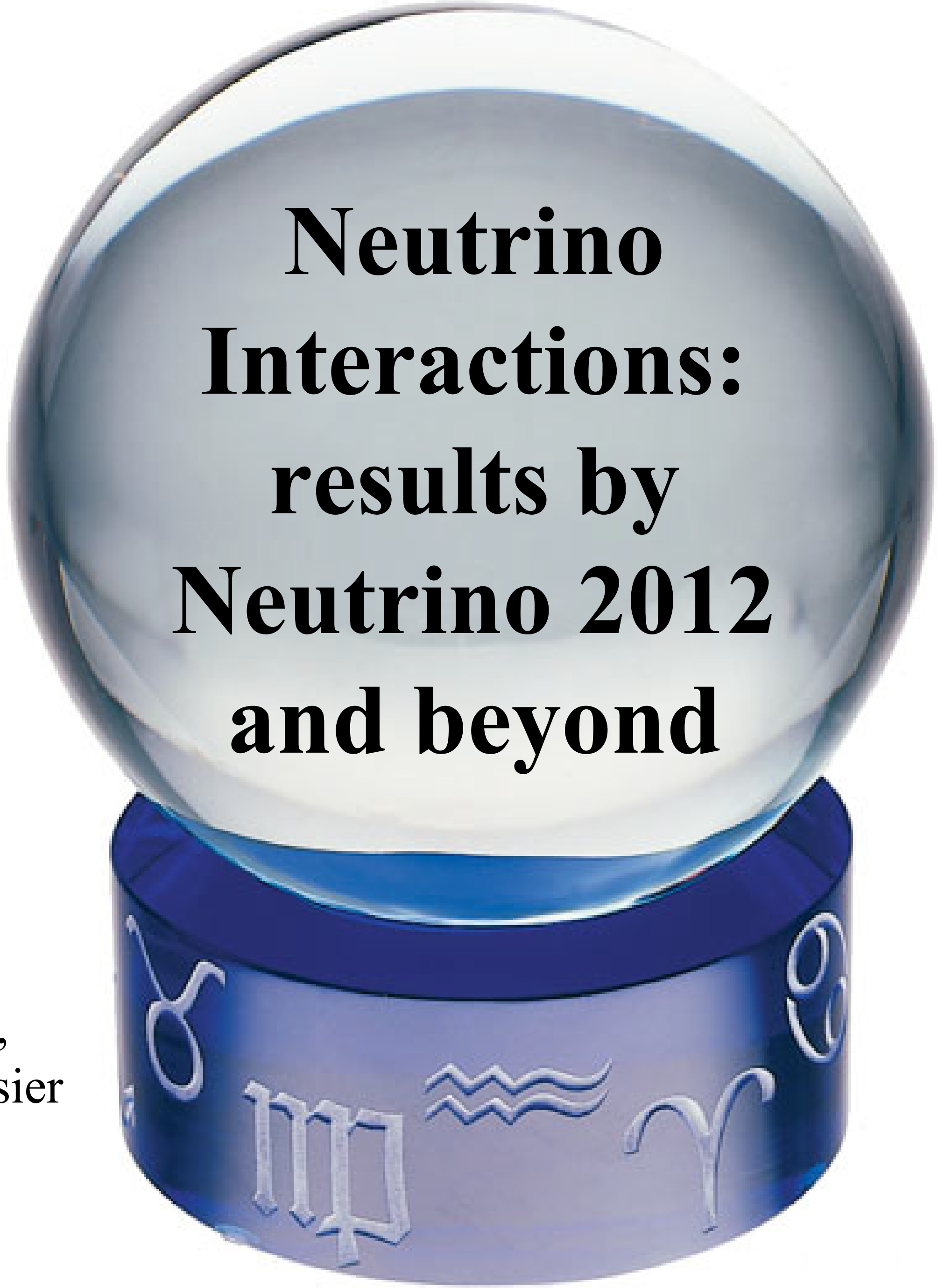
Neutrino Interactions: results by Neutrino 2012 and beyond



Special thanks to:
The MINERνA Collaboration,
T. Nakaya, C. James,
B. Fleming, M. Messier

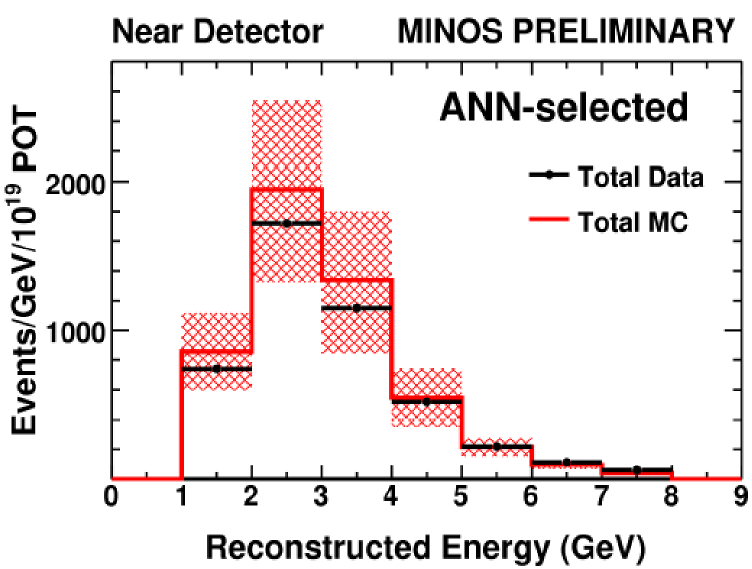
Deborah Harris
Fermilab
Neutrino 2010
Athens
June 18, 2010

Outline

- Top 3 Reasons to study Neutrino Interactions
- Ingredients for an effective program
- How does the current (and future) program do?
  - MINERνA
  - T2K 280m near detector
  - NOνA Near Detector
  - MicroBooNE
- Current Status
- Results by Neutrino 2012
- What's missing?

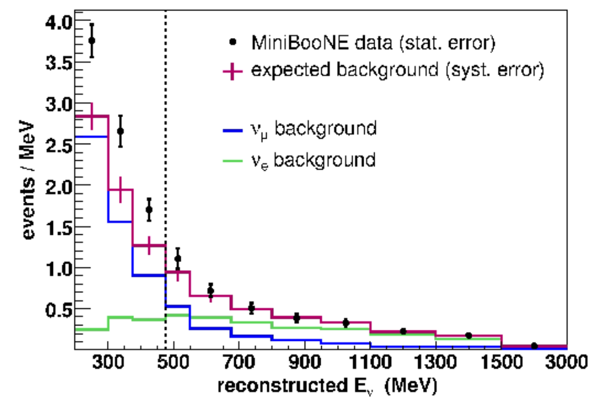
Reason #3: need interactions to measure oscillations

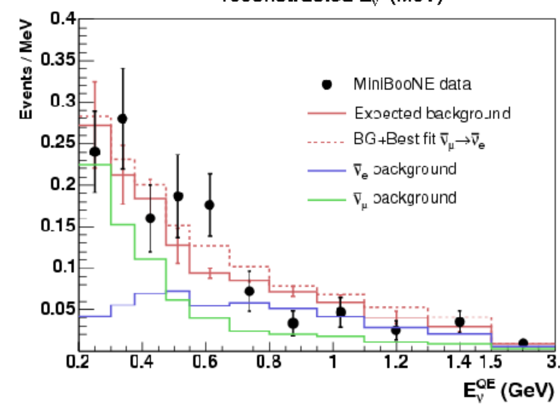
- MINOS $\nu_{\mu\rightarrow}\nu_e$ search
  - Plot below shows ν_e Near Detector candidates after all cuts
  - Near detector data and MC disagree by 15%,
  - Red error band is from hadronic shower uncertainties



Ryan Patterson, FNAL W&C 2010

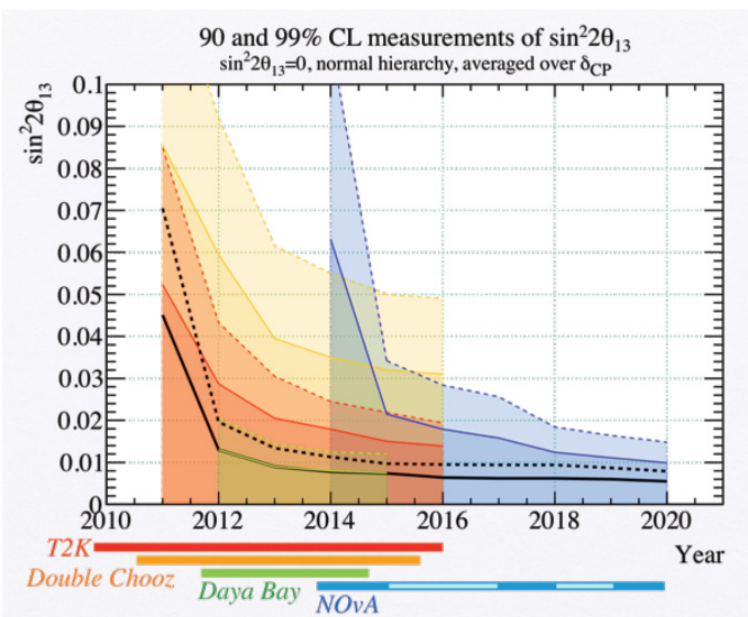
- MiniBooNE low energy excess in neutrino mode
  - Is this a new interaction?
  - Systematic error for future

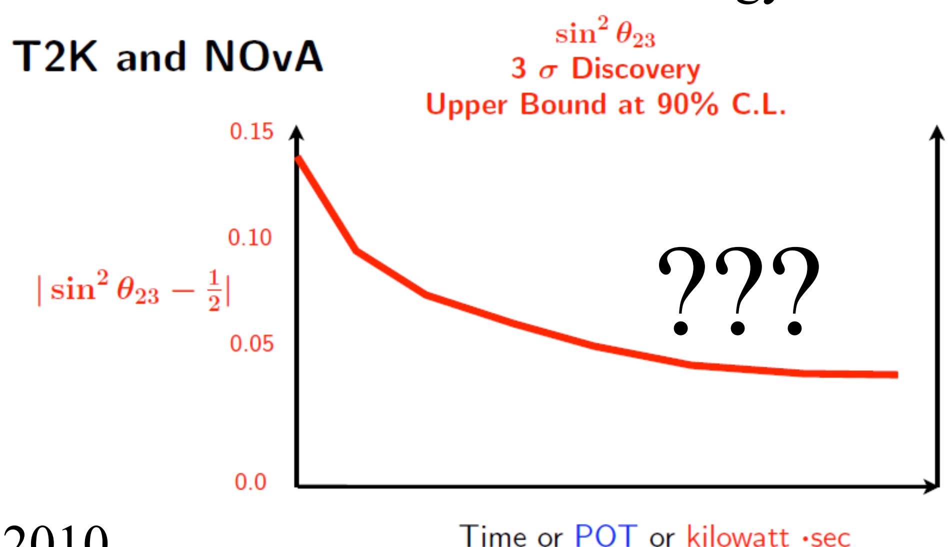




Reason #3: need interactions to measure oscillations

- $\nu_{\mu\rightarrow}\nu_e$ search
  - Seeing excess above background is not the same as measuring θ_{13}
  - You need precise prediction for signal and background both!
  - Near detectors can't do it all
- $\nu_{\mu\rightarrow}\nu_\mu$ search
  - Measuring θ_{23} precisely means you need to measure Δm^2_{23} accurately
  - Need to understand how visible energy appears in detectors
  - Near Detector tells you nothing about relation between true and measured neutrino energy!

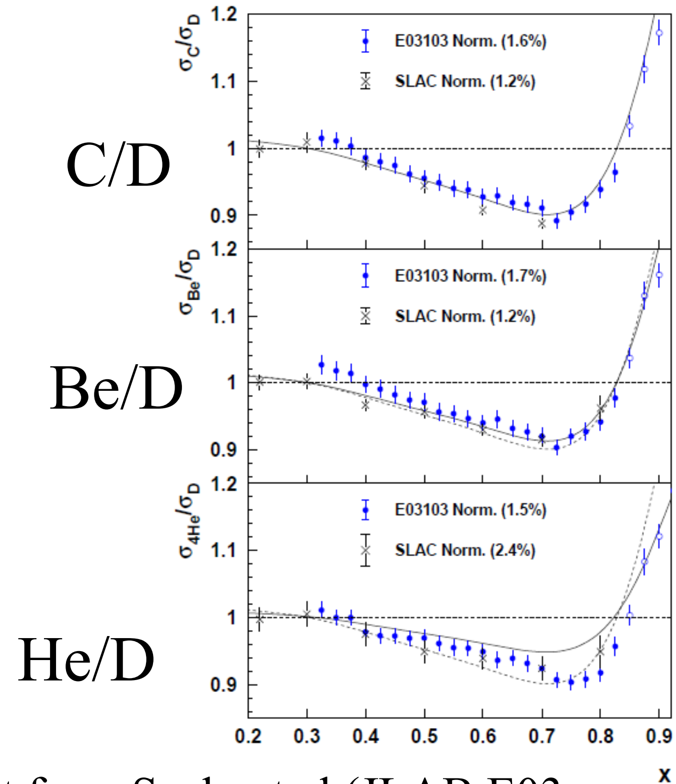




Plots from S. Parke, Neutrino 2010

Reason #2: Neutrinos probe the nucleus in ways electrons cannot

- Deep Inelastic Scattering:
  - "EMC Effect" well-measured in charged lepton scattering (ratio of nuclear F_2 nuclear structure functions to deuterium)
  - In neutrino scattering, there are only hints from fitting several experiments, each with different targets, but also with different fluxes

