



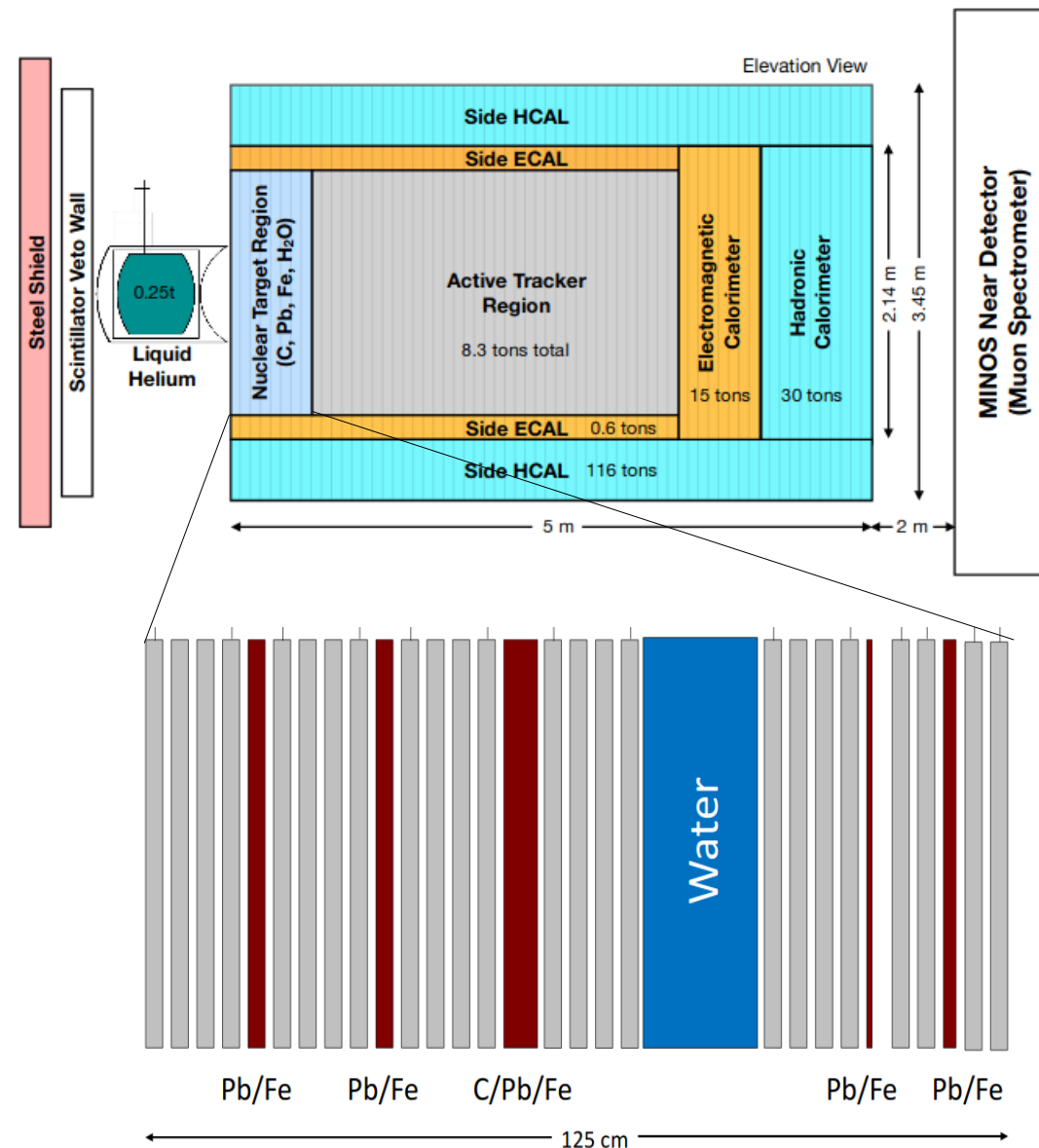
MINERvA: Past, Present, and Future

Andrew Olivier
for the MINERvA Collaboration
55th Annual Fermilab User's Meeting
June 16, 2022



What is MINERvA?

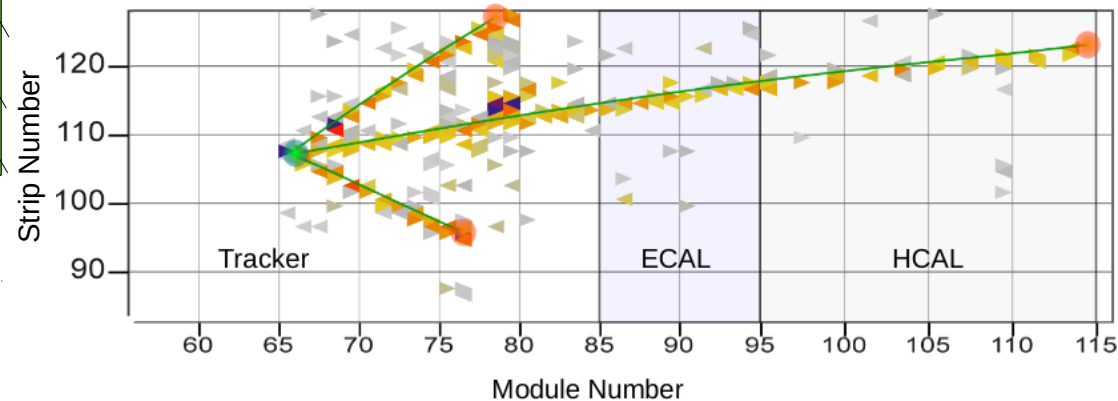
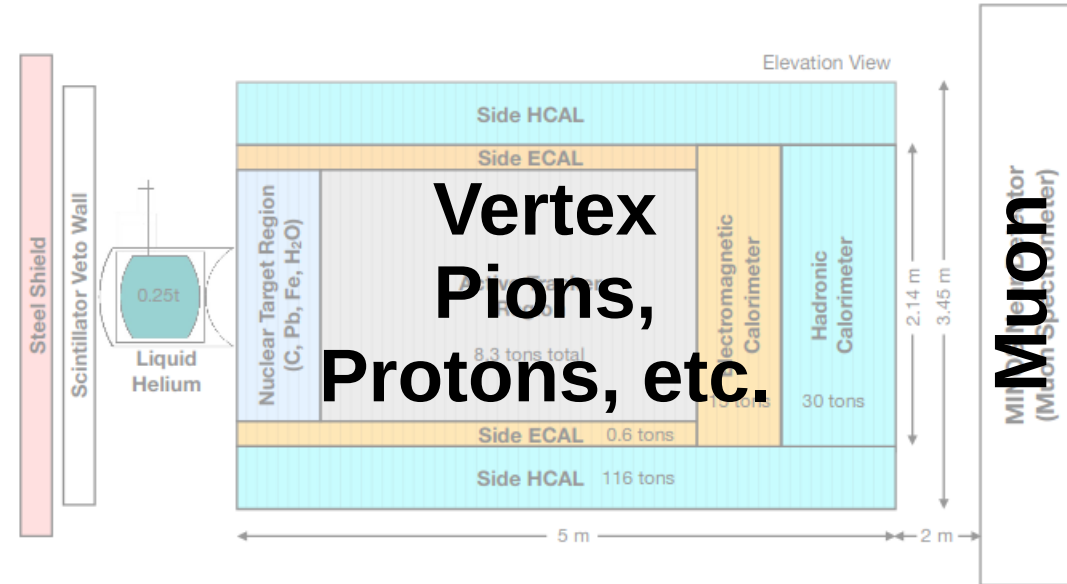
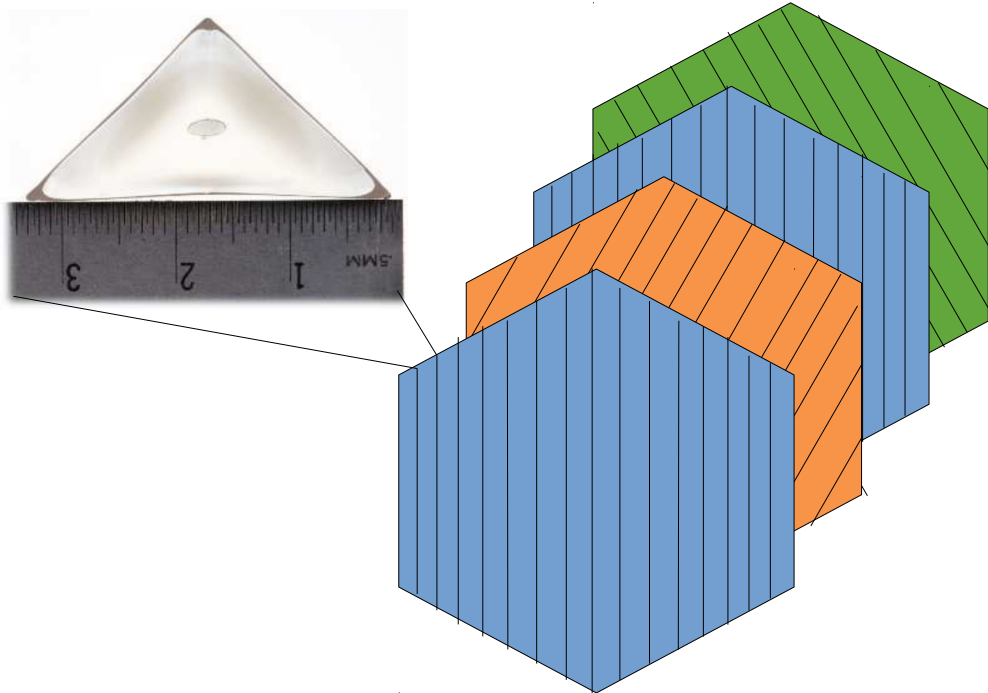
- Main INjector ExpeRiment for ν -A scattering
- We measure neutrino cross sections!
- Technology: polystyrene (CH) fine-grained scintillator tracker
- Passive nuclear targets illuminate nucleus dependence



