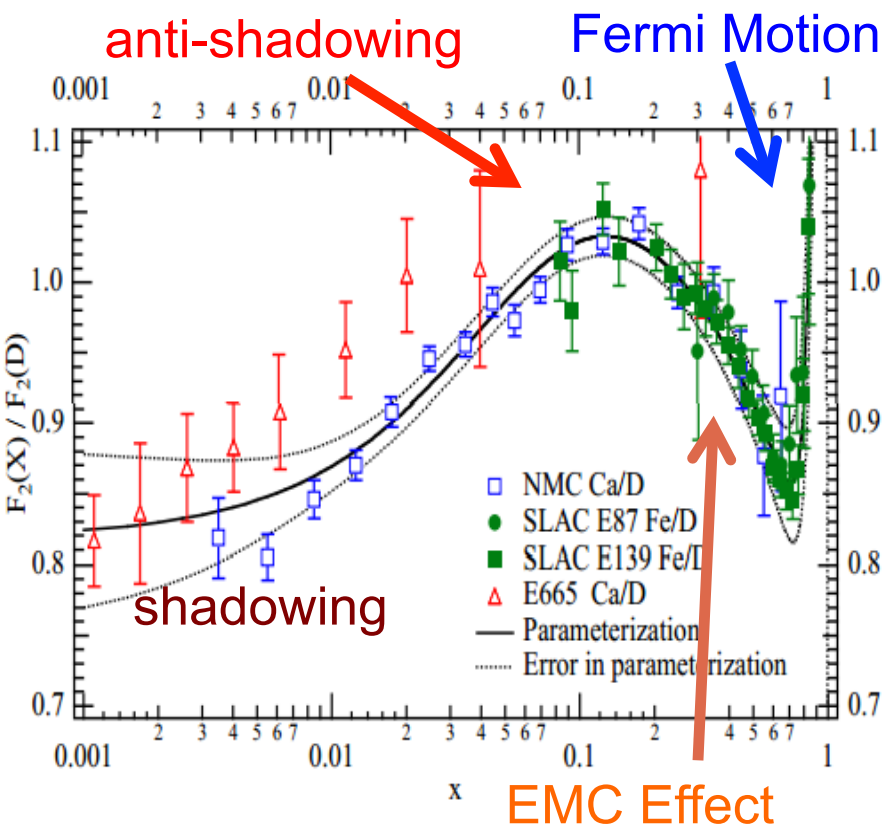
Neutrino-Nucleus Deep Inelastic Scattering (DIS) In MINERVA

DIPAK RIMAL
University of Florida
(On behalf of MINERvA Collaboration)

UF
UNIVERSITY of FLORIDA

Neutrinos in Nuclear Medium

- Neutrino detectors use large A materials (Pb, Fe, Ar, C, H_2O etc.) to enhance event rate.
- Nuclear effects due to bound nucleons in these nuclei smear energy reconstruction of incoming neutrinos.
- These effects are extensively studied in electron scattering experiments, not so much in neutrino physics.
- General strategy has been to adapt the effects from electron scattering directly into neutrino scattering theory.



Bjorken x = $Q^2/2ME_{had}$

A. Bodek, I. Park, and Y. K. Yang
Nucl. Phys. Proc. Suppl 139, 113 (2005)

Neutrino & Charged Lepton DIS

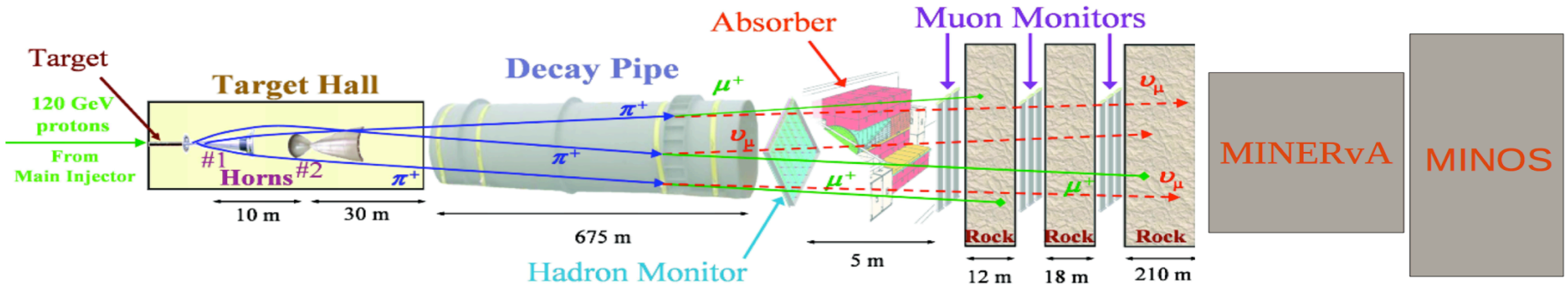
- Neutrino and charged lepton DIS are not identical: Neutrinos are sensitive to the axial component of form factors xF_3 and F_2.

$$\frac{d^2\sigma^{\nu A,\bar{\nu}A}}{dxdy} = \frac{G_F^2 M_W^4}{\left(Q^2+M_W^2\right)^2}\frac{ME_\nu}{\pi} \left[xy^2F_1^{\nu A,\bar{\nu}A} + \left(1-y-\frac{xyM}{2E_\nu}\right)F_2^{\nu A,\bar{\nu}A} \pm xy\left(1-\frac{y}{2}\right)F_3^{\nu A,\bar{\nu}A}\right].$$

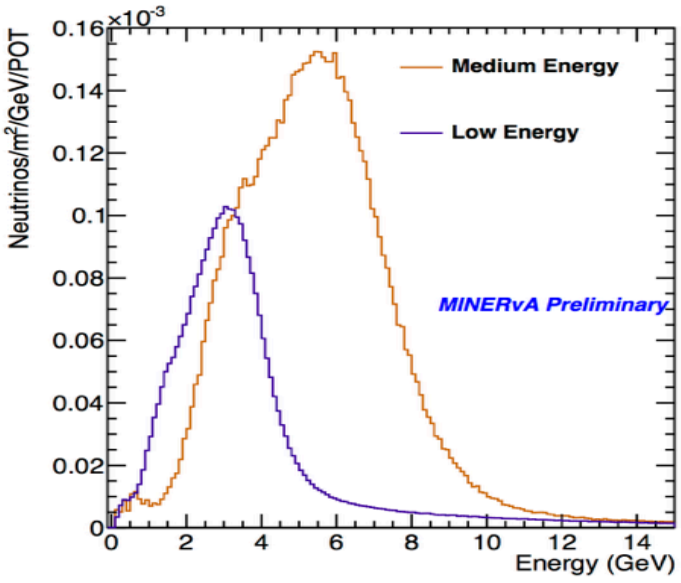
- Nuclear effects in charged lepton scattering like “EMC Effect” are not fully explained.

- MINERvA has the chance to see EMC like effect in Neutrino DIS.

