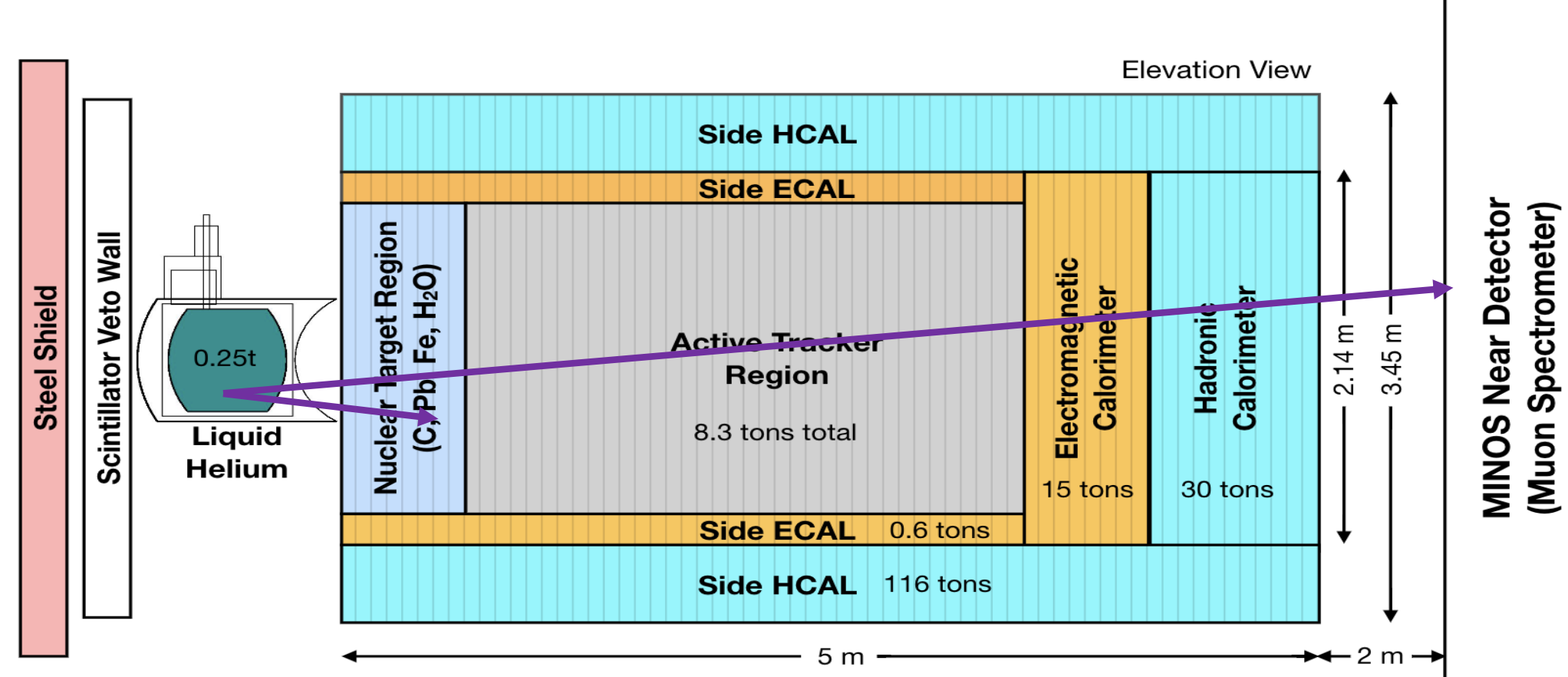# Multi-Differential Semi-Inclusive Charged-Current Muon Neutrino Cross Sections on Helium-4 in MINERvA and the Helium-to-CH Target Cross Section Ratio

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on Behalf of the MINERvA Collaboration

MINERvA's Helium Target


Elevation View

- **MINERvA** was **a dedicated neutrino cross-section** measurement **experiment** using multiple targets (**He**, Fe, C, CH, and Pb) **to explore A-dependence**.
- On-axis with the NuMI beamline at Fermilab.
- Helium target obtained **4.69 X10^{20} POT** from the NuMI ME beam with $\langle E_\nu \rangle \approx 6$ **GeV**.

