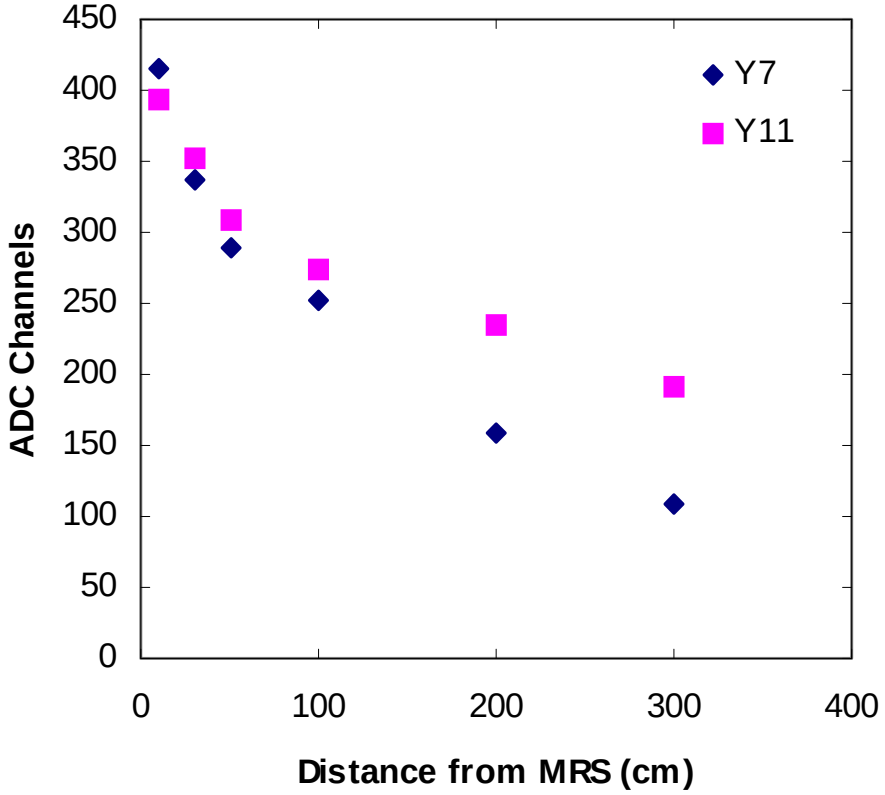




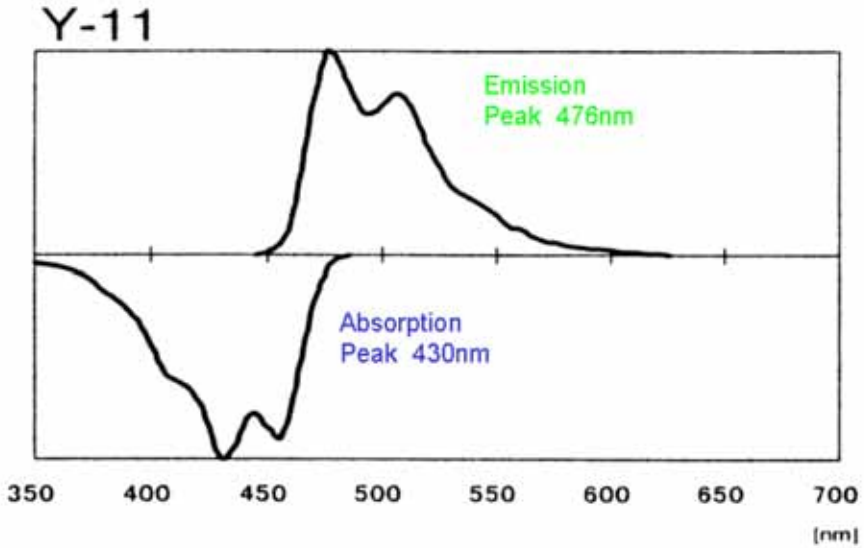
Scintillator emission spectrum

D. Beznosko, A. Dyshkant, C.K. Jung, C. McGrew, A. Pla-Dalmau, V. Rykalin, "MRS Photodiode Coupling with Extruded Scintillator via Y7 and Y11 WLS Fibers", FERMILAB-FN-0796, Feb 2007

