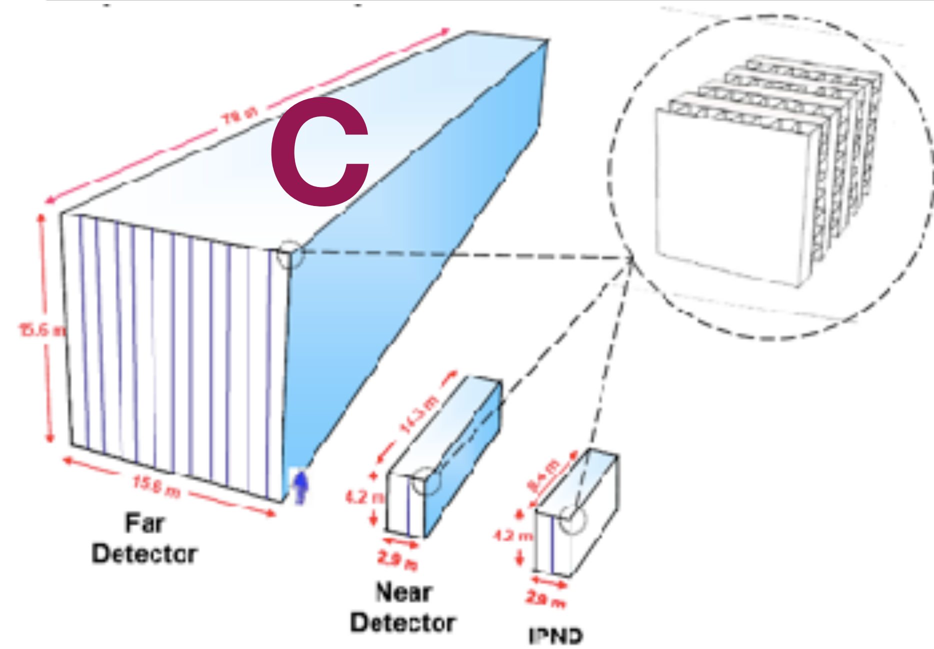
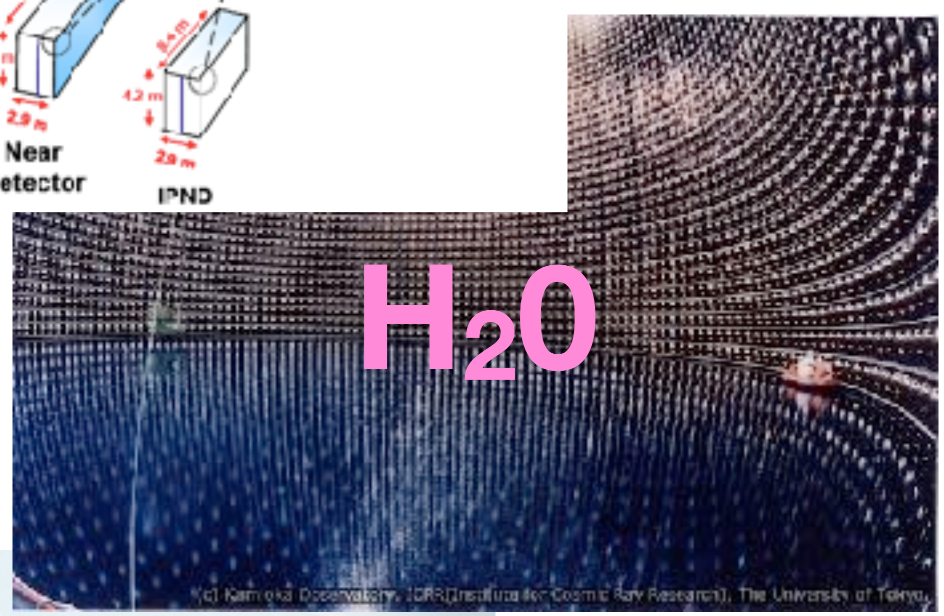
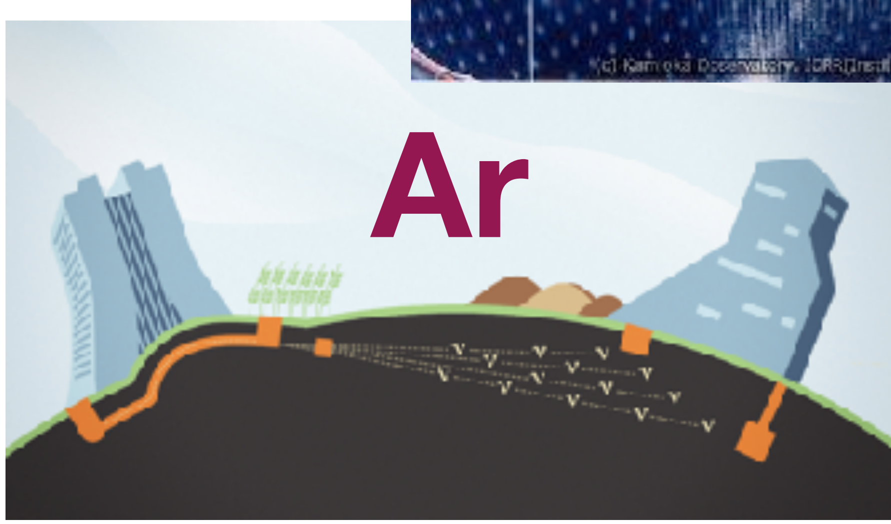
Deep Inelastic Scattering Cross Section Ratios in MINERvA

Anne Norrick
The College of William and Mary
on behalf of the MINERvA Collaboration
NuINT 2017

Neutrinos and Nuclei





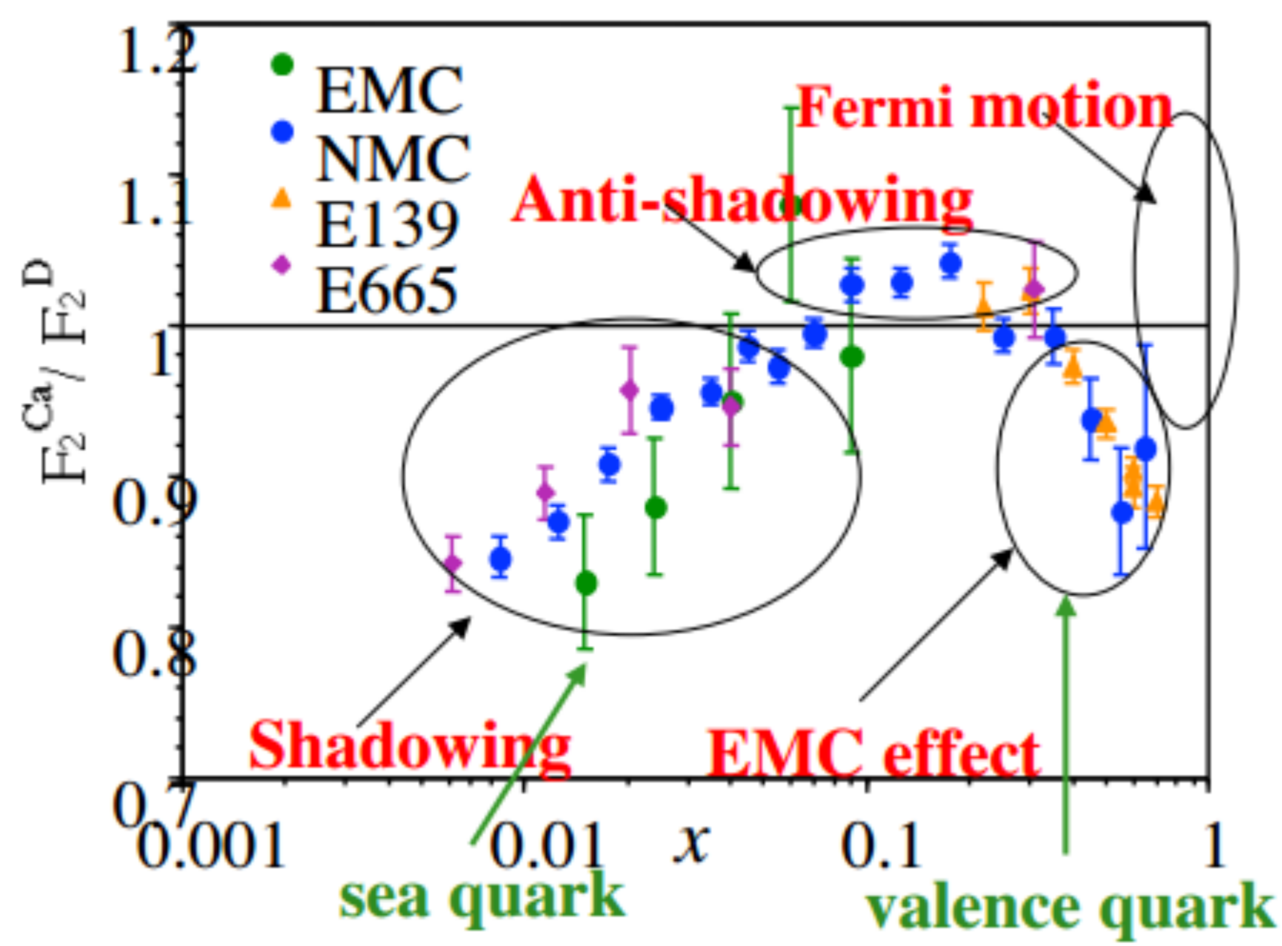


- Neutrino detectors require heavy nuclei for high statistics.
- Large nuclei are complicated environments, and both interactions between nucleons, and interactions between partons can change the kinematics of the final state.
- All of these effects contribute to uncertainties in cross sections for oscillation experiments.
- Starting point in our understanding of these is charged lepton scattering.

Nuclear Media Modifications with Charged Leptons

- Charged lepton scattering experiments measure cross sections on heavy targets, compare them to lighter targets.
- If the quark-parton model was perfect, this ratio would sit at one. However, the quark-parton model needs to be built up into real hadronic systems, not simply free quarks.
- Charged lepton scattering experiments have shown that the nucleus is much more than just the sum of its partons.