Signal Definition

- $\nu_\mu + {}^4He \rightarrow \mu^- + Np + M\pi$
  - $M + N > 1$
- $2\ GeV < E_\mu < 50\ GeV$
- $\theta_\mu < 12\ Deg$
- $\theta_{Np+M\pi} < 55\ Deg$
- $E_p > 105\ MeV$
- $E_\pi > 55\ MeV$

- We define the helium signal as a charged-current (CC) ${}^4He$ - ν_μ event with a final-state muon and at least one additional track.
- The muon phase space is defined by acceptance and reconstruction efficiency in MINOS.
- At least one charged final state (FS) hadronic particle is reconstructed.

Data-Driven Background Constraint
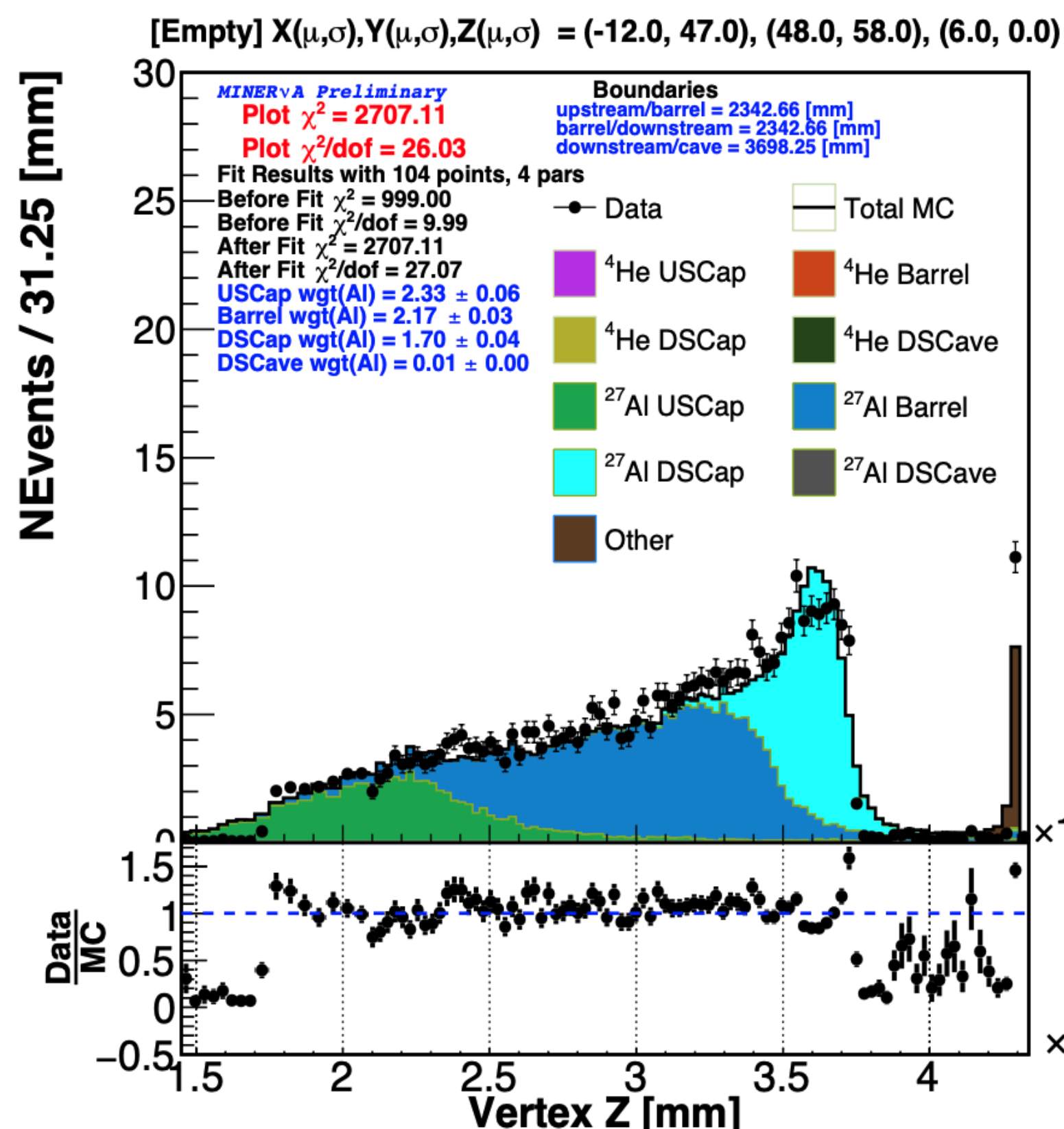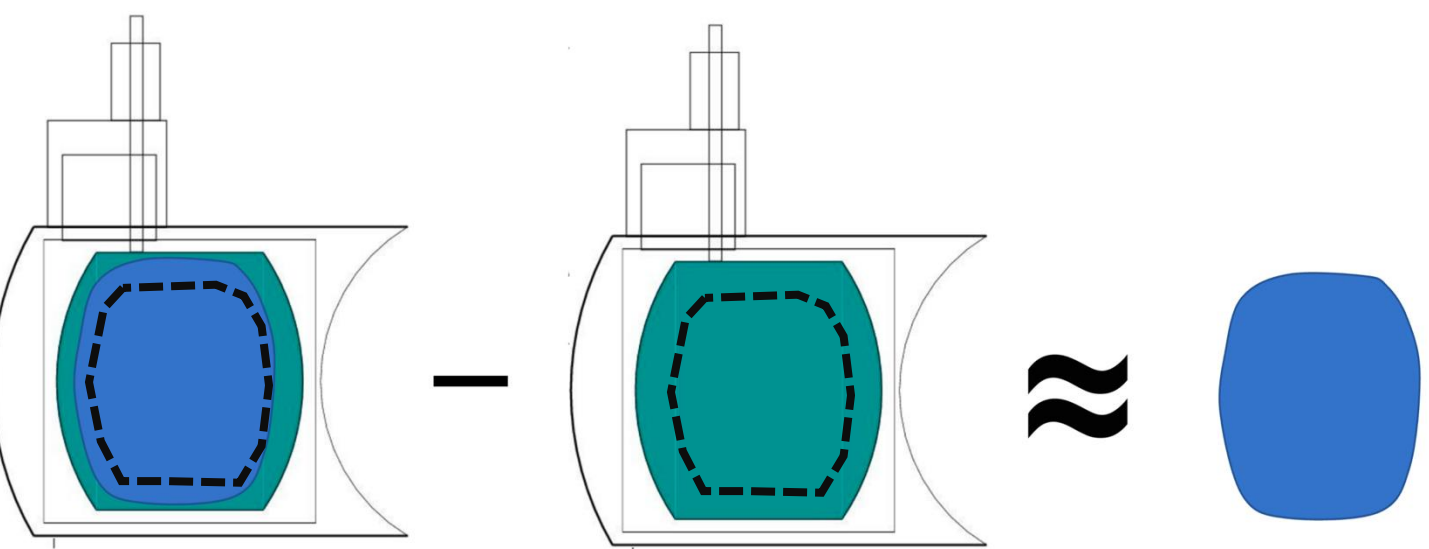
- Subtracted Empty target data from Full target data to remove backgrounds.
