Recent results from MINERνA

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THE 24th INTERNATIONAL WORKSHOP ON NEUTRINOS FROM ACCELERATORS
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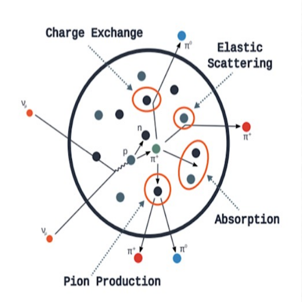
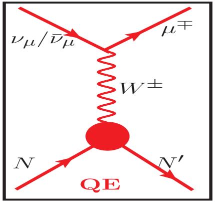
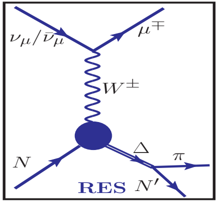
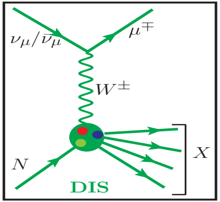
MINERνA Physics Motivation

- For better understanding of neutrino properties, we require precision measurements of the oscillation parameters
- Pursuit of neutrino oscillation physics has forced us into a rather complex (few GeV) region of neutrino interaction physics
- The oscillation experiments will be detecting ν interaction with nuclear targets
- Current and future oscillation experiments like NOvA, T2K, DUNE and Hyper-K are searching for CP violation in weak sector and Beyond-the-Standard model physics