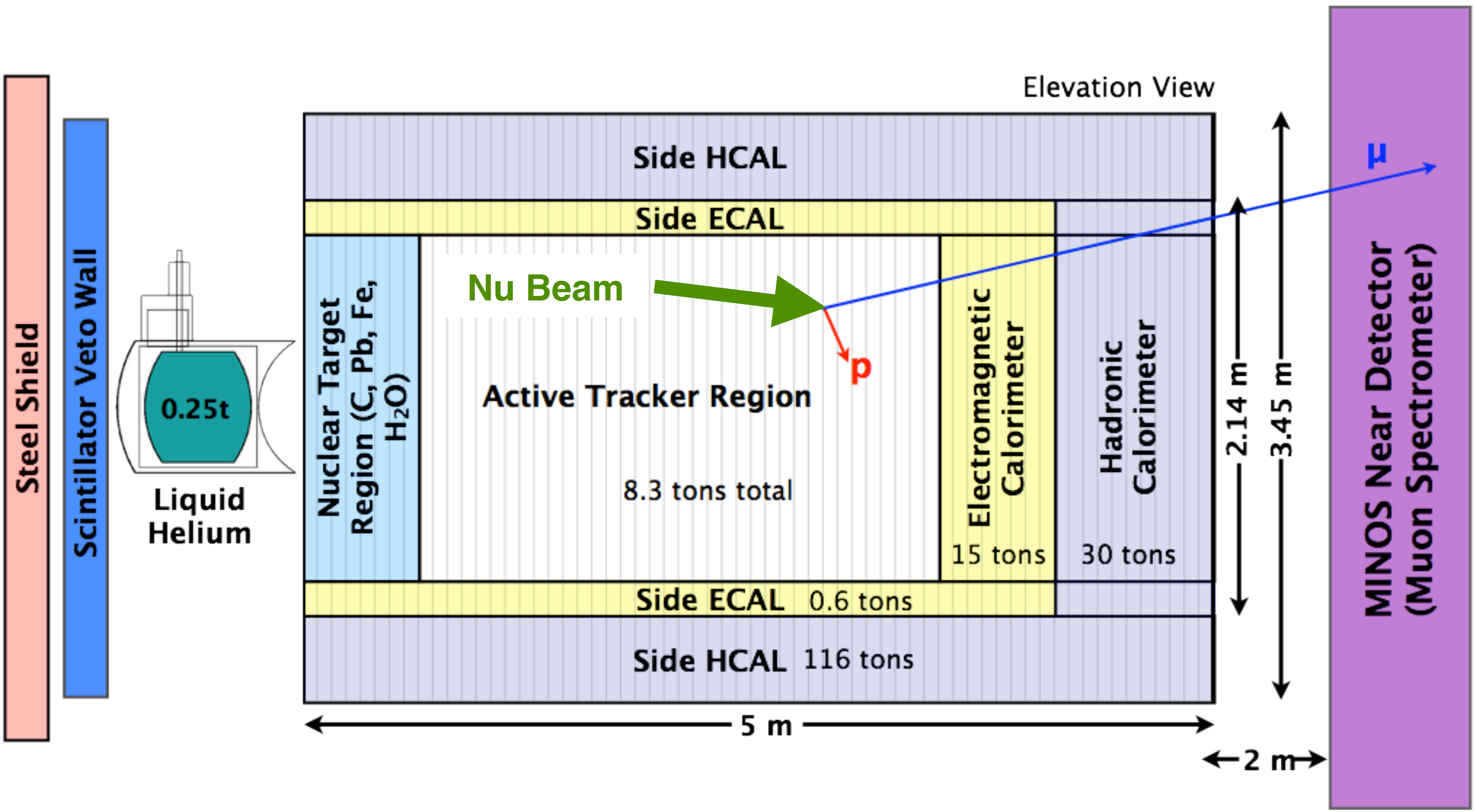
Charged Lepton Scattering



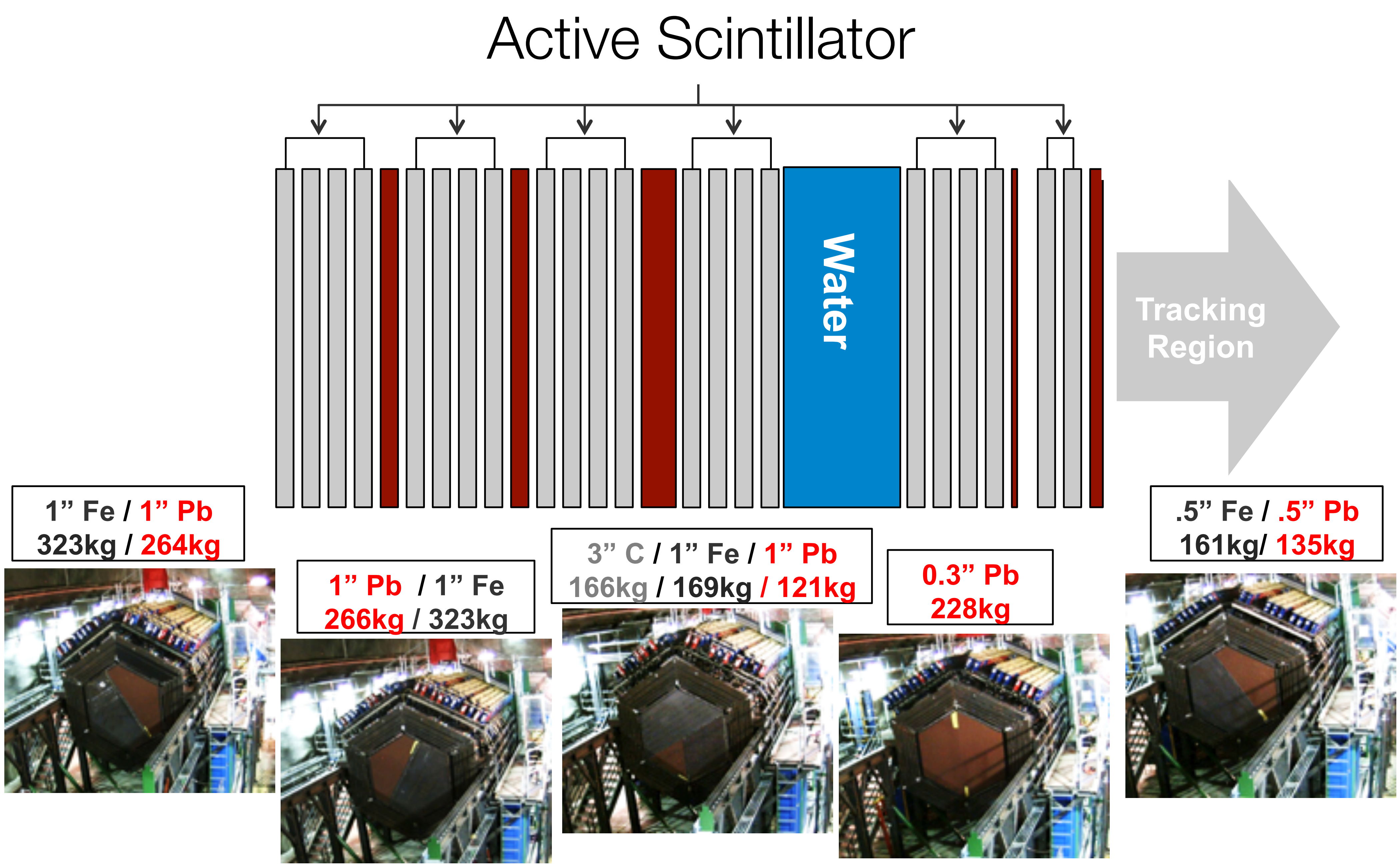
Plot Adapted by Brian Tice

Results in: J J Aubert *et al.* 1983 *Phys. Lett. B* **123** 275.

The MINERvA Detector

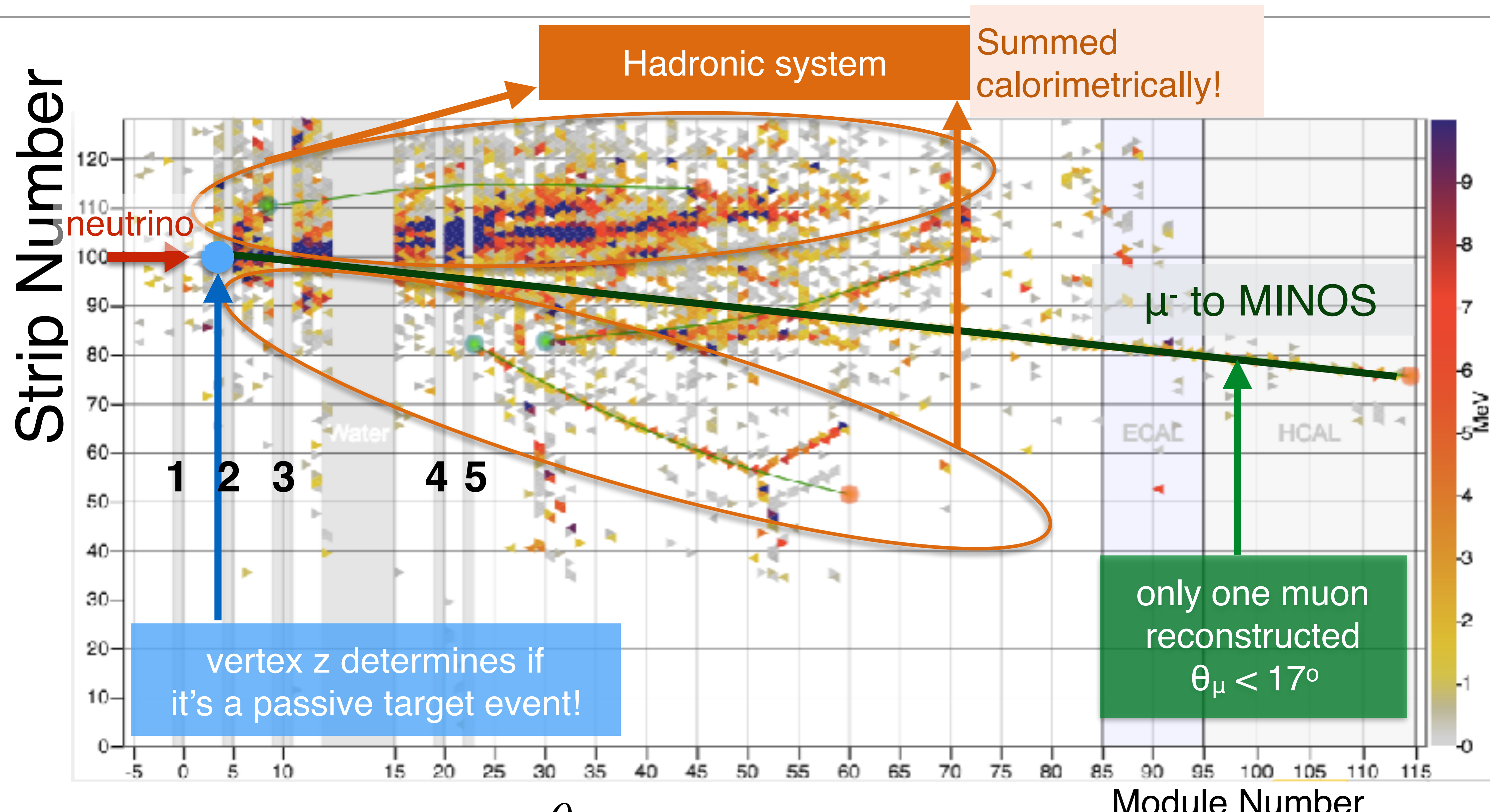


The MINERvA Detector



MINERvA measures scattering on different targets simultaneously using the same beam line.

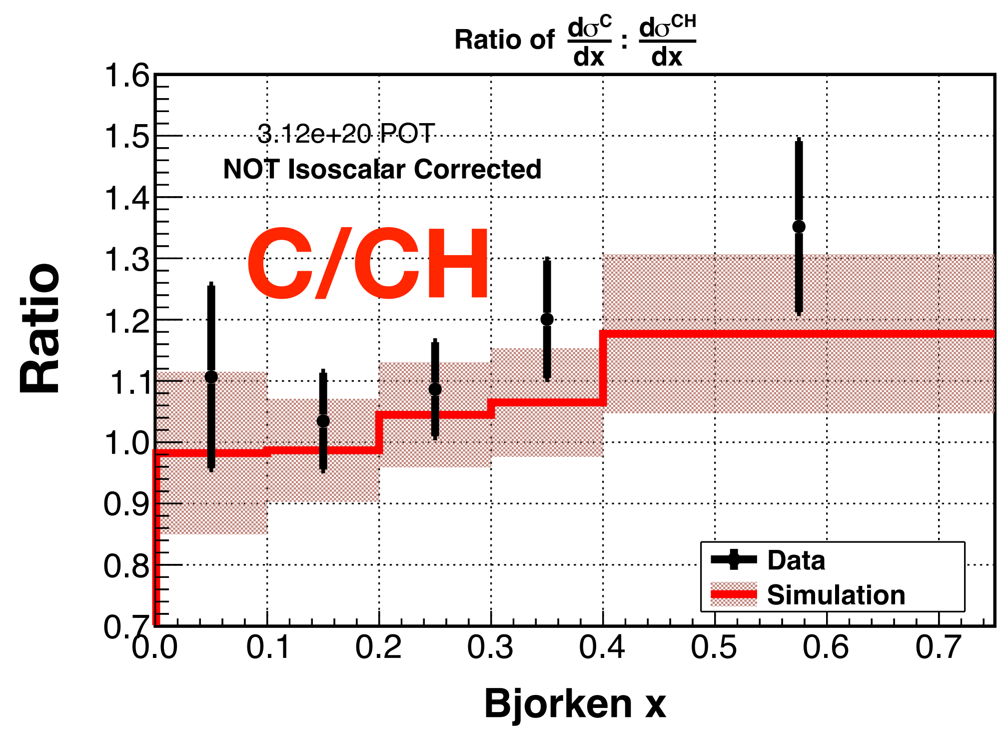
Signal Selection and Reconstruction

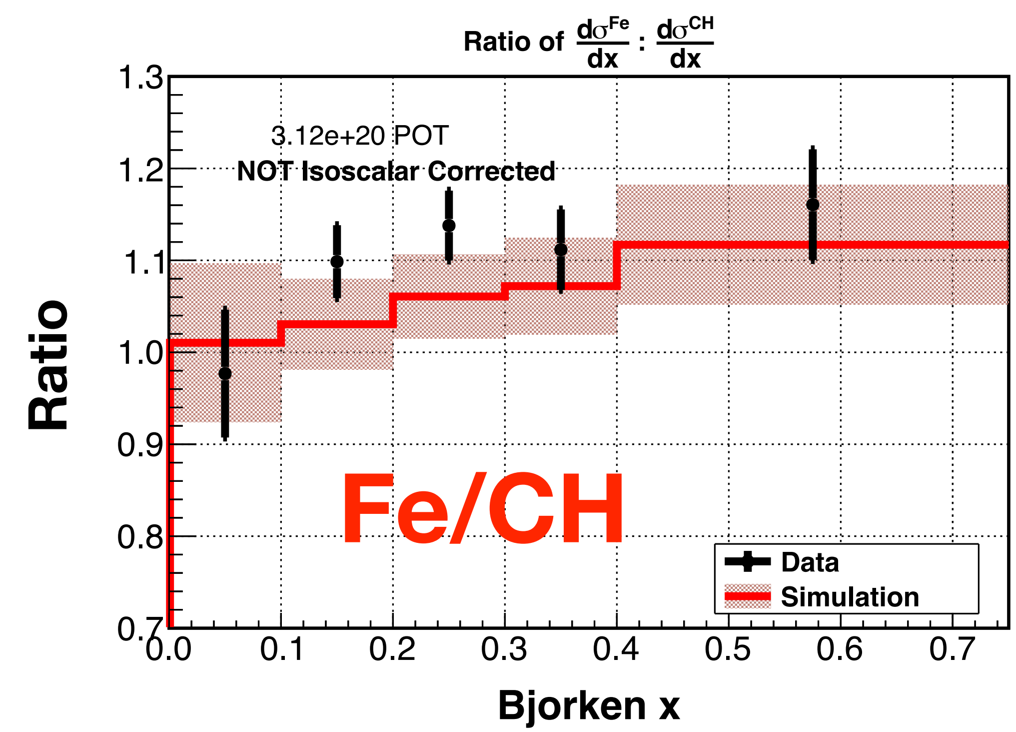


$$Q^2 = 4E_\nu E_\mu sin^2\frac{\theta_\mu}{2} \quad W^2 = M_N^2 + 2M_N E_{had} - Q^2$$

