Latest MINERvA Results on Neutrino Cross Section Measurements

Maria Mehmood on behalf of the **MINERvA Collaboration**

Lake Louise Winter Institute 2024

Some of the latest results coming out of MINERvA

- The results that we'll be looking at today are **cross section measurements** of **different neutrino processes** on **different targets**

Simultaneous Measurement of Muon Neutrino ν_μ Charged-Current Single π^+ Production in CH, C, H_2O, Fe, and Pb Targets in MINERvA

A. Bercellie,[1] K. A. Kroma-Wiley,[2,1] S. Akhter,[3] Z. Ahmad D

https://arxiv.org/pdf/2209.07852.pdf

Phys Rev Lett 131, 011801

Simultaneous measurement of ν_μ quasielastic-like cross sections on CH, C, H_2O, Fe, and Pb as a function of muon kinematics at MINERvA

J. Kleykamp,[1,*] S. Akhter,[2] Z. Ahmad Dar,[3,2] V. Ansari,[2] M. V

https://arxiv.org/pdf/2301.02272.pdf

Phys Rev Lett 130, 161801

Neutrino-induced coherent π^+ production in C, CH, Fe and Pb at $\langle E_\nu \rangle \sim 6$ GeV

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X.-G. Lu,[19,20] E. Maher,[21] S. Manly,[8] W.A. Mann,[13] C. Mauger,[1] K.S. McFarland,[8] B. Messerly,[11,**]
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G.N. Perdue,[7,8] K.-J. Plows,[20] R.D. Ransome,[23] D. Ruterbories,[8] H. Schellman,[6] H. Su,[11] M. Sultana,[8]
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(The MINERνA Collaboration)

https://arxiv.org/pdf/2210.01285.pdf

Phys Rev Lett 131, 051801

The results that we'll be looking at today are **cross section measurements** of **different neutrino processes** on **different targets**

- Cutting edge neutrino oscillation experiments on the horizon!
- Knowledge of how neutrinos interact with various nuclei is required to be able to measure the neutrino energy for neutrino oscillation experiments
- Cross section measurements describe the probability of neutrino interactions occurring at a given neutrino energy

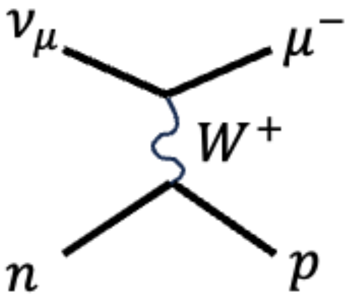
The results that we'll be looking at today are **cross section measurements** of **different neutrino processes** on **different targets**

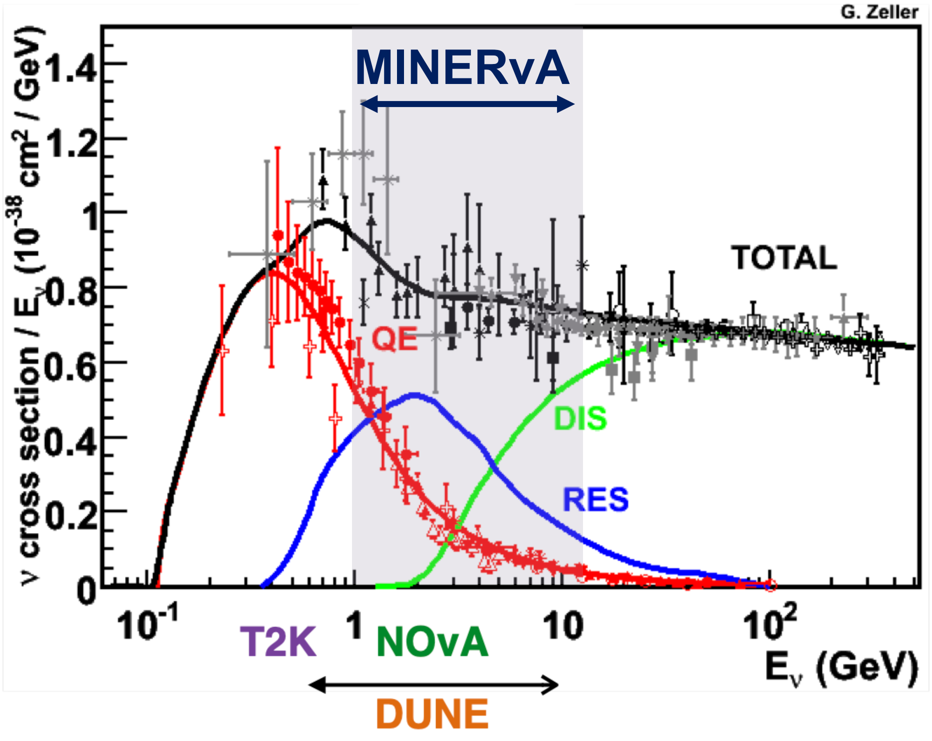
- Lots of measurements made on light nuclei
- To extrapolate results to other targets, like Ar for DUNE, **need to understand neutrino cross section scaling as a function of the mass number A**

The results that we'll be looking at today are **cross section measurements** of **different neutrino processes** on **different targets**

- When a few GeV neutrinos interact with a particle detector we get a range of different neutrino interactions:

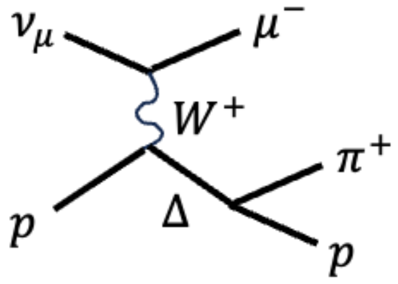
Quasi-elastic scattering:
Neutrino scatters elastically off the nucleon and ejects a nucleon from the target



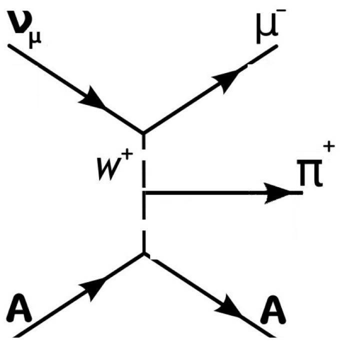


J.A. Formaggio, G. Zeller, Reviews of Modern Physics, 84 (2012)

Resonant production:
Neutrino excites target nucleon to an excited state

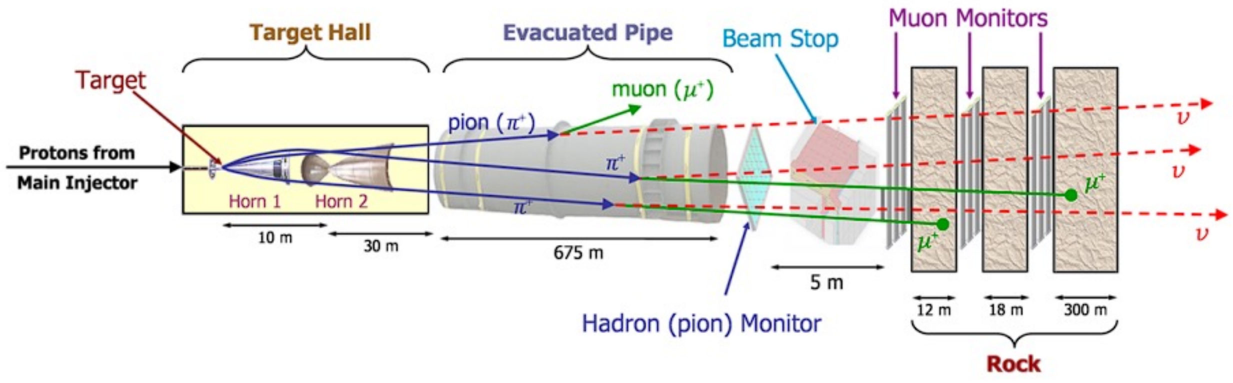


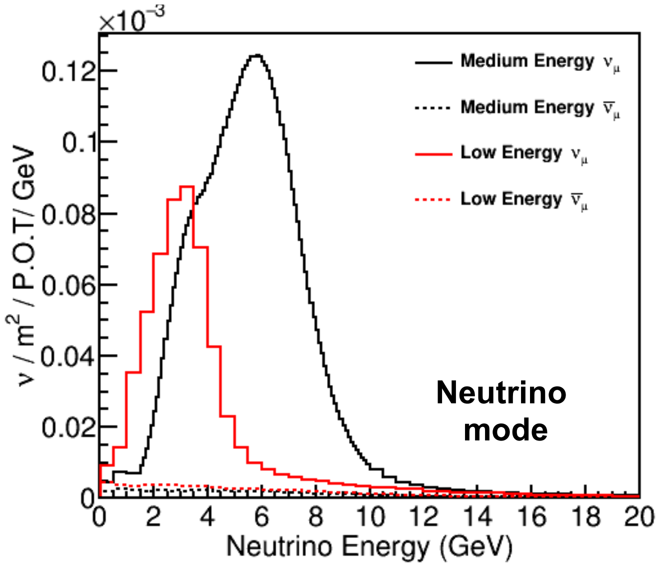
Coherent pion production:
Nucleons in nucleus recoil in phase and the nucleus remains in its initial quantum state



