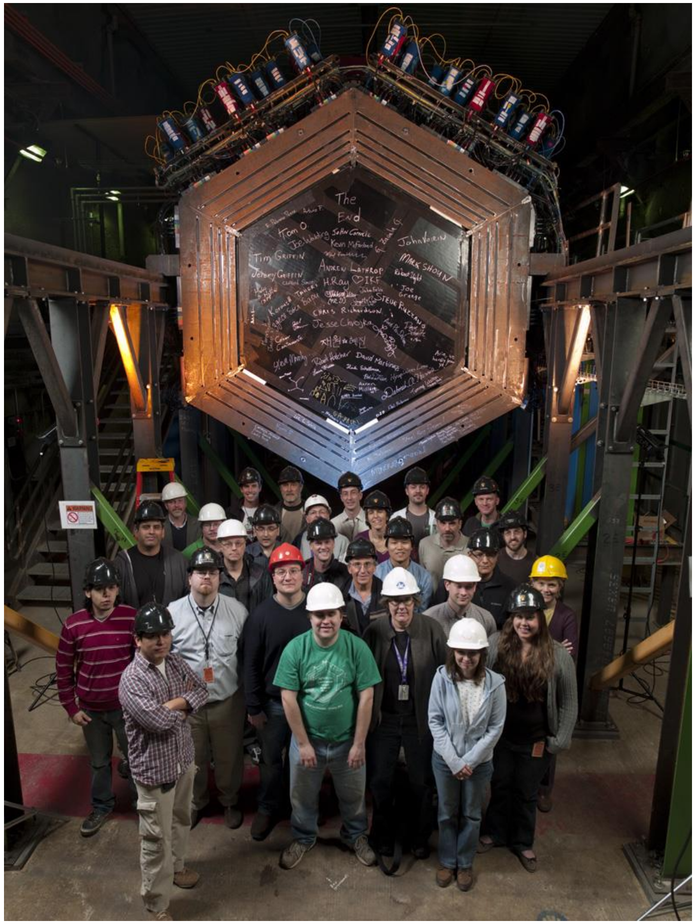
MINERνA and cross-sections:



MINERνA: well designed for the physics relevant to this session, physics results, plans

Limitations. What can we expect? What can we learn?

Flux. Need I say more?

S. Manly (Clint couldn't make it)

University of Rochester

Representing the MINERνA collaboration

NUFACT 2013

August 19-24, 2013

Beijing, China

MINERνA and cross-sections: why we care in the oscillation session

Assume quasielastic kinematics to determine E_ν

Neutrino beam → Near detector → ***Model*** *Even more important if near and far detectors are not the same material* → Far Detector

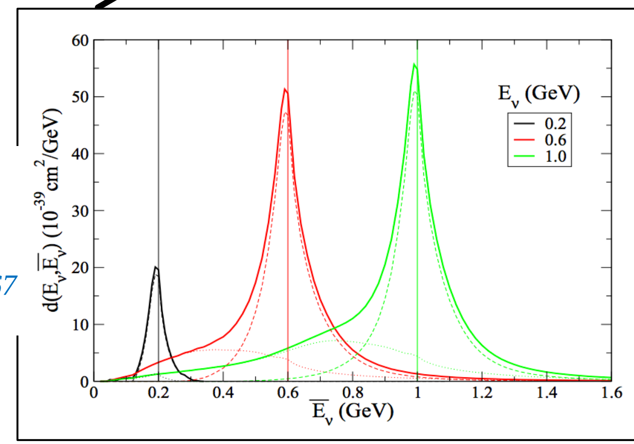
Long baseline

Measure flux and backgrounds in near detector and propagate to far detector and the uncertainties "cancel out"

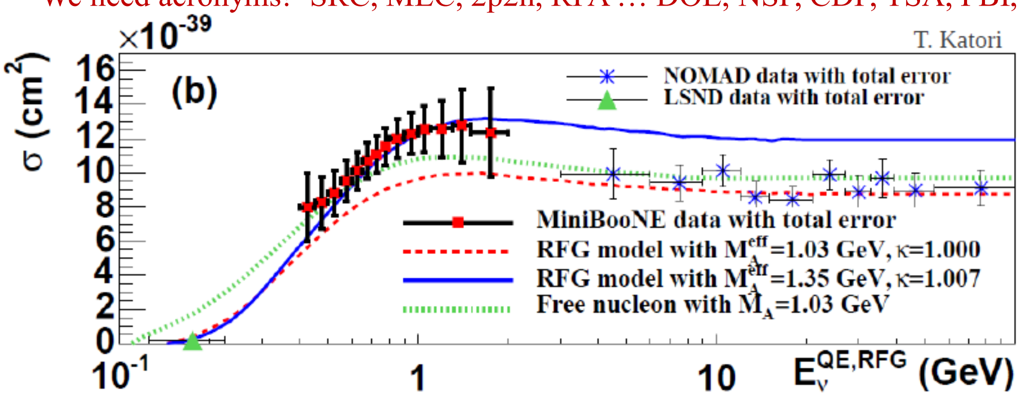
Cross-sections don't cancel simply/completely, even in the limit of identical detectors.

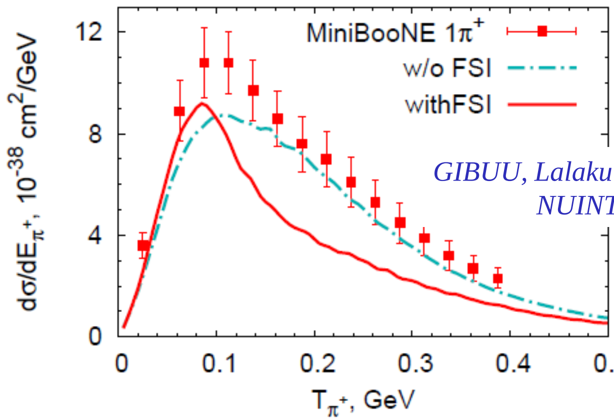
Martini et al. arXiv:1211.1523

Also:
J. Sobczyk arXiv:1201.3673,
Lalakulich et al. arXiv:1208.367
Nieves et al. arXiv:1204:5404



We need acronyms! SRC, MEC, 2p2h, RPA … DOE, NSF, CDF, TSA, FBI, whatever





GIBUU, Lalakulich and Mosel, NUINT 2012

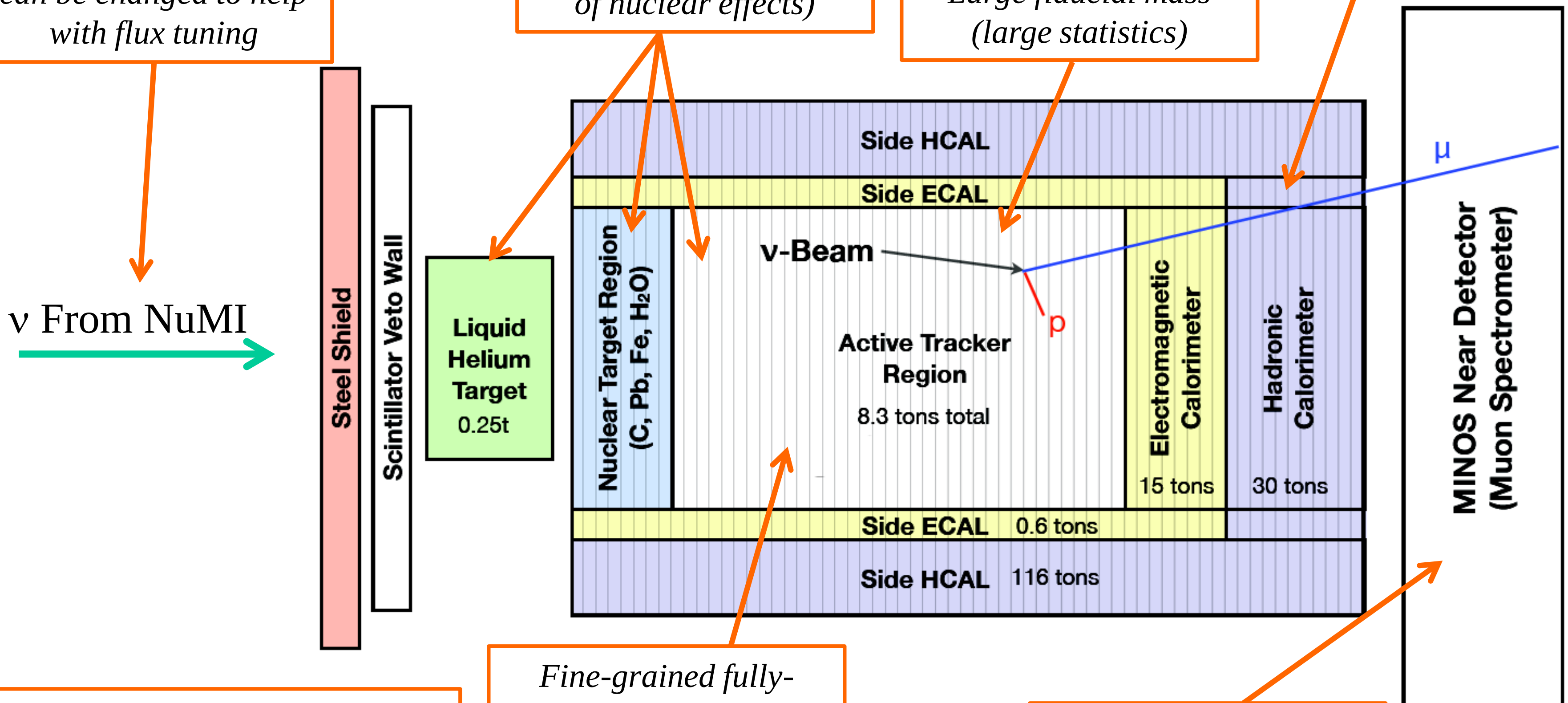
MINERνA: The Good

Intense beam, covers interesting energy range, configuration can be changed to help with flux tuning

Nuclear targets (can explore A-dependence of nuclear effects)

Large fiducial mass (large statistics)

Containment (particle ID and topology ID)