DIS: Q^2 >1 GeV^2, W > 2 GeV

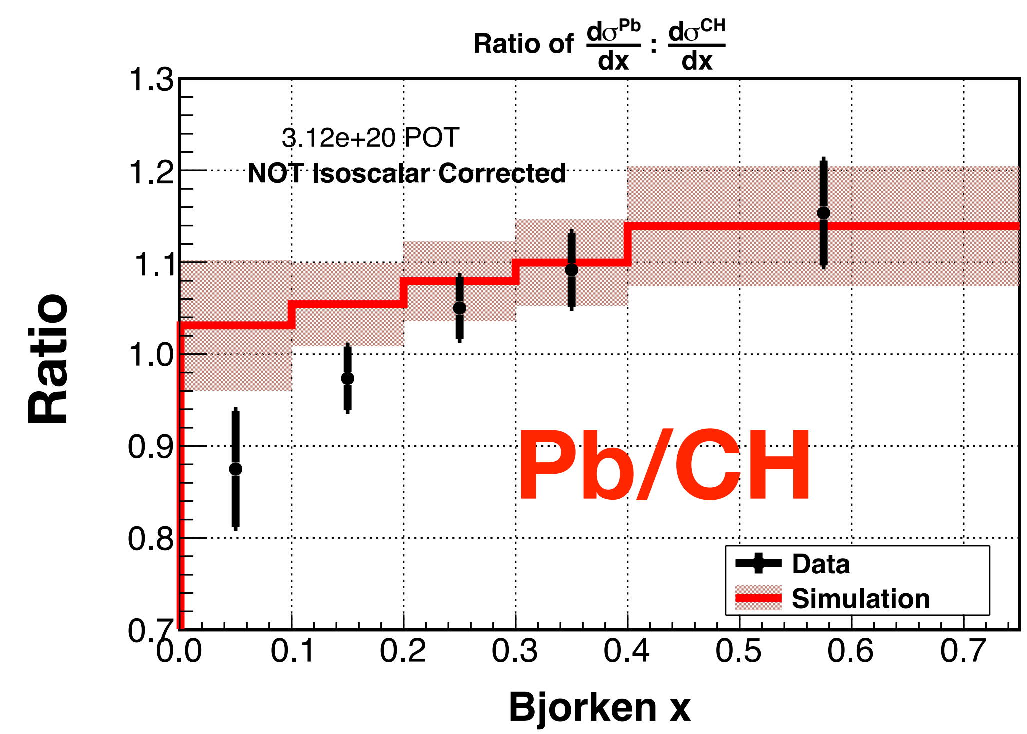
Deep Inelastic Scattering: Cross Section Ratios



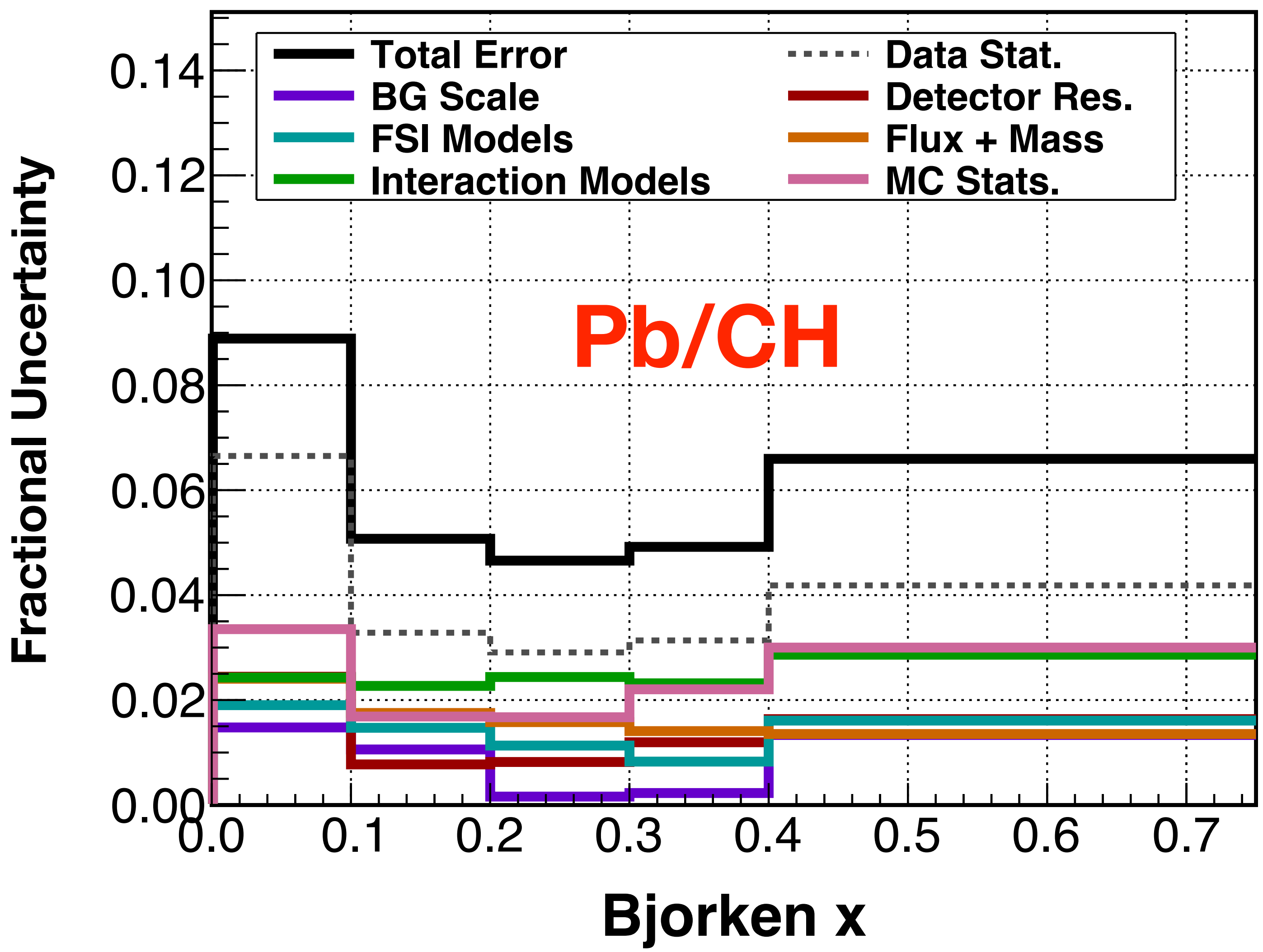


- x range of 0.3-0.75 shows agreement, while the low x MC overestimate is consistent with nuclear shadowing.
- Phys Rev D. 93, 071101 (2016)

$$x = \frac{Q^2}{2M_N E_{had}}$$



Fractional Uncertainties

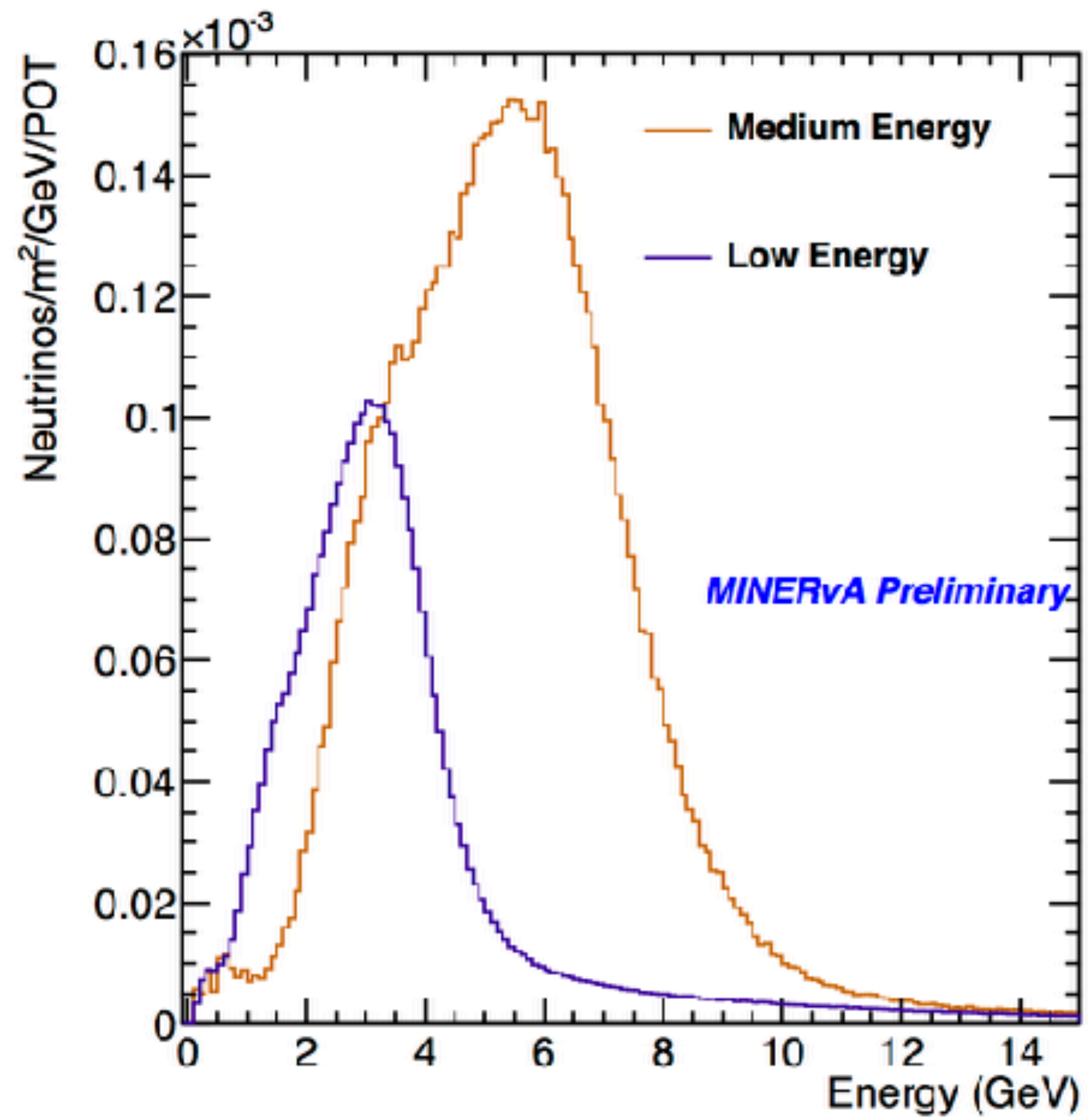


$$x = \frac{Q^2}{2M_N E_{had}}$$

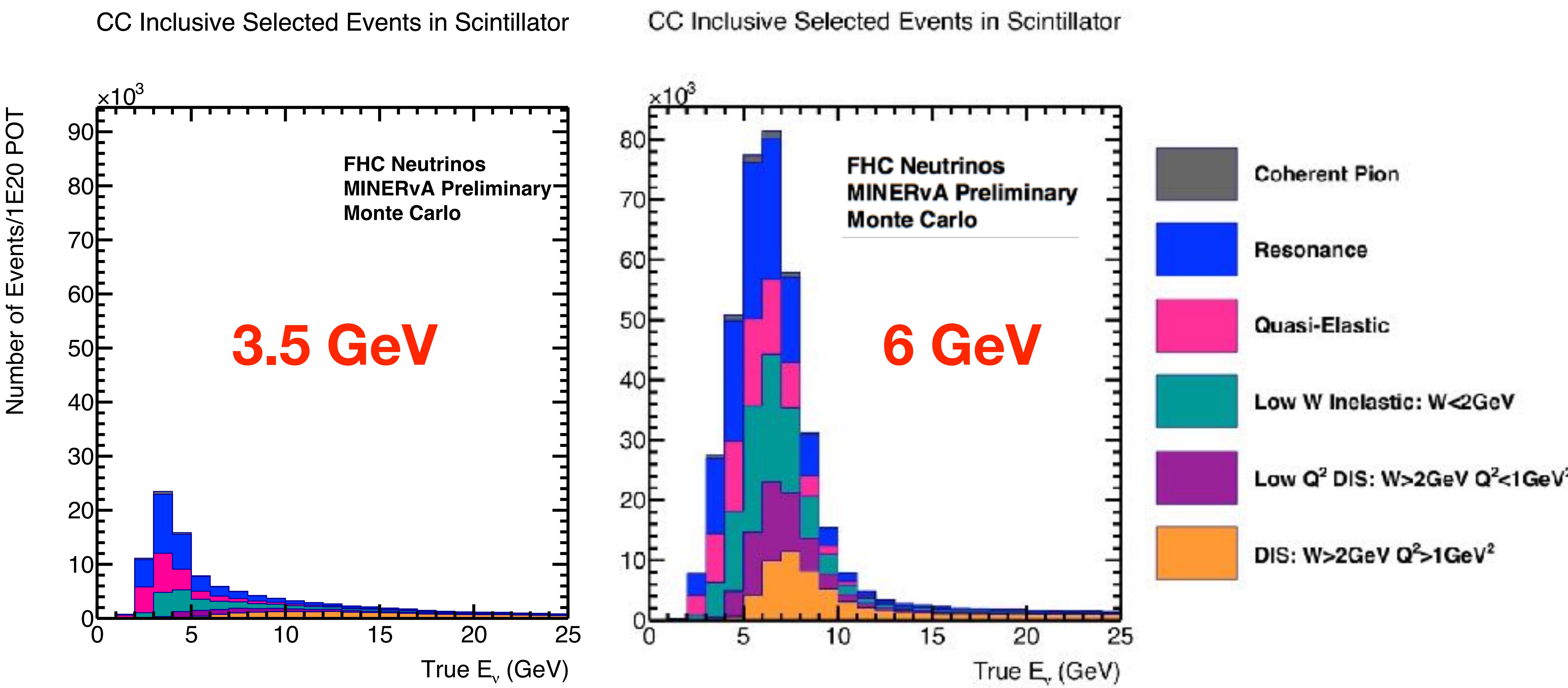
- Ratio analyses have the advantage of largely canceling the uncertainty on the neutrino flux.
- This analysis is statistics limited, but as the statistical error decreases, Final State Interaction model uncertainties will become the dominant uncertainty.

6 GeV Energy Beam

- The NuMI beam line is tunable, and in Fall 2013, the beam line was tuned to focus higher energy pions.
- This resulted in a neutrino beam with a 6 GeV peak energy.
    - Neutrino cross section increases with higher energies.
    - The flux increases by roughly a factor of three.
    - We've already increased our statistics by a factor of three.
- We have taken over 12E20 Protons on Target in neutrino mode.
- Currently running in antineutrino mode.