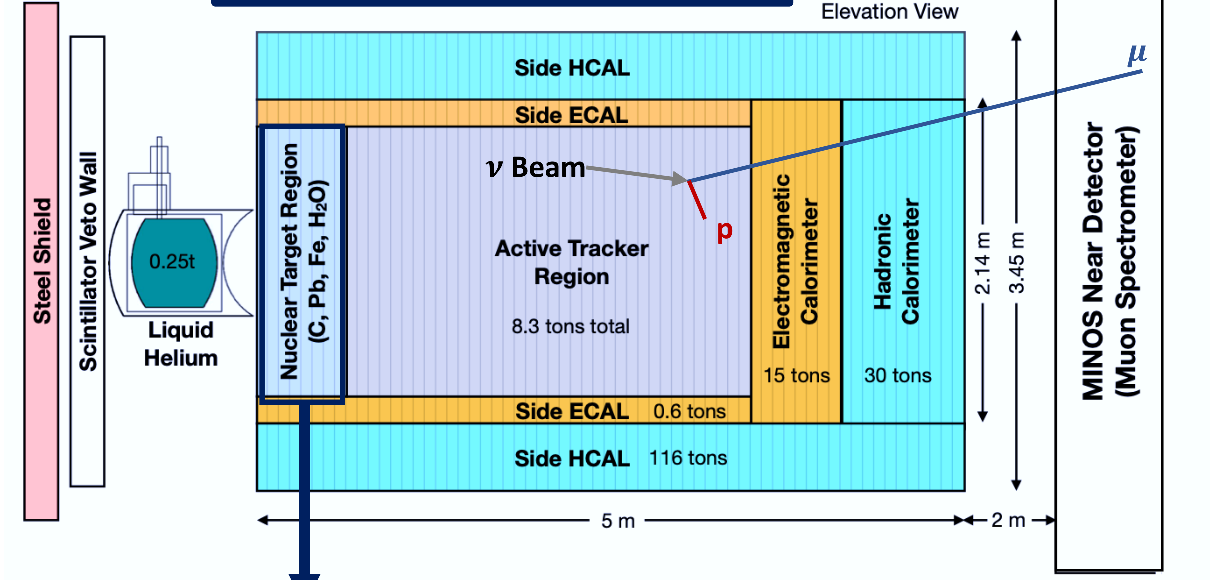
The results that we'll be looking at today are **cross section measurements** of **different neutrino processes** on **different targets**