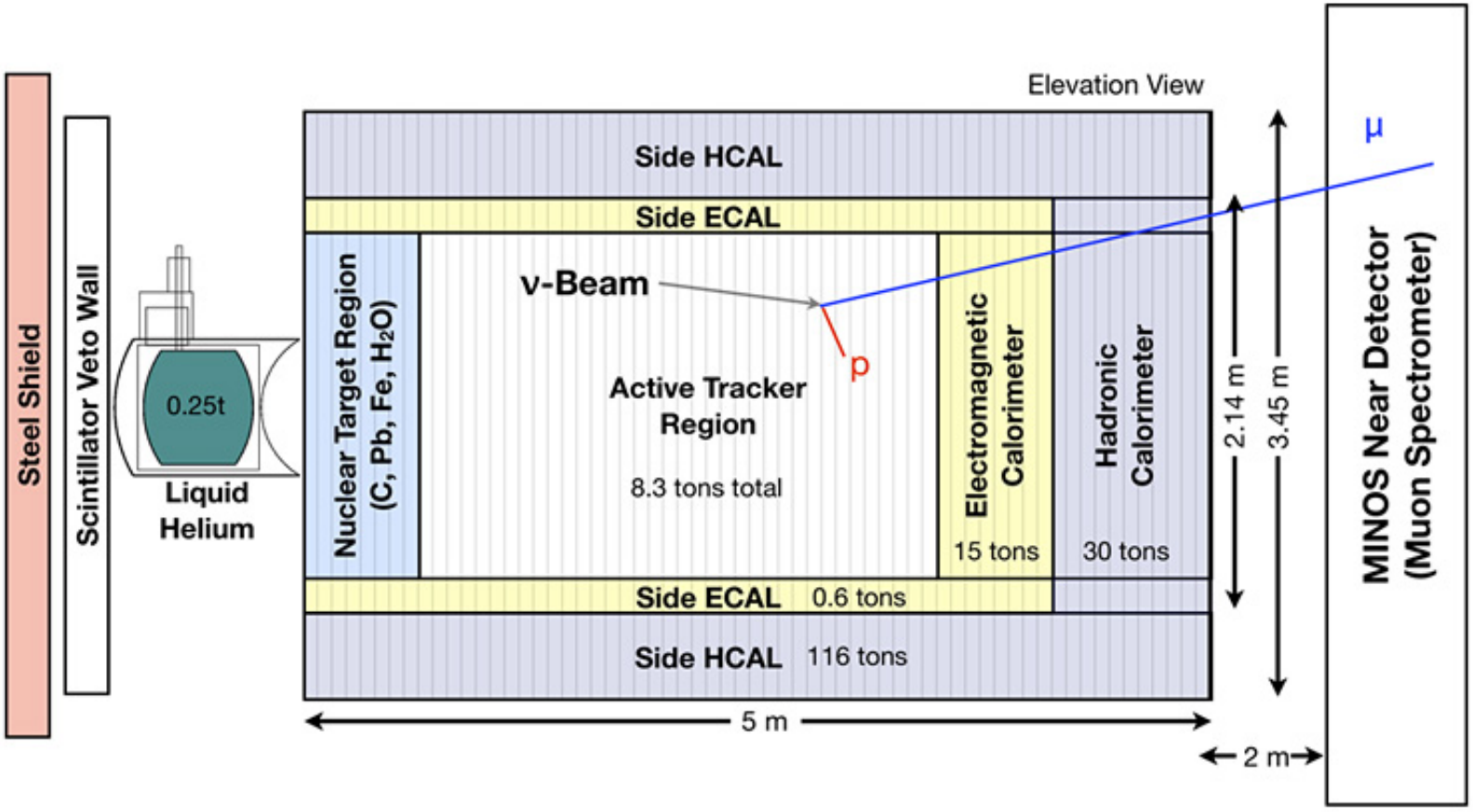
MINERvA@NuMI



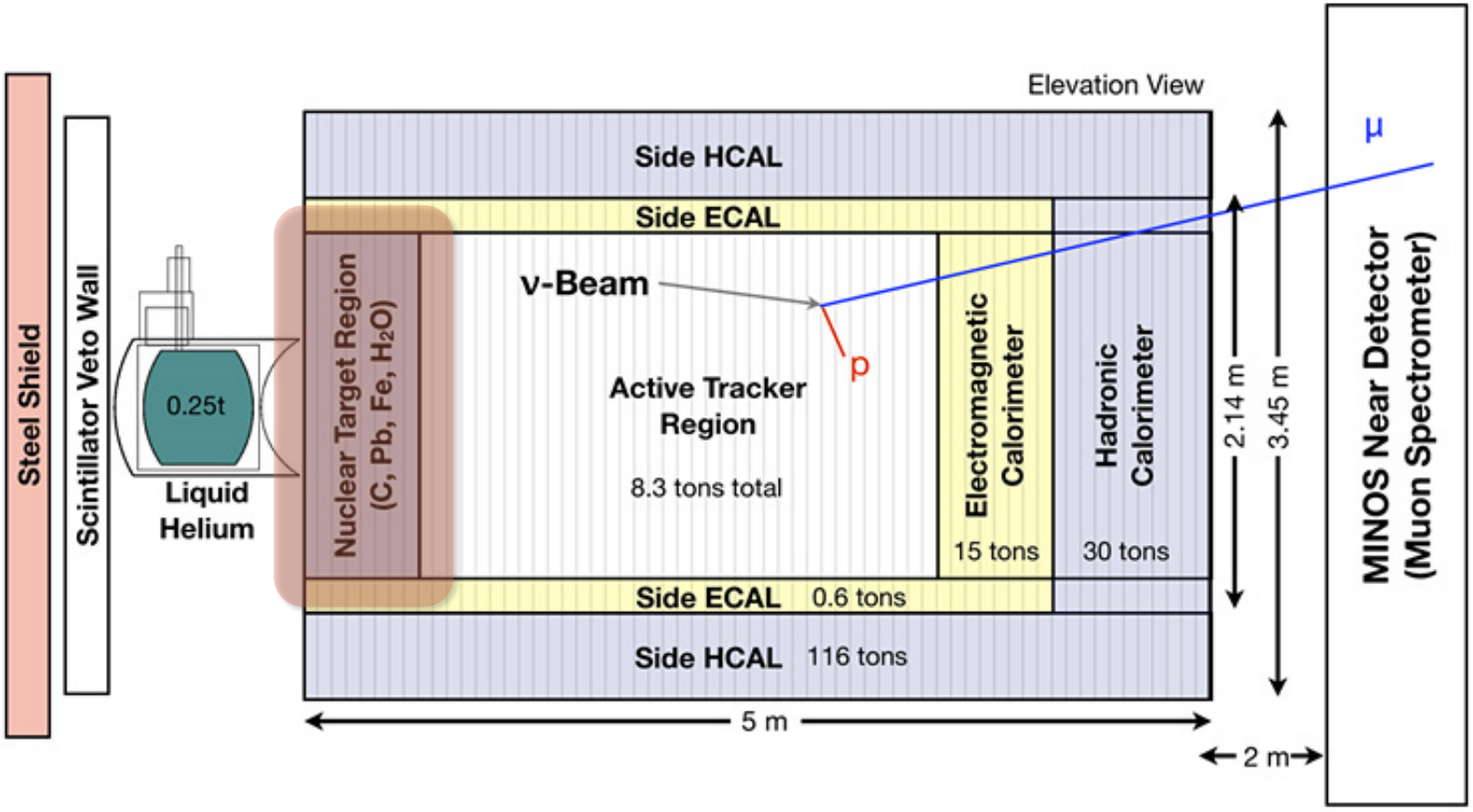
- 120 GeV protons impinged on graphite target produces mesons which decay in flight to produce neutrino beam.
- The NuMI beamline is tunable:
  - Low Energy (LE) <3.5 GeV>
  - Medium Energy (ME) <6 GeV> mode
- Today's results are from LE tune.



MINERvA


Elevation View
Steel Shield
Scintillator Veto Wall
0.25t
Liquid Helium
Side HCAL
Side ECAL
Nuclear Target Region (C, Pb, Fe, H2O)
ν-Beam
p
Active Tracker Region
8.3 tons total
Electromagnetic Calorimeter
15 tons
Hadronic Calorimeter
30 tons
Side ECAL 0.6 tons
Side HCAL 116 tons
μ
MINOS Near Detector (Muon Spectrometer)
2.14 m
3.45 m
5 m
2 m

