

CC ν_μ $1 \pi^+$ production at MINERvA

New Perspectives 2023 Conference



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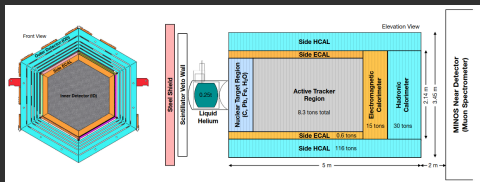
División de Ciencias e Ingenierías
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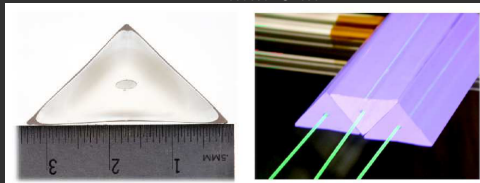
MINERvA Experiment



- The MINERvA experiment (Main INjector ExpeRiment ν -A)
- Neutrino cross section measurements in 6 different materials.

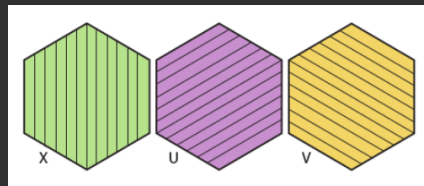


MINERvA Detector Sketch

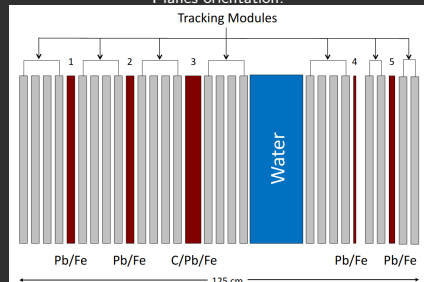


Plastic scintillator strips.

Images from <https://arxiv.org/pdf/1305.5199.pdf>



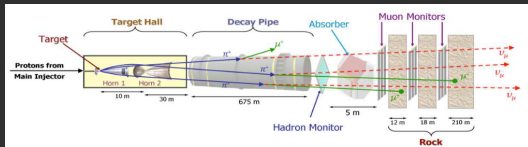
Planes orientation.



Target region.

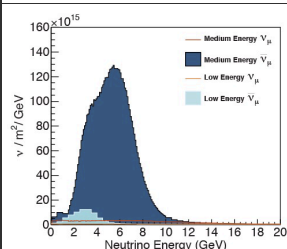
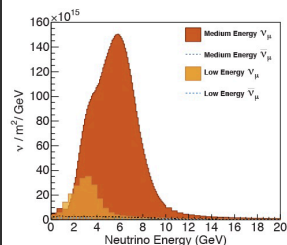


NuMI (Neutrinos at the Main Injector) Beam



- The data taken by the detector is divided in two eras, Low Energy era (LE) and Medium Energy era (ME), for neutrino (ν_μ) and antineutrino ($\bar{\nu}_\mu$) modes.

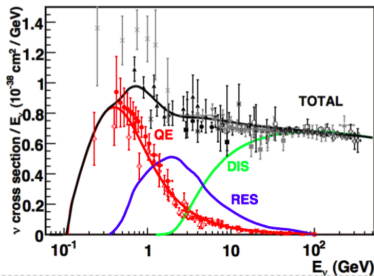
- LE $\langle E_\nu \rangle = 3$ GeV (2009-2012)
- ME $\langle E_\nu \rangle = 6$ GeV (2013-2019)



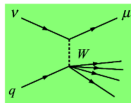
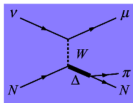
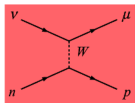
Top: ν_μ mode. Bottom: $\bar{\nu}_\mu$ mode



MINERvA Experiment



J.A. Formaggio, G.P. Zeller, Rev. Mod. Phys. 84, 1307 (2012)

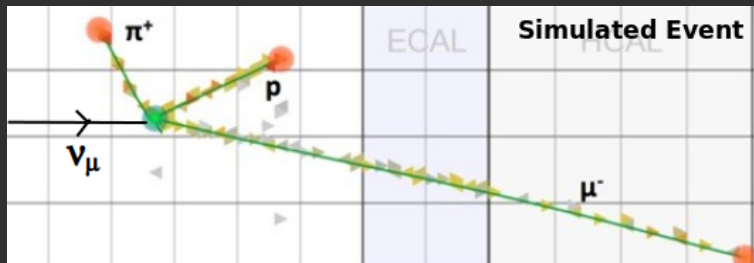


- Why MINERvA matters to oscillation experiments?
 - Developed techniques to reduce flux uncertainties
 - Reduce cross section uncertainties
- In MINERvA we use GENIE as neutrino event generator
- Inclusive Analysis
- Exclusive Analysis



Signal definition

- CC $\nu_\mu A \rightarrow \mu^- \pi^\pm X$ at MINERvA analysis. Depending of the analysis, it can be on the tracker or targets region.