- Used vertex positions as Sidebands for BG estimation.
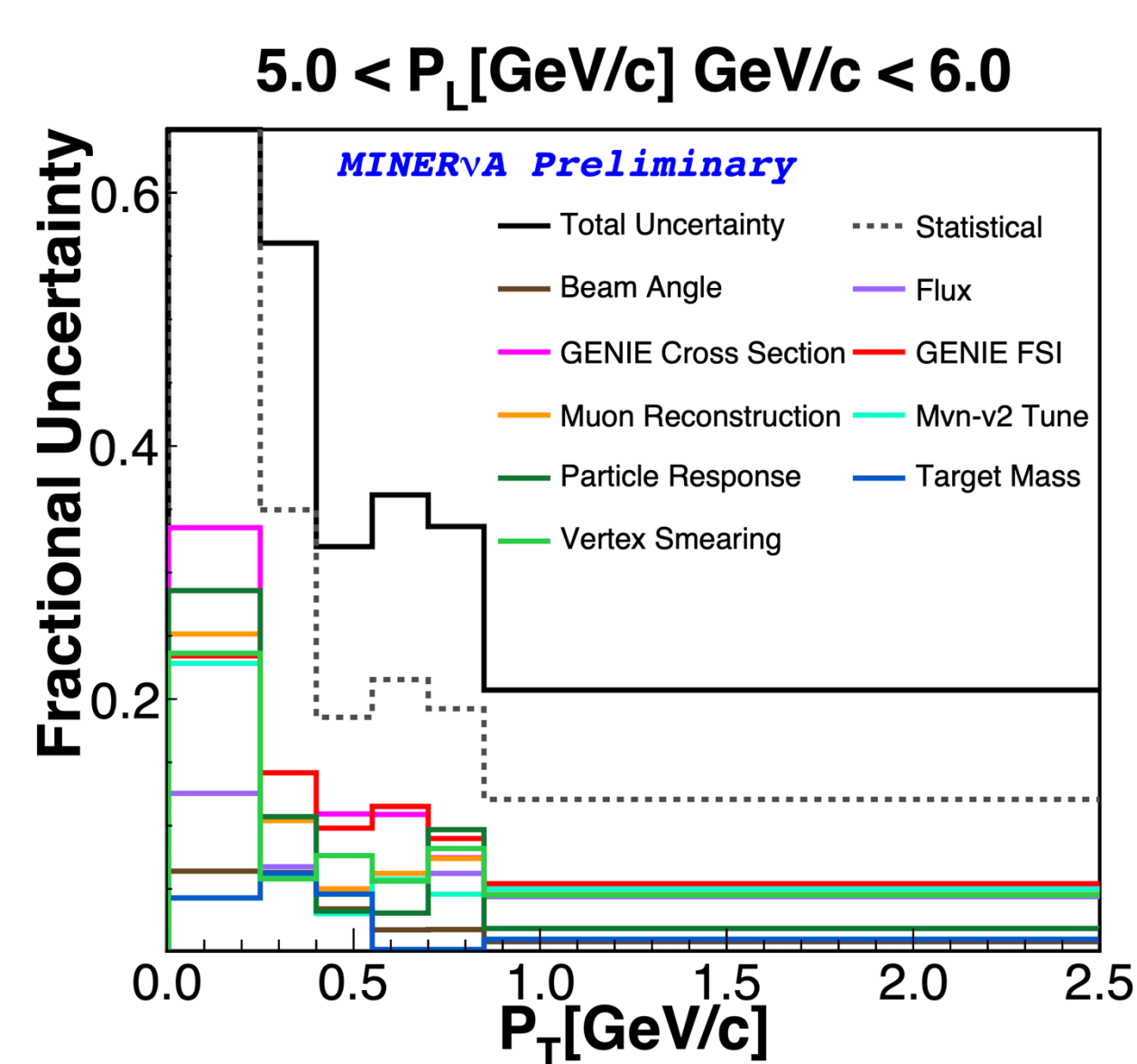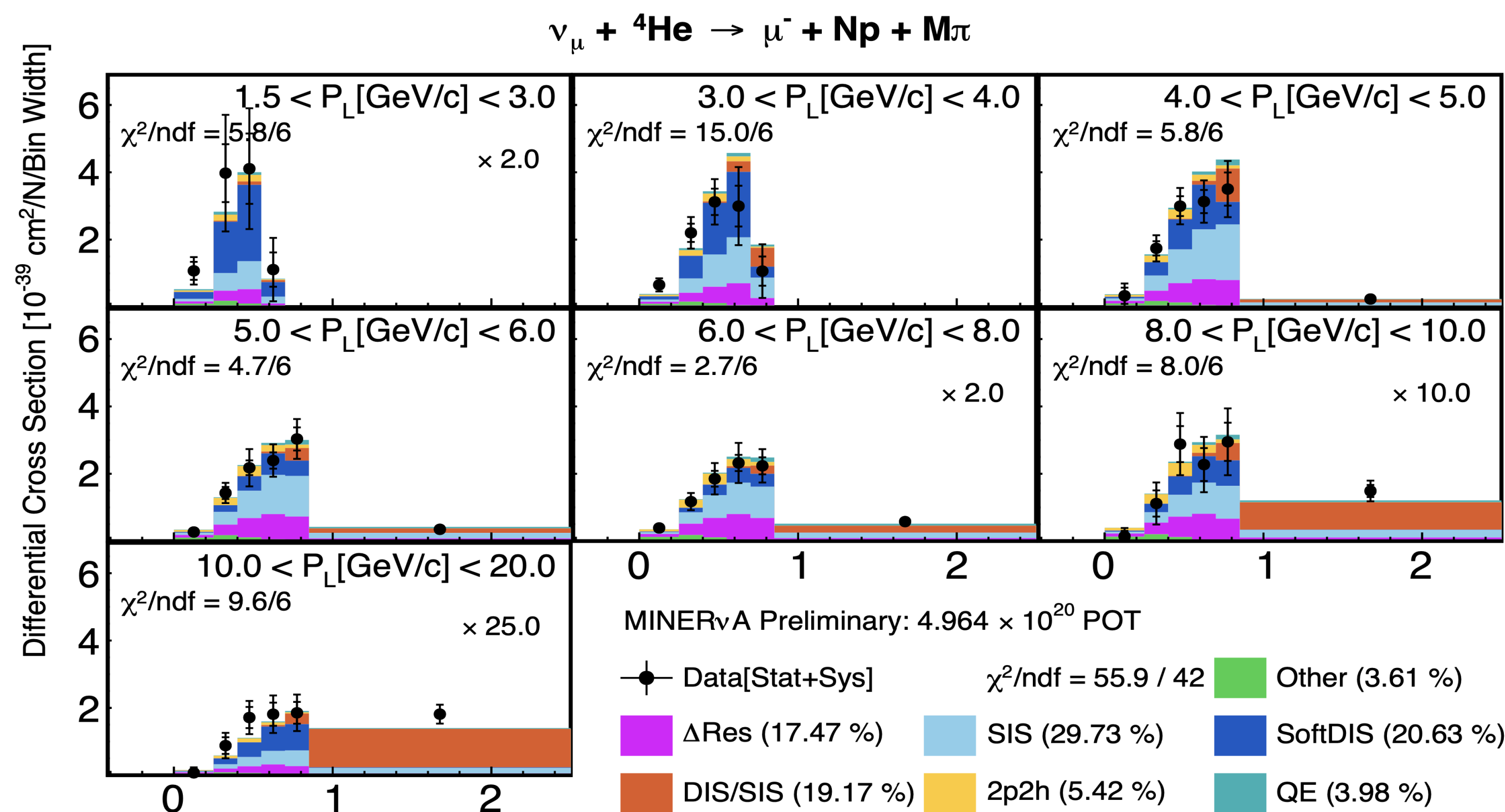
Event Selection - 4,272 Measured Helium Events
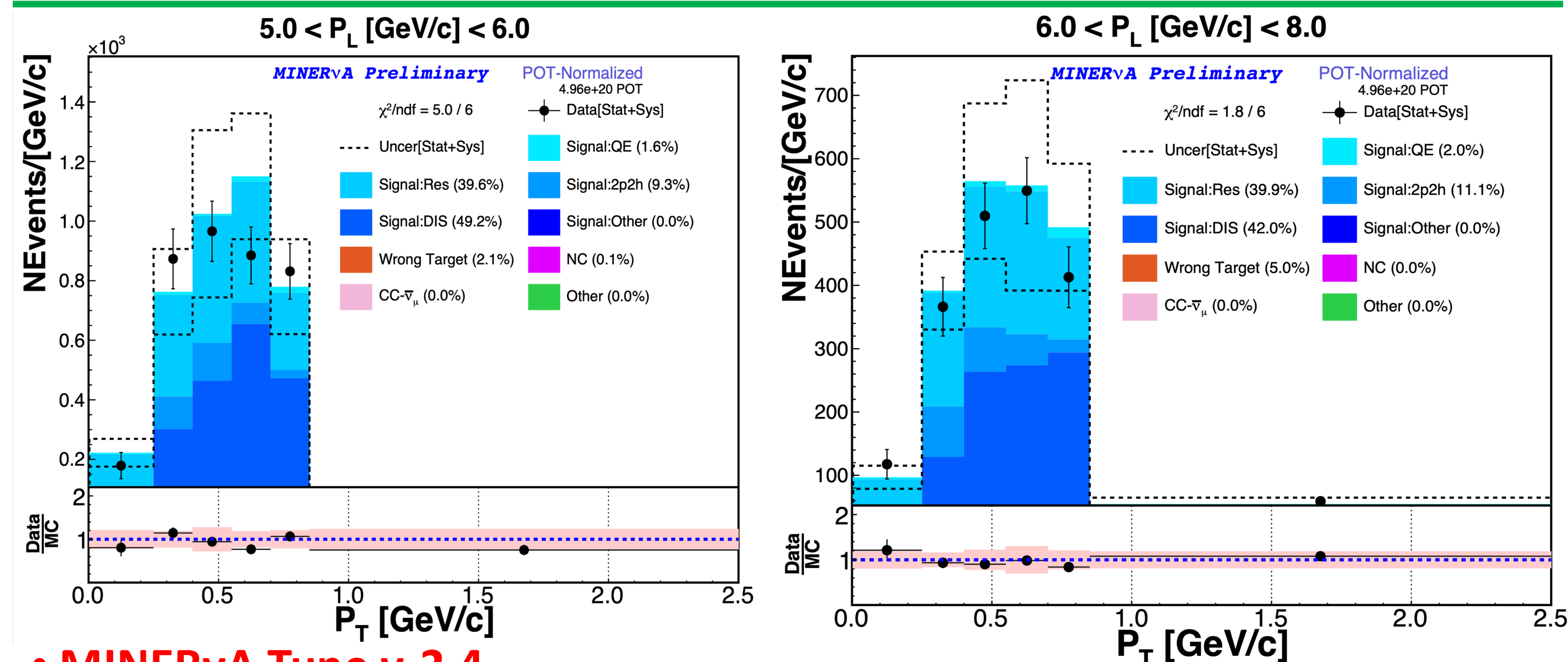
MINERvA Tune v-2.4

