# 2p2h DSECAL nubar

MINERvA
17 October 2016

# High Priority results for Oscillation Experiments

- NOvA
  - 2p2h/RPA in plastic for neutrinos and antineutrinos
    - Studying the energy dependence of multi-nucleon effects will be important
  - Electron neutrino CCQE cross sections in the plastic
  - This was only measured once ever, but at low statistics in neutrino mode

- DUNE
  - 2p2h/RPA in lead and iron for neutrinos and antineutrinos
    - No other way to get to this in near term at 1st oscillation peak for DUNE
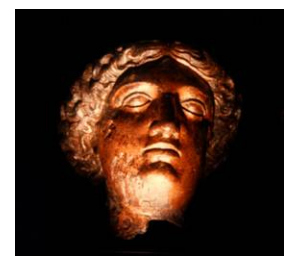 - ν_μ CCQE in nuclear targets

E$_v$ and 2p2h
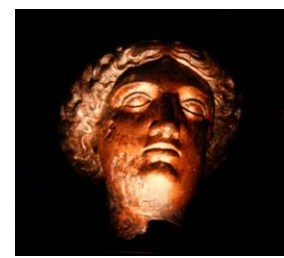
- At right is result from Phys. Rev. Lett. 116, 071802 (2016)
  - You saw 2D result earlier and NOvA's 1D equivalent before
  - Missing "dip region" → 2p2h
- Below ME data: high/low E$_v$ data/MC double ratio. Roughly independent of neutrino energy for same q$_0$-|q$_3$|