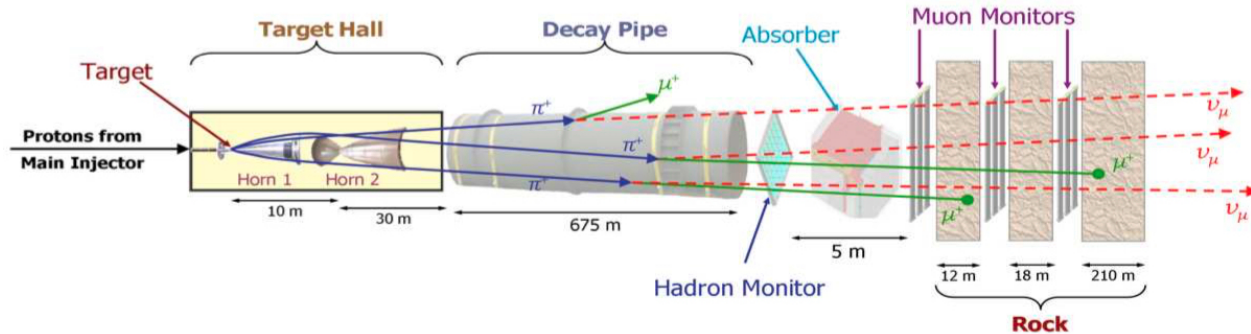
Nucl. Inst. and Meth. A743 (2014) 130

How MINERvA Works

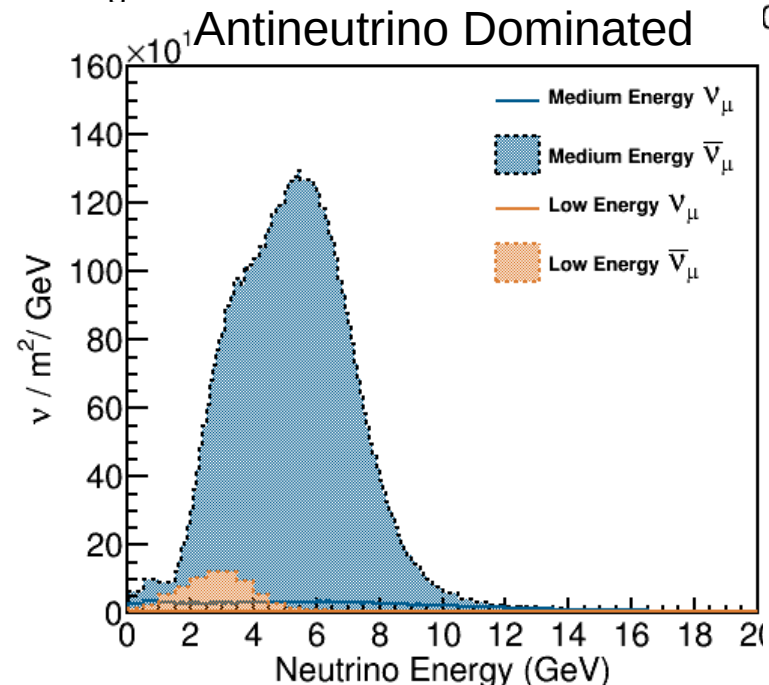
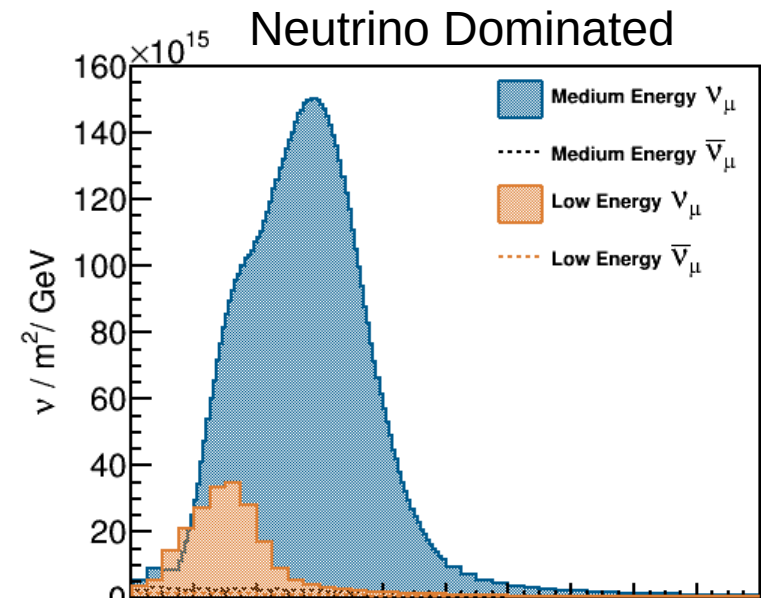
- MINOS data provides precise muon momentum
- Tracker consists of stacked planes of scintillator strips
- Each strip sees charge as light
- Put 3 views of strips together to reconstruct 3D images



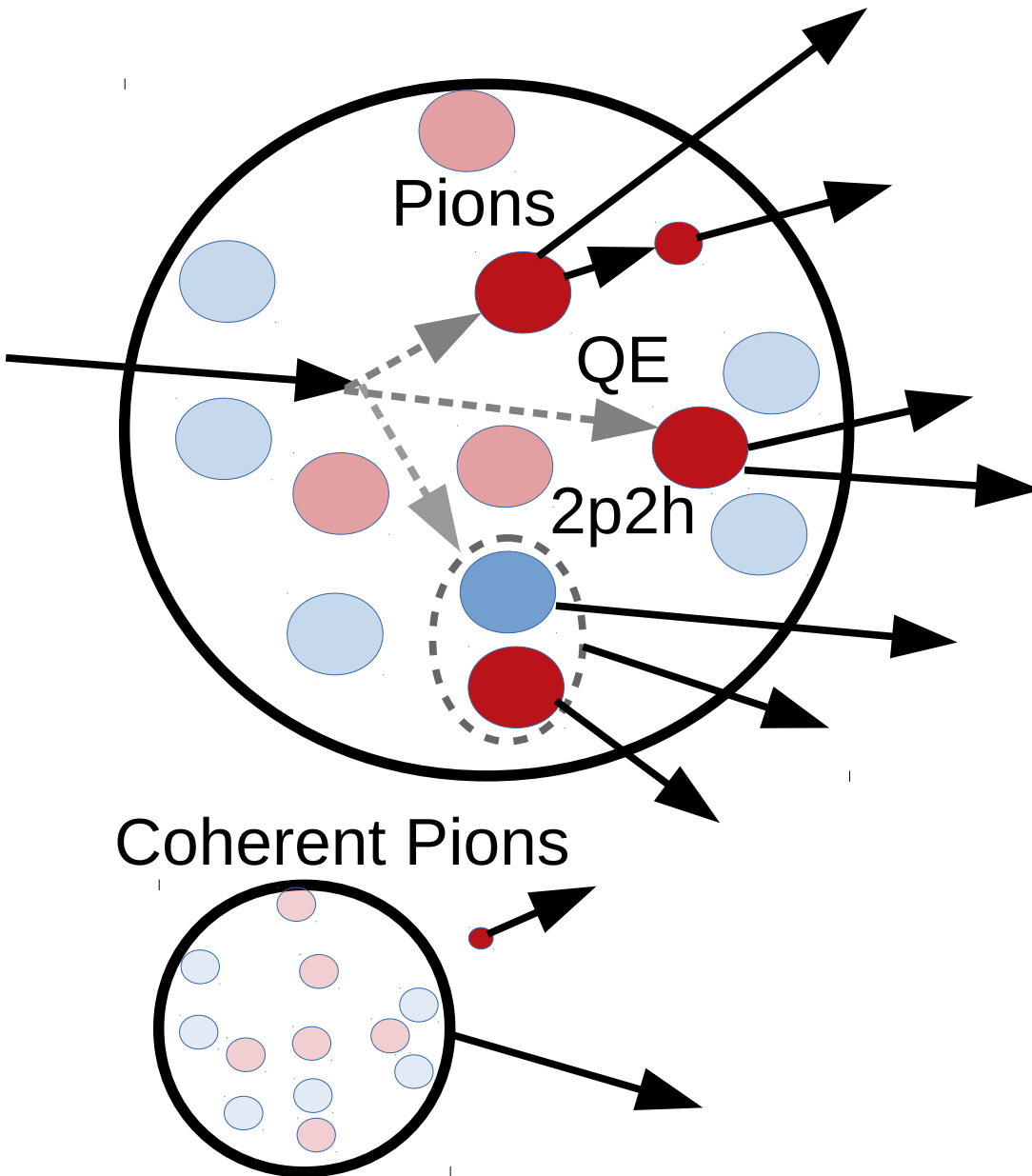
MINERvA's Data



- 2 data eras: Low Energy (LE) and Medium Energy (ME)
- ME \sim NOvA era, BUT MINERvA is on axis
- 12×10^{20} POT in each mode
- Thank you Fermilab Accelerator Division for many years of quality beam