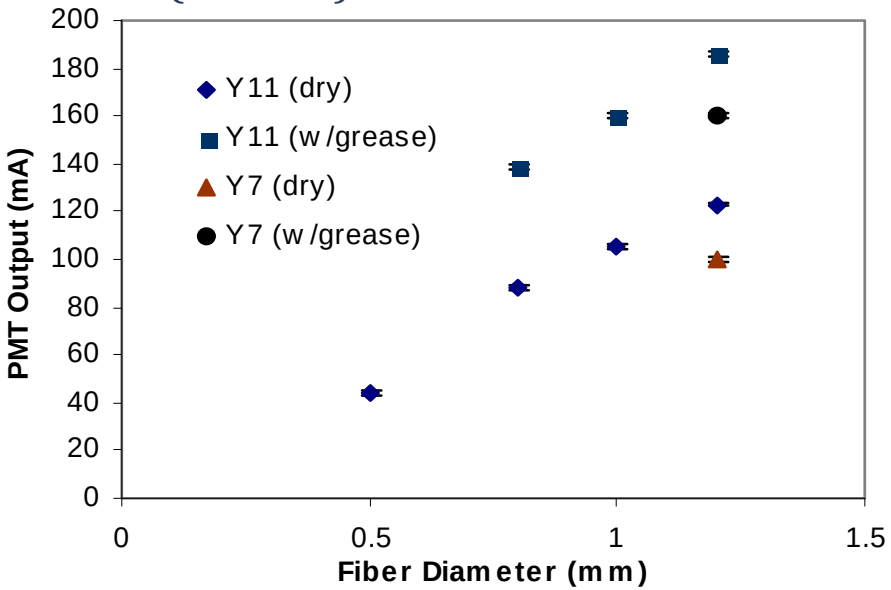
WLS fiber



Response of Y11 and Y7 WLS fibers vs. distance from photodetector. Y11 was selected for POD. Y11 attenuation lengths: 35.5±0.3 cm and 463.4±1.2 cm



Absorption and emission spectra for WLS fibers (bottom)

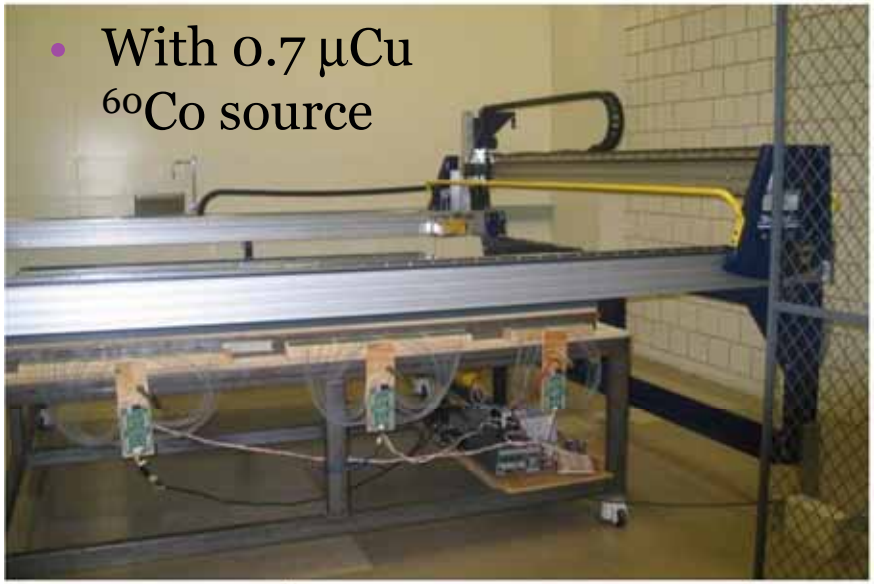


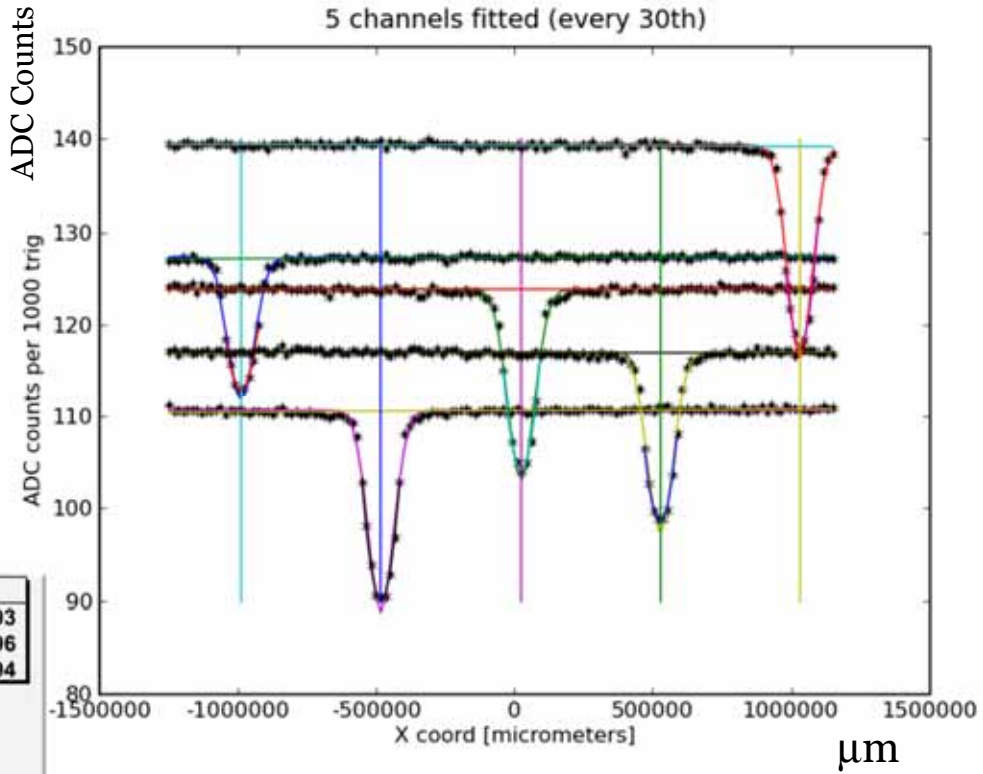
The PMT output for various WLS fibers (with and without optical grease for each fiber tested).

