MINERνA

Status and Results

NEUTEL 2013

XV International Workshop on Neutrino Telescopes

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Venice, Italy

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University of Pittsburgh
(Representing the MINERνA collaboration)

Outline

→ **What is MINERνA?**

→ **Why Measure ν cross-sections?**

→ **Analysis Efforts and Status**

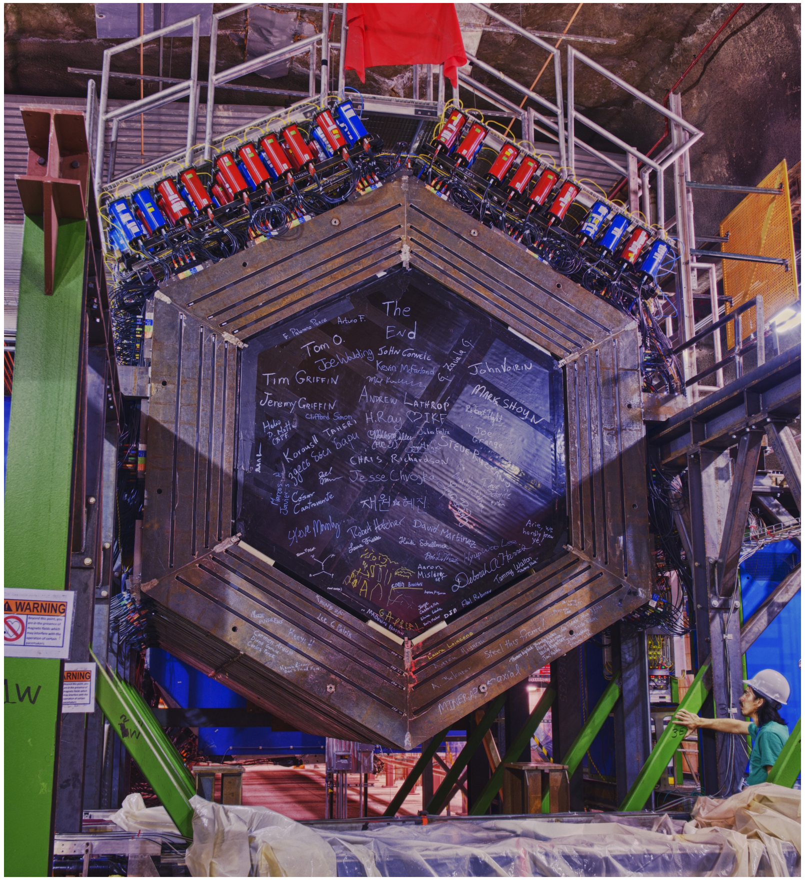
 - **Inclusive CC ν cross-sections**

 - **Pion Production**

 - **ν and anti-ν CCQE**

→ **Flux Constraints**

→ **Summary and Outlook**

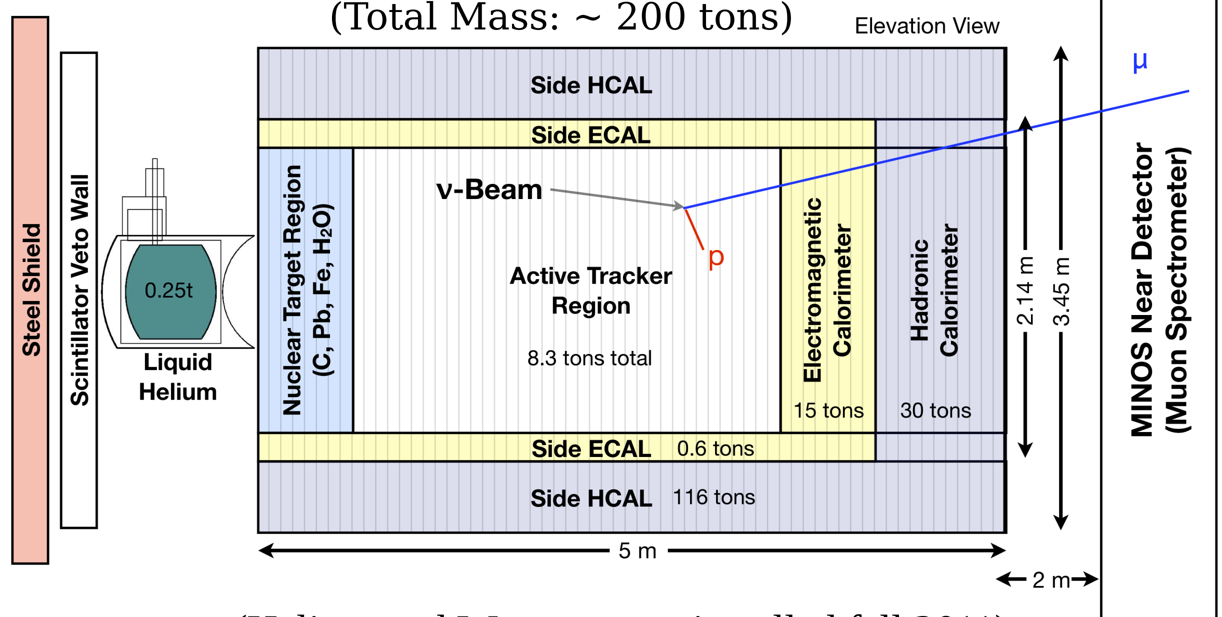


What is MINERνA?

- Dedicated neutrino-nucleus cross-section experiment running at Fermilab in the NuMI beamline.
  - Will perform detailed study of neutrino interactions on a variety of nuclei.
  - Using Low Energy Neutrinos
    - Visualized with a fully active, high resolution detector and large statistics

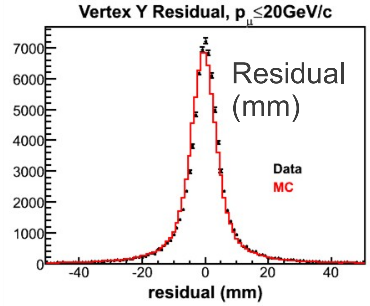
120 modules of tracker, targets, and calorimetry

(Total Mass: ~ 200 tons)

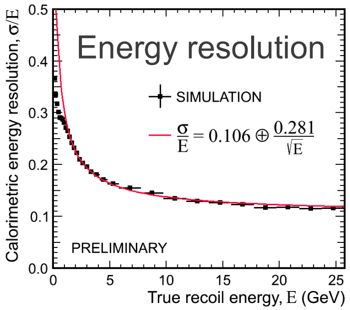


(Helium and Water targets installed fall 2011)

Detector Capabilities

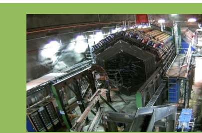


- Good tracking resolution (~3 mm)



