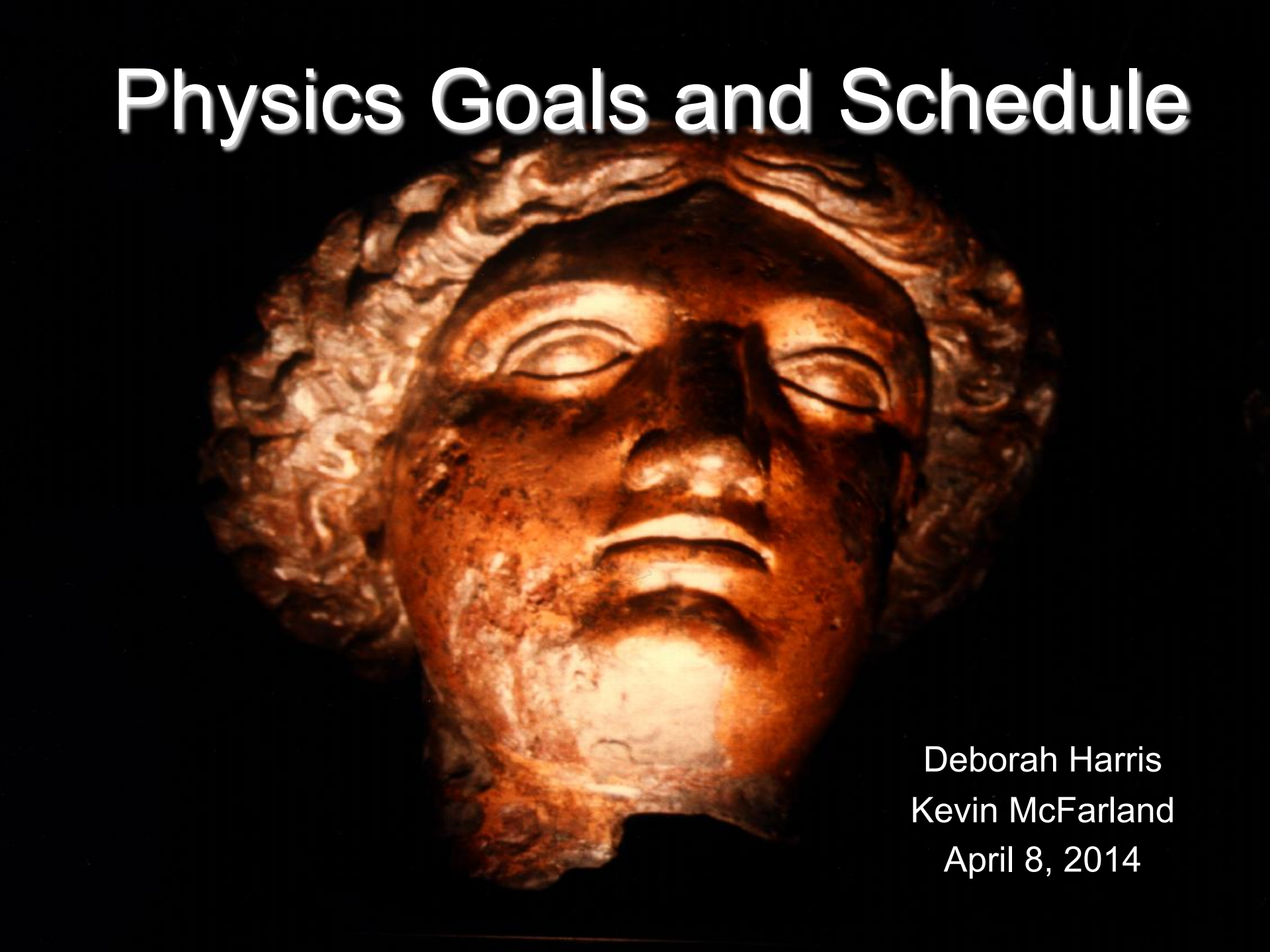
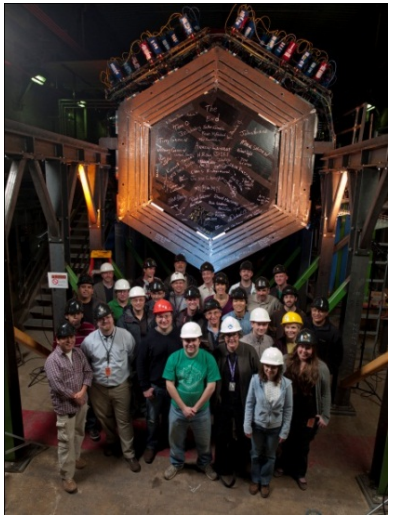
Physics Goals and Schedule



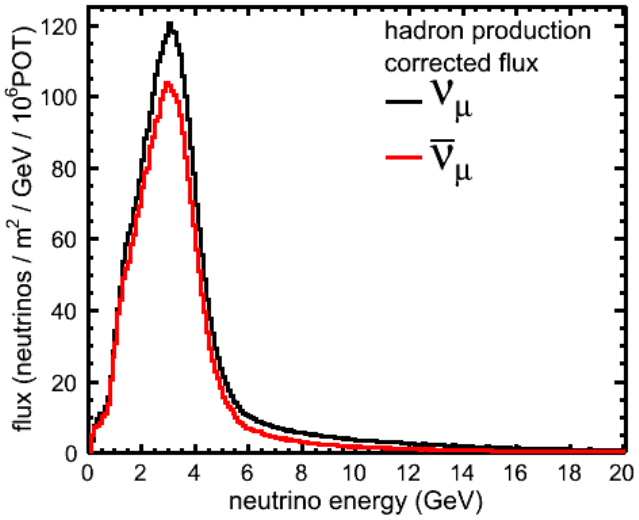
Deborah Harris
Kevin McFarland
April 8, 2014