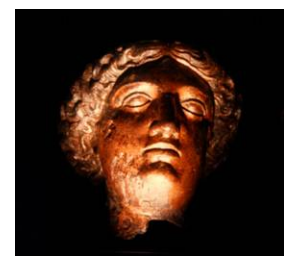

IN PROGRESS

NEW KINEMATICS in ME beam
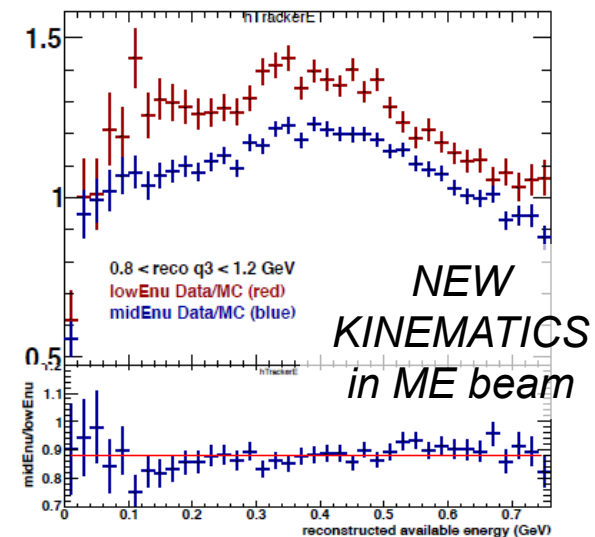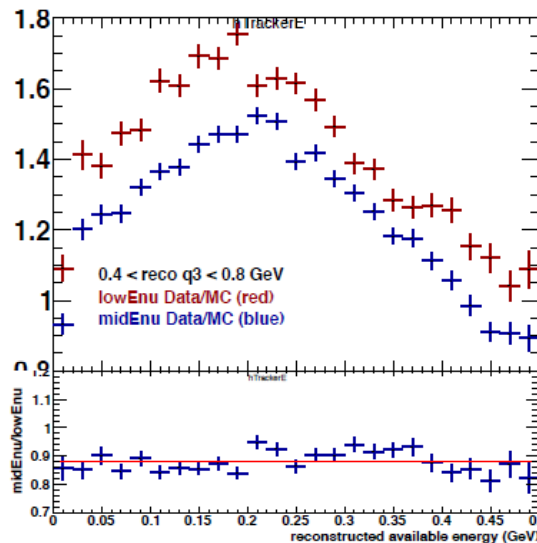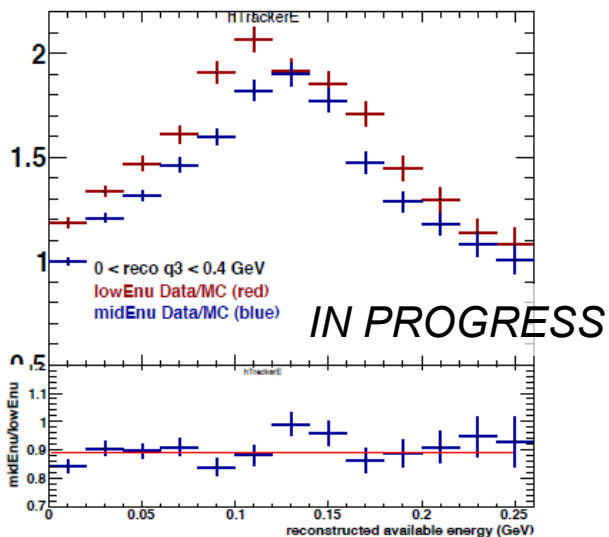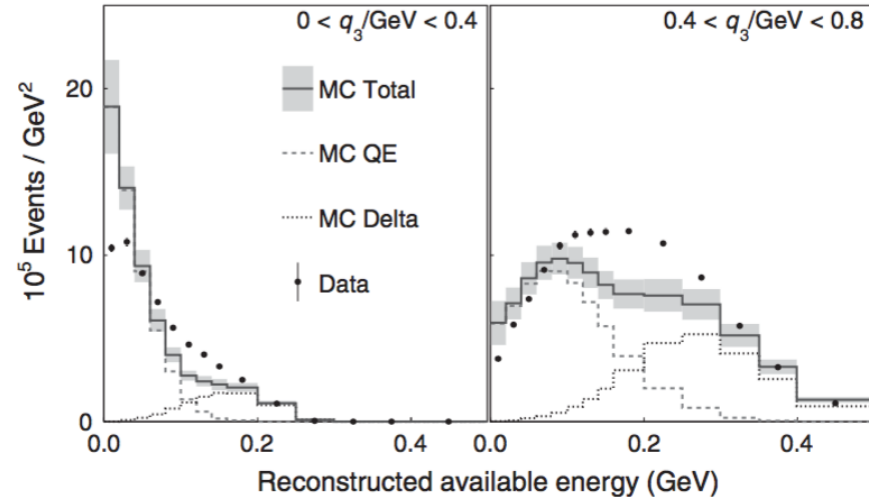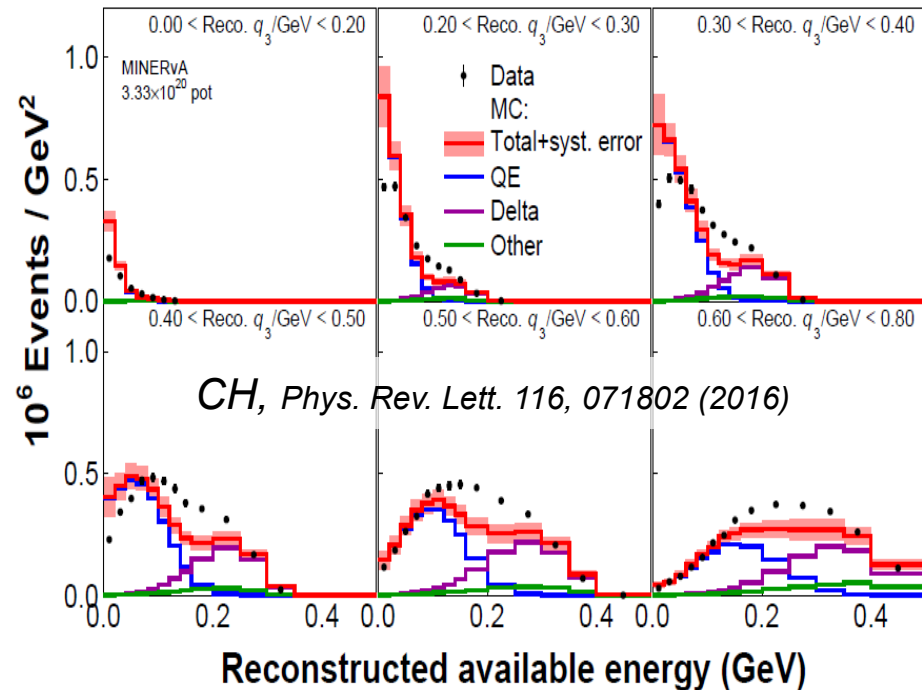
Nuclear Targets: 2p2h