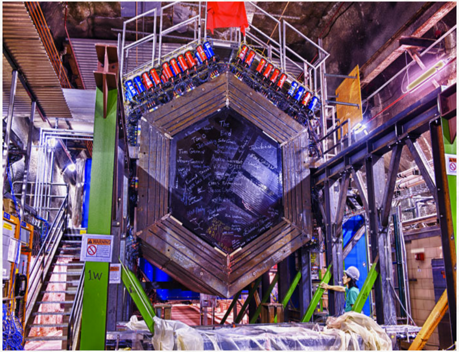


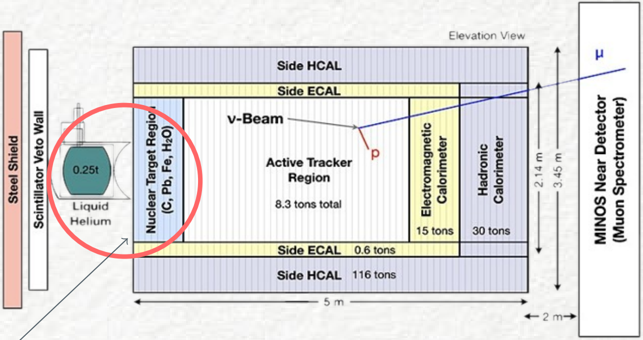


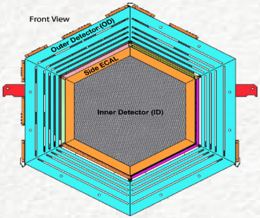


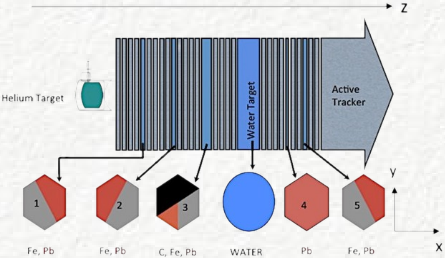


Main INjector ExpeRiment for $\nu - A$



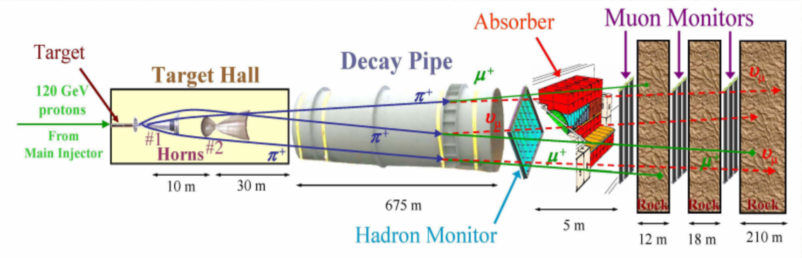


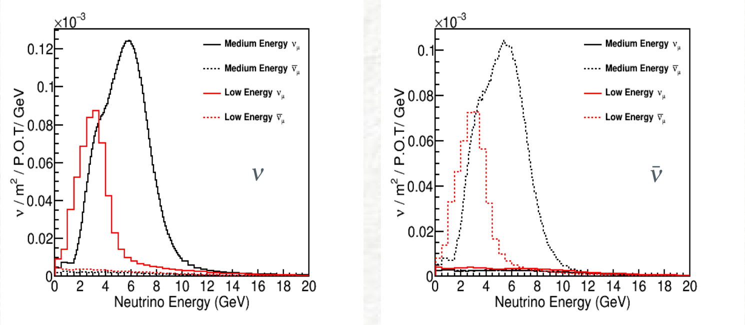




- MINERνA, a scintillator based neutrino detector designed for measuring $\nu_\mu/\bar{\nu}_\mu - A$ cross sections
- Located in NuMI beamline and recorded data between 2009 and 2019

The NuMI beamline and flux at MINERvA





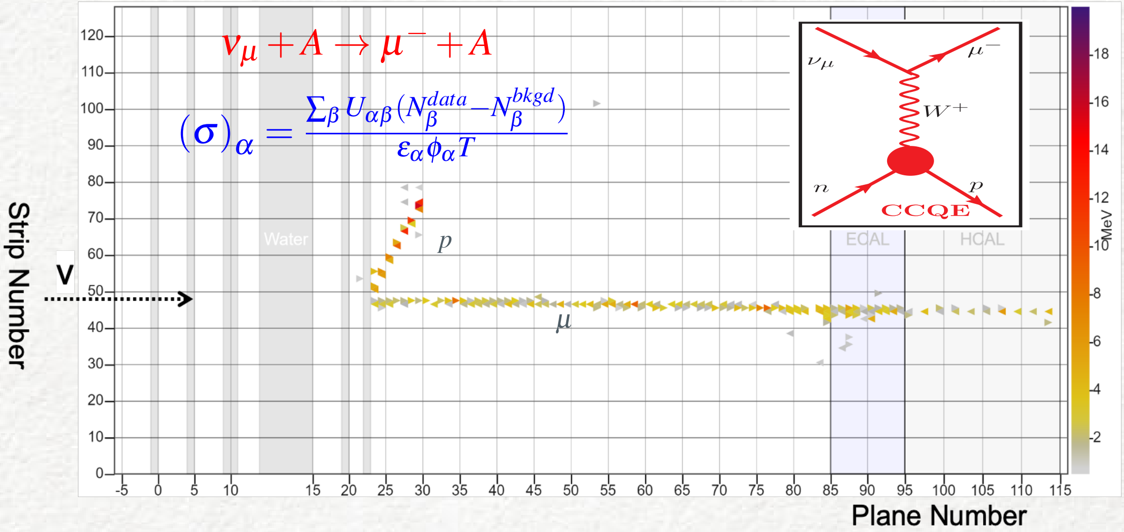
- MINERvA had two run periods, low energy and medium energy

POT (LE mode):
4×10^{20} (ν) | 1.7×10^{20}($\bar{\nu}$)
POT (ME mode):
12.1×10^{20} (ν) | 12.4×10^{20}($\bar{\nu}$)

Special thanks to everyone at Fermilab accelerator and computing division!