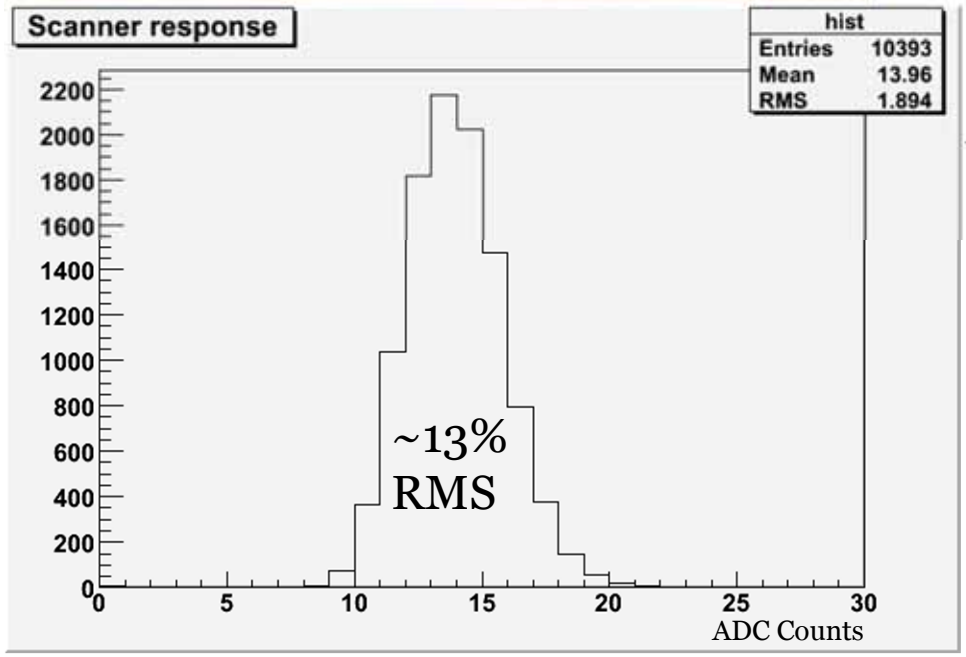
D. Beznosko, A. Dyshkant, C.K. Jung, C. McGrew, A. Pla-Dalmau, V. Rykalin, "MRS Photodiode Coupling with Extruded Scintillator via Y7 and Y11 WLS Fibers", FERMILAB-FN-0796, Feb 2007