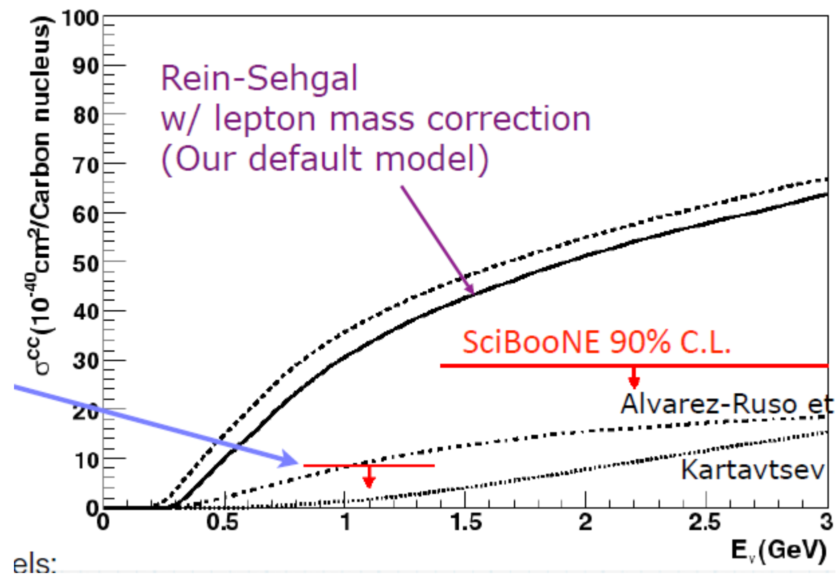


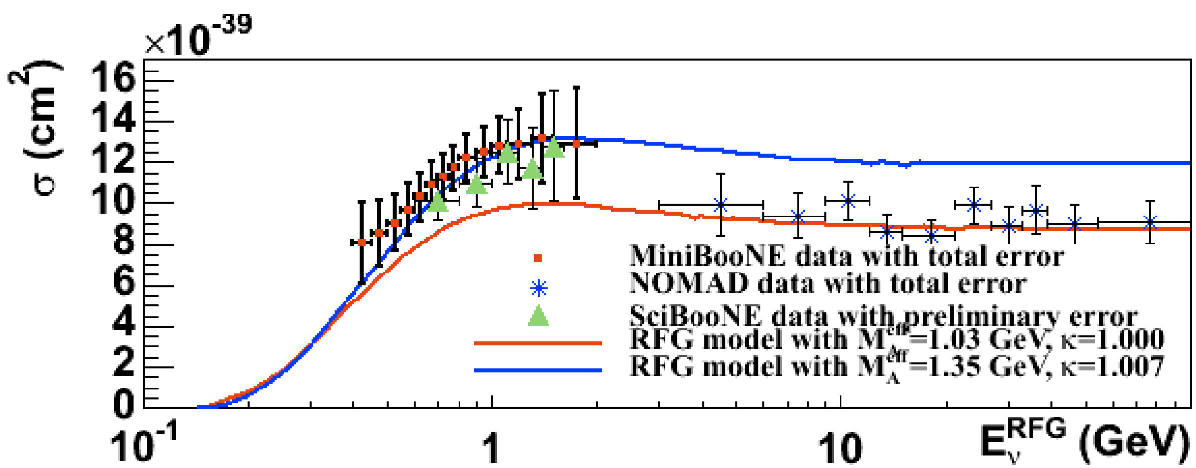
Plot from Seely et al (JLAB E03-103), PRL (103), 2009

- Quasi-elastic Scattering:
  - Axial Mass measurements probe behavior of proton, hints that there are differences between nuclei, are there differences between ν and e^-?

Reason #1: We don't understand the details of how neutrinos interact

- Theories don't agree on sizes of cross sections (example: coherent pions)
- Experiments are often in conflict with each other

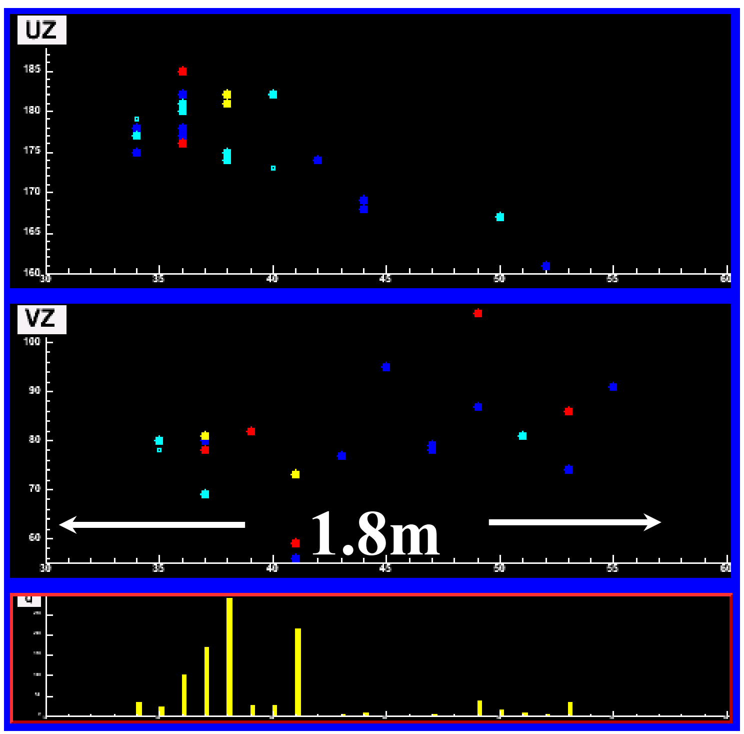


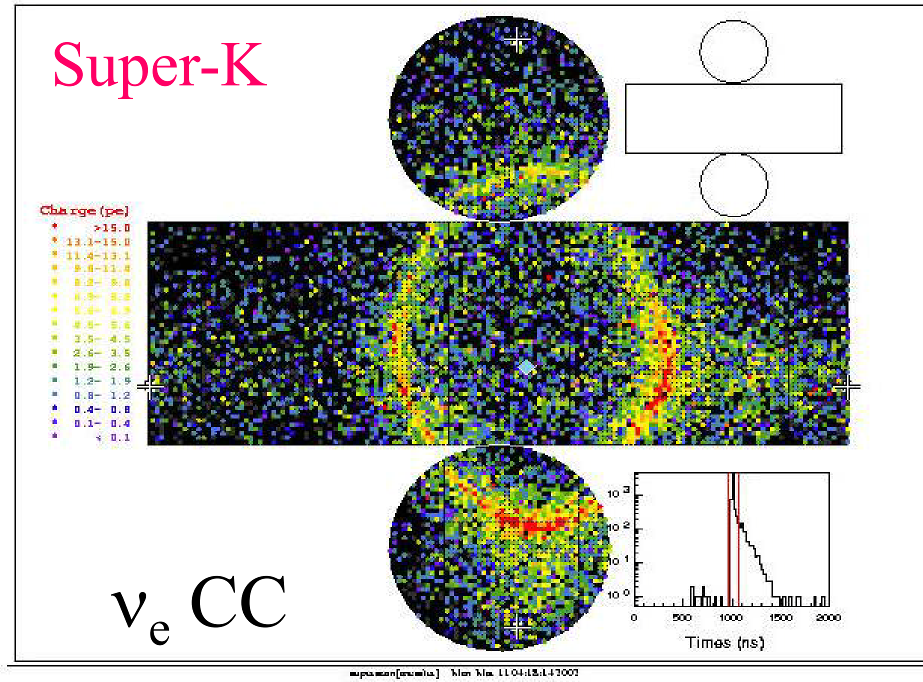


Ingredients for Effective Program

Ingredient #1: More Sensitive Detectors!

- MINOS Detector
  - 1” steel between scintillator means hard to characterize final state particles

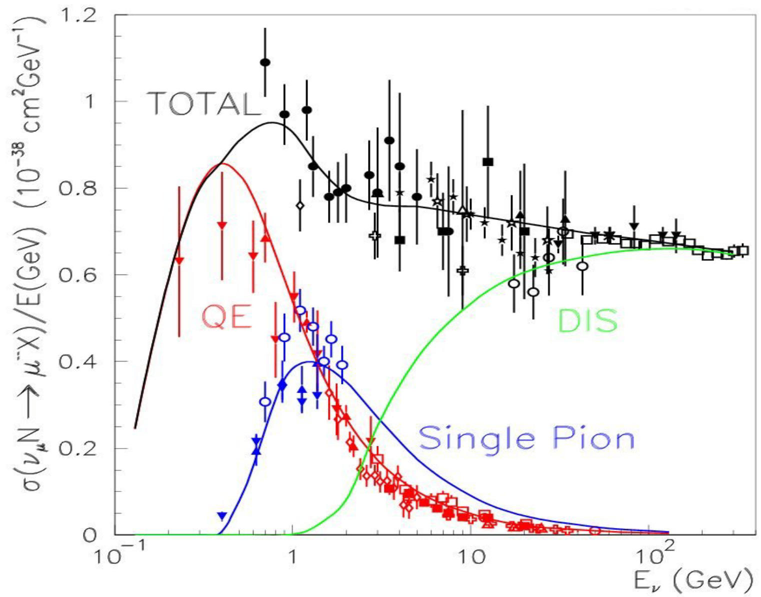


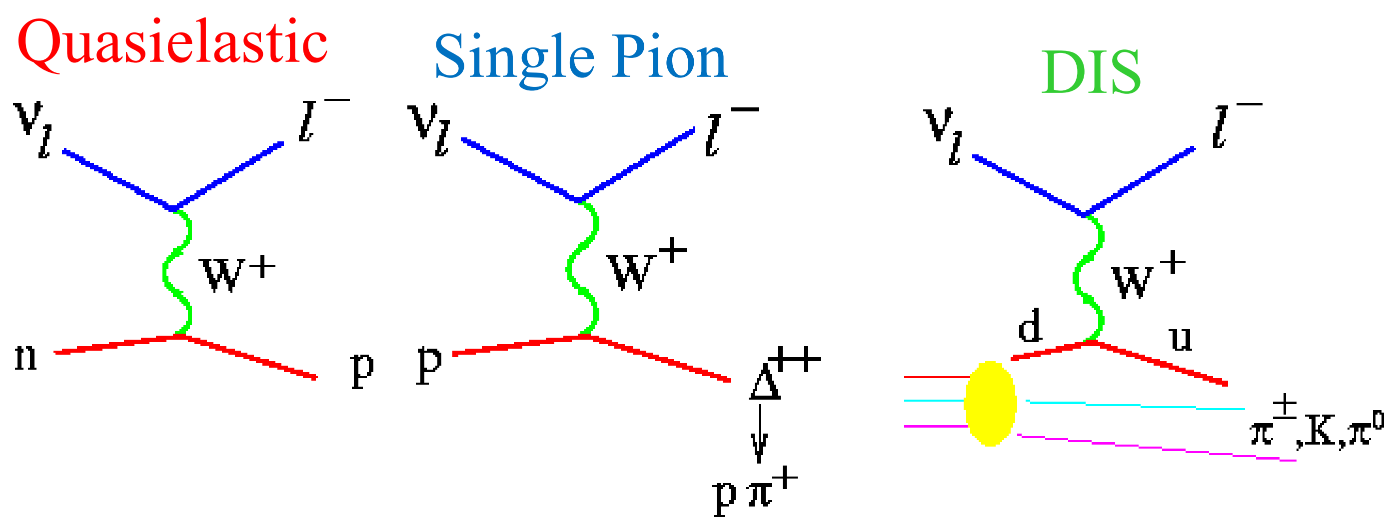


- Super-Kamiokande
  - Cerenkov technique places momentum threshold on measuring outgoing protons

Ingredient #2: Broad Range of Neutrino Energies

- Different Energies means different channels to explore
- Broad and Narrow bands of energy allow for dσ/dE measurements, and neutral current measurements at one energy

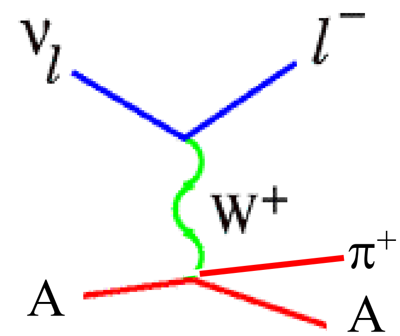


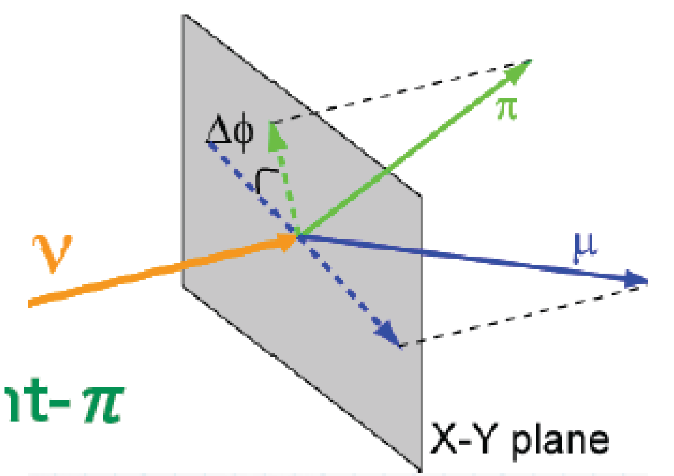


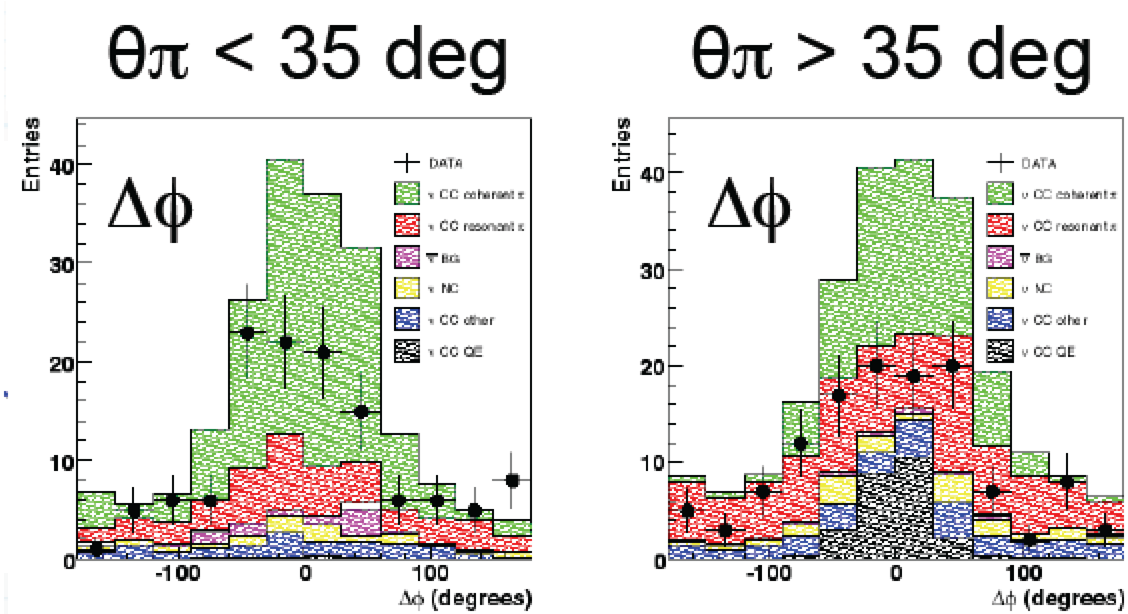
Ref: G.Zeller

Ingredient #3: High Statistics

- We have data from bubble chambers with low statistics
- We want to study kinematic distributions, not just total rates
  - Example: coherent pion production (SciBooNE, NuInt09)