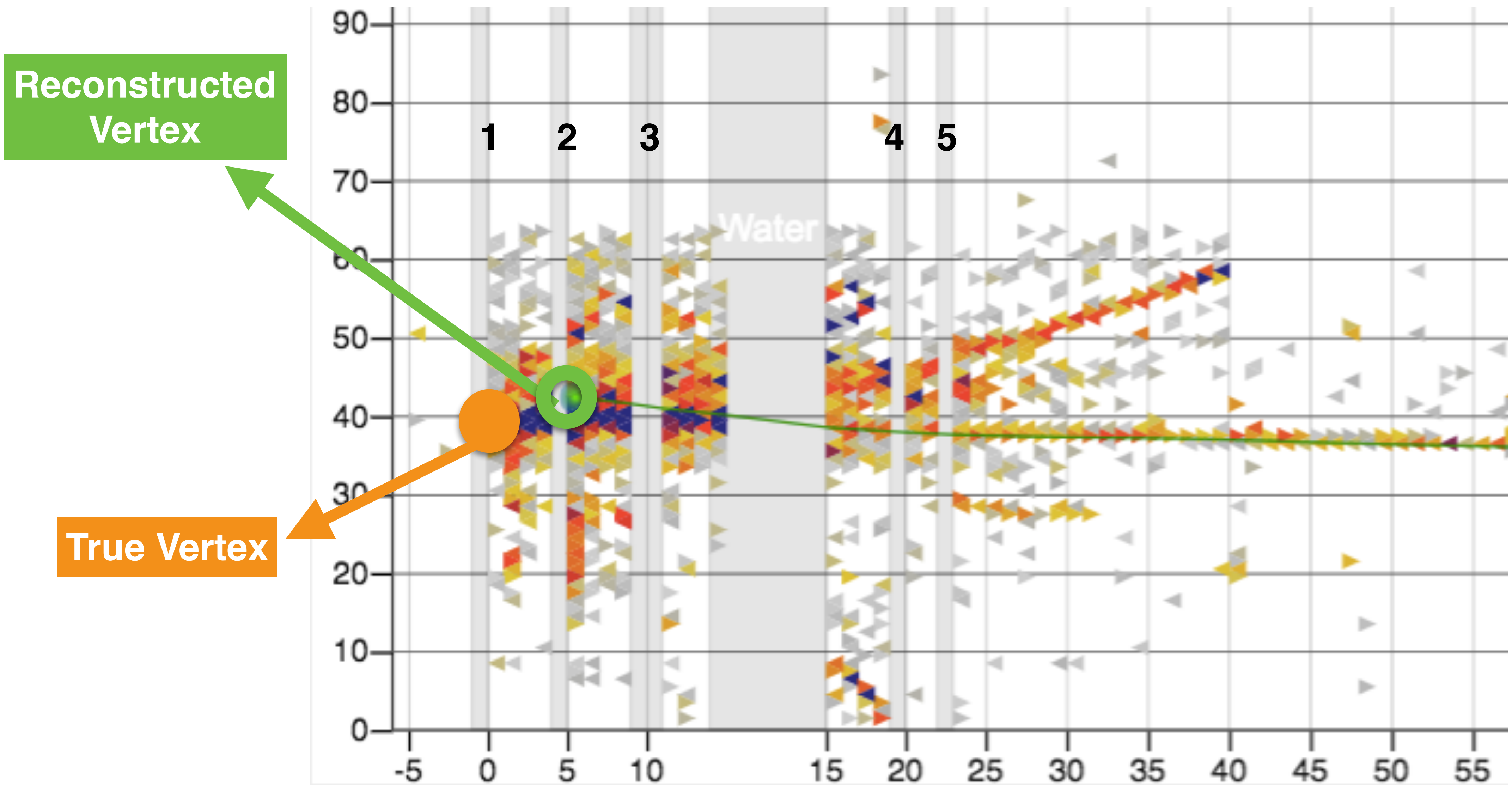


Improvements for the 6 GeV Beam



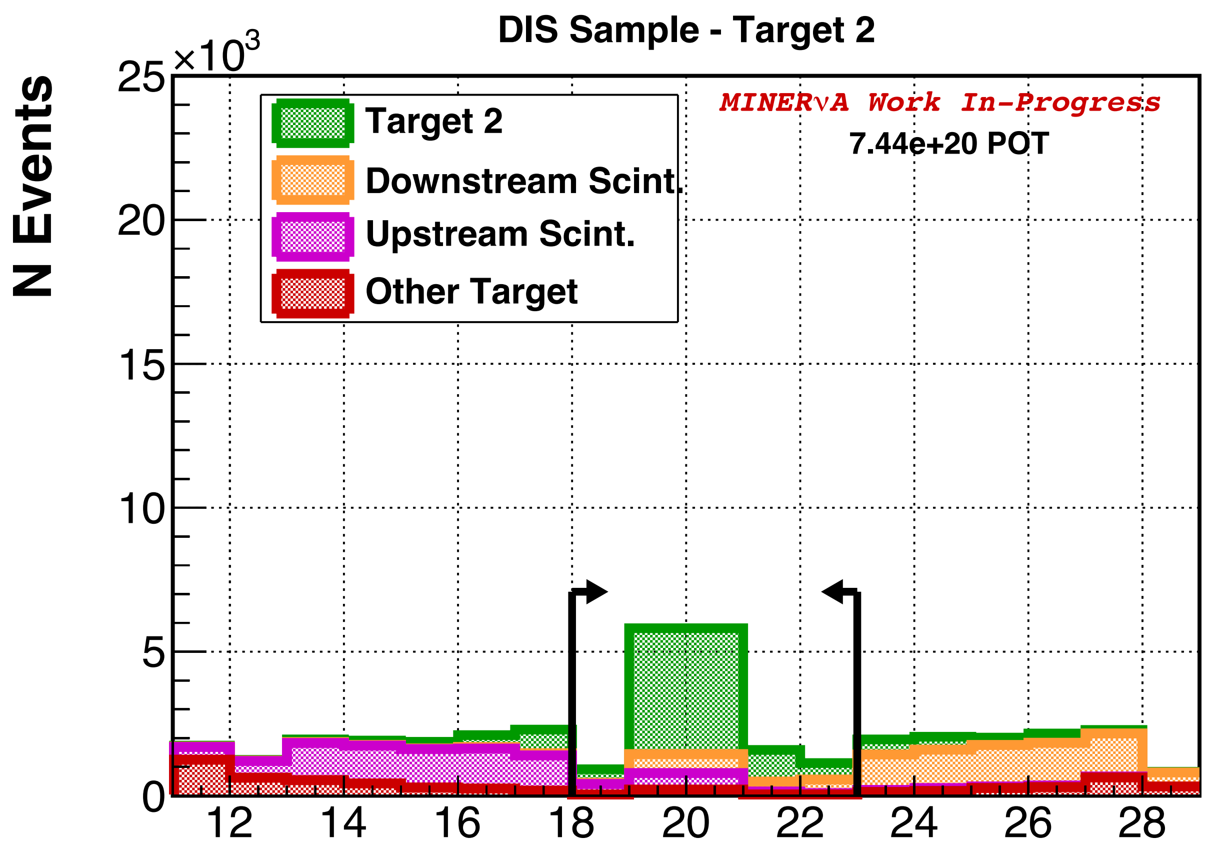
- Large inelastic scattering sample to explore.

Improvements for the 6 GeV Beam

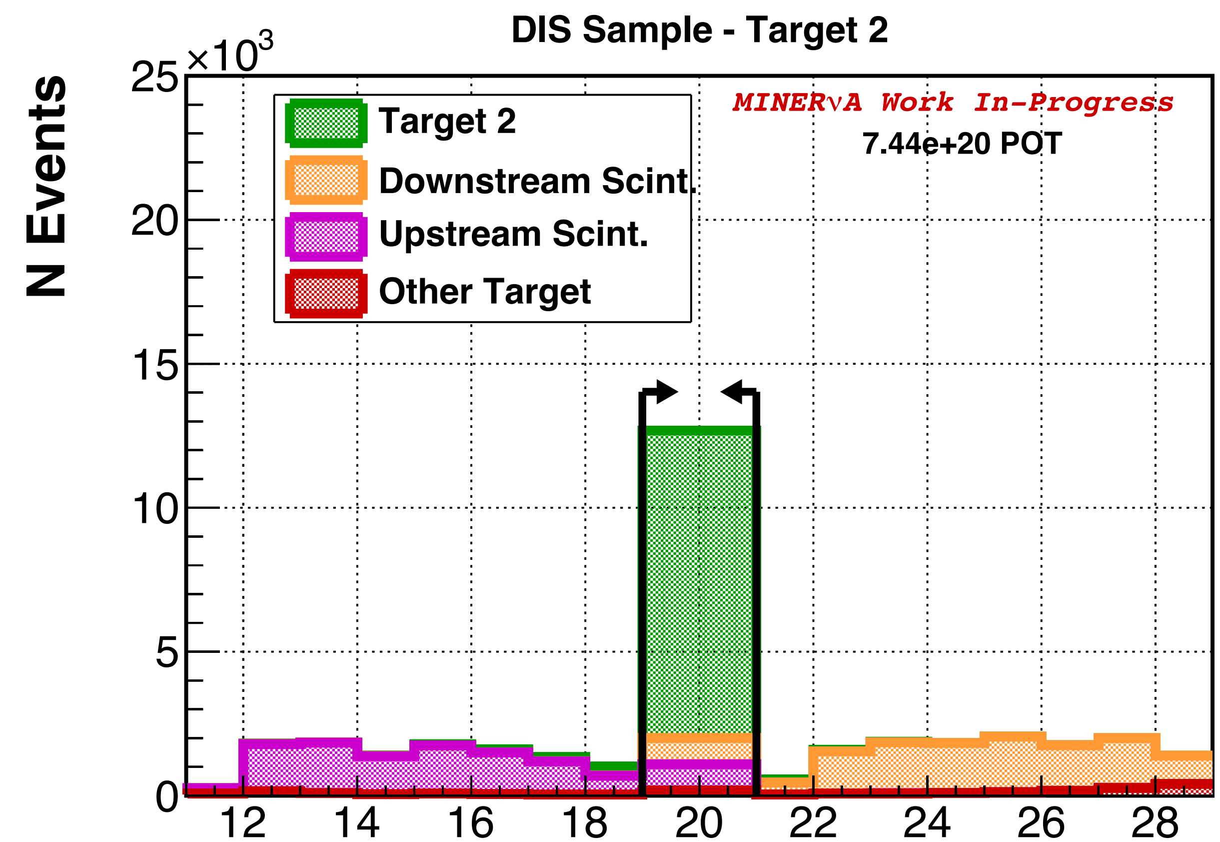


- Correctly vertexing a DIS event in the passive nuclear targets is difficult, as the hadronic showers are large and messy.

Improvements for the 6 GeV Beam



Track Based Vertexing



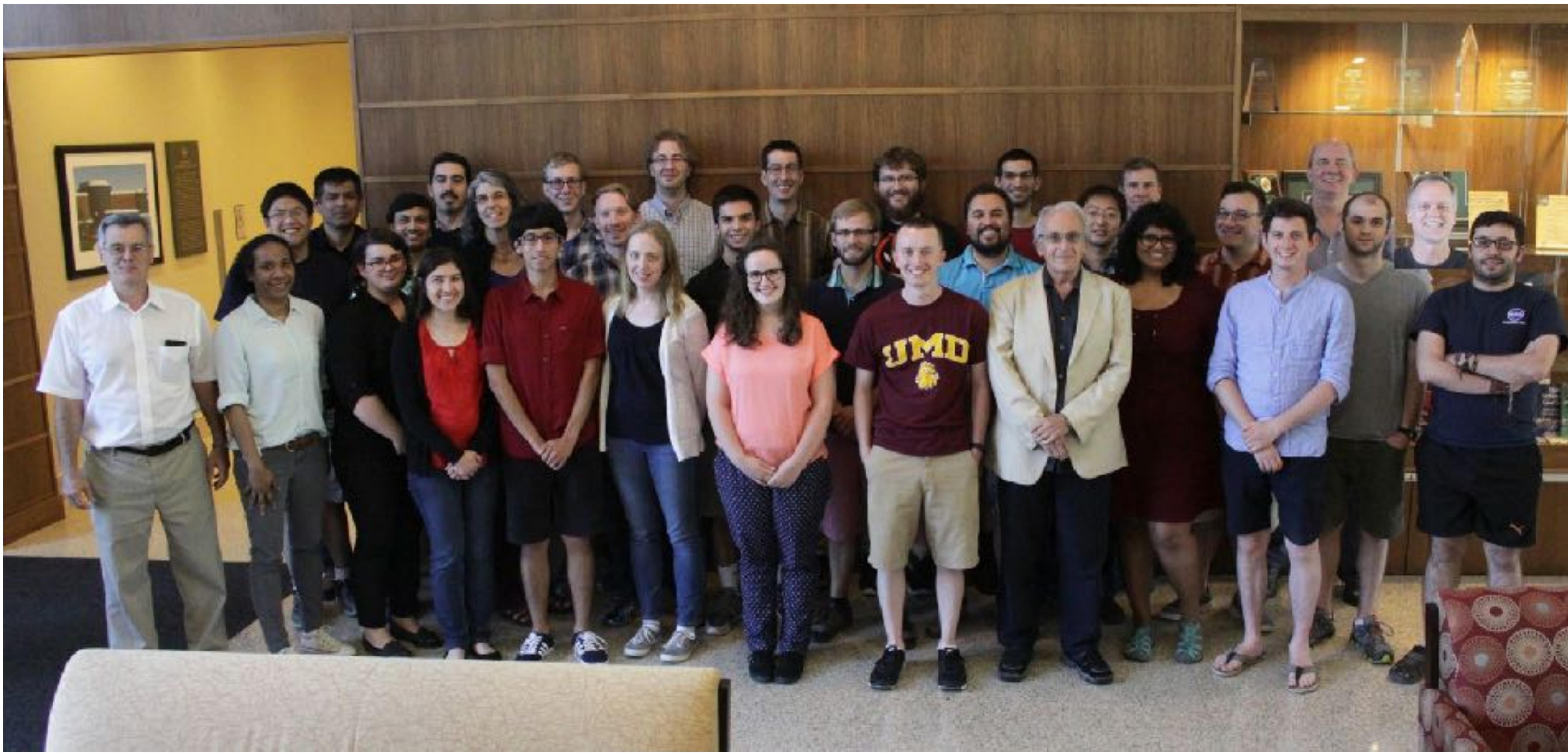
Machine Learning Vertexing

- By using image based Machine Learning, we can improve the vertex reconstruction.
- I encourage you to visit Marianette Wospakrik and Anushree Gosh's poster in the poster session to learn more about it.