- MINERvA's plan to explore nuclear dependence is to compare scintillator (CH) to iron and lead

  – Without Ar data in the foreseeable future, plan is to test model dependence on other nuclei
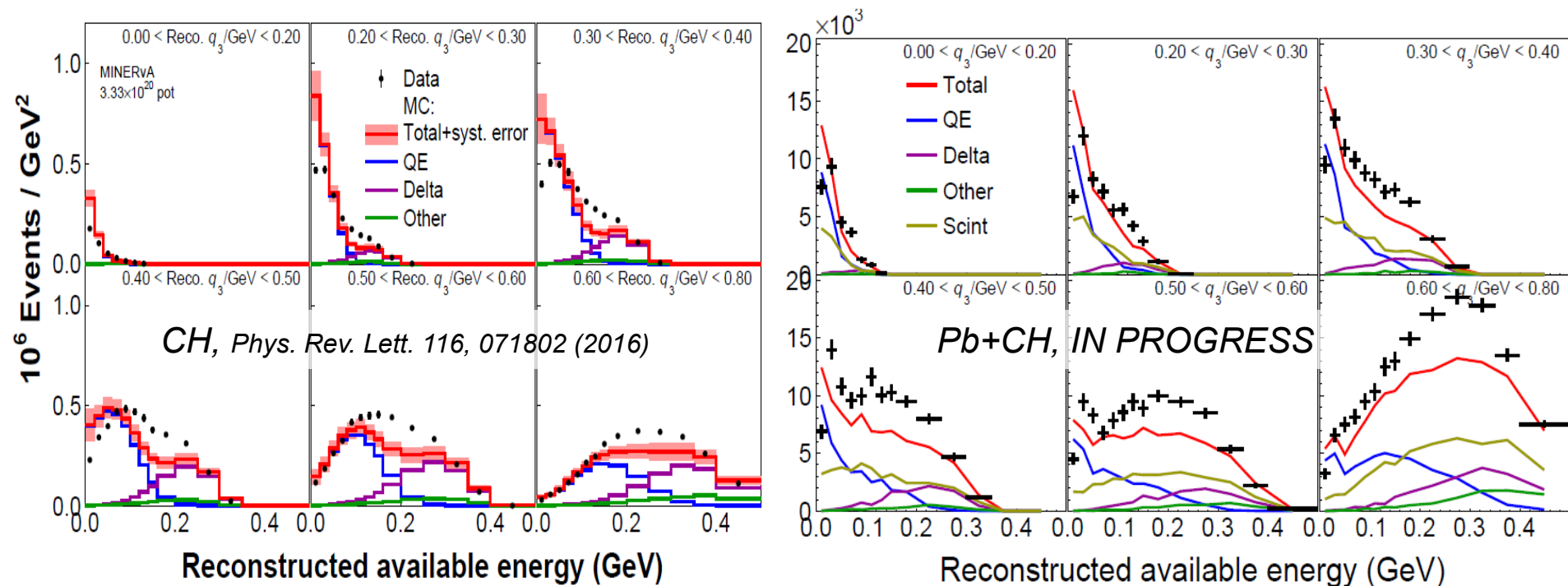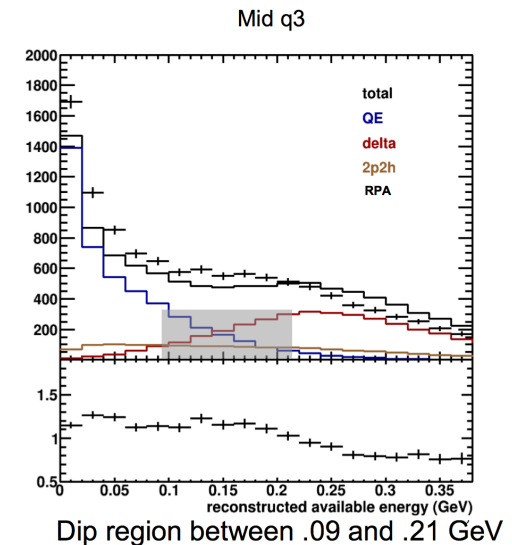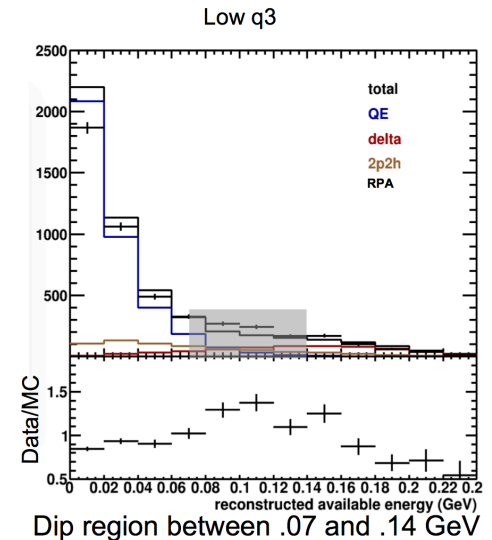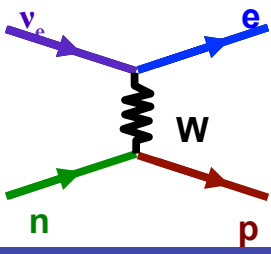
Antineutrinos: 2p2h