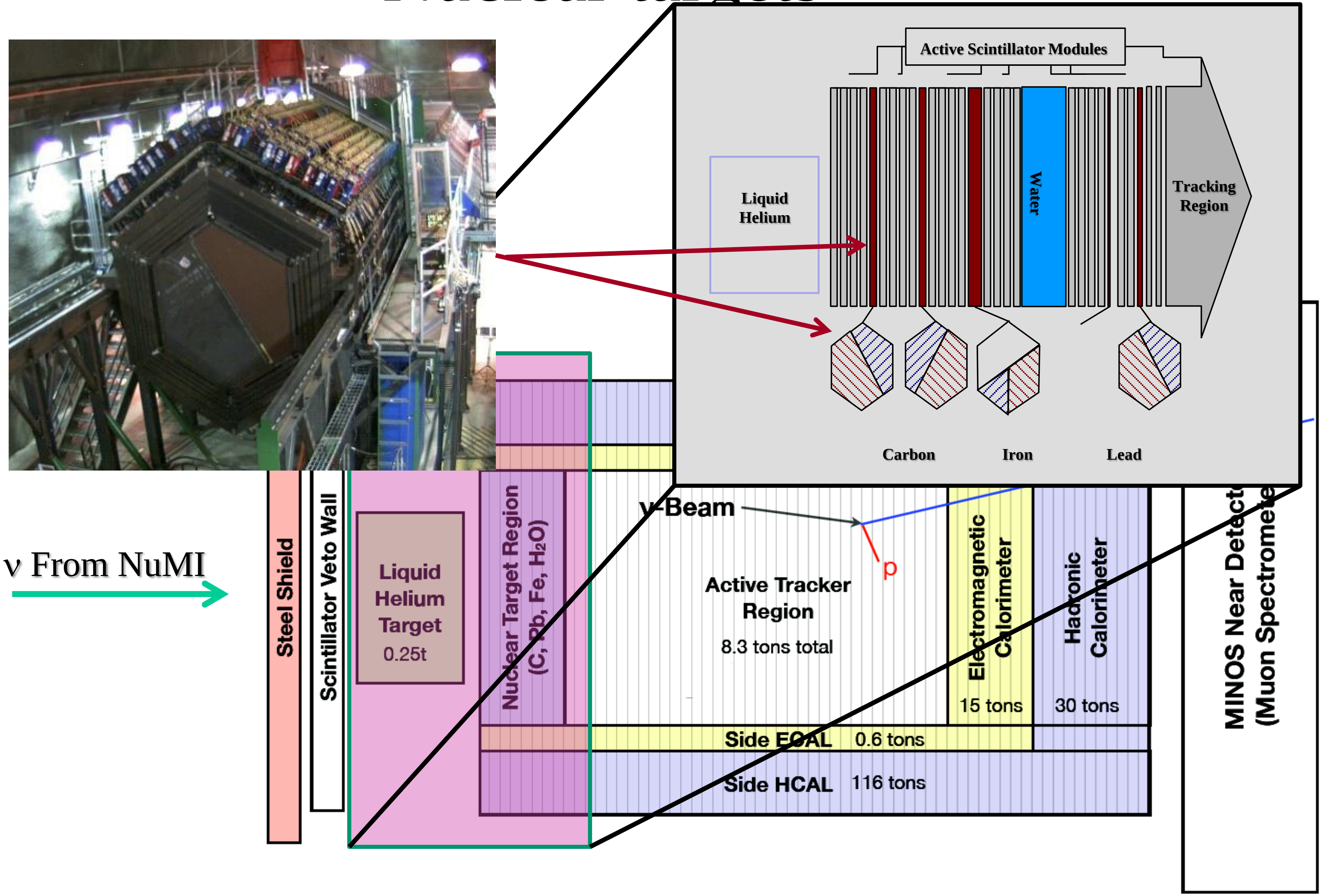


Ran a mini-MINERνA in a test beam in 2010, constrains our uncertainty in hadronic response

Fine-grained fully-active tracking (can select topologies and see vertex activity)

Magnetic spectrometer (momentum and sign analyze muons)

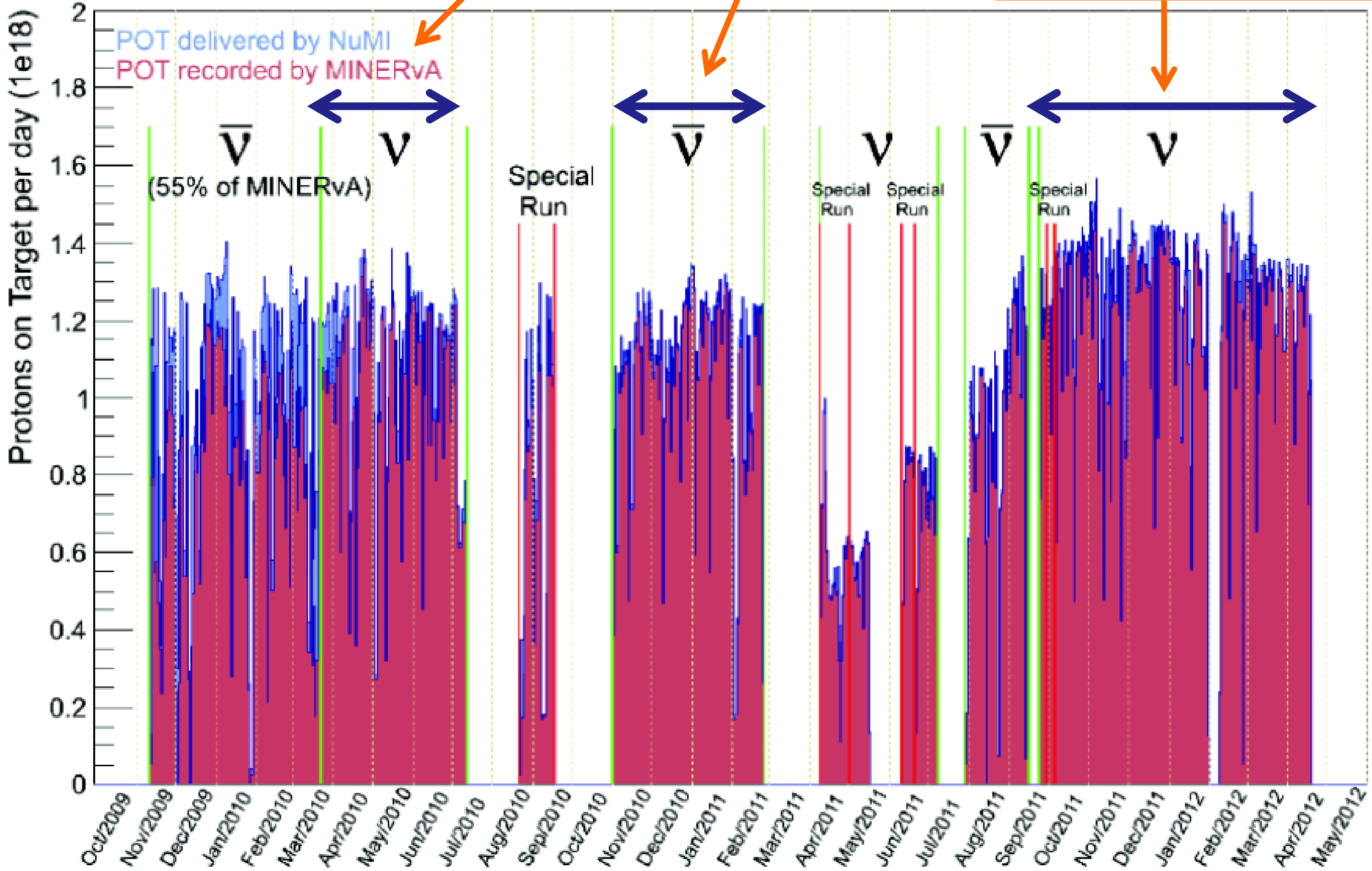
Nuclear targets



Used for recent ν_μ CCQE PRL

Used for recent $\bar{\nu}_\mu$ CCQE PRL

To be included in most upcoming results in the next 9 months



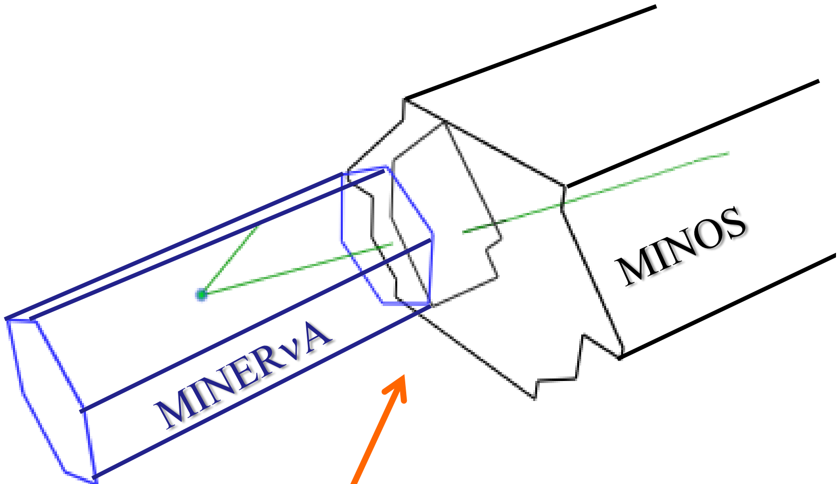
ν_μ LE
3.98×10^{20} POT

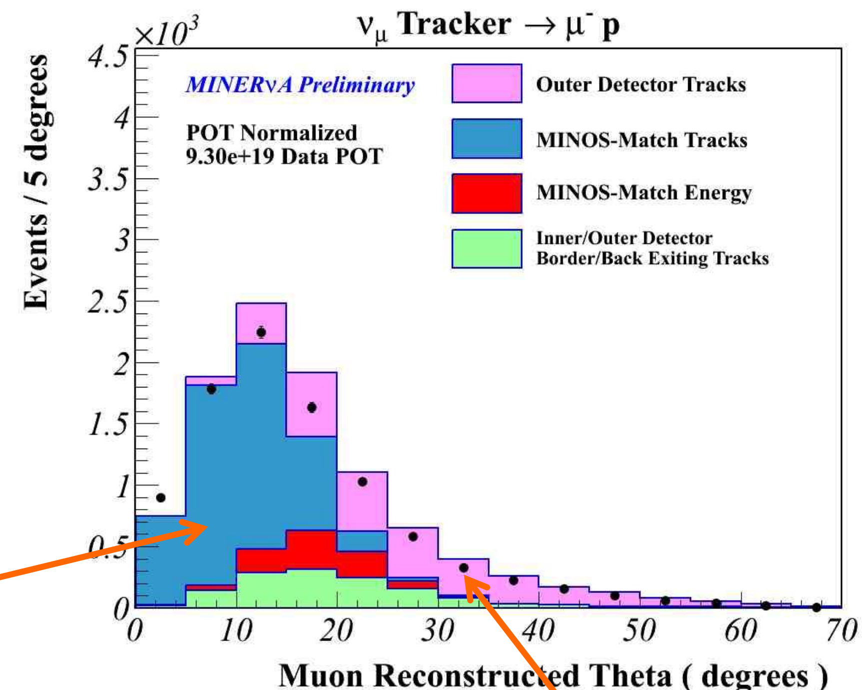
$\bar{\nu}_\mu$ LE
1.7×10^{20} POT

Special runs
4.94×10^{19} POT

Live time:
97.1% MINERνA
93.3% MINOS ND

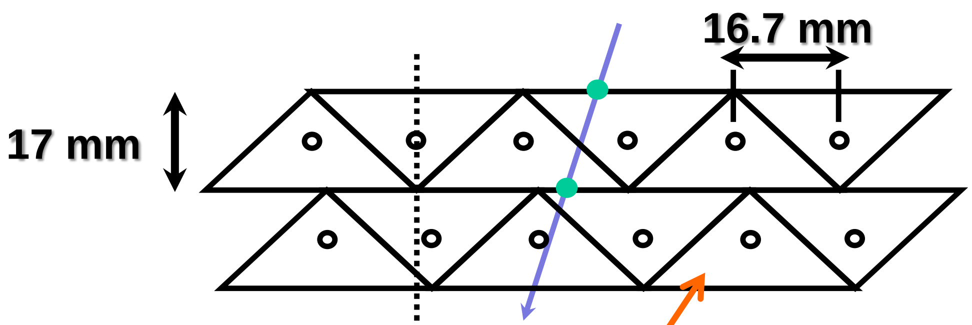
The Bad





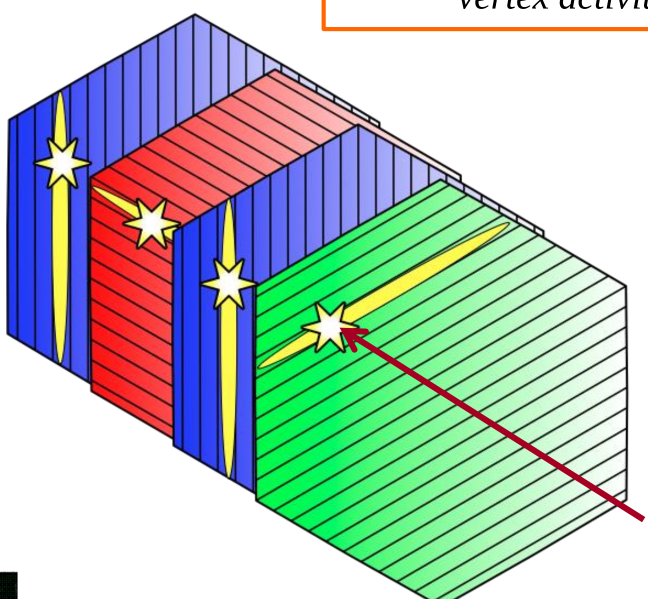
Matched muon acceptance imposes angular and low-end momentum and high-end Q^2 constraints, a hit in statistics and phase space of differential xsec coverage