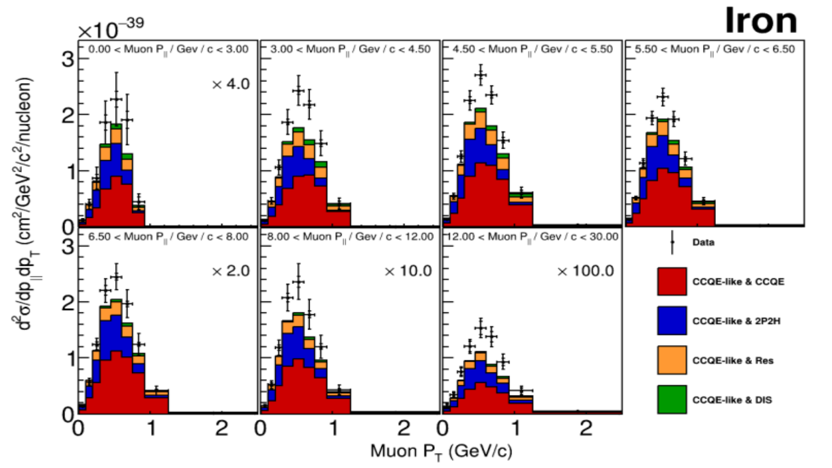
Today's topics

- Nuclear dependence on :
  - Neutrino CCQE-like: A-dependence on C, CH, H_2O, Fe, Pb
  - Neutrino CC1π^+: A-dependence on C, CH, H_2O, Fe, Pb
  - Neutrino CC1π^0: A-dependence on Fe, Pb
- Antineutrino CCQE-like on CH



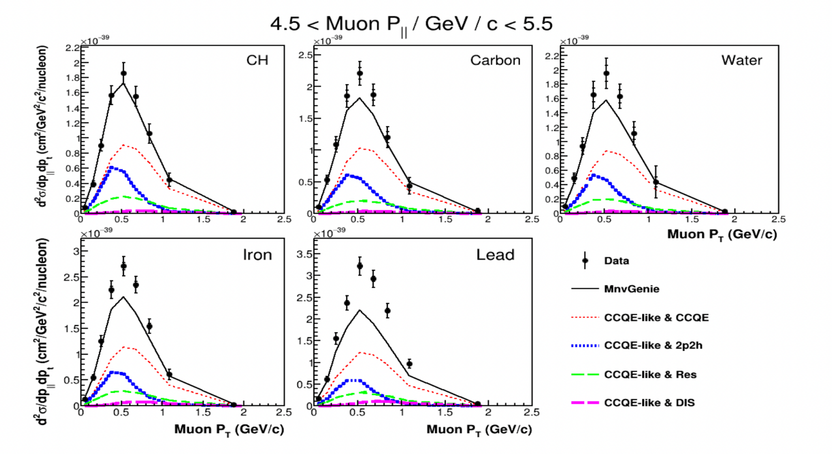
- Double differential cross sections vs muon kinematic variables have been measured

ν_μ CCQE-like on CH, C, H_2O, Fe, Pb: *Phys.Rev.Lett.130(2023)161801*



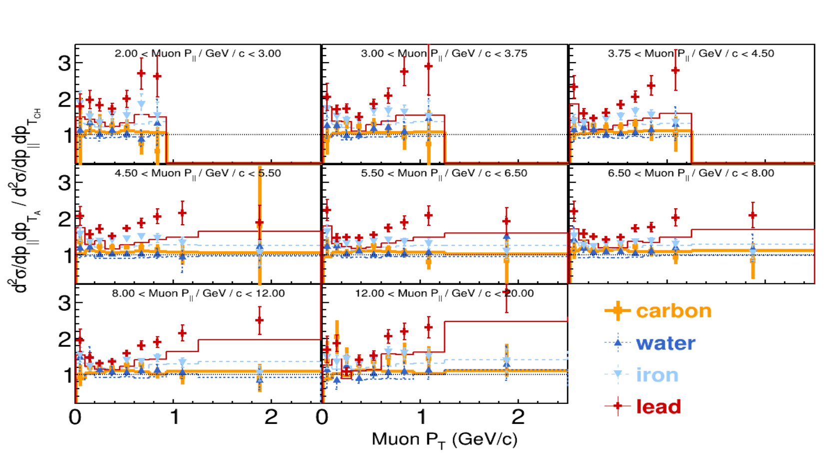
- The double differential cross sections obtained in terms of muon traverse and longitudinal momentums
- Interactions simulated using GENIE 2.12.6 with additional tunes (details in Raquel's Plenary talk & in backup)
- In most of the bins, GENIE simulation underpredicts the data in Fe

