Practice Talk

- The following is a rough draft of the talk I'd like to give at CAP
- As you are aware, the official plot situation is changing rapidly
  - (e.g. the INGRID plots were released last night, and the FGD plots were updated 2 hours ago)
- In some cases I'll be showing older plots for which updated versions should be available in time for my talk on Monday
- I've left a little room for a couple more slides depending on what becomes available

Status of the T2K Experiment

Michael Wilking
TRIUMF
CAP Congress, 7-June-2010

Neutrino Mixing

Flavor States

Note: $c_{ij} = \cos(\theta_{ij})$, $s_{ij} = \sin(\theta_{ij})$

Mass States

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \times \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} e^{i\alpha_1}/2 & 0 & 0 \\ 0 & e^{i\alpha_2}/2 & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

"Atmospheric ν"
(Super-K, K2K, MINOS)
θ_{23} = 45°±8° (90% C.L.)

Not yet observed
CHOOZ upper limit:
$\sin^2 2\theta_{13} < 0.19$
(90% C.L.)

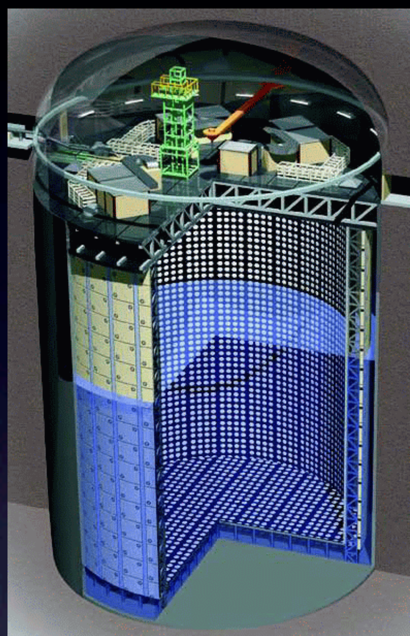
"Solar ν"
(SNO, KamLAND)
θ_{12} = 34.4°±1.3°

Majorana phases;
Not yet observed

- The neutrino states that participate in the weak interaction (flavor states) are related to the mass states via a mixing matrix
- Two of three mixing angles are well measured and very large
- The remaining angle, θ_{13}, is very small and currently unmeasured
- CP violation is controlled by the parameter δ
    - If θ_{13} = 0, there is no CP violation in the lepton sector

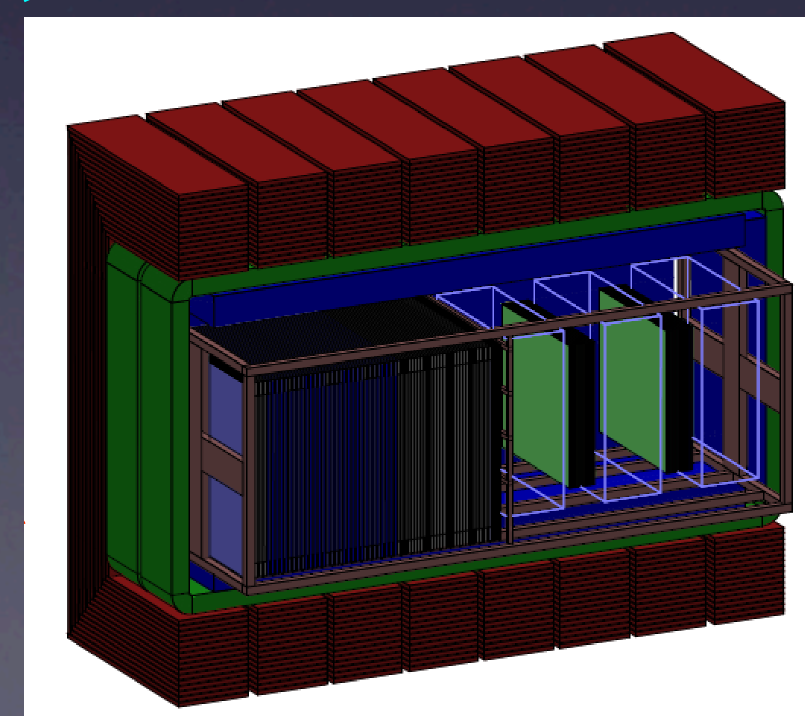
The T2K Experiment

Super-K Detector



J-PARC Accelerator

Near Detector



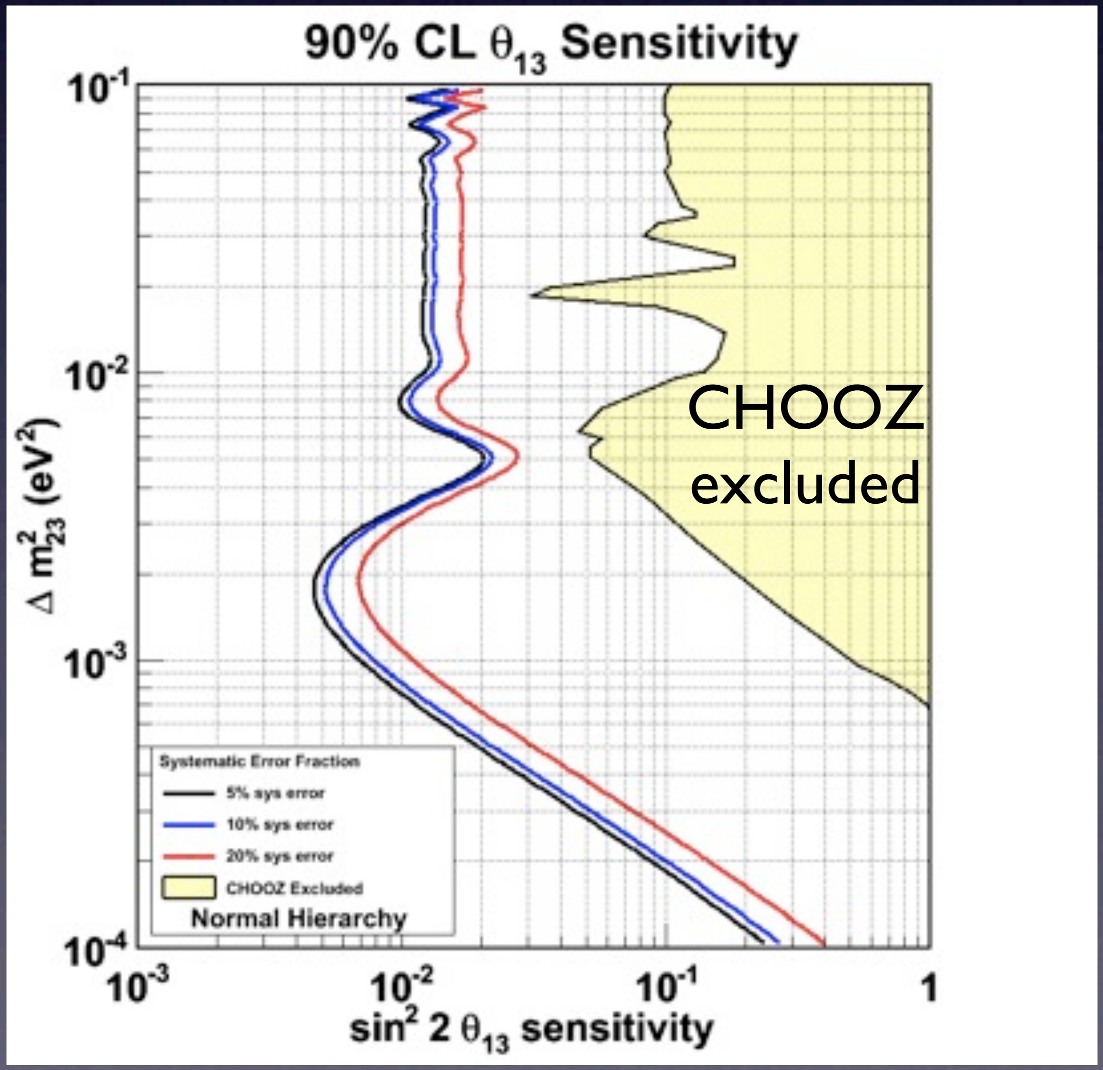
- The T2K experiment searches for $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_X$ oscillations in a high purity ν_μ beam
- A near detector located 280 m downstrem of the target measures the unoscillated neutrino spectrum
- The neutrinos travel 295 km to the Super-KamiokaNDE water Cherenkov detector
  - Super-K searches for the appearance of ν_e
  - The measured ν_μ spectra at the near and far detectors are compared to search for ν_μ disappearance

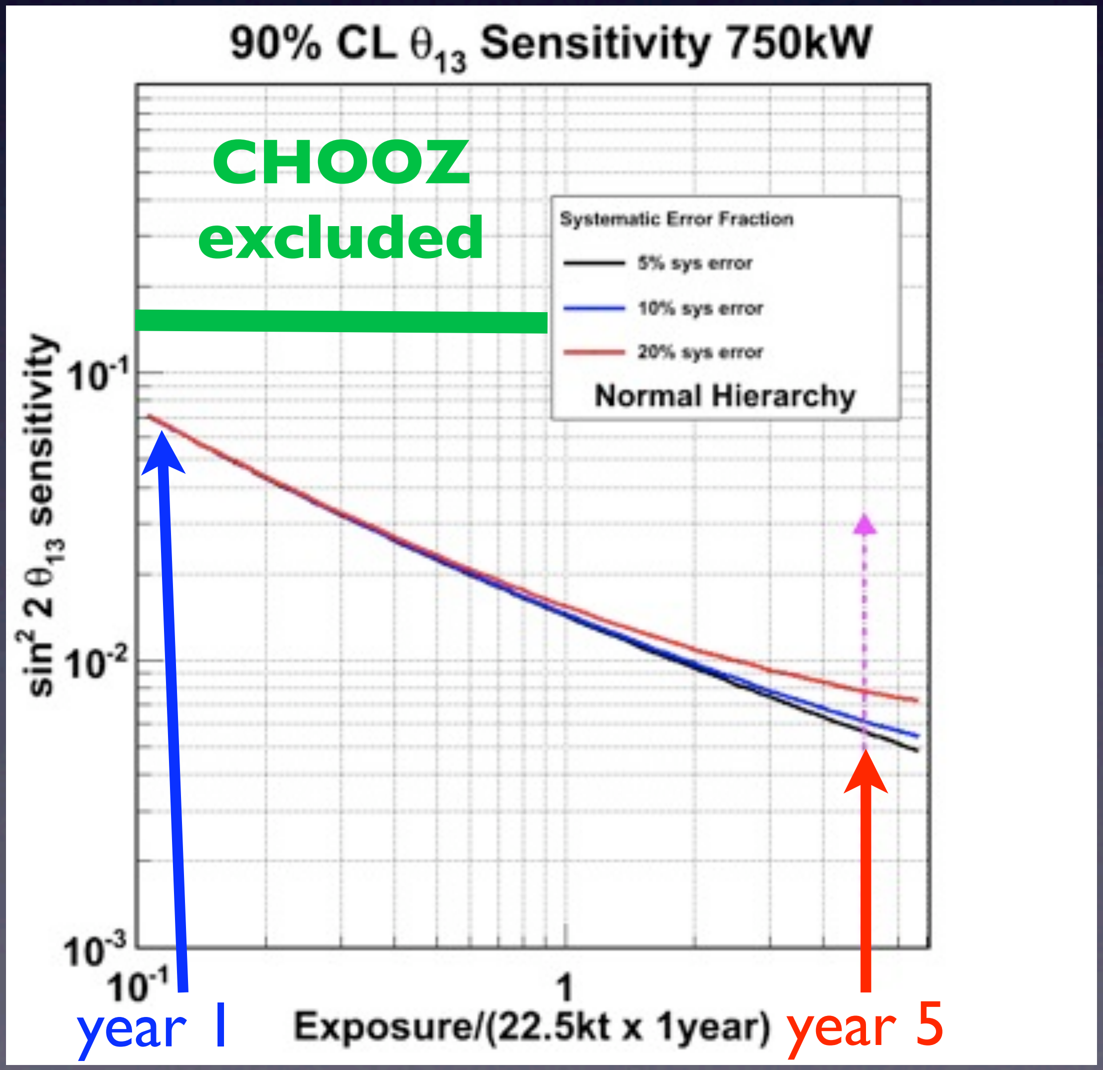
T2K Collaboration

- 500 members from 62 institutions
- 12 countries (Canada, France, Germany, Italy, Japan, South Korea, Poland, Russia, Spain, Switzerland, UK, and USA)