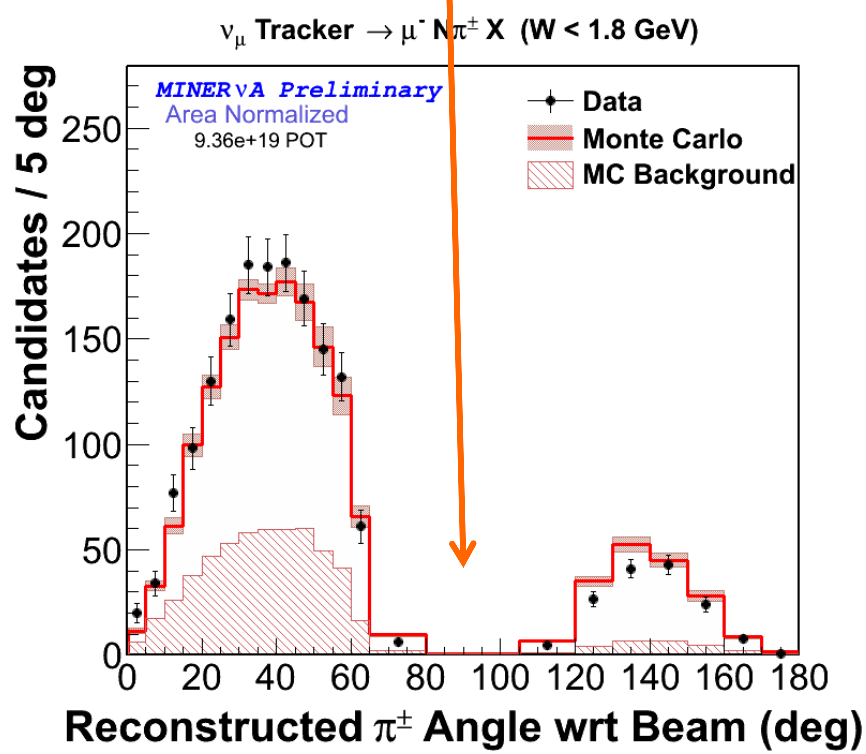
Currently working to reconstruct/understand stopped and side-exiting muons to improve acceptance



Fine-grained fully-active tracking
… but not quite a bubble chamber for looking at vertex activity

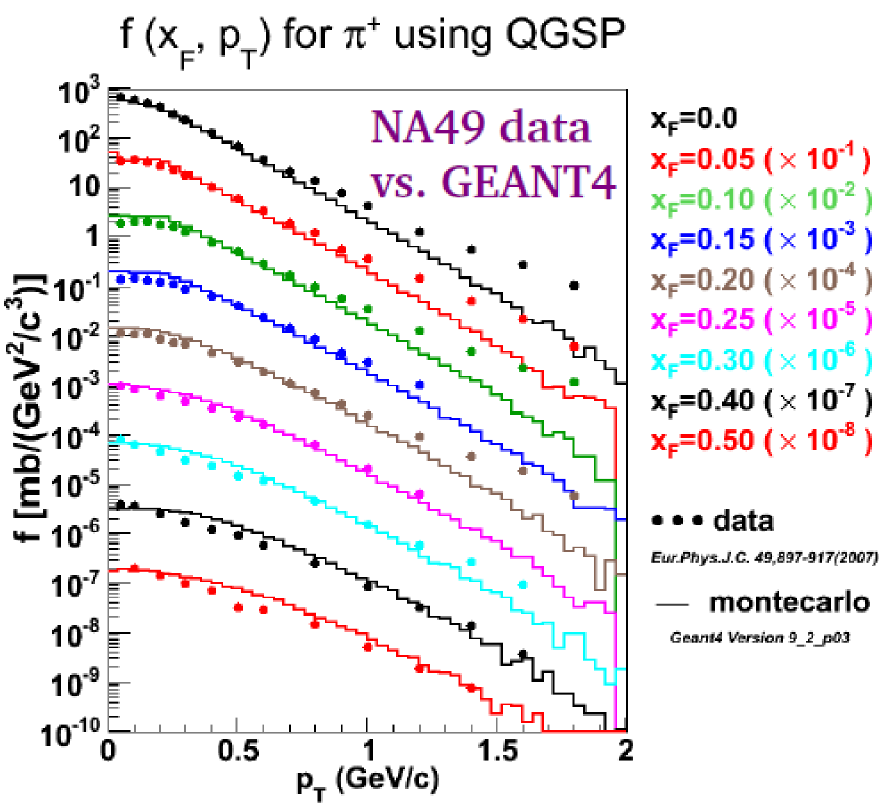
Construction of tracker gives a hole in reconstruction at 90^o





The Ugly

Flux for these results: GEANT4 + reweighting using external hadron production data from NA49

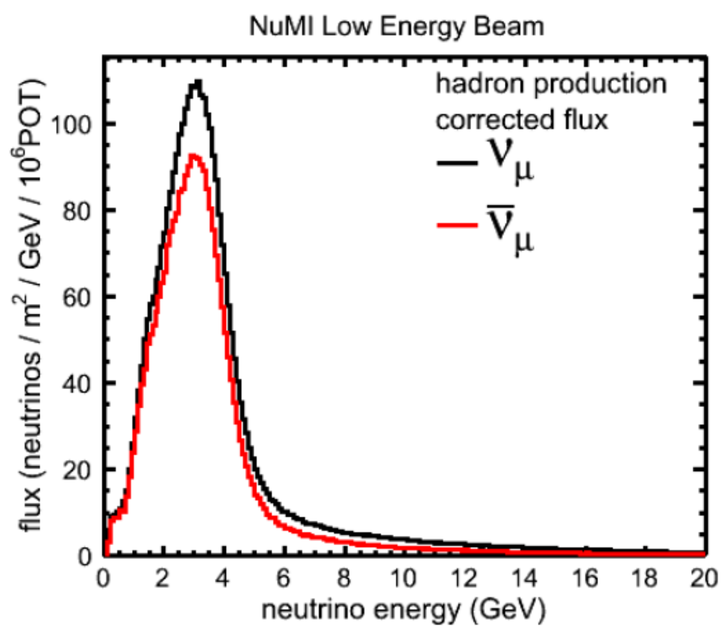


Uncertainties: 7.5% statistical, 2-10% systematic.
Biggest systematic is from reinteractions inside and outside of target.

<u>Flux tuning handles</u>:

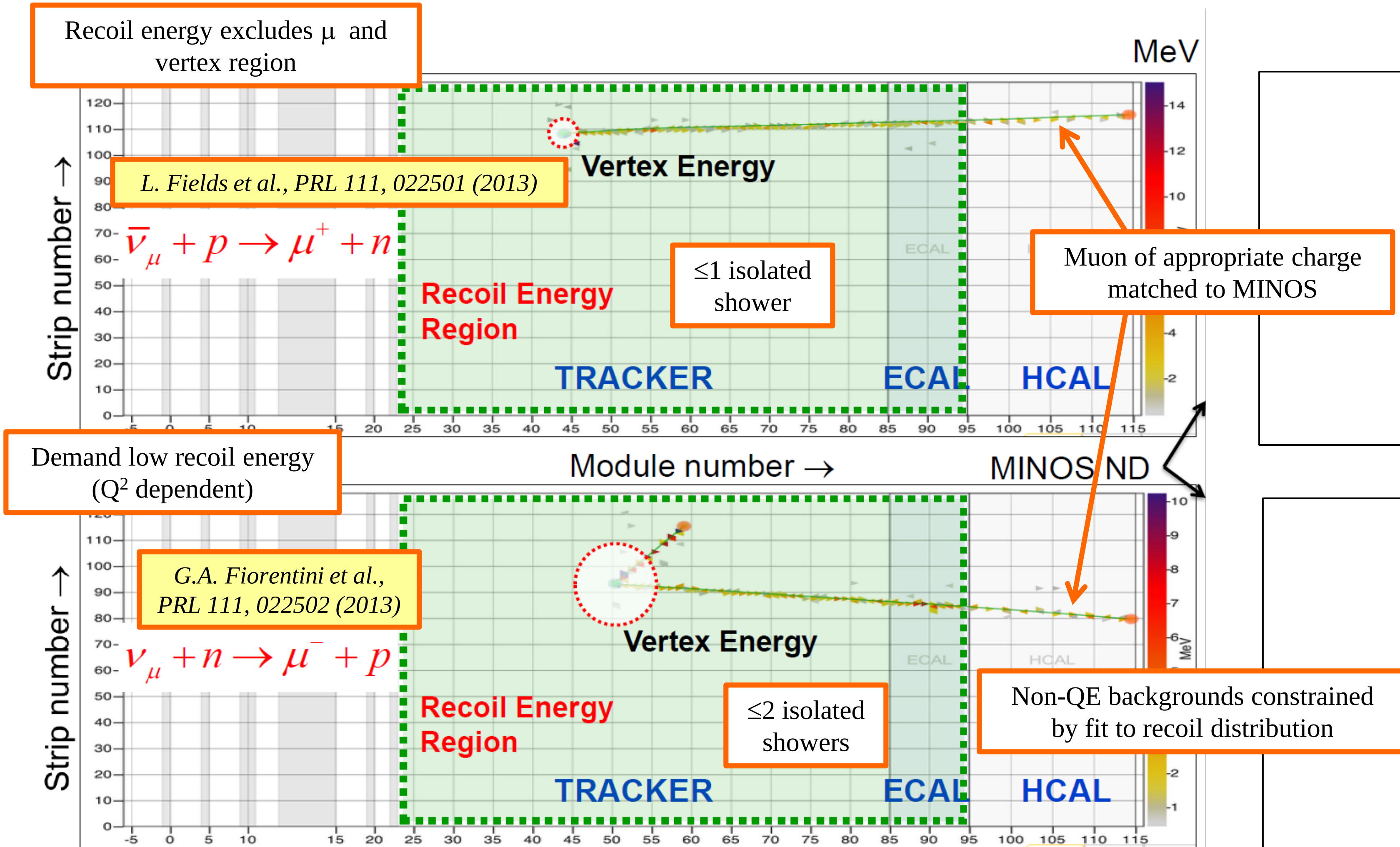
- External hadron production data
  - (NA49 now, NA61 in future)
- Muon flux from muon monitors
- Data from special runs with different horn current and target position configurations
- Low nu analysis *See: arXiv: 1207.1247 and Eur. Phys. J. C 72, No. 4, 1973 (2012)*
- ν-e scattering