ν_μ CCQE-like on CH, C, H_2O, Fe, Pb: *Phys.Rev.Lett.130(2023)161801*



- The cross sections vs different materials in highest-statistics $P_{||}$ bin
- Model agrees with the data fairly well in scintillator, which it is tuned to
- Model underpredicts all other heavier targets, and magnitude increases with mass number

ν_μ CCQE-like on CH, C, H_2O, Fe, Pb: *Phys.Rev.Lett.130(2023)161801*

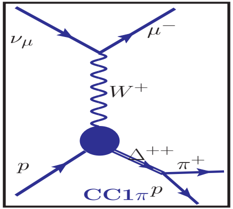


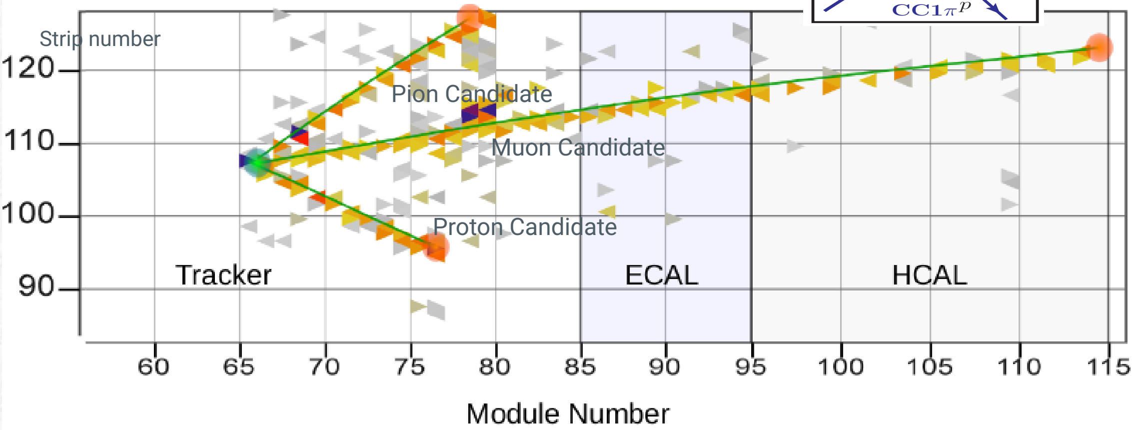
- Ratios of cross section on passive nuclear targets to cross section on CH were measured
- Model underpredictions holds: performance increasing poorly with increasing mass number

ν_μ CC1π on CH, C, H_2O, Fe, Pb: *Phys.Rev.Lett. 131 (2023) 011801*

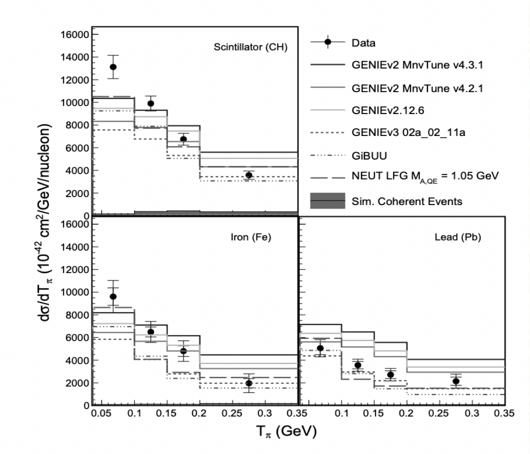
$$\nu_\mu + p \rightarrow \mu^- + p + \pi^+$$