θ_{13} Sensitivity

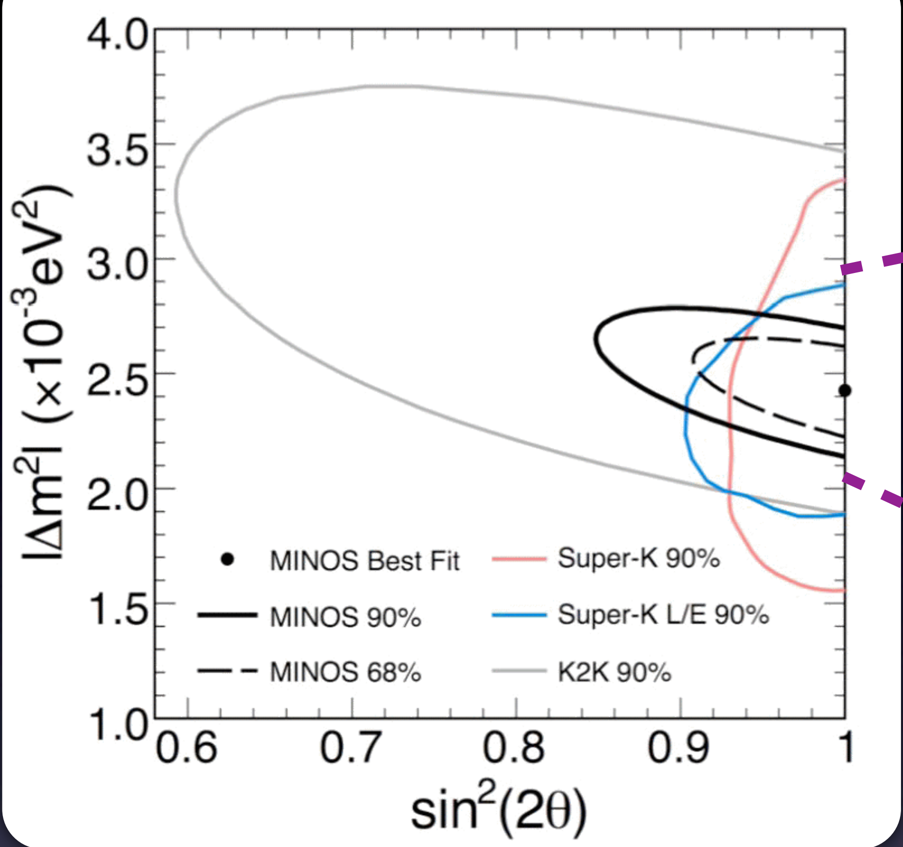
- Search for the appearance of electron neutrinos
- Over the full 5 year run, T2K will improve the current limit on θ_{13} by an order of magnitude
- In the first year of running, sensitivity is comparable to that of CHOOZ
- The plots show sensitivities for 5% (black), 10% (blue), and 20% (red) systematic uncertainties
  - First 1-2 years will be dominated by statistical uncertainty



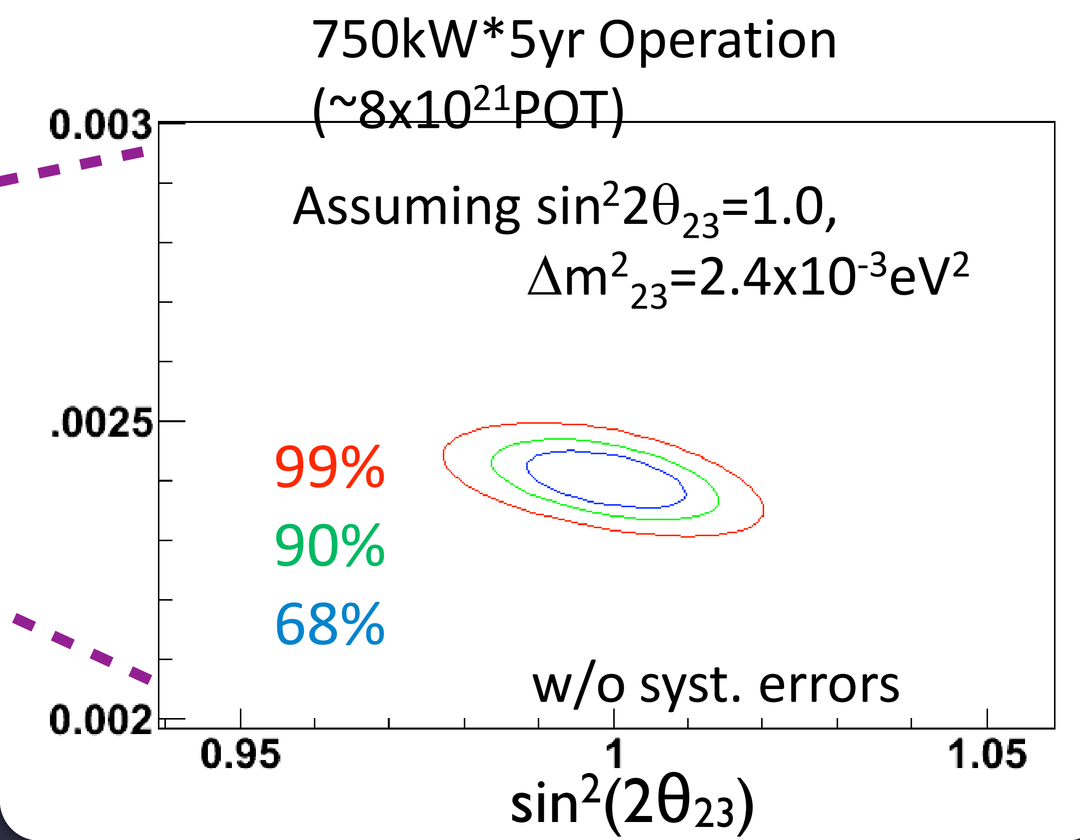


θ_{23} Sensitivity

Previous Measurements



T2K Sensitivity

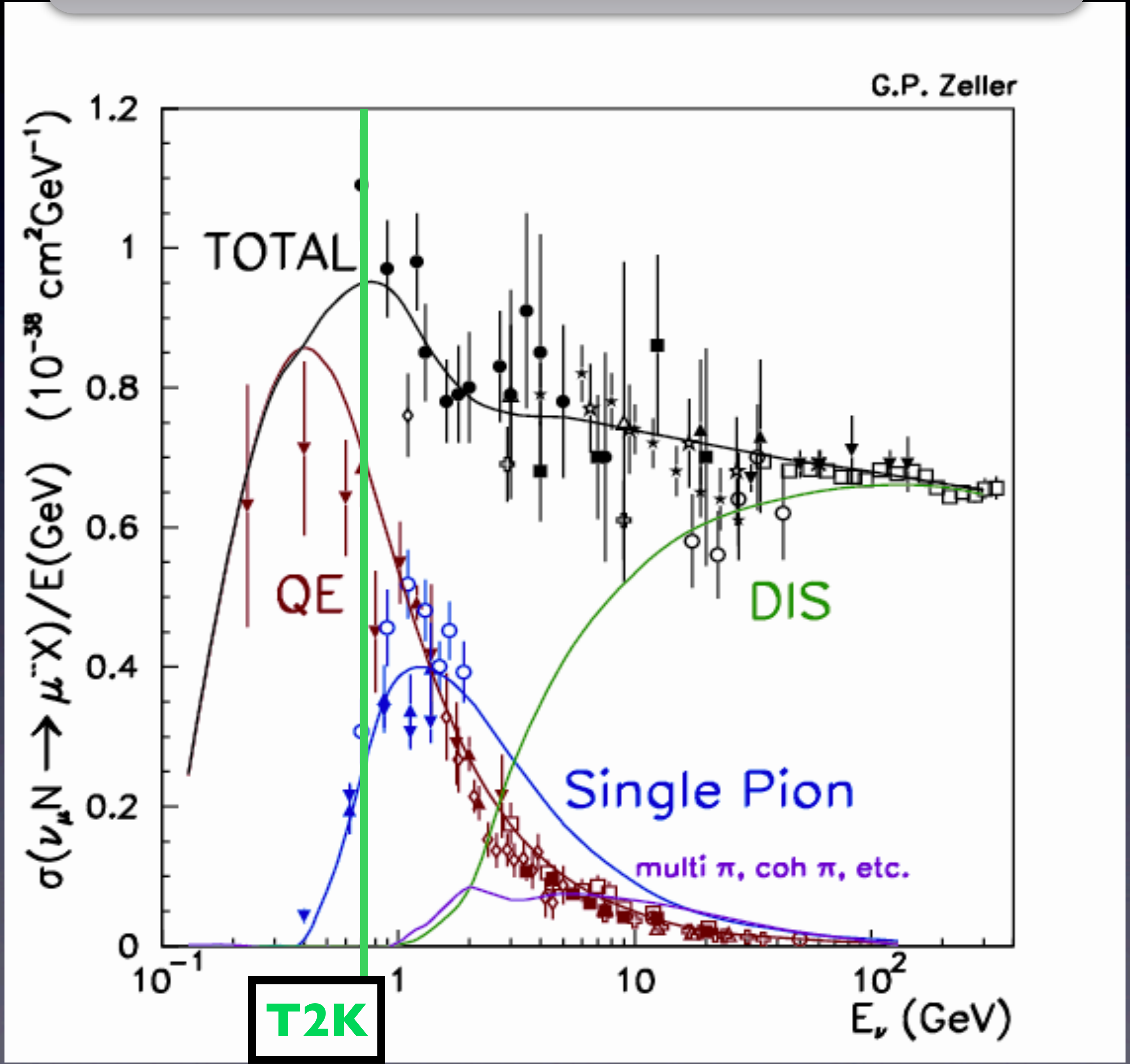


- Search for the disappearance of muon neutrinos
- Current knowledge of the atmospheric mixing parameters comes from MINOS, K2K, and Super-K
- T2K can make very precise measurements:
  - $\delta(\Delta m^2_{23}) \sim 10^{-4}$
  - $\delta(\sin^2(2\theta_{23})) \sim 0.01$

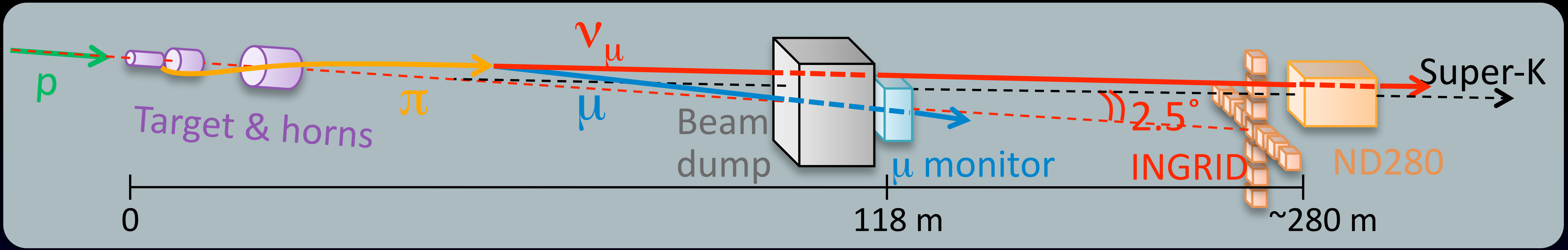
Neutrino Interactions

- Neutrinos are detected through a variety of processes
- Signal mode is CCQE
  - $\nu_{\mu/e} + n \rightarrow \mu^-/e^- + p$
  - allows flavor tagging of the neutrino via the charged lepton
  - dominant process at T2K energies
- Largest charged-current background is $CC\pi^+$
  - $\nu_{\mu/e} + N \rightarrow \mu^-/e^- + N + \pi^+$
  - comparable size to CCQE
- Largest background to ν_e search at Super-K is $NC\pi^0$
  - $\nu_{\mu/e} + N \rightarrow \nu_{\mu/e} + N + \pi^0$
  - Only $\pi^0 \rightarrow \gamma\gamma$ detected in the final state
  - γ and e^- are indistinguishable