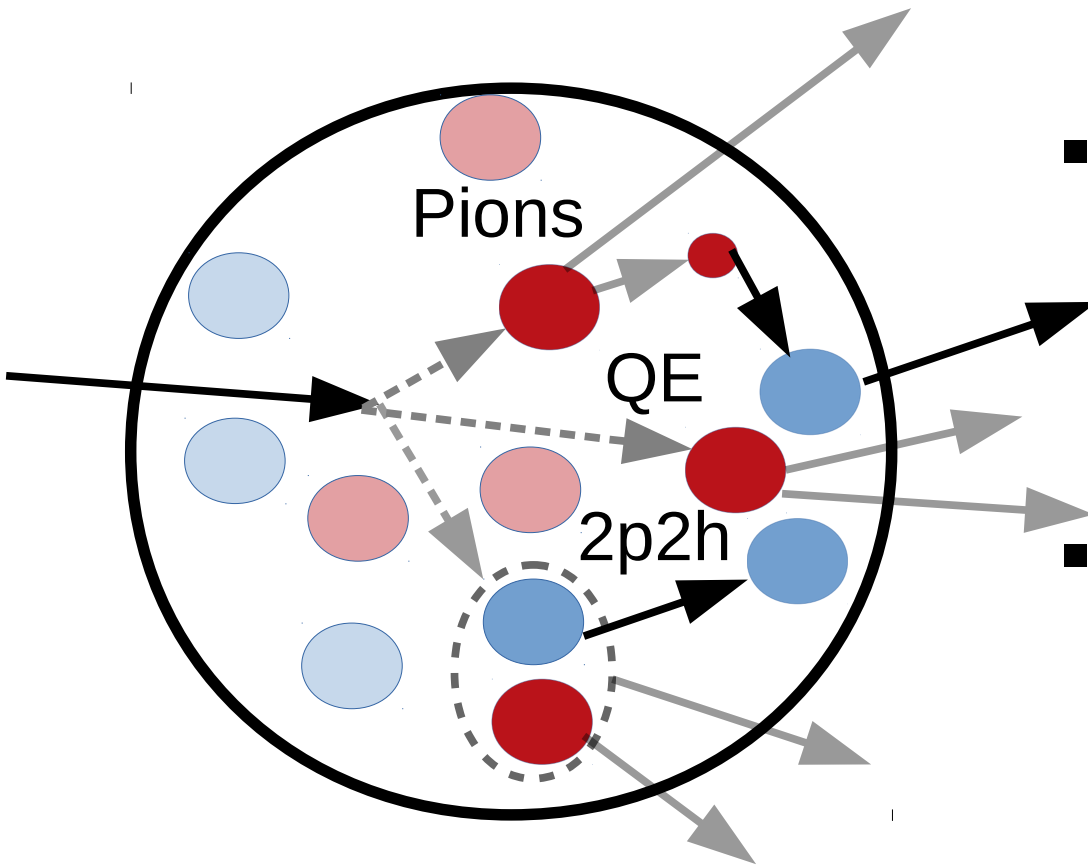


Processes We Study



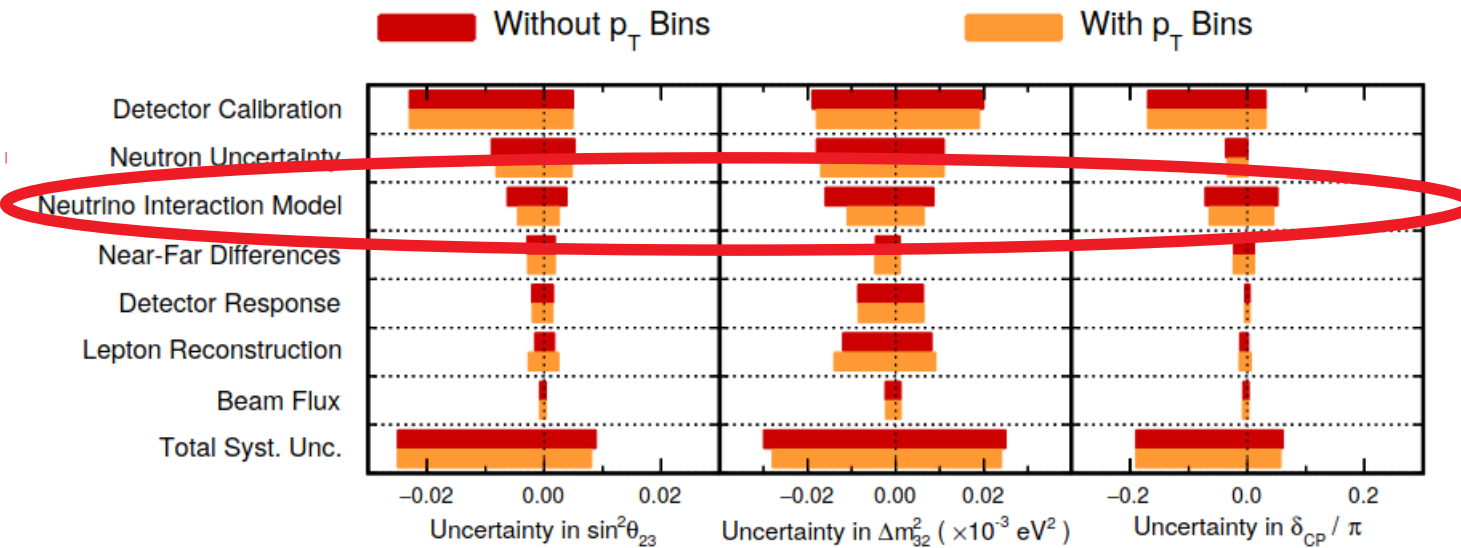
- Interaction on nucleons:
 - Quasi-Elastic interaction: “billiard ball scattering”. Simple kinematics $\rightarrow E_\nu$ measurement
 - Pion production
 - “2p2h”: interaction on multiple nucleons
- Deep Inelastic Scattering: interaction on quarks \rightarrow lots of hadronic energy
- Coherent: interaction on entire nucleus

Even More Complicated: FSI



- Final State Interactions:
 - Additional nucleons
 - Pions absorbed
 - Hadron momenta changed
- Tools we can use against them:
 - QE kinematics from muon
 - Coherent pion production: interacts with whole nucleus
 - Transverse Kinematic Imbalance (TKI)

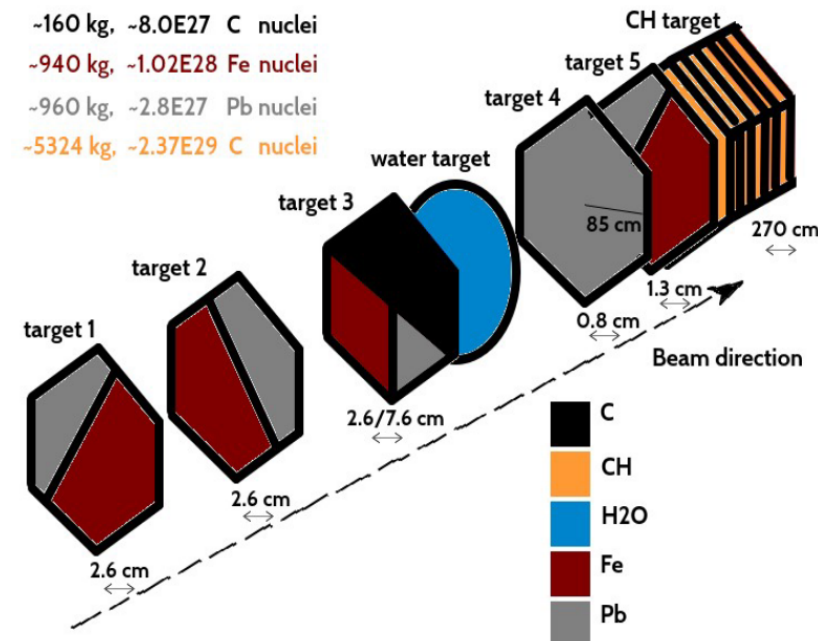
Why Measure Cross Sections?