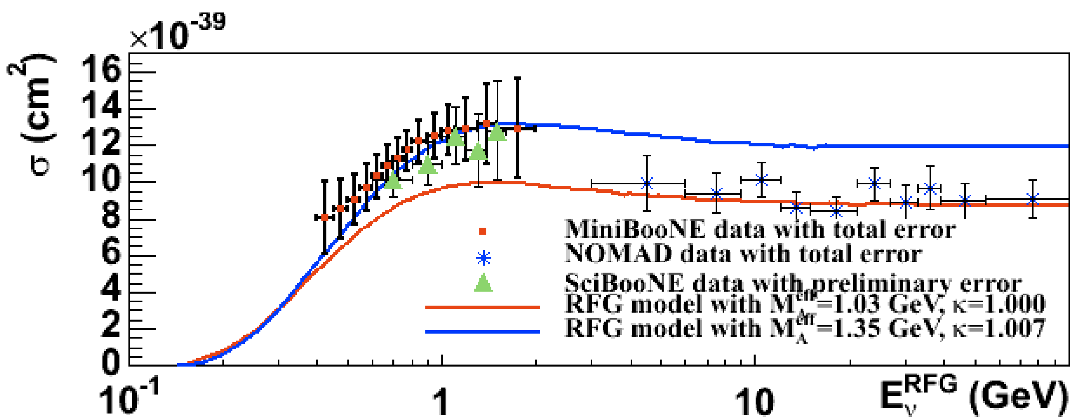


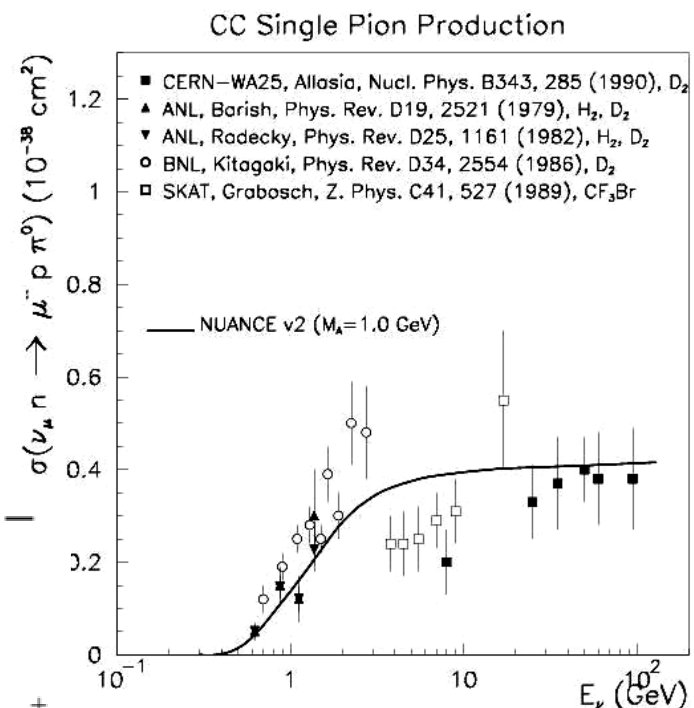


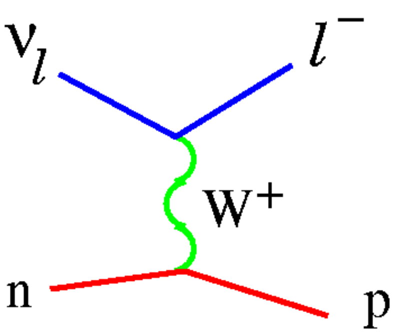


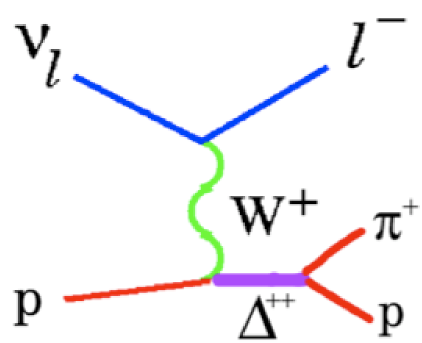
Ingredient #4: Low Flux Uncertainties

- History of strange jumps between different experiment's measurements of same process --even with charged current processes!



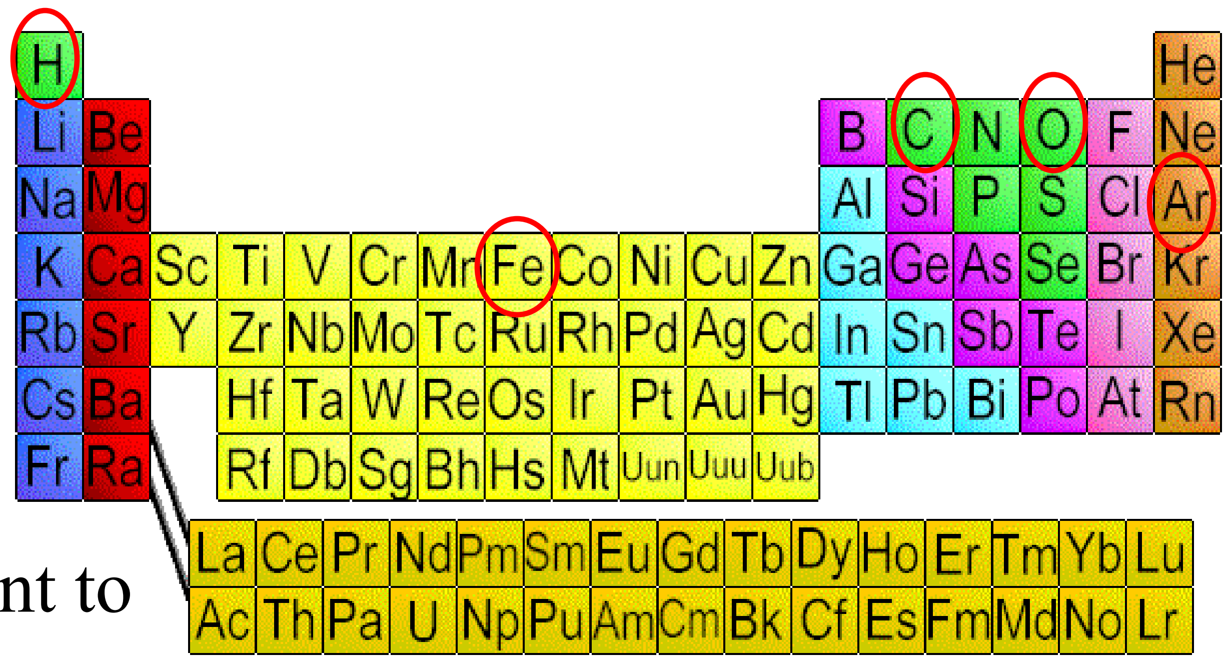






Ingredient #5: Broad Range of nuclear targets

- Nuclear effects best studied over as broad a range in A as possible



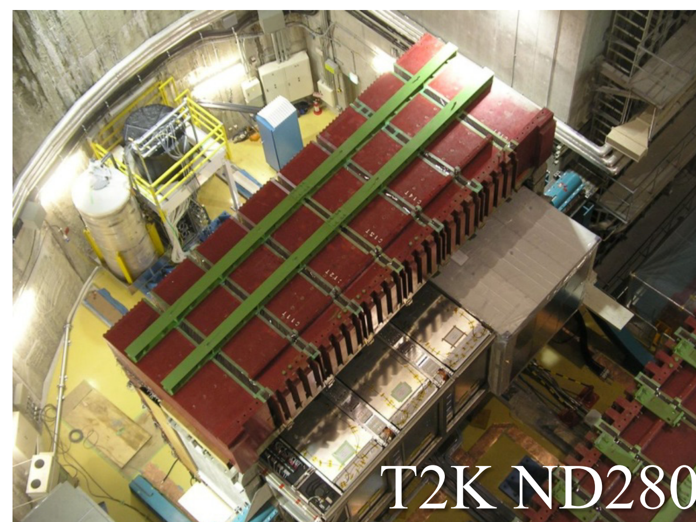
- Oscillation experiments want to study interactions over the far detector target material

Elements in current and future precision oscillation experiments

Current Program Scoresheet

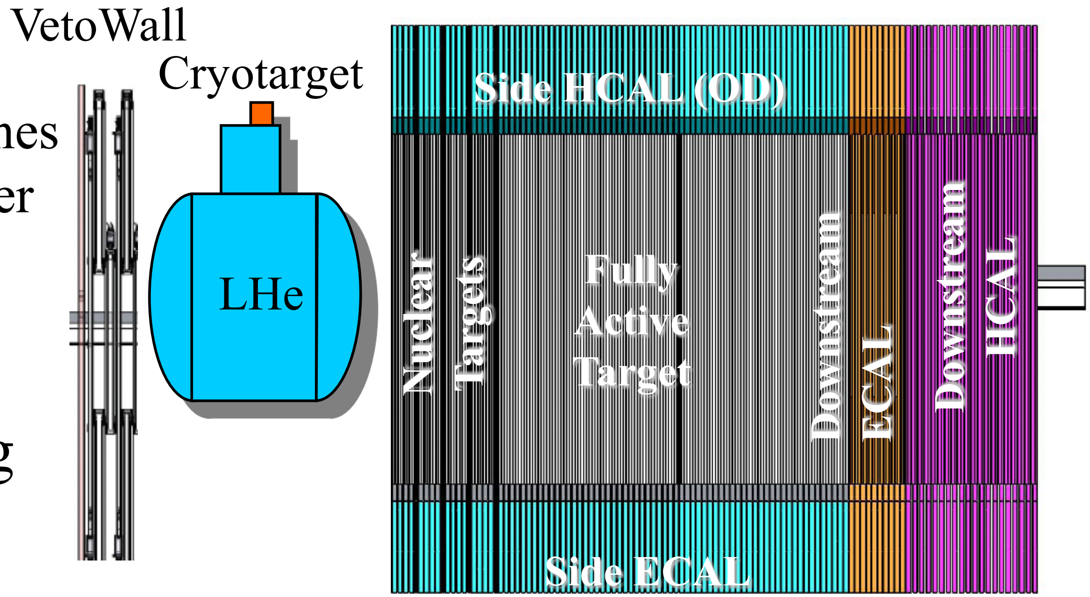
How does the current program do?

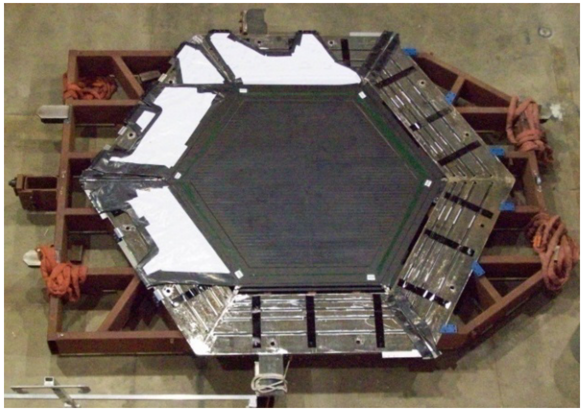
- MINERνA: running in NuMI Beamline at Fermilab
  - Fine-grained scintillator detector
  - Nuclear targets of He, C, H20, Fe, Pb
- T2K 280m Near Detector: running in T2K Beamline at J-PARC
  - Fine-grained scintillator, water, and TPC's in a magnetic field
- NOνA near detector: to run in 2013
  - Liquid scintillator in off-axis beam, running above ground before 2013
- MicroBooNE: to run after 2013
  - Liquid Argon TPC in Booster Neutrino Beam



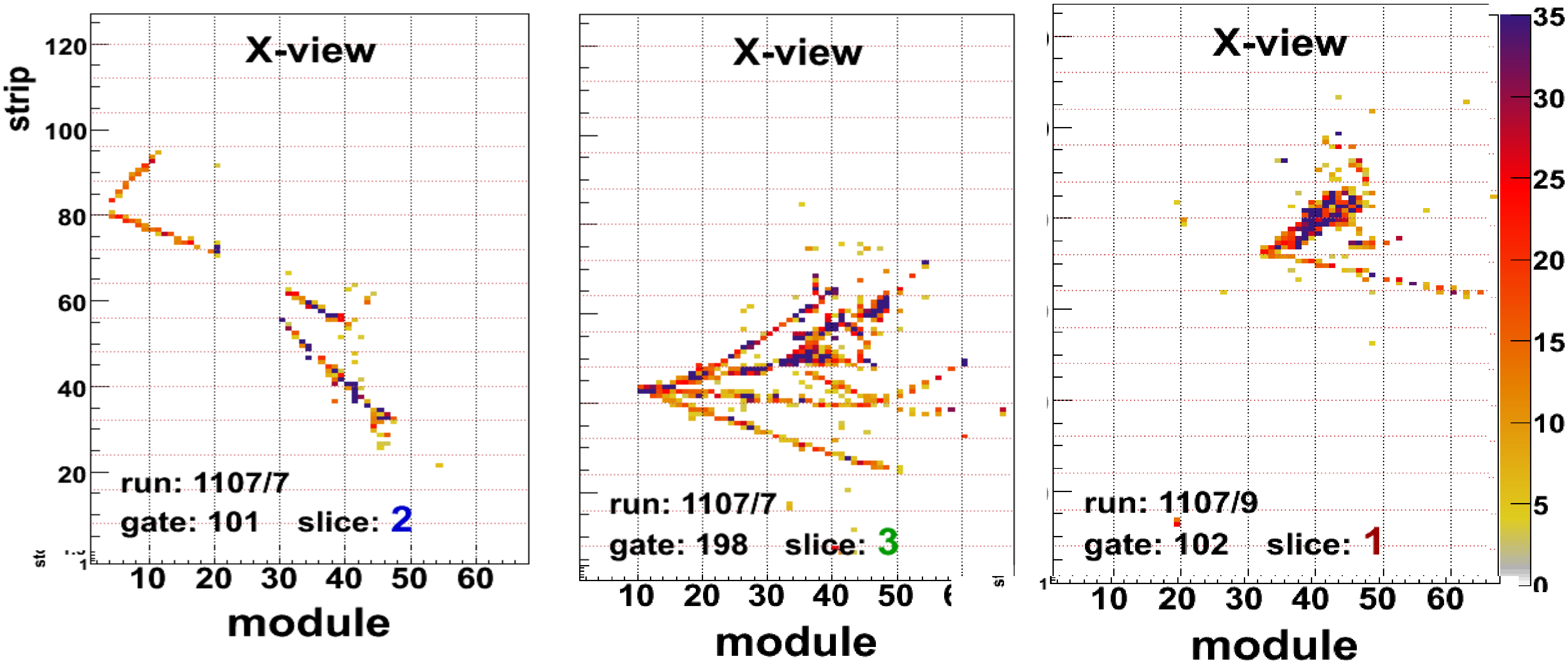
MINERνA Detector

- 120 modules
  - 1-2 frames of scintillator planes read out by WLS & clear fiber
  - Side calorimetry
- Signals to 64-anode PMT's
- Front End Electronics using Trip-t chips (thanks to D0)
- Side and downstream electromagnetic and hadronic calorimetry
- MINOS Detector gives muon momentum and charge