MINERvA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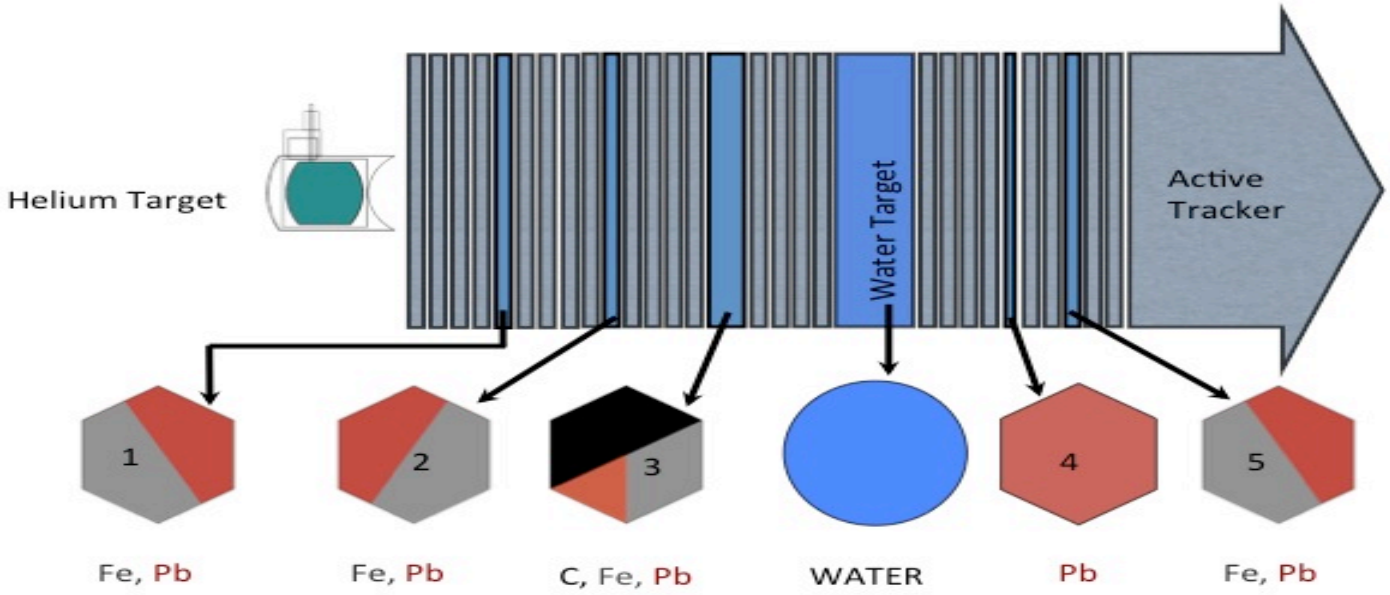
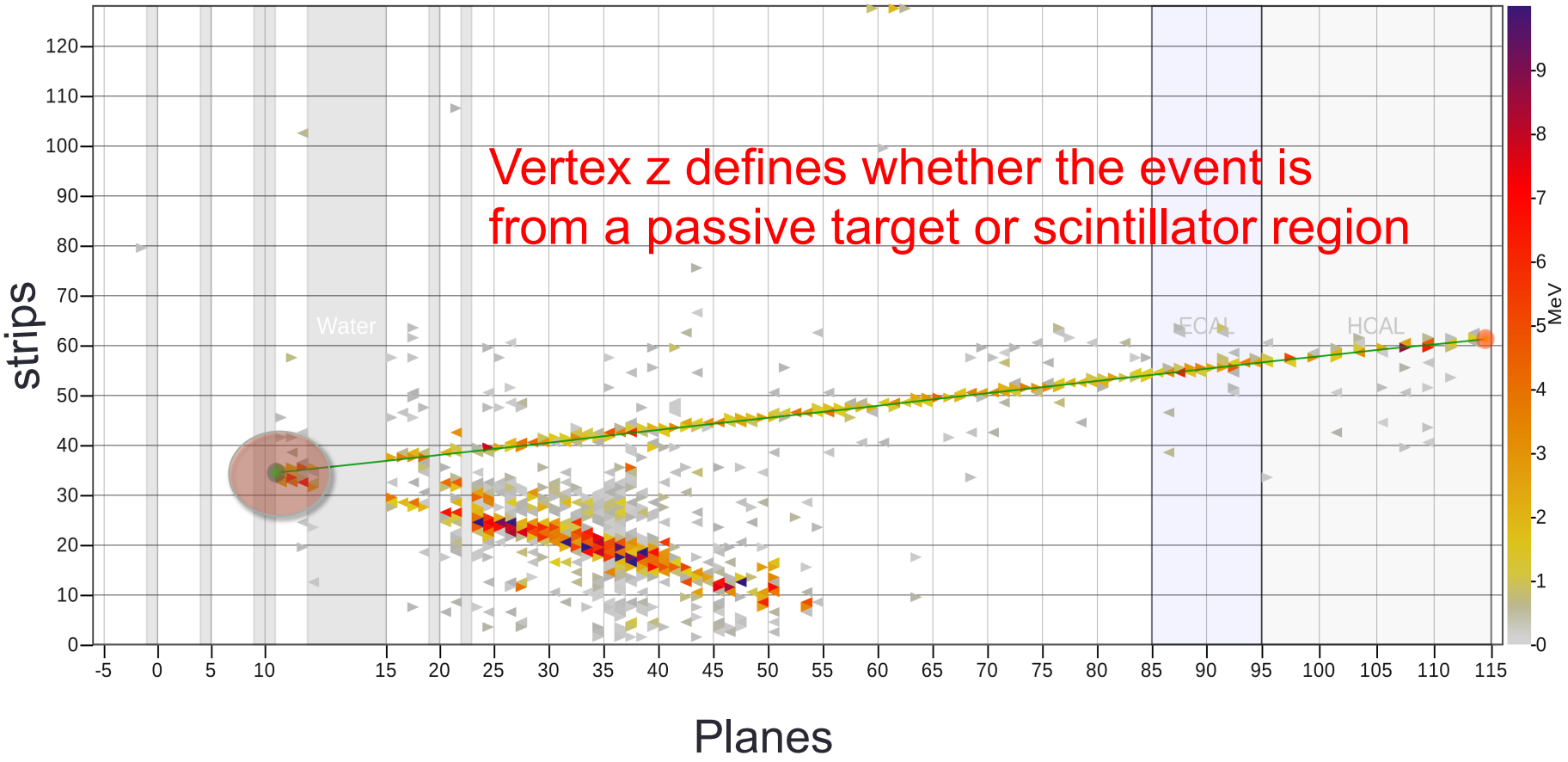
MINOS Near Detector (Muon Spectrometer)

MINERvA Nuclear Targets

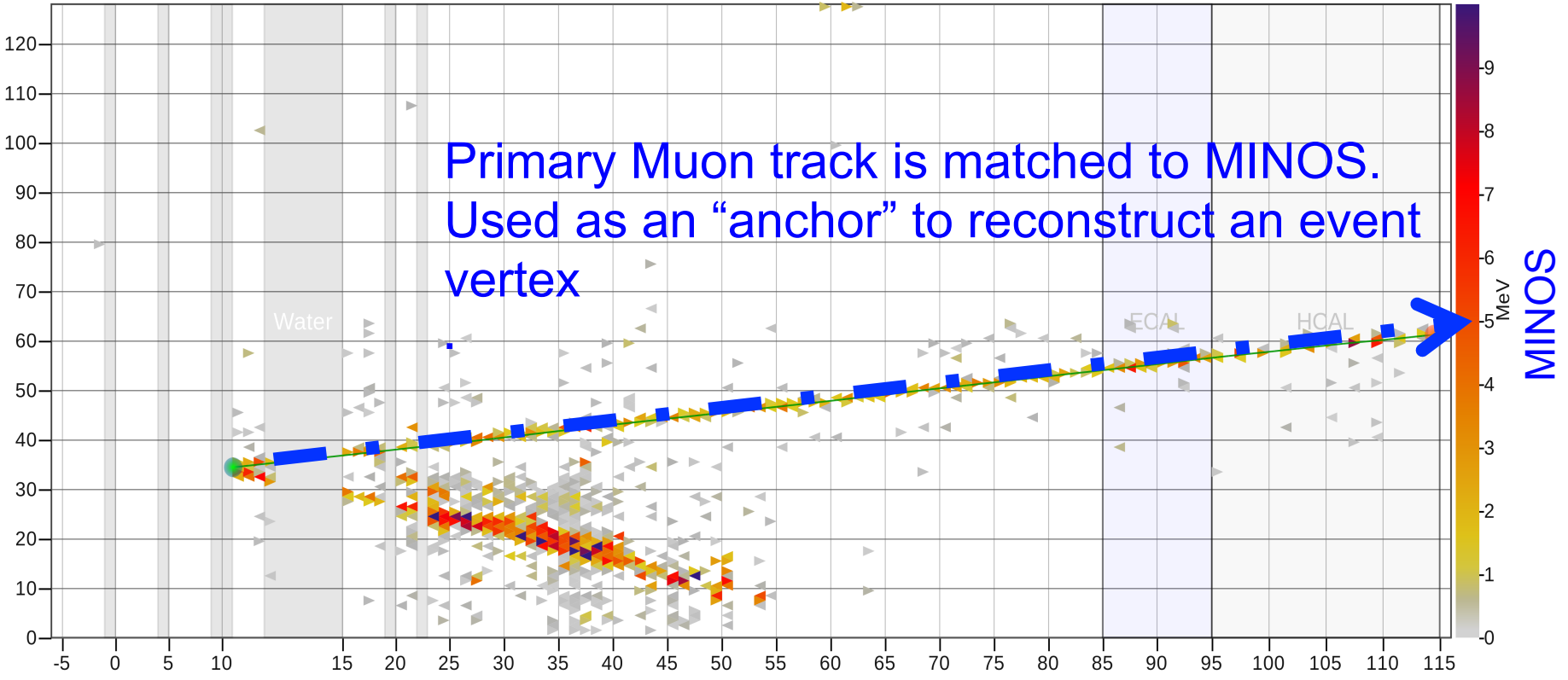


- MINERvA measures neutrino scattering on different nuclear targets simultaneously with the same neutrino beam.