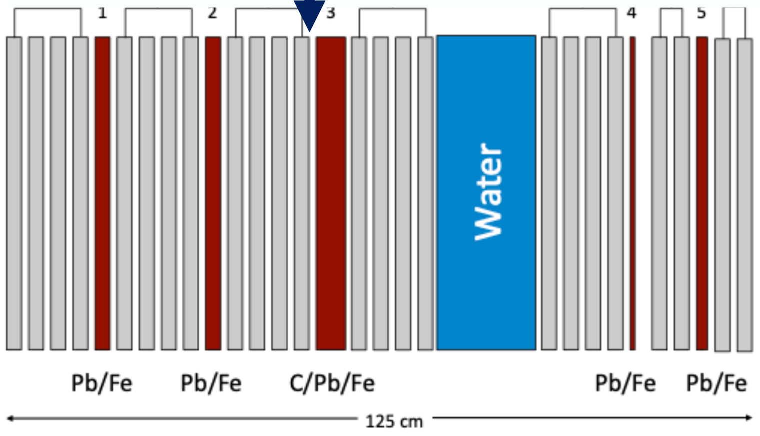
The NuMI Beamline





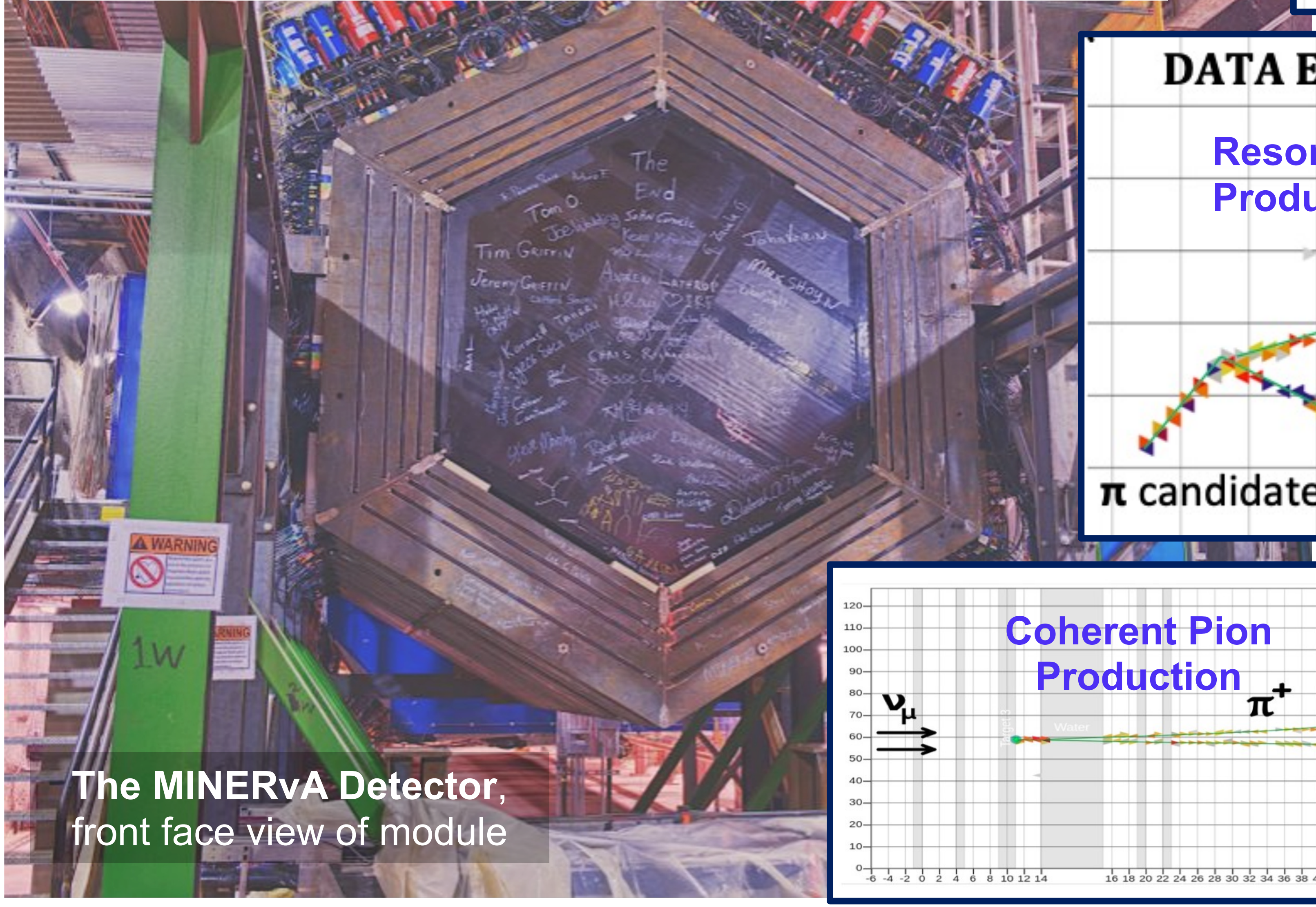
The MINERvA Detector



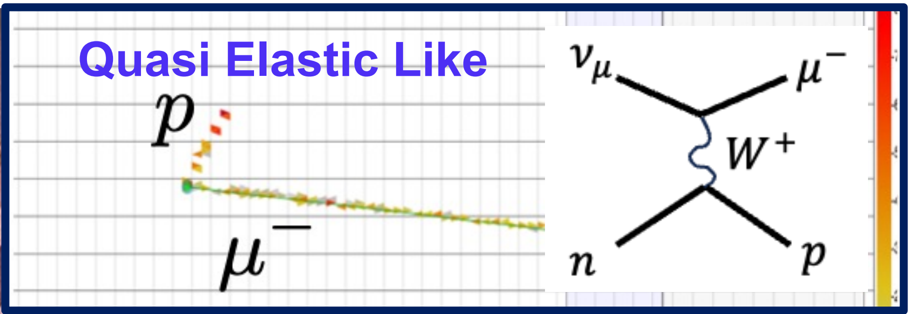


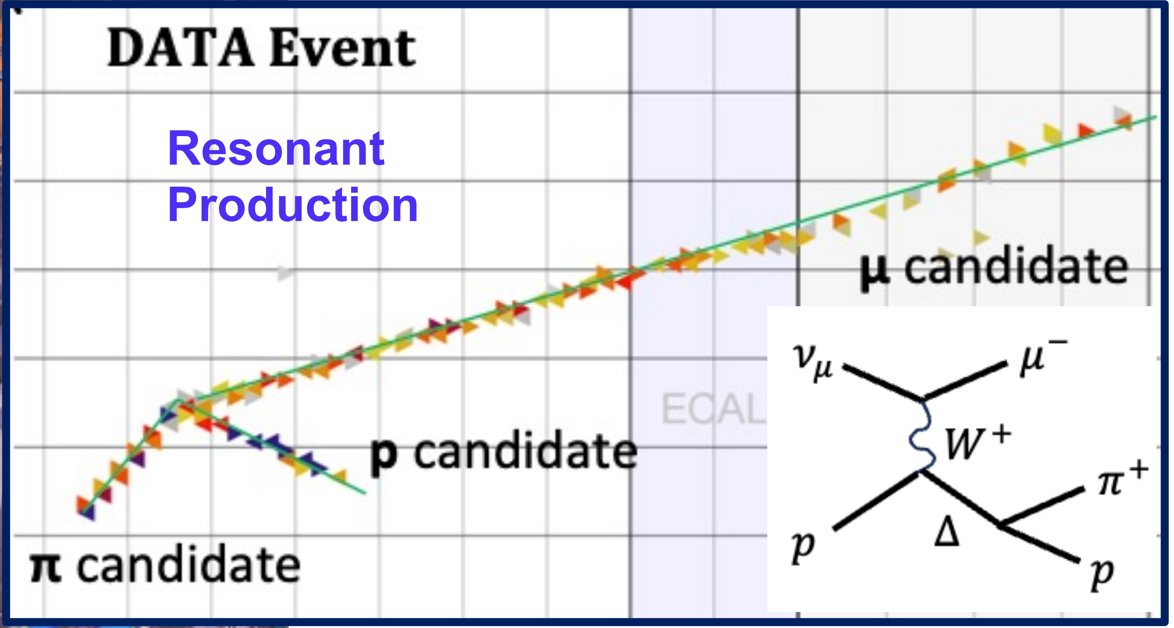
The MINERvA detector sideview. **Segmented with target planes** and interspersed with scintillator planes

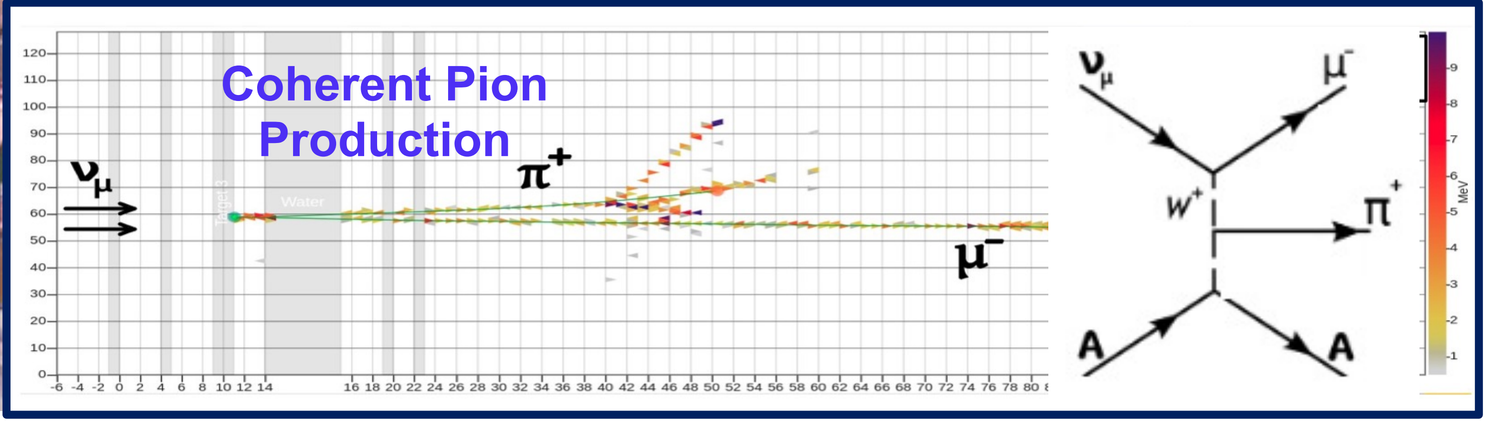
Event Displays for Different Neutrino Interactions



The MINERvA Detector,
front face view of module



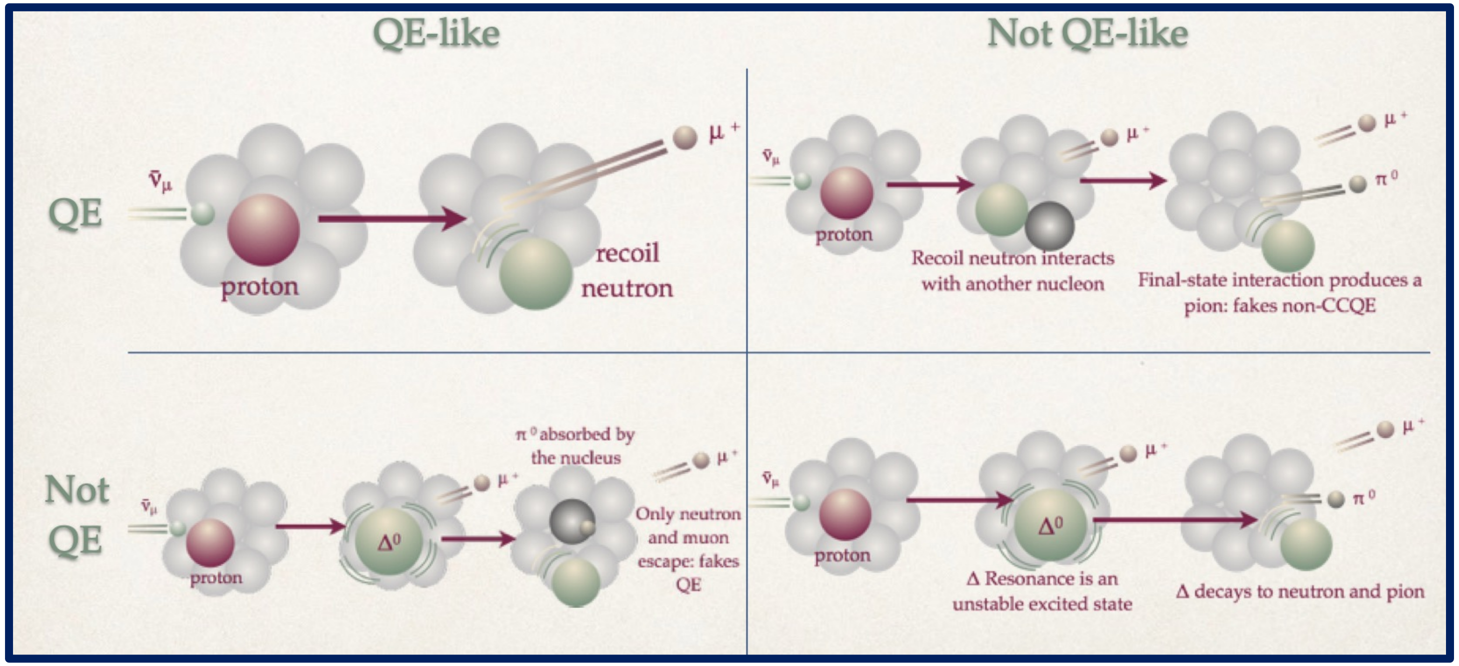




Challenges in the Field of Neutrino Physics

- Difficult to **reconstruct the neutrino energy**
- **Nuclear effects** complicate the landscape
  - Can cause energy smearing
  - Can change kinematics of the final state particles
- **Heavier targets have more nuclear effects**, hence more complicated, measurements on hydrogen and deuterium are great for single nucleon, but need to get to A