<https://arxiv.org/abs/2108.08219>

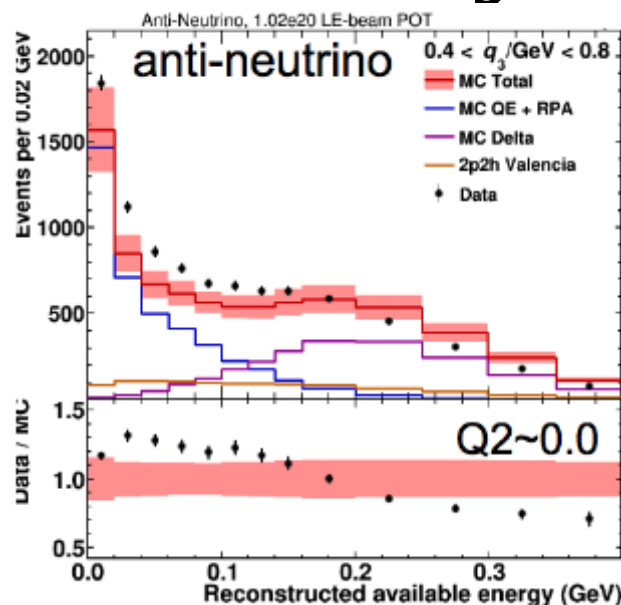
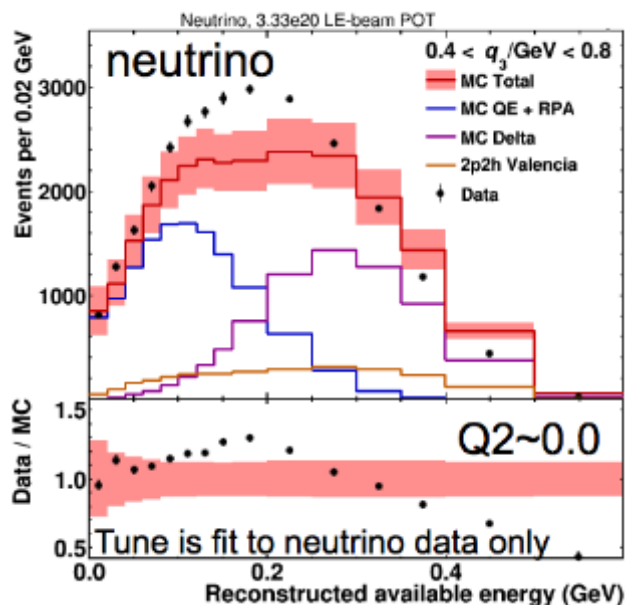
Figure by A. Ramirez Delgado

- Reduce interaction model uncertainty for oscillation experiments
 - Even ND fit doesn't completely cancel
 - Future oscillation experiments planning for large statistics → reduction in systematics
- First measurement of material ratios!

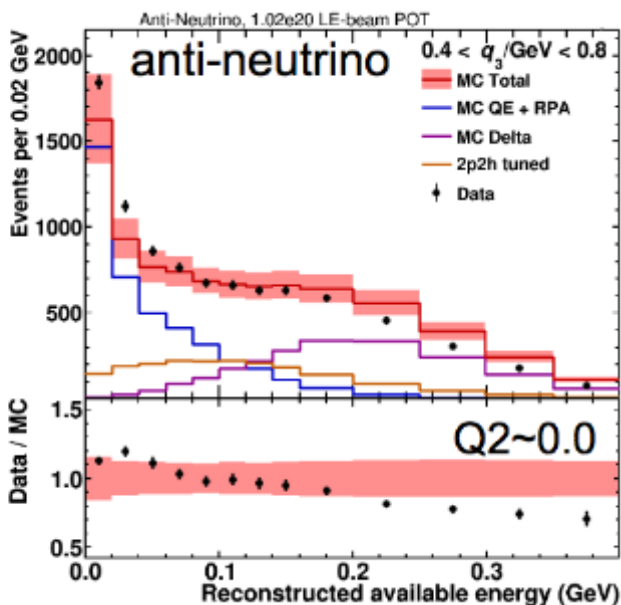
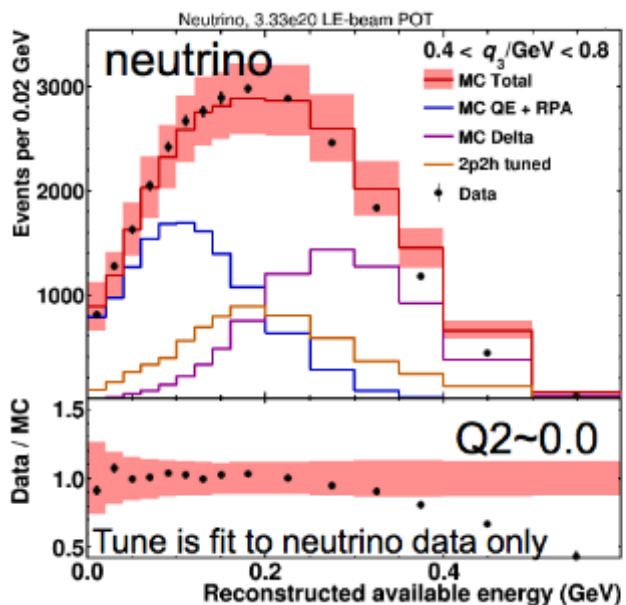


MINERvA's Physics Tune

Before



After



- Original low recoil inclusive publication found data excess in “dip” region
- MnvTunev1
 - 2p2h enhancement
 - RPA modification
 - Non-resonant pion suppression
- Subsequent anti-neutrino measurement improved by tune!

Phys. Rev. Lett. 116, 071802

Phys. Rev. Lett. 120, 221805 (2018)

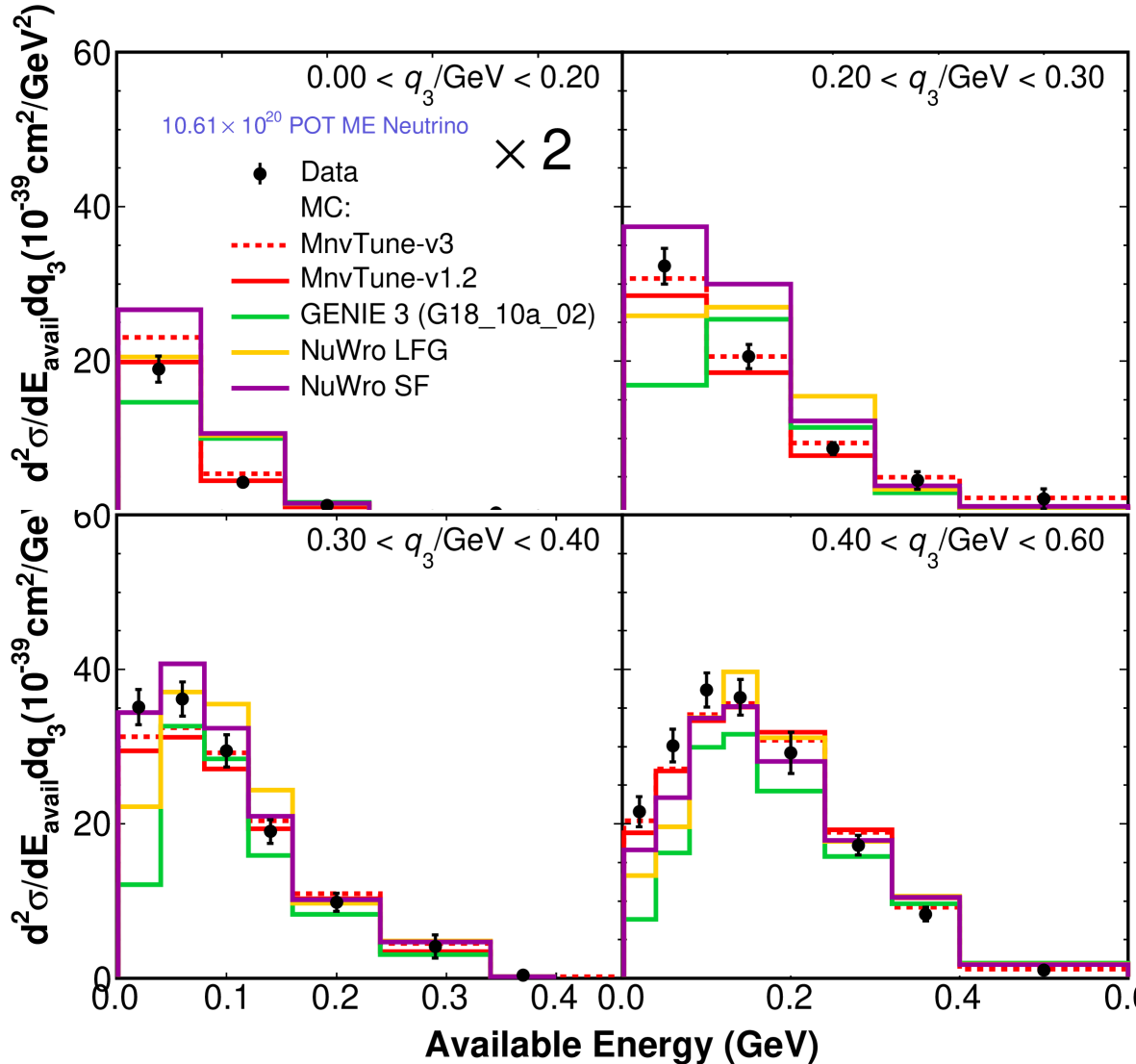


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Recent MINERvA Results



Momentum Transfer in ME



- Finer binning in q_3
- Supersedes previous result with better CV model
- Covariance makes agreement worse than by-eye comparison