Signal Selection and Event Reconstruction

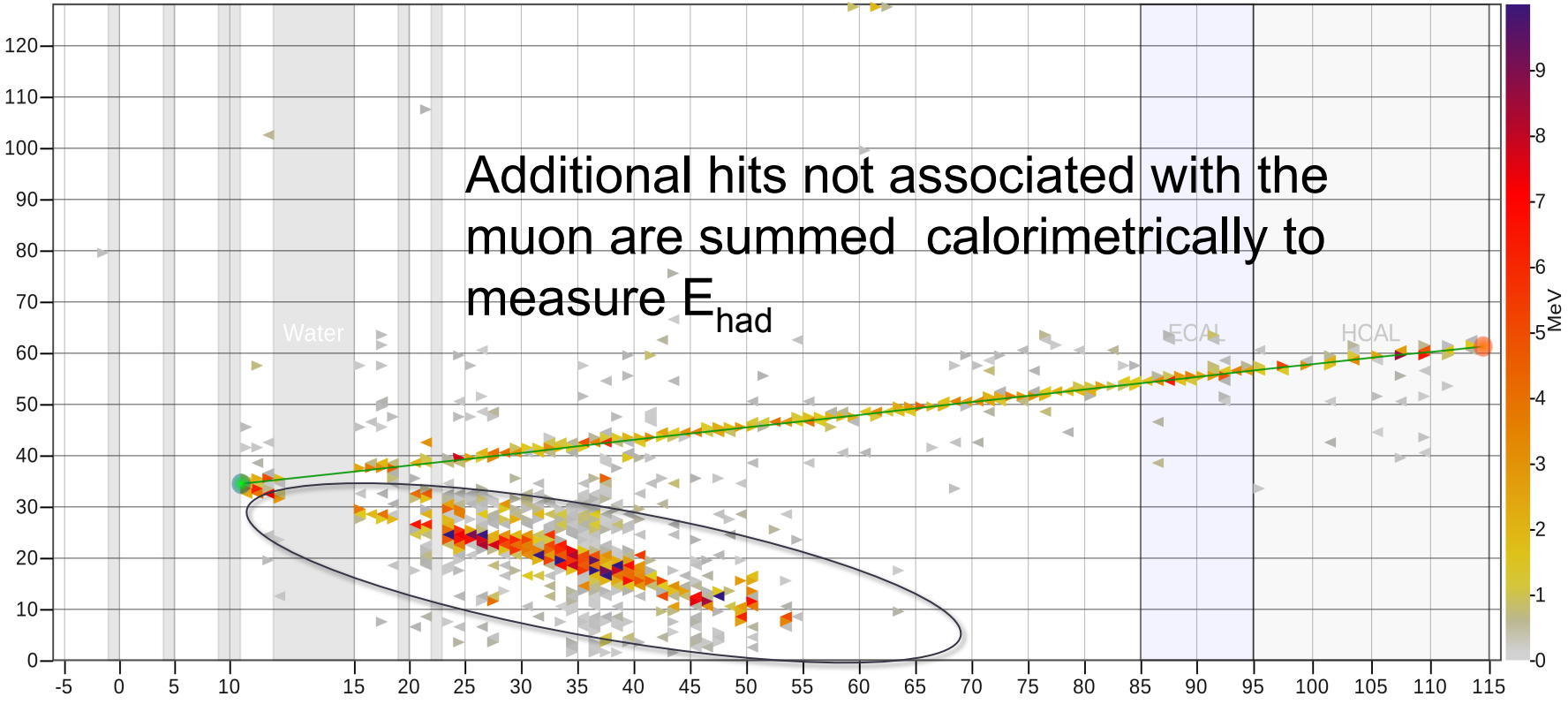


Signal Selection and Event Reconstruction



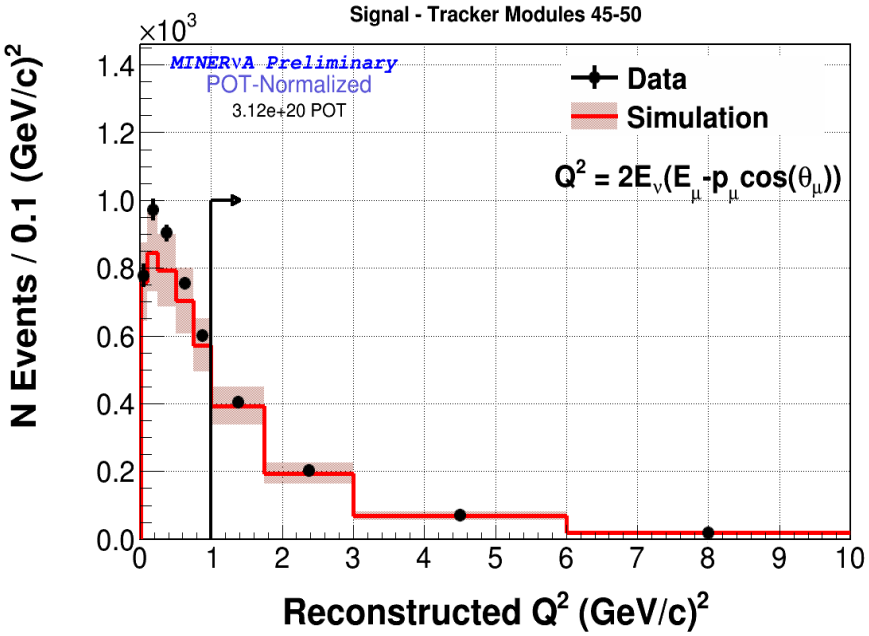
MINOS acceptance is poor for high angle muons, so we only accept events with $\theta_{\mu} < 17°$

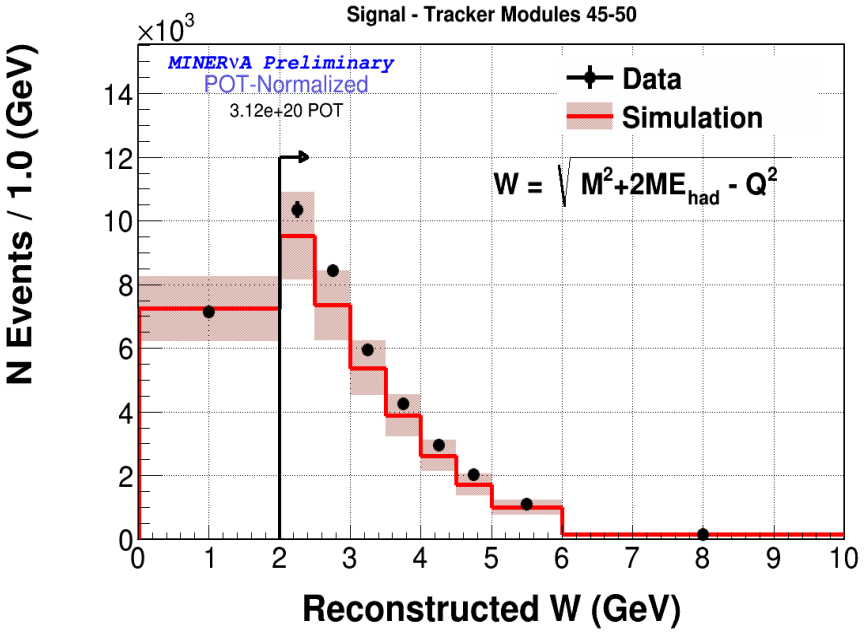
Signal Selection and Event Reconstruction