MINERνA Events



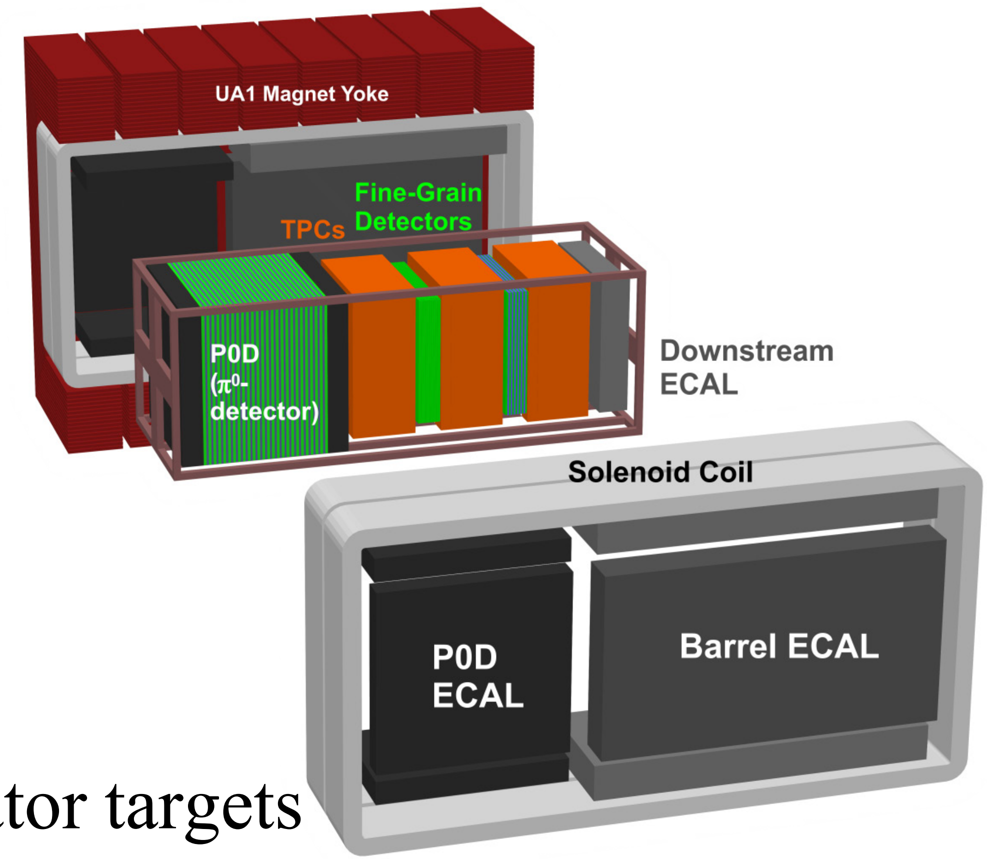
One view, three different events during antineutrino running

See detached Vertices, multi-particle final states, electromagnetic showers

See posters from J. Mousseau and D. Schmitz on MINERνA calibration and test beam effort

T2K 280m Near Detector

- P0D: optimized to study electromagnetic final states in water and scintillator
- TPC: precise tracking and momentum, plus particle identification
- Magnetic field 0.2T
- FGD: Additional scintillator targets
- Side electromagnetic and hadronic calorimetry

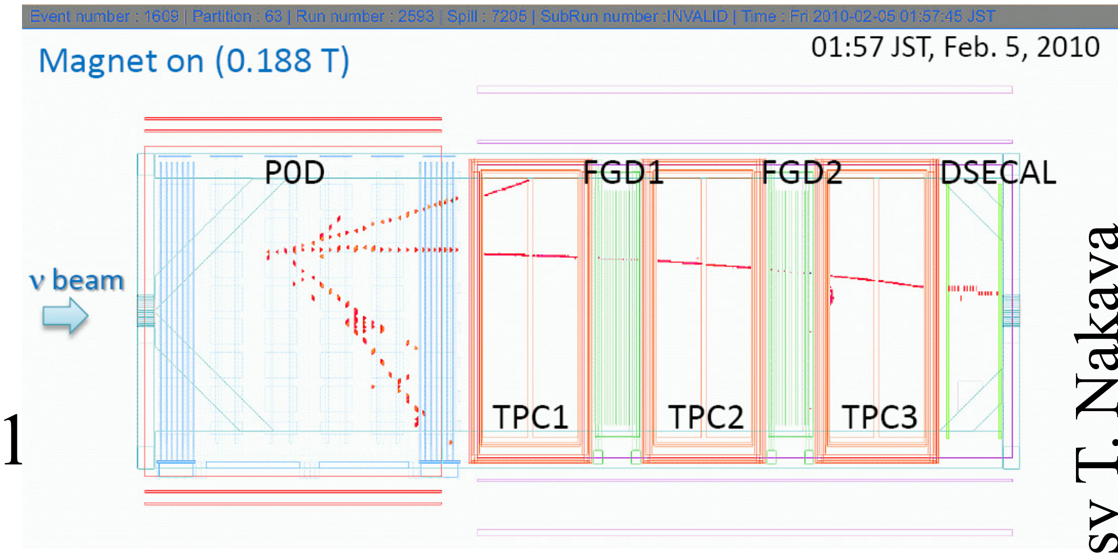


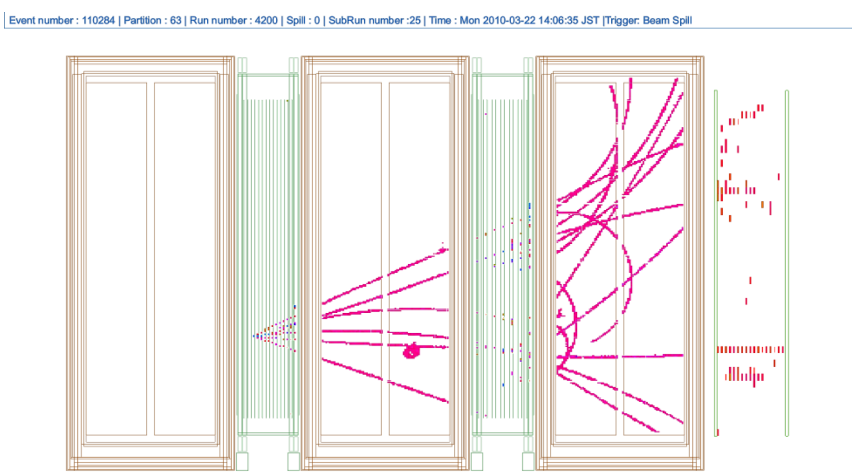
(see talk by T. Kabayashi at this meeting)

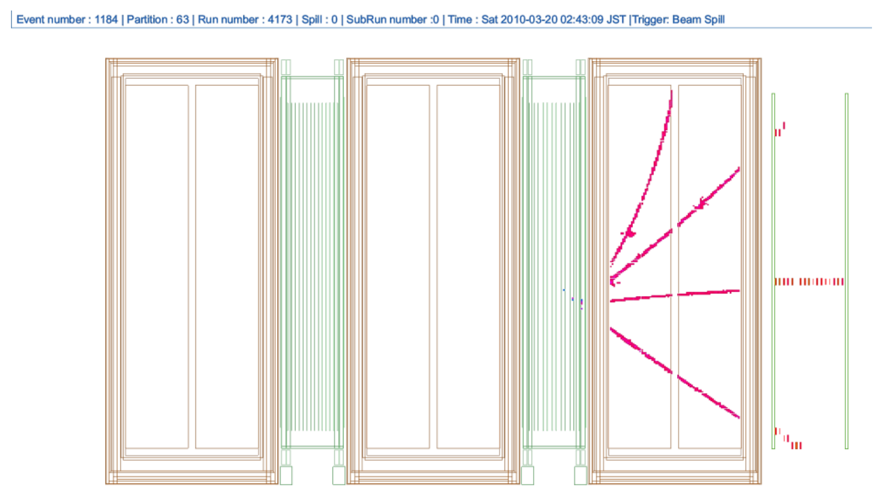
Figure from T. Nakaya

T2K 280m Events

- Charge sign identification
- Multi-track capabilities
- Events in P0D, FGD1 FGD2 shown below



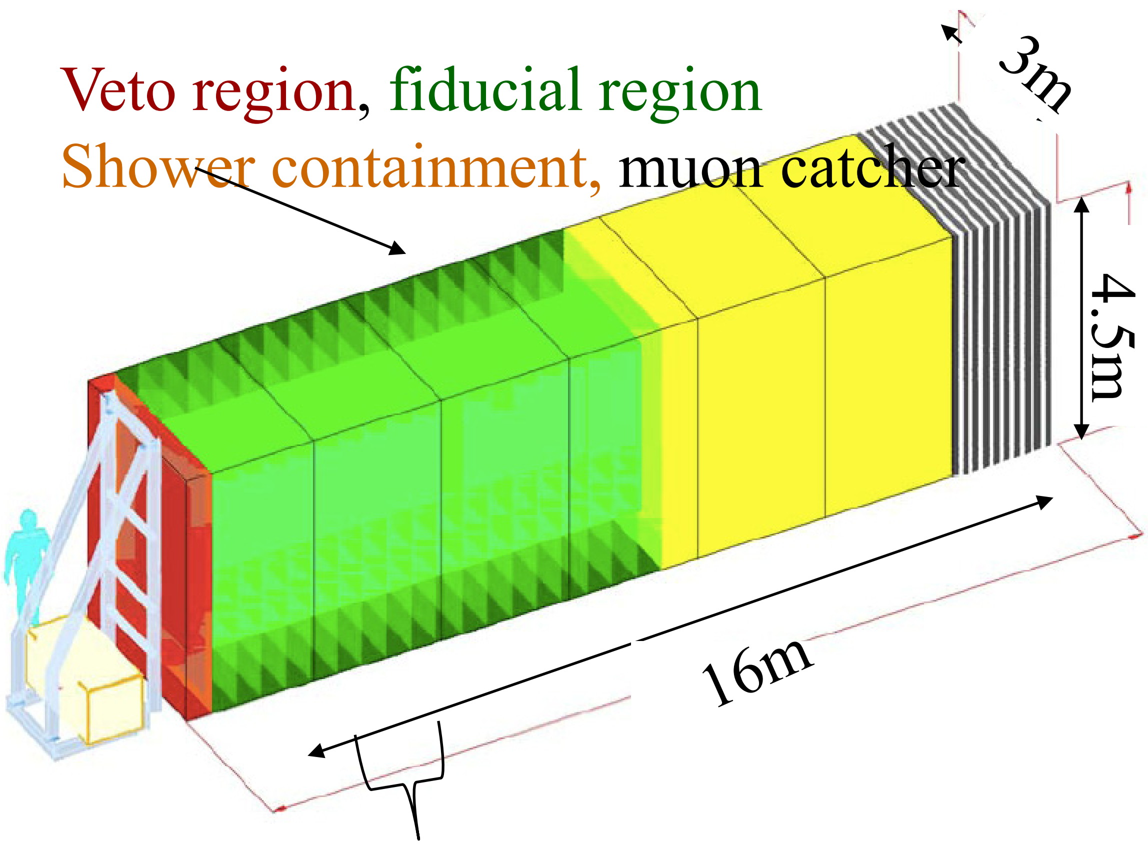




Events courtesy T. Nakaya

NOvA Near Detector

- Scintillator extrusion cross section of 3.87cm x 6cm , but with added muon range stack to see 2 GeV energy peak



•Range stack: 1.7 meter long, steel interspersed with 10 active planes of liquid scintillator

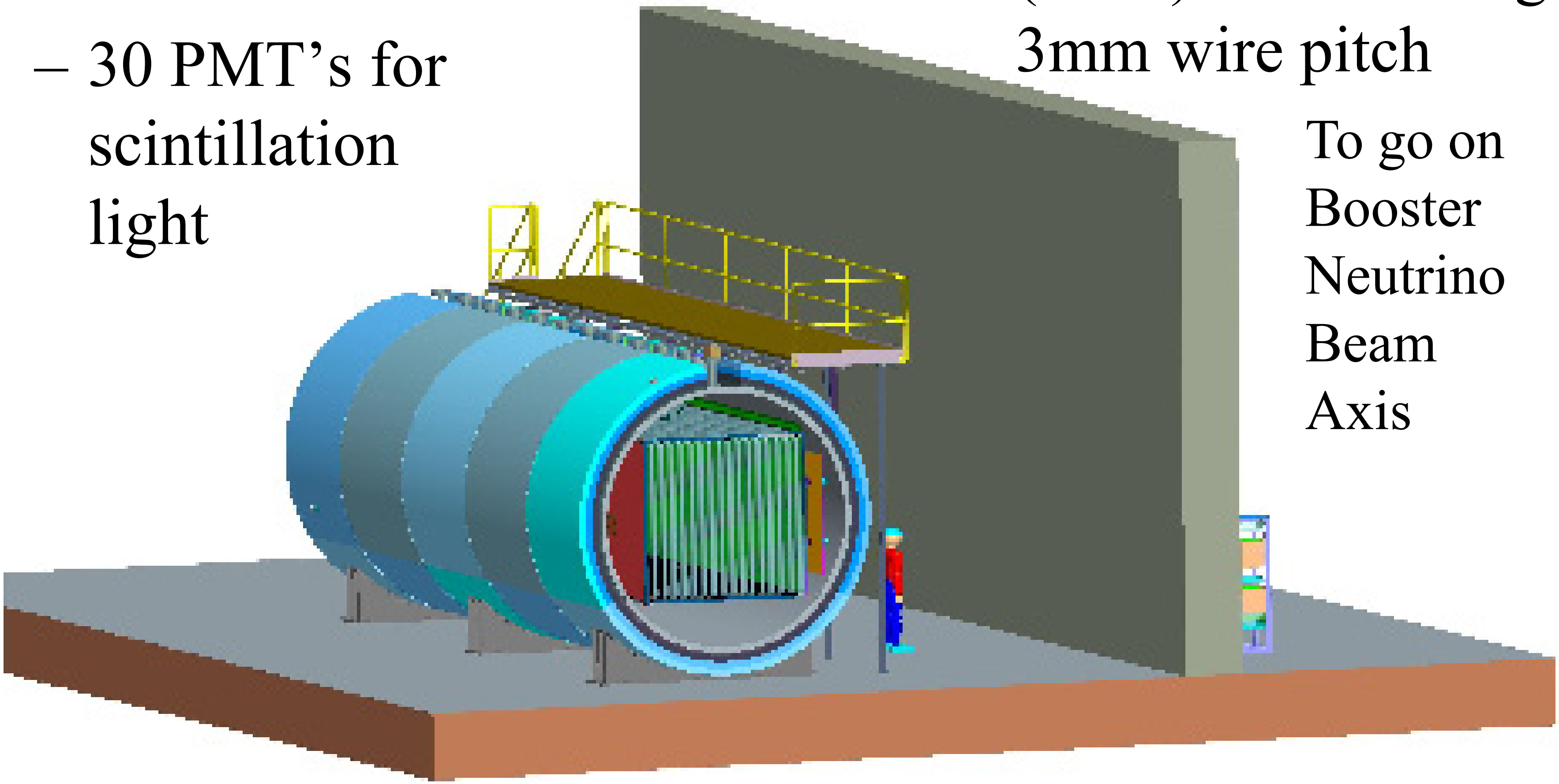
•First located on the surface, than moved to final underground location