Have data



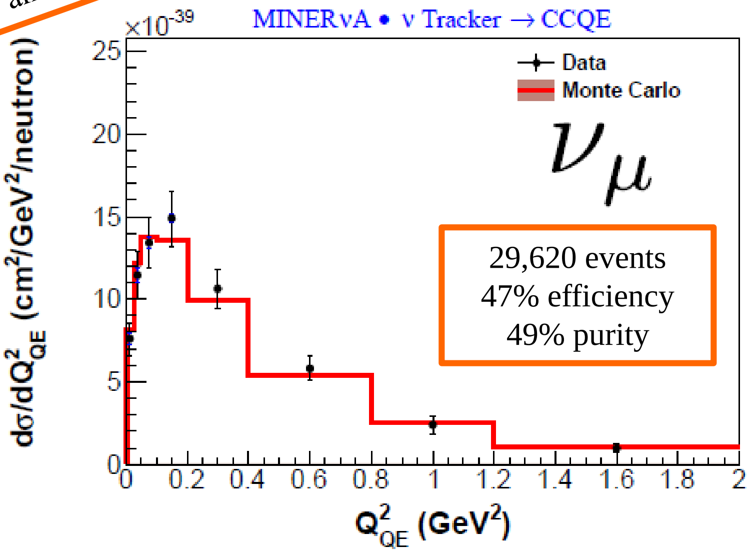
Recent results: ν and $\bar{\nu}$ CCQE

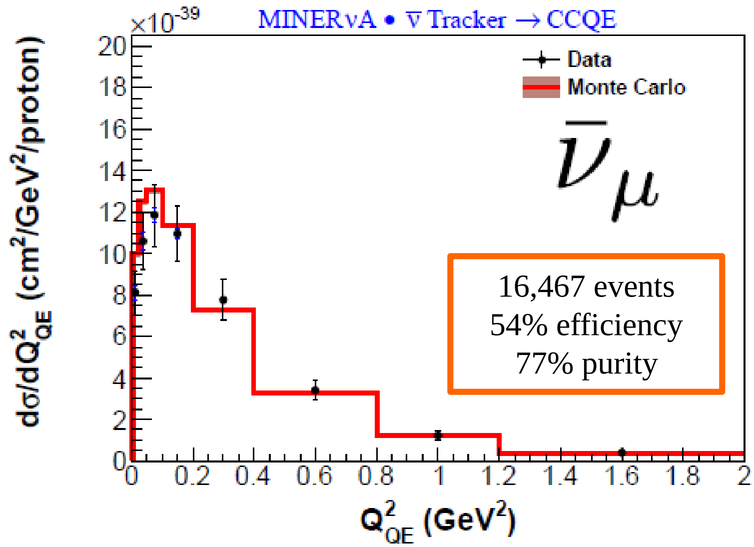
See slides by C. Marshall in WG2 (Tuesday at 10:30) for more detail

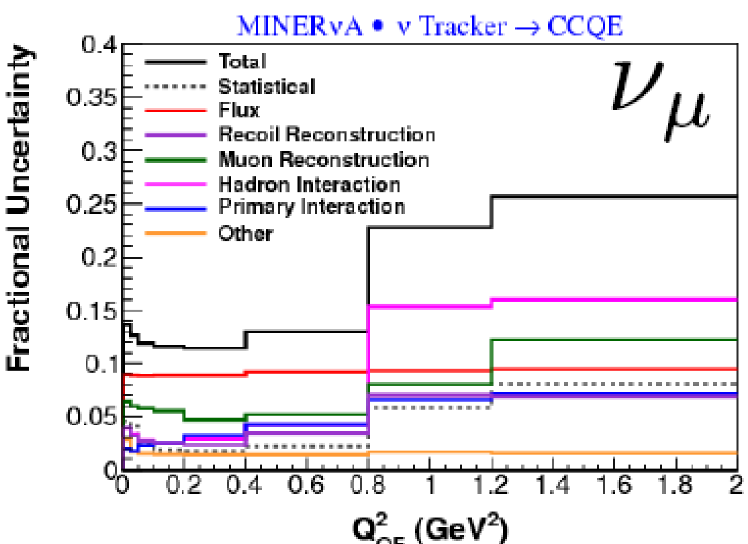


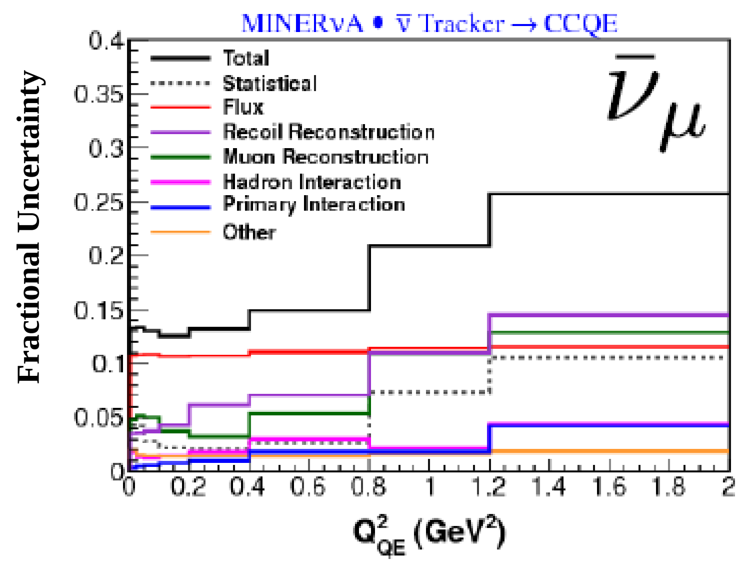
dσ/dQ² – POT normalized

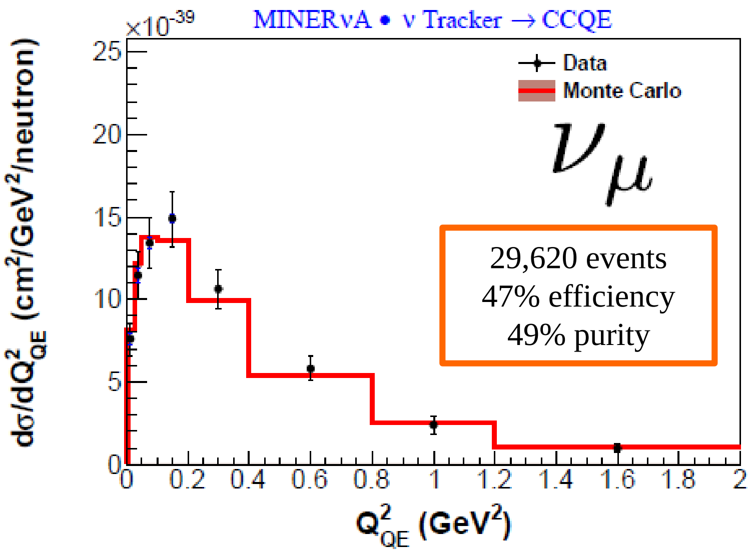
After background subtraction and unfolding

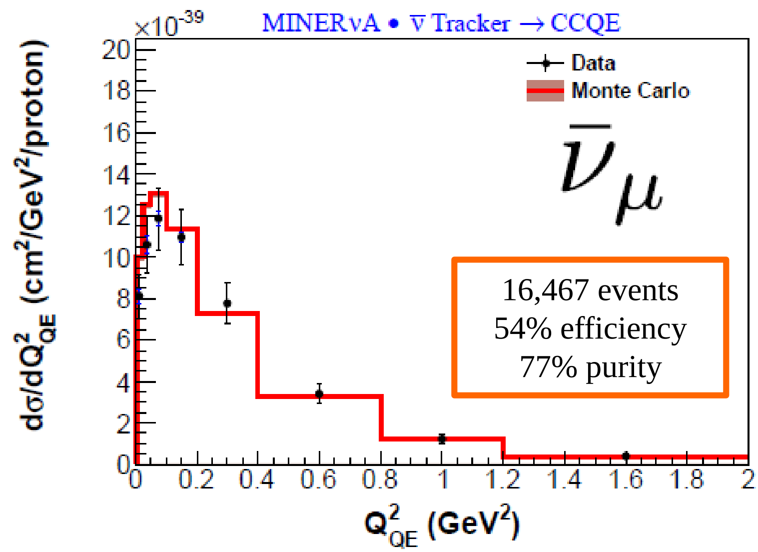


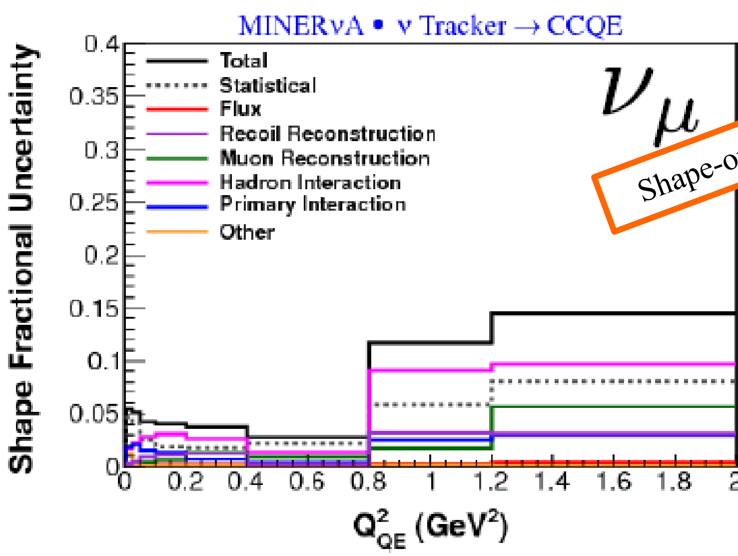




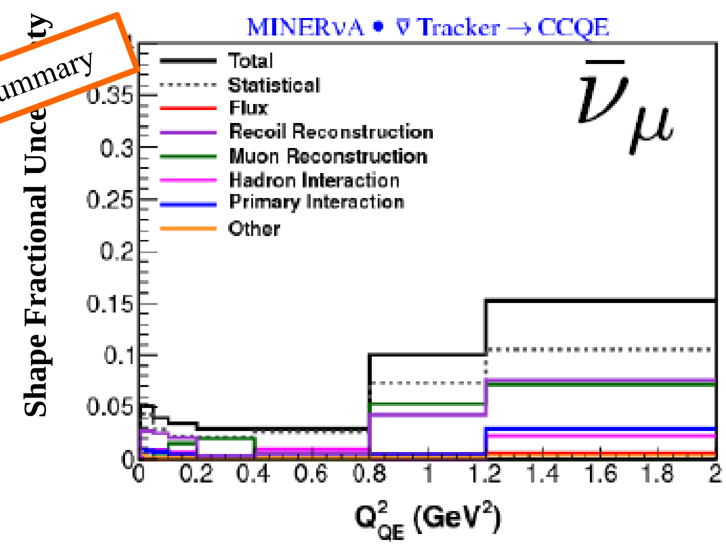








Shape-only error summary



Model comparisons

M_A = 1.35 best fit to MiniBooNE data Phys.Rev.Lett. 100, 032301 (2008)