- Base model: GENIE 2.12.6
- 43% reduction in ν_μ - induced non-resonant single pion production based on reanalyzed data from former neutrino bubble chamber experiments[1].
- In-situ 2p2h enhancement in the dip region for CCQE-like events[3].
- In-situ pion suppression at low Q^2 [4].

Extracted Cross Sections

$$\nu_\mu + {}^4He \rightarrow \mu^- + Np + M\pi$$

MINERvA Preliminary: 4.964×10^{20} POT

Data[Stat+Sys]	χ^2/ndf = 55.9 / 42
ΔRes (17.47 %)	SIS (29.73 %)
DIS/SIS (19.17 %)	2p2h (5.42 %)
Other (3.61 %)	SoftDIS (20.63 %)
QE (3.98 %)	

- W – TRUE invariant mass of recoil system
- Q^2 – TRUE four momentum transfer

SIS/DIS: $Q^2 > 1$ [GeV^2], W > 2 [GeV]
Soft DIS: $Q^2 < 1$ [GeV^2], W > 2 [GeV]
SIS (Shallow Inelastic Scattering): W < 2 [GeV]

Pion Resonant
ΔRES: Mother to pion is a Δ

- The top figure presents the **2D extracted unfolded cross-sections** (D'Agostini, 3 iterations) **in slices of** muon longitudinal momentum (P_L) **as a function of** muon transverse momentum (P_T) relative to the neutrino beam.
- The bottom left figure displays the fractional uncertainty in the extracted unfolded cross-section.