MINERνA Overview



- MINERνA is studying neutrino interactions in unprecedented detail on a variety of different nuclei
- Low Energy (LE) Beam Goals:
  - Study both signal and background reactions relevant to oscillation experiments (current and future)
  - Measure nuclear effects on exclusive final states
    - » as a function of measured neutrino energy
    - » Study differences between neutrinos and anti-neutrinos
- Medium Energy (ME) Beam (NOνA) Goals:
  - Structure functions on various nuclei
  - Study high energy feed-down backgrounds to oscillation expt's
- NuMI Beamline provides
  - High intensity, wide range of available energies
- MINERνA detector provides
  - Reconstruction in different nuclei, broad range of final states

NuMI Low Energy Beam Flux

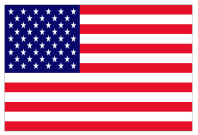


~65 Particle, nuclear and theoretical physicists from 20



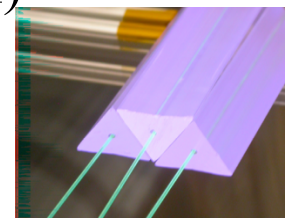


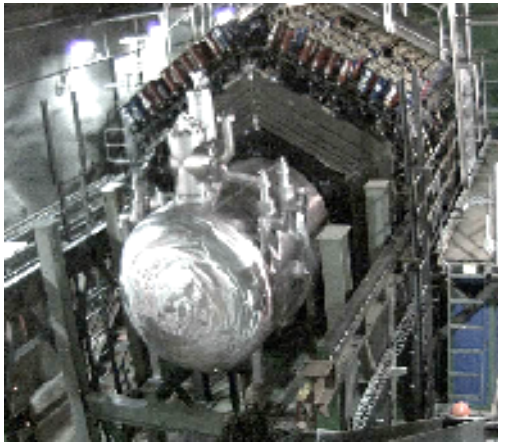




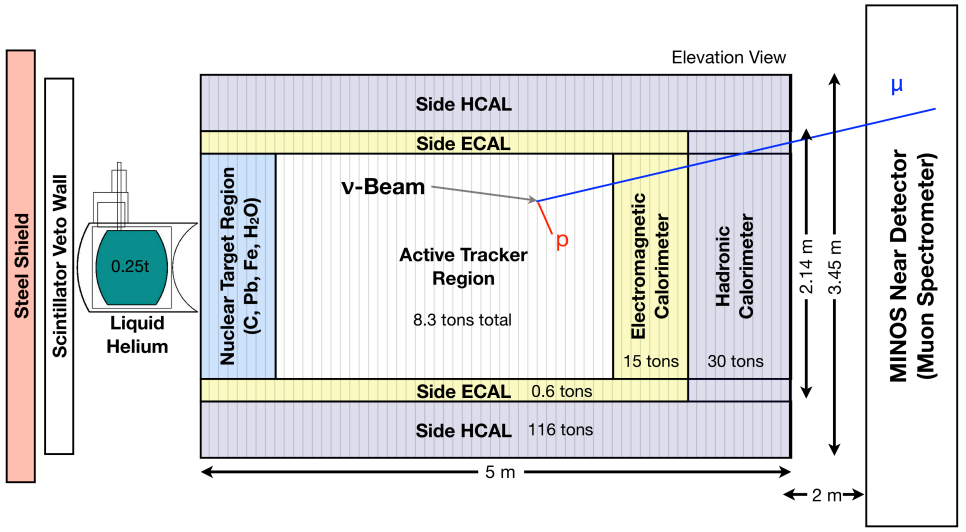
MINERvA Detector Basics

- Nuclear Targets
  - Allows side by side comparisons between different nuclei
  - Pure C, Fe, Pb, LHe, water
- Solid scintillator (CH) tracker
  - Tracking, particle ID, colorimetric energy measurements
  - Low visible energy thresholds
- Side and downstream electromagnetic and hadronic calorimetry
  - Allow for event energy containment
- MINOS Near Detector
  - Provides muon charge and momentum