Final State Interactions



Quasi Elastic Like Example
Credit: Cheryl Patrick

First result:

Simultaneous Measurement of Muon Neutrino ν_μ Charged-Current Single π^+ Production in CH, C, H_2O, Fe, and Pb Targets in MINERvA

A. Bercellie,[1] K. A. Kroma-Wiley,[2,1] S. Akhter,[3] Z. Ahmad Dar,[4,3] F. Akbar,[3] V. Ansari,[3] M. V. Ascencio,[5,*]

The first result takes us for a **drive** …
through the periodic table

$$\nu_\mu + A \rightarrow \mu^- + \pi^+ + nucleon(s)$$

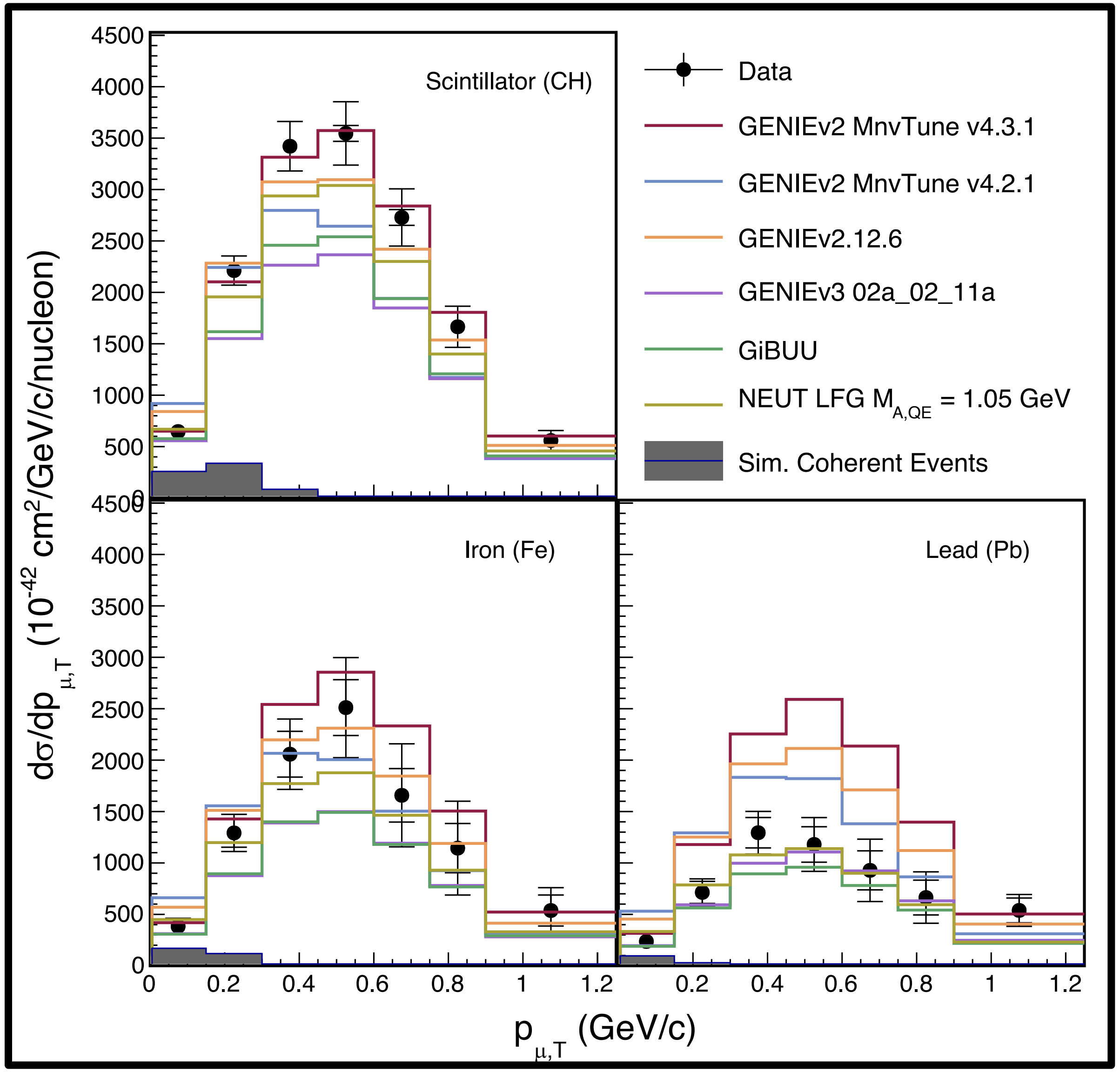
CC Single π^+ Production

Driving through the periodic table!

Studying **CC single pi+ production** events on various nuclei

Cross Sections on A

CC Single π^+ production



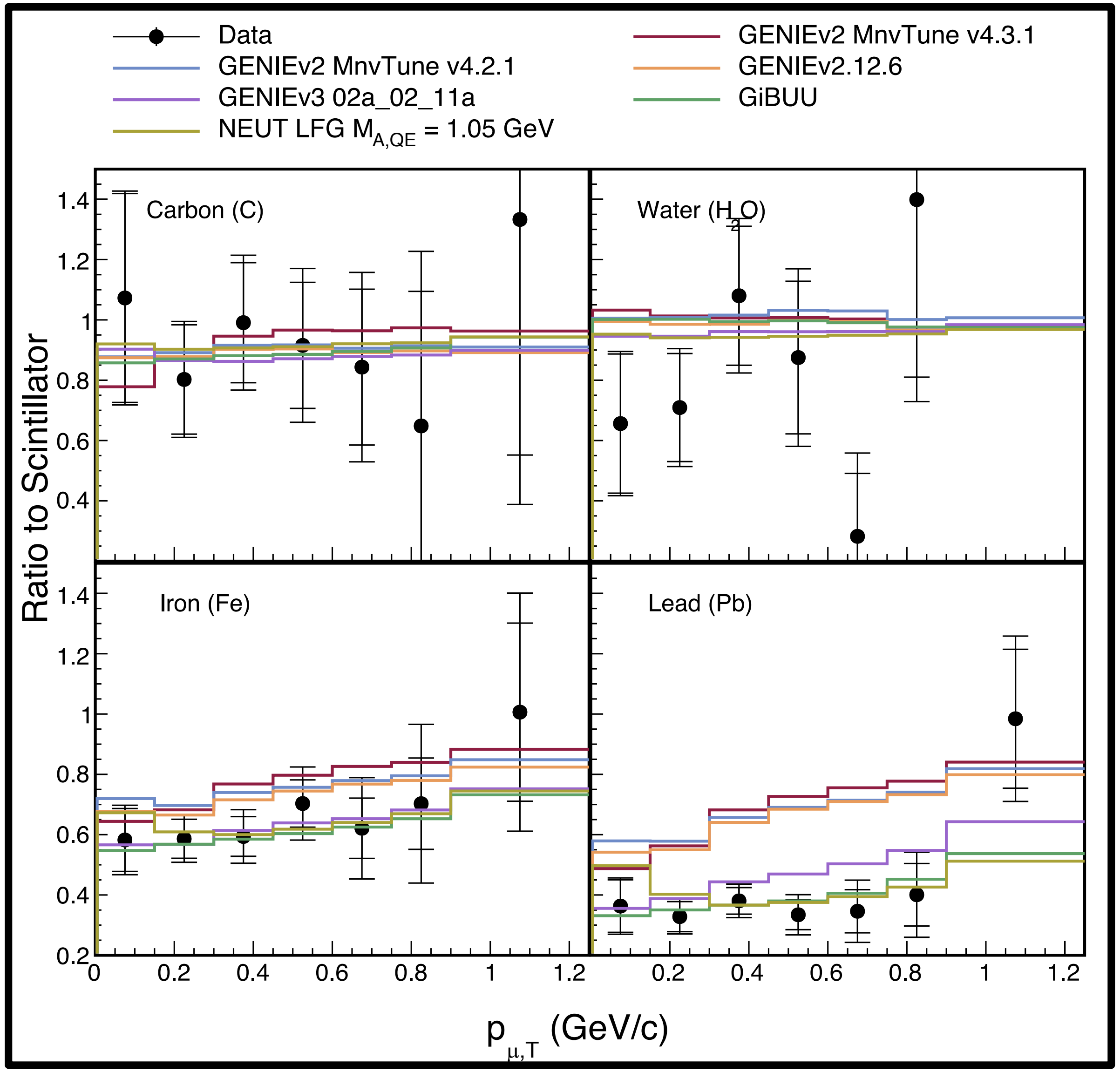
- For events with charged pions, we need a precise model of pion production to reconstruct neutrino energy
  - Essential for neutrino oscillation experiments