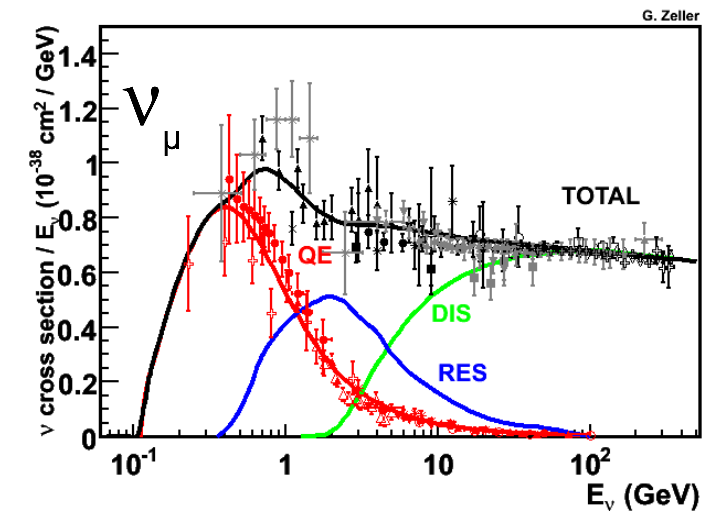
- Calorimetry for both charged hadronic particles and EM showers
- Timing information (few ns resolution)
- Containment of events from neutrinos up to several GeV (except muon)
- Muon energy and charge measurement from MINOS
- Particle ID from dE/dx and energy+range
  - But no charge determination except muons entering MINOS

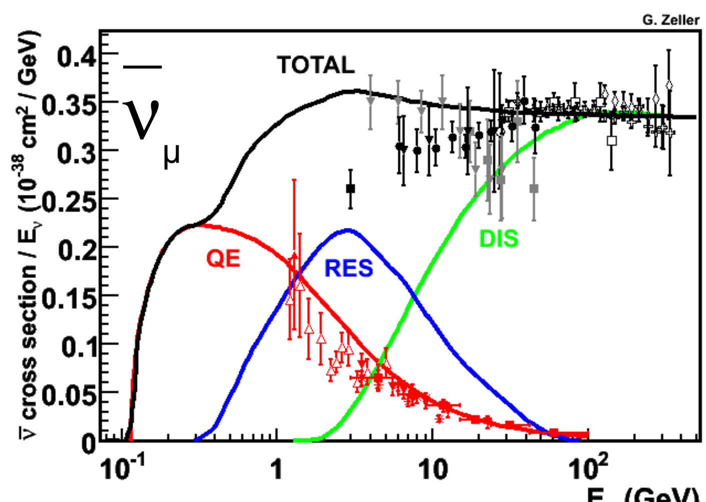
Why is MINERνA Needed?

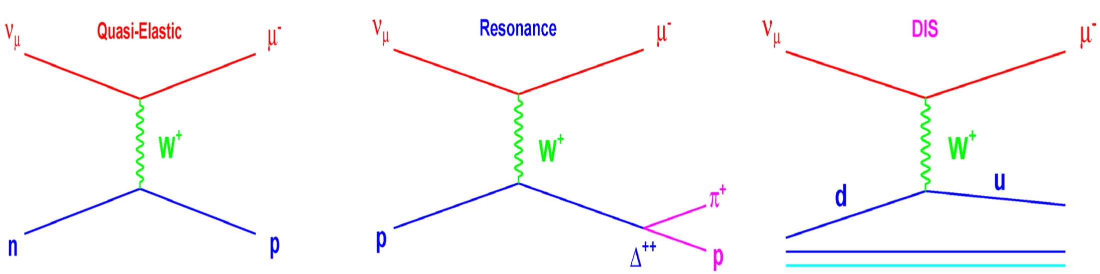


- Existing data between 1-20 GeV poorly understood:
- Mainly bubble chamber data
- Wide band neutrino beams
  - Low statistics samples
  - Large uncertainty on flux. *i.e.* large systematic errors.

Rev. Mod. Phys. 84, 1307–1341 (2012)







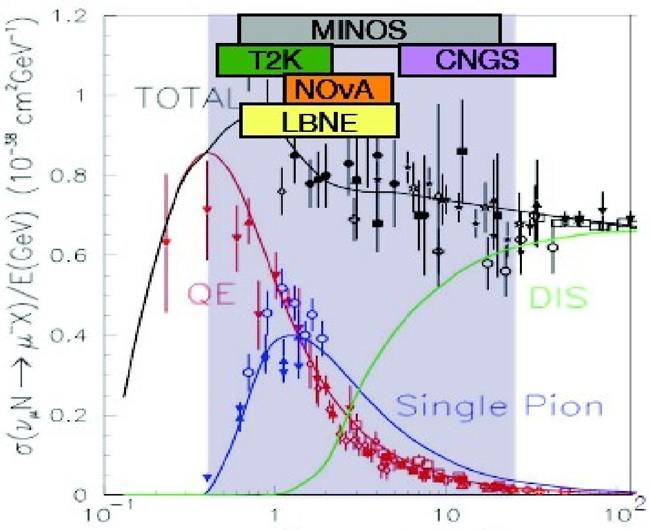
Why do we care that the cross-sections are poorly know?

- **ν oscillations:**

→ We are now in a period of precision neutrino oscillation measurements
→ Recall oscillation probability depends on E_ν
- However Experiments Measure E_{vis}
- E_{vis} depends on Flux, σ, detector response, interaction multiplicities, target type, particle type produced and final state interactions: E_{vis} not equal to E_ν

→ Appearance Oscillation Measurements:
- Large Θ_{13} and CP violation - systematics important
- Backgrounds to ν_e searches:
  - CC ν_μ events with π^0 and "lost" μ
  - NC π^0: $\nu_{\mu/e} + N \rightarrow \nu_{\mu/e} + N + \pi^0$
  - Intrinsic ν_e in beam (Specific to NuMI beam)

G. Zeller



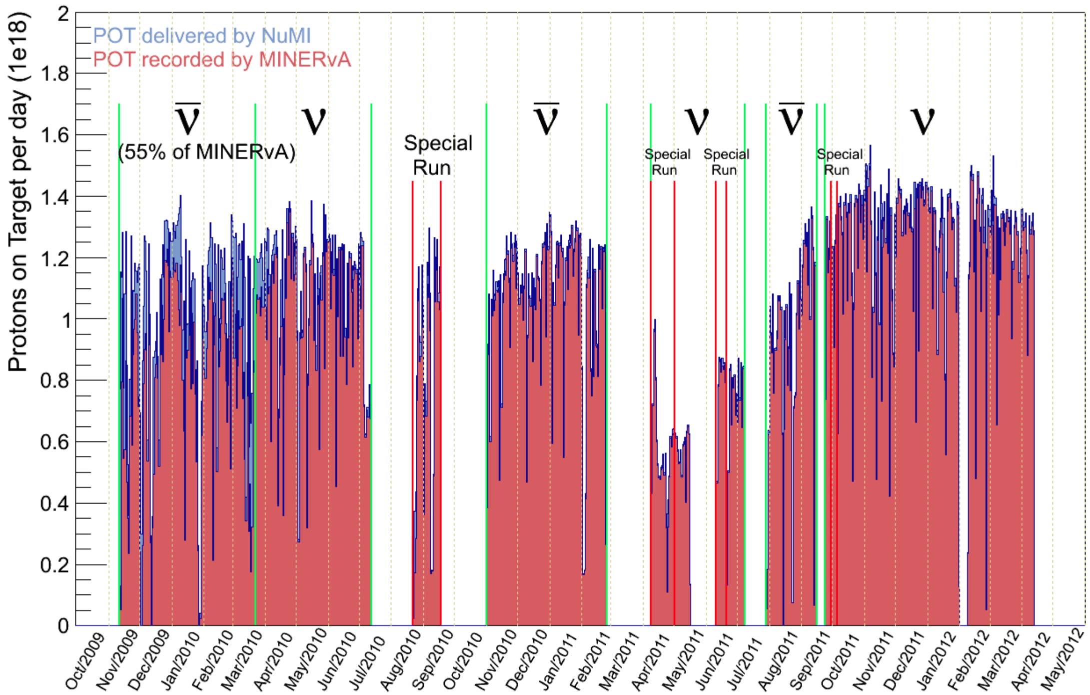
MINERνA Energy Range

- **Neutrinos a weak-interaction probe of nuclear structure**

→ Probe of axial form factor
→ ***A*** dependence of neutrino interactions
→ Strange production