$$E_\nu = E_\mu + E_{\mathrm{had}}$$

Signal Selection



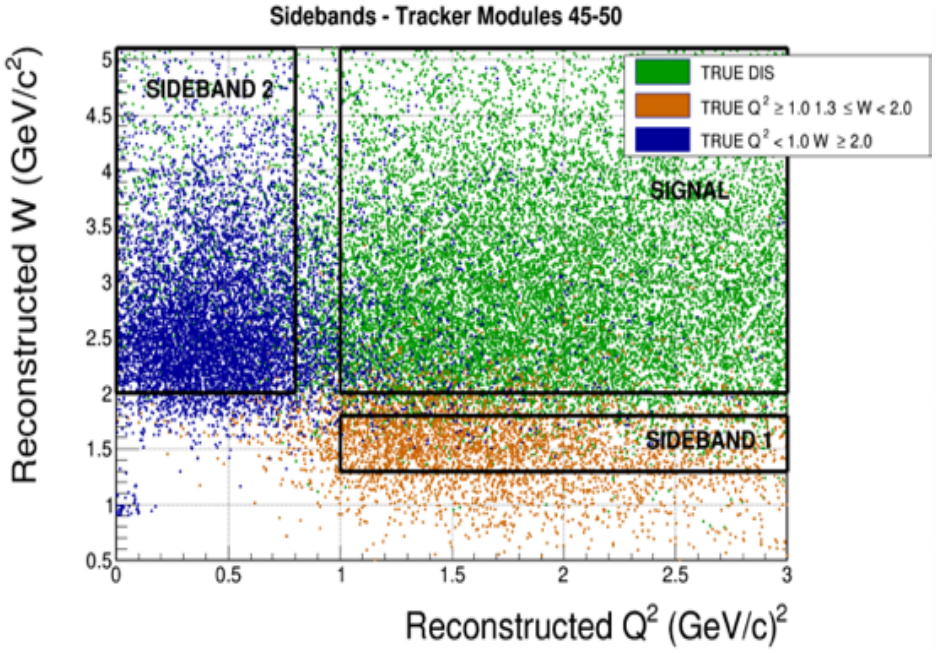


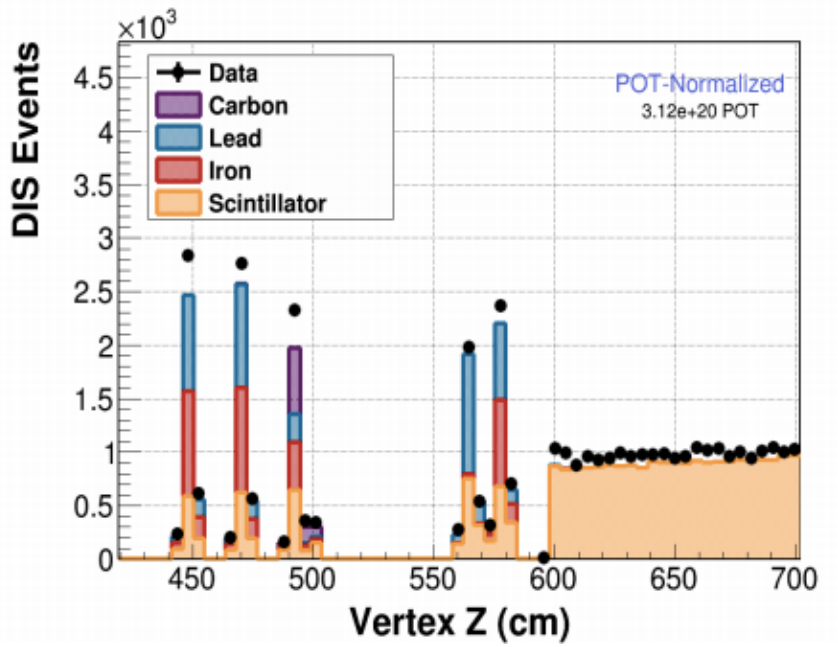
DIS Events:

Q^2: 4-momentum transferred by the neutrino $Q^2 > 1\ GeV^2$

W: Invariant mass of the hadronic system $W > 2$ GeV

Background Subtractions

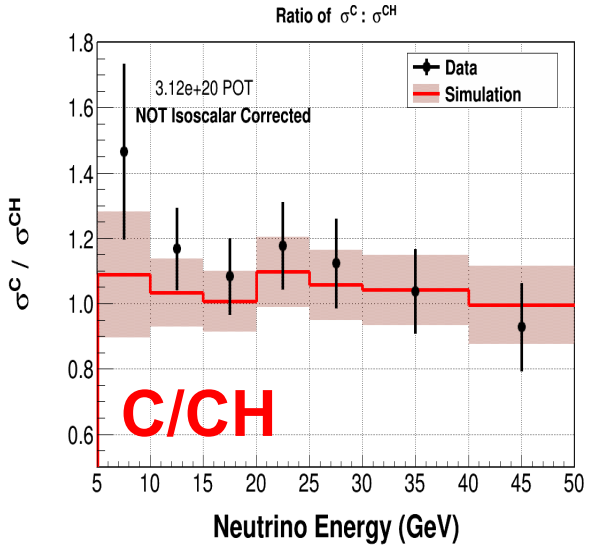


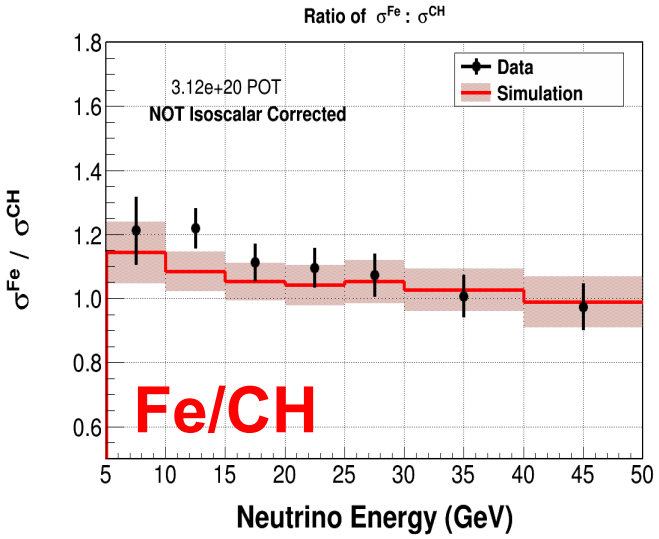


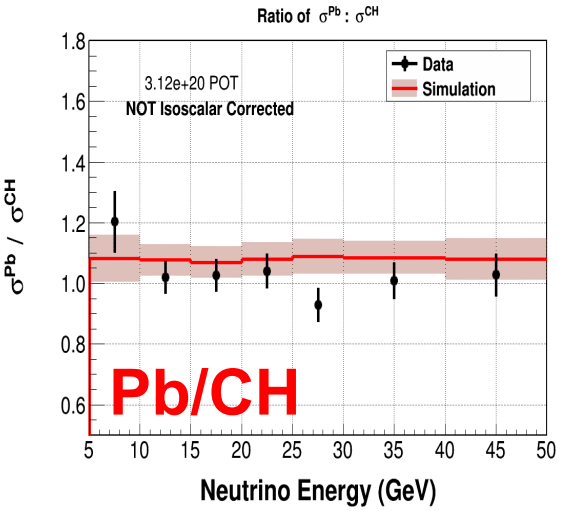
Two types of Background:

- Physics sideband
- Scintillator background

DIS Ratios: $\sigma(E_\nu)$



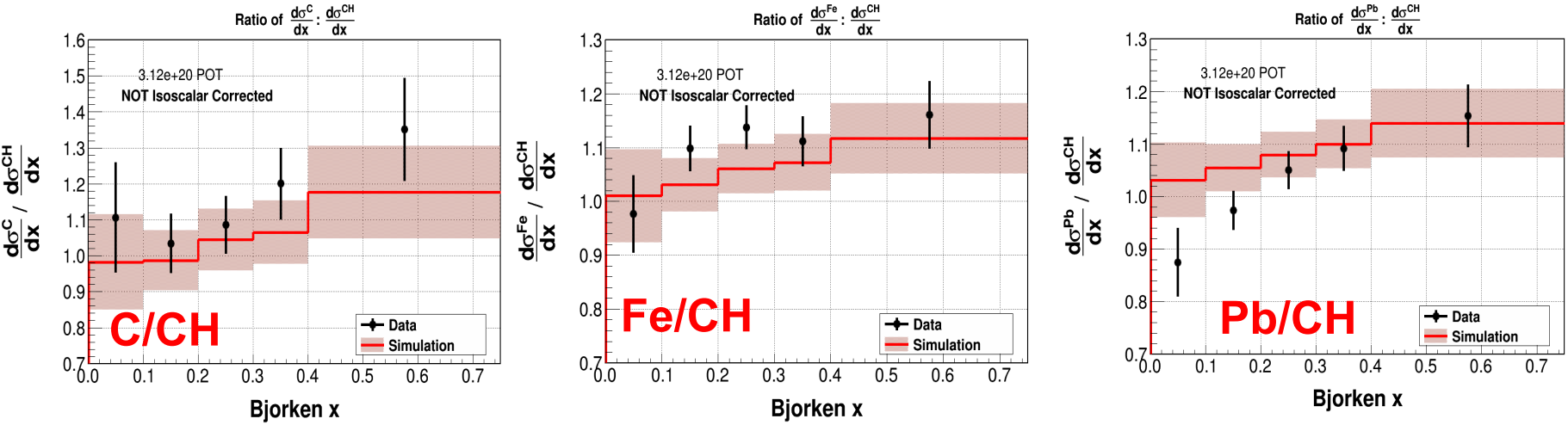




- Ratios of the cross section of heavy nuclei (Fe, Pb) to lighter CH can confirm the presence or absence of the nuclear effects.
- We observed no significant nuclear effects in neutrino energy distribution

J. Mousseau et al. Phys. Rev. D 93, 071101 (2016)

DIS Ratios: dσ /dx



- x dependent ratios directly translate to x dependent nuclear effects.
- Our simulation assumes the *same* x-dependent nuclear effects for C, Fe and Pb. We observe no significant deviations from this.
- The shape of the data in low x, especially with Pb, points to additional nuclear shadowing.