GENIE v3 and Tune Comparison
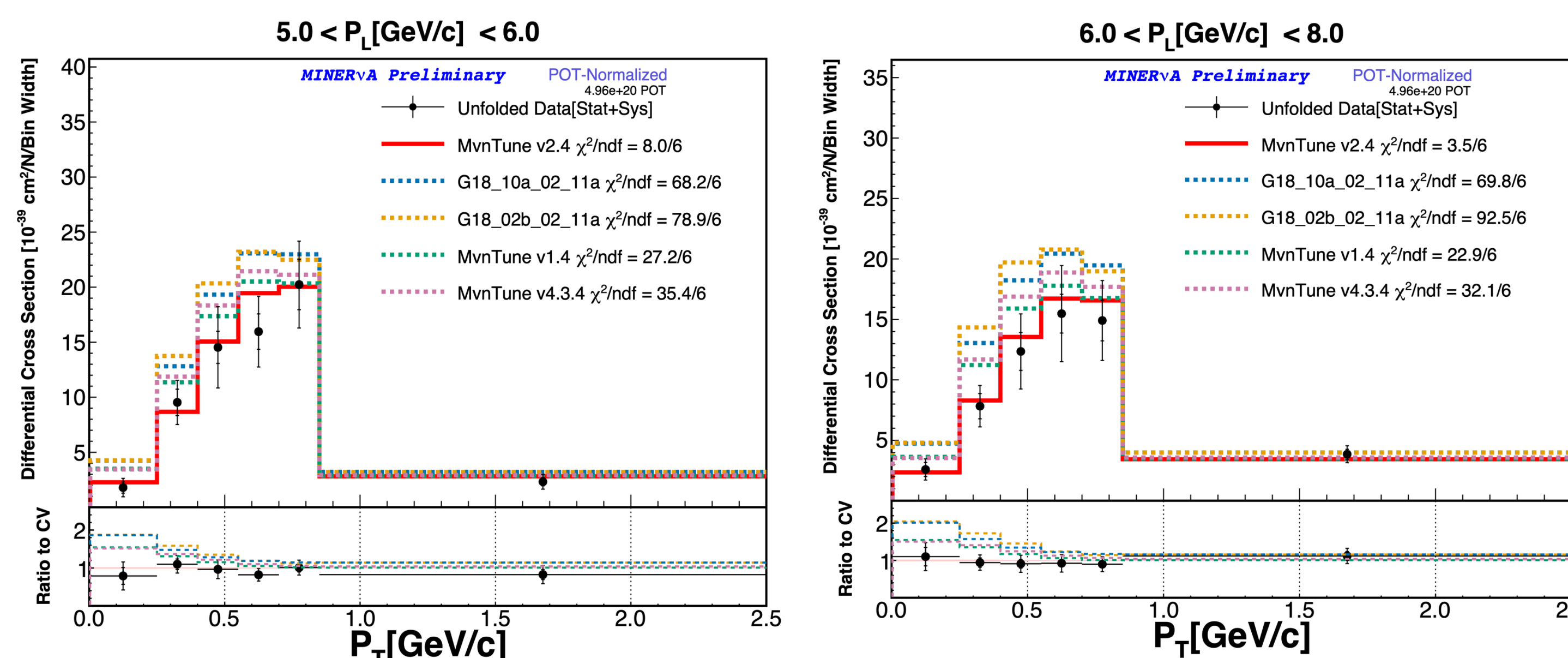
- GENIE v3 model and Minerva Tune comparisons with the extracted unfolded cross-section.