MPPC – Rad. Source Scanning

- With 0.7 μCu ^{60}Co source





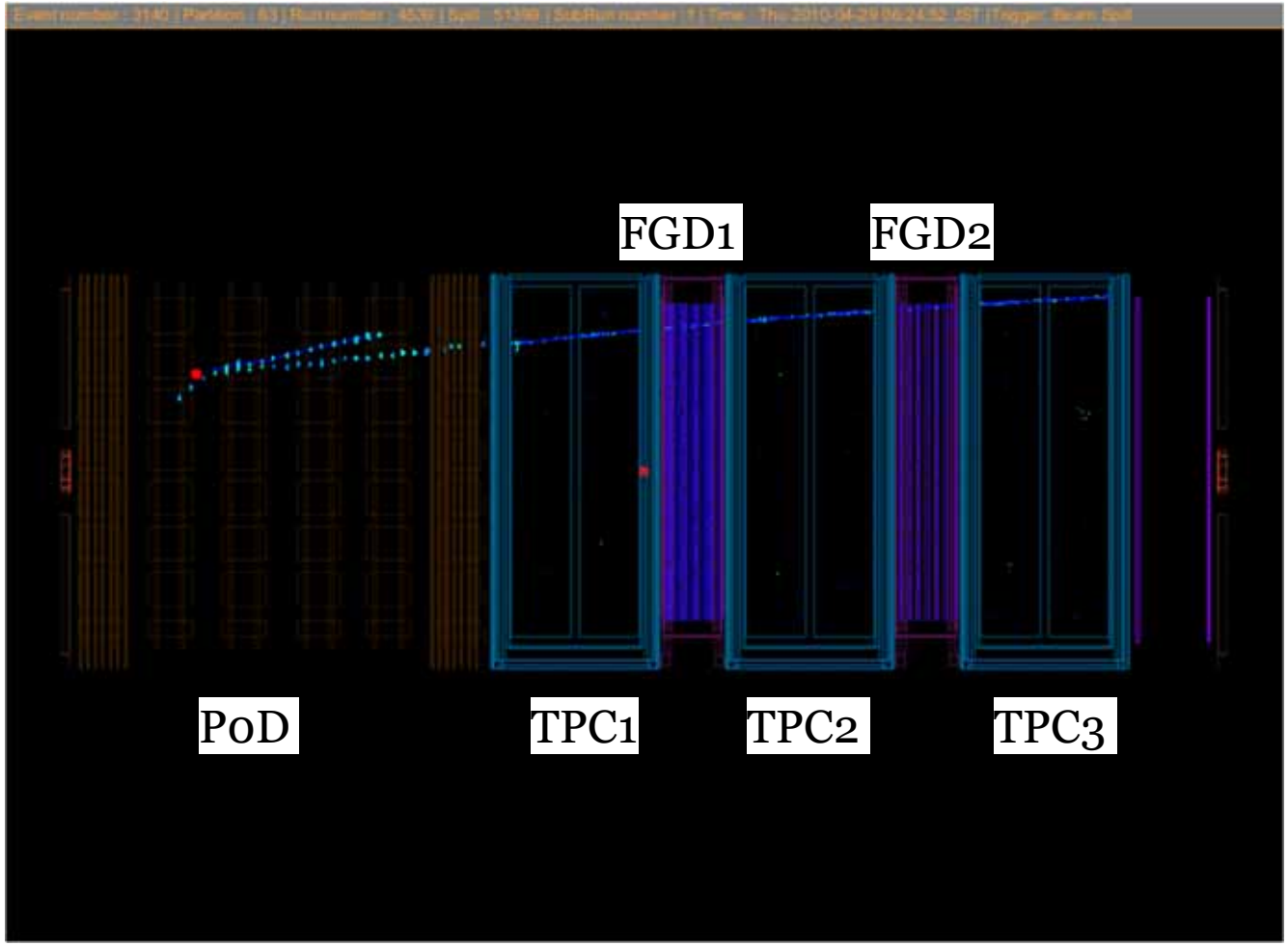


Average response of all bars with source position at 0,0 is plotted (no attenuation correction needed)

~13% rms channels response spread using manufacturer supplied biasing voltage values