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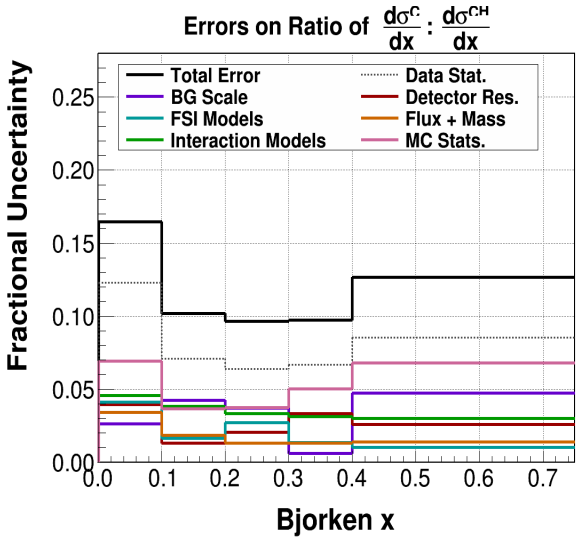
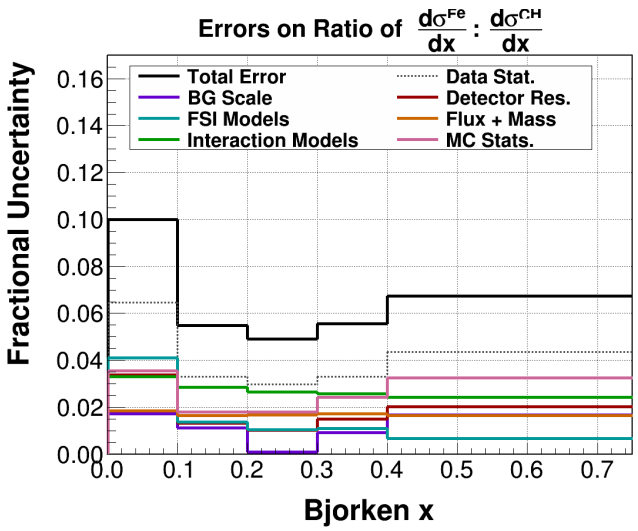
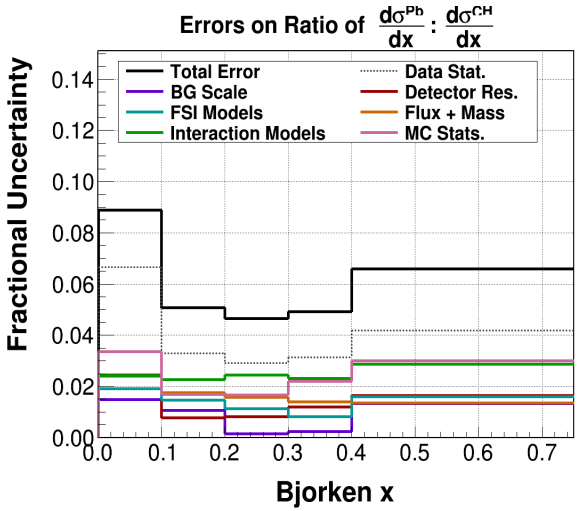
Systematic Uncertainties







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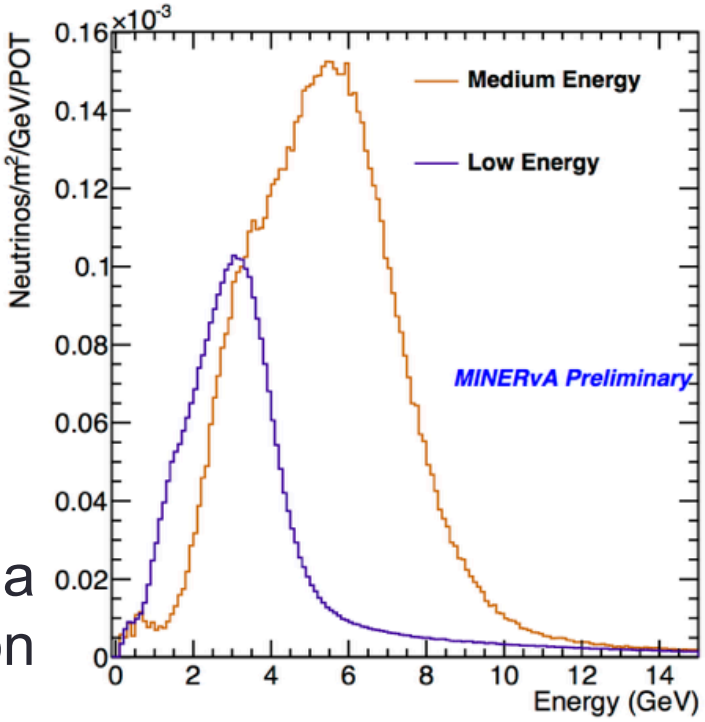
- Uncertainties are dominated by data statistics for the most part.
- Correlations in data introduced from unfolding are *NOT* accounted for in data statistical uncertainty

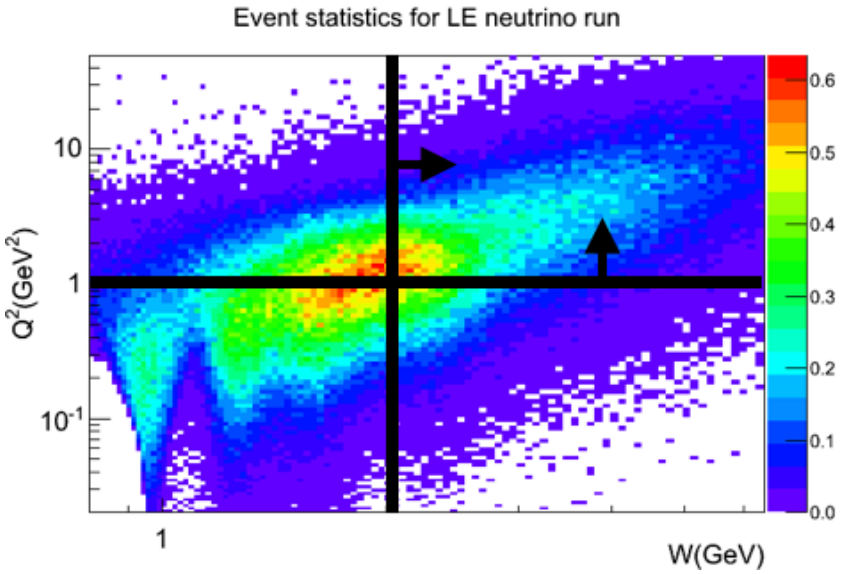
Looking Forward: NuMI @ 6 GeV

- In Fall 2013, the NuMI beamline was tuned to focus higher energy pions.
- This resulted in a neutrino beam with a 6 GeV peak energy.
- The flux increases by roughly a factor of three.
- We've already increased our statistics by a factor of three: collected 12E20 Protons on Target in neutrino mode.
- Currently running in antineutrino mode.