Looking Forward

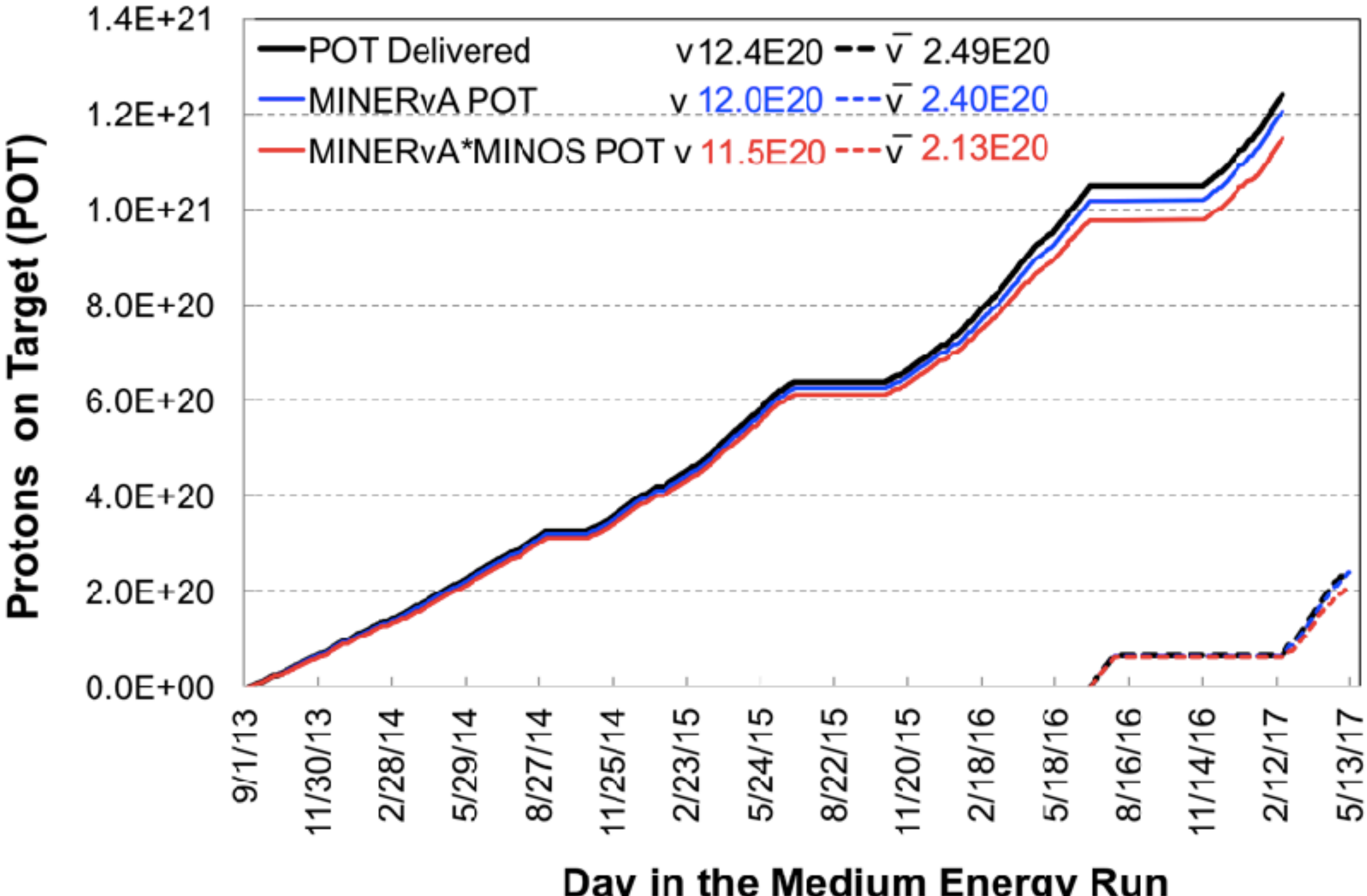
- MINERvA has finished data taking in neutrino mode, with 12E20 POT on disk.
- We've started taking antineutrino data, with 3.5E20 on disk already. MINERvA is approved for 6E20 POT in antineutrino mode.
- Improvements in our reconstruction will result in improved purity and efficiency and reduced systematic uncertainties in our 6 GeV analysis.
- Please stay tuned for exciting results in the near future!

Thank you



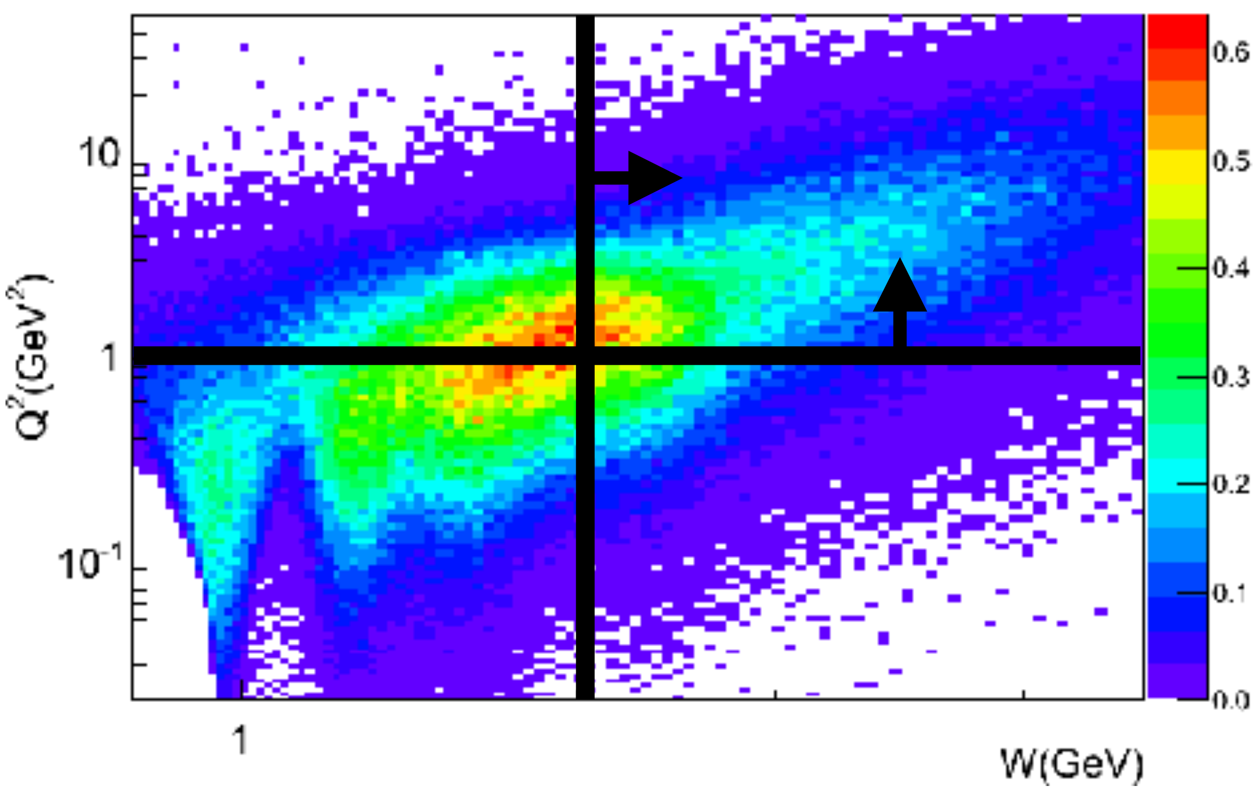
Backup

Protons Delivered

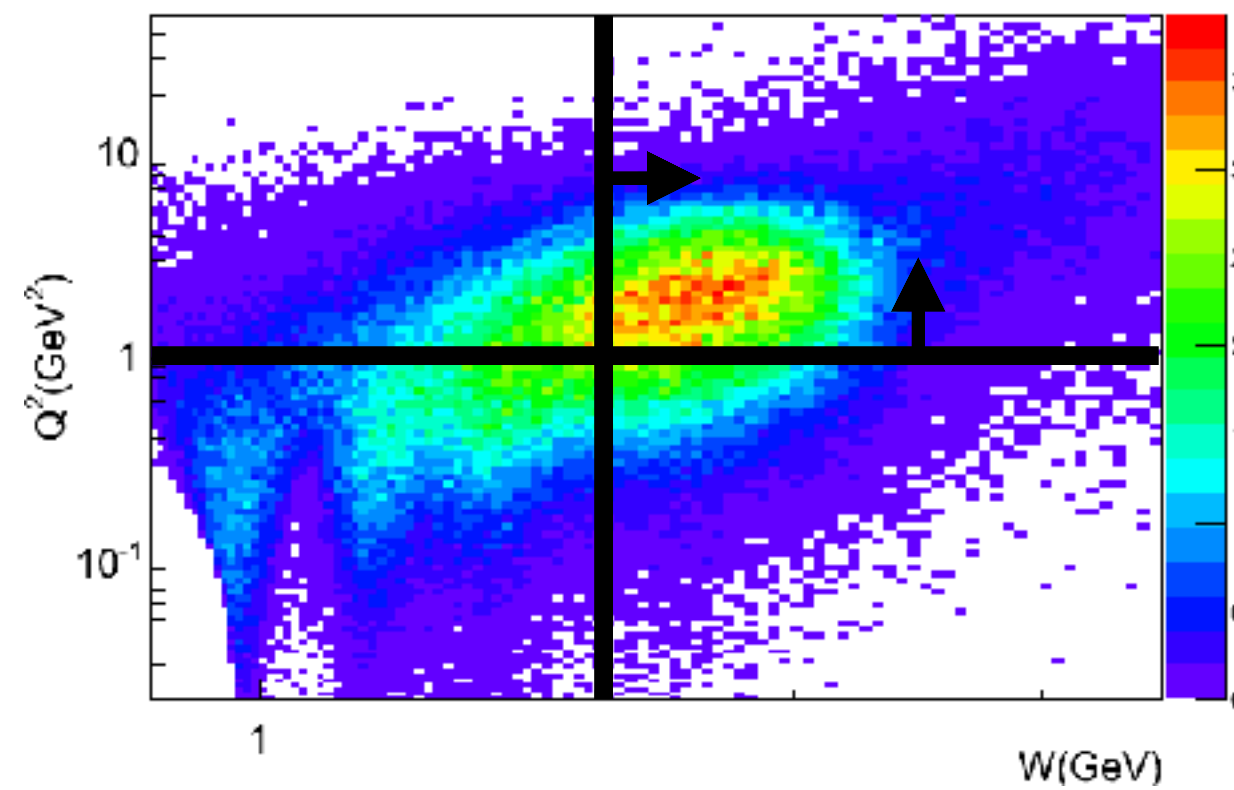


<6 GeV> Data Set Potential

<3.5 GeV> Run



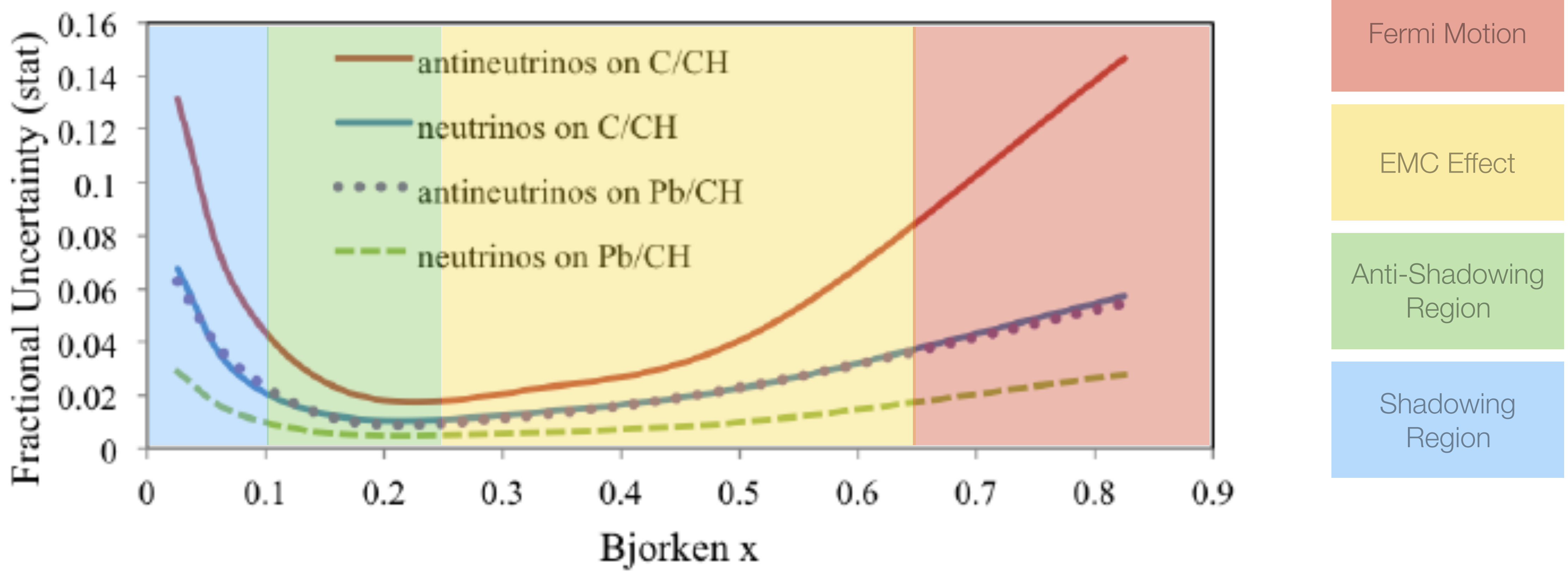
<6 GeV> Run



- Statistics are improved by roughly a factor of 3 for each proton on target, and we have taken around 3 times the data.
- The focusing peak of the beam has moved into the DIS kinematic range.