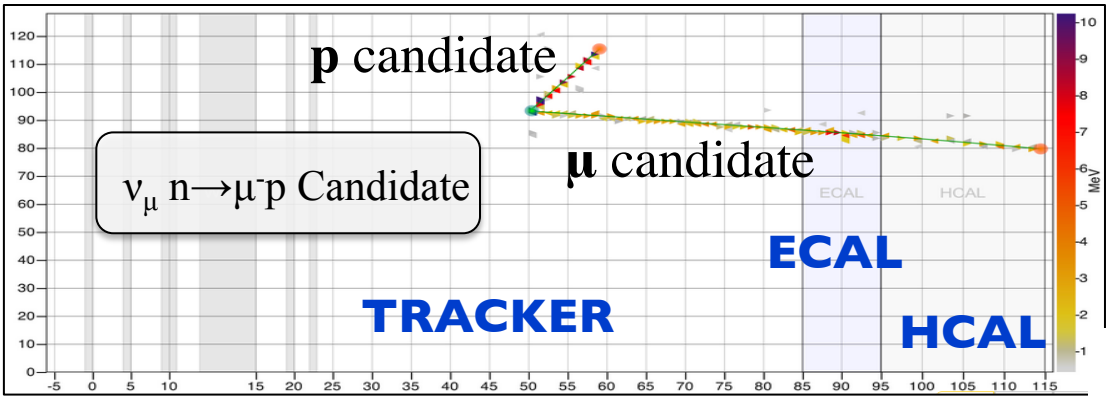


LHe cryotarget

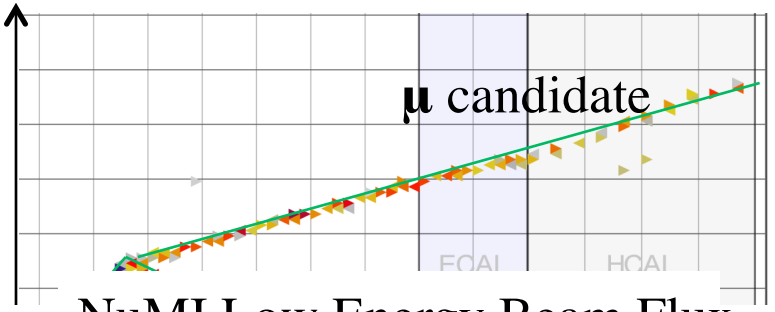


Events in MINERvA

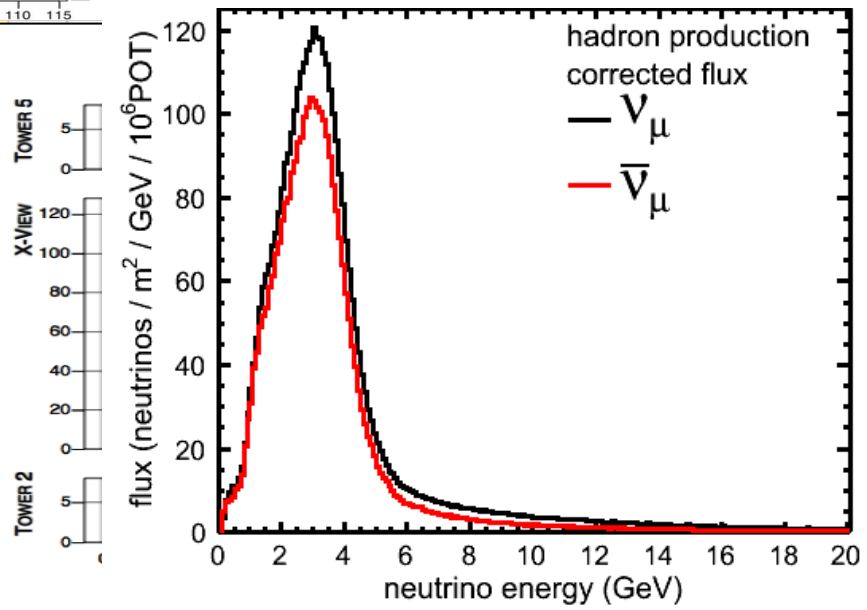
One out of three views shown, color = energy



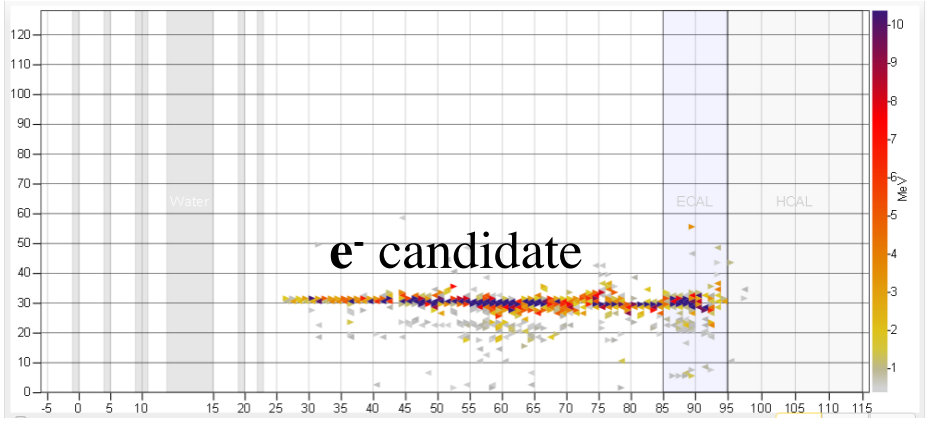
νμ p→μ-Δ++, Δ++→pπ+ Candidate



NuMI Low Energy Beam Flux



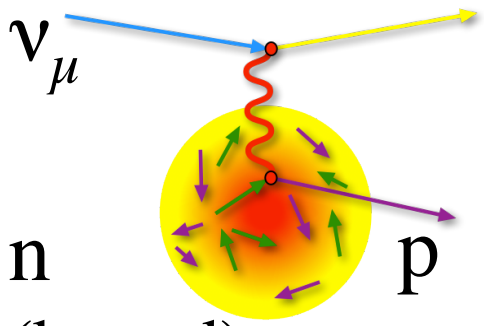
νμ e-→ νμ e- Candidate



Current Data Set Goals

- Low Energy (LE) Beam Goals:
  - Study both signal and background reactions relevant to oscillation experiments (current and future)
    - » Quasi-elastic Cross Sections
    - » Charged Pion production (charged and neutral pions)
  - Measure nuclear effects on exclusive final states
    - » as a function of measured neutrino energy and scattering kinematics
    - » Study differences between neutrinos and anti-neutrinos
- More General Neutrino Experiment Goals (both LE and ME)
  - Constrain neutrino flux predictions using neutrino-electron scattering
  - Use special runs in alternate beamline configurations to constrain hadron production model
    - » In concert with world's collection of hadron production data
  - Analyze test beam data set(s)
    - » publish NIM article describing detector performance