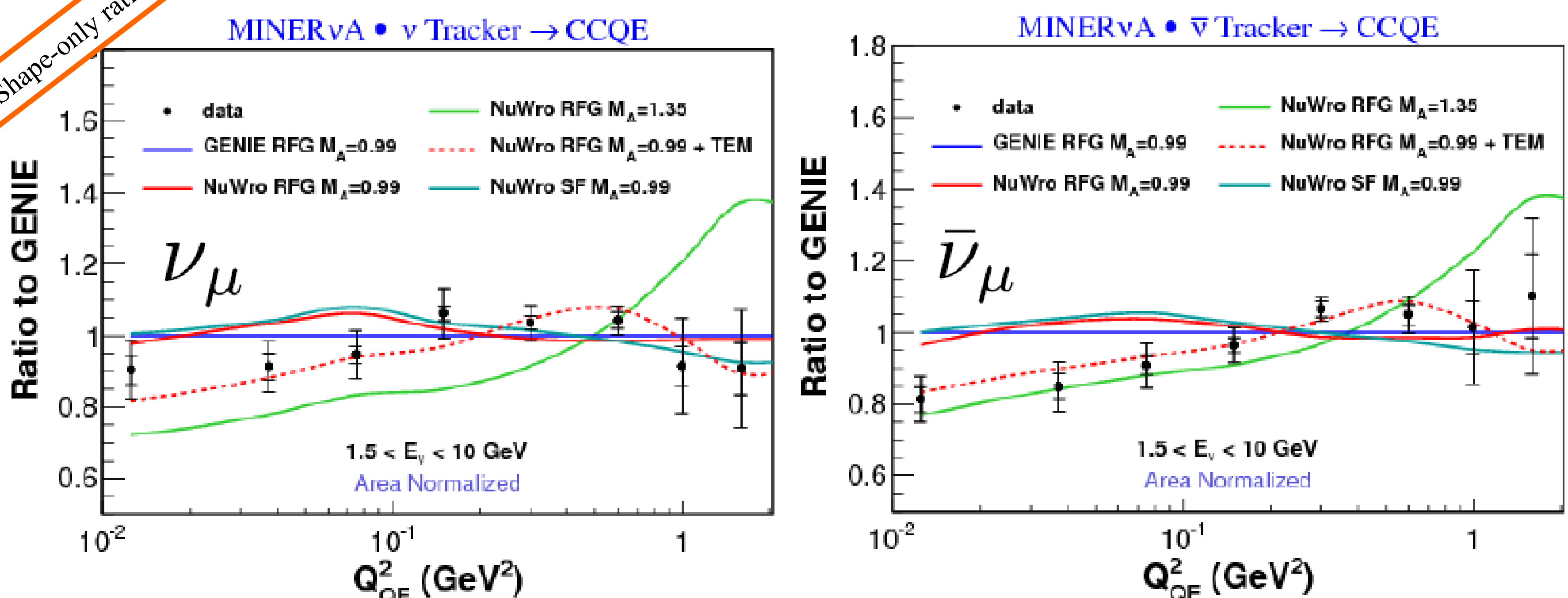
TEM empirical model based on electron scattering data Eur. Phys. J. C 71, 1726 (2011)

GENIE independent nucleons in mean field Nucl.Instrum.Meth. A 614:87-104 (2010)

SF more realistic nucleon momentum-energy relation Nucl.Phys. A579, 493 (1994)

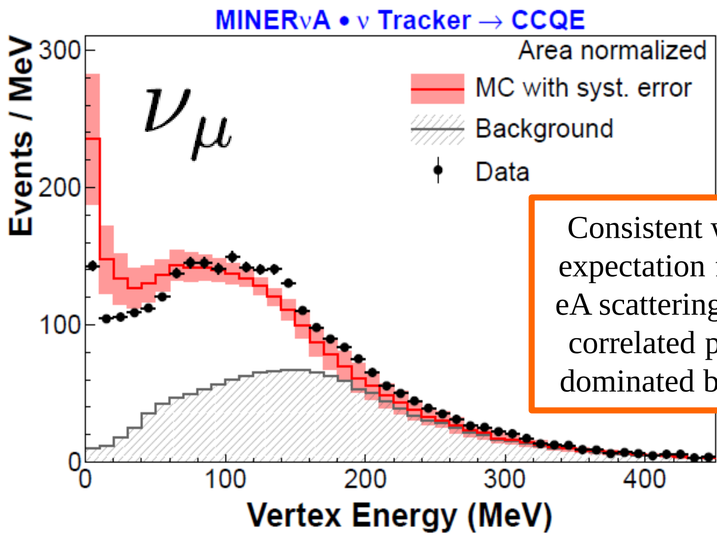
Shape-only ratio

Also see Gran et al., arXiv 1307.8105 [hep-ph] for comparison with Valencia 2p2h with RPA

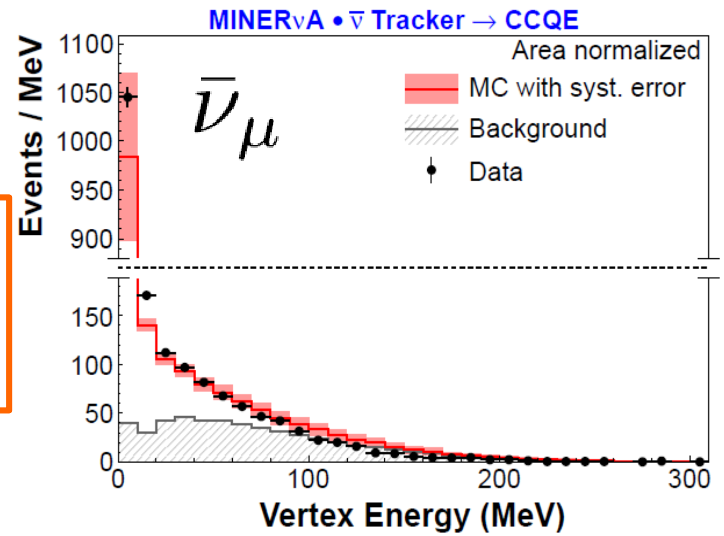


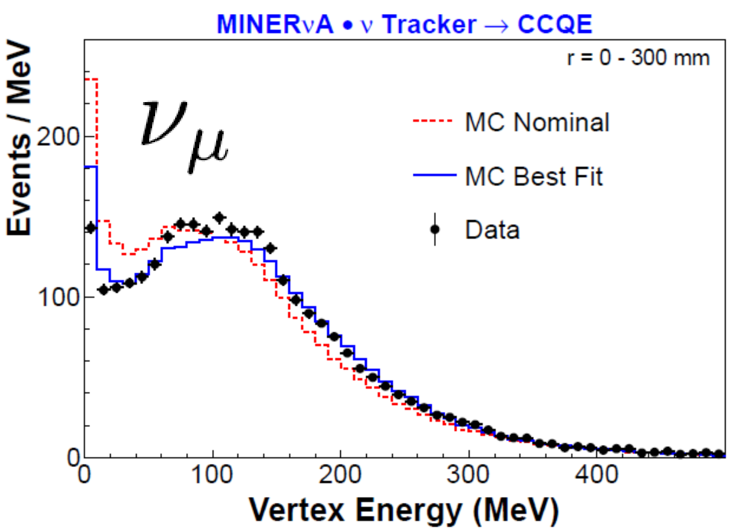
TEM: emperical, adjust magnetic form factors of bound nucleons to reproduce enhancement in the transverse cross-section in eA scattering attributed to meson exchange currents in the nucleus

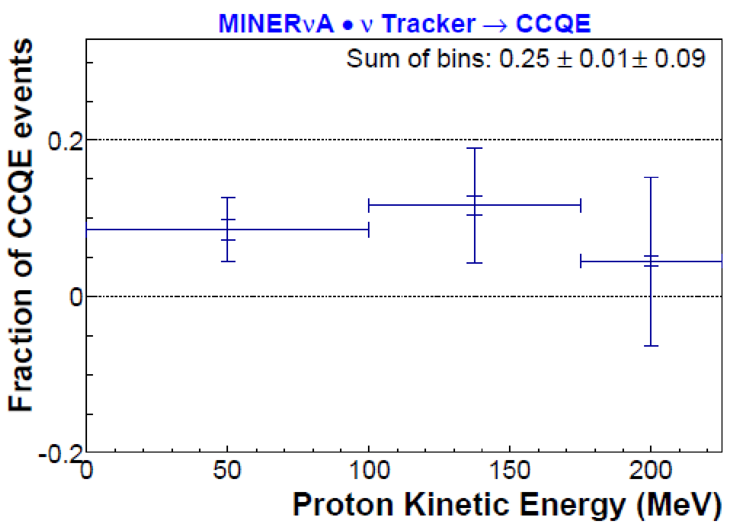
Energy near the vertex



Consistent with expectation from eA scattering that correlated pairs dominated by np