(see talk by K. Heller at this meeting)

MicroBooNE

- Liquid Argon TPC
  - 150/89 tons total/active
  - 30 PMT's for scintillation light

TPC:
$(2.5\text{m})^2\text{x}10.4\text{m}$ long
3mm wire pitch

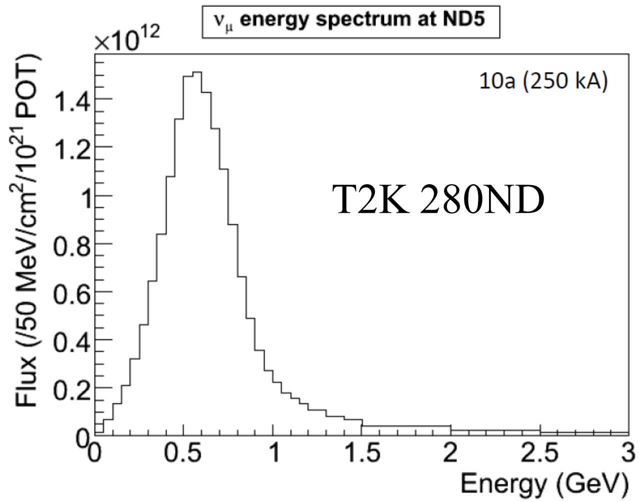


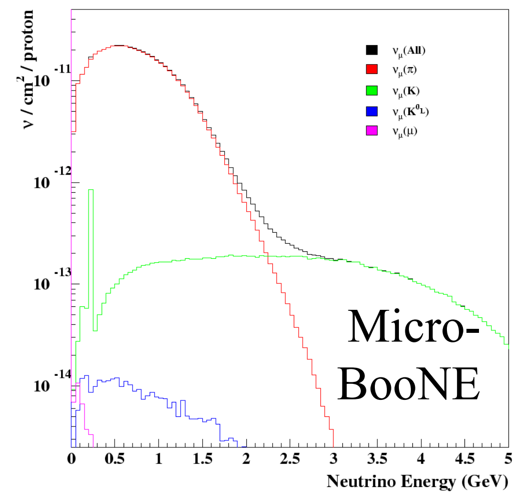
To go on Booster Neutrino Beam Axis

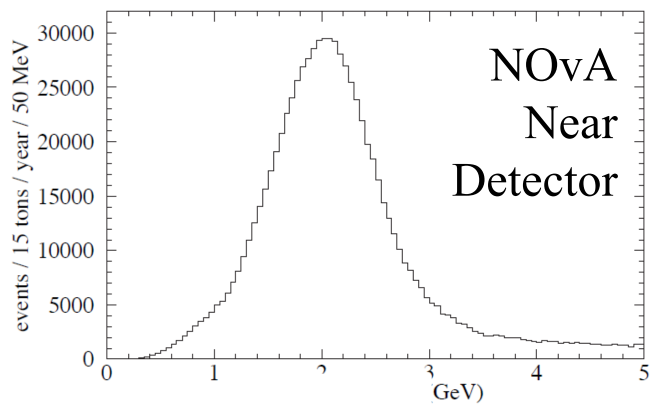
See M. Soderberg's talk, Tuesday

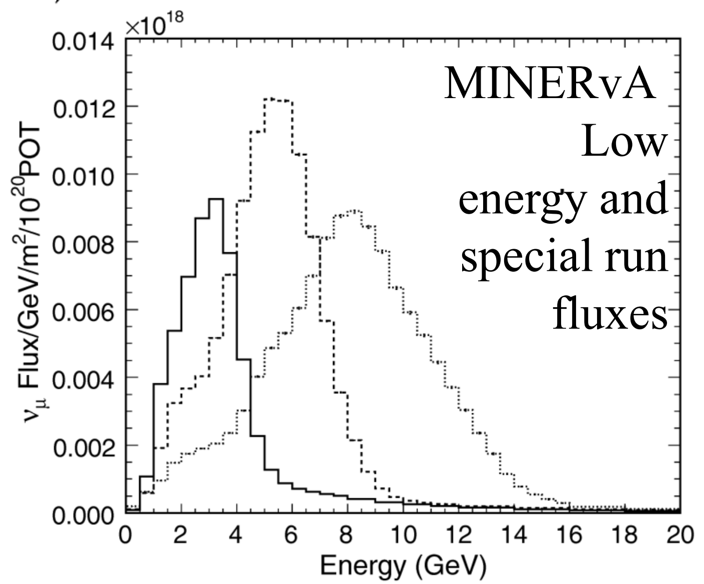
Next Ingredient: Broad Range of Energies

- T2K 280m ND: 600MeV narrow band
- MicroBooNE: 1GeV broad band
- NOνA: 2GeV narrow band
- MINERνA: broad band, tunable peak energies from 3 to 8 GeV









Next Ingredient: Statistics

- MINERvA Statistics (for $4x10^{20}$ Protons On Target in Low Energy beam, $12x10^{20}$ POT in Medium Energy beam)
  - NEUGEN prediction
  - Acceptance corrections not included
  - 3 ton fiducial mass assumed

Interaction Channel	Charged Current
Quasi-Elastic	0.8M
Resonance Production	1.7M
Transition (Resonance to DIS)	2.1M
Deep Inelastic Scattering	4.3M
Coherent Pion Production	89 K CC / 44 K NC
Total CC events on Scintillator	**9M events**

- T2K 280m ND Statistics: (for 5×10^{21} protons on target, Steve Boyd, NuINT'09)
  - **300k/150k** Quasi-elastic events
  - 26k /14k π^0 events

P0D events, ε~55%, purity~60%

Event Type	C/Pb/Brass	Water
NC π^0	20k	8k
NC multi-π^0	6k	6k

Statistics, continued

- NOvA Near Detector:
  - Few hundred events on the surface before 2012
  - Underground, events per year (20 tons fiducial): (Ref: M. Messier)

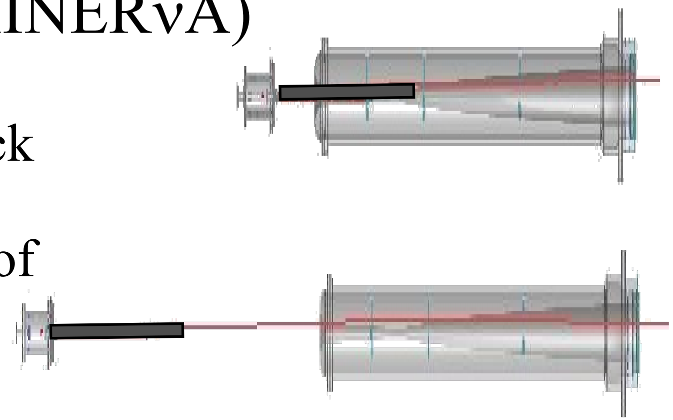
NOvA (6×10^{20} POT)	Charged Current	Neutral Current
Elastic	440k	172k
Resonant	654k	230k
DIS	578k	192k
coherent	16k	10k
total	1700k	604k

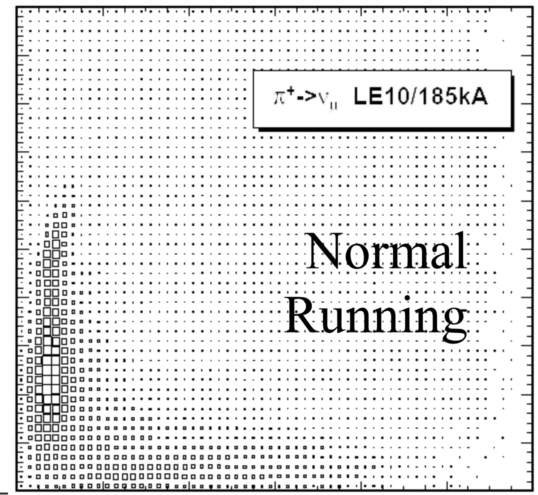
- MicroBooNE:
  - Events for 6e20 POT, 70 tons fiducial volume (Ref, B. Fleming)

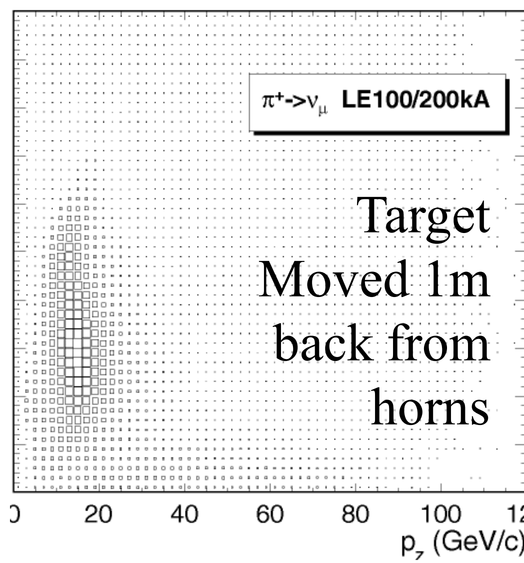
MicroBooNE (6×10^{20} POT)	Charged Current	Neutral Current
Elastic	53k	17k
Resonant (1 π)	28k	10k
DIS	1k	0.4k
coherent	2.3k	1.5k
total	84k	29k

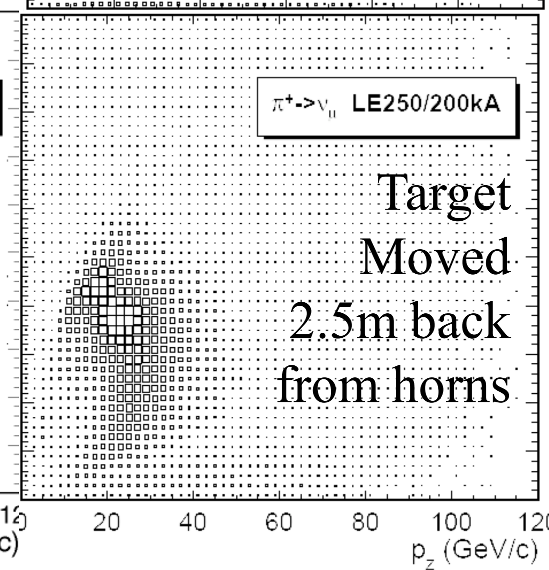
Next Ingredient: Understanding the Flux, I

- NuMI Beamline (MINERνA) can vary
  - Horn current (p_T kick supplied to π's)
  - Target Position (x_F of focused particles)
- Plots show (x_F ,p_T) of π^+ contributing to neutrino flux.
- Minerva will acquire data from total of 8 beam configurations
- Muon monitors provide independent check
- To see more: S. Kopp talk, L. Loiacono Poster