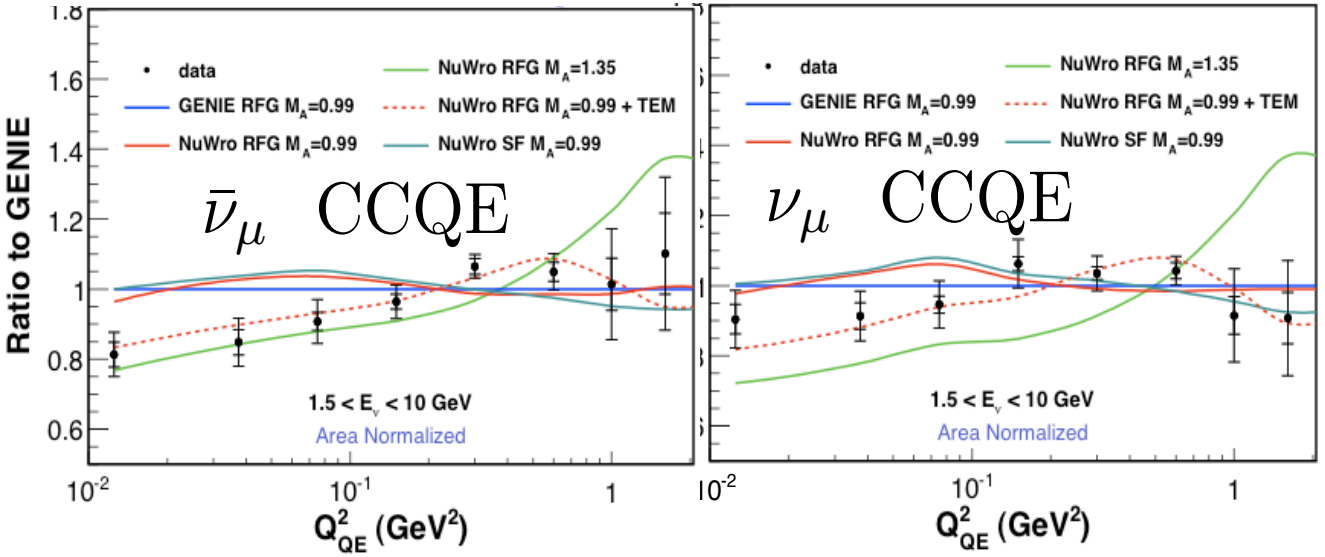
Neutrino & Anti-Neutrino CCQE

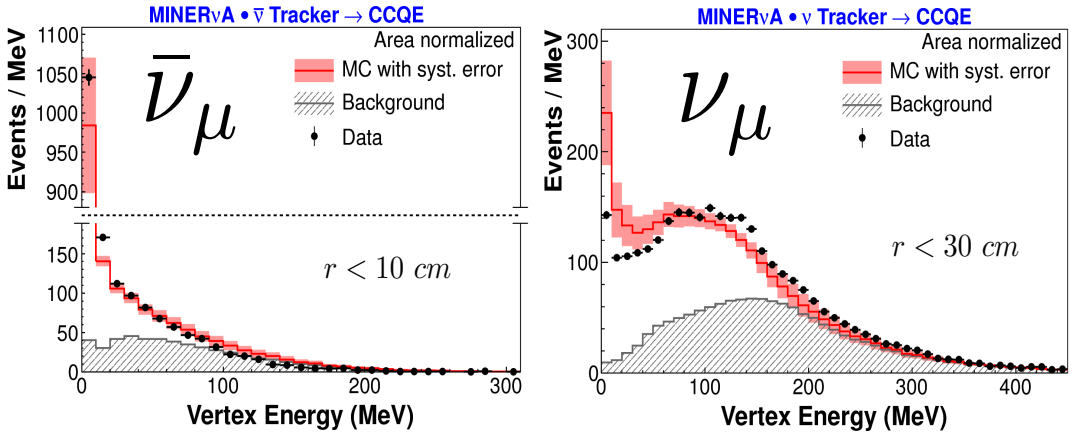


Phys Rev. Lett. 111, 002051 and 002052 (2013)

What is effect of nucleus?

Compare shape of $d\sigma/dQ^2$ to models



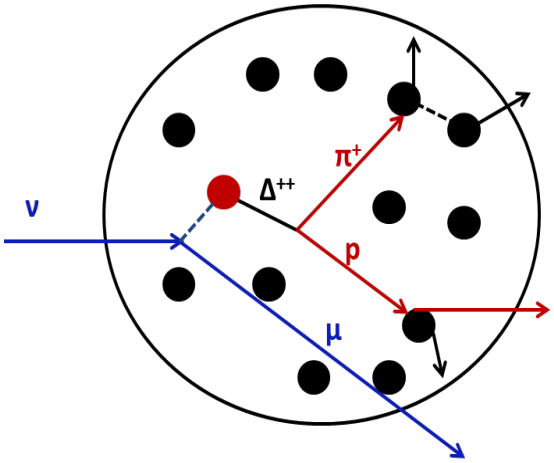


Look for energy near vertex consistent with extra nucleons

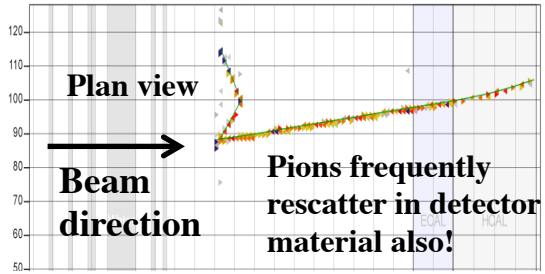
Data would prefer if 25±9% of events ejected initial state np pairs (final state nn or pp)