Charged Current Cross Sections



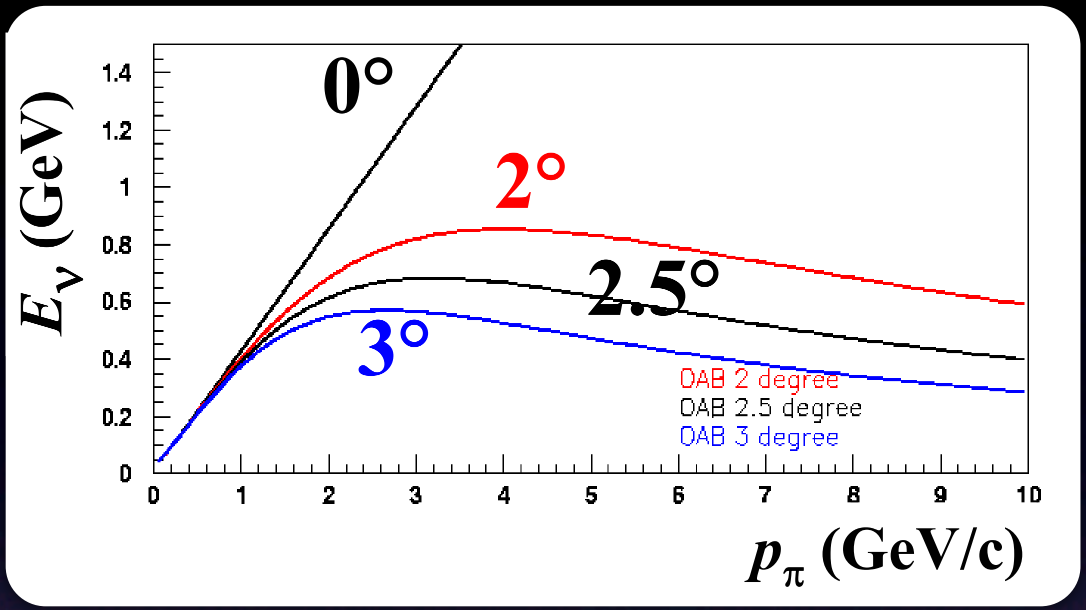
Neutrino Beam

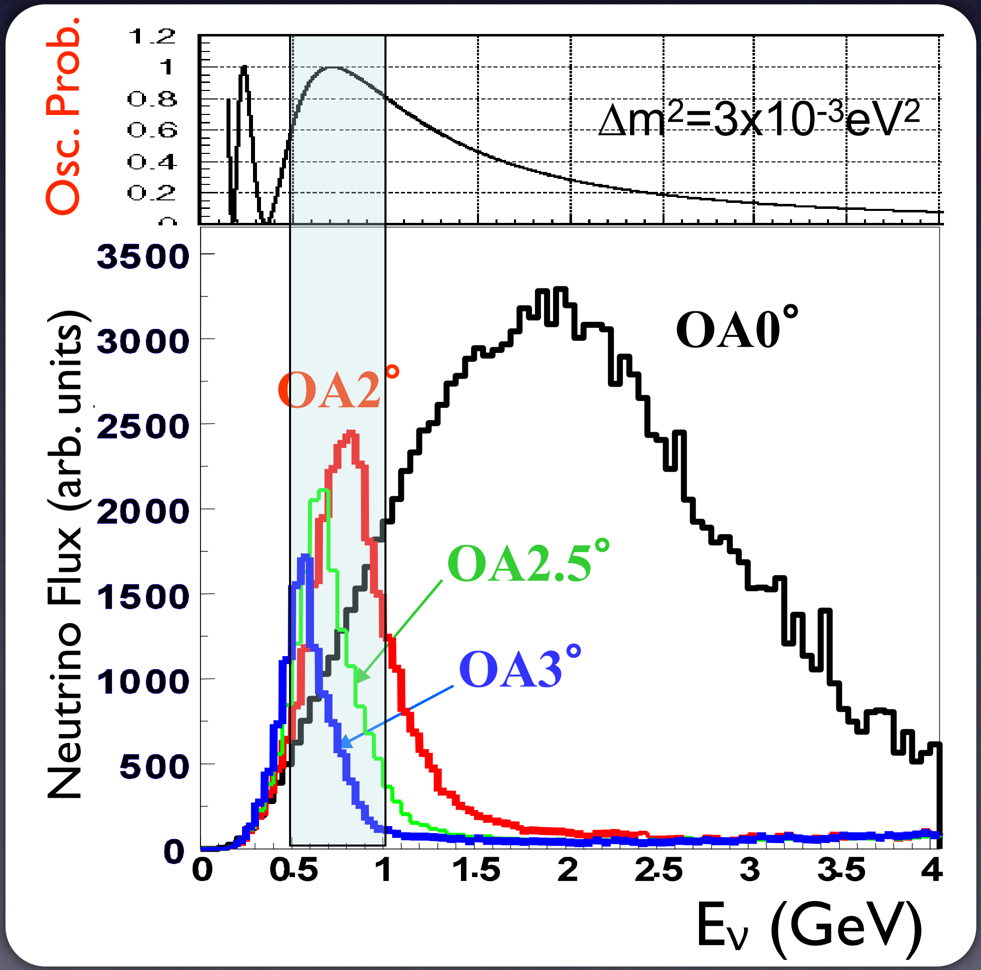


- The J-PARC main accelerator ring produces a beam of 30 GeV protons that interact in a carbon target
- The secondary mesons produced are focused by series of 3 cylindrical magnetic horns
- The mesons have 100 m in which to decay before reaching the graphite beam dump
- Behind the beam dump is a muon monitor that measures the position of >5 GeV muons to further constrain the beam direction
- The direction of the neutrino beam itself is measured by a cross-shaped array of iron/scintillator modules (INGRID)
- The near detector measures the flux in the direction of Super-K, which is 2.5° away from the mean direction of the neutrino beam

Off-Axis Neutrino Flux

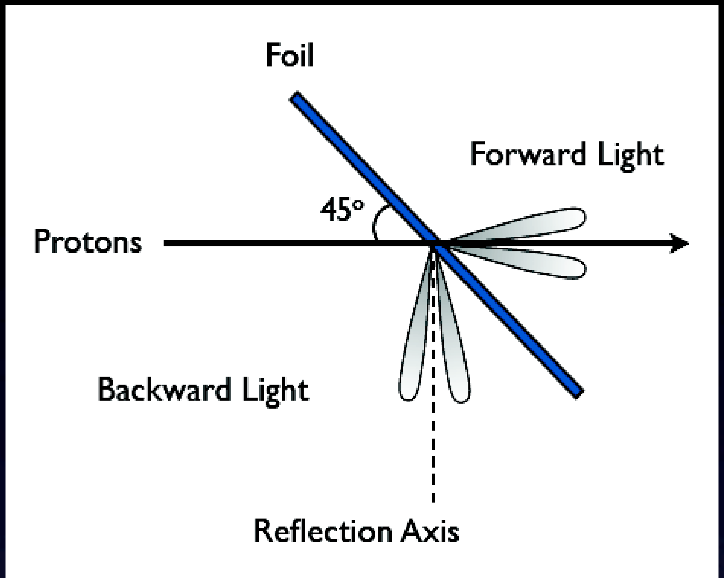
- Neutrinos from pion decay have mean energies proportional to the pion momentum when measured along the direction of the beam
- By pointing the beam slightly away from the detector, the neutrino energies from higher momentum pion pions converge





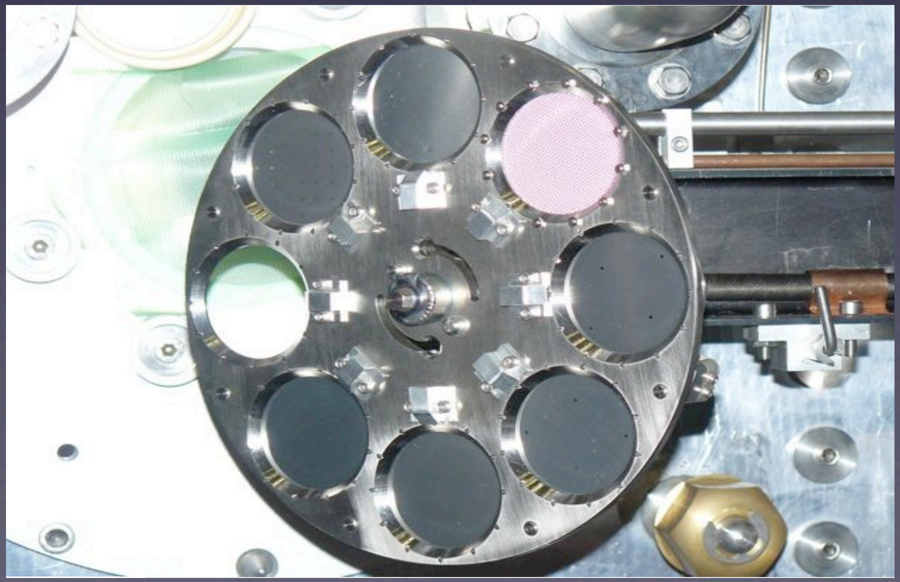
- In this way, the neutrino energy spectrum can be tuned to maximize the flux in the oscillated energy range
- This also provides a way to minimize the high energy tail
  - reduces the NCπ^0 background to the νe appearance search
  - reduces the multi-pion and deep inelastic scattering background to ν_μ disappearance

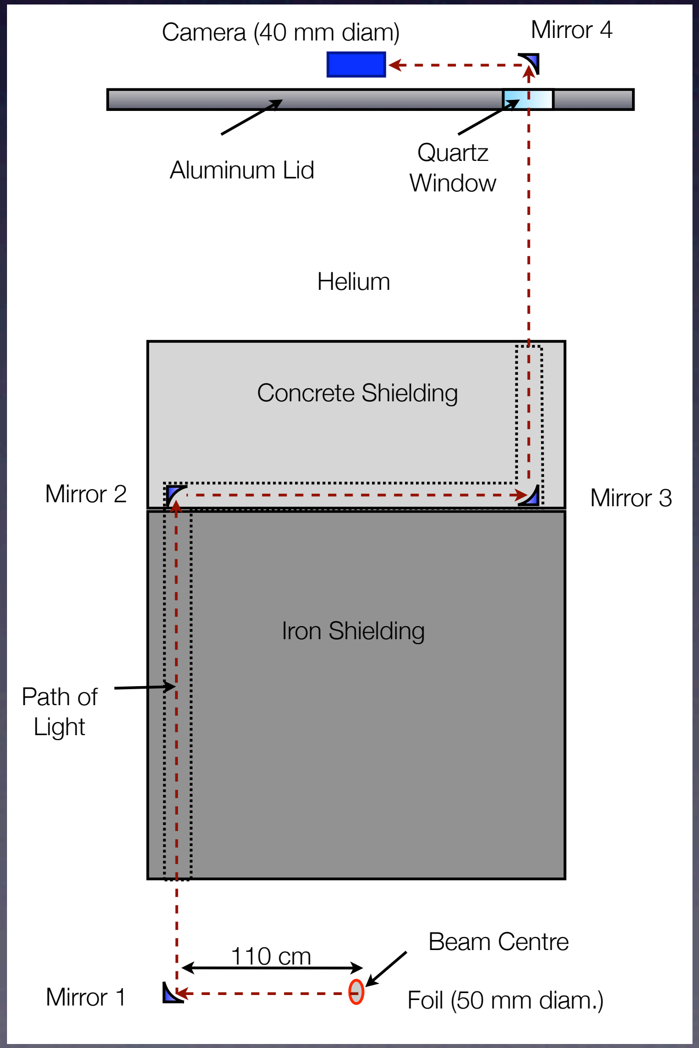
Beam Monitoring



- A series of beam monitors measure the mean beam position along the length of the beamline
- The final monitor, attached to the horn assembly, is OTR (Optical Transition Radiation monitor)
- Titanium foils oriented at 45° relative to the beamline produce reflected light perpendicular to the beam direction

- The reflected light is guided along small passages through the shielding by a series of mirrors
- The shape and position of the beam are imaged by a 40 mm camera