- MINERvA can also explore this process in antineutrinos, and especially antineutrinos in the nuclear targets.

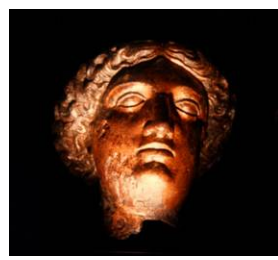- Statistics shown at right: 1E20POT LE

Low q3

Dip region between .07 and .14 GeV

Mid q3

Dip region between .09 and .21 GeV

Anti-neutrinos in Plastic, IN PROGRESS

CH, *Phys. Rev. Lett. 116, 071802 (2016)*
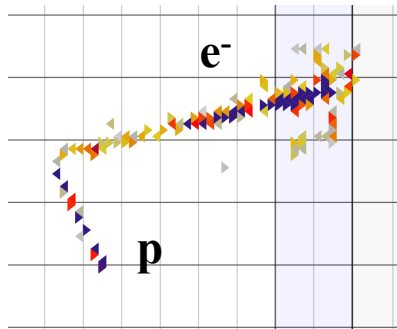
Reconstructed available energy (GeV)
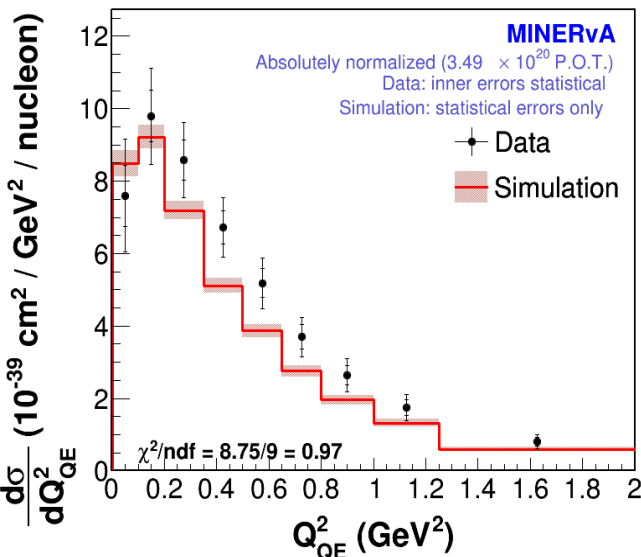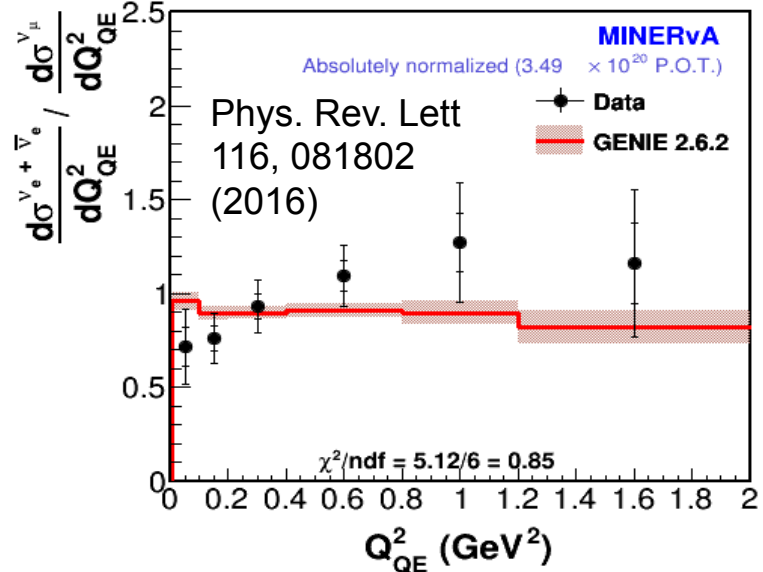
In Detail: ν_e CCQE