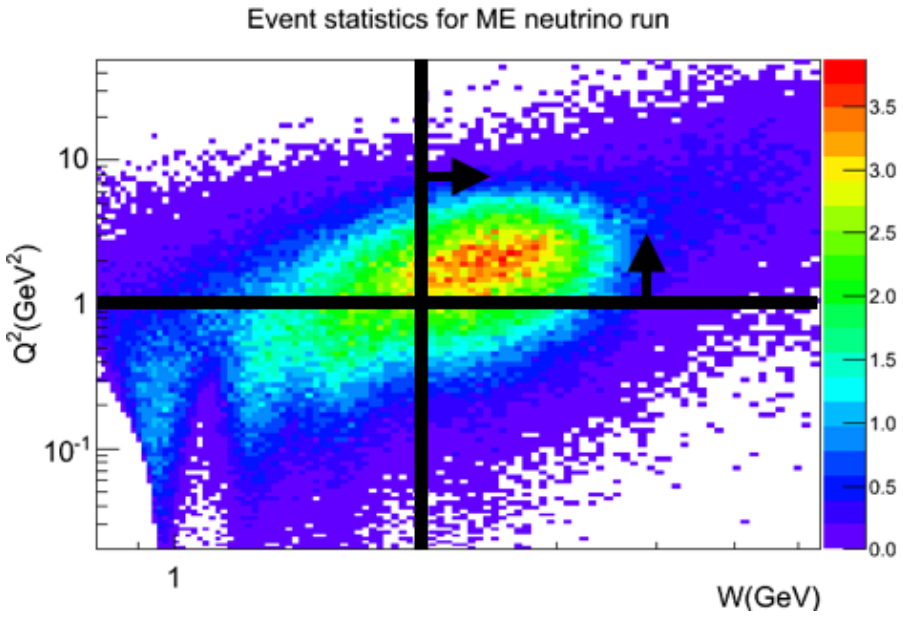


Improvements for 6 GeV Beam

<3.5 GeV> Run

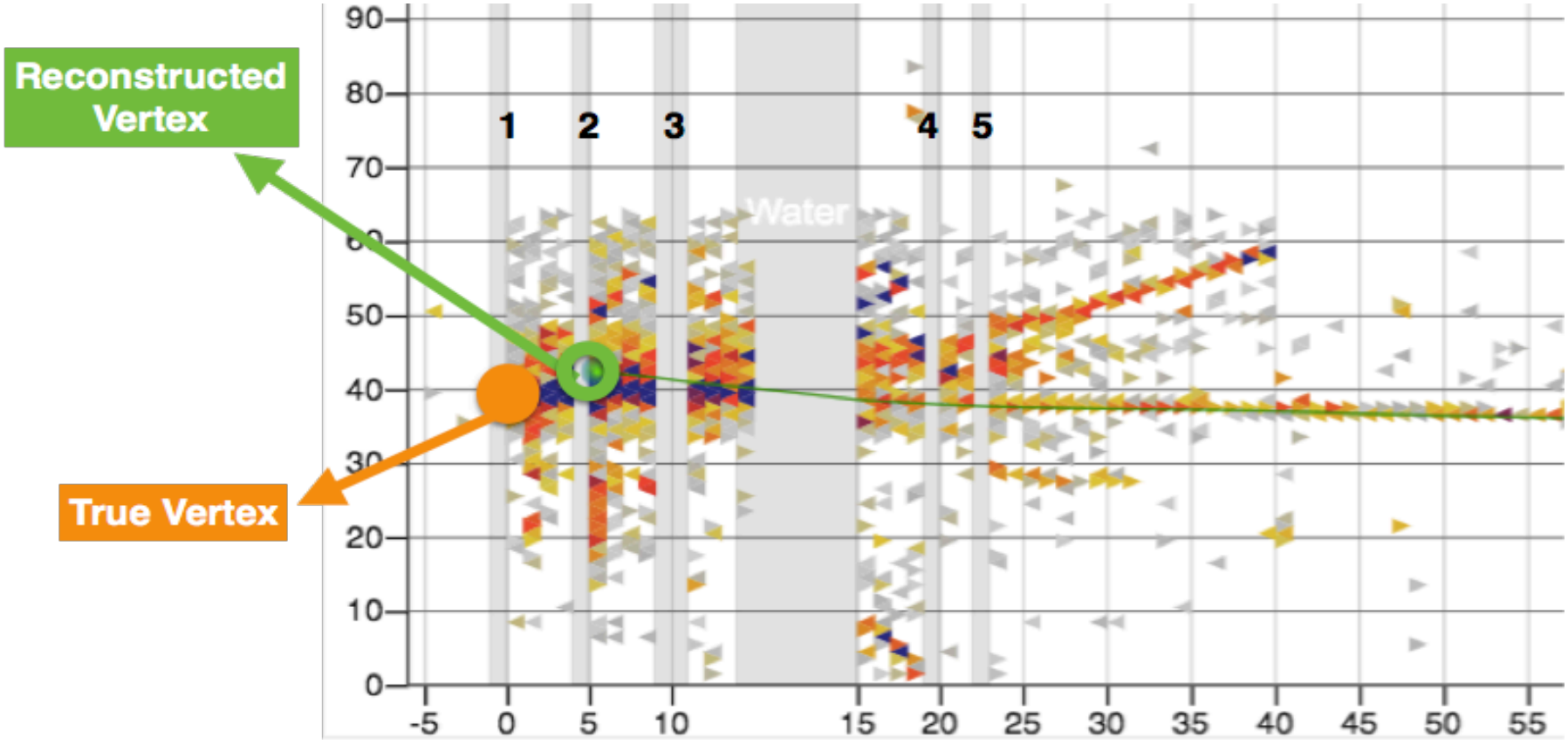


<6 GeV> Run



- 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.

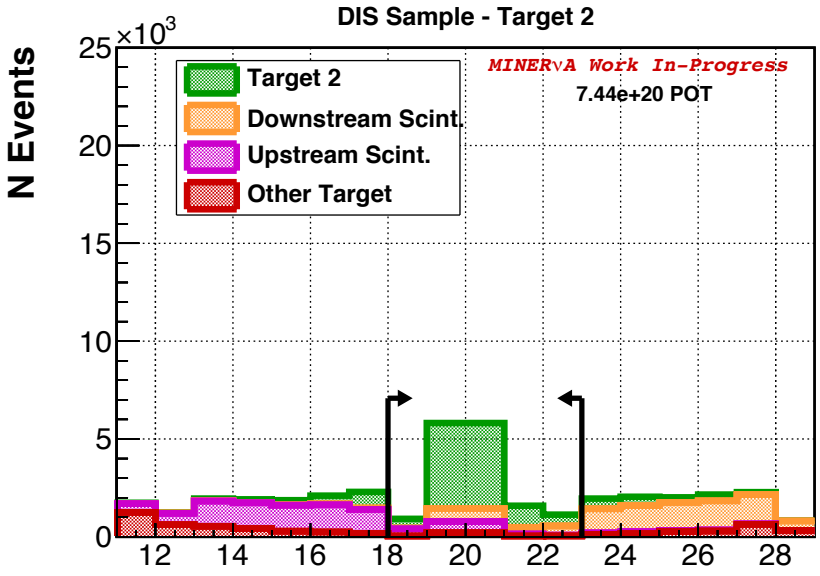
Improvements for 6 GeV Beam



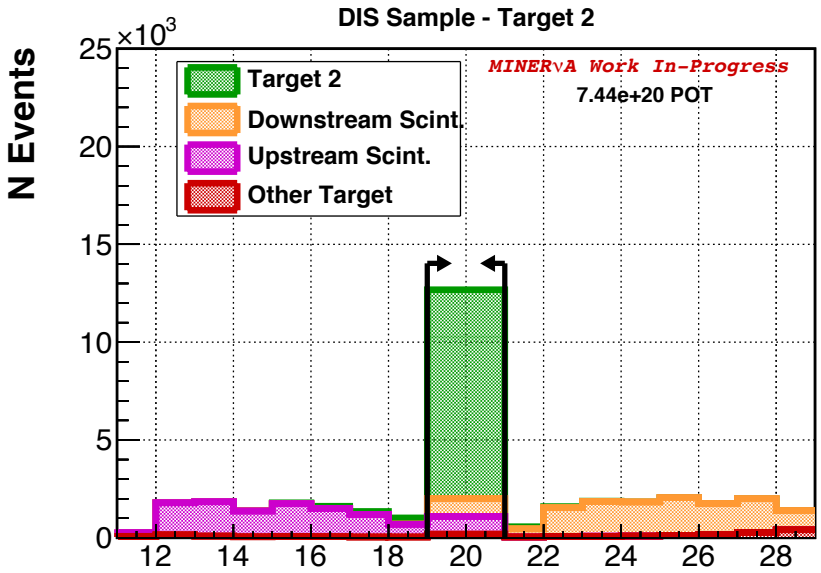
- Correctly vertexing a DIS event in the passive nuclear targets is difficult, as the hadronic showers are large and messy.