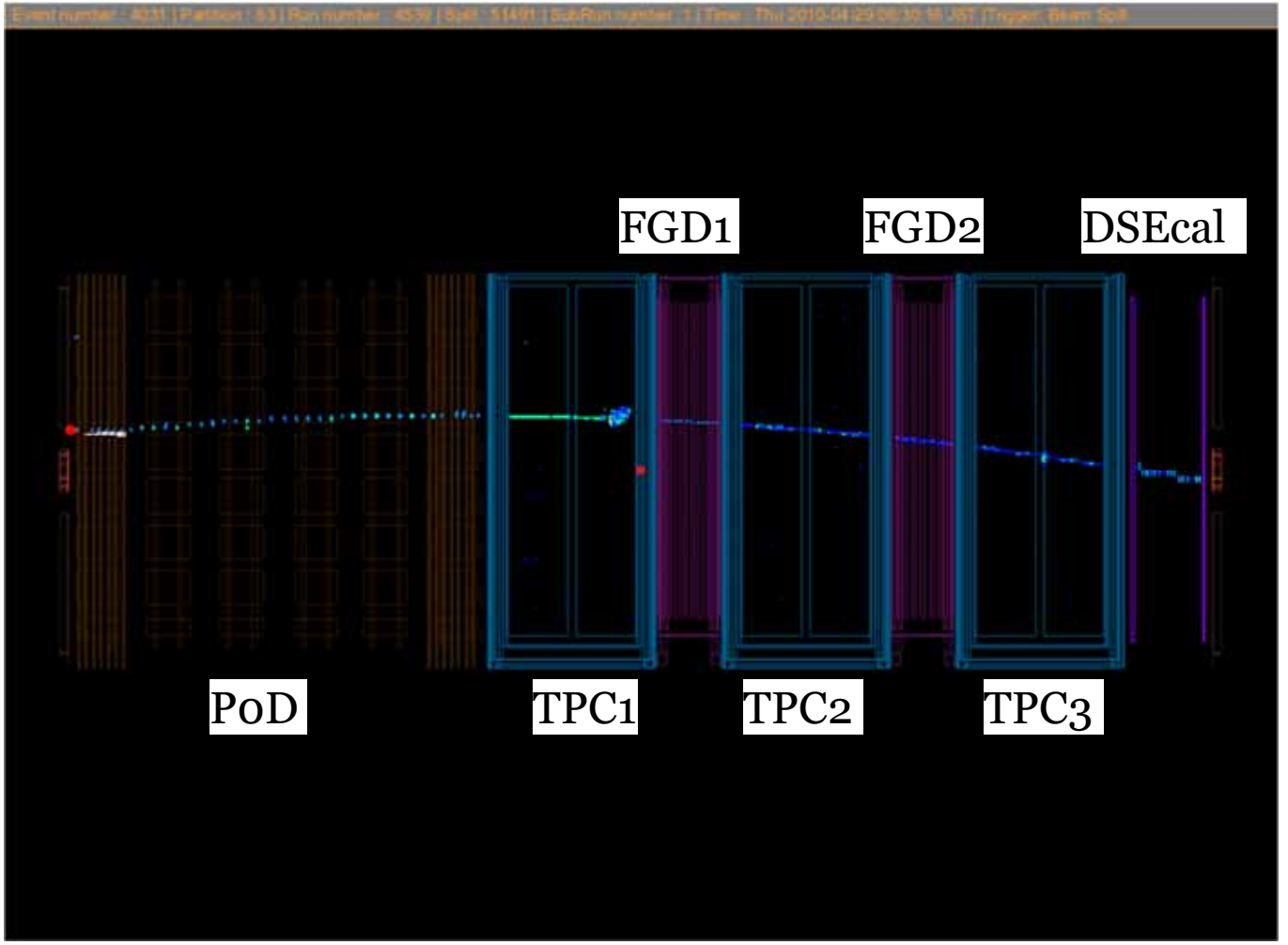
ND280 Detector with Magnet Open

Neutrino Event Display in ND280



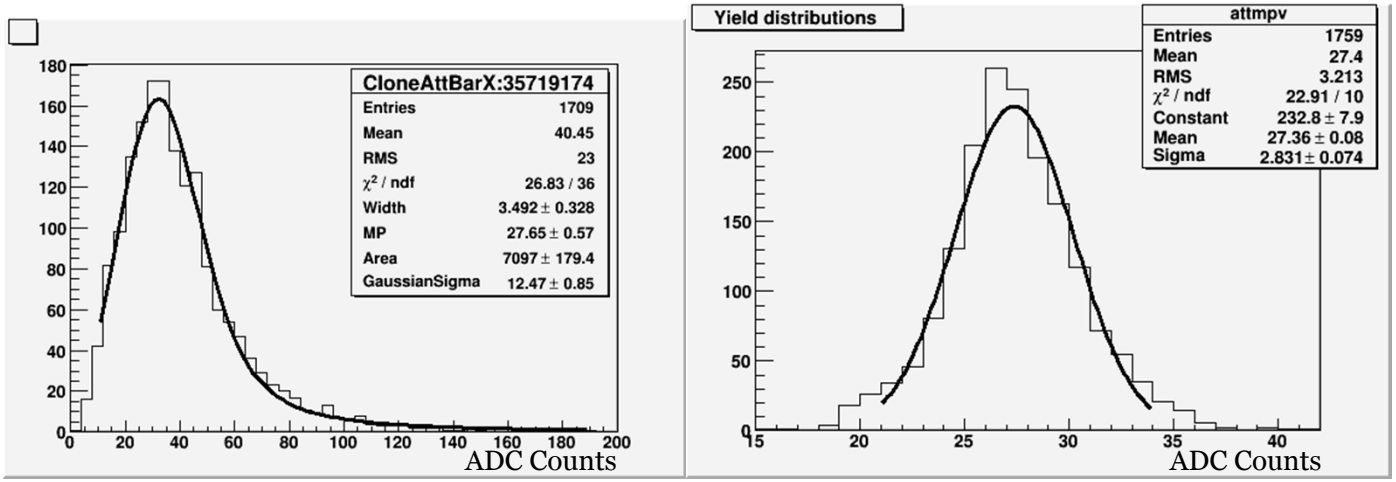
- Neutrino event in PoD.
  - 2 tracks contained in PoD