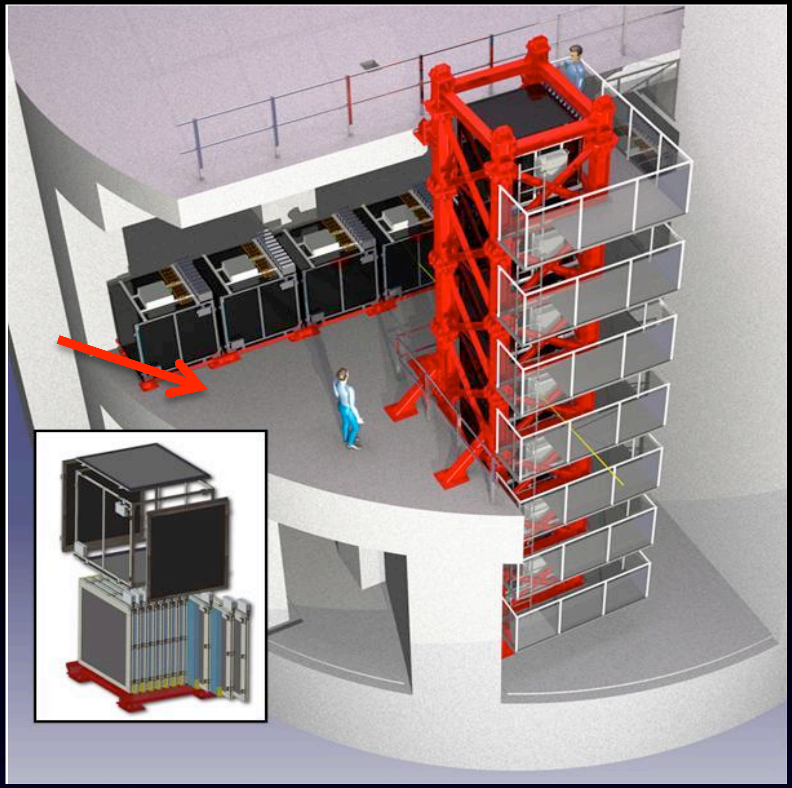


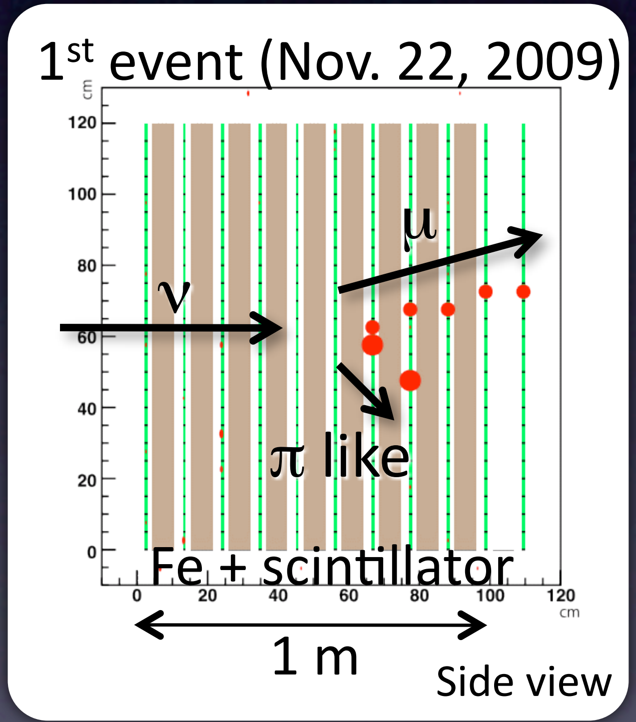


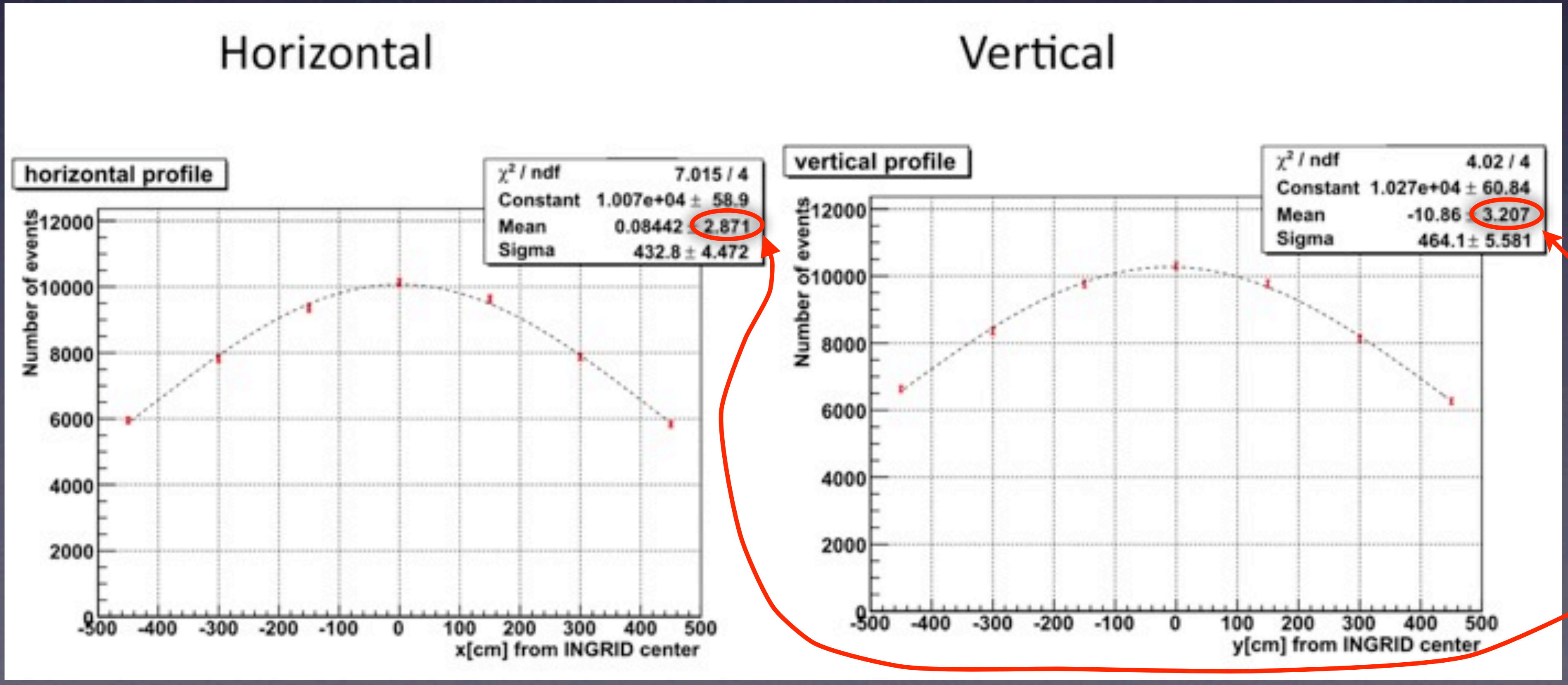
- Built by Unversity of Toronto, York University, and TRIUMF
- See talk by Vyacheslav Galymov

INGRID

- On-axis detector that measures the direction of the neutrino beam
- Composed of 14 modules of alternating iron and scintillator
- Each module counts the number of muon tracks originating within the module
- Variation of rates across the modules provides the mean direction of the beam
- Require ~20 cm uncertainty in the position to constrain the beam to < 1mrad



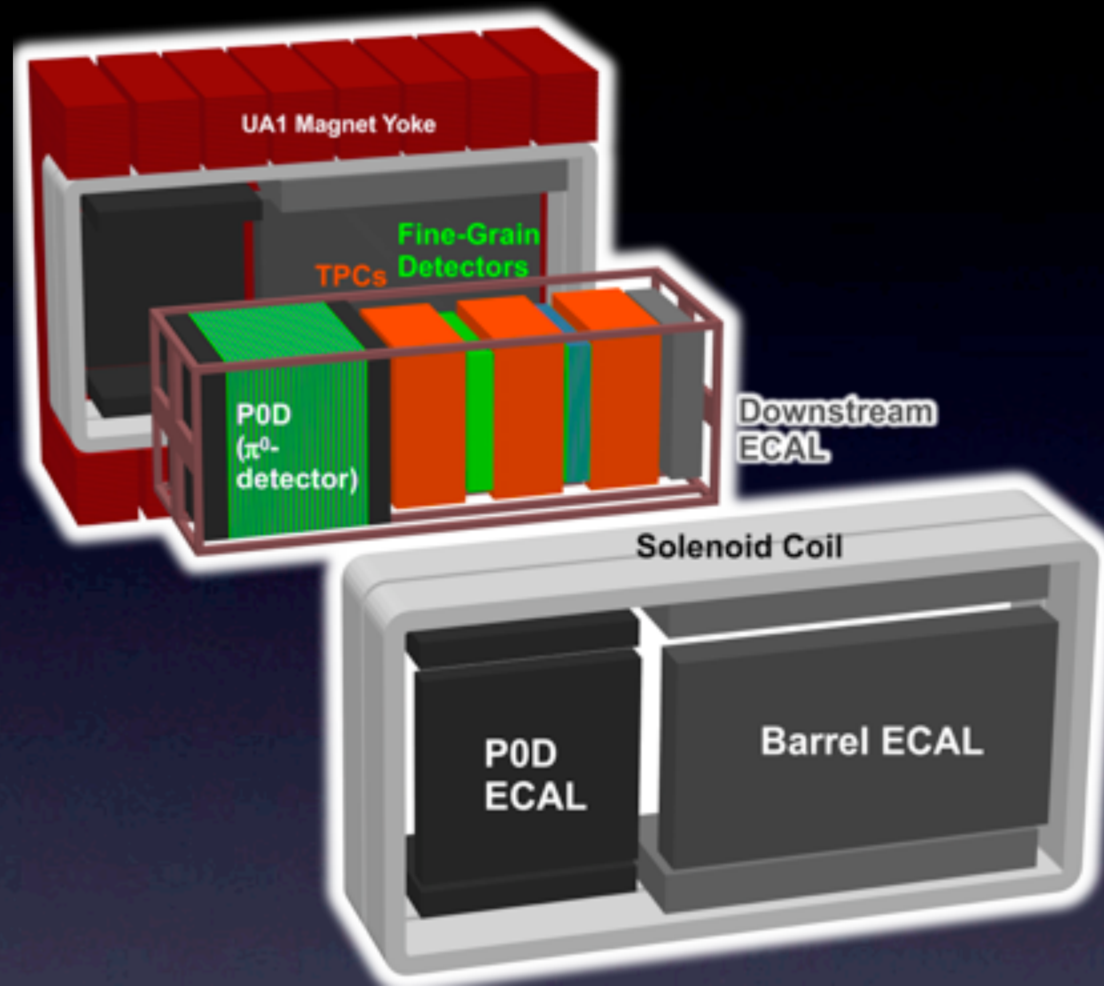


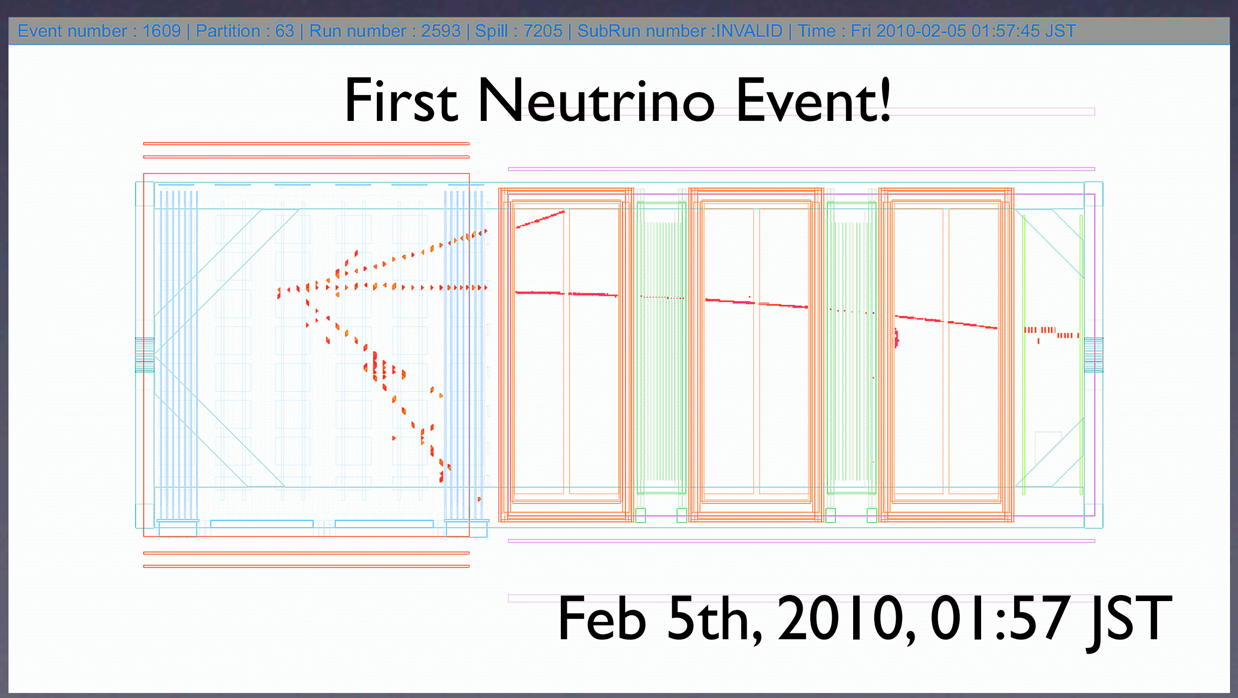


Preliminary Results: 2-4 cm statistical-only uncertainty

ND280

- Enclosed in the 0.2T US1 magnet
- Side Muon Range Detector (SMRD)
  - Scintillator strips embedded within the magnet yokes
  - Used to detect sideways going muons and provides a veto or trigger for cosmic events
- Energy Calorimeter (ECAL)
  - Alternating layers of lead and scintillator
  - Lines the inside of the magnet to detect photons escaping the inner detector
- π^0 Detector (P0D)
  - Measures π^0 production to constrain $NC\pi^0$ backgrounds at Super-K
  - Large mass of lead and scintillator layers to boost production rate and induce photon conversions
  - Intermediate layers can filled with water to measure carbon/$H_2 0$ cross section differences
- Fine-Grain Detectors (FGDs)
  - Alternating XZ and YZ layers of 1x1x190 cm^3 scintillator bars
  - Provides a neutrino target mass and measures the interaction vertex
- Time Projection Chambers (TPCs)
  - Strong electric field drifts ionizations to the side readout modules
  - Primary momentum measurement
  - Provides dE/dx for particle ID