(Transverse to the neutrino beam)

- <u>On the x axis</u>: Transverse Muon Momentum
  - Proxy for momentum transferred to nucleus
- Compared with model predictions: GENIE, GiBUU, NEUT which are all discrepant for at least one target material
  - Models are assuming some A dependence, but their A-scaling is not a great match

Cross Section **Ratios**

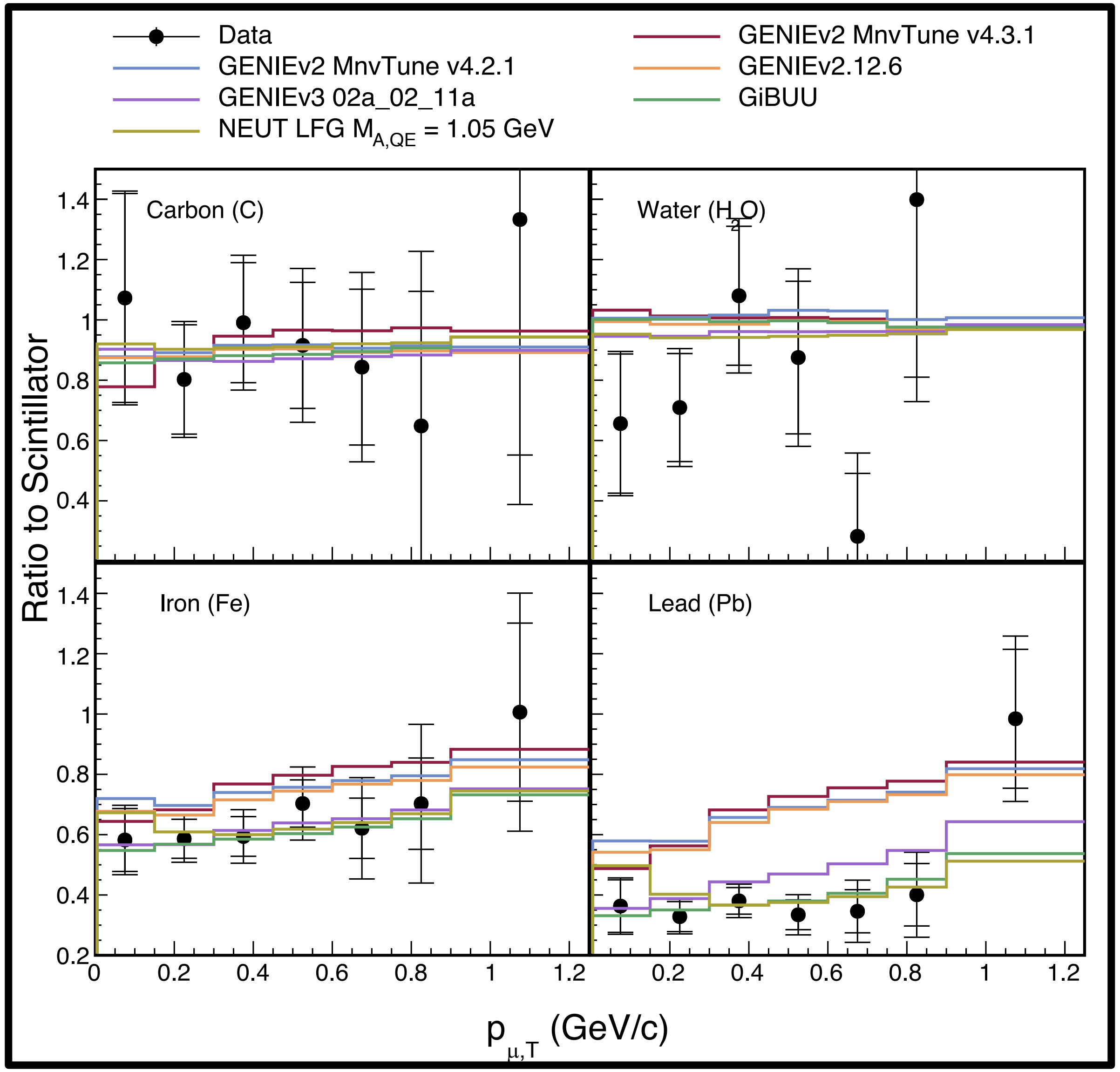
CC Single π^+ production



- <u>On the x axis</u>: Transverse Muon Momentum
- Cross section ratios of carbon or water to CH are 1
- Ratio of iron to scintillator: **0.8**
- Ratio of lead to scintillator: **0.5**
  - No large modifications in the shape of the ratio over pT or pion kinetic energy
- Same A-scaling across the kinematic variables probed
- Current models do not capture this A-scaling

Cross Section **Ratios**

CC Single π^+ production



- Ratio of pions produced on Fe or Pb compared to scintillator is **less than** predicted by current models

Is it because of fewer pions getting produced?

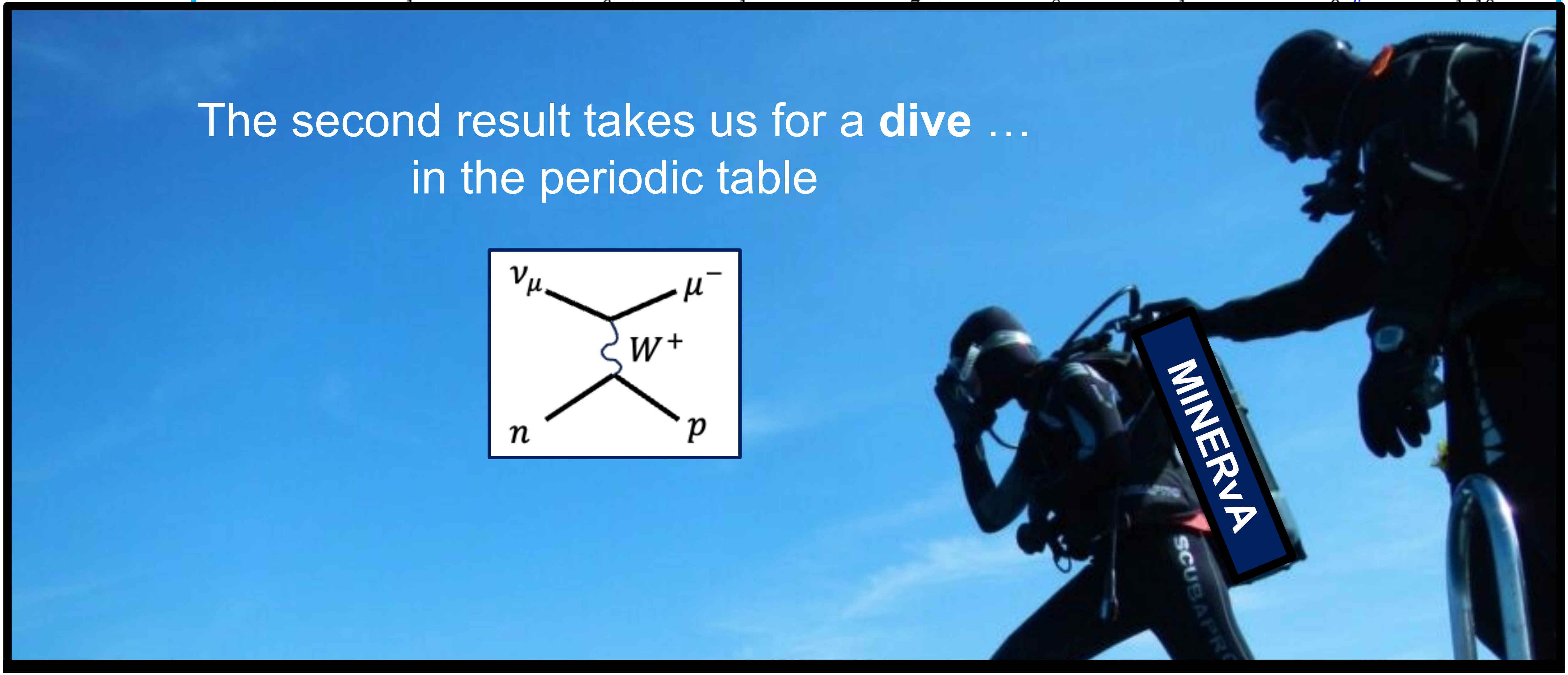
Is it because of more pions being absorbed than predicted?