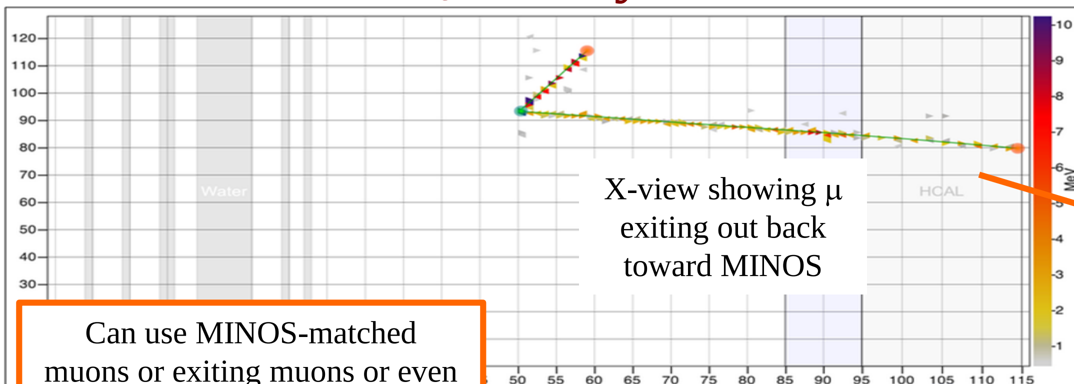




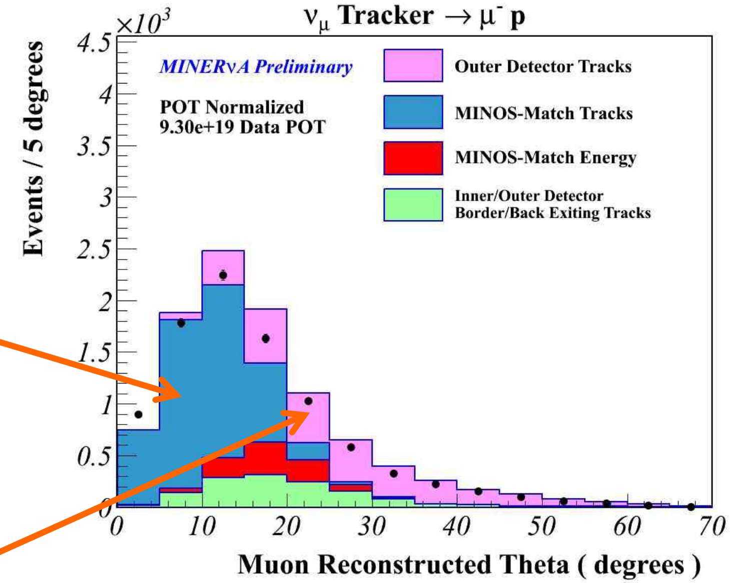


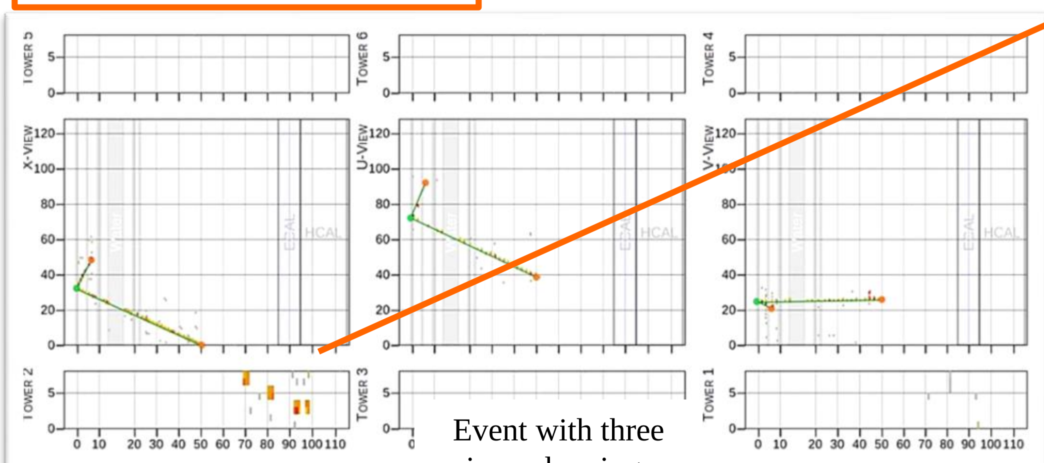
CCQE – more coming soon

2-track CCQE analysis



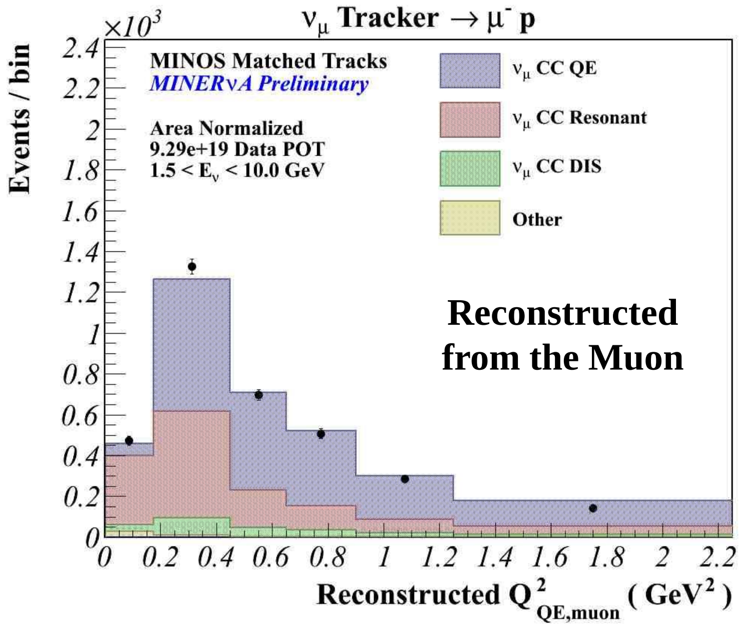
Can use MINOS-matched muons or exiting muons or even stubs in MINOS

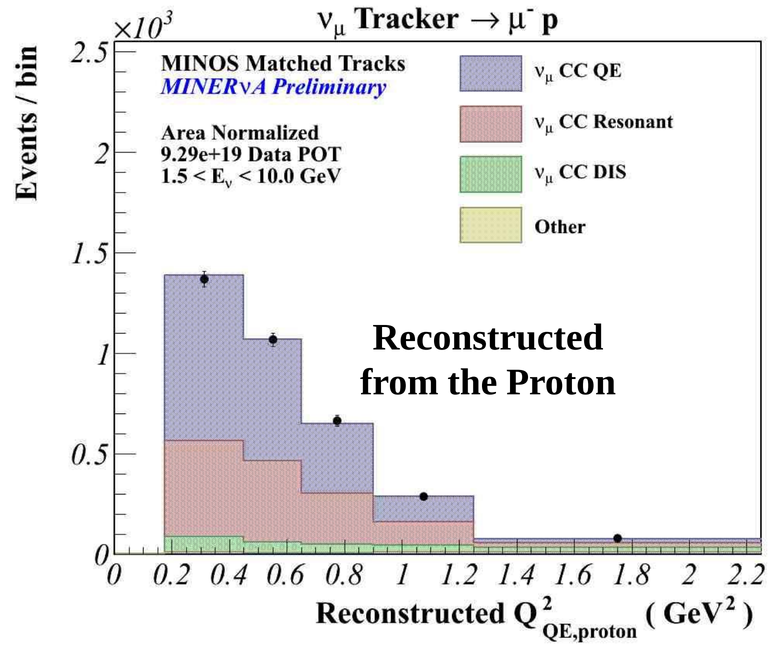




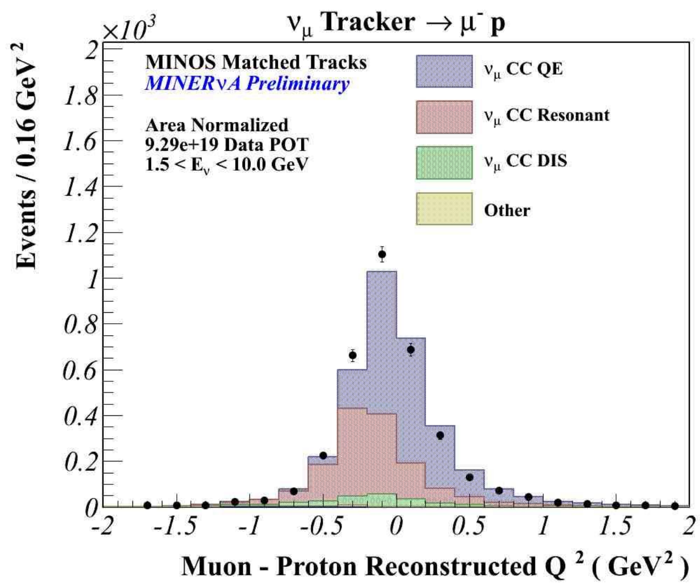
Event with three views showing μ exiting out side

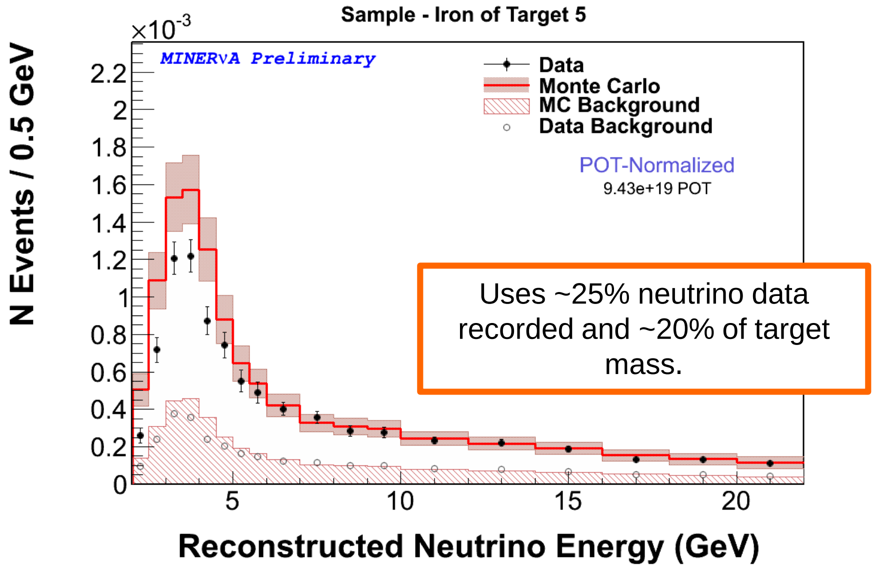
- ➢ Complementary (different recoil reconstruction)
- ➢ Can compare kinematics reconstructed from proton to that from muon (FSI)
- ➢ Include "exiting" muons to increase high-Q^2 acceptance, use p for kinematics rather than μ
- ➢ Nuclear target analysis with 2-tracks has lower backgrounds than the 1-track analysis