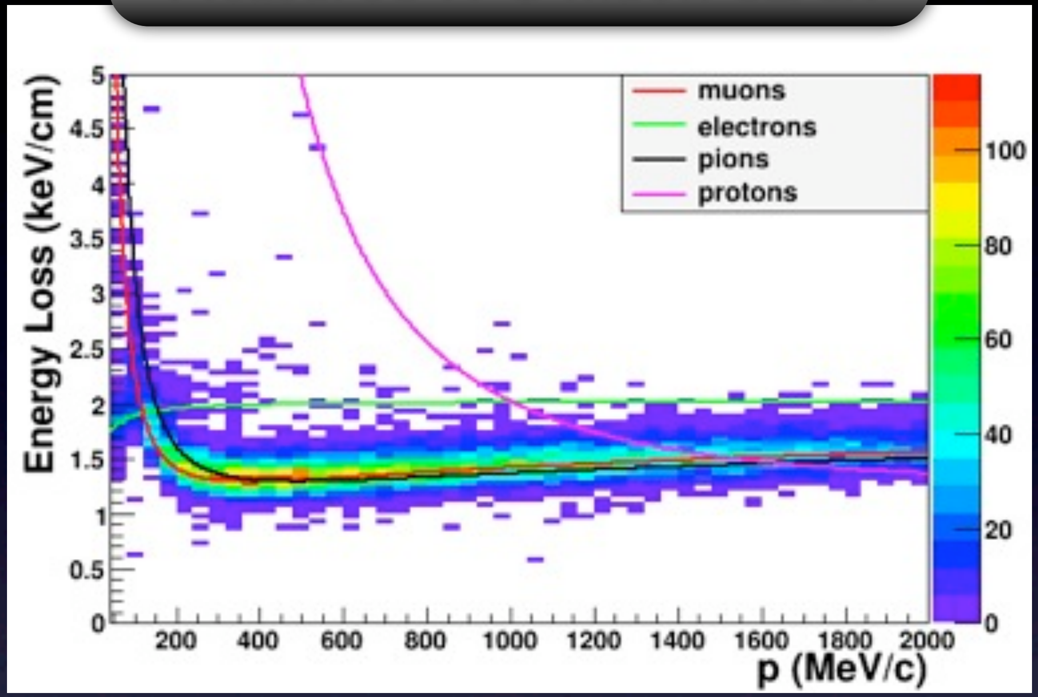


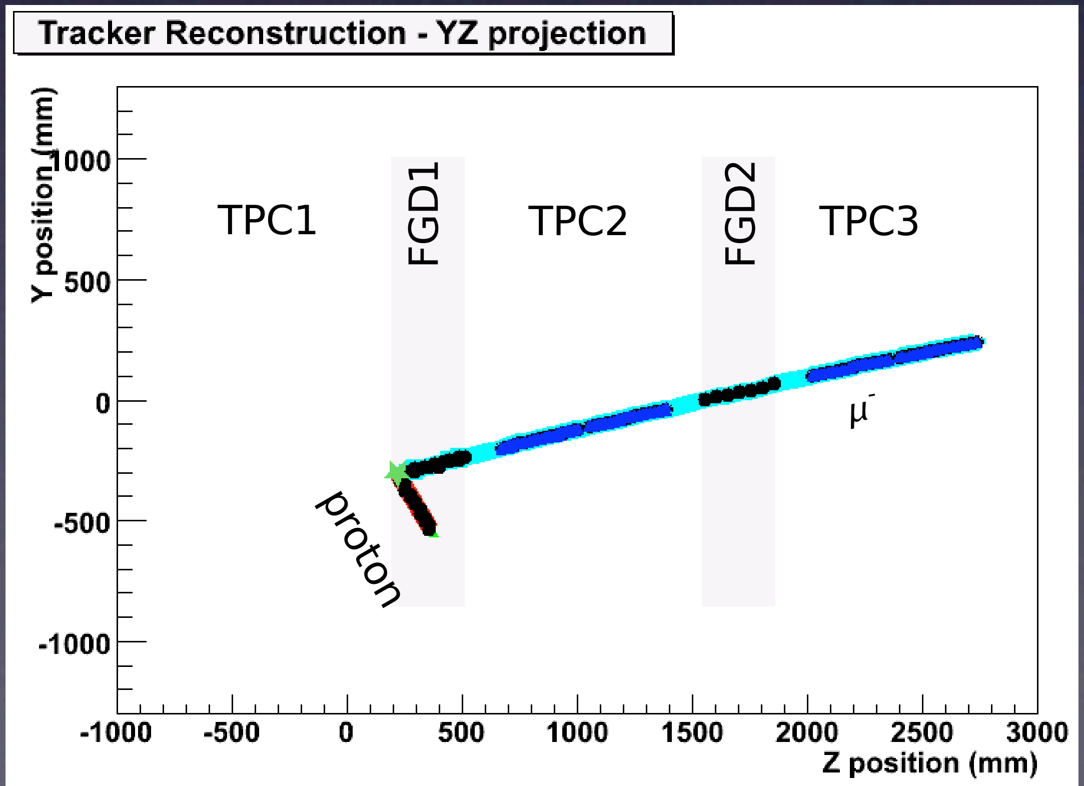


ND280 Tracker

- The tracker portion of the near detector is composed of the FGDs and TPCs
- Primary purpose is to measure muons and electrons from CCQE interactions
  - FGDs measure interaction vertices and low energy protons and pions
  - TPCs provide a precision momentum measurement of particles exiting the FGD, as well as particle identification via dE/dx
- In FGD2, every other scintillator is replaced with a panel of water to provide a means for measuring Carbon/Oxygen cross section differences

Measured TPC muon dE/dx

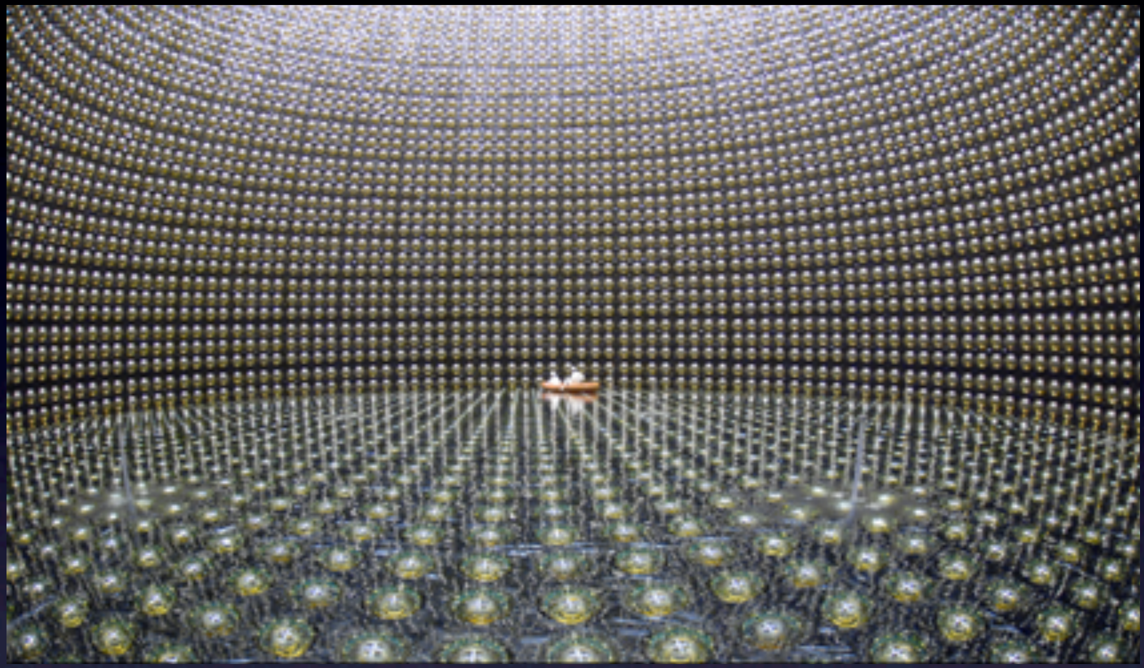


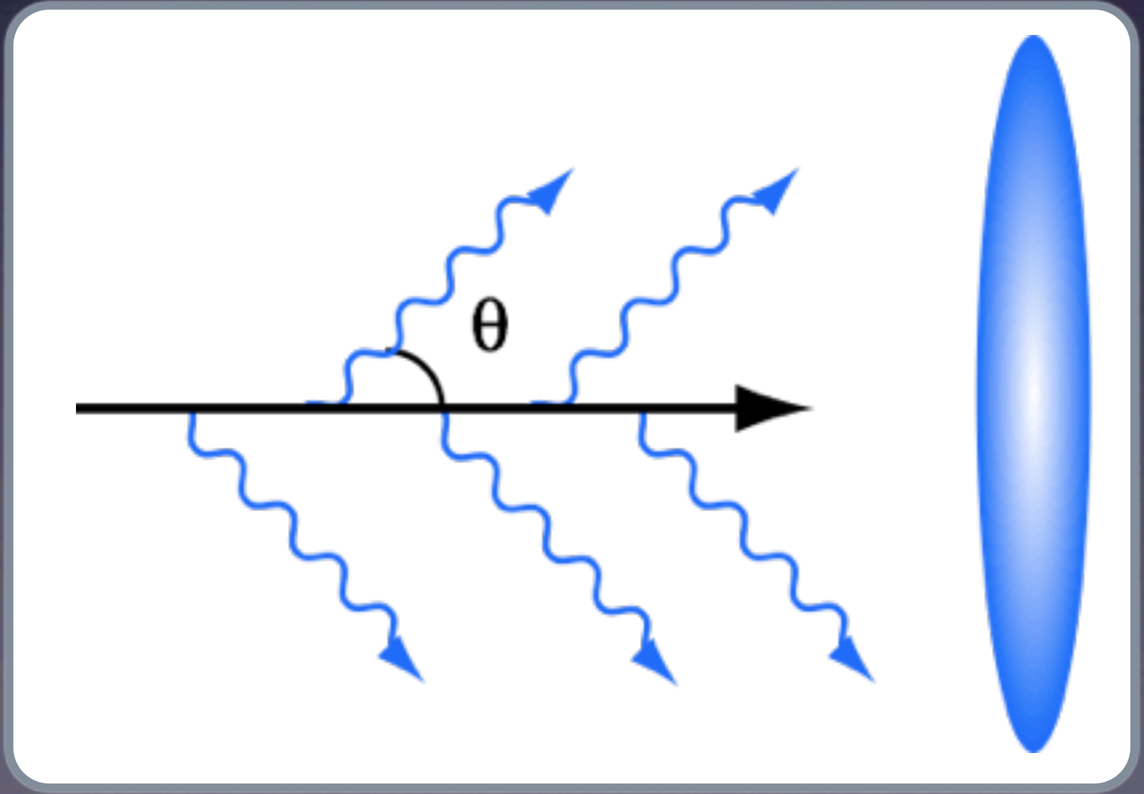


- The FGDs and TPCs were constructed at TRIUMF and shipped to Japan June-October of 2009
- For more detailed descriptions of the tracker at this conference, see:
  - TPC detector talks by Casey Bojechko and Jordan Myslik
  - FGD detector talk by Caio Licciardi

Far Detector: Super KamiokaNDE

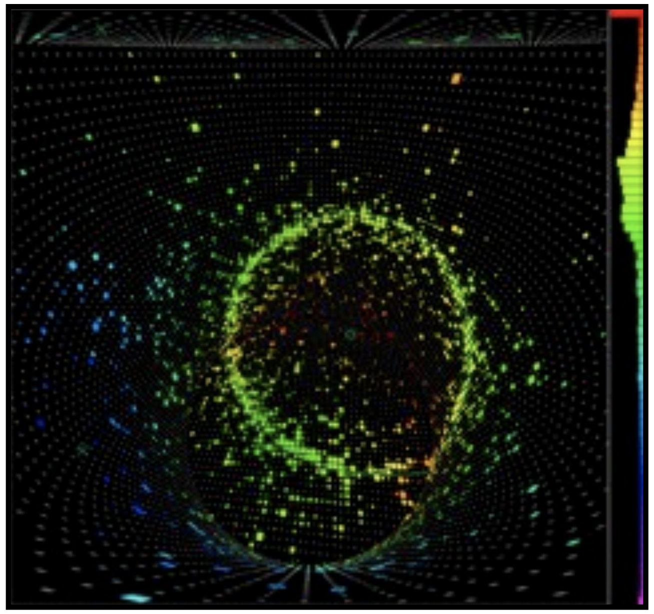
- 50 kton water Cherenkov detector
  - Cherenkov radiation produced by charged particles is imaged as a ring on the tank wall
- Cylindrical shape: 39.3 m diameter, 41.4 m height
- The inner tank is lined with 11129 photomultiplier tubes (20 in diameter)
  - provides 40% coverage of the inner surface
- The outer veto region contains 1885 8 in tubes



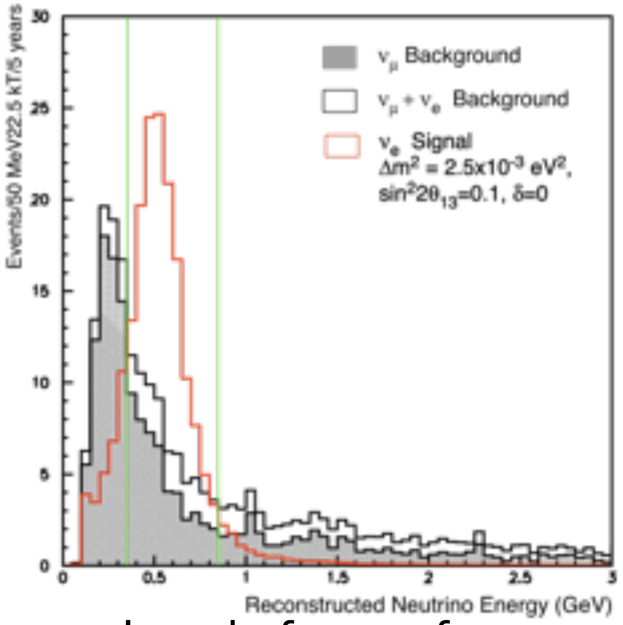


Super-K Event Identification

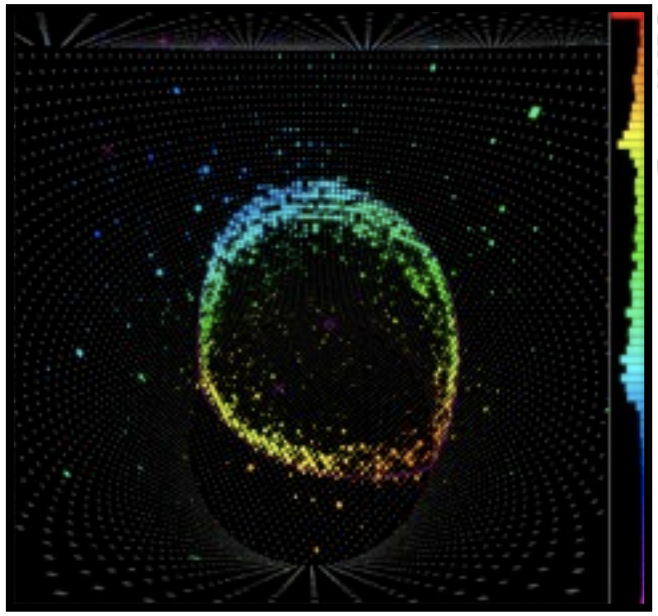
- Electrons undergo large amounts of scattering, creating thin fuzzy rings
- Muons travel in straight paths and produce rings with sharper edges
- μ/e separation ~99% at 600 MeV/c
- NCπ^0 events produce two photons from π^0 decay
  - photons convert to e^+/e^- pairs that produce e-like Cherenkov rings
  - If the other photon goes undetected, becomes a background to ν_e appearance