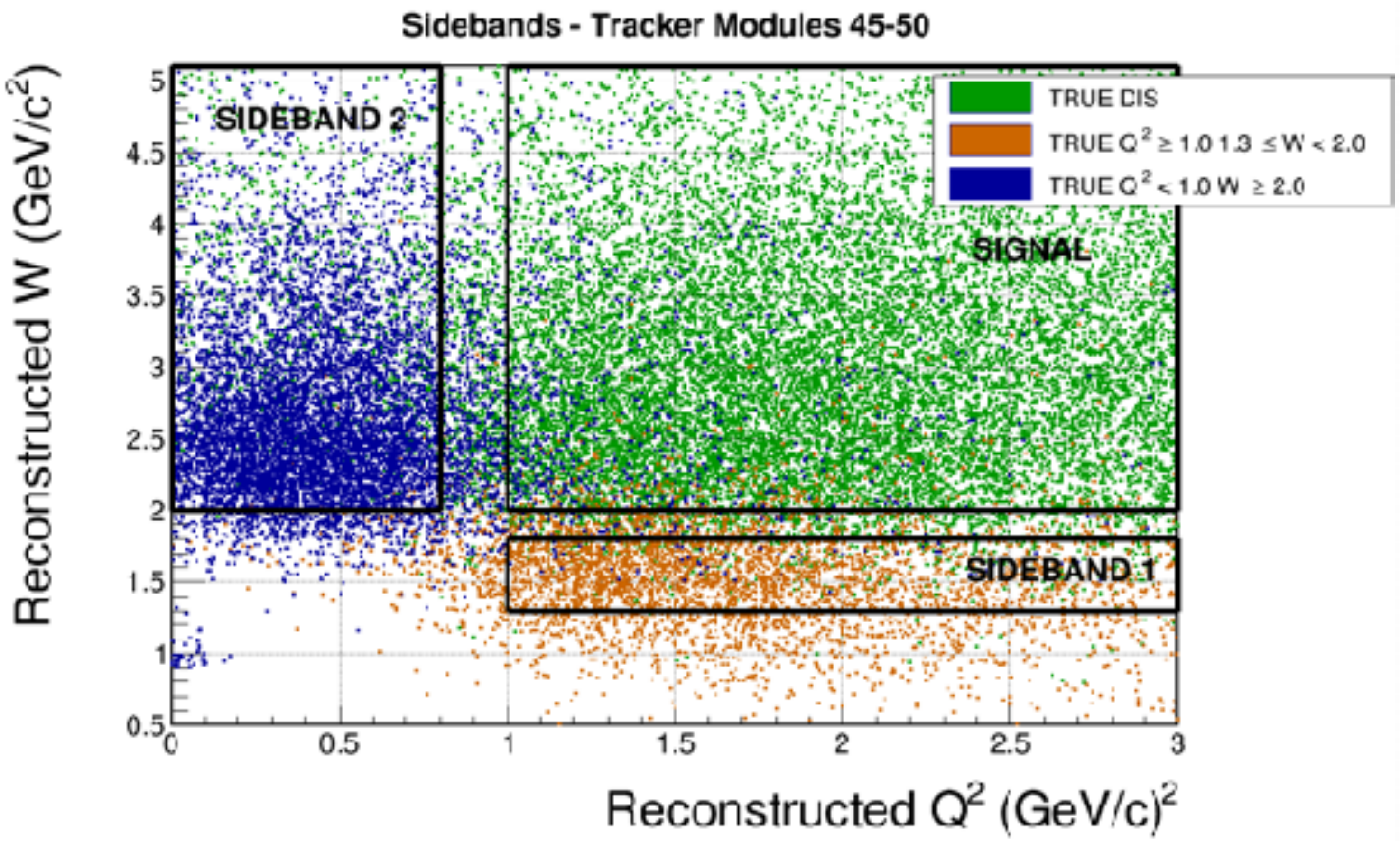
Example: Iron

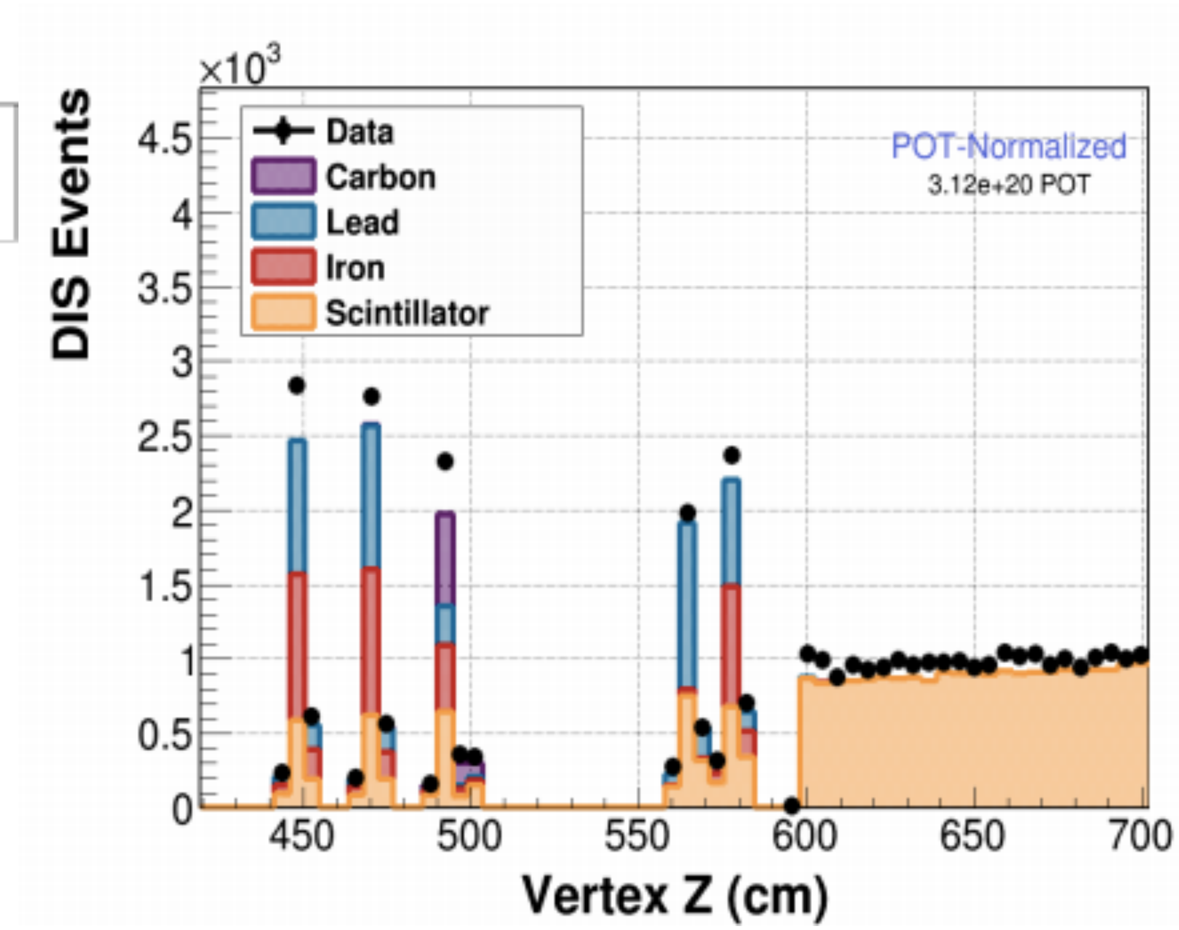
Fractional Statistical Uncertainty on 6 GeV Ratio Analysis



- For a projected 10×10^{20} Protons on Target, the fractional statistical error is less than 6% over all Bjorken x in neutrino mode.
- This is going to be a systematics limited analysis.

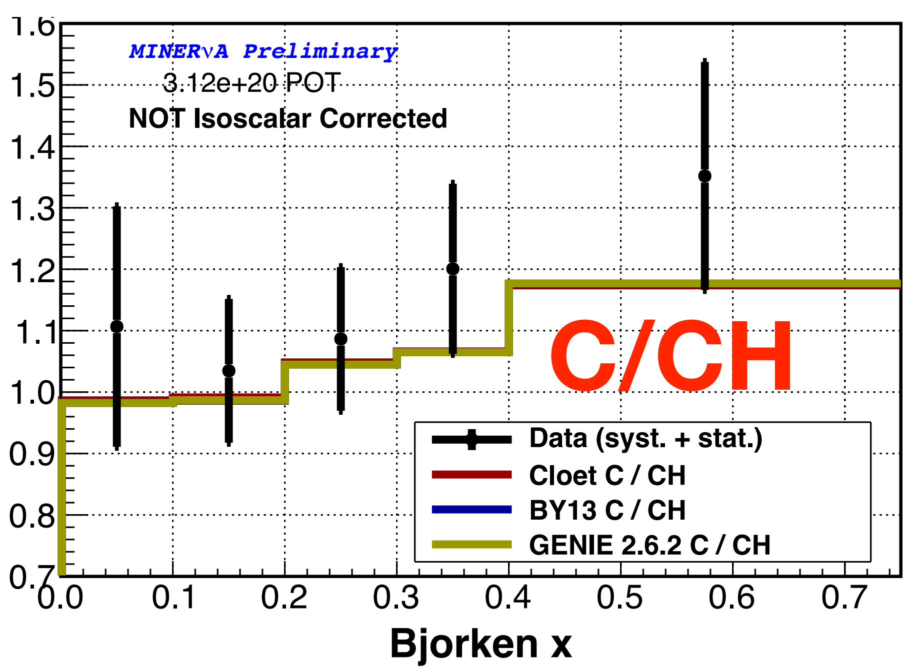
3.5 GeV Analysis: Background Subtraction

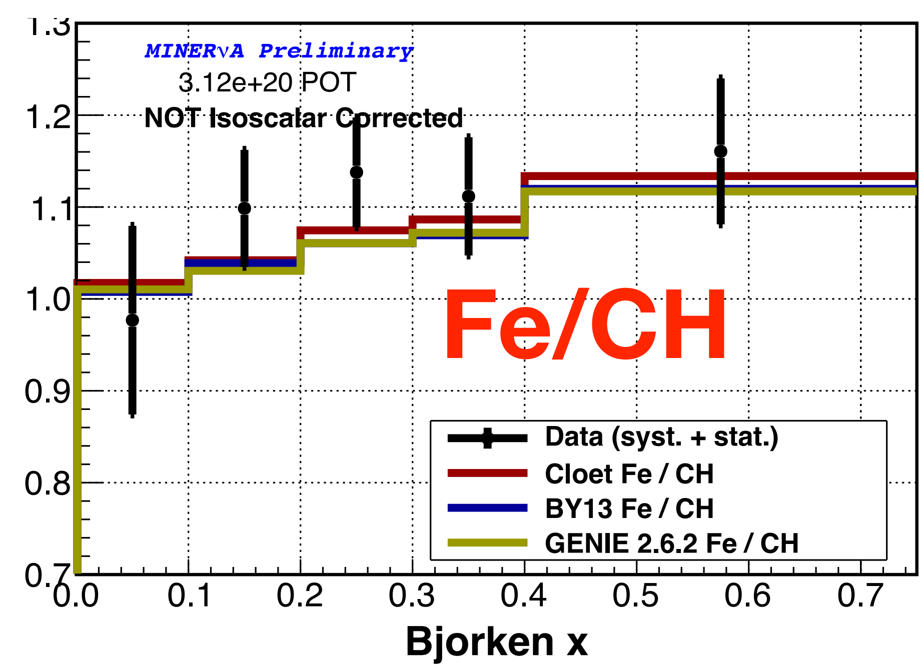




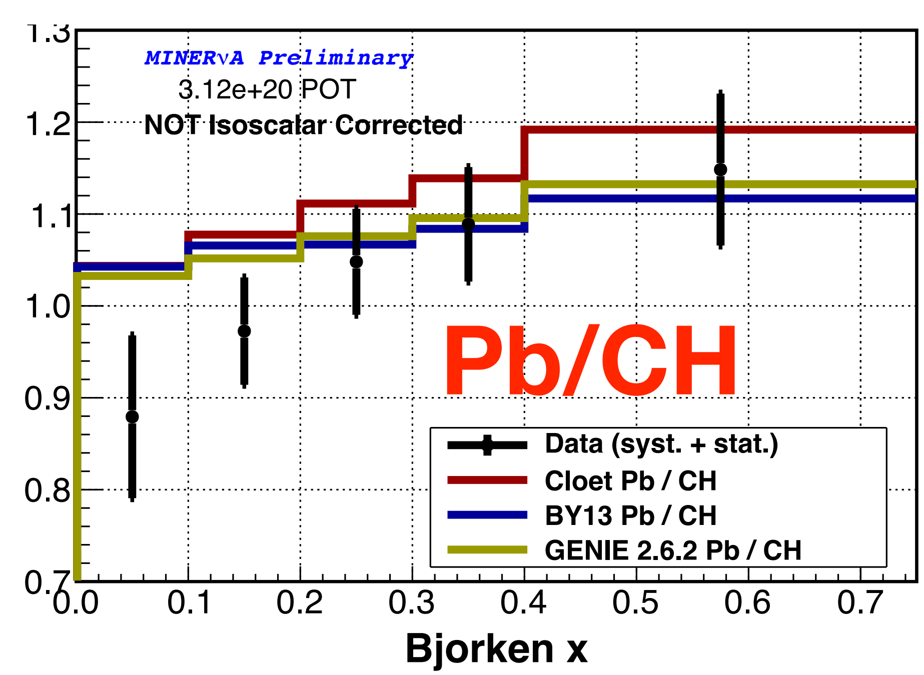
- Two types background subtraction:
  - Physics Sideband
  - Plastic Background