- Above question remains to be answered … *stay tuned!*

Second result:

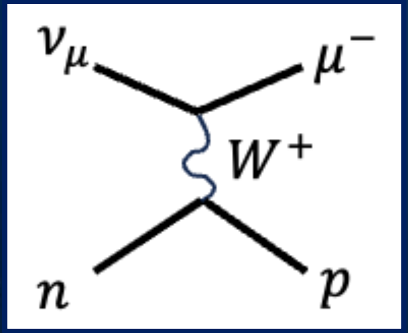
Simultaneous measurement of ν_μ quasielastic-like cross sections on CH, C, H_2O, Fe, and Pb as a function of muon kinematics at MINERvA

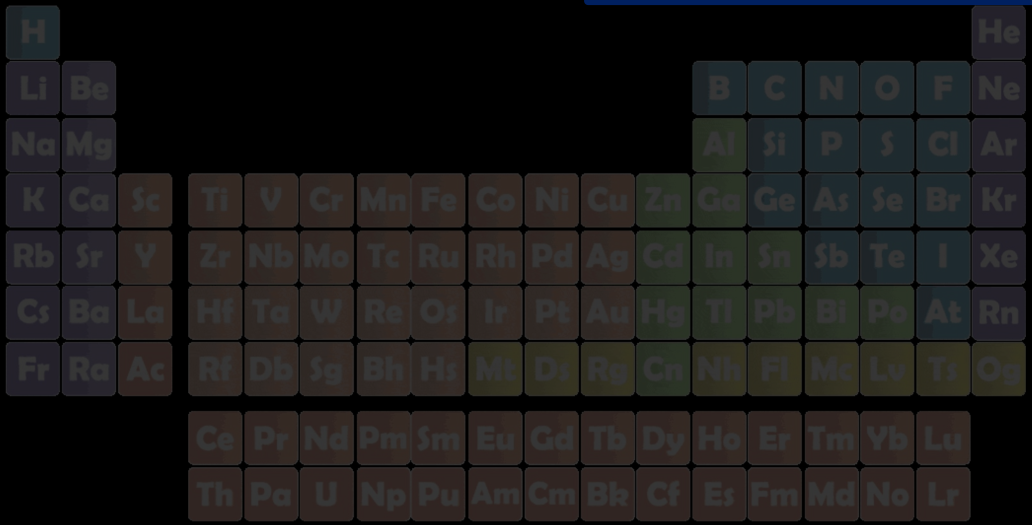
J. Kleykamp,[1,*] S. Akhter,[2] Z. Ahmad Dar,[3,2] V. Ansari,[2] M. V. Ascencio,[4,†] M. Sajjad Athar,[2] A. Bashyal,[5,‡]



Diving into the periodic table!

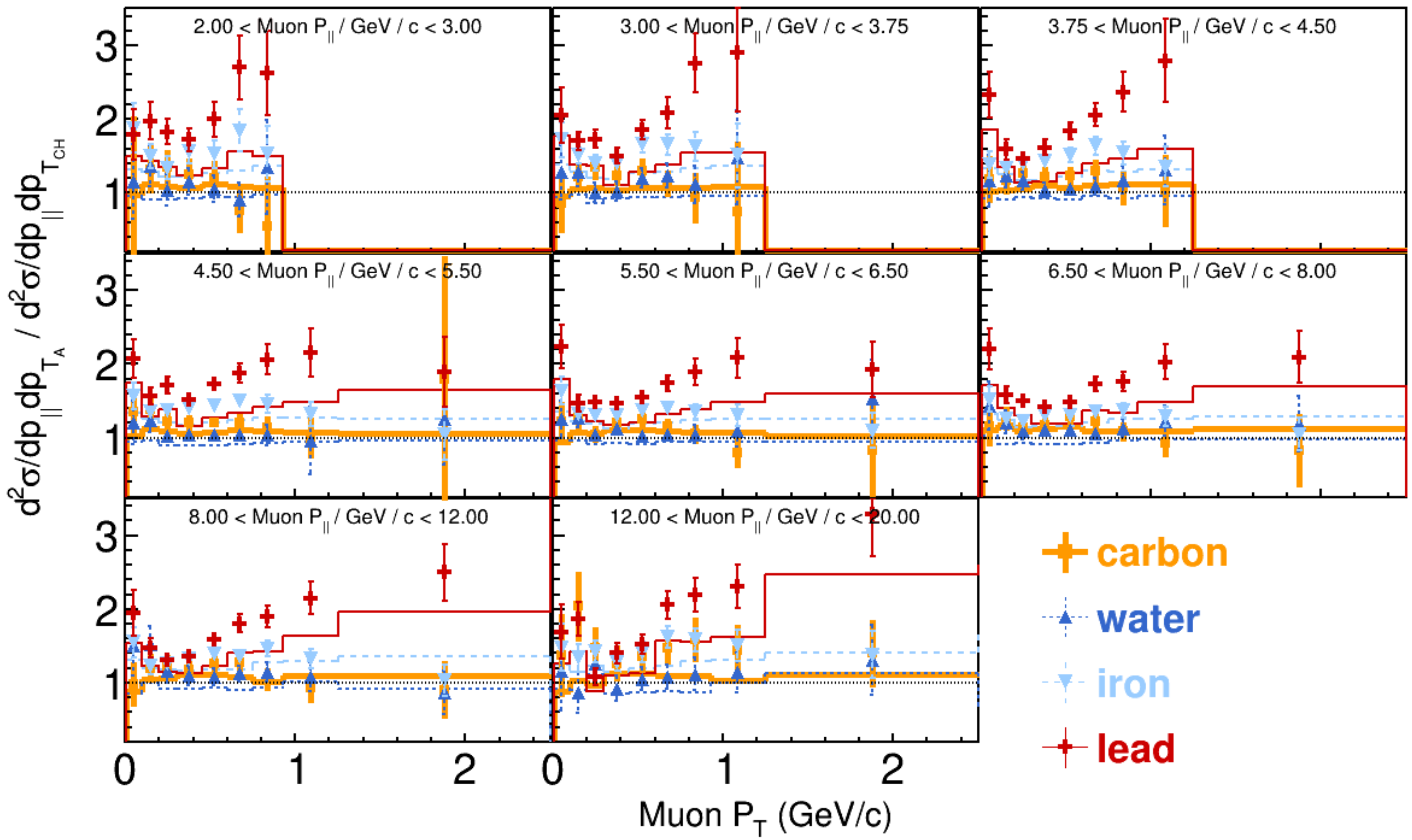
Studying **QE like interactions** on various nuclei