Neutrino Event Display in ND280

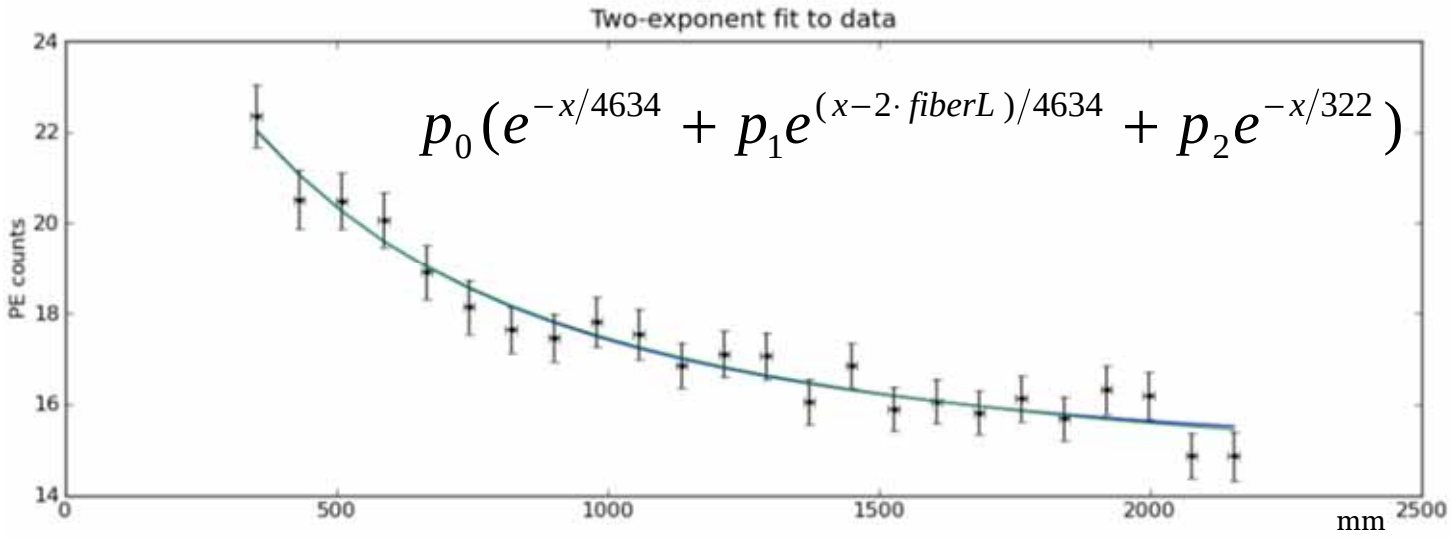


- 'Sand' muons going through PoD/TPC1/FGD1/TPC2/FGD2/DSECAL

Cosmics Data calibration – channels response and fiber light attenuation

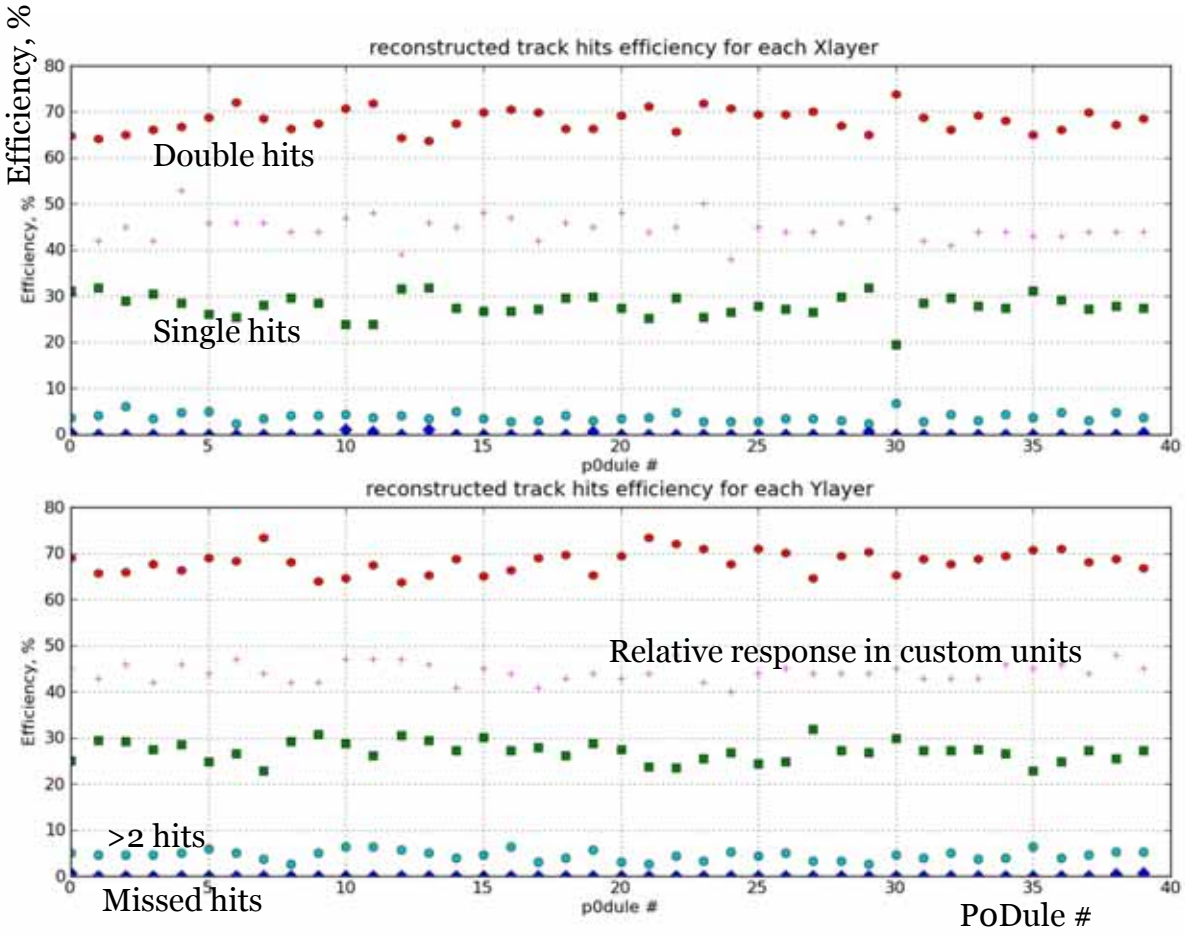


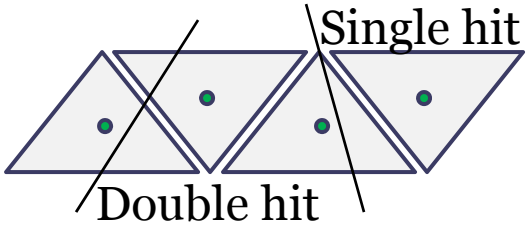
Single channel response and all channels spread (~12% rms)