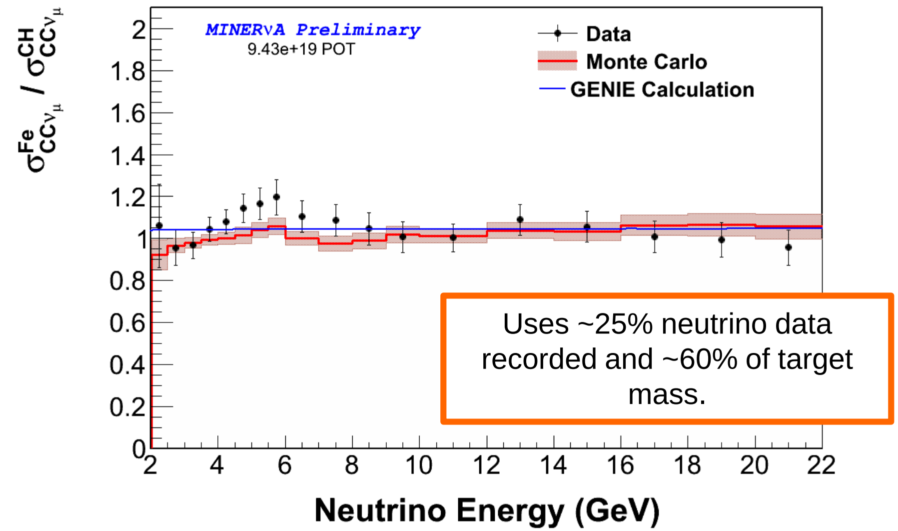


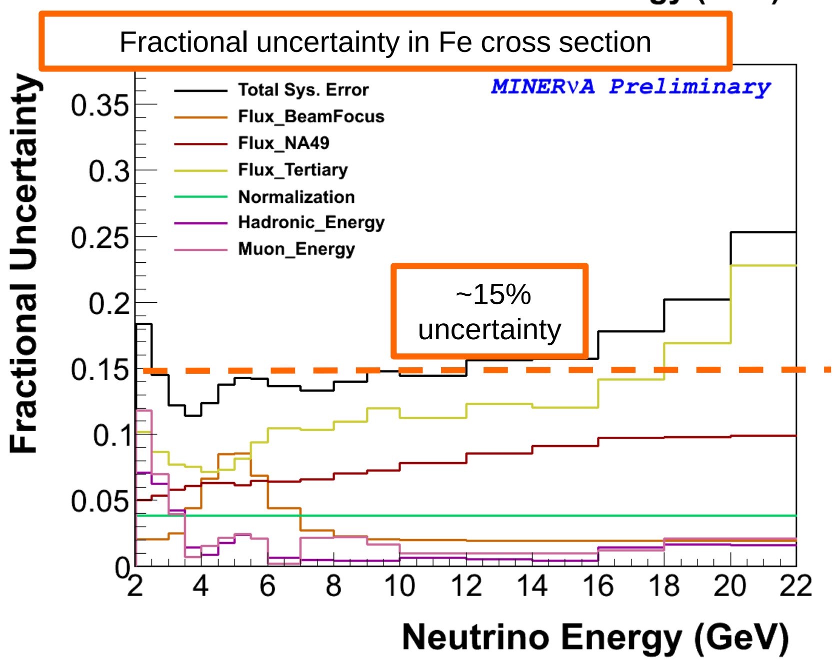


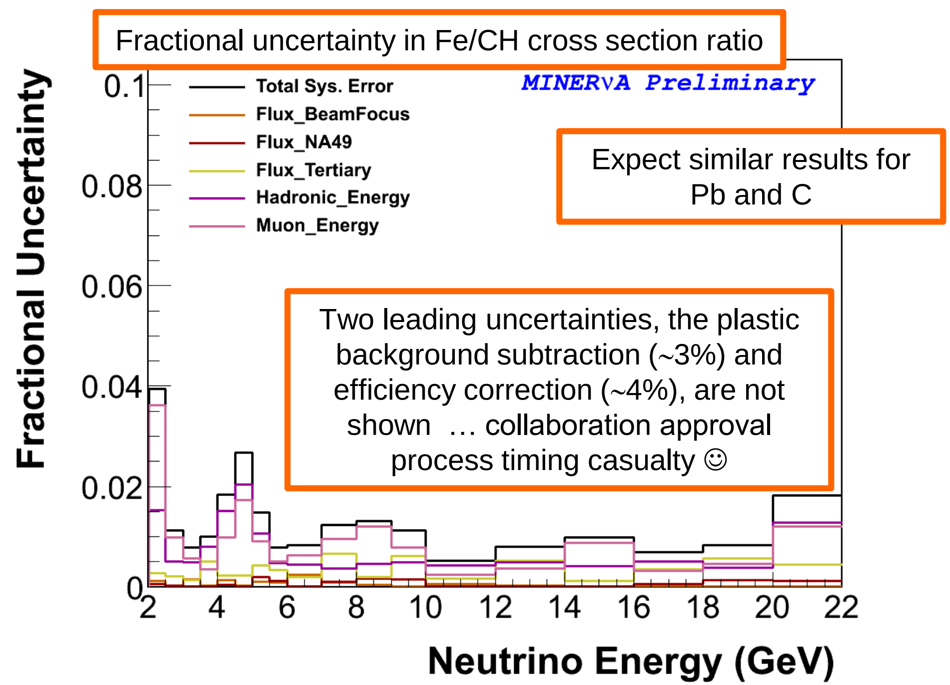
Compare Q^2 as reconstructed by the muon to that reconstructed from the pion




Sample - Iron of Target 5
×10^-3
MINERνA Preliminary
Data
Monte Carlo
MC Background
Data Background
POT-Normalized
9.43e+19 POT
Uses ~25% neutrino data recorded and ~20% of target mass.
N Events / 0.5 GeV
Reconstructed Neutrino Energy (GeV)

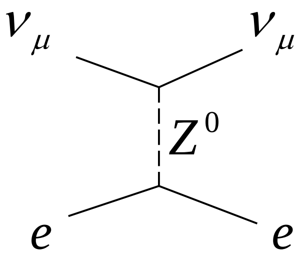

MINERνA Preliminary
9.43e+19 POT
Data
Monte Carlo
GENIE Calculation
Uses ~25% neutrino data recorded and ~60% of target mass.
$\sigma^{Fe}_{CC\nu_\mu} / \sigma^{CH}_{CC\nu_\mu}$
Neutrino Energy (GeV)

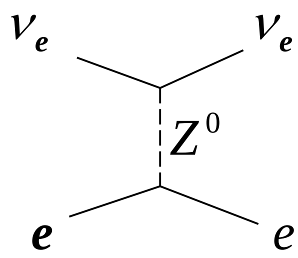

Fractional uncertainty in Fe cross section
MINERνA Preliminary
Total Sys. Error
Flux_BeamFocus
Flux_NA49
Flux_Tertiary
Normalization
Hadronic_Energy
Muon_Energy
~15% uncertainty
Fractional Uncertainty
Neutrino Energy (GeV)


Fractional uncertainty in Fe/CH cross section ratio
MINERνA Preliminary
Total Sys. Error
Flux_BeamFocus
Flux_NA49
Flux_Tertiary
Hadronic_Energy
Muon_Energy
Expect similar results for Pb and C
Two leading uncertainties, the plastic background subtraction (~3%) and efficiency correction (~4%), are not shown … collaboration approval process timing casualty ☺
Fractional Uncertainty
Neutrino Energy (GeV)

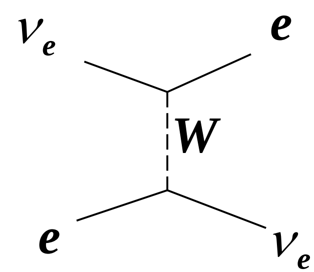
ν-e⁻ scattering

(demonstration of a simple, robust, cheap way to measure integrated flux)





+

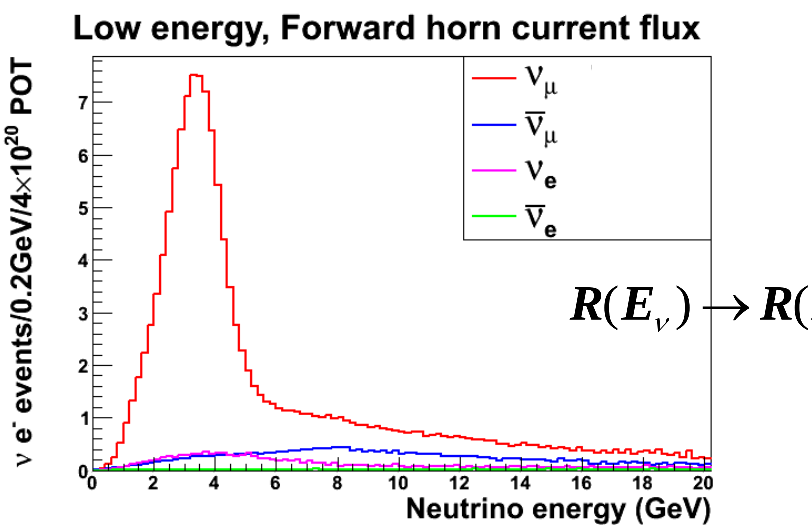


Got flux?

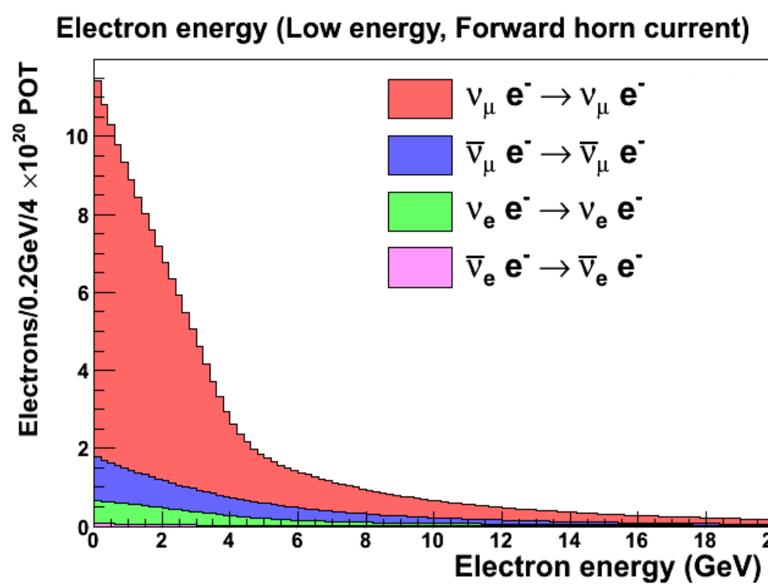
$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$$
$$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$$

$$\nu_e + e^- \rightarrow \nu_e + e^-$$
$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$

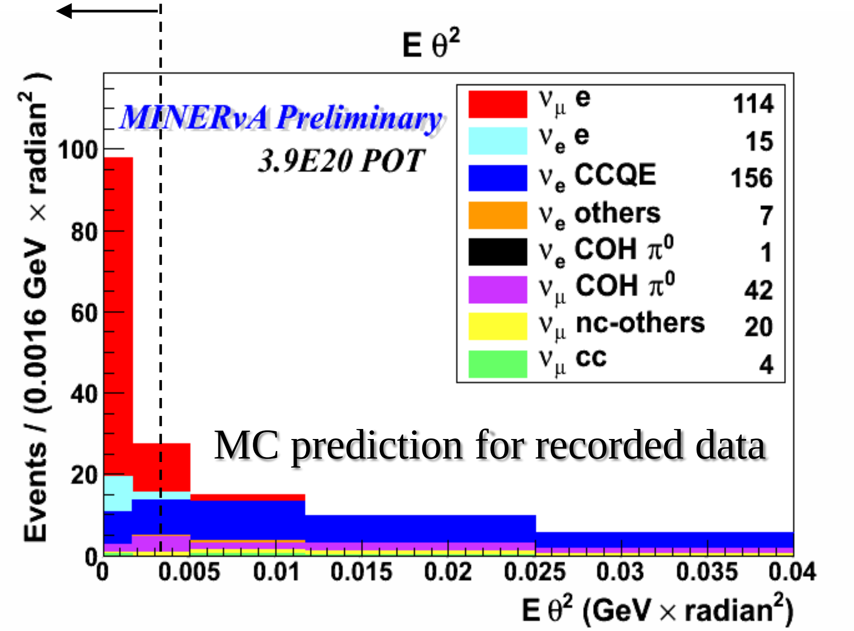
$$R(E_e) = \int \Phi(E_\nu) \frac{d\sigma(E_\nu, E_e)}{dE_\nu dE_e} dE_\nu$$