Cross Section **Ratios**

Quasielastic-like



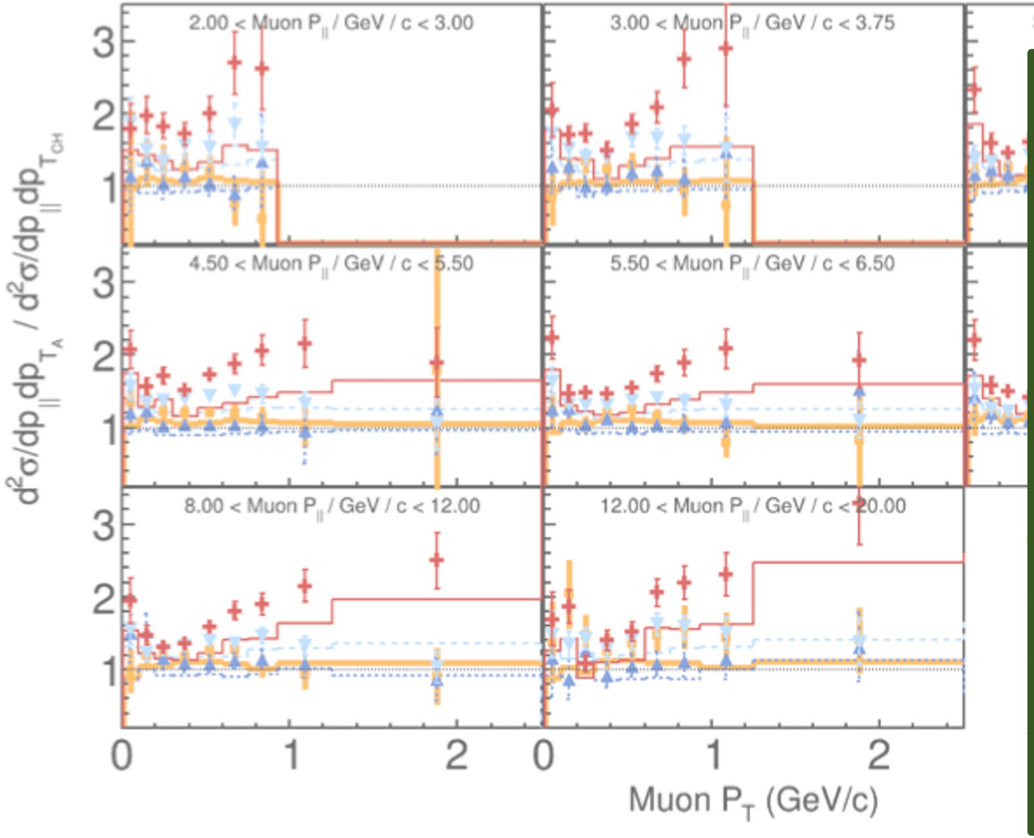
- **2-Dimensional plot** with **muon transverse momentum** on the x axis and panels of **muon longitudinal momentum**
- Double differential cross section ratio taken with scintillator for different target materials

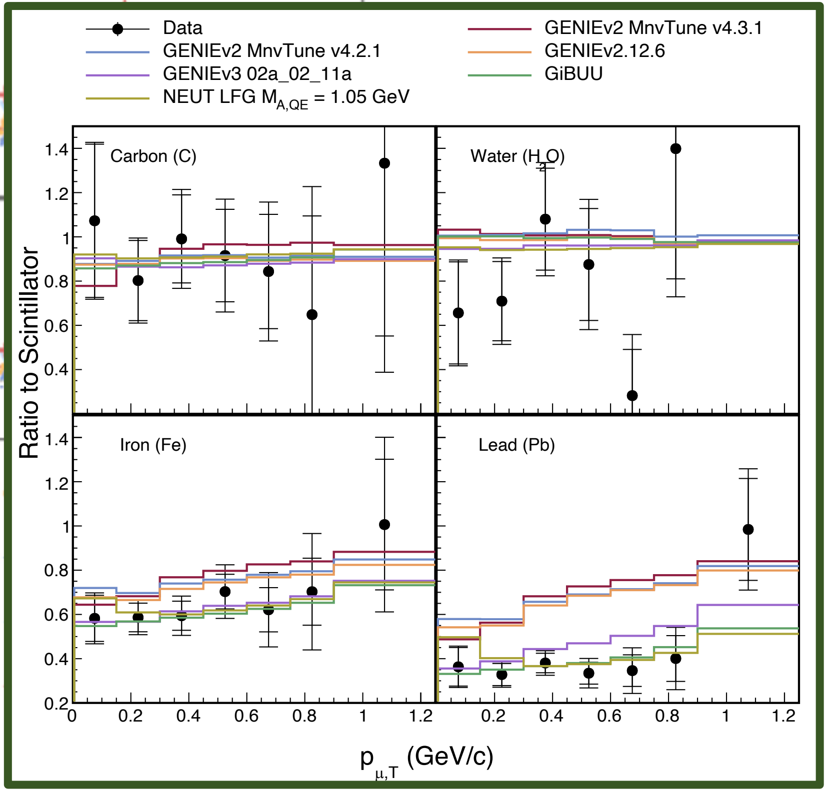
Cross Section **Ratios**

Quasielastic-like

At low pT: significant contribution from <u>pion production followed by absorption</u>

At high pT: QE interactions dominate

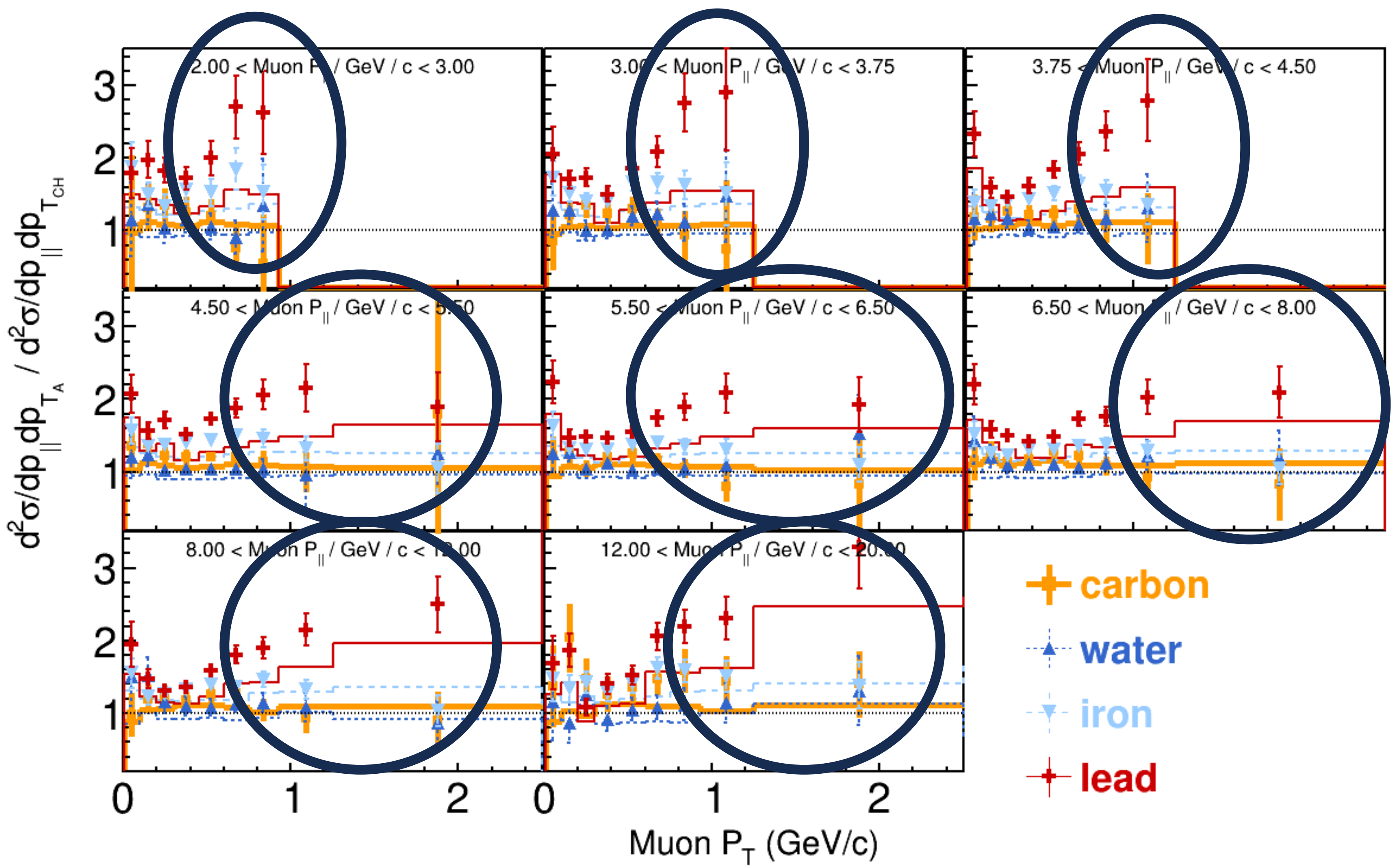




From the first result: A-scaling for single pion production on Fe and Pb is **less than** what's predicted → since the pions are appearing as signal in the QE-like result that indicates there are more pions getting absorbed for higher A nuclei **AS OPPOSED TO** less pions getting created

Cross Section **Ratios**

Quasielastic-like



At HIGH pT, the A-scaling for the QE xsec ratio is higher than predicted!