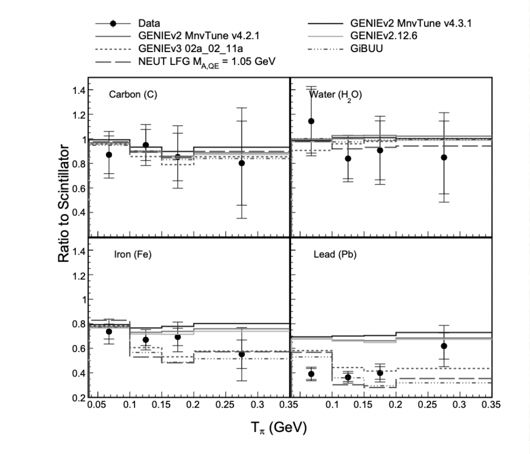
$$(\sigma)_\alpha = \frac{\sum_\beta U_{\alpha\beta}(N_\beta^{data} - N_\beta^{bkgd})}{\varepsilon_\alpha \phi_\alpha T}$$





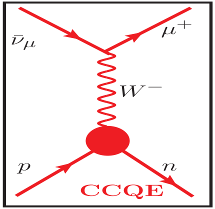
ν_μ CC1π on CH, C, H_2O, Fe, Pb: *Phys.Rev.Lett. 131 (2023) 011801*

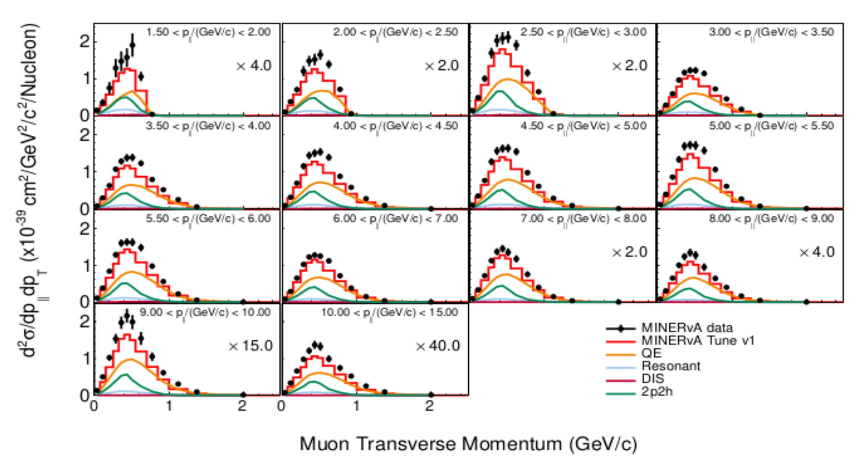




- Carbon and water ratios consistent with unity (stats. limited)
- Model overpredicts pions in heavy nuclei, opposite trend to CCQE-like discrepancy
- Points to pion absorption as potential source of mismodeling

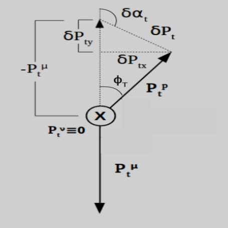
$\bar{\nu}_\mu$ CC 0π on CH: *Phys.Rev.D 108 (2023) 032018*

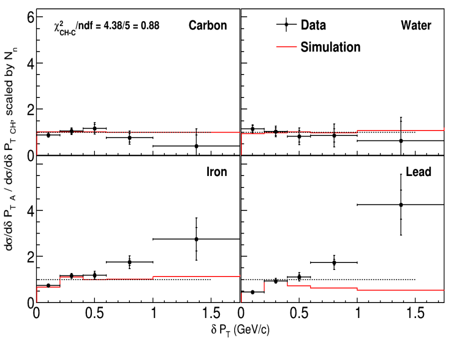




- More statistics, more phase space in comparision to our LE measurements
- Measurements indicate model underpredictions in all $p_{||}$ bins
- This study is the background to CCE analysis on hydrogen target: discussed by Prof. Kevin McFarland