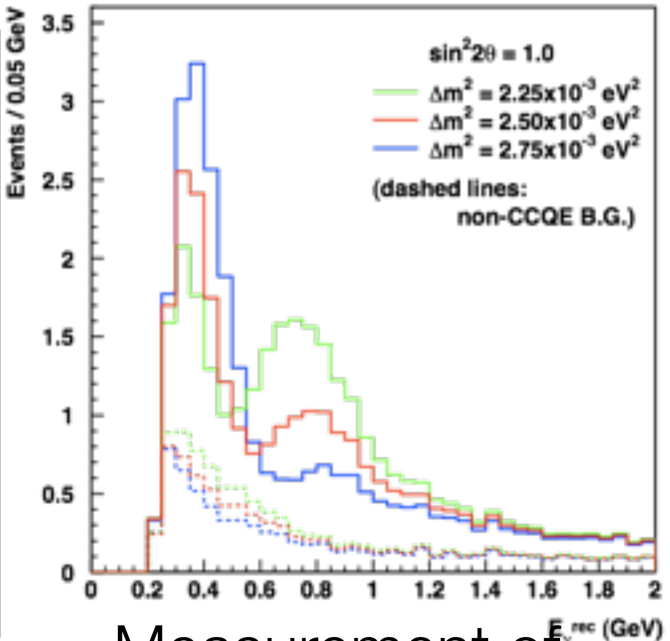
SK electron-like



Look for ν_e from oscillations

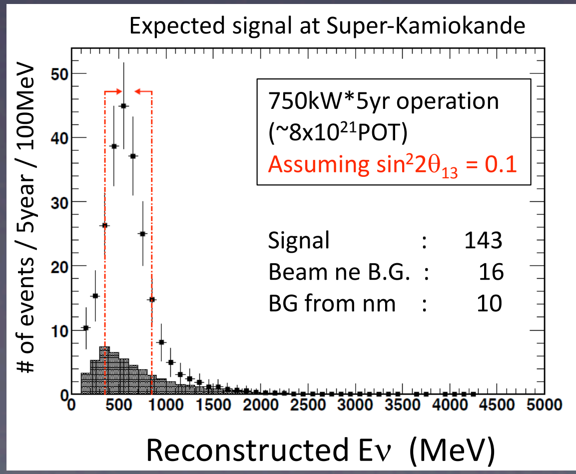


SK muon-like



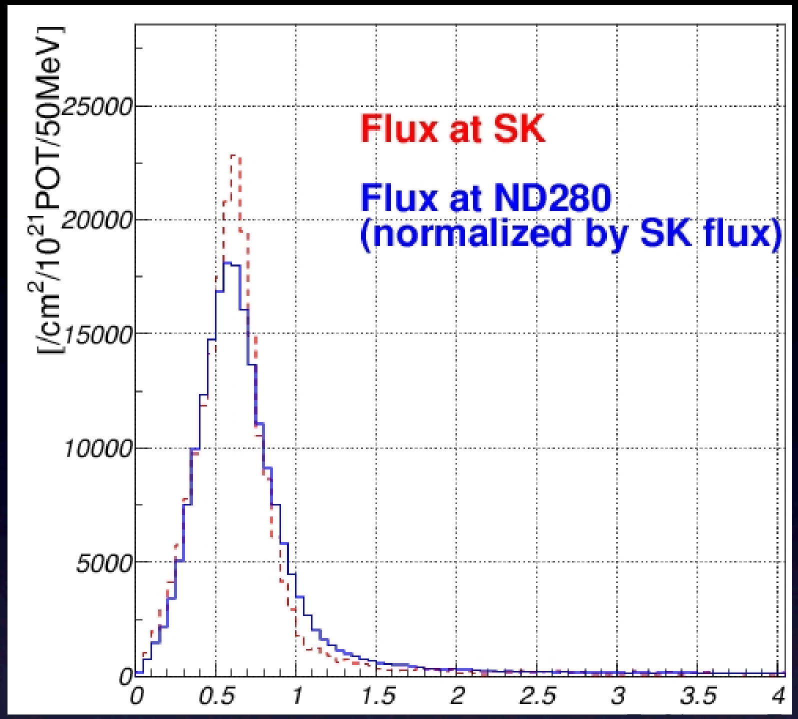
Measurement of oscillated ν_μ spectrum

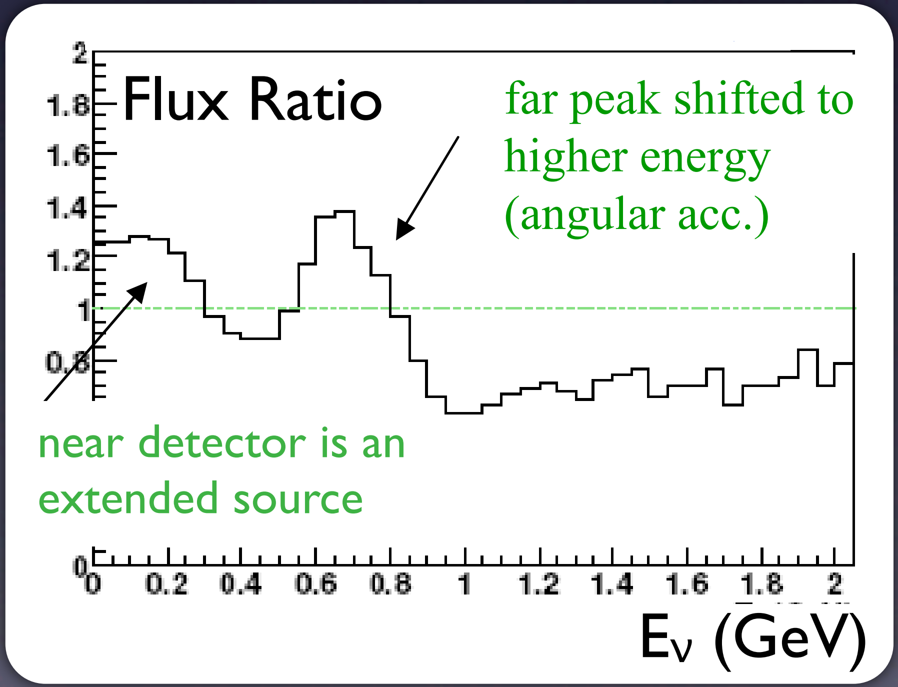
PRACTICE TALK NOTE:
Why are there 2 versions of the ν_e plot floating around?



Near to Far Extrapolation

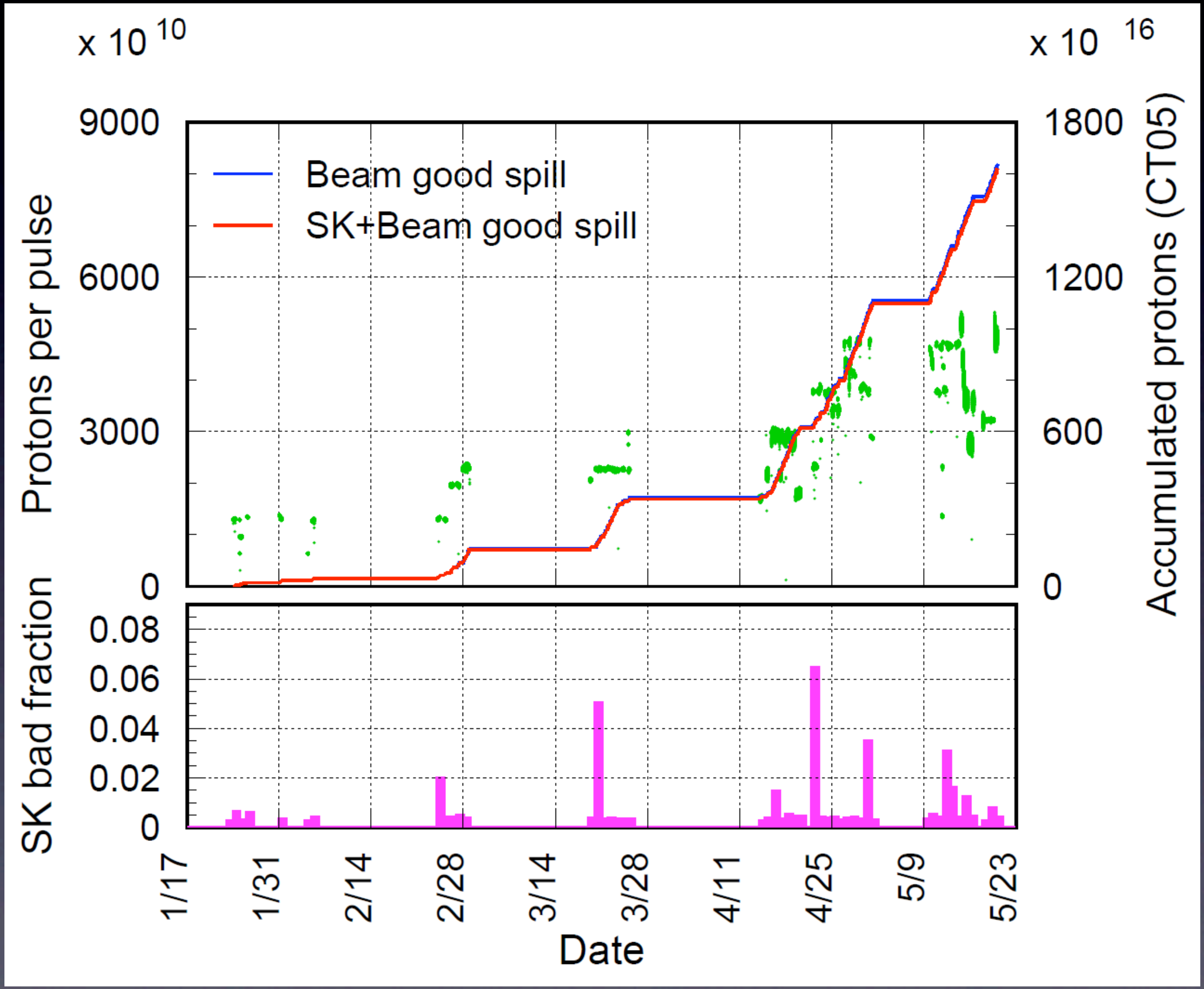
- The T2K experiment is not a simple ratio of measured event rates
- The flux is not the same at the near and far detector
  - Need well tuned beam Monte Carlo to predict flux ratio
  - Beam monitoring, muon monitor, and INGRID are needed
  - Input from external pion and kaon production experiments
    - The NA61 experiment measures these cross sections using a T2K replica target
- The far detector is composed of oxygen, while the near detector is predominantly carbon
  - Measure O/C ratios using FGD1/FGD2 and P0D water in / water out
- The detector behavior is very different for the near and far detector
  - Careful study of the near detector is needed using, cosmics, light injection, etc.
  - Despite 15 years of operation, T2K presents new challenges for the Super-K detector
    - find low energy photons from π^0 decay
    - resolve an oscillation in a very sharp energy peak
- Still plenty of work to be done





Data Accumulation

- Physics data taking began in January 2010
- Rapid improvements in the accelerator have boosted the delivered beam to 6×10^{13} protons/pulse
- In April-June, rapid accumulation of protons as only T2K was(is) receiving beam
- We hope accumulate 50 $kW \times 10^7 s$ of beam by the conclusion of the first data period at the end of June



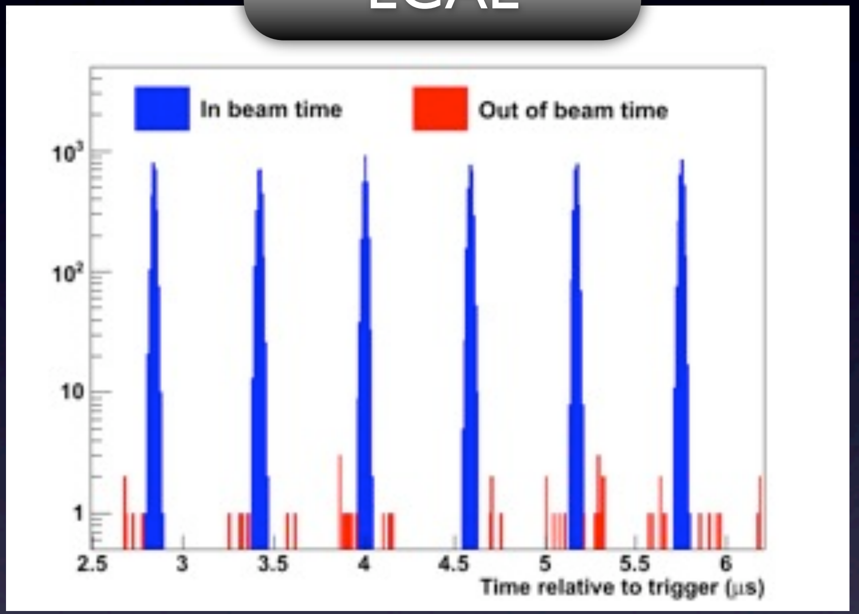
PRACTICE TALK NOTE:

These are Super-K good spills. Do we have a more relevant version of this plot?