- p0=16.7±0.33, p1= 0.774±0.043, p3=0.355±0.027
- chi2/dof 1.08

P0D Hits efficiency



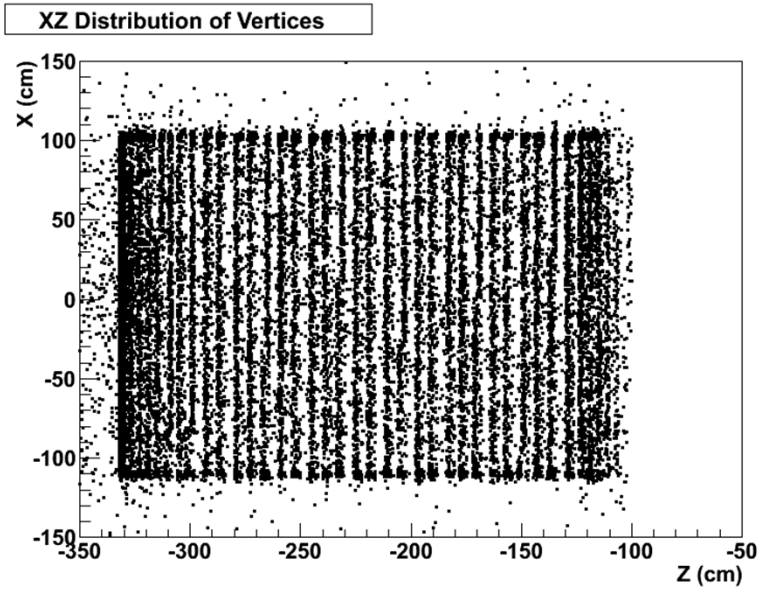


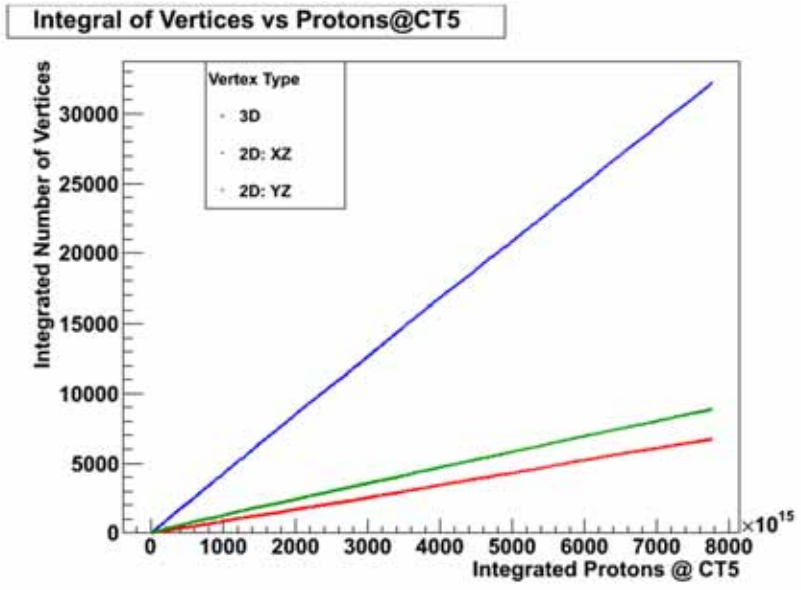
- Track reconstruction hit efficiency for 1-38 PoDules
- Values for first and last PoDule are biased by selection
- Using 'sand' muon long tracks