- Transverse kinematic imbalance: isolate nuclear effects

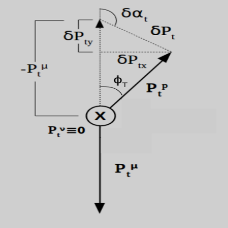


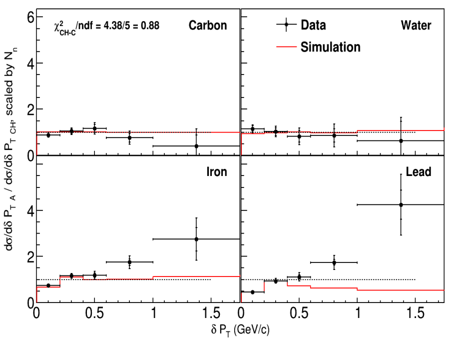


Jeffrey Kleykamp, FNAL Wine and Cheese Seminar, 3-24-23

ν_μ CCQE-like (left) & ν_μ CC1π^0 (right): *Papers in Preparation*

- Transverse kinematic imbalance: isolate nuclear effects





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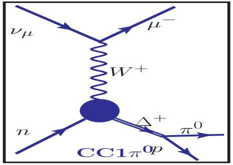
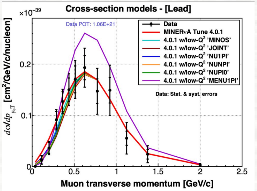
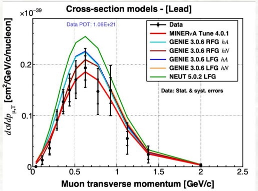
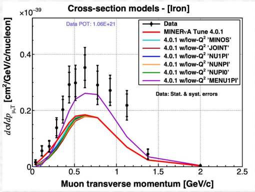


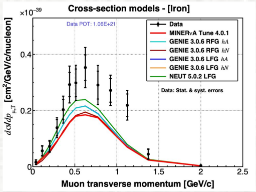
"Internal" models

"External" models









G. Diaz and A. Bercellie, FNAL W&C Seminar, 12-02-2022

Coming soon

Quasi-elastic

- 3D vs transverse kinematic imbalance variables
- Nu/Antinu ratios
- Neutron tagging

Low hadronic recoil

- Interactions with 2+ neutrons
- Electron neutrinos and Electron antineutrinos
- Interactions with charged pions

Inelastic

- Many Deep Inelastic Scattering (DIS) results
- Shallow Inelastic Scattering (SIS) results
- Interactions on Helium

And more!

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Data preservation at MINERνA

MINERνA has produced a data preservation product to ensure more physics can be extracted from the data going into the DUNE era!
Analysis framework and data preservation tuples Snowmass 2021 Contributed Paper

Thank You!

The End?
Tom O.
Tim Griffin
Jeremy Griffin
John Voirin
Mark Shoun
Andrew Lathrop
Jesse Chvojka

Backup

MINERνA tunes

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

MnvTunev 4.0.1: GENIE 2.12.6 with the following tunes

- Enhancement of 2p2h cross-section for low hadronic recoil interactions
- Modification of QE cross-section as function of q_0 and q_3
- Modification of resonant and non-resonant single-pion production cross-section from ANL/BNL bubble chamber re-analysis

MnvTunev 4.2.1: MnvTunev 4.0.1 with following tunes

- Reweight from recent MINERvA coherent π^+ production data
- Ad-hoc enhancement of coherent π^+ production on CH and H_2O to account for diffractive π^+ production

MnvTunev 4.3.1: MnvTunev 4.2.1 with following tunes

- Additional tune using the ratio of non-hydrogen cross sections extracted for the analysis on scintillator in data and simulation