- **Need Precision understanding of Low energy (Few GeV) ν_μ & $\bar{\nu}_\mu$ cross sections.**

Data Collected and Expected Sample Sizes



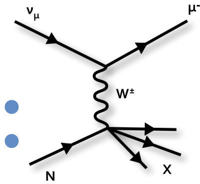
Target	Fiducial Mass (tons)	ν_μ CC Events in 1.0e20 POT
Plastic	6.43	313k
Helium	0.25	14k
Carbon	0.17	9.0k
Water	0.39	20k
Iron	0.97	54k
Lead	0.98	57k

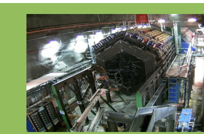
Recently completed low energy (LE, peak ~3 GeV) running:

→ LE neutrino mode 3.98×10^{20} POT
→ LE anti-neutrino mode 1.7×10^{20} POT
→ Flux-calibration runs 4.94×10^{19} POT

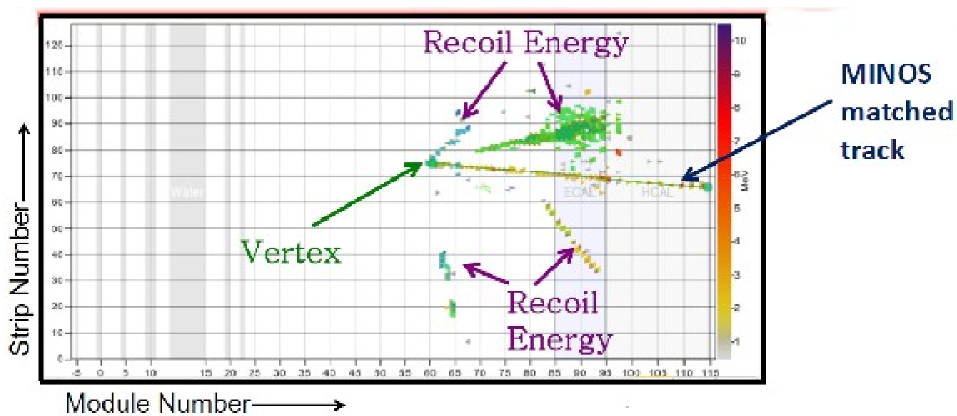
→ We will soon start taking data in the NOνA era with a higher energy beam: (ME, peak ~6 GeV) ¬

CC Inclusive:

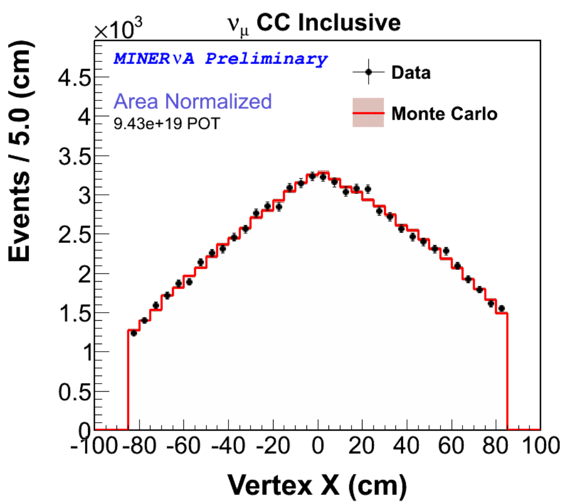


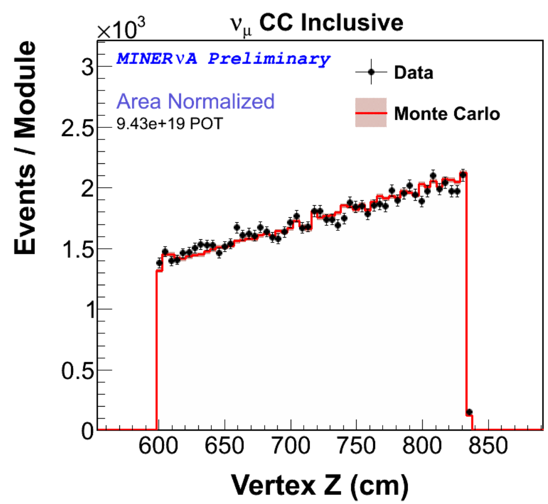


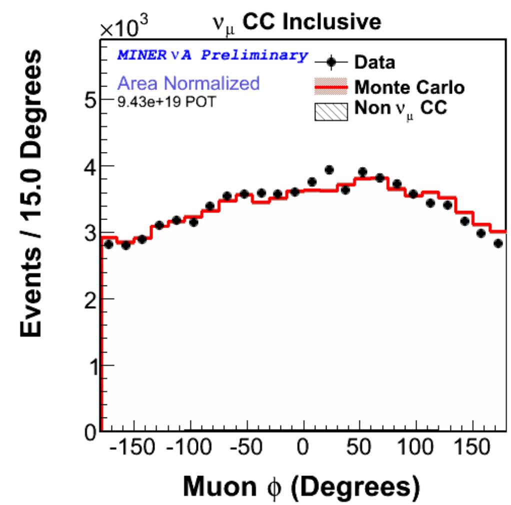
ν_μ / $\bar{\nu}_\mu$ inclusive charged current scattering:



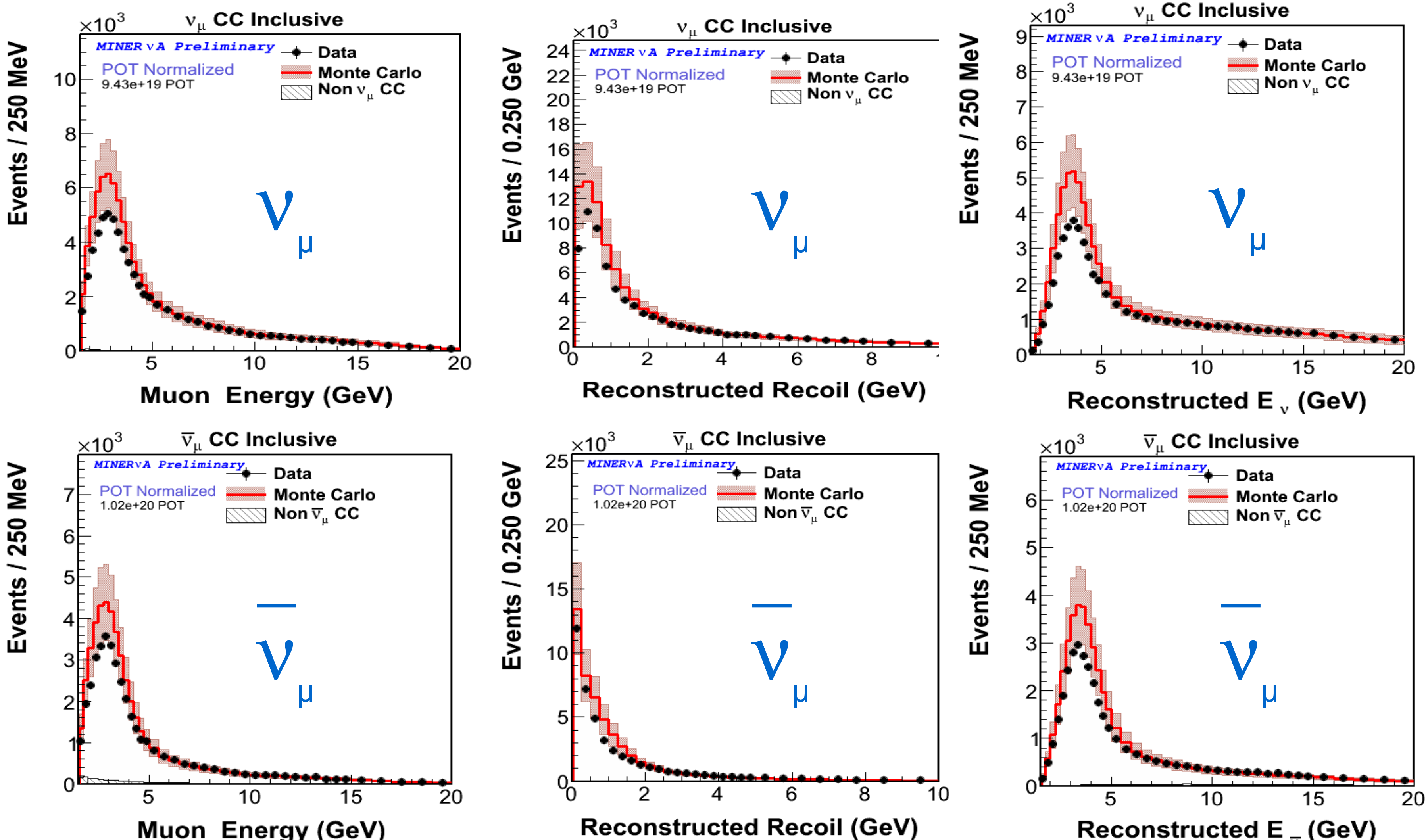
MINOS matched Muon + Recoil Energy (Sum of visible energy, weighted by amount of passive material)





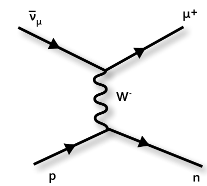


$\nu_\mu / \bar{\nu}_\mu$ Inclusive: Kinematic Variable Distributions



(All plots absolutely normalized)

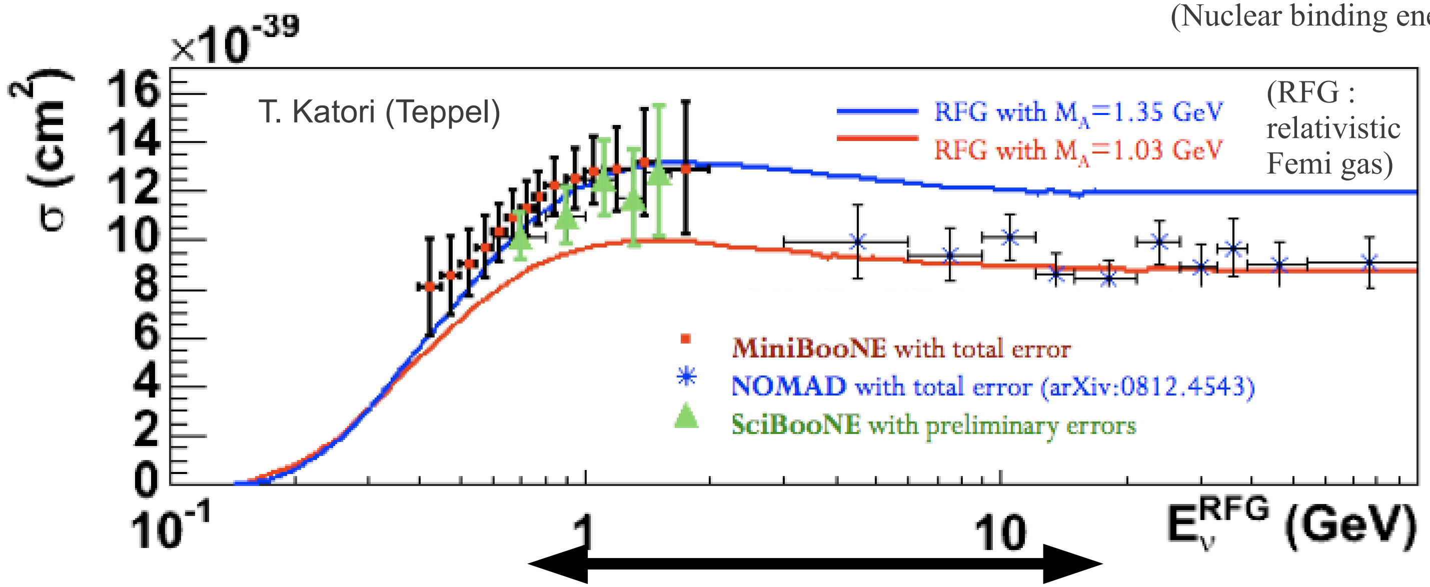
CCQE Scattering:



- Considered a possible standard candle for neutrino oscillation experiments
- ~30% discrepancy in the QE cross section measurements between MiniBooNE/SciBooNE and NOMAD
  - Could be be due to the axial mass M_A or nuclear effects
  - Could Depend on Energy Reconstruction Assumptions
    - Reconstructed neutrino energy Eν (CCQE)

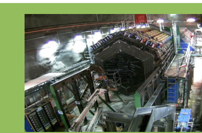
$$E_\nu^{QE} = \frac{m_n^2 - (m_p - E_b)^2 - m_\mu^2 + 2(m_p - E_b)E_\mu}{2(m_p - E_b - E_\mu + p_\mu \cos(\Theta_\mu))}$$

(Nuclear binding energy E_b = 30 MeV)

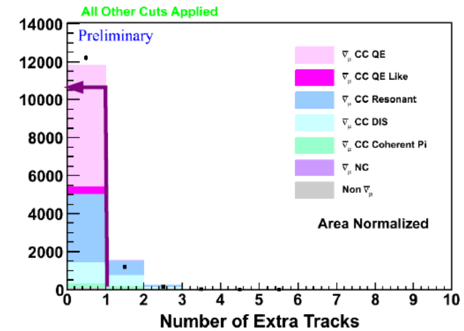


Minerva nicely covers region of interest

$\bar{\nu}_\mu$ CCQE Analysis

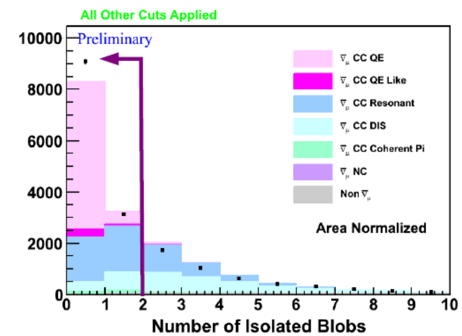


- Start by requiring a single track in MINERνA matched in MINOS of correct sign:



Number of Extra Tracks

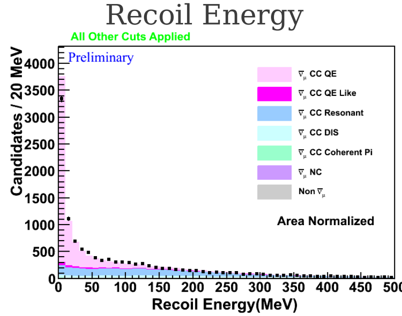
- Require no more than one isolated contiguous energy deposition – "Blob":



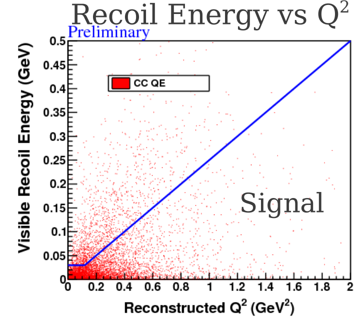
Number of Extra Isolated Blobs

- Cut on all non-track energy in tracker + Ecal
  → Require less than 30 MeV of recoil at low Q^2 and to $Q^2/4$ at higher Q^2

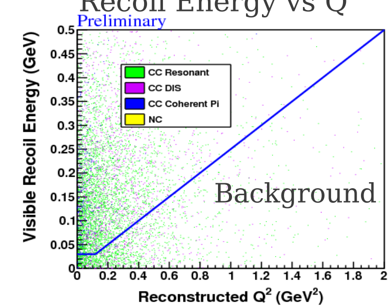
Recoil Energy



Recoil Energy vs Q^2



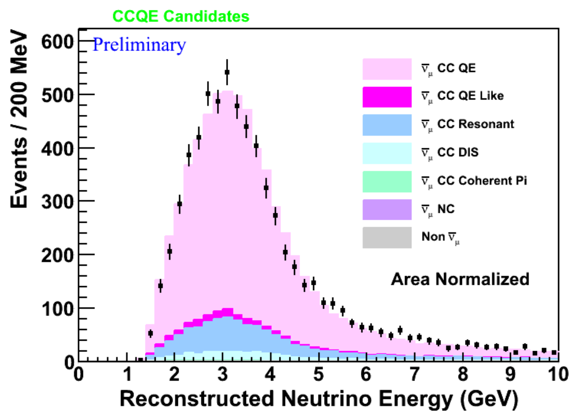
Recoil Energy vs Q^2



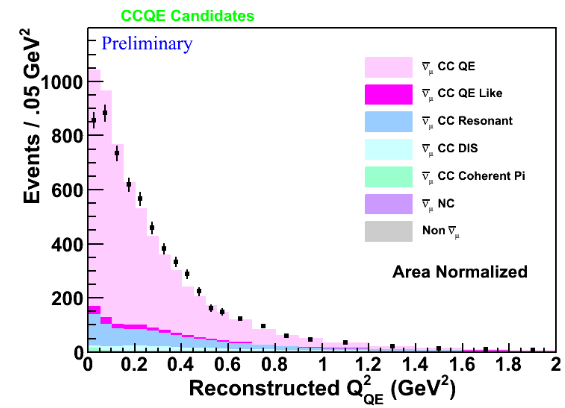
Total efficiency: ~40% Total purity: ~75%

(Uses ~1/3 of POT on tape)

$\bar{\nu}_\mu$ CCQE Results

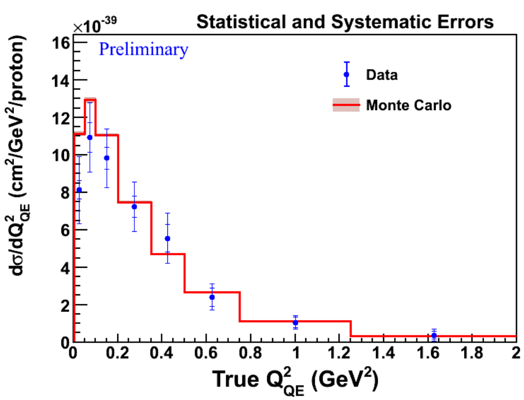


$$E_\nu = \frac{m_\mu^2 - (m_p - E_b)^2 - m_\mu^2 + 2(m_p - E_b)E_\mu}{2(m_p - E_b - E_\mu + p_\mu \cos\theta_\mu)}$$



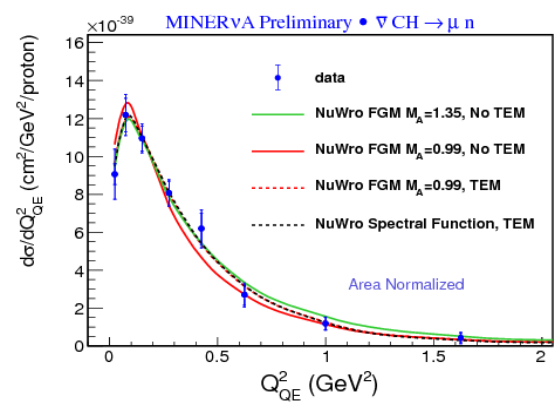
$$Q^2 = 2E_\nu(E_\mu - p_\mu \cos\theta_\mu) - m_\mu^2$$

Unfolded distributions (BK subtracted) are normalized by efficiency, flux & proton number to produce final cross-sections: Uses simple matrix inversion method of unfolding



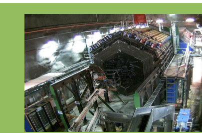
GENIE 2.6.4; M_A = 0.99 GeV
RFG: Pauli-blocking: No MEC

- Systematic uncertainties are dominated by flux, recoil and muon reconstruction.
- We expect to reduce our errors with an improved understanding of our flux, better unfolding method and statistics



Comparison with Models - NuWro: Golal, Jusczak, Sobczyk arXiv:1202.4197
MEC model: Bodek, Budd, Christy Eur. Phys. J. C(2011) 71:1726