Cross-section vs Q^2 and vertex energy support multi-nucleon hypothesis

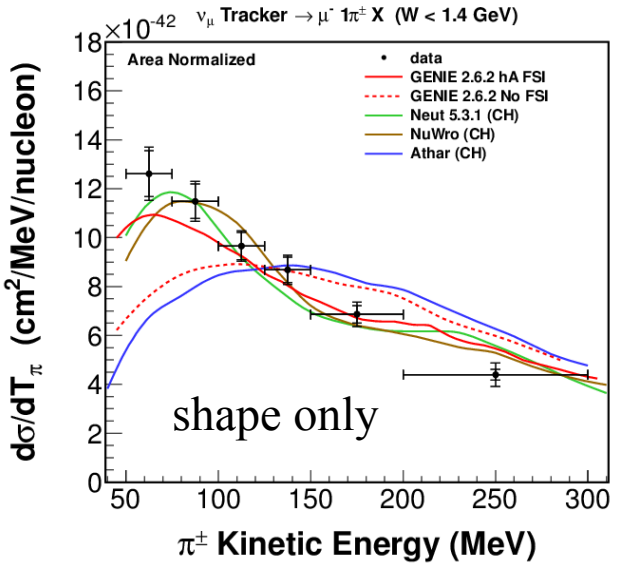
Charged Pion Production

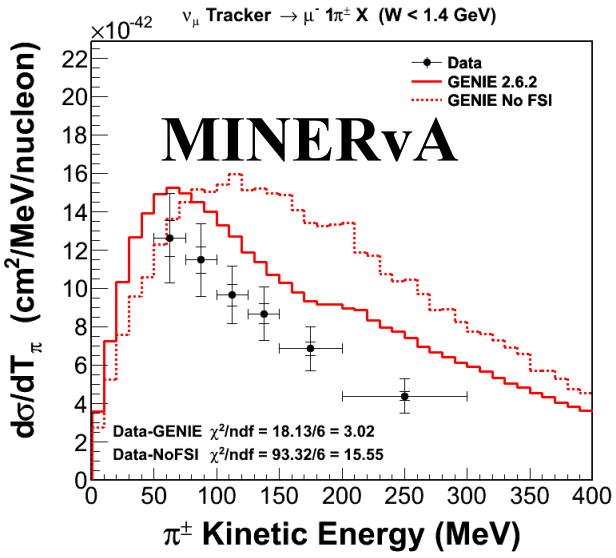


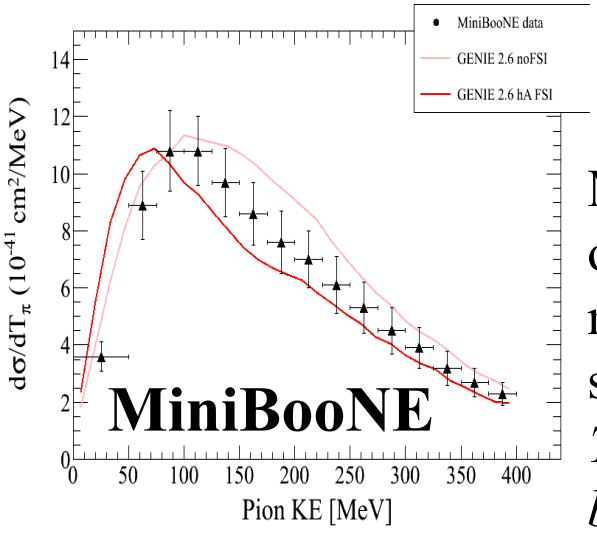
Do we correctly model nuclear rescattering, "final state interactions"?



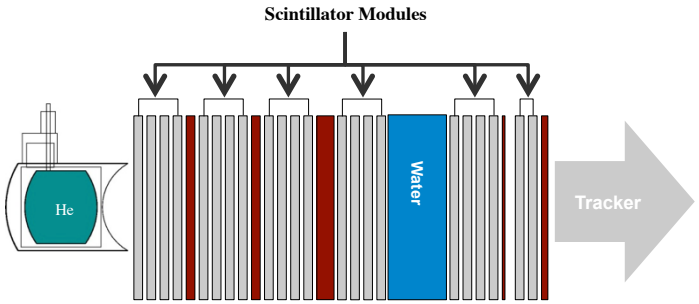
Our data on pion momenta requires this FSI





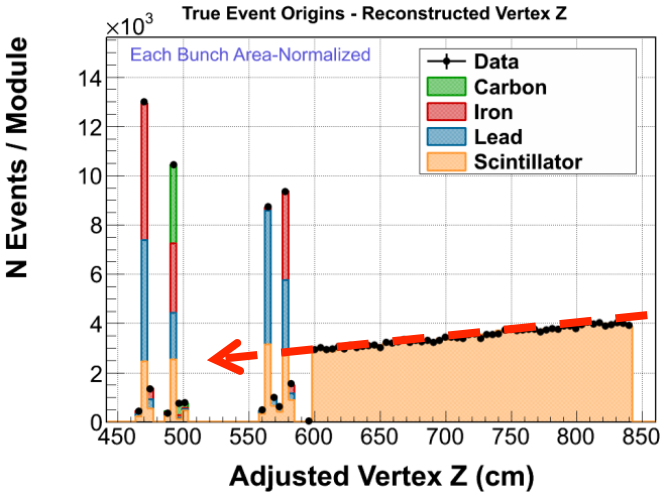


MiniBooNE's measurement of same reaction sees harder momenta, more events and suggest less FSI.
There is significant tension between the experiments.



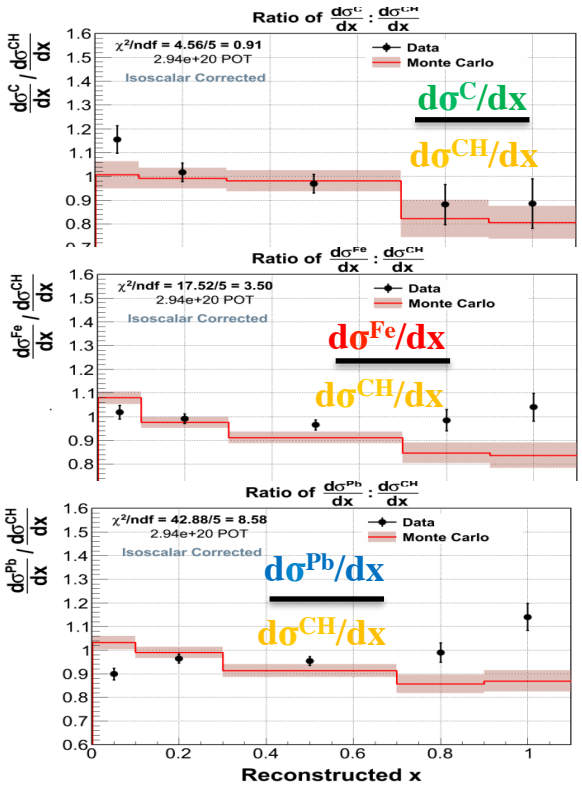
Ratios of CC Reactions on Nuclei

How are inclusive charged current reactions modified by nucleus?
"EMC effect in neutrinos"



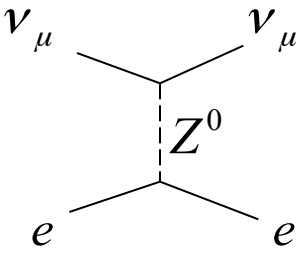
Targets are passive and there is background from nearby scintillator.

Use events in the tracker modules to predict and subtract the plastic background



We observe two primary effects not predicted in models used in oscillation experiments:

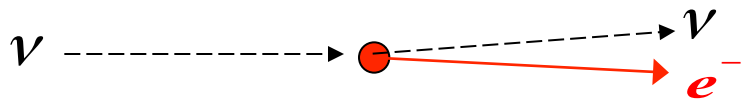
1. *At low x, "shadowing" is large and increases with heavier nuclei*
   (Large shadowing at our low Q^2? Axial current?)
2. *At high x, see higher rate for heavy nuclei*
   (Inadequate modeling of initial state momenta? Pauli blocking poorly modeled?)