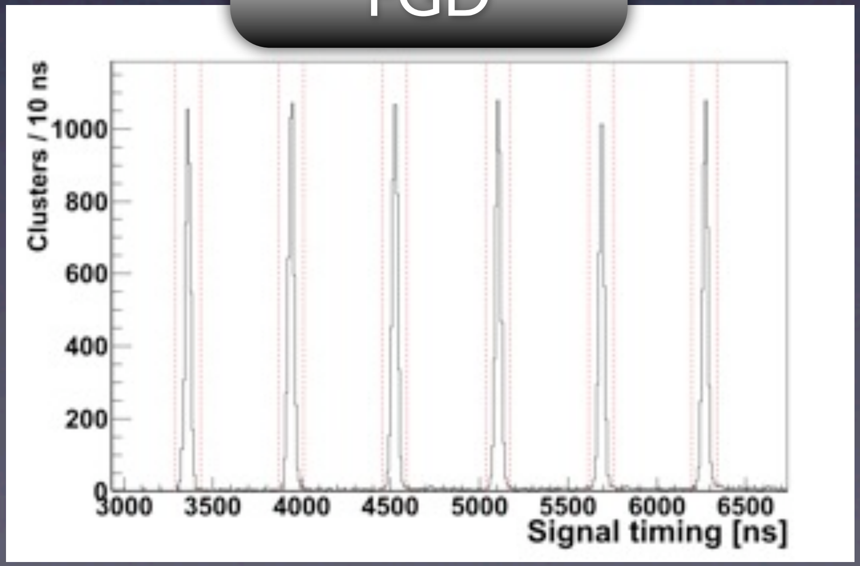
Reconstructed Timing

- The beam is delivered in six bunches separated by 581 ns
- By requiring a minimal number of hits with more than a few photo-electrons of charge, the bunch structure is clearly visible in all detectors
  - The ECAL, P0D, and INGRID collect data for ~500 ns followed by a brief reset period
  - The P0D shows the time distribution before and after the hit charge selection cuts