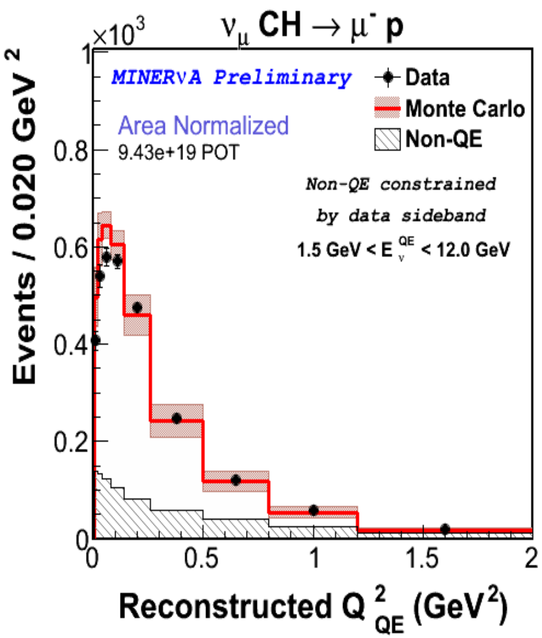
ν_μ CCQE Analysis and Results

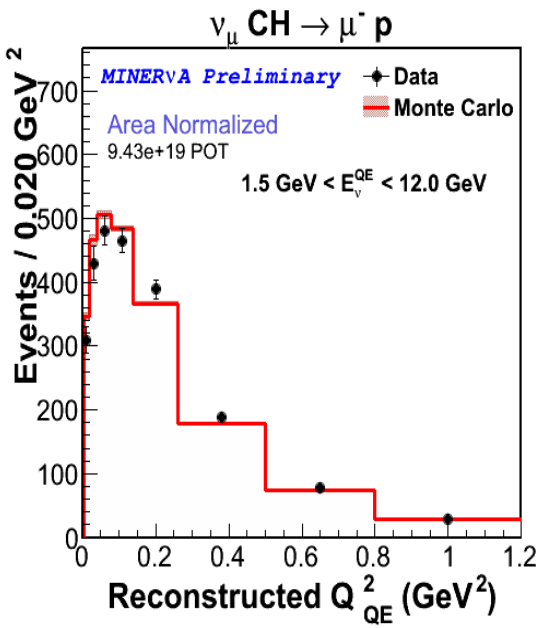


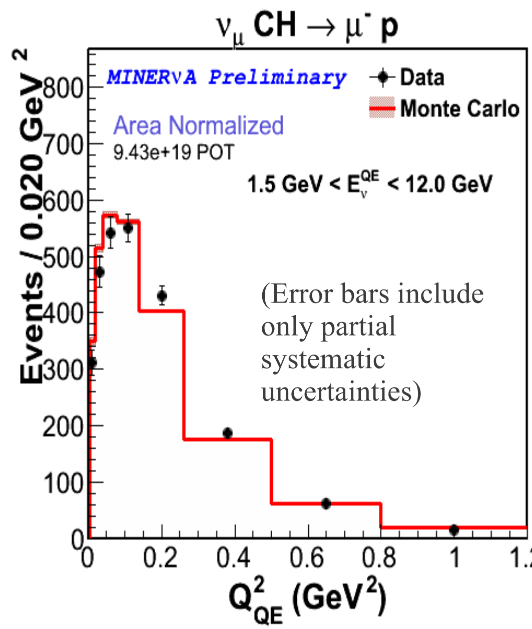
Sample selection similar to anti-nu analysis:

→ Requires MINOS-matched track, no more than 2 tracks, less than two isolated blobs and little recoil energy (with vertex energy excluded)

→ Recoil distributions have slightly different structure (due to presence of proton rather than neutron in final state)







Raw Background Subtracted Unfolded

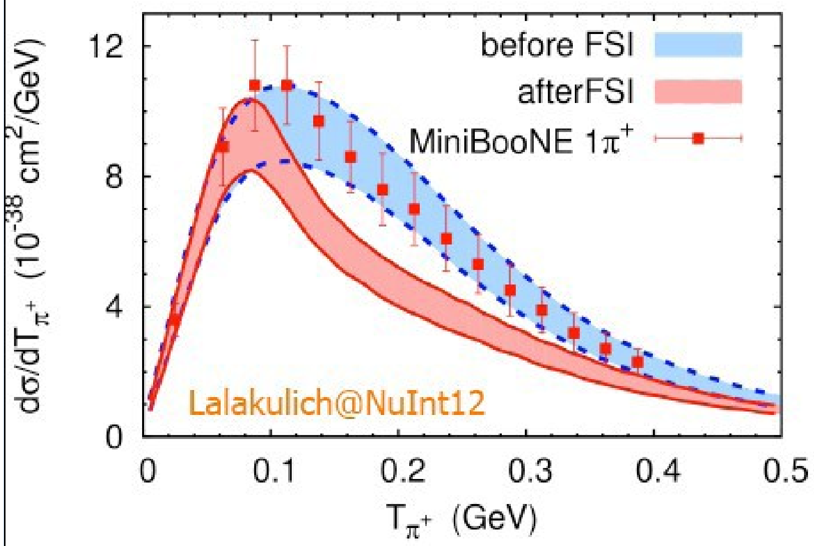
(Unfolding method for the nu-mode analysis uses iterative Bayesian unfolding)

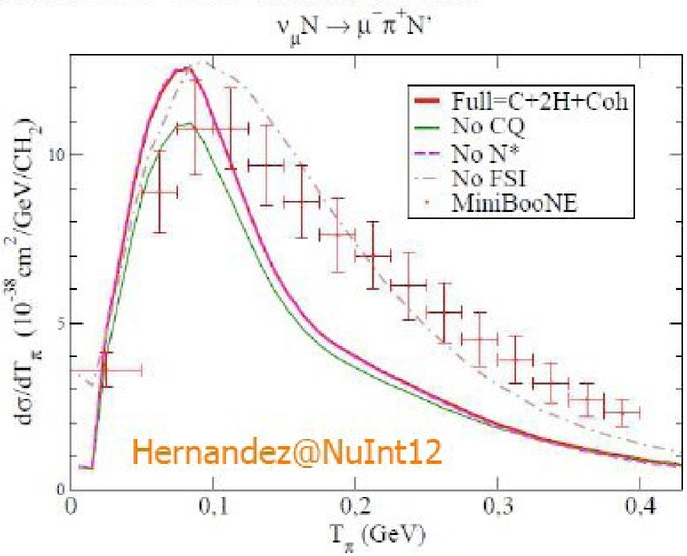
→ Full efficiency corrected cross sections are coming soon.

Pion Production: Interesting State of Affairs…

L.Alvarez-Ruso, NuInt2012

- State of the art calculations describe better the data without FSI





- Transport
- 13 resonances
- Resonance propagation
- contribution from DIS

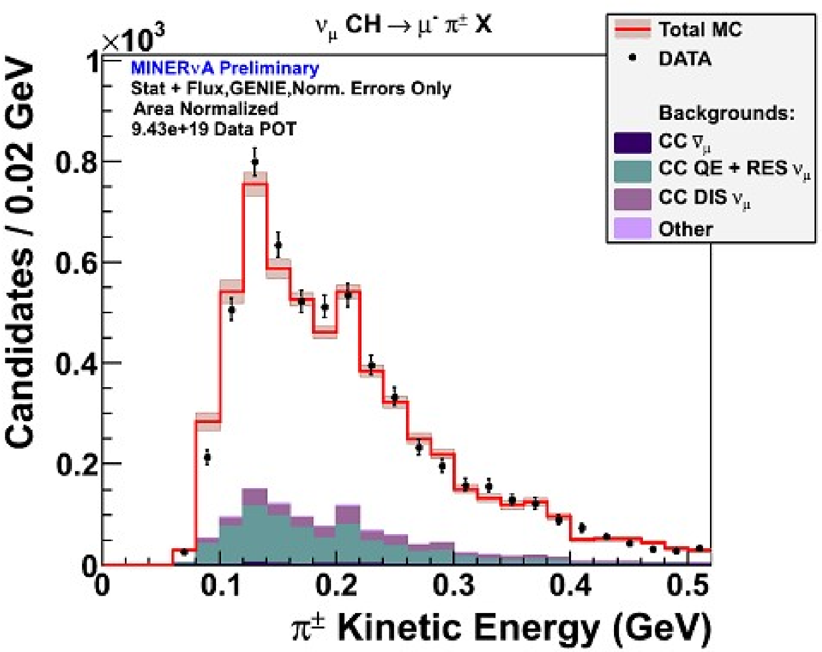
- Cascade
- 2 resonances
- No resonance propagation
- No DIS