Deep Inelastic Scattering: Model Comparisons





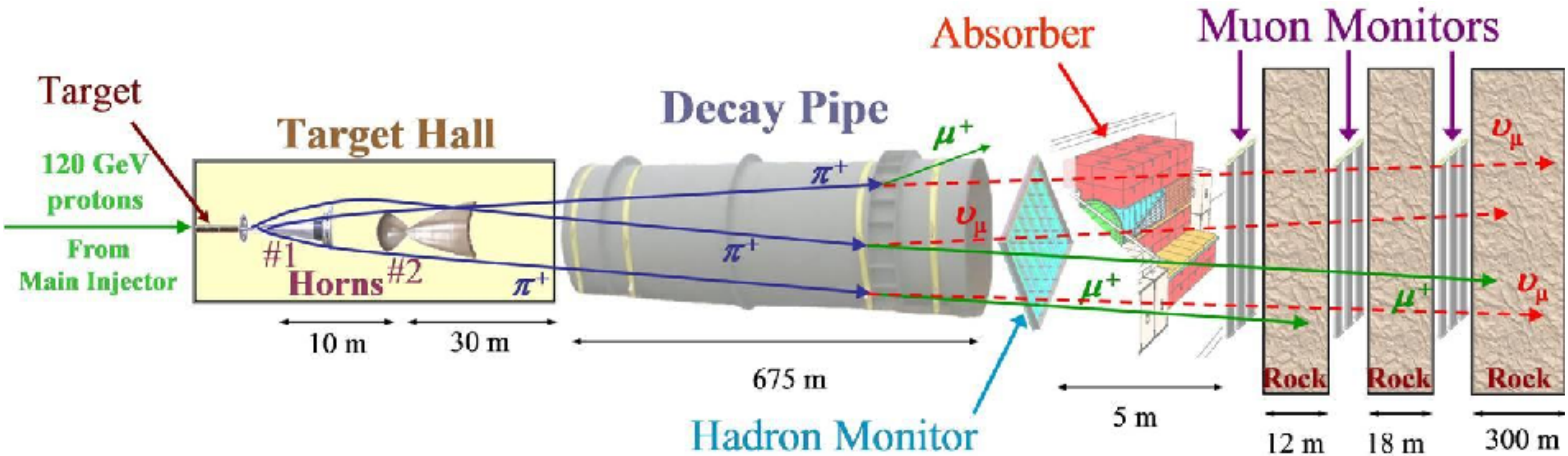
- Models abound, but we really need more data before we can discriminate between the models.
- Models shown here can be found in:
  - C. Andreopoulos et al., NIM A614, 87-104 (2010
  - A. Bodek and U.K. Yang, arXiv:1011.6592 [hep-ph]
  - I.C. Cloet, Phys. Lett. B642, 210 (2006)

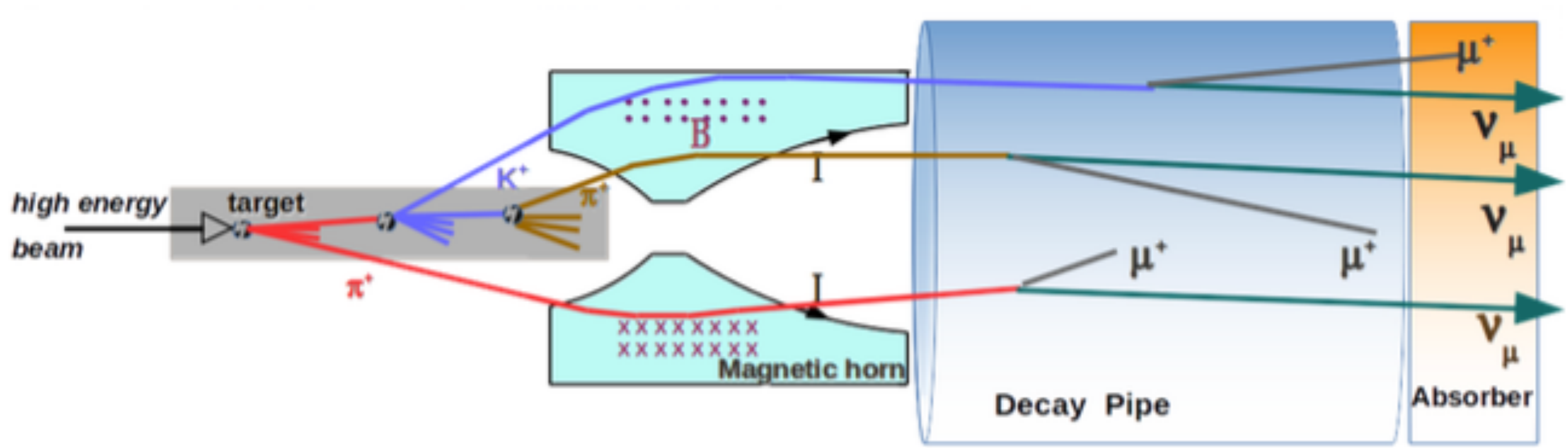


GENIE Simulation

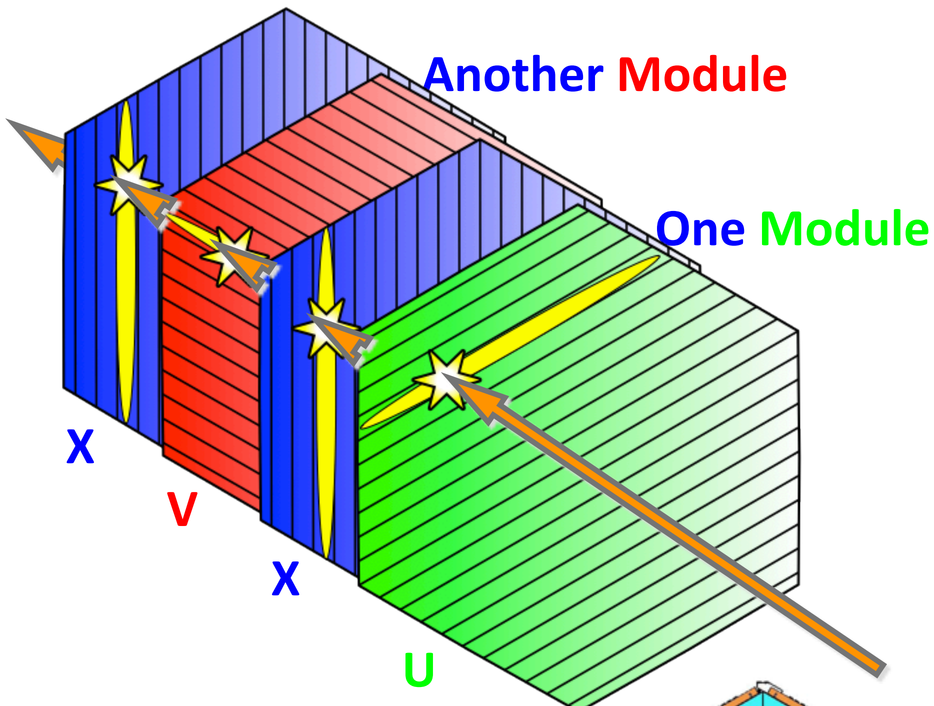
- **G**enerates **E**vents for **N**eutrino **I**nteraction **E**xperiments.
- http://genie.hepforge.org
- Propagates a flux of neutrinos (specified by function, histogram, or ntuple) through a geometry (Geant4-compatibility is an option) and simulates the initial interaction and propagation of hard vertex products through the nuclear medium. Geant4 takes over when particles leave the nucleus.
- ROOT provides many core utilities. GENIE also heavily leverages other HEP and FOS software - LHAPDF, GSL,Pythia, log4cpp, etc.
- Andreopoulos, C. and Bell, A. and Bhattacharya, D. and Cavanna, F. and Dobson, J. et al. "The GENIE Neutrino Monte Carlo Generator". Nucl.Instrum.Meth. A614. 87-104. 2010.