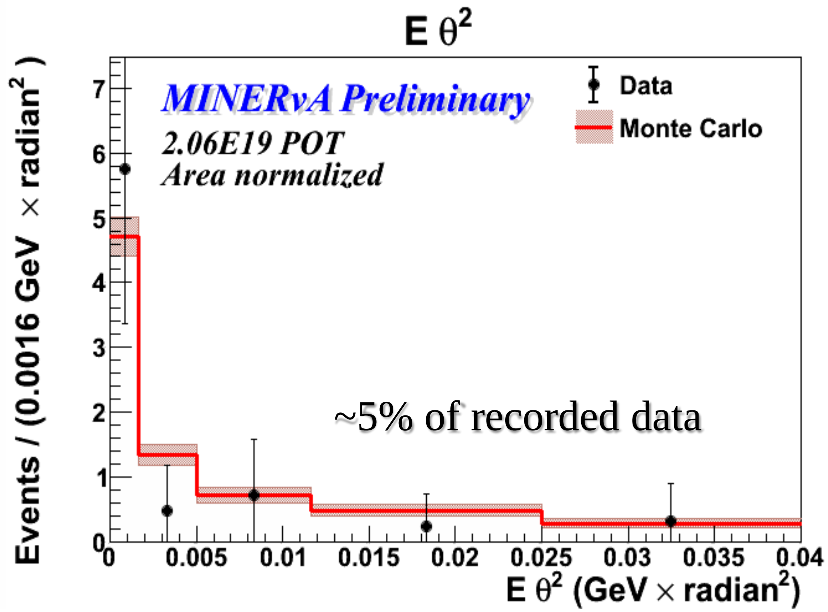


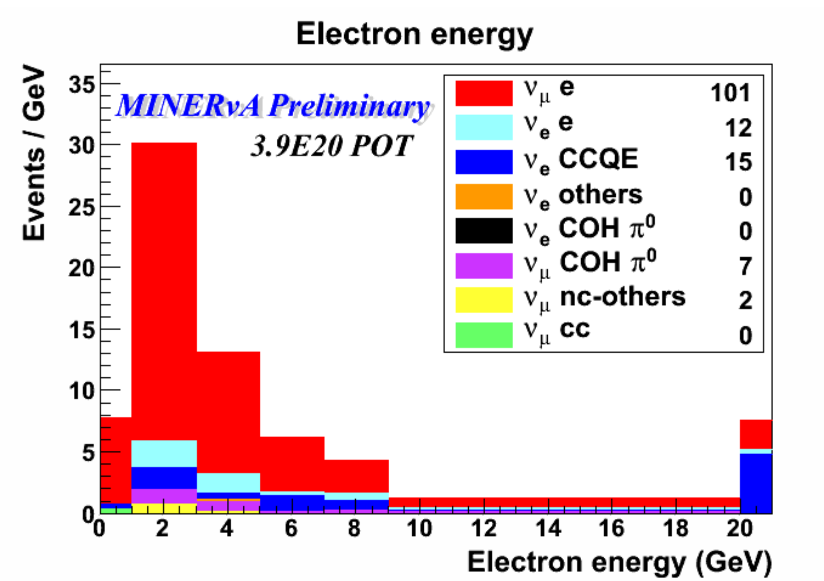
$$R(E_\nu) \rightarrow R(E_e)$$



$E\theta^2 < 0.0032$

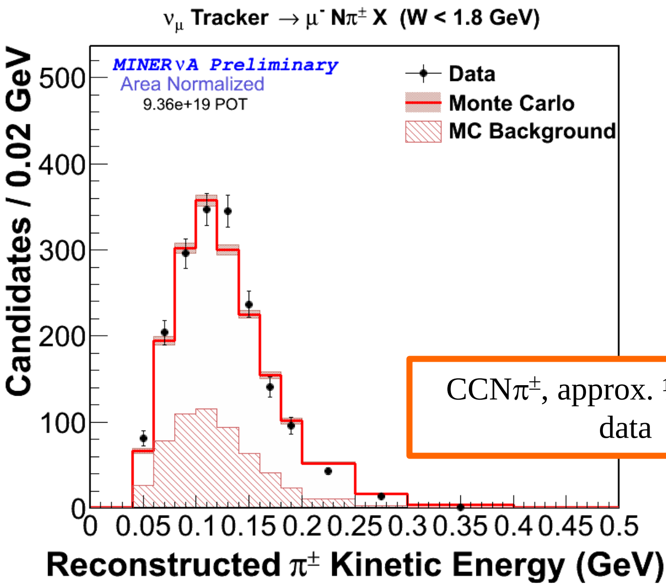




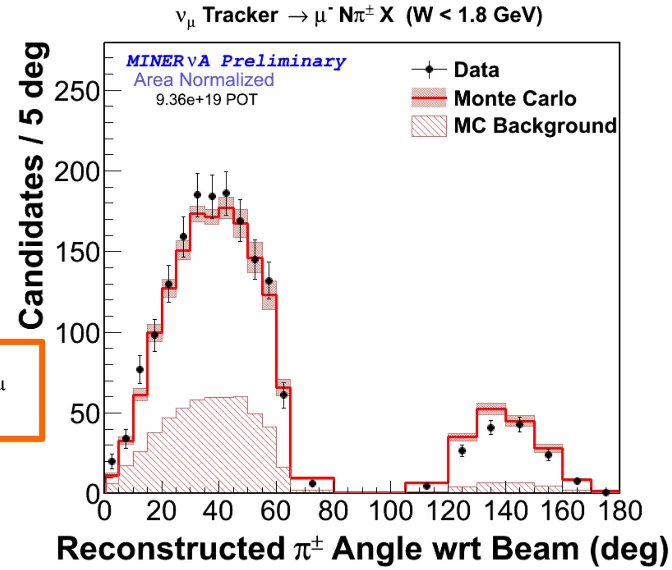


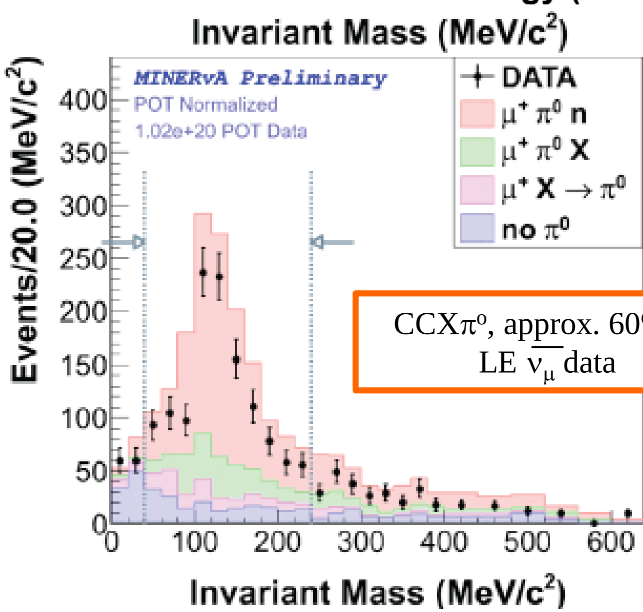
- $E_e > 0.8$ GeV
- Purity=0.8, efficiency=0.6
- Full LE data set expect 10% statistical error on absolute flux
- Currently working on sideband background analysis and increased stats
- For ME, expect <3% stat. error

Yes, we see pions as well …



CCN$\pi^\pm$, approx. ¼ of LE ν_μ data





CCXπ^o, approx. 60% of LE $\overline{\nu_\mu}$ data

- Expect results on resonant charged and neutral pion production and coherent charged pion production this year (all on scintillator)

Results to expect in the near-term

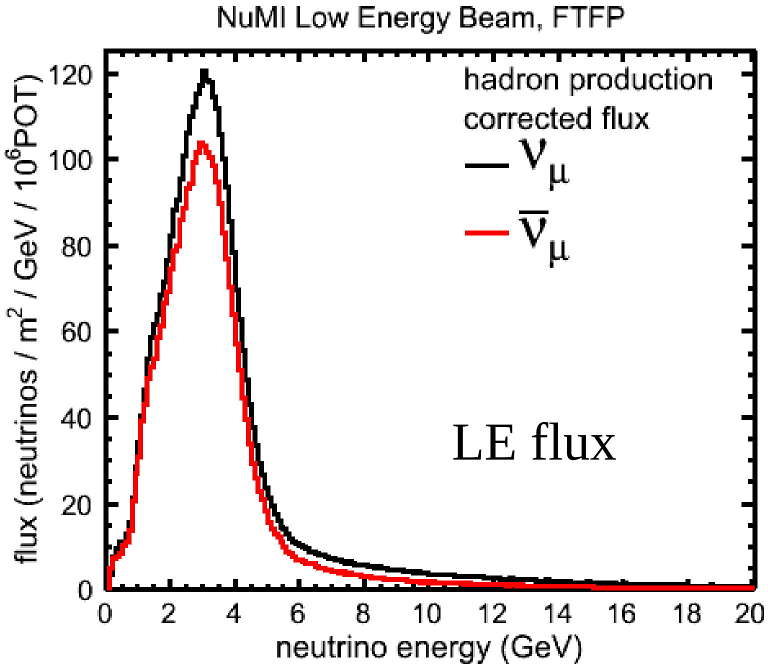
(All NuMI LE configuration)

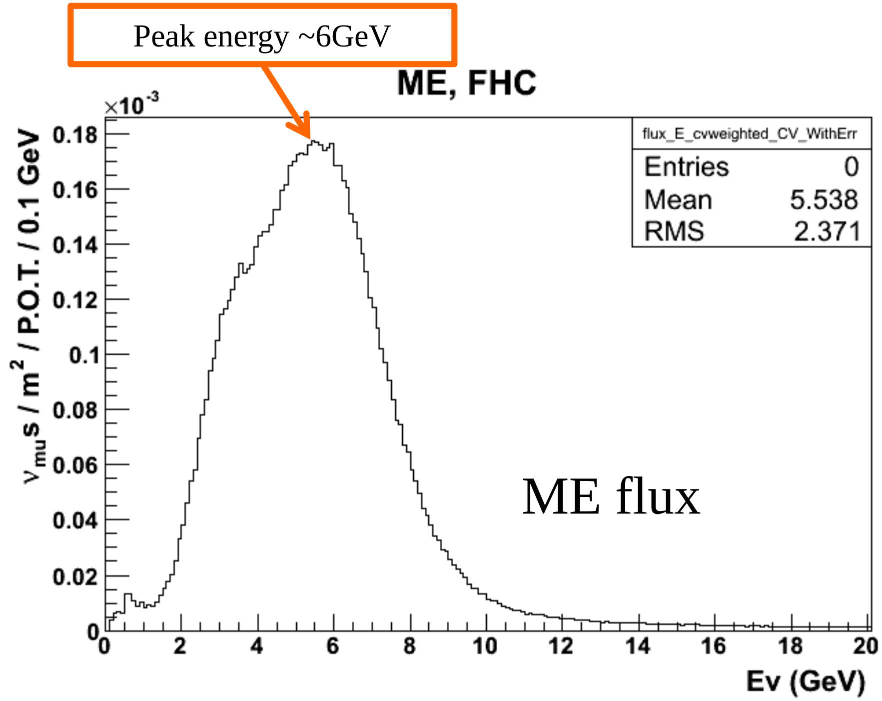
- 2-track CCQE (on scintillator and nuclear targets)
- CC inclusive production in nuclear targets
- ν-e^- scattering (on scintillator)
- CC $1\pi^\pm$ production (on scintillator)
- CC coherent $\pi^\pm$ production (on scintillator)
- CC π^o production (on scintillator)
- ν_e CCQE (on scintillator)

See talk by A. Bravar in WG2 (Wednesday at 16:50) for more detail

See talk by A. Higuera in WG2 (Wednesday at 13:30) for more detail

Beyond the LE sample





- In hand:
  - 3.98×10^{20} POT LE ν_μ
  - 1.7×10^{20} POT LE $\bar{\nu}_\mu$

- ME running just beginning, expect to accumulate:
  - 12×10^{20} POT ME ν_μ
- Fewer events for QE and resonance regions. DIS, low-x physics more of a focus
- Higher statistics (e.g., ×10 for ν-e scattering)

Summary

- Ongoing CCQE and vertex region measurements offer opportunities to refine nuclear models important for understanding CCQE kinematics and cross section
- Near-term ν-A and pion production differential cross sections will provide data for improving models of nuclear effects and FSI, as well as to constrain/set errors for models currently being used
- ν-e scattering in scintillator can measure ν flux relatively simply and cheaply

What can MINERνA do for you?

Or, perhaps for you or someone you know, it isn't what MINERνA can do for you, but rather what you can do for MINERνA …

Got postdoc? MINERνA has openings and offers interesting and important physics to do.