- **Discrepancy with the base model grows with the mass number**
- A-scaling not constant as a function of momentum transferred to the nucleus and <u>not predicted by models</u>

Third result:

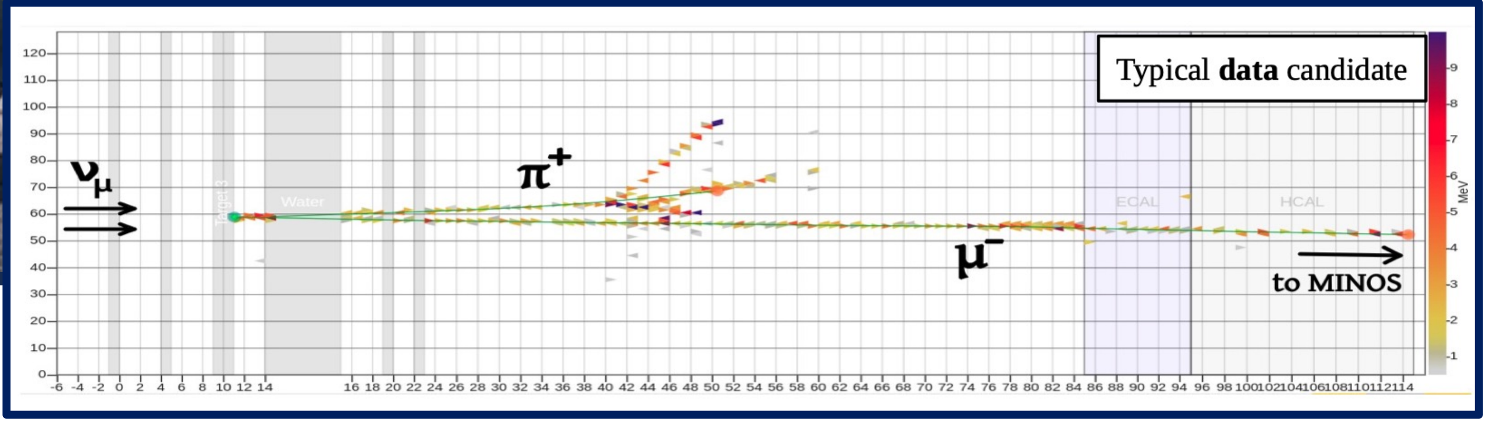
Neutrino-induced coherent π^+ production in C, CH, Fe and Pb at $\langle E_\nu \rangle \sim 6$ GeV

M.A. Ramírez,[1,2] S. Akhter,[3] Z. Ahmad Dar,[4,3] F. Akbar,[3] V. Ansari,[3] M. V. Ascencio,[5,*] M. Sajjad Athar,[3]

The third result gives us a **ride…** through the periodic table … **on a motorcycle**

- Event sample is a fraction of CC1pi+ sample used for the first result

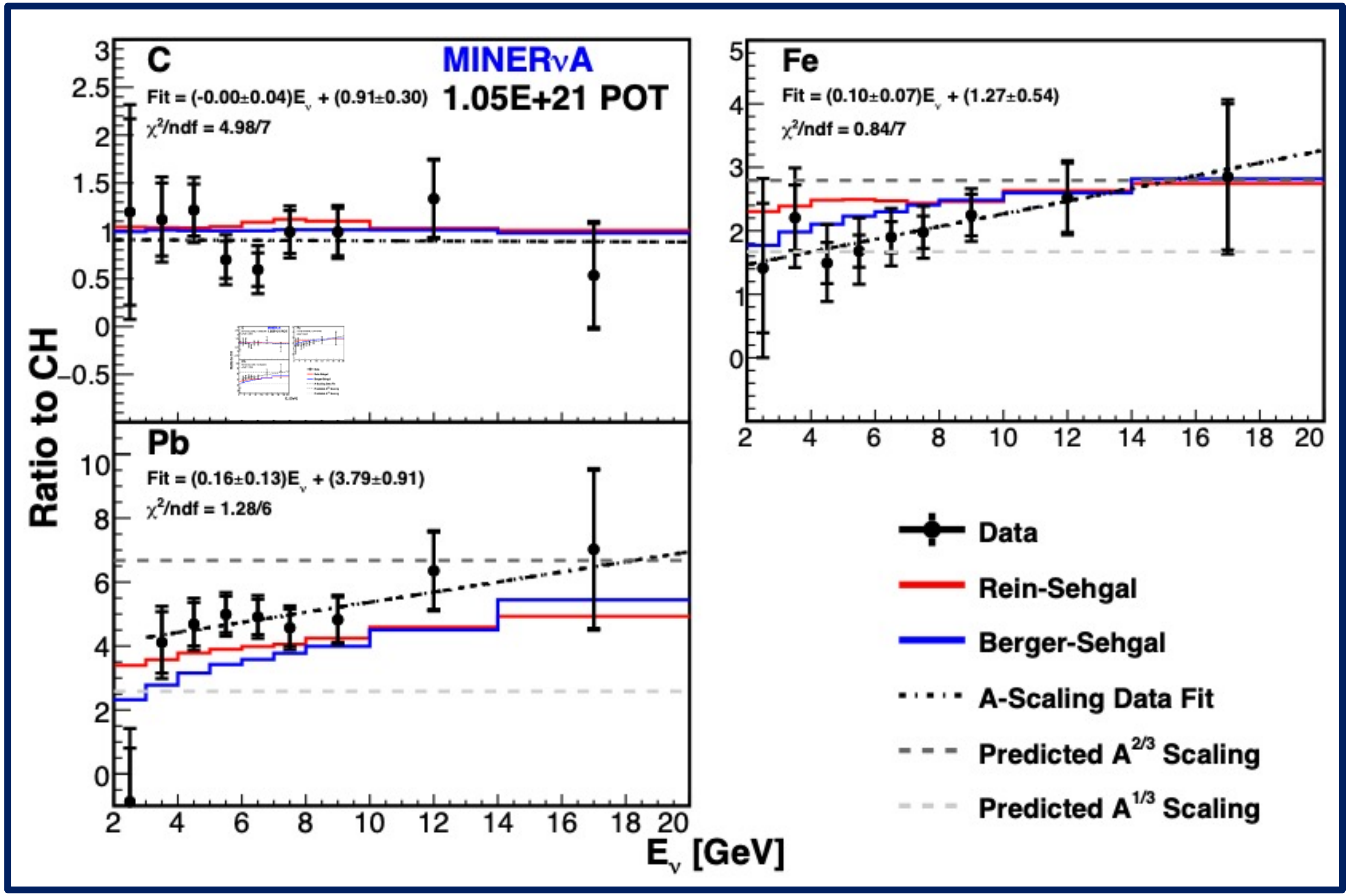
Coherent π^+ production



Cross Section **Ratios**

Coherent π^+ production

- Absolute neutrino cross section ratios to scintillator
- For xsec ratios of Fe and Pb, A-scaling increases from around $A^{1/3}$ at low neutrino energies to $A^{2/3}$ for neutrino energies > 10 GeV
- This estimate of the cross-section's A-scaling can be used to extrapolate to other target materials like Ar for DUNE



Conclusion

- **Interpreting cross section measurements** can be difficult because of **nuclear effects**
- **We have models of neutrino interactions on bare nucleons and then we need to add the effects of the nucleus on top of that**
  - Important to understand the relationship between nuclear effects and cross section measurements to achieve precision in oscillation experiments
- Models for cross sections aid in neutrino oscillation experiments by enabling them to translate the number of events that they see at a far detector to some incoming neutrino flux
- More simultaneous measurements of neutrino interactions on different nuclei in the pipeline, please stay tuned!
  - Also, a data preservation product will be available!

THANK YOU!

Backup