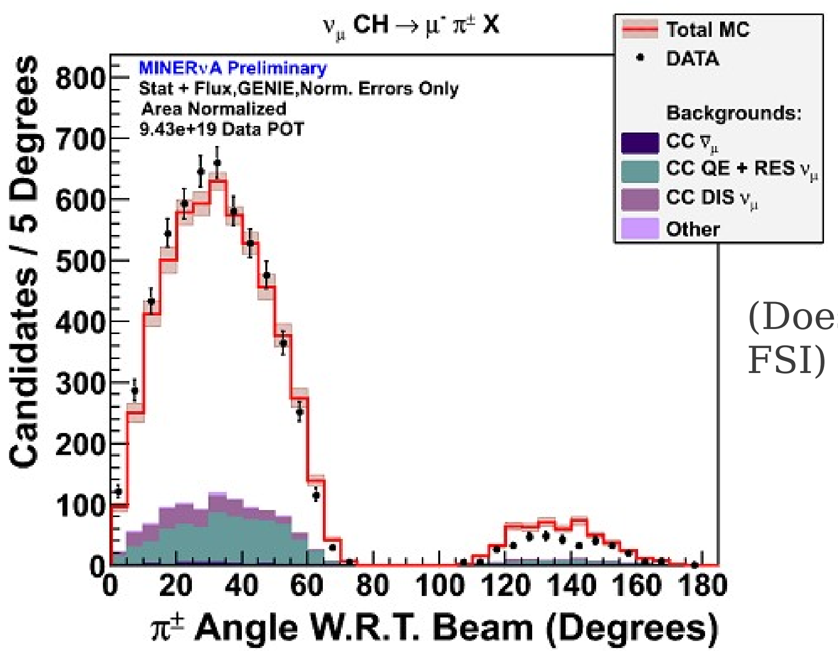
Pion Production: ν_μCC $\pi^\pm$

→ The signal definition: *At least* one $\pi^\pm$ leaving the nucleus (Data: 9.43×10^{19} POT)

→ **Event selection**: Reconstructed vertex inside fiducial volume, One μ^- MINOS matched track, Hadronic visible energy less than 2.5 GeV, At least one hadronic (non-muon) track, The hadronic track is *pion-like (Our understanding of detector particle type response from test-beam data)*

Pion kinetic energy and angle



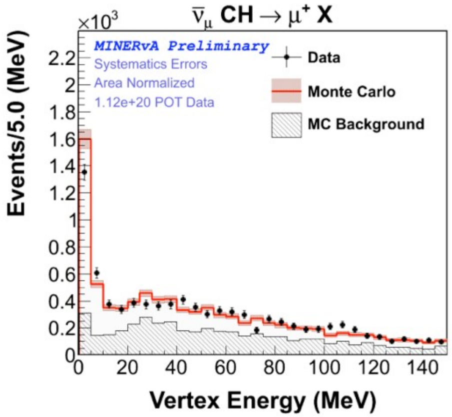


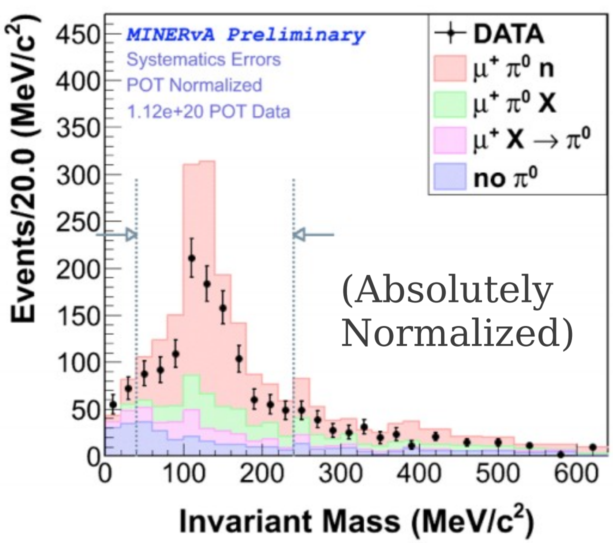
(Does include FSI)

Pion Production: $\bar{\nu}_\mu$ CC $1\pi^0$

→ The signals definition: One π^0 leaving the nucleus (Data: 1.12×10^{20} POT)

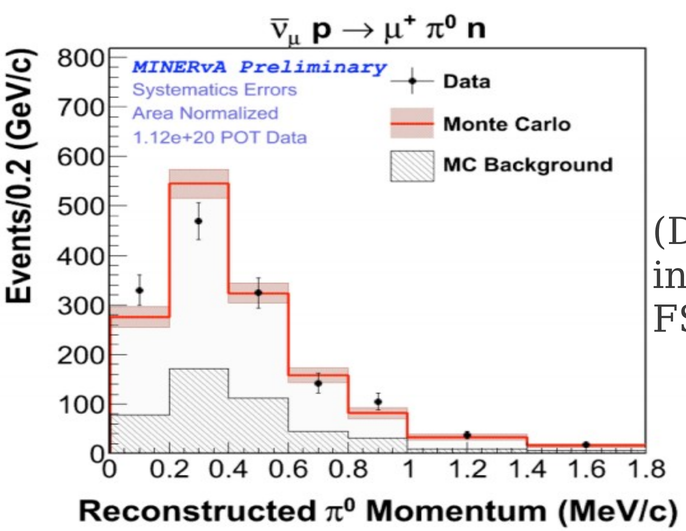
Event Selection: Reconstructed vertex inside fiducial volume, One μ^+ MINOS matched track, Two EM showers (shower hits must be within 25 ns of the vertex time), Visible energy in the target region less than 20 MeV





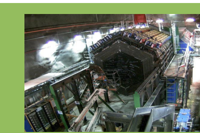
(Absolutely Normalized)

Mass and Momentum Distributions with Vertex Energy Cut < 13 MeV



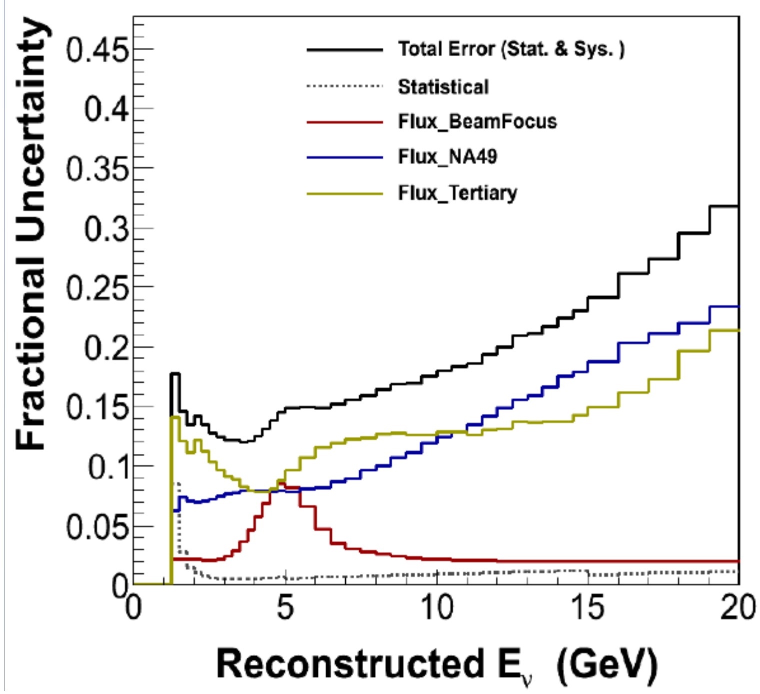
(Does include FSI)