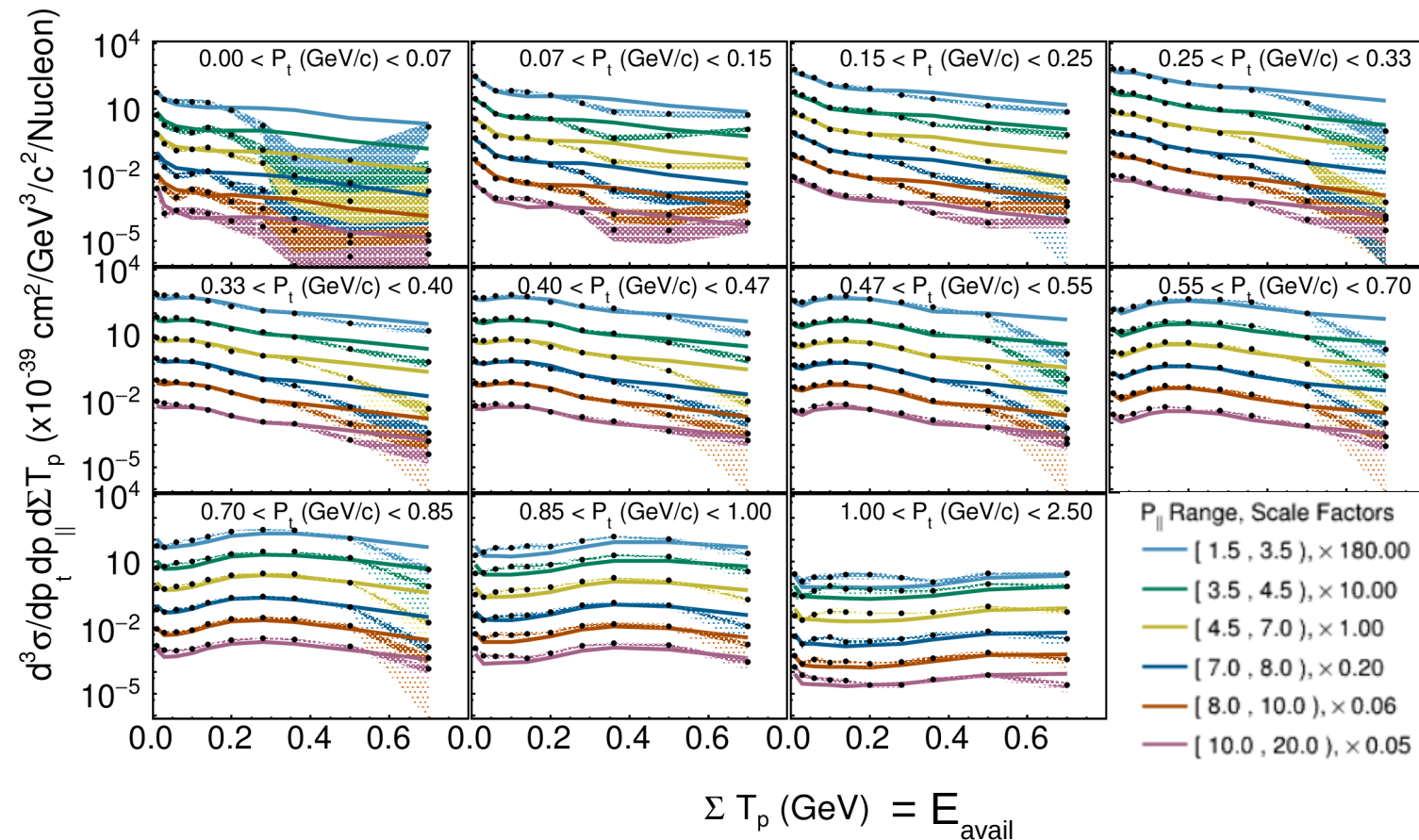
MC/Generators	χ^2	χ^2/NDF
MnvTune-V3	1100.75	25.02
MnvTune-V1.2	963.154	21.89
NuWro SF	10122.9	230.07
NuWro LFG	16072.9	365.29
GENIE 3 (G1810a_02)	13522.1	307.32

<https://arxiv.org/abs/2110.13372v1>



Massive CCQE-Like Statistics

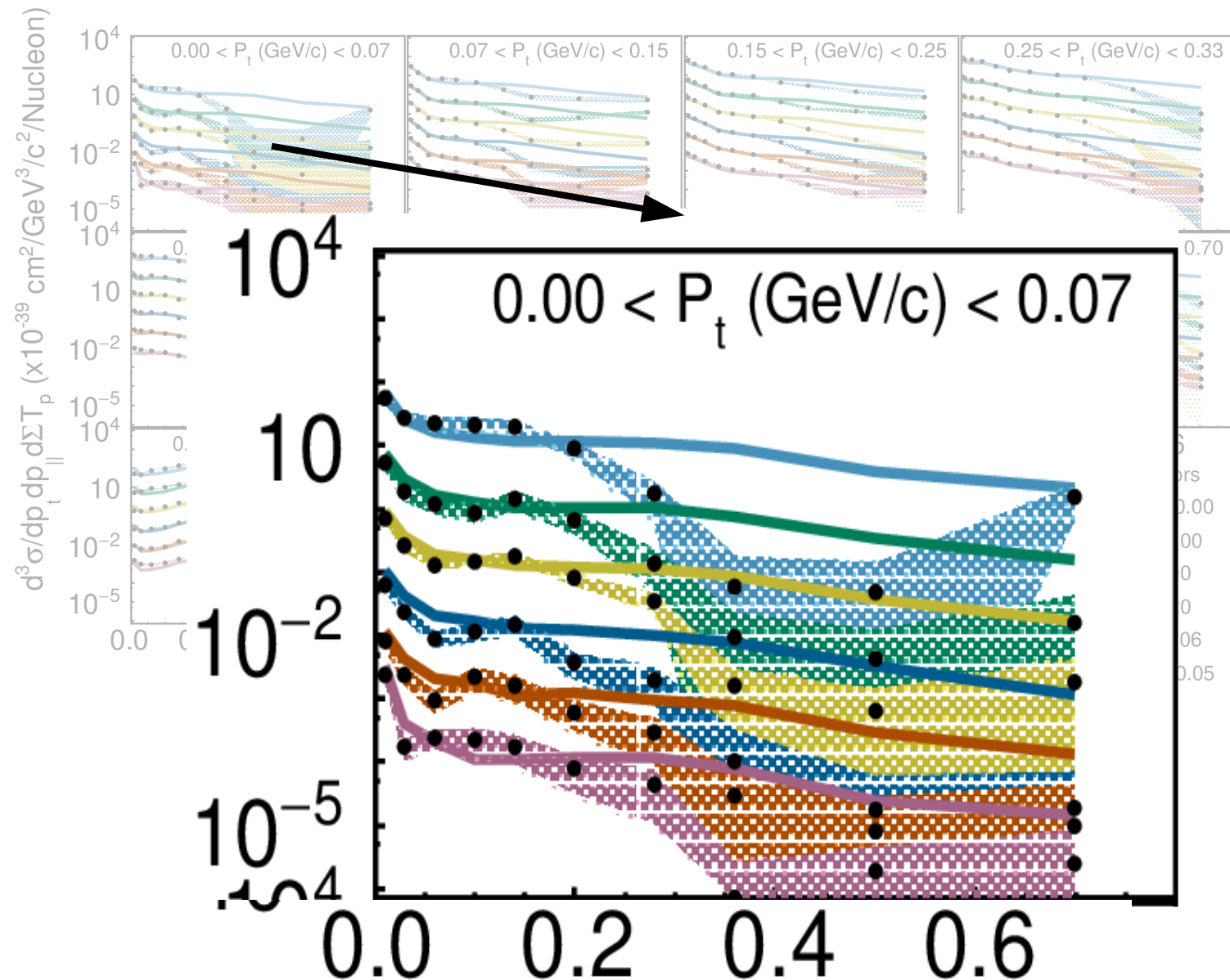
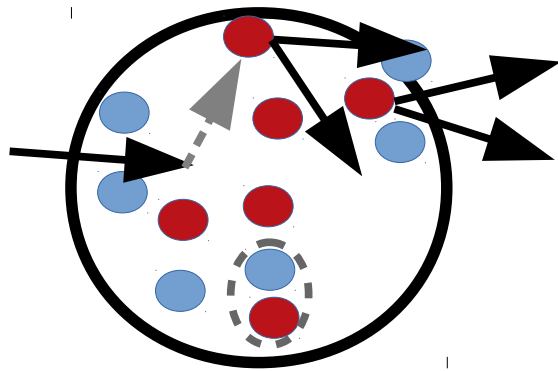
- QE-like result now also binned in E_{avail} !
- 3,390,718 events
- z-expansion CV
- Modeling p_{\parallel} well: same trend across all T_p , p_T bins