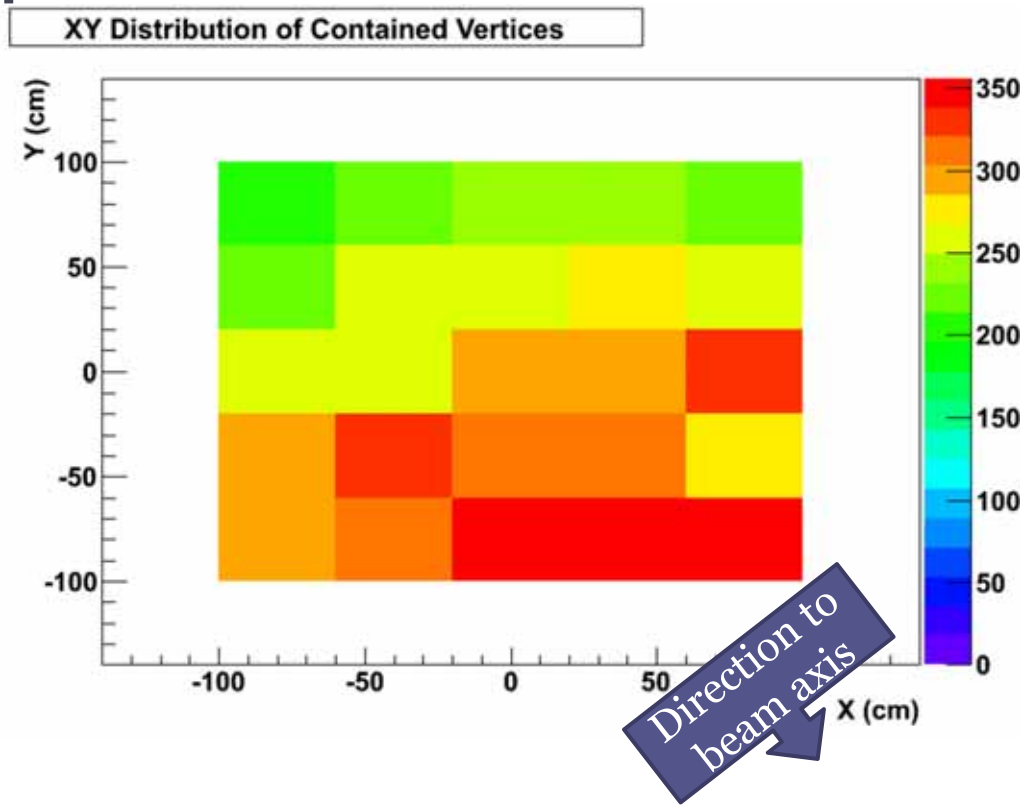
- Total efficiency = 99.965 %
  - % of 1 hits = 27.475
  - % of 2 hits = 68.367
  - % >2 hits = 4.122
- % of 0 hits = 0.035

Theoretical probability of 0 hits for 15 bad channels, no double-bad ones
(15/10400)*0.27=~0.039%
not all edge/side bars are included in data sample

P0D Performance plots





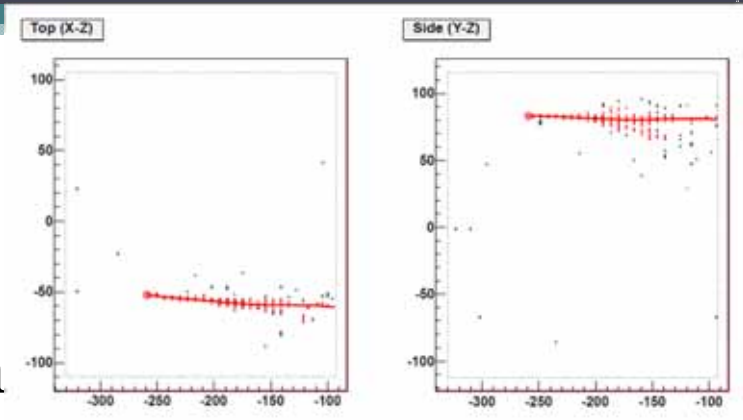


- PoD neutrino beam data
  - XZ distrib. of vertices
  - XY distrib. of vertices
  - Integral of vertices vs Protons on Target

π^0 Analysis Overview

- NCπ^0 production contributes one of the largest sources of background to the ν_e appearance search
  - Use measurement of NCπ^0 in the PoD to constrain systematic uncertainty in the NCπ^0 background expectation at SK
- Strategy:
  Measure NCπ^0 production on water:
  - Require neutrino interaction in water target
  - Perform separate measurements of water in/water out
  - Make statistical subtraction to get water in cross section
- Reconstructing π^0's
  - Require vertex in fiducial volume
  - Require no tracks identified as muon-like
  - Reconstruct NCπ^0 events from EM showers produced by decay photons
  - Identify π^0's using invariant mass

ν_e Analysis Overview



- Measure beam ν_e contamination
- Selection Criteria:
  - Vertex in fiducial volume
    - Water Target in Z, 25 cm from X/Y sides. For a future water in/out subtraction
  - Single 3D Track
  - Width based PID
    - Selecting wide tracks rejects muons and charged pions
  - Kinematic Cut - theta < 45 deg, E_nu > 1.5 GeV., to measure high energy neutrinos from Kaon decays in secondary beam first
    - lower E_nu to measure pion component.

CC1π^+/CCQE Analysis Overview

- As input to MC tuning for oscillation analysis
- CC1π^+/CCQE ratio removes flux uncertainty and reduces systematics
- Selection Criteria:
  - Using PoD contained 1, 2 and 3-track events
  - Vertex in fiducial volume (Water Target in Z, 25cm from X/Y sides)
  - Use Track length and angle-to-Z axis cut to obtain very pure CCQE sample from 1 track events
    - For CCQE baseline direct comparison
    - For energy spectrum comparison between data and MC files
- Fit combined MC CCQE, CC1π^+ and 'other' samples to data and determine the ratio

Summary

- PoD detector was built and commissioned successfully
- During run periods, performance is within expected specifications and is stable
- A range of physics measurements with PoD-only contained events or together with tracker (e.g. CC inclusive analysis) are in progress
- Water-in water-out measurements to be performed when larger dataset is accumulated