ν_e CCQE is oscillation signal, but almost no cross section data.

We all assume fundamental coupling is universal, but know nuclear effects are not!
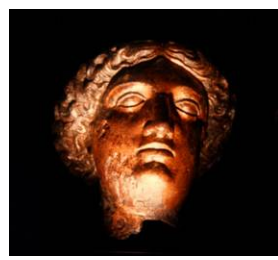

Measured cross sections and ν_e/ν_μ ratio consistent with GENIE model @ 1σ (~10-20% uncertainties) Absolute level is high

Phys. Rev. Lett 116, 081802 (2016)

Also found an unsimulated background of photon like events, which we believe are due to diffractive production of π^0 from protons in scintillator.
(a 2nd PRL, arXiV:1604.01728, currently in journal review)

ME fluxes for ν_e

- From L. Aliaga's thesis
- ME beam (FHC) provides factor of 6.9/4.1 ν_e 's per POT
- Provides factor of 705/287 ν_μ 's per POT!
- Pions decay farther down the decay pipe, leaving muons less time to decay

	integral ($\nu/m^2/10^6$POT)	Uncertainty (%)
Gen2-thin ν_μ	704.6	7.26
Gen2-thin $\bar{\nu}_\mu$	0.39	10.98
Gen2-thin ν_e	6.90	6.76

TABLE 7.1: ν_μ, $\bar{\nu}_\mu$, and ν_e **Gen2-thin** integrated fluxes in 0-20 GeV.

	integral ($\nu/m^2/10^6$POT)	Uncertainty (%)
Gen2-thin ν_μ	287.0	7.78
Gen2-thick ν_μ	280.8	5.37
Gen2-thin $\bar{\nu}_\mu$	233.5	7.46
Gen2-thick $\bar{\nu}_\mu$	238.6	5.51
Gen2-thin ν_e	4.11	7.06
Gen2-thick ν_e	4.07	4.93

TABLE 5.2: Integrated flux for ν_μ and $\bar{\nu}_\mu$ in **Gen2-thin** and **Gen2-thick** for neutrino energy in 0-20 GeV.
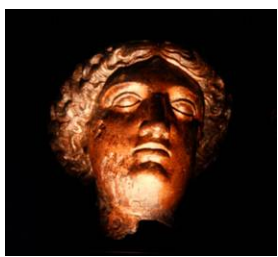
Extrapolating