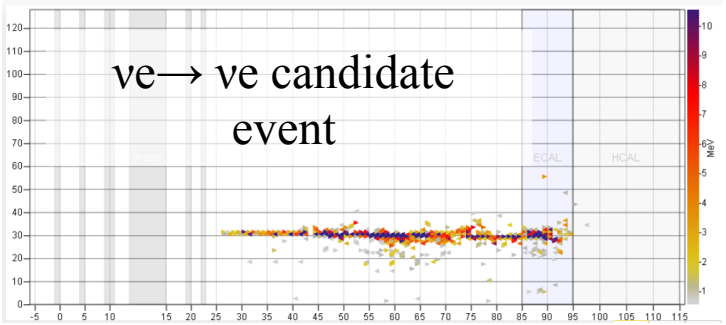


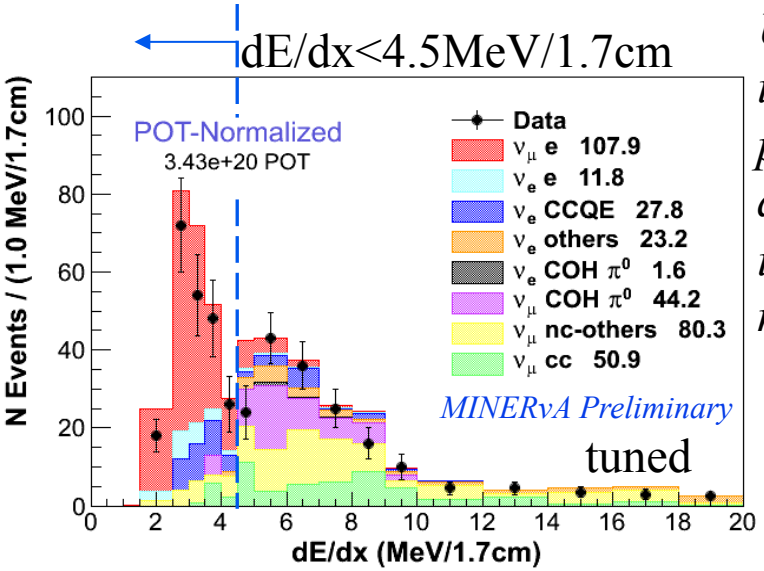
Neutrino-Electron Scattering

Can we isolate a sample of these well-predicted events to directly measure neutrino flux?

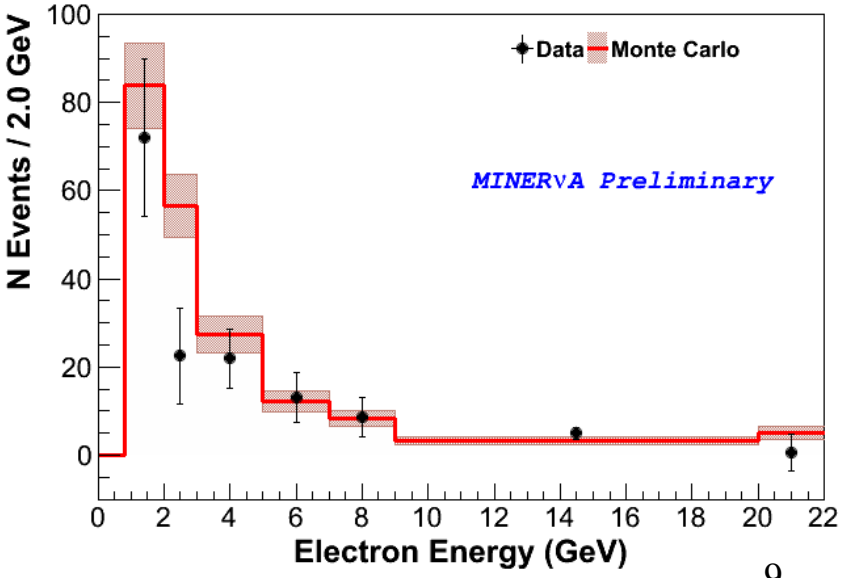
Very forward single electron final state







Use early ionization to reject photons and direction to reject interactions on nucleons



Measurement in LE NuMI beam constrains flux at precision similar to hadroproduction uncertainties

Technique will be even more powerful in NOvA era beam with higher energy and rate

Schedule and Data Management/ Computing Needs, I

- Quasi-elastic Cross section vs Q^2 for ν's and anti-ν's
  - published in June 2013
- Cross Section ratios between Fe, Pb, C and CH
  - submitted for publication in early March 2014
- Neutrino Charged Pion production on CH
  - February 2014 Wine and Cheese
  - Few items remaining, not computing intensive, paper in internal review process, goal of submission for publication in April 2014
- Neutrino Electron Scattering
  - December 2014 Wine and Cheese
  - Few items remaining, not computing intensive, goal of submission for publication as methods paper in May 2014