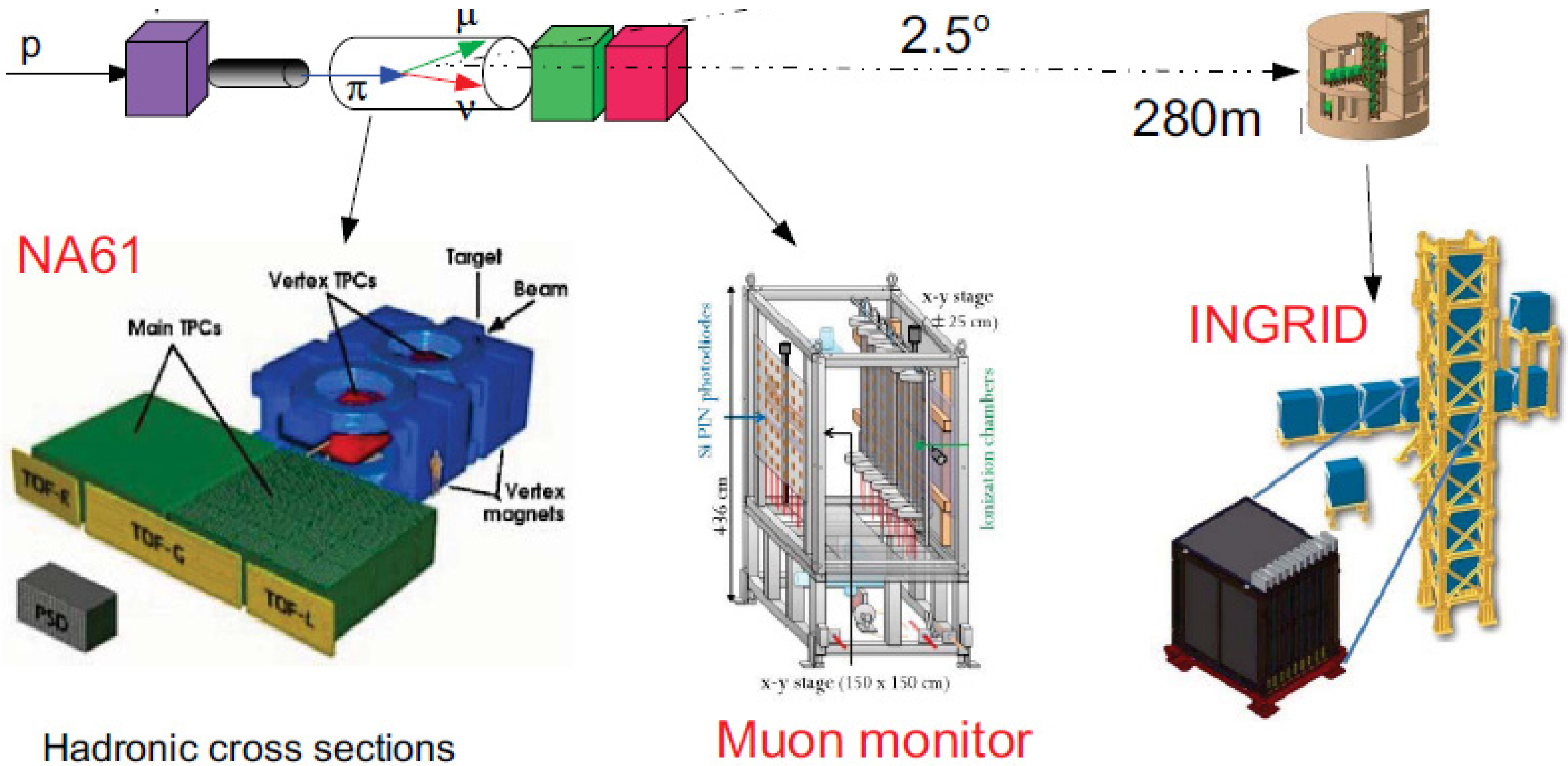






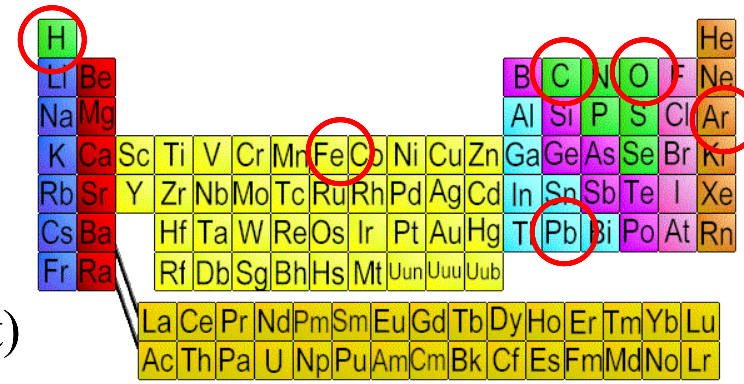
Understanding the Flux, II

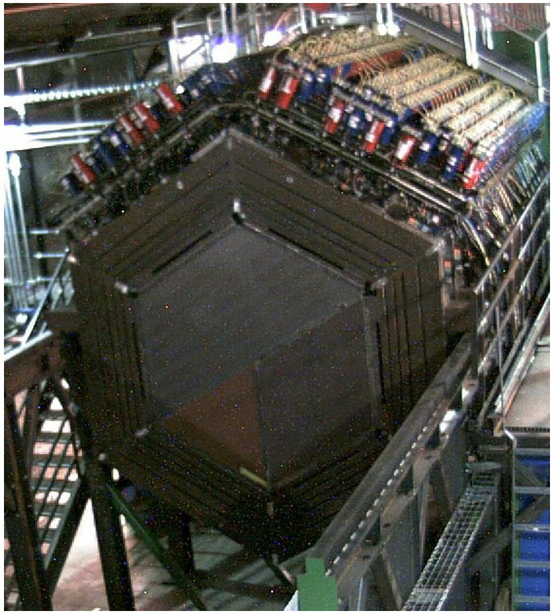
- T2K will combine different neutrino detectors with muon and proton monitoring (S. Boyd, NuINT’09)
- Hadron production experiment (NA61) (see A. Blondel’s talk)



Need Broad Range of Nuclear Targets

- MINERνA has targets from He to Pb, plus water and scintillator:
- Near million-event samples
  (4×10^{20} POT Low Energy beam plus 12×10^{20} POT in Medium Energy beam, 85cm radius cut)
- See poster by B. Osmanov



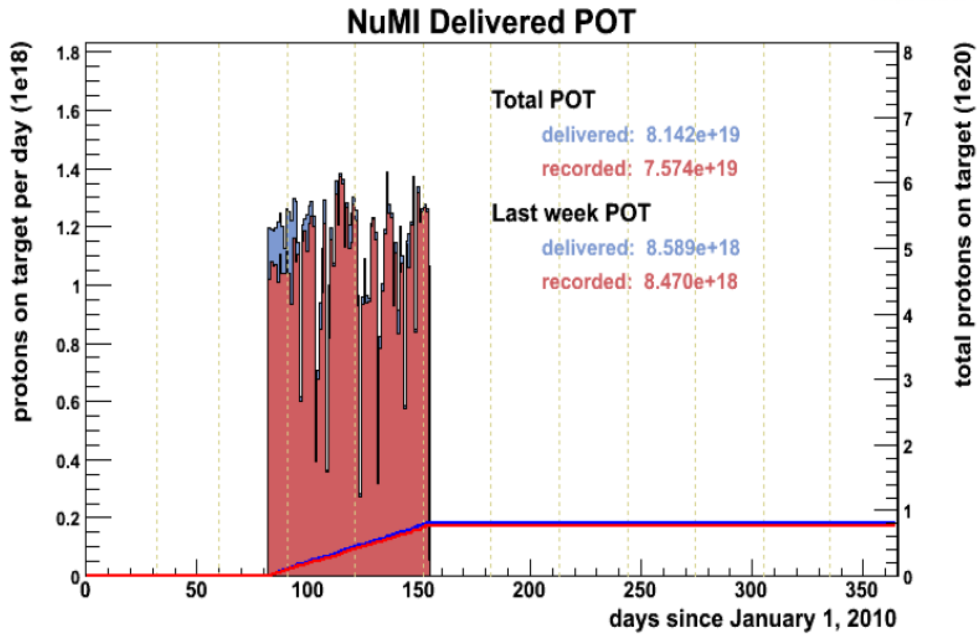


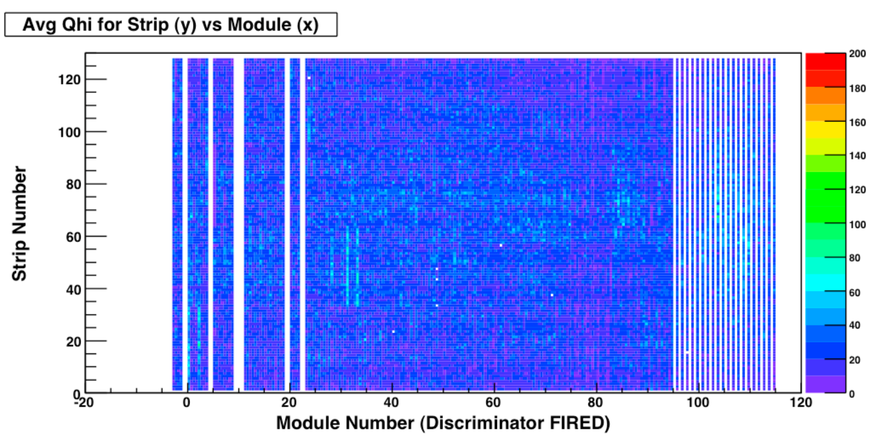
Target	Mass in tons	Events (Million)
Scintillator	3	9
He	0.2	0.6
C (graphite)	0.15	0.4
Fe	0.7	2.0
Pb	0.85	2.5
Water	0.3	0.9

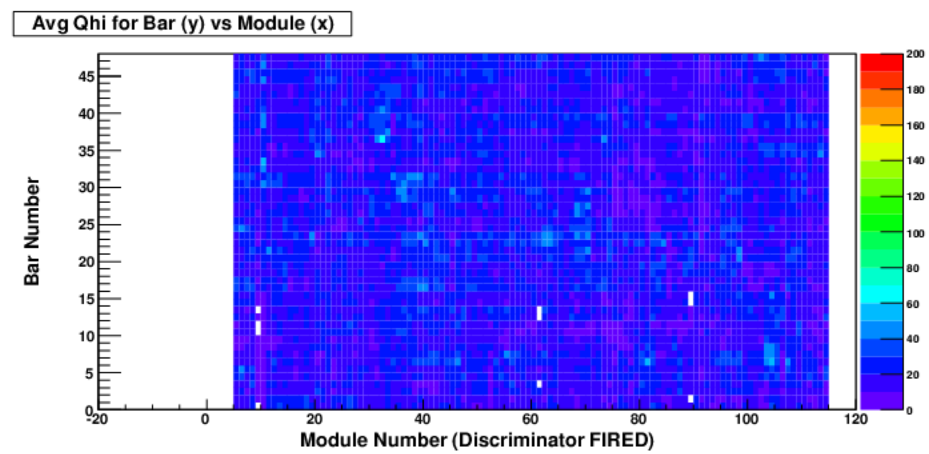
Current Status of Data-Taking

MINERνA Running Status

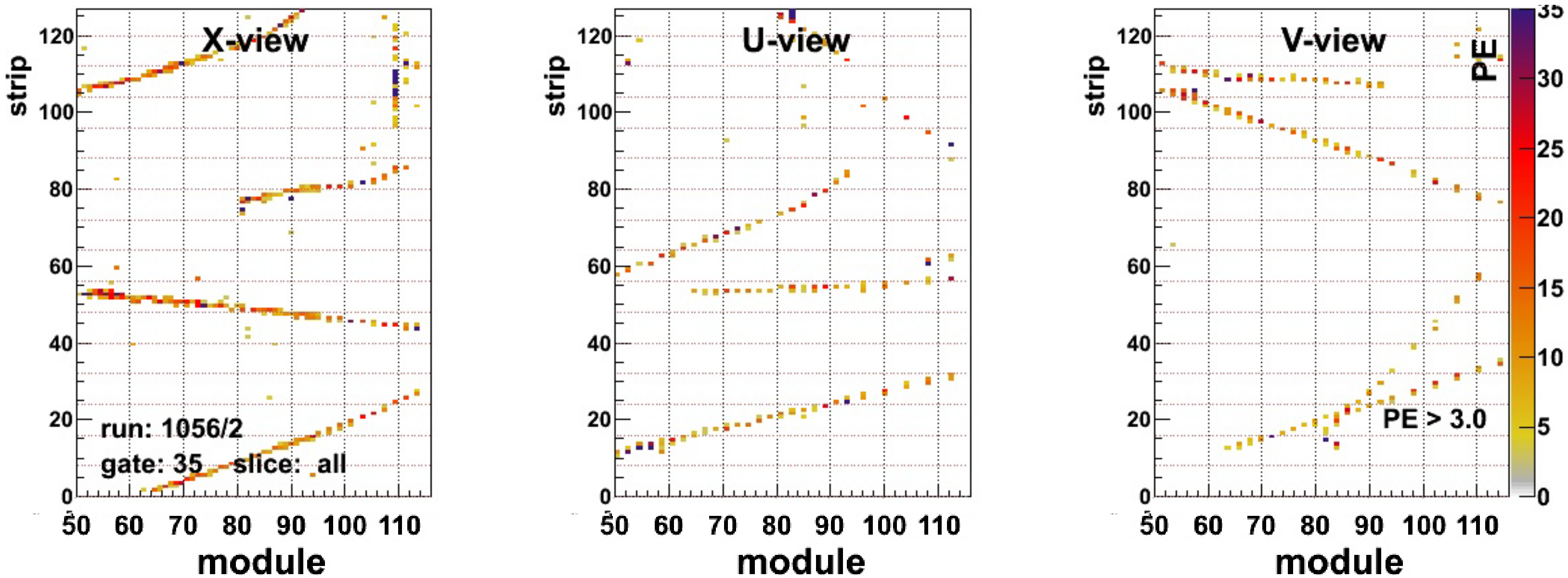
- Accumulated 0.84e20 Protons on Target of anti-ν beam with 55% of detector and Fe/Pb target
- Accumulated 0.8e20 Protons on target in Low Energy neutrino Running with full detector
- Detector Live times typically above 95%
- Less than 20 dead channels out of 32k channels