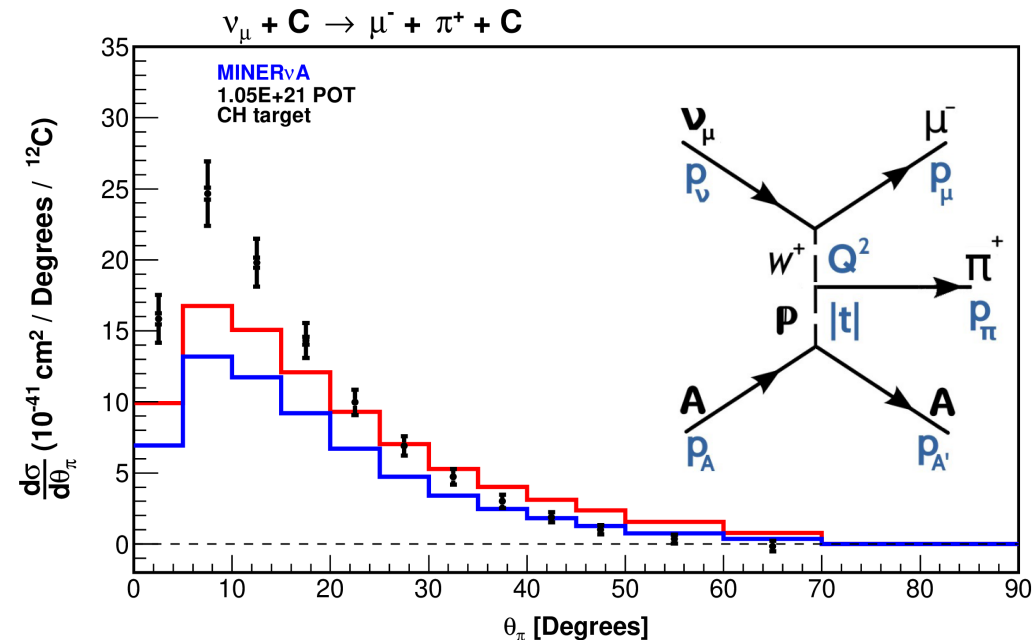
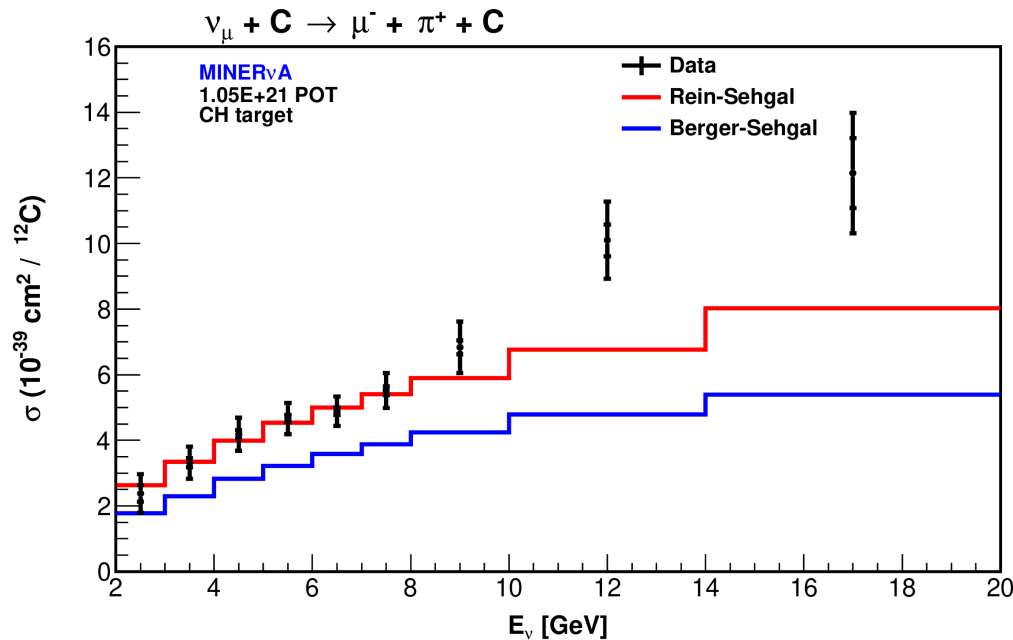
<https://arxiv.org/abs/2110.13372v1>

3D CCQE-Like Cross Section

- Low “extra” momentum but high hadronic energy?
- Test of FSI!



Coherent Pion Production...

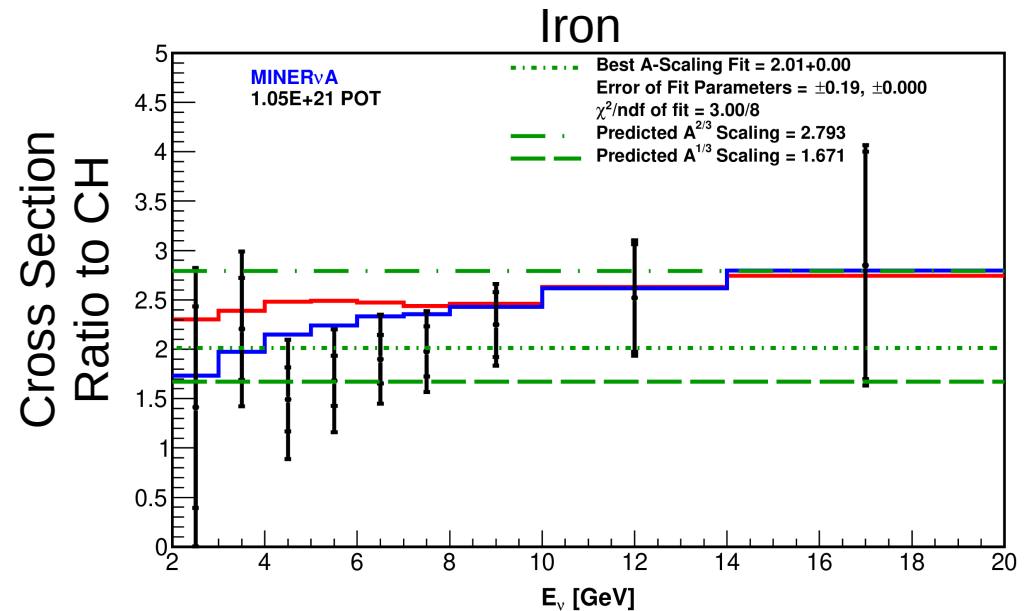
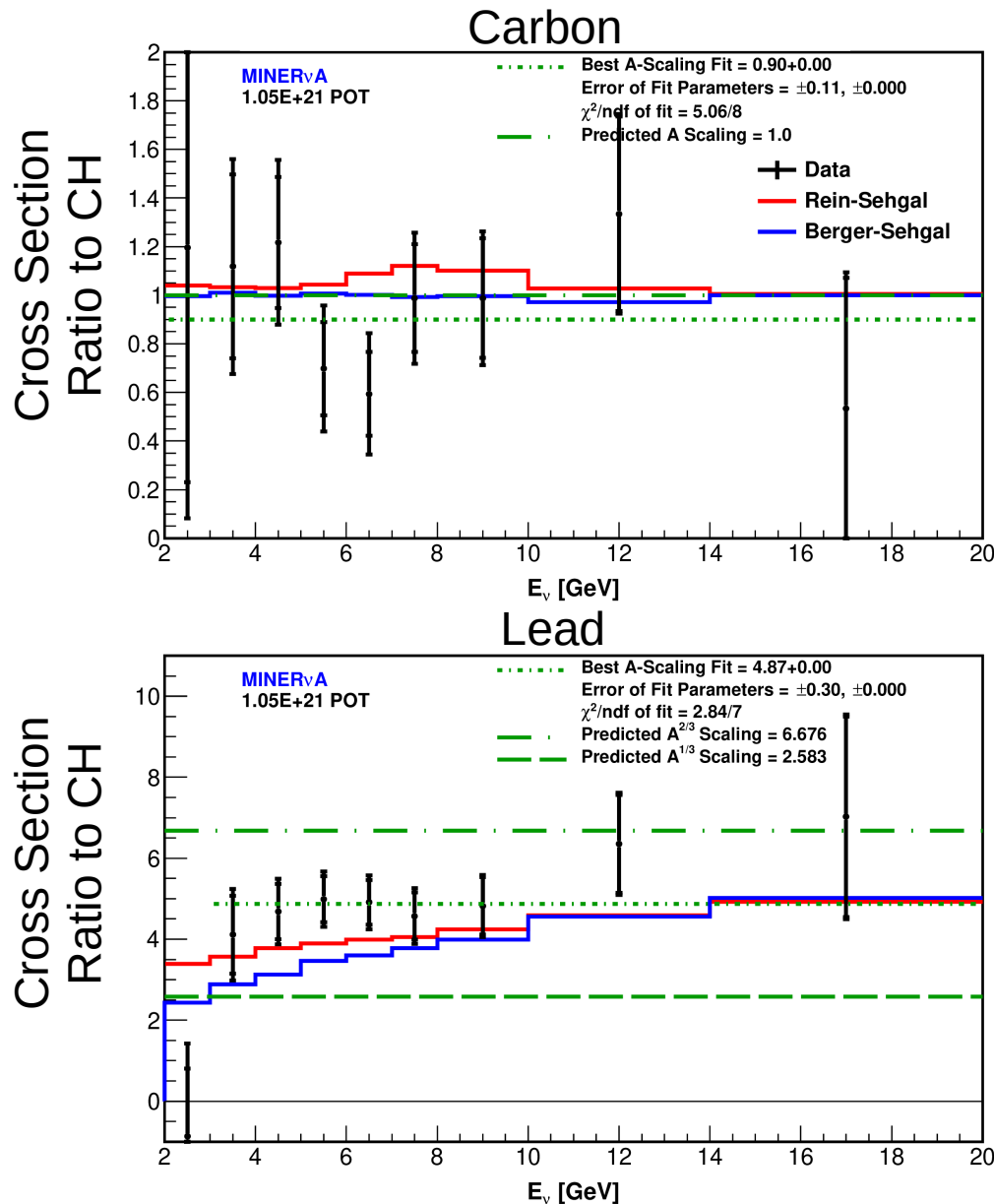