Schedule and Data Management/ Computing Needs, II

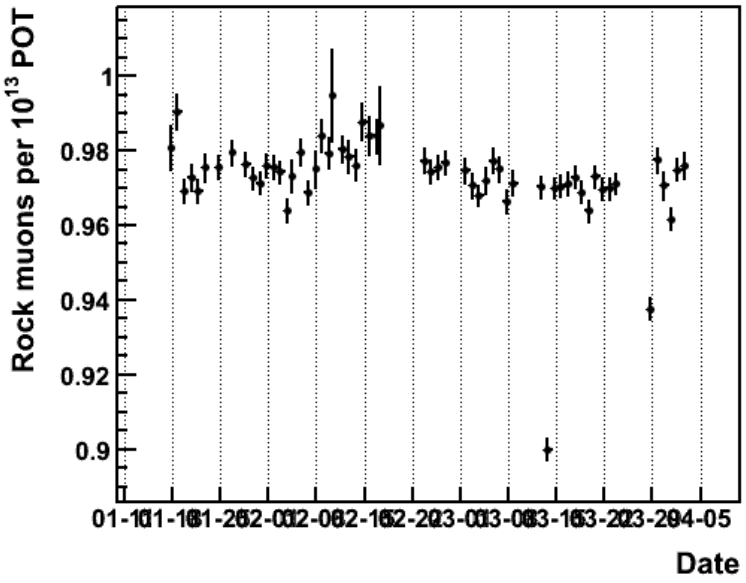
- ν Quasi-elastic Analysis focused on proton in final state
  - Plan to release result at May 9 Wine and Cheese (NuINT conference too)
  - Need to make "shifted Monte Carlo samples" to evaluate systematics that cannot be evaluated using reweighting techniques with new processing
    - » Need 92TB of space on disk for adequate samples for this
    - » Will also use substantial grid slots to generate these samples on time
  - Goal is to submit corresponding paper to journal in May 2014
- Coherent charged pion production in ν's and anti-ν's
  - Will also make use of shifted MC samples listed above
  - Goal here is to get result this summer, with paper on similar timescale
- Charged Current Neutral Pion production with anti-ν's
  - See above…

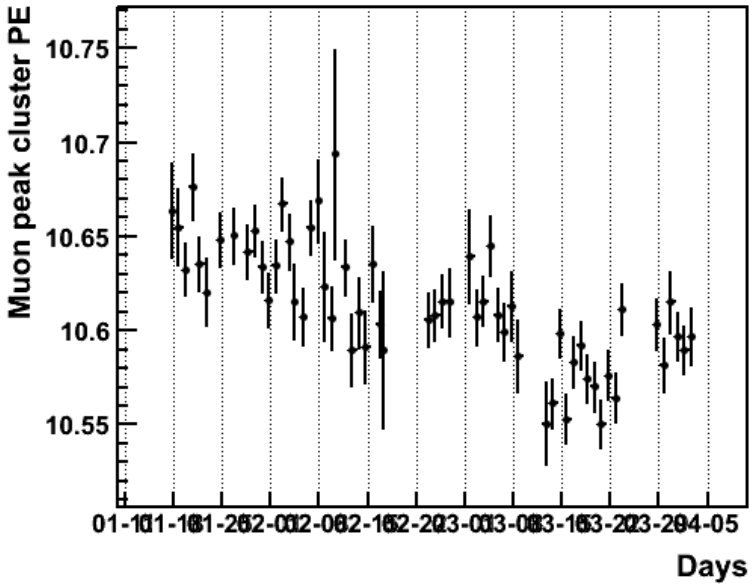
Schedule and Data Management/ Computing Needs, III

- Special Run Analysis to constrain hadron production models:
  - Critical need for simulation of accidental activity in MINOS near detector
  - Robert Hatcher has been working on this, does seem to be nearing completion
  - Once this is ready for production, will need a whole new set of Monte Carlo to be generated
  - Another 96TB for this new MC set at a minimum
  - Timescale for this is also this summer
- Many other analyses will also rely on the new MC and the new flux coming from this analysis
  - Absolute cross sections versus neutrino energy
  - Double Differential cross sections for Quasi-Elastic Scattering

What about the Medium Energy Data?

- We are also taking Medium Energy data with high livetimes
- We are monitoring that data at much higher level now than ever before http://nusoft.fnal.gov/minerva/minervacal/daily_muon_monitoring.html

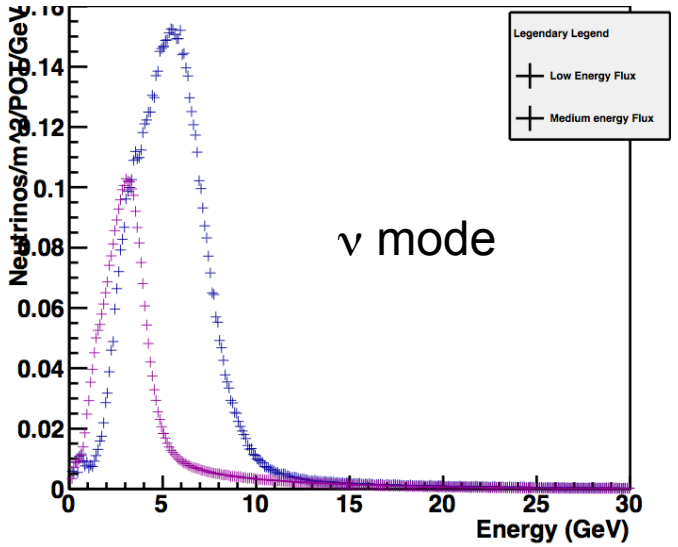


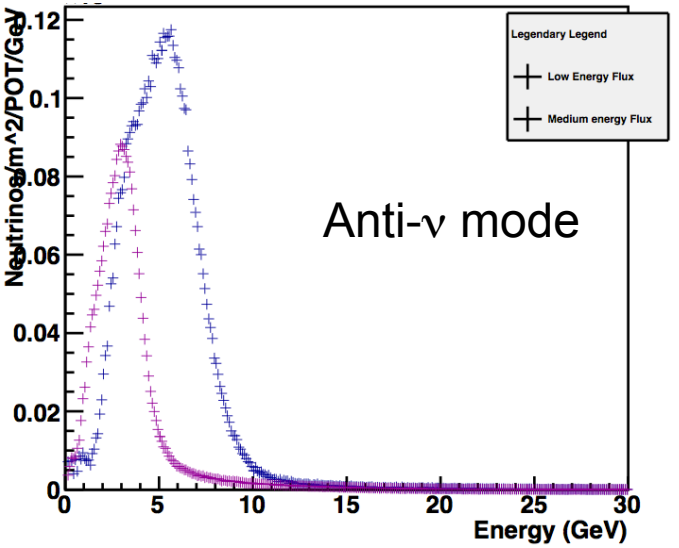


- Also want to be calibrating that data as we go, instead of running calibration after run is complete (a la Low Energy Run)