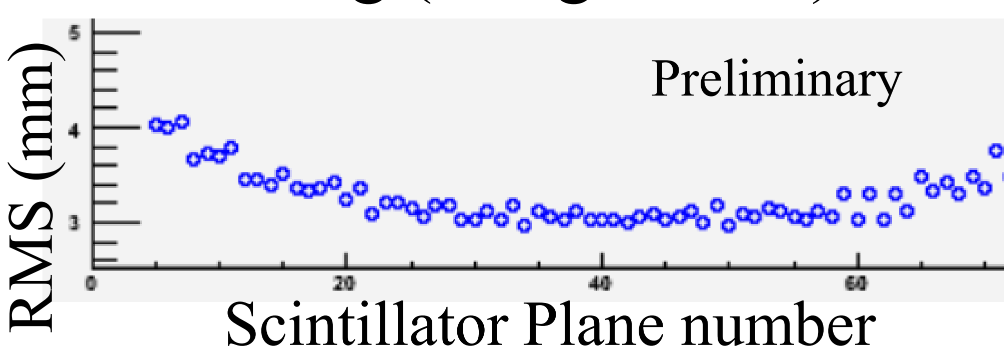


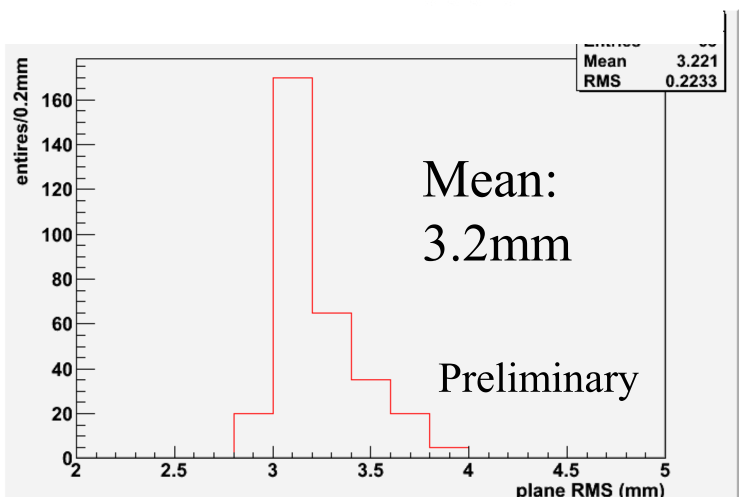


MINERνA Tracking Performance



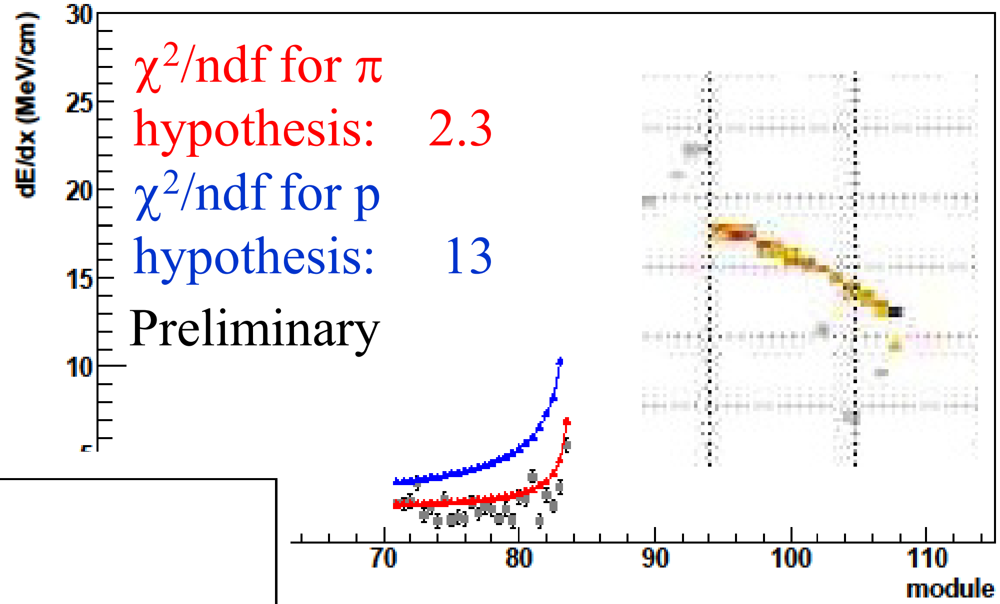
- Tracking (using muons)

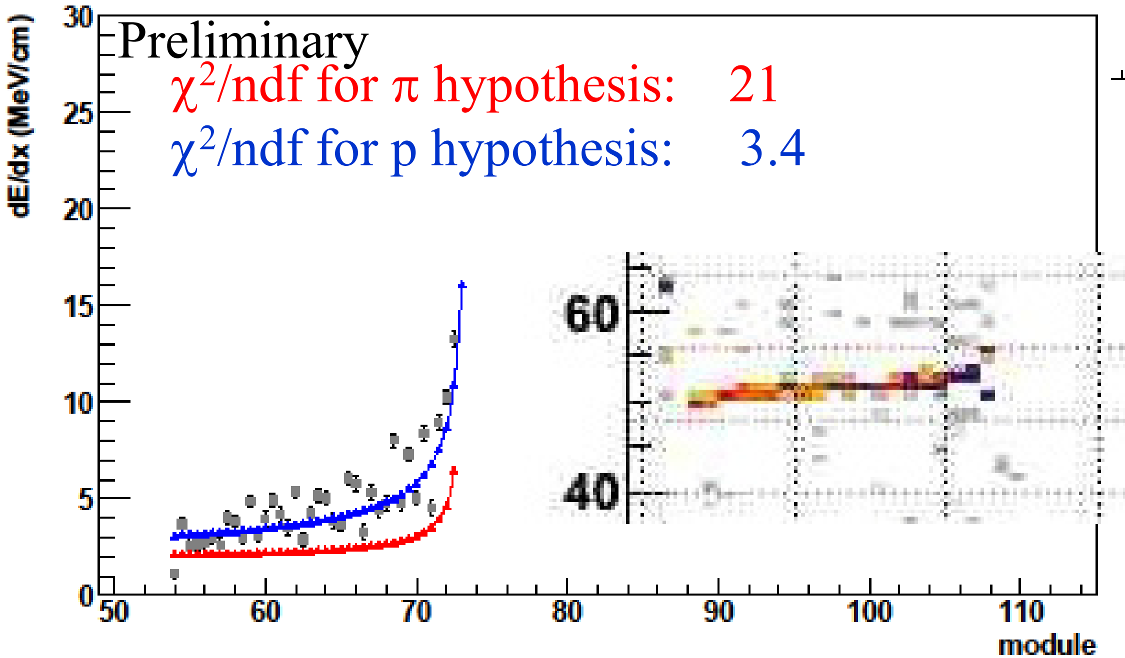




MINERνA Particle Identification

- Reconstruction of single-track events that range out in the detector:

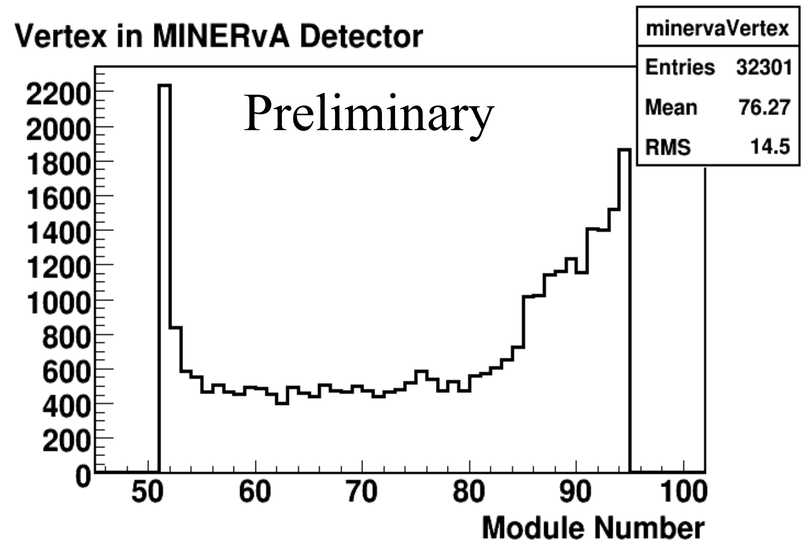


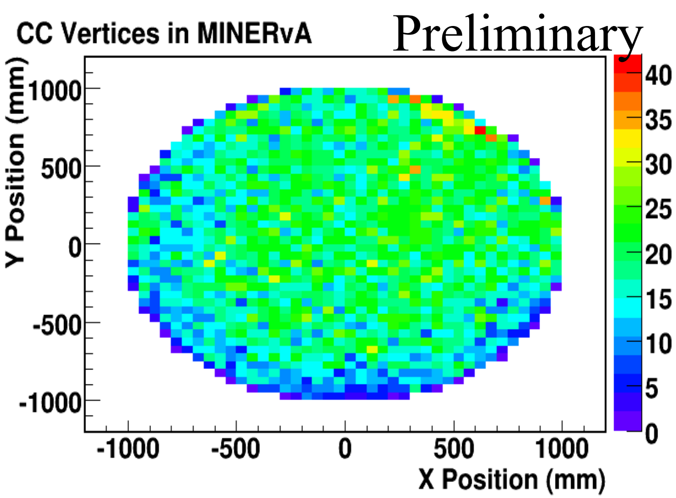


Note: lowest χ^2/ndf is still large because scintillator response calibration is not yet applied here

MINERνA Neutrino Event Vertex Distributions

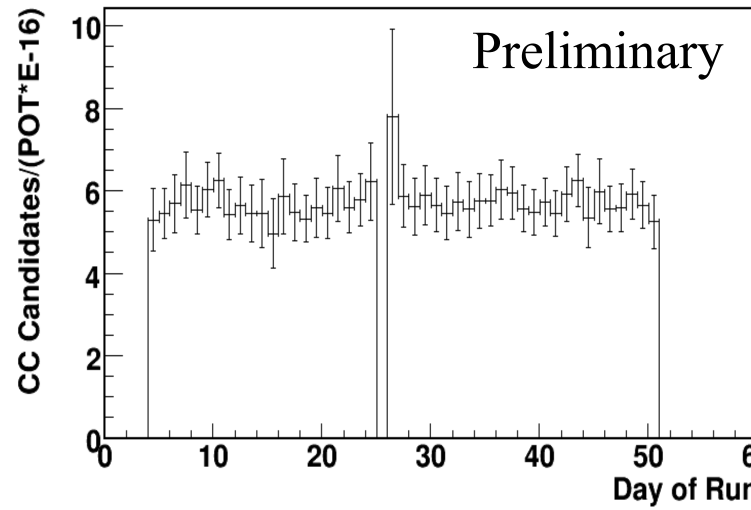
- From a bit less than half of the anti-ν running
- Require at least one track in the event, and a match to a track in the MINOS detector
- Remove events with tracks outside of 1m radius, and those with track vertices in first 3 modules or Hadron Calorimeter modules

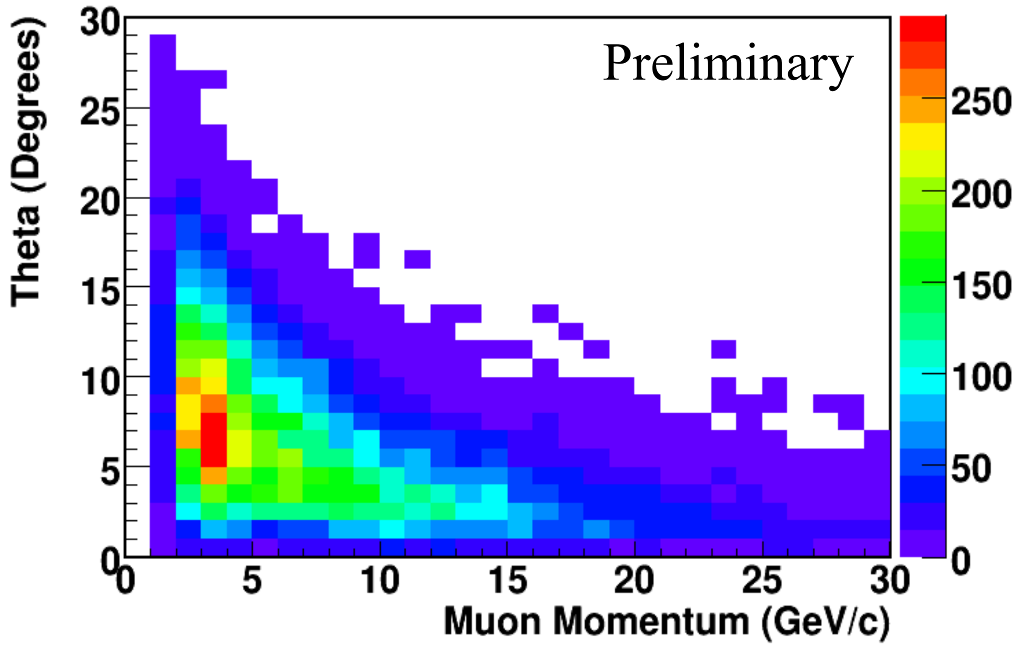




MINERνA Neutrino Event Distributions

- Same cuts as described above, antineutrino beam
- Wrong-sign background not yet removed

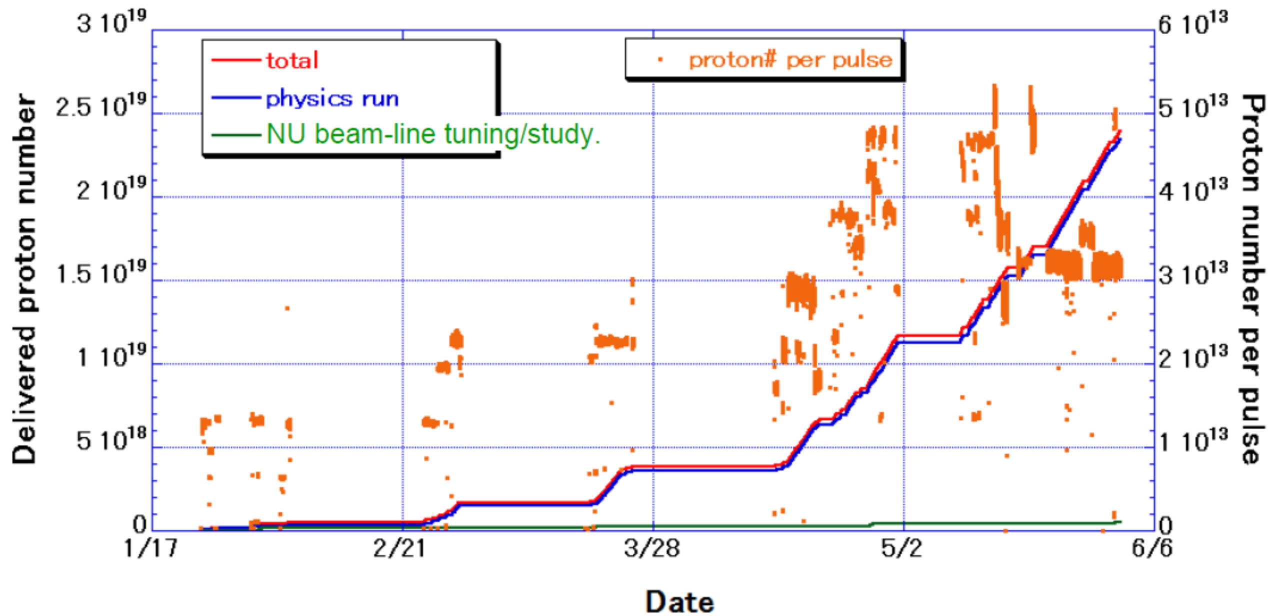




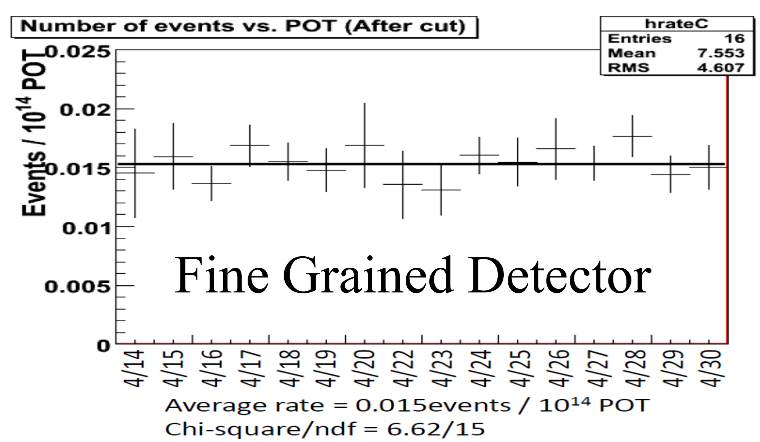
- Angle with respect to beam (theta) measured by MINERνA
- Muon momentum from MINOS reconstruction plus rough estimate from MINERνA path length