- When cay we measure CCQE cross section ratios to 5%?
- Need factor of 4 higher than this plot, and we get a factor of 1.7 from the flux
- Neutrino mode:
- Antineutrino mode: assume nuebar/numubar ratio is the same as in neutrino mode
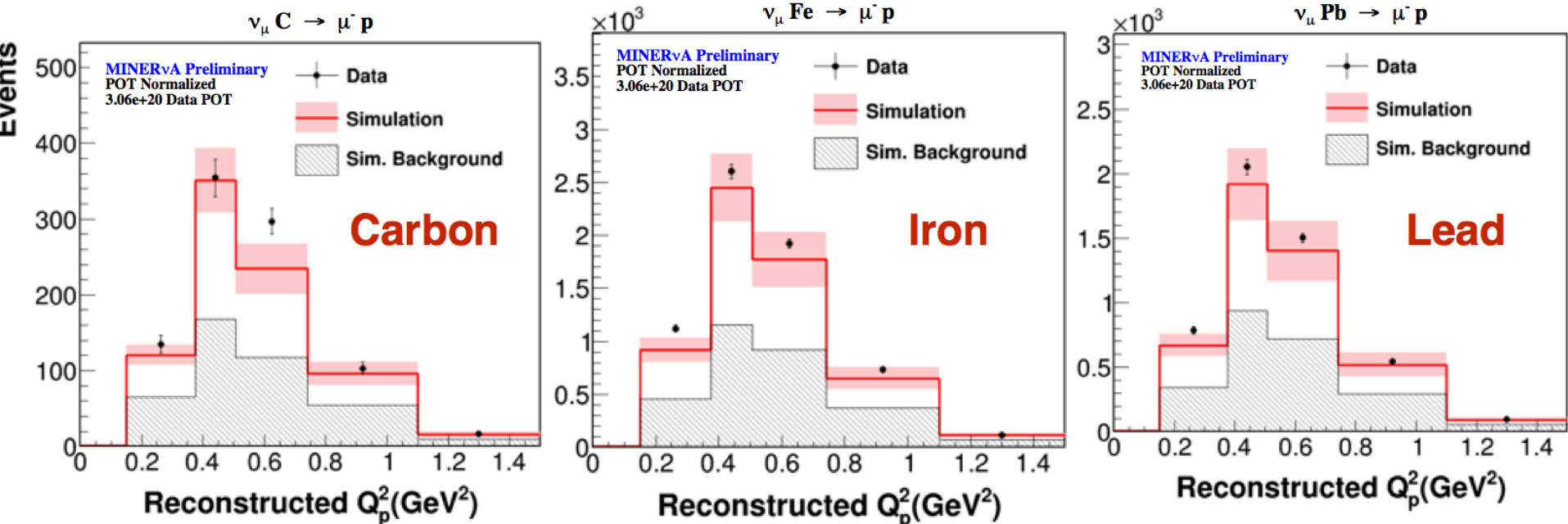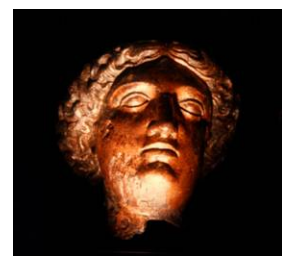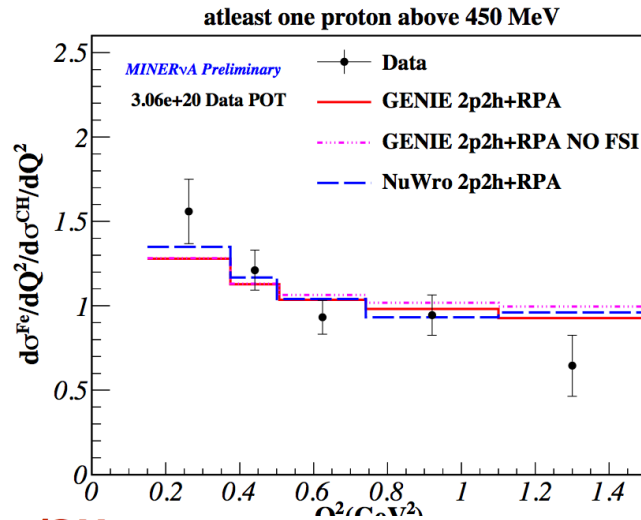- Get 70% as many antineutrinos/POT as neutrinos/POT
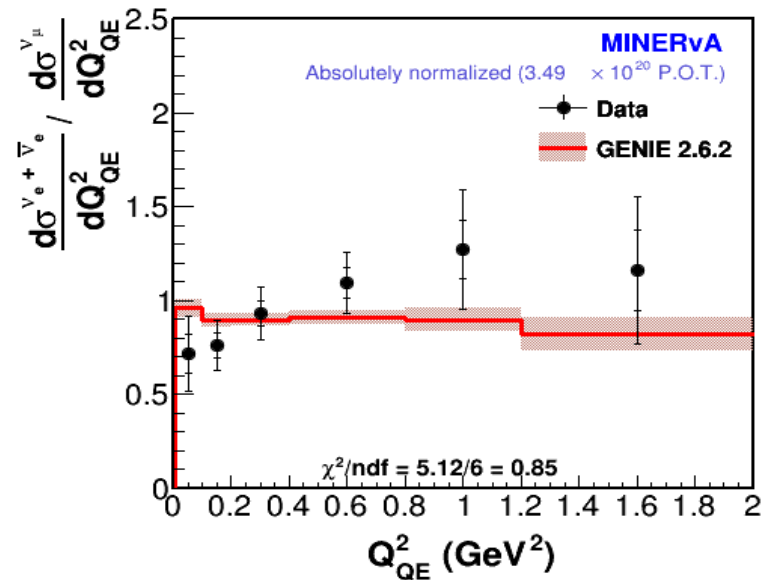
CCQE in Nuclear Targets