Alejandro Ramirez W&C Seminar: June 10, 2022

- Coherent: neutrino interacts off of whole nucleus
- Signal: low momentum transfer \rightarrow very forward

- Rare process \rightarrow leverage high statistics!
- Models related to NC coherent π^0 production which is an important electron neutrino background

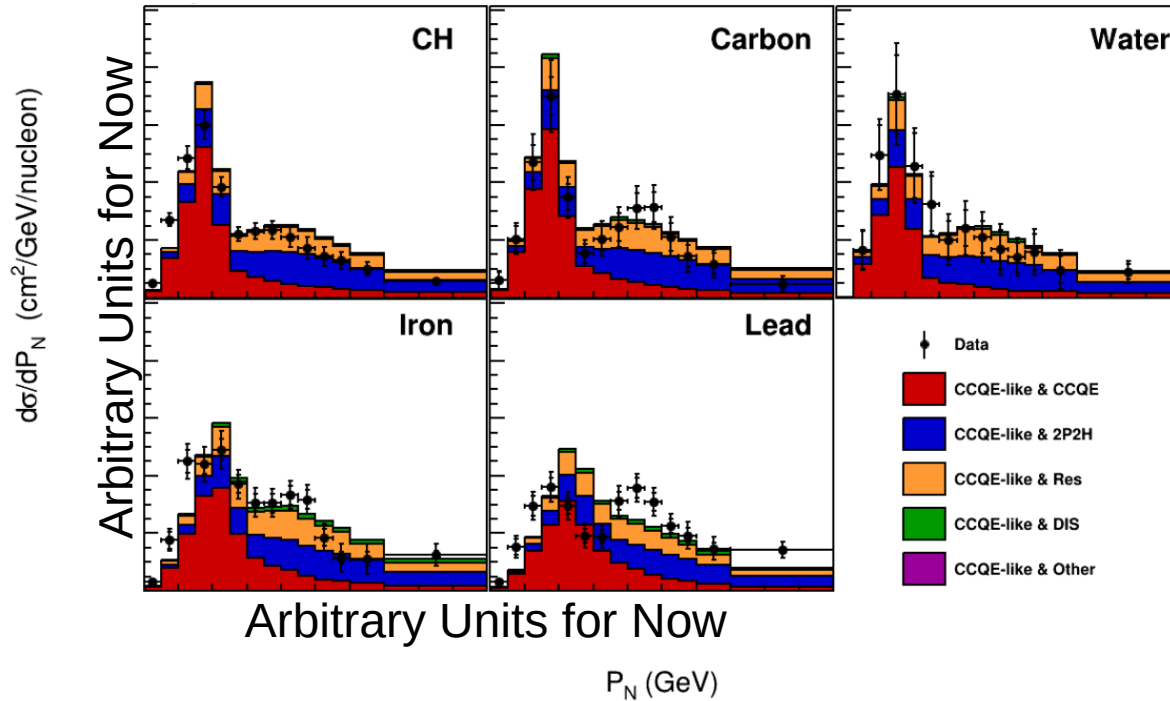
...As A Function of Nucleus!



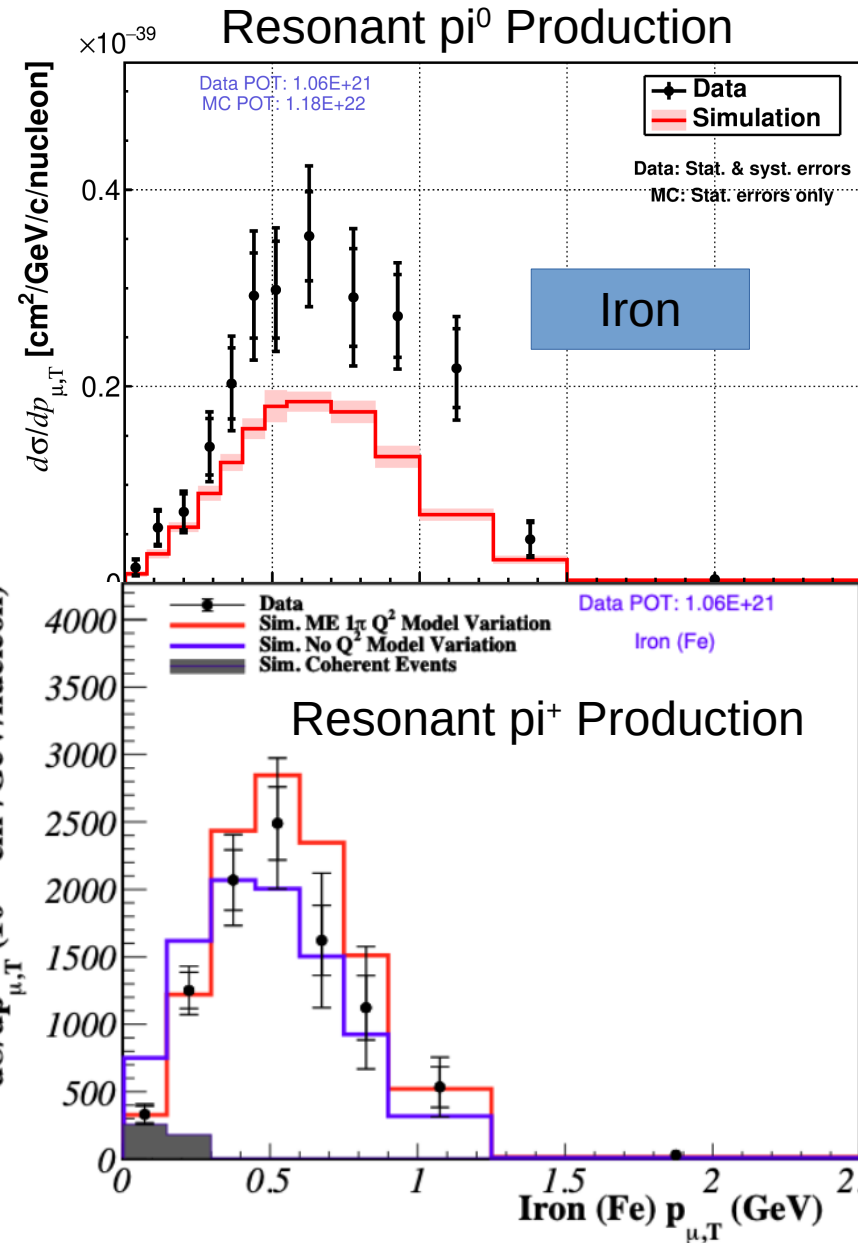
- First ME nuclear targets result
- Rare process on small targets
- Coherent \rightarrow A-scaling is prime model test