Improvements for 6 GeV Beam

- Apply machine learning algorithm (Deep Neural Network) based approach to identify the target planes.



Track Based Vertexing



Machine Learning Vertexing

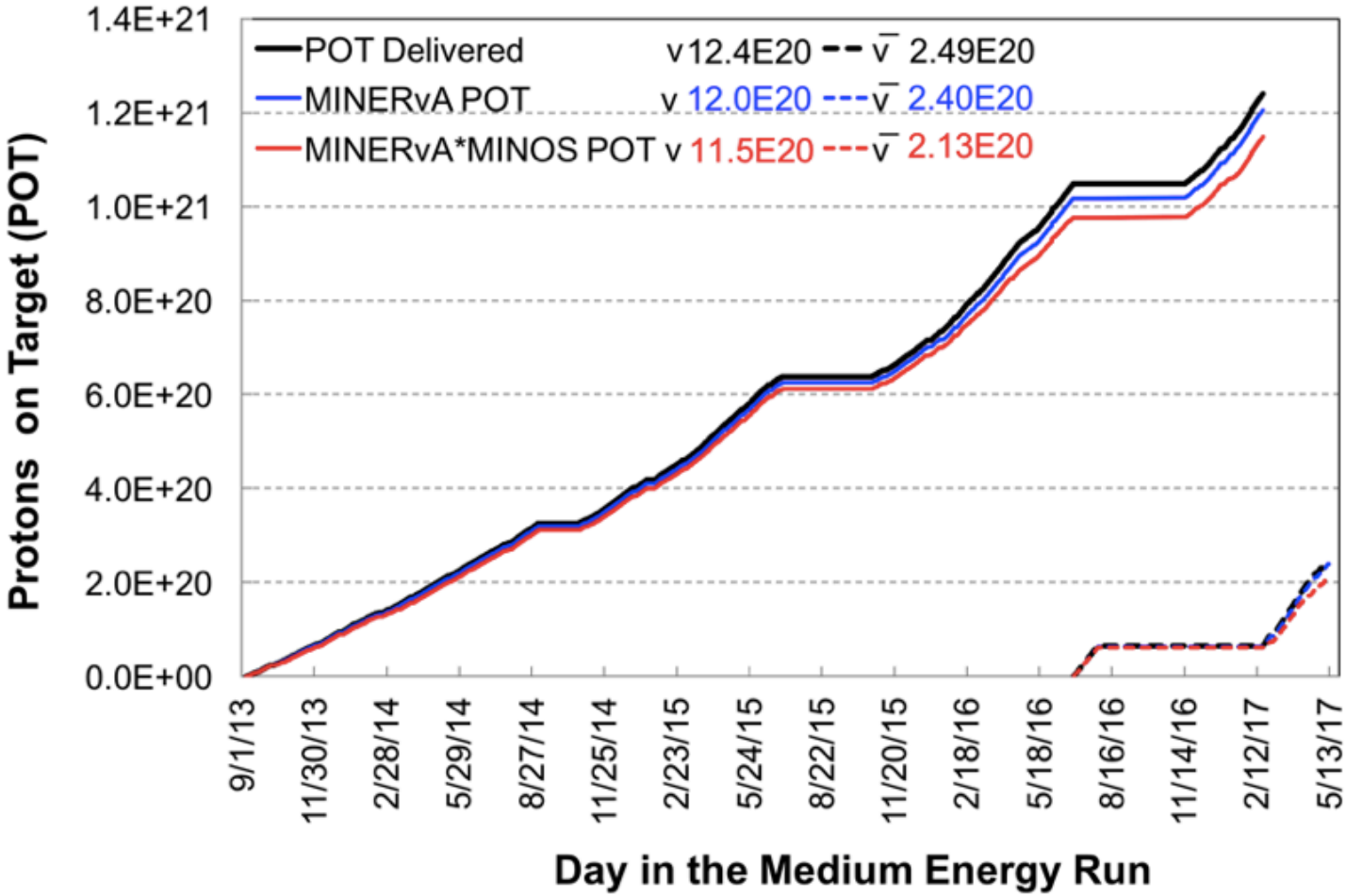
- By using image based Machine Learning, we can improve the vertex reconstruction. Talk by J. Miller on 2nd Aug on Computing, Analysis tools and Data Handling

Summary

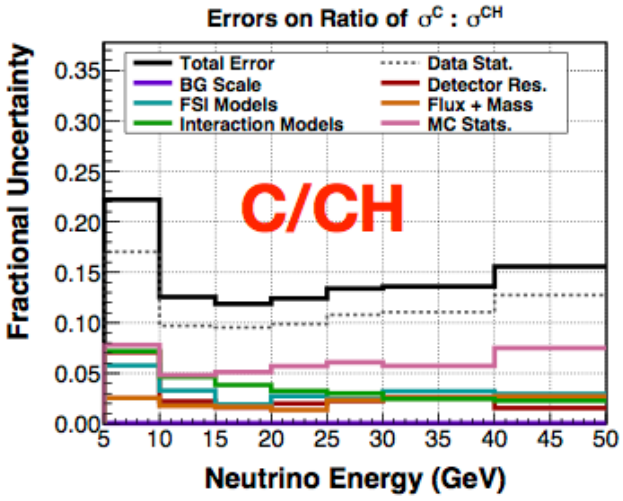
- MINERvA's LE data is indicative of additional nuclear shadowing: limited by statistics!
- MINERvA has finished data taking in neutrino mode in ME, with 12E20 POT on disk → Statistics rich DIS sample.
- We've started taking antineutrino data, with 3.5E20 on disk already. MINERvA is approved for 6E20 POT in antineutrino mode.
- Improvements in our reconstruction will result in improved purity and efficiency and reduced systematic uncertainties in our 6 GeV analysis.
- Stay tuned for exciting results!

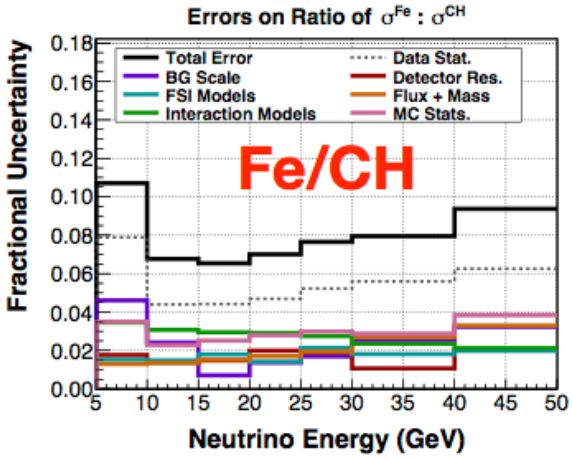
Thank You

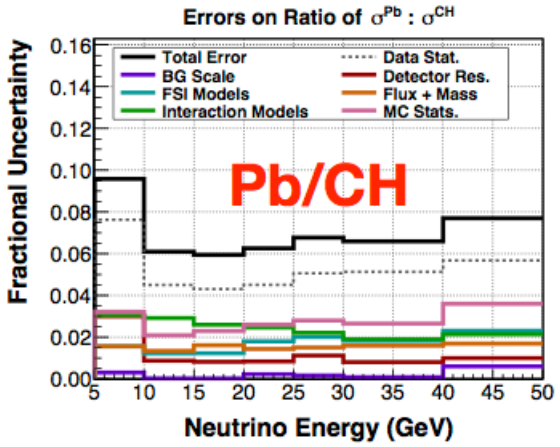
Back up


POT Delivered
MINERvA POT
MINERvA*MINOS POT
ν 12.4E20
ν̄ 2.49E20
ν 12.0E20
ν̄ 2.40E20
ν 11.5E20
ν̄ 2.13E20
Protons on Target (POT)
1.4E+21
1.2E+21
1.0E+21
8.0E+20
6.0E+20
4.0E+20
2.0E+20
0.0E+00
9/1/13
11/30/13
2/28/14
5/29/14
8/27/14
11/25/14
2/23/15
5/24/15
8/22/15
11/20/15
2/18/16
5/18/16
8/16/16
11/14/16
2/12/17
5/13/17
Day in the Medium Energy Run

DIS Uncertainty (3.5 GeV)







Isoscalar Corrected Ratios