Flux: Absolute Cross-section Errors

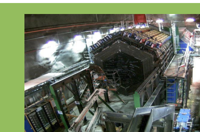


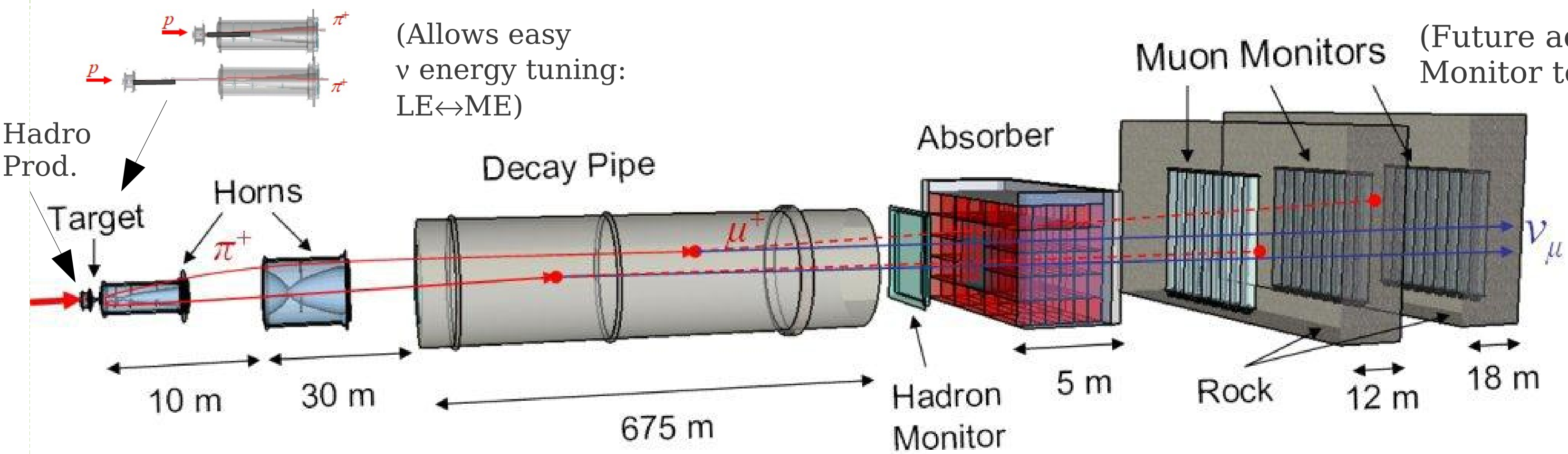
- Statistical errors are expected to be very small.
- The total error on absolute cross section measurements will be dominated by the systematic error on the determination of the neutrino flux:

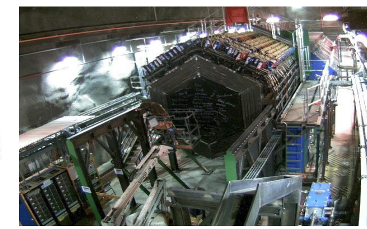
Present Total Uncertainties: Reconstructed E_ν



Flux: Our ν Beam (NUMI)

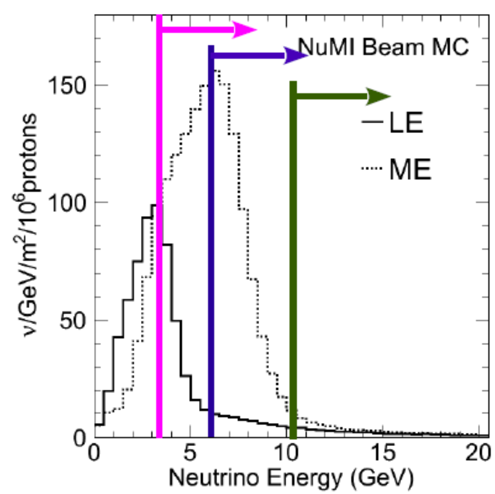






MINERvA

→ Magnetic horns focus pions and kaons, which then decay into muons and neutrinos



Muon Monitor 1: $E_{\mu,\pi} > 4.2$ GeV & $E_{\nu} > 1.8$ GeV

Muon Monitor 2: $E_{\mu,\pi} > 11$ GeV & $E_{\nu} > 4.7$ GeV

Muon Monitor 3: $E_{\mu,\pi} > 21$ GeV & $E_{\nu} > 9.0$ GeV

Flux: How to Reduce Our Errors

Will Use Multi-prong approach:

→ Use the Muon Monitor Data.

→ Take Special runs:

- Vary the beam parameters (horn current, target position).

→ Use ν_μ – atomic electron interactions

→ Using low ν-method (MINOS, Phys. Rev. D 81, 072002 (2010) and D. Bhattarchya, PhD Thesis, Univ. of Pittsburgh (2009))

→ Using external hadron production data.

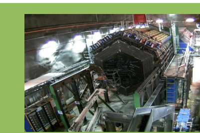
- Constraint the MC flux to get the right shape and uncertainty

Redundancy should improve our accuracy …

→ Hope to reduce absolute flux errors to below 10%

(Items in red – Inputs to our MC flux simulations)

Conclusions



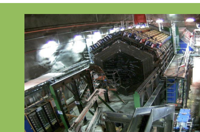
- MINERνA will precisely study neutrino interactions in 1-20 GeV:
  - Using a fine-grained, high-resolution, detector
  - Using the high flux NuMI beam.

- MINERνA is improving our knowledge of:
  - Neutrino cross sections at low energy, low Q^2.
  - A-Dependence in neutrino interactions (Targets He, C, Fe, Pb and H_2O)

- These data will help resolve longstanding discrepancies between experiments and will be important for minimizing systematic errors in oscillation experiments.

- First publications early summer.

The Collaboration Thanks You



- University of Athens, Athens, Greece
- Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
- UC Irvine, Irvine, CA
- University of Chicago, Chicago, IL
- Fermi National Accelerator Lab, Batavia, IL
- University of Florida, Gainsville, FL
- University of Geneva, Geneva, Switzerland
- Universidad de Guanajuato, Guanajuato, Mexico
- Hampton University, Hampton, VA
- Institute for Nuclear Research, Moscow, Russia
- James Madison University, Harrisonburg, VA
- Mass. Coll. of Liberal Arts, North Adams, MA
- University of Minnesota-Duluth, Duluth, MN
- Northwestern University, Evanston, IL
- Otterbein College, Westerville, OH
- University of Pittsburgh, Pittsburgh, PA
- Pontificia Universidad Catolica del Peru, Lima, Peru
- University of Rochester, Rochester, NY
- Rutgers University, Piscataway, NJ
- Universidad Tecnica Federico Santa Maria, Valparaiso, Chile
- University of Texas, Austin, TX
- Tufts University, Medford, MA
- Universidad Nacional de Ingenieria, Lima, Peru
- College of William & Mary, Williamsburg, VA

Title

Backup

Motivation

Other ν scattering physics:

- Axial form factor of the nucleon
  - Accurately measured over a wide Q2 range.
- Resonance production in both NC & CC neutrino interactions
  - Statistically significant measurements with 1-5 GeV neutrinos
  - Study of "duality" with neutrinos
- Coherent pion production
  - Statistically significant measurements of A-dependence
- Strange particle production
  - Important backgrounds for proton decay
- Charm particle production at threshold
  - Charm mass
- Parton distribution functions
  - Measurement of high-x behavior of quarks
- Generalized parton distributions using weak probes
- Nuclear effects
  - Expect significant differences for ν-A vs e/μ-A nuclear effects