Coming Soon

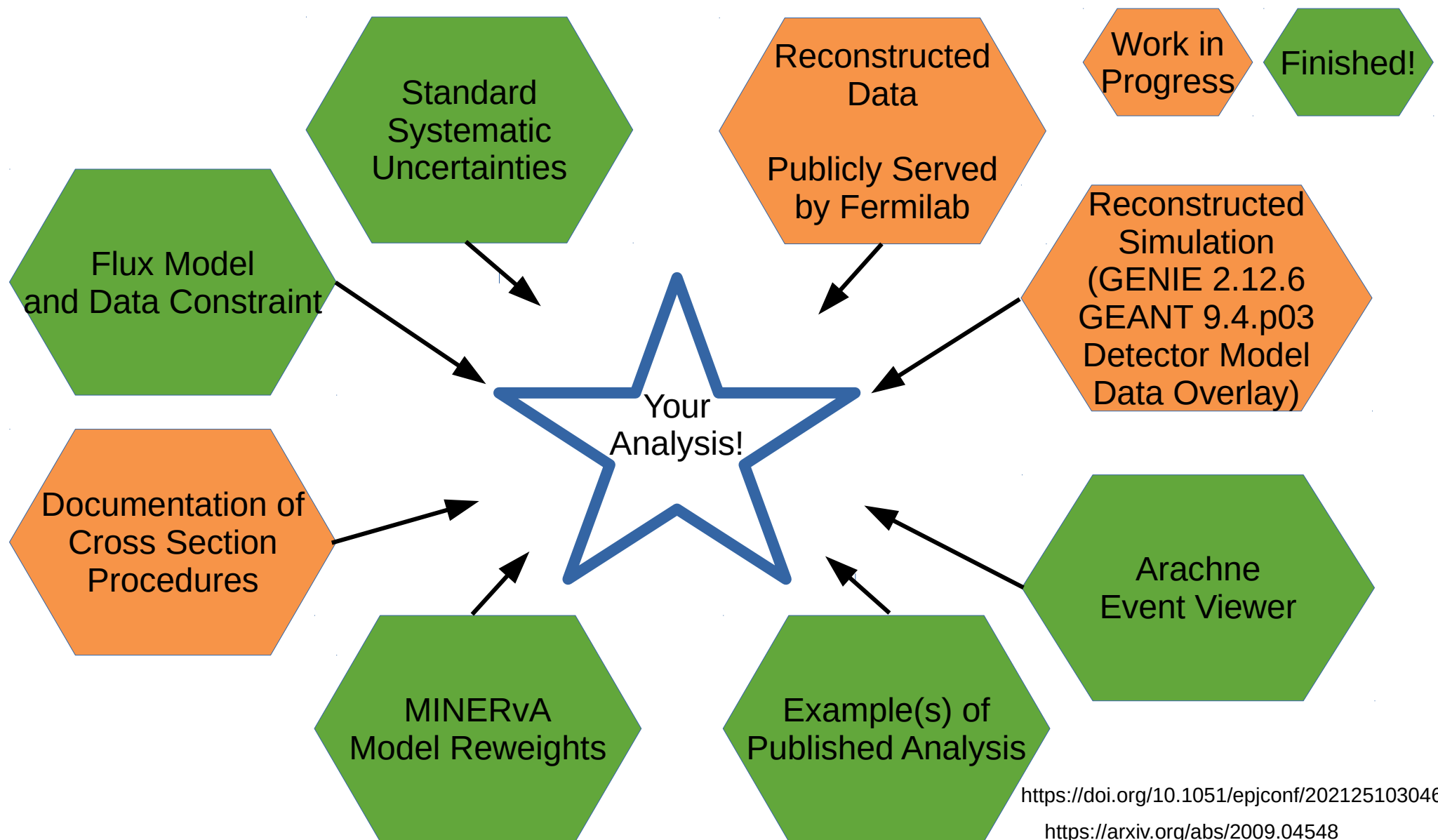
QE-like



- More nuclear targets
- More pions
- More QE-like
- TKI variables



The Future: Data Preservation



The Future: Data Preservation



<https://doi.org/10.1051/epjconf/202125103046>

<https://arxiv.org/abs/2009.04548>



Conclusions

- Starting publication of MINERvA's medium energy era results
 - More statistics
 - More observables
 - More nuclear dependence measurements
- See Alejandro's Wine & Cheese seminar from last week
- Future: MINERvA data publicly analyzable through data preservation



Thank You



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Backup Slides



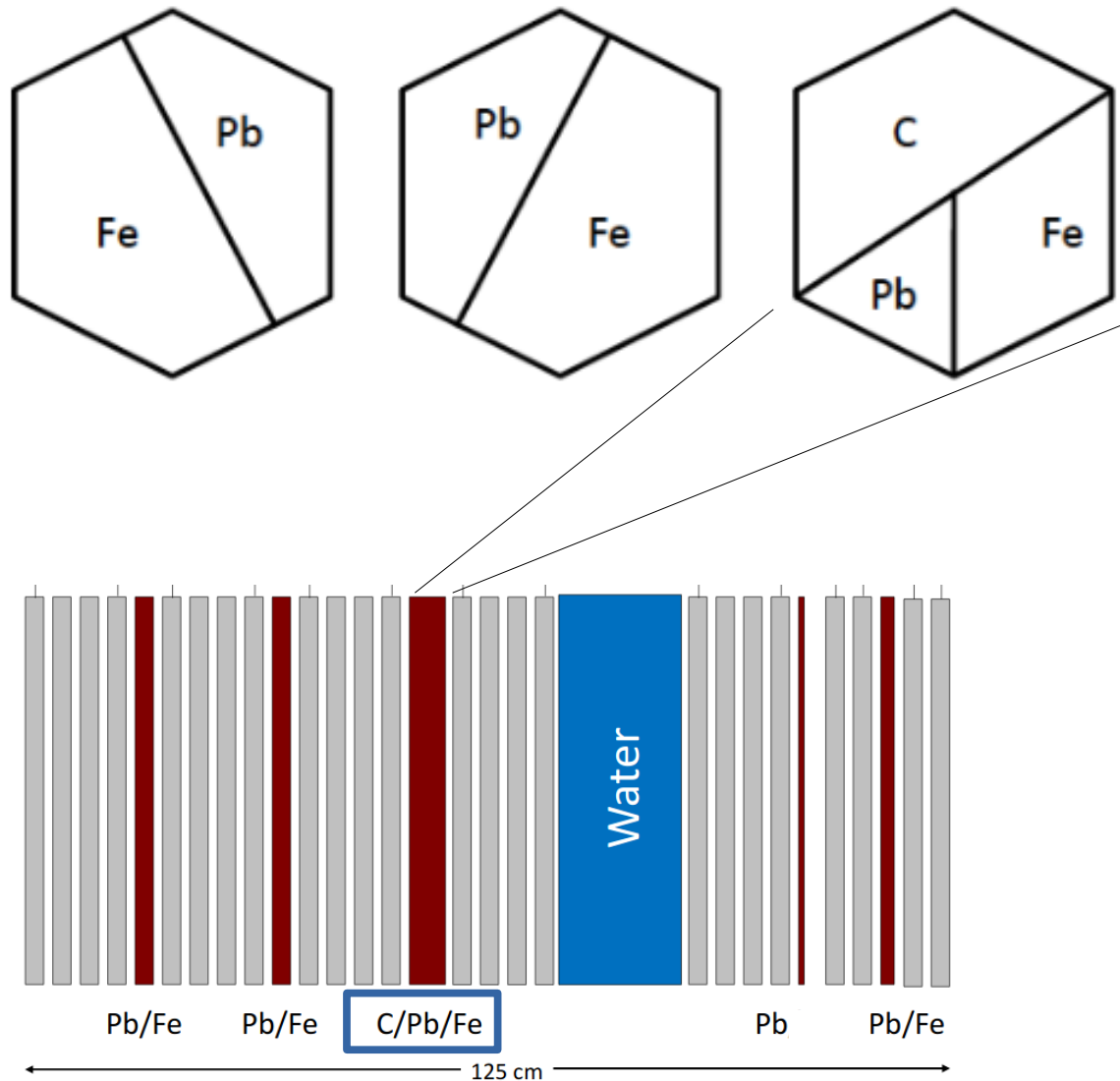
MINERvA's Model Tunes

- GENIE: Generates Neutrino Interactions for Experiments
 - Simulates kinematics of initial neutrino interaction and propagation out of the nucleus
 - Low energy: 2.8.4
 - Medium energy: 2.12.6 (Valencia 2p2h added)
- MnvTunev1: GENIE 2.12.6 with the following tunes:
 - 2p2h enhancement by a Gaussian up to 50% in some regions
 - Valencia RPA suppression
 - Non-resonant pion production suppression
 - MnvTunev1.2 also includes bug fixes for relativistic kinematics of outgoing hadrons and suppression of coherent pion production
- MnvTunev3: reweights GENIE 2.12.6 to look like:
 - The 2p2h model designed to accompany SuSA
 - Bodek-Ritchie high momentum QE enhancement

Variables of Interest

- E_{avail} : Available energy
 - Energy in non-neutron final state particles = energy we can reconstruct calorimetrically
 - Full energy of pions + KE of anything else that's not a neutron
 - Technically ignores rest mass of nucleon resonances
- TKI
 - Transverse Kinematic Imbalance
 - Use a charged hadron with the muon to look for missing momentum
 - Very sensitive to effects of FSI and interactions off of correlated nucleons (i.e. 2p2h)
 - p_N : neutron momentum under a QE hypothesis for neutrino CCQE

MINERvA's Nuclear Targets



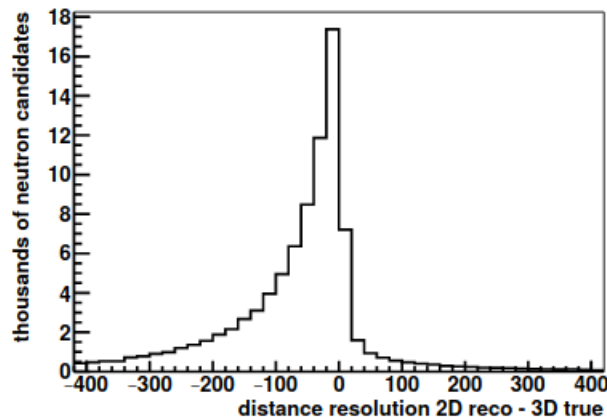
- Passive nuclear targets upstream of tracker
- Let us study A -dependence of neutrino cross sections
- Determine interaction material by x, y coordinates

MINERvA's Tracker



- Only read out on one end → timing resolution
- Modules have 4 planes → raises minimum proton energy for 3D reconstruction

Distance from Vertex



Timing