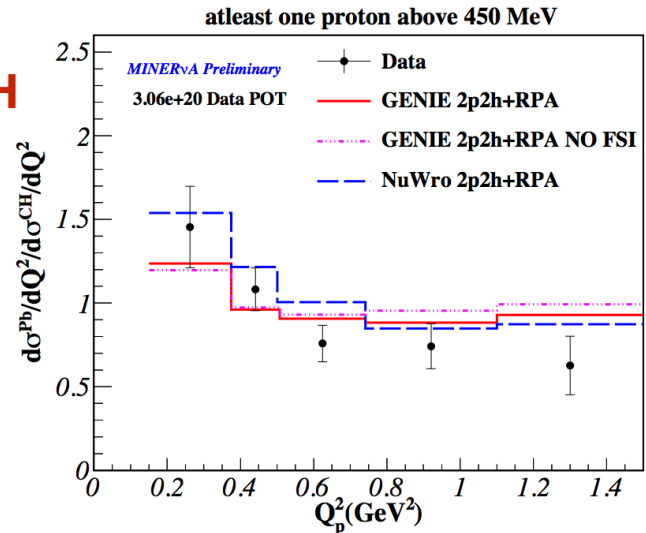- October 7 Wine and Cheese Seminar: first direct ratio of CCQE cross section on different materials