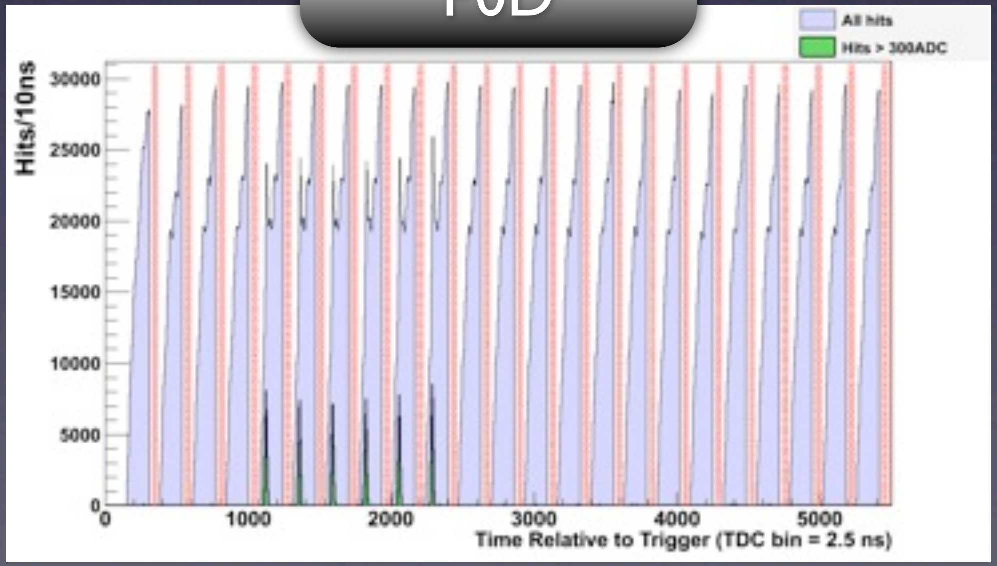
ECAL



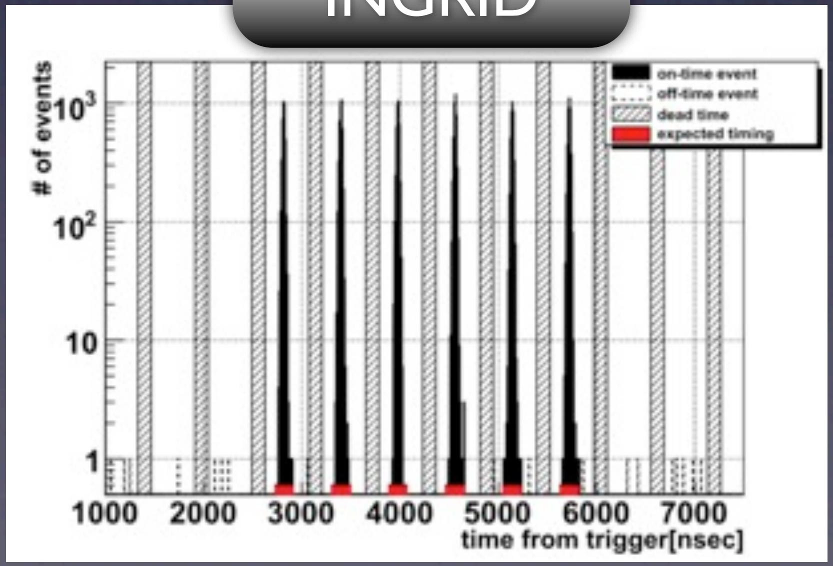
FGD



P0D

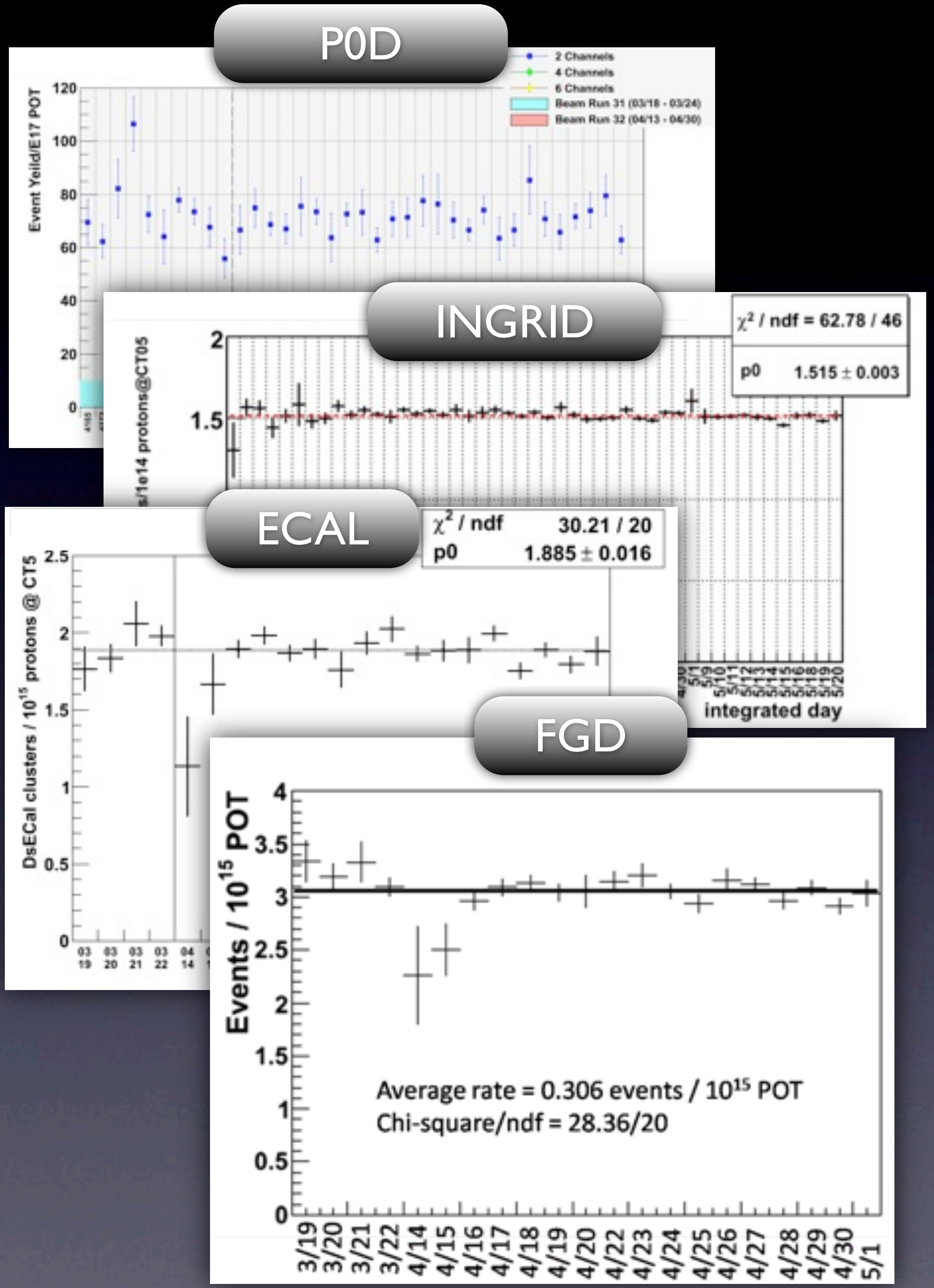


INGRID

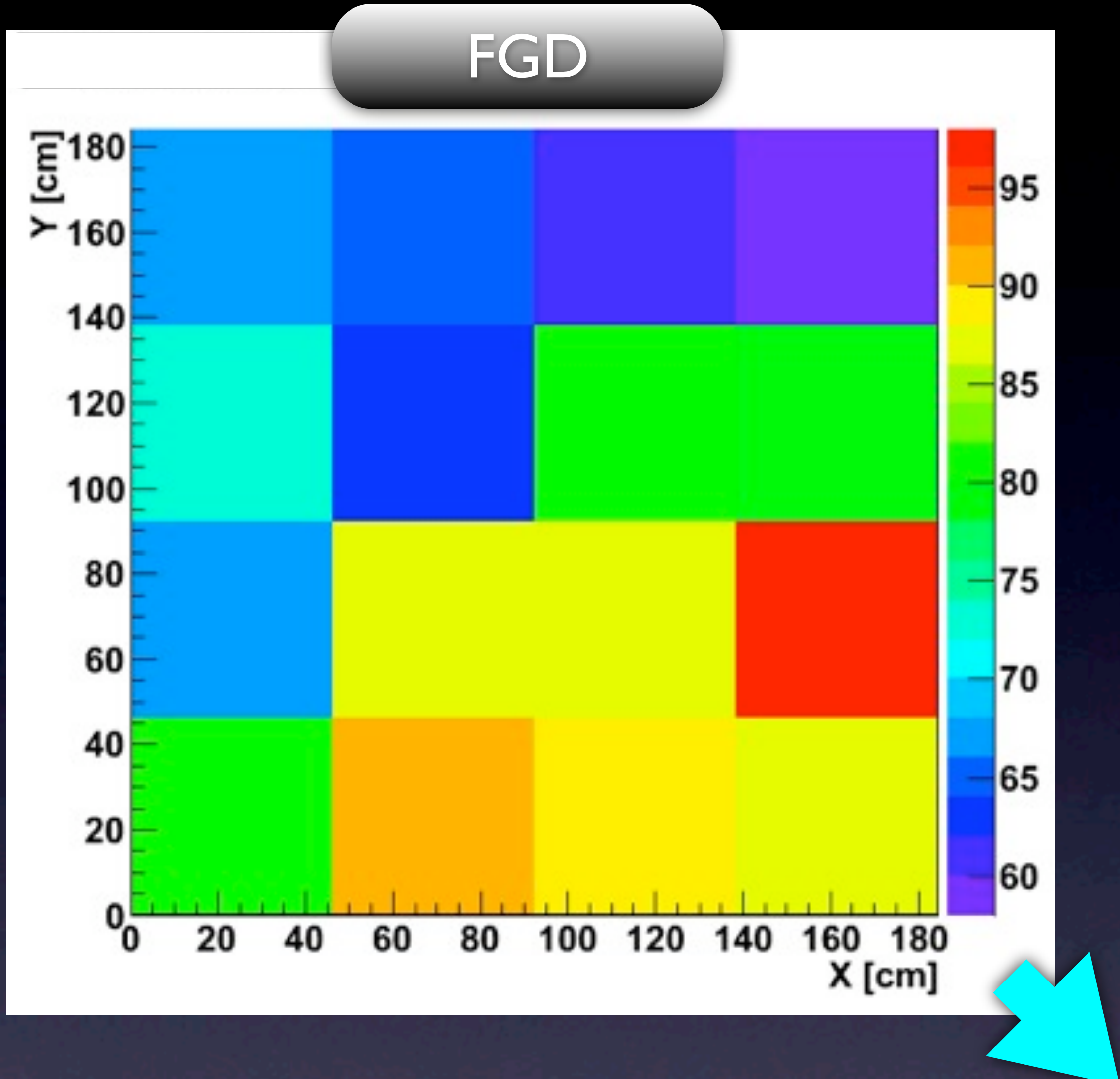


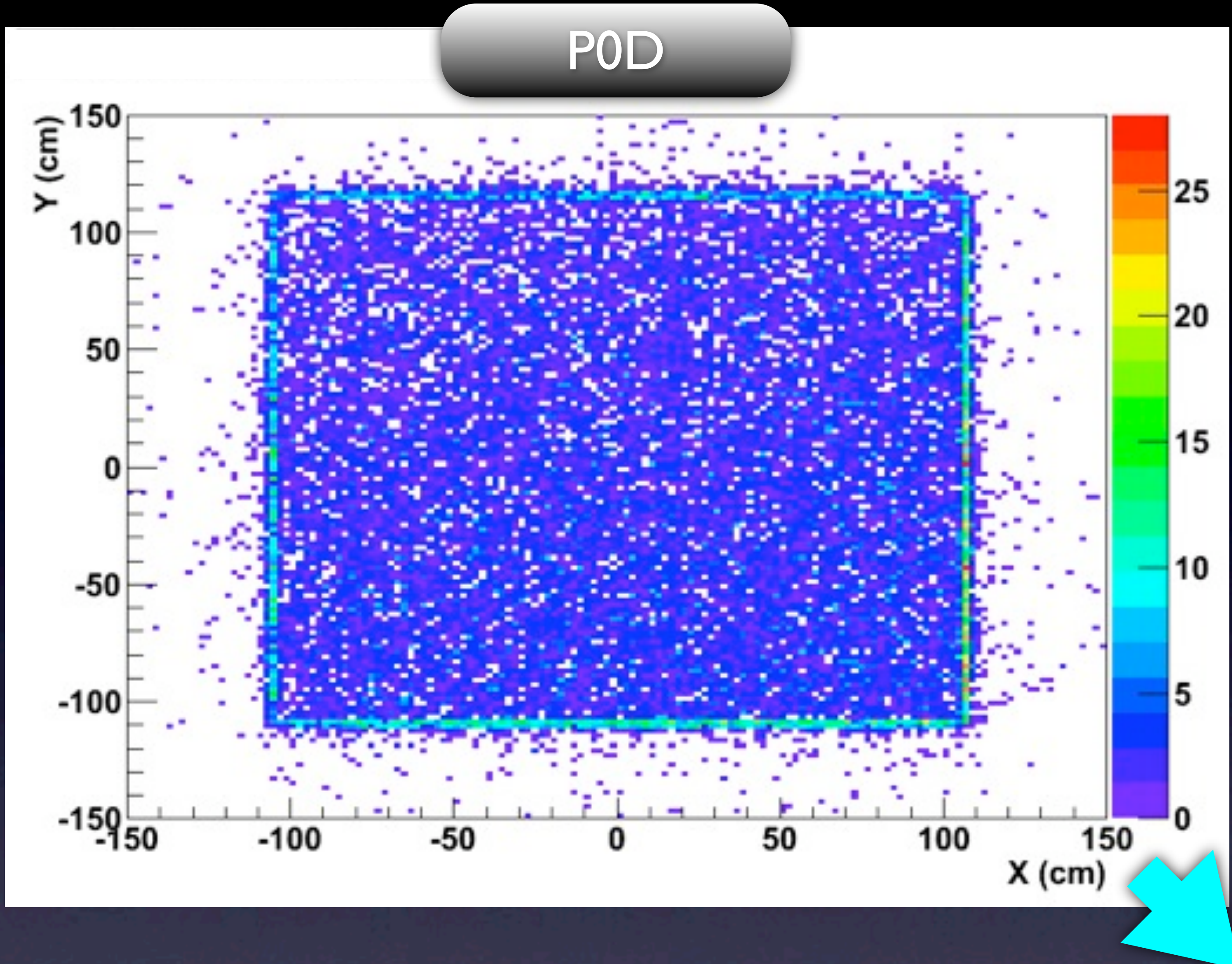
ND280 Event Rates

- Neutrino events are now being reconstructed in all detectors
- The number of events per POT is stable over time



Vertex Distributions





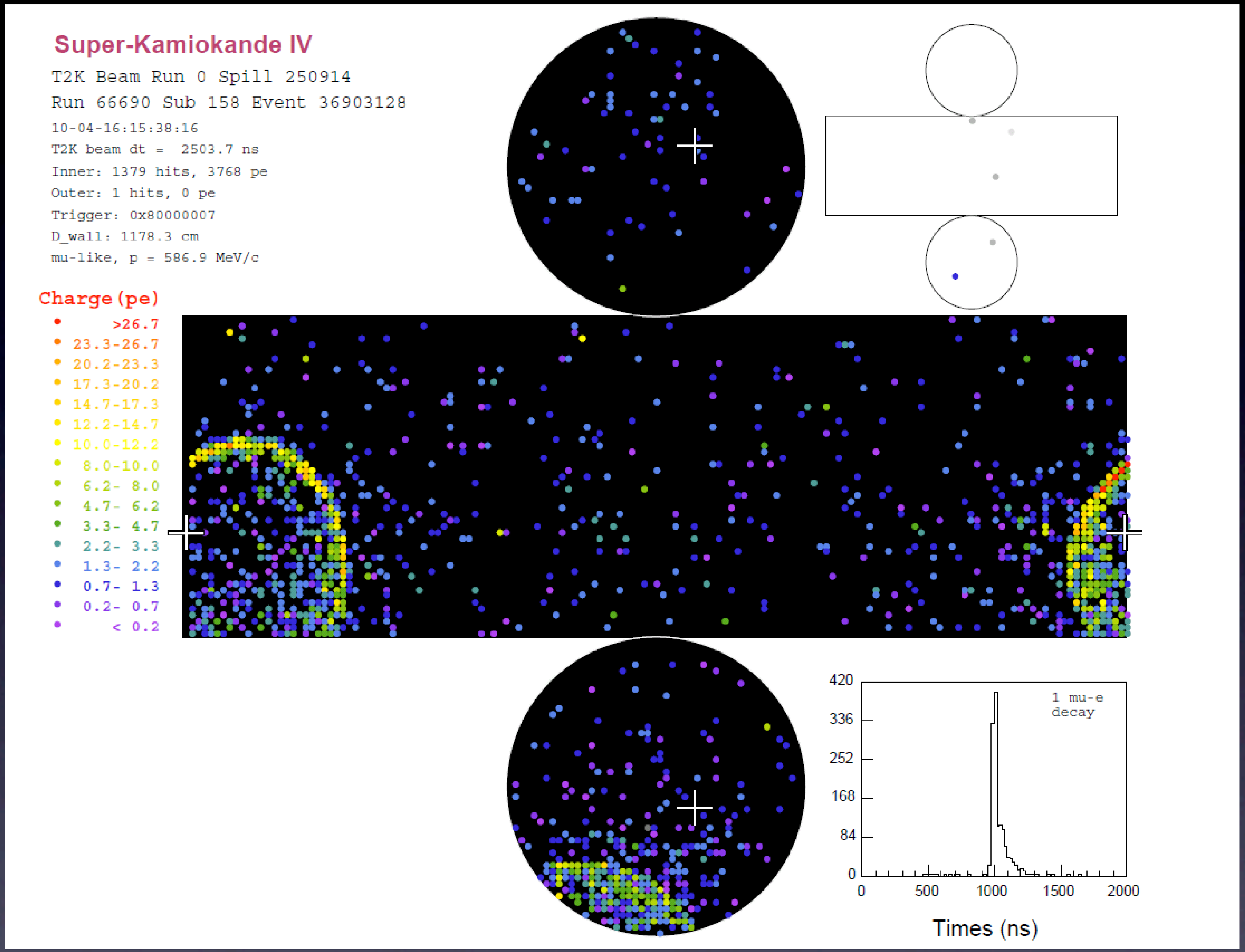
Beam Center

Beam Center

- Both the P0D and FGD can reconstruct event vertices
- In the FGD, after selecting only CC-like events that originate within the detector, an excess is seen in the region closest to the beam center
- Without any requirement that a track originates within the detector, an excess of events entering the P0D from the beam center is observed

Super-K Events

- We have begun seeing the first T2K beam events at super-K!
- The display shows one of our first νμ candidate events
- **PRACTICE TALK NOTE:** Identify the beam direction

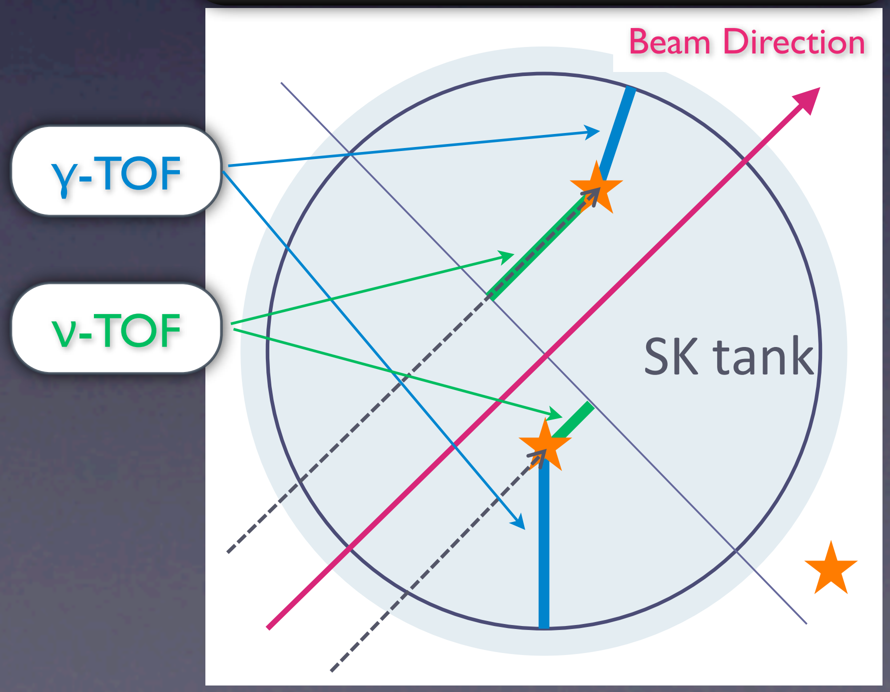


Neutrino spectrum analysis is underway!

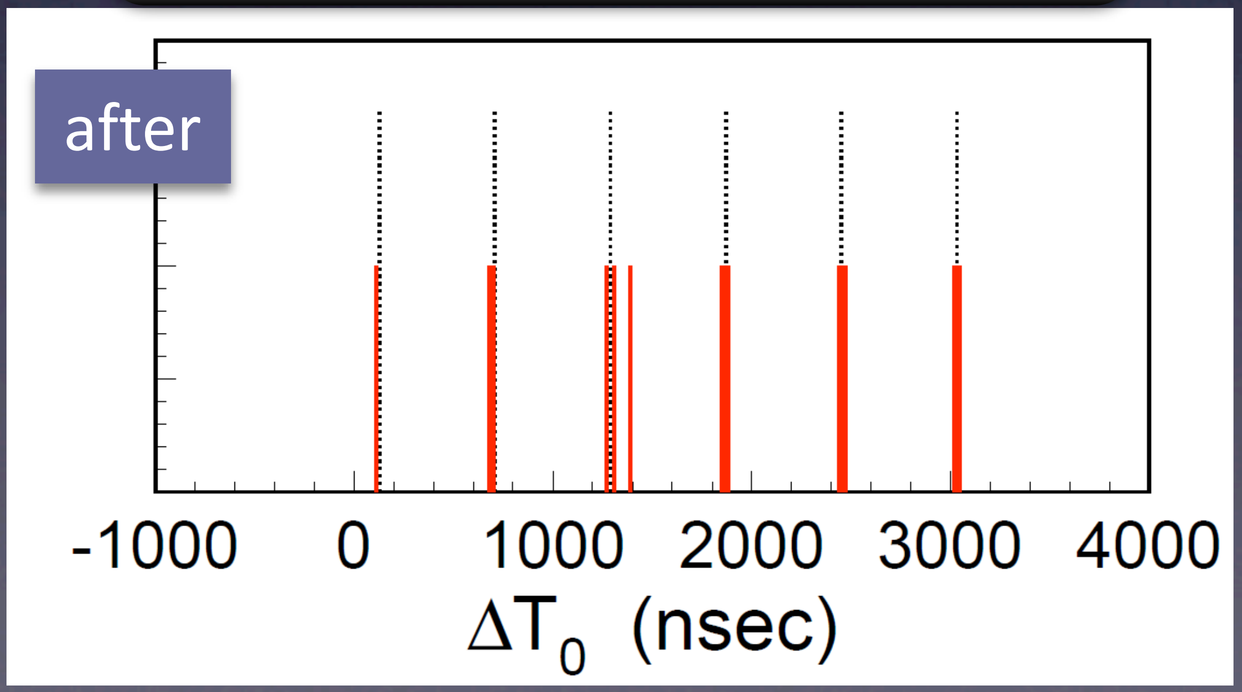
Super-K Event Timing

- Can check the time structure of T2K events in Super-K
- Correct for time of flight (TOF) of the neutrino, and the resulting Cherenkov photons based on the reconstructed event vertex
- The resulting time distribution shows the beam bunch structure for Super-K events

Vertex Time Correction



Corrected Event Time Distribution



Summary

- T2K can improve the limits on θ_{13} by as much as an order of magnitude
  - comparable sensitivity to current limits with the first year of data
- Events have now been observed in both the near and far detectors
  - Data in both detectors are consistent with beam time structure
  - Event rates are stable with POT
- First year of data taking will conclude at the end of June
  - Detailed analysis efforts are underway
- Many exciting physics results to follow...