What Medium Energy Beam Brings

- More neutrino flux per proton on target (POT)
- More POT per year (already have 1.8E20 POT (ν mode) in 7 months, compared to 4E20 in 2 years)
- Higher energy ν's means (often) higher cross sections
- Current data set ALREADY could extend statistics of LE results in new energy and kinematic reach
  - Cross section ratios for nuclear targets
  - Coherent pion production
  - Quasi-elastic Cross Sections
- New students and post-docs are here NOW to do these analyses, but we don't have the computing to handle it





Quasi-elastics in the ME Beam

- Higher energy beam means
  - higher reach in momentum transfer
  - Measuring multi-nucleon effects at double the energy
- Original absolute cross section measurement was systematics limited and we already have similar statistics now (1.8EPOT compared to 3.5EPOT)
- Could already be saying something interesting with data set we have in hand
  - Calibration machinery in place but not all complete
  - Currently no way we could generate any reasonable MC set for this data due to disk space issue

Cross Section Ratios across different Nuclei

- Hit-level simulation on Medium Energy event sample, using cuts and reconstruction techniques from Low Energy analysis:

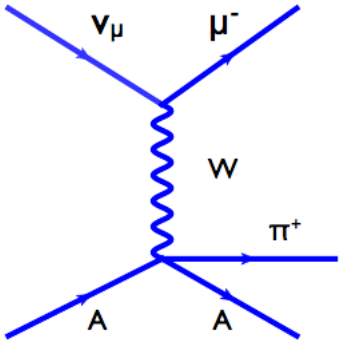
Ratio of events/POT ME / LE:

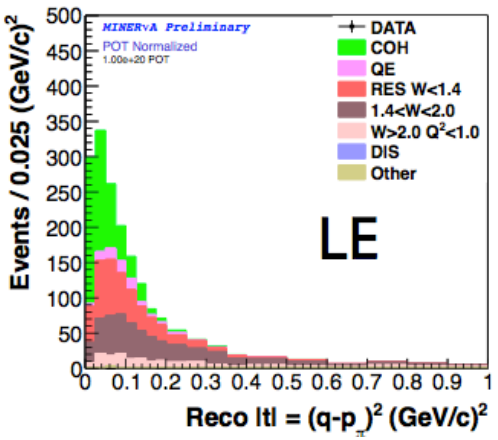
Bjorken x	0-0.1	0.1-0.3	0.3-0.7	0.7-0.9	0.9-1.1
Carbon	3.0	3.5	3.6	3.6	3.2
Iron	3.0	3.6	3.6	3.5	3.5
Lead	3.4	4.0	4.1	4.1	4.4
Scintillator	4.1	4.7	4.9	4.7	4.8

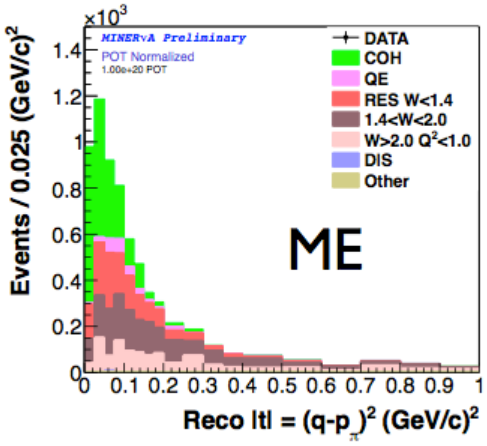
- At 1.8E20 POT accumulated, we already have between 1.5 and 2.4 times the statistics of the full data set in the Low Energy run

ν Coherent Pion Production

- ν scatters off nucleus coherently
  - Neutral current analog is very uncertain background to oscillation
  - Puzzling history: not seen at low energies, only high



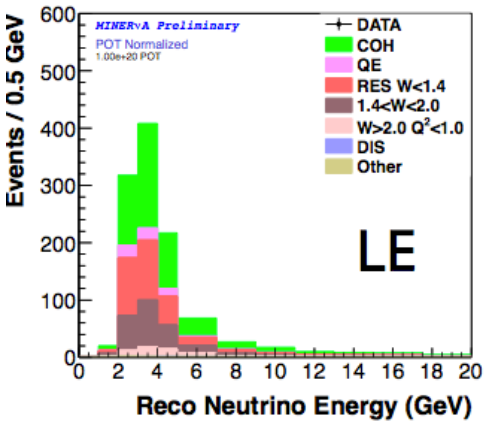


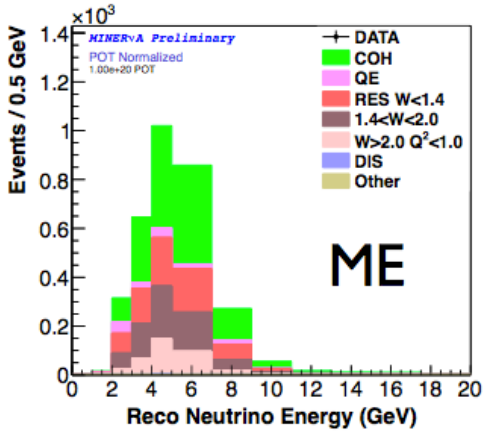


Cut at $t<0.15 GeV^2$

- Cut on t variable also valid, statistics better

Beam Mode	Events (per 10^{20} POT)	Signal Purity	Stat error (at 10^{20} POT)
LE	1260	44%	6.4%
ME	4480	44%	3.4%





Summary

- MINERvA has several physics results "around the corner"
  - Analyses and students are mature, many students on limited time scales due to funding
  - Need to generate ~100TB worth of shifted Monte Carlo samples to complete analyses ASAP
  - These samples will first help May 9 Wine and Cheese result but also a handful of other upcoming results
- Precision Absolute cross sections in MINERvA currently stalled because of lack of simulation of accidental activity in MINOS
  - Once that simulation is ready to go into production we will need to generate
    - » Central value monte carlo at ~50E20POT for 10x data statistics (42TB)
    - » Shifted monte carlo samples for neutrino and antineutrino datasets (96TB)
- All this has to happen while taking physics quality ME data
  - Have statistics already to extend some LE results, need MC and space for it