P_T^μ Cross Section CH to Helium Ratio
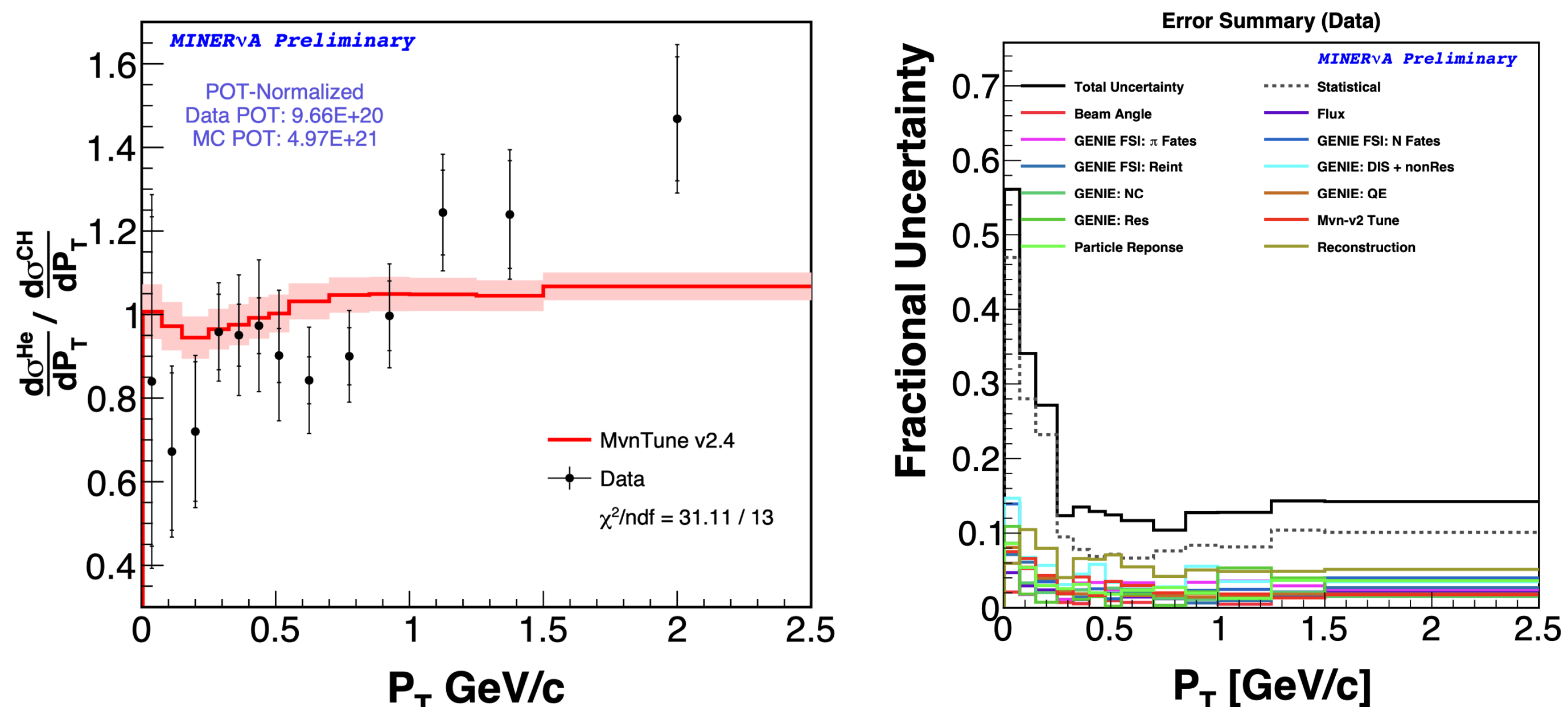
- A Cross-section Ratio Helium to MINERvA's active tracker (CH) was measured by applying the helium signal definition to CH.

Conclusions

- Presented MINERvA's helium target and BG-subtracted event selection using data-driven background constraints.
- Extracted 2D CC helium-neutrino differential cross section with interaction breakdown and preliminary model comparisons.
- Presented CH-to-helium cross section ratio.

References

1) Rodrigues, P., Wilkinson, C. & McFarland, K. Constraining the GENIE model of neutrino-induced single pion production using reanalyzed bubble chamber data. *Eur. Phys. J. C* **76**, 474 (2016). https://doi.org/10.1140/epjc/s10052-016-4314-3
2) Gran, R. *Model uncertainties for Valencia RPA effect for MINERvA*. http://arxiv.org/abs/1705.02932
3) P. A. Rodrigues *et al.* (MINERvA Collaboration), Phys. Rev. Lett. **116**, 071802 (2016).
4) Stowell, P *Tuning the GENIE Pion Production Model with MINERvA Data*. https://doi.org/10.1103/PhysRevD.100.072005
5) Aaron S. Meyer, Minerba Betancourt, Richard Gran, and Richard J. Hill Phys. Rev. D **93**, 113015 (2016)