T2K 280m ND Running Status

- Accumulated 0.234×10^{20} Protons on target between 23 January 2010 and 1 May 2010 in Neutrino Running
- Fewer than 100 dead channels out of 46k channels

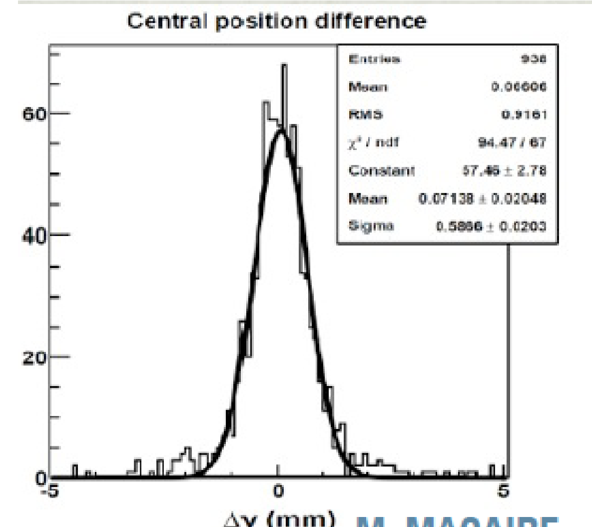


System	Channels	Bad chan.	Fraction
DSECAL	3400	11	0.3%
SMRD	4016	3	0.07%
P0D	10400	7	0.07%
INGRID	8360	8	0.1%
TPC	124416	12	0.01%
FGD	8448	55	0.7%

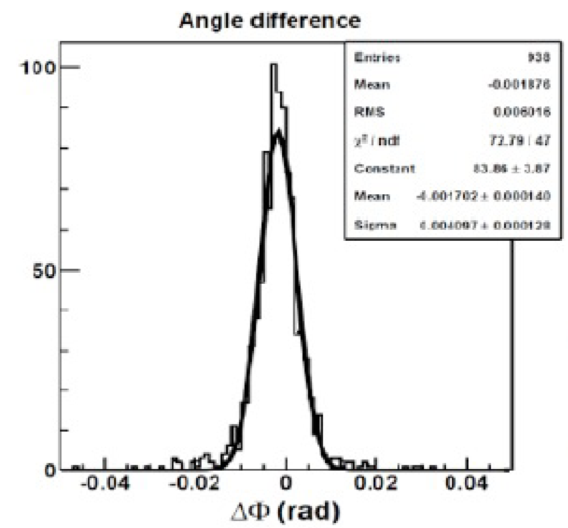


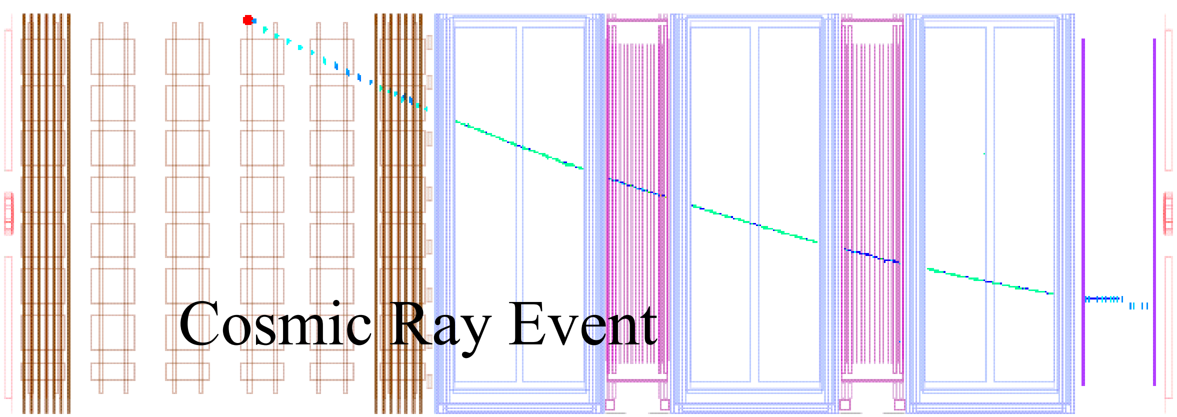
T2K Detector Performance

- TPC provides sub-mm tracking resolution
  - Reconstruct tracks in 2 adjacent modules
  - Compare vertical displacement and angle in 2 modules
  - Work is ongoing, already seeing 0.6mm position resolution



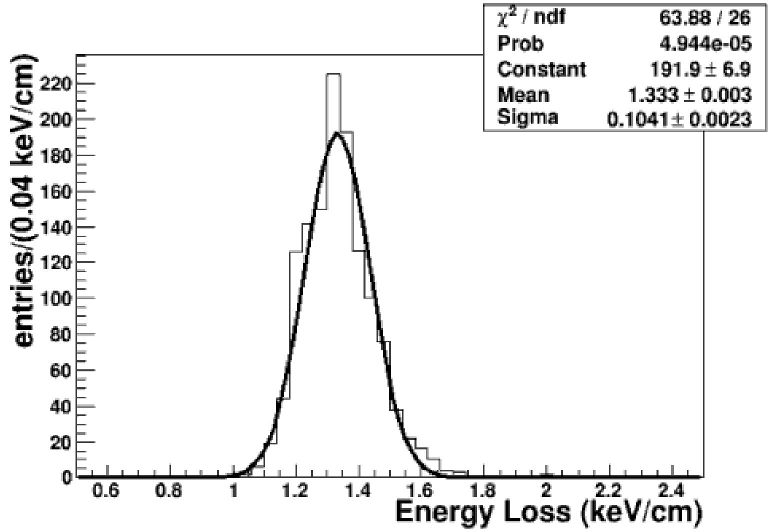
M. MACAIRE

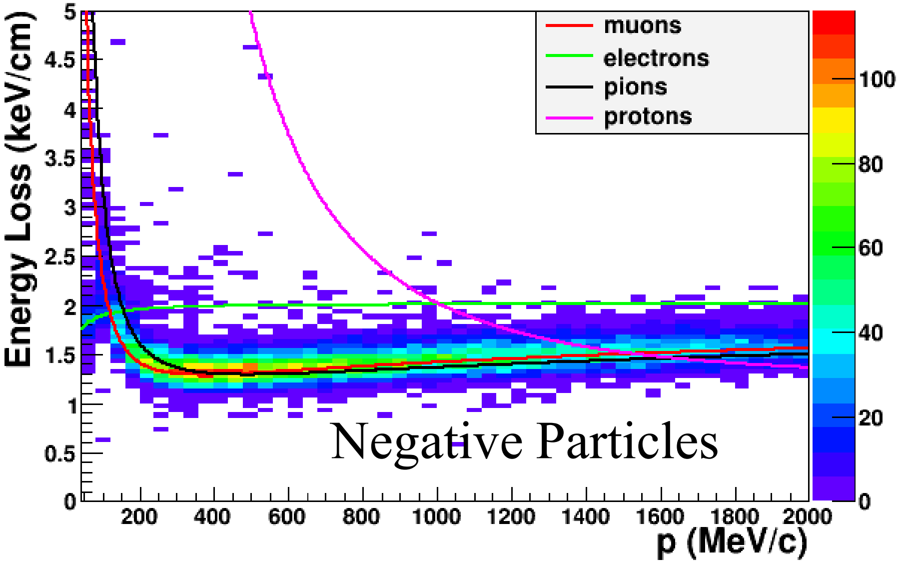


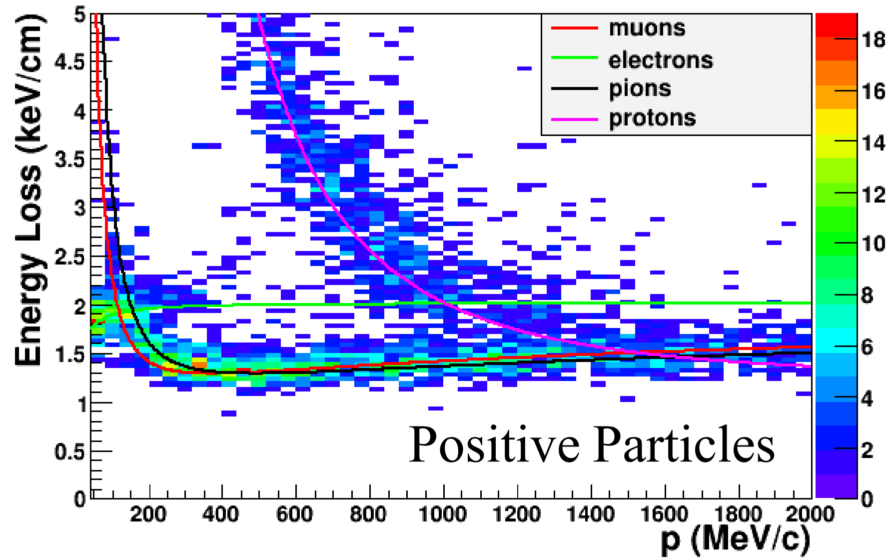


T2K 280ND Run Status

- Energy Loss in Time Projection Chamber







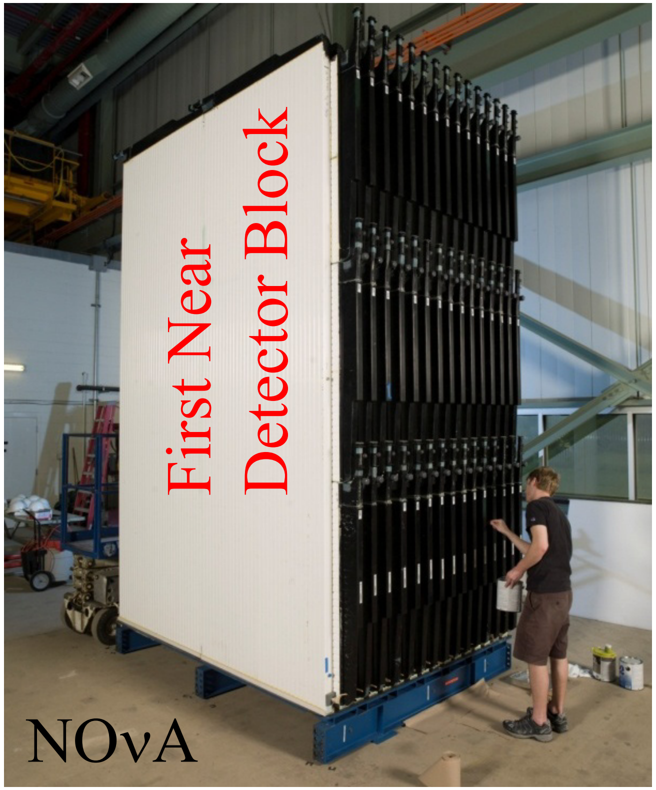
Plots courtesy T. Nakaya

Results by Neutrino 2012

- MINERνA
  - Plan to take 4×10^{20} POT in neutrino beam by then, plus special runs to understand neutrino flux (0.9×10^{20})
  - Current focus is on antineutrino data set
    - Low multiplicity final states
    - Nuclear Effects
    - NC elastic events
- T2K 280m ND
  - Expect to get to 1×10^{21} POT per year by then,
  - QE and π^0 production are main focus of effort

Results by 2012

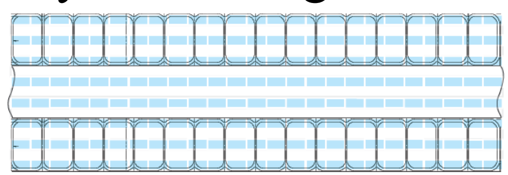
- NOνA Near Detector
  - Will have run in 110mrad off axis NuMI beam (on ground level in new building)
  - First glimpse of neutrino events in new geometry (few thousand low energy events)
  - Starting to excavate underground enclosure by summer 2012



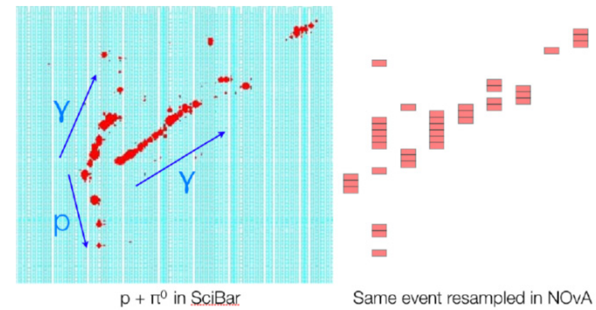
- MicroBooNE
  - Expect to be assembling and installing TPC in the vessel
  - Goal is to fill with Argon by end of Shutdown (Feb 2013)

What ingredients are missing?

- Off axis fine grained detector at NOvA energies: new proposal for SciNOvA experiment (10 tons)
  - Many times the granularity

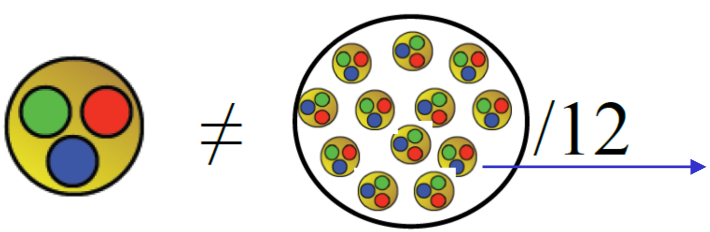


  - 1M events in a 1 year run!



Sci-NOvA (per year)	Charged Current	Neutral Current
Elastic	220k	86k
Total	845k	302k

- Neutrino Interaction measurements on H_2 and D_2
  - Measure free nucleon scattering at high statistics



$$F_2^{\nu p} = 2x\,(d + \bar{u} + s)$$

$$F_2^{\bar{\nu} p} = 2x\,(u + \bar{d} + \bar{s})$$

At high x $\quad \dfrac{F_2^{\nu p}}{F_2^{\bar{\nu} p}} = \dfrac{d}{u}$

Conclusions

- Demand for neutrino interaction measurements has never been greater
- Important ingredients are being put in place to get to a new level of understanding
  - New extremely sensitive fine-grained detectors
  - Broad ranges of energies to access many channels
  - High statistics
  - New ideas for reducing flux uncertainties
  - Broad range of nuclear targets