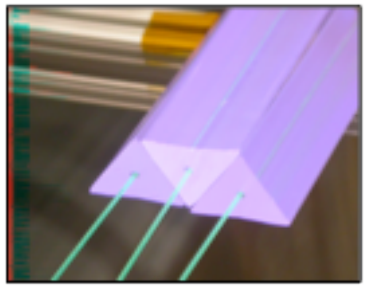
NuMI Beamline

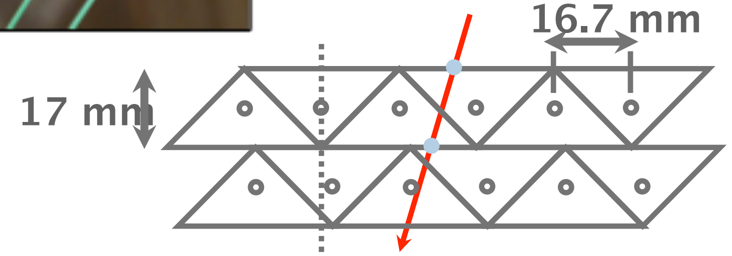


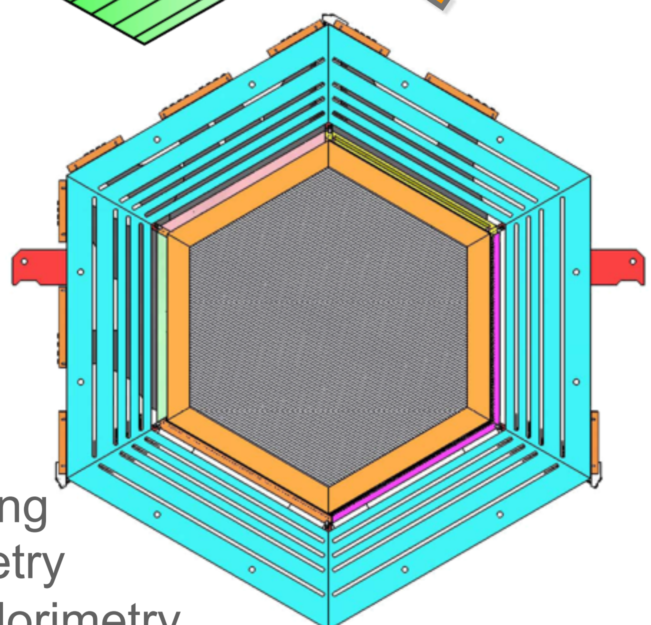


More Minerva Detector

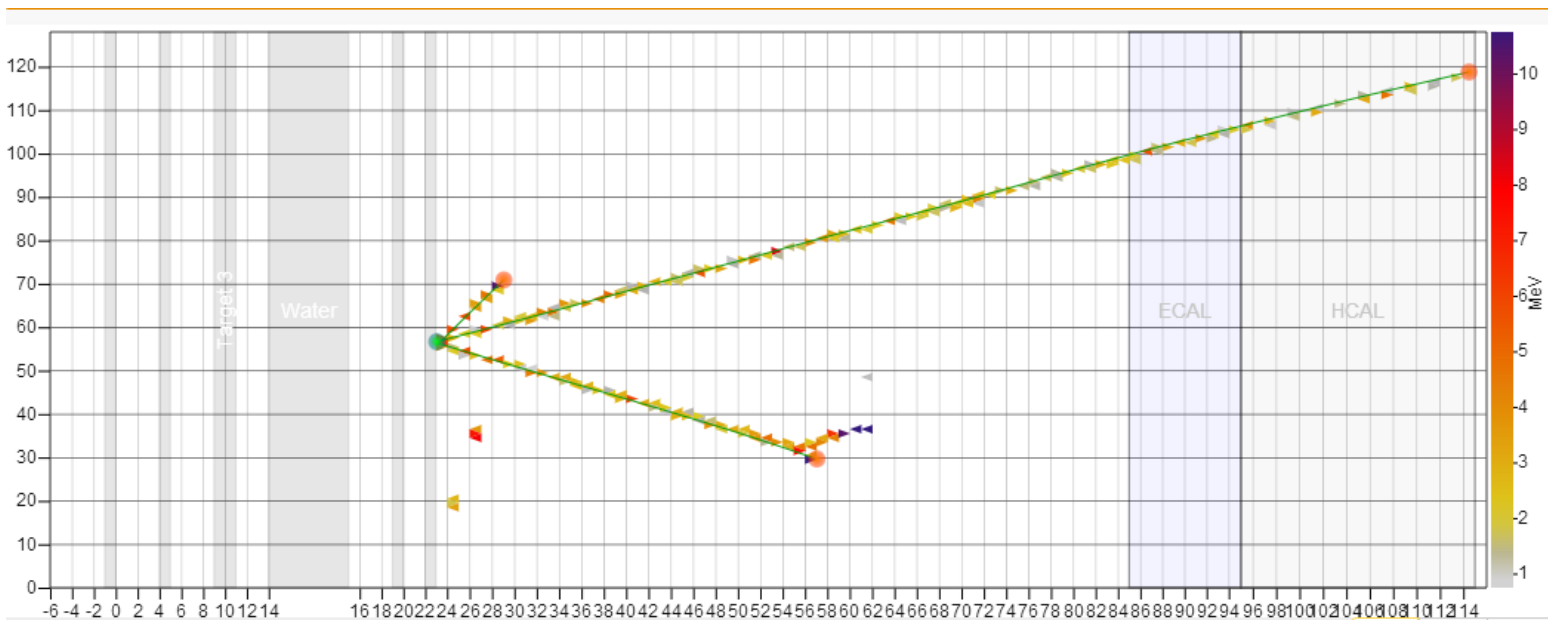




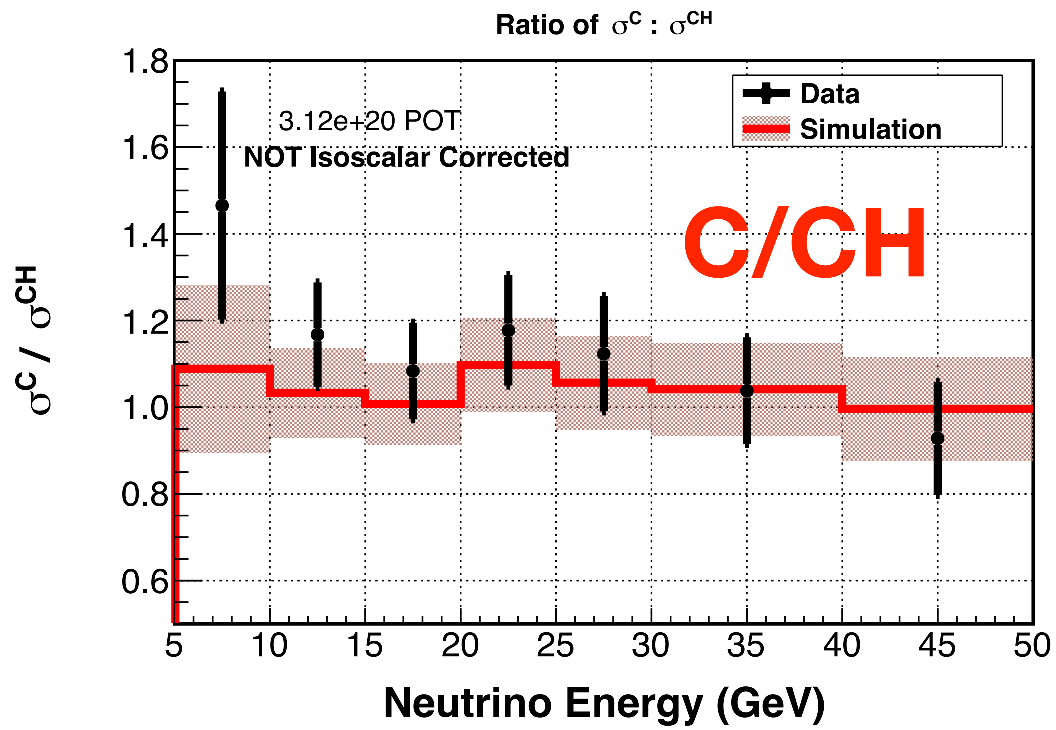


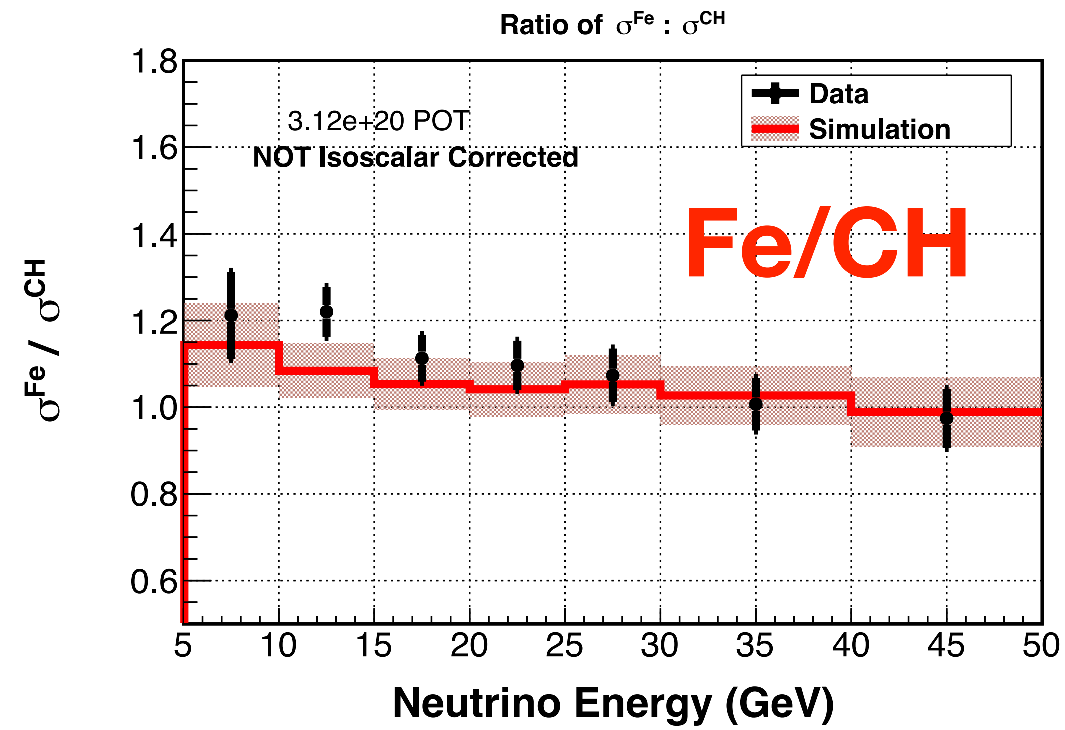


Scintillator - tracking
Lead - EM calorimetry
Steel - hadronic calorimetry

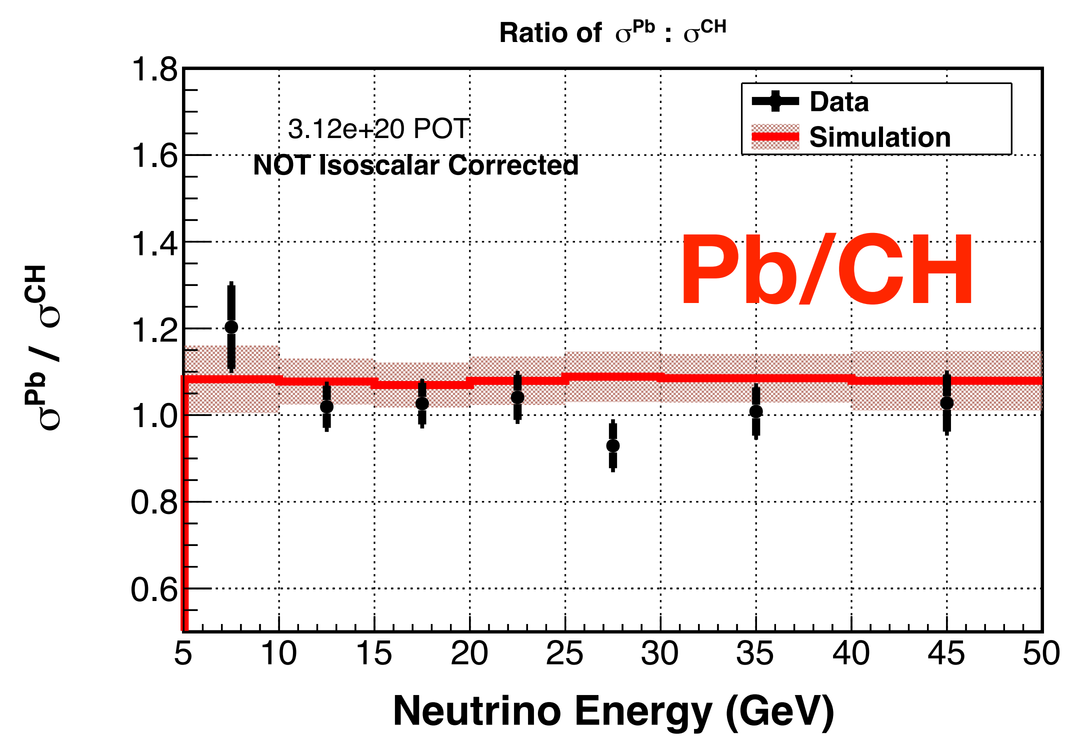


3.5 GeV Beam DIS: Cross Section Ratios

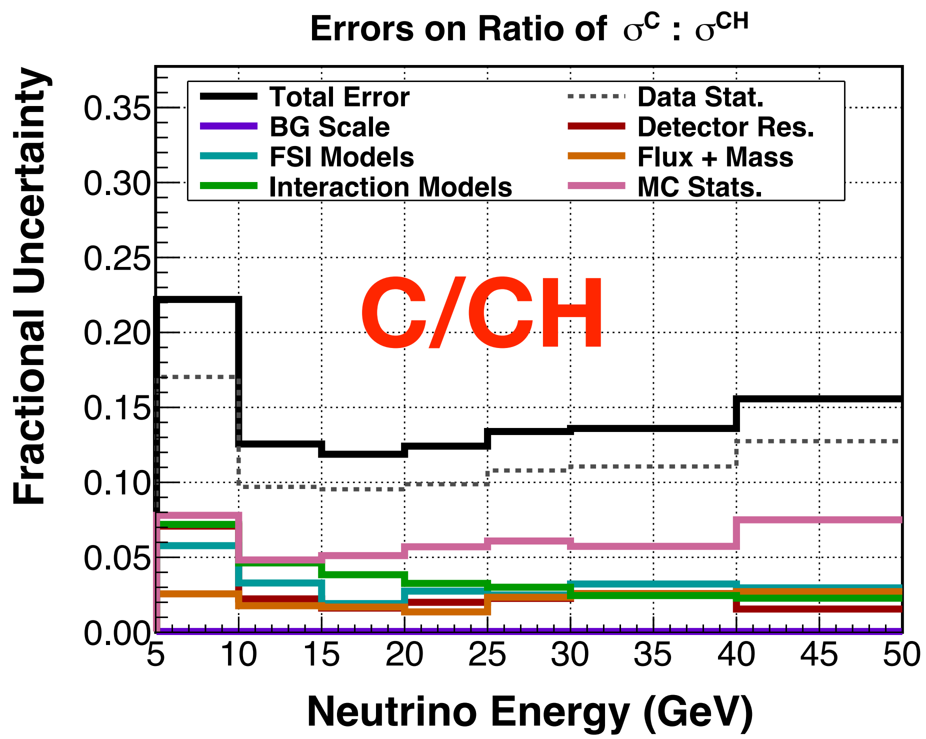


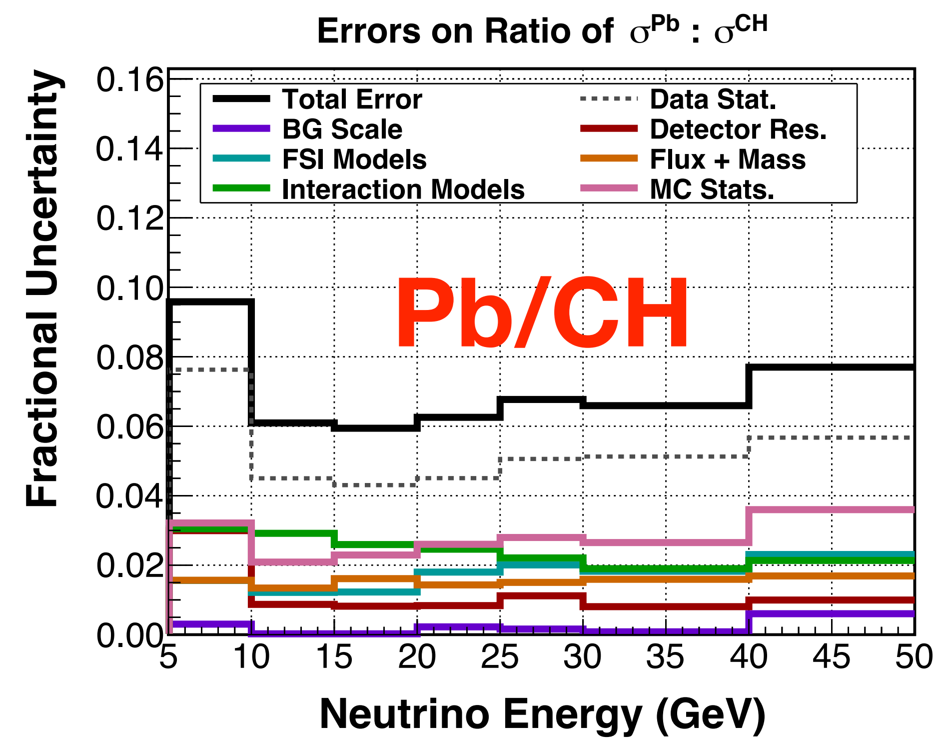


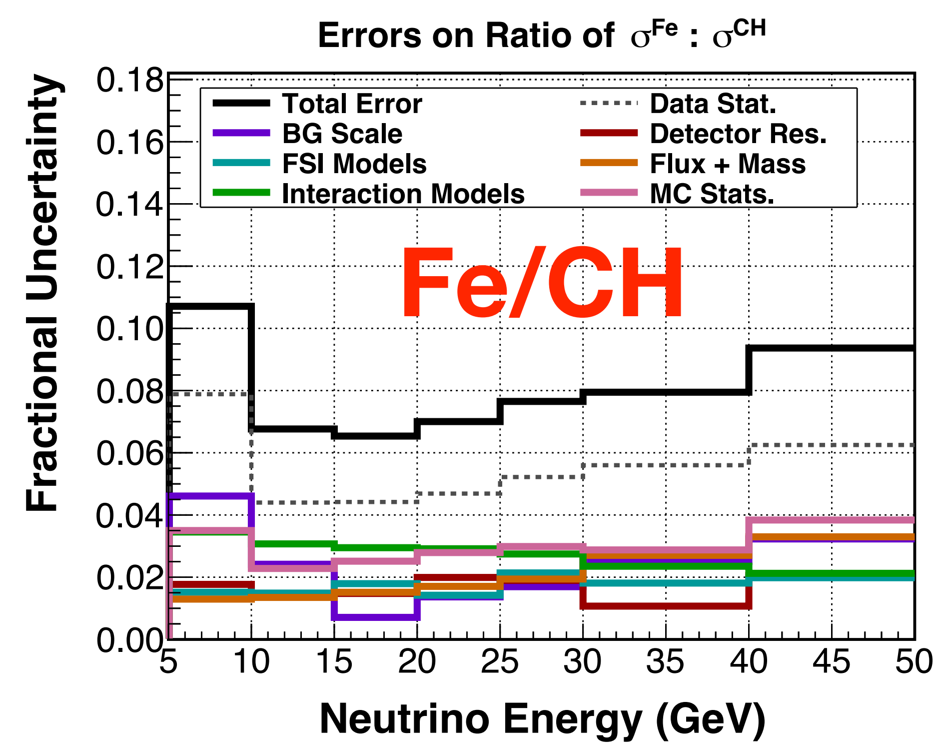
- Effects are largest in our heaviest nuclei, Lead, and is less visible in the lightest nuclei, Carbon.



3.5 GeV DIS Uncertainty vs Energy







- Ratio analyses have the advantage of largely canceling that uncertainty.
- Flux errors on a typical neutrino beam sit around 10%.
- This analysis is statistics limited, but as the statistical error decreases, Final State Interaction model uncertainties will become the dominant uncertainty.