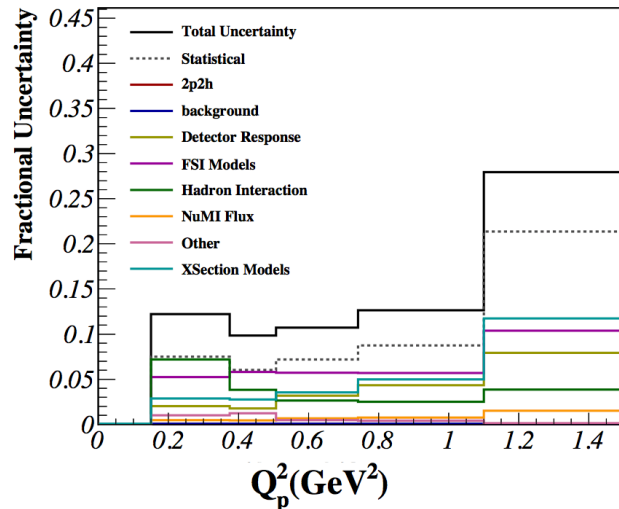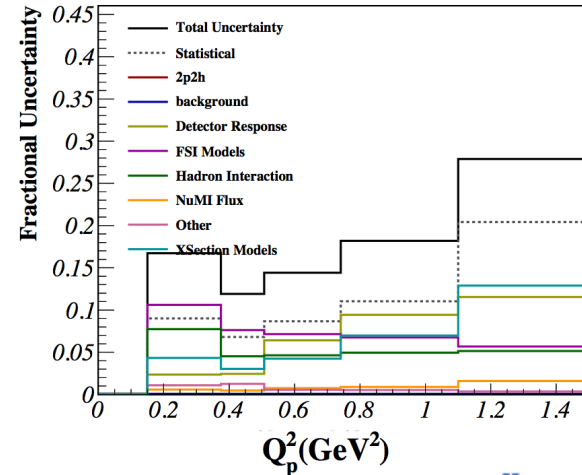# Cross Section Ratios and Uncertainties
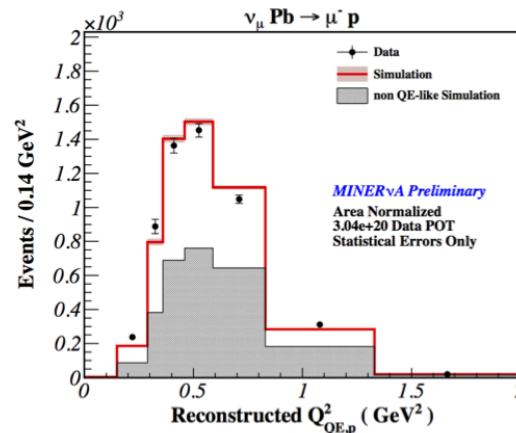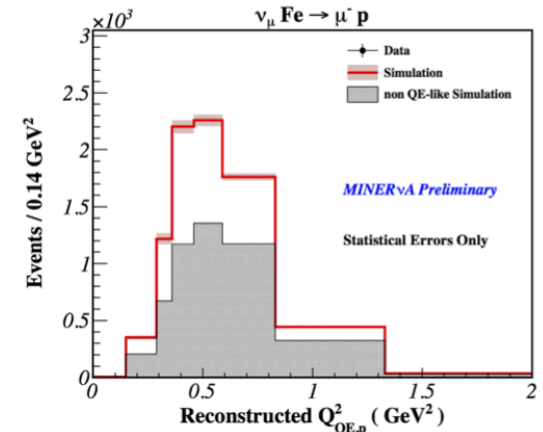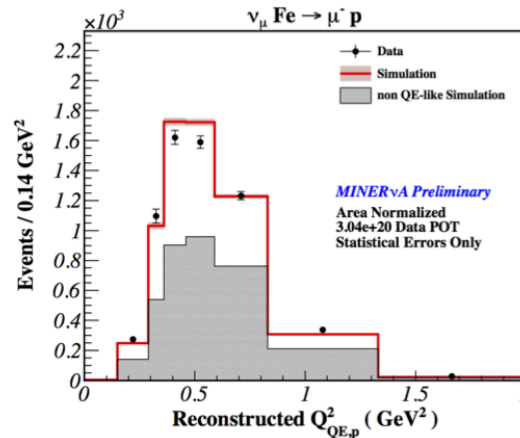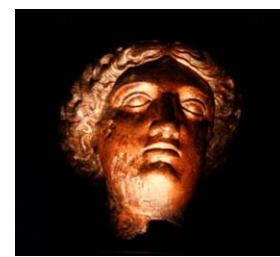
Extrapolating to ME beam
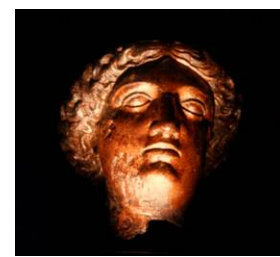
- From December 2014 PAC document

- LE on the left, ME on the right, 1E20 POT for each

- Increase in statistics per POT: about 50% more

- Current neutrino sample has factor of 4.5 improvement in statistics now
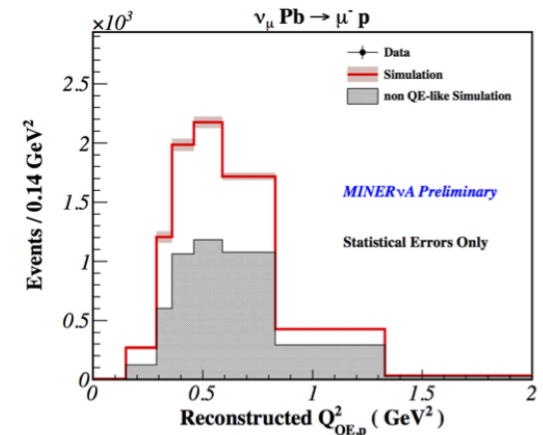
Acoplanarity

- Another way to drill down on Final State Interactions: angle between neutrino-proton and neutrino-muon planes