<https://minerva.fnal.gov/>



Differential Cross Section

Events Selected

Unfolding

Backgrounds

$$\left(\frac{d\sigma}{dx}\right)_\alpha = \frac{\sum_j U_{j\alpha} (N_{data,j} - N_{data,j}^{bkgd})}{A_\alpha (\Phi T) (\Delta x)}$$

Acceptance

Flux

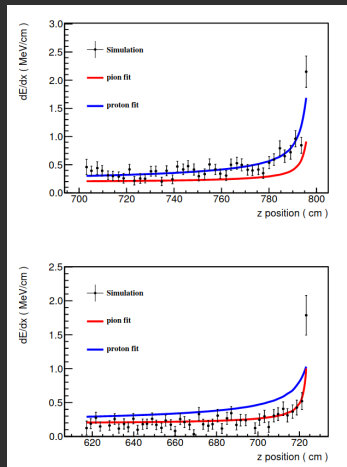
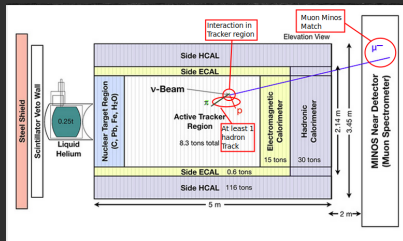
Targets

Bin-width



Event Selection

- Vertex in the tracker or targets.
- μ^- cuts.
- At least one hadron track.
- One Michel electron.
- dE/dx Particle Identification.
- $W_{exp} = m_N^2 - Q^2 + 2m_N E_{had} < 1.4 \text{ GeV}$.

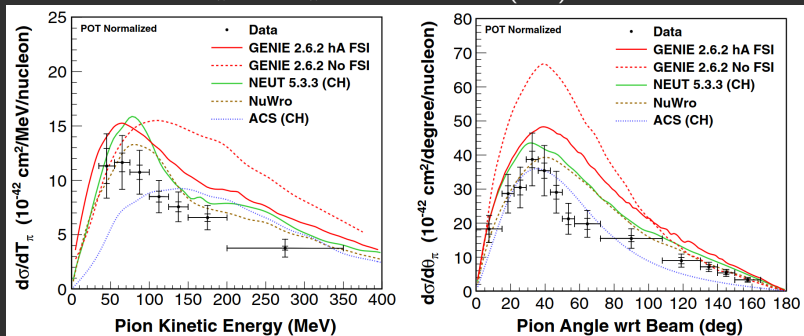


dE/dx simulated profiles for protons (Top) and pions (bottom).
Nucl. Inst. and Meth. A743 (2014) 130



Cross Section for LE Analysis

- Cross Section for T_π and θ_π on scintillator (CH).

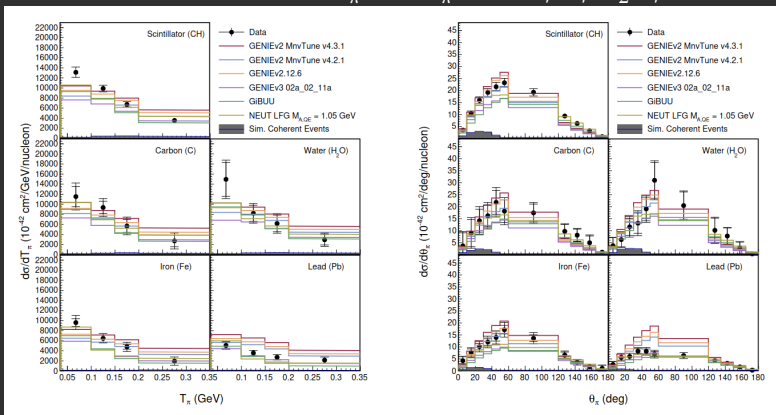


Measured cross section compared with different models. PHYSICAL REVIEW D 92, 092008 (2015)



Cross Section for ME Analysis in MINERvA targets

- More data! Cross Section for T_π and θ_π on CH, C, H₂O, Fe and Pb.



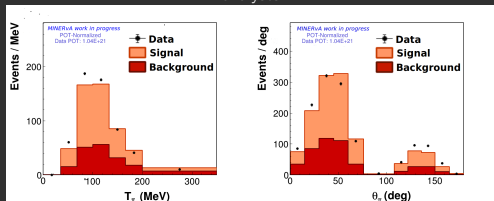
Measured cross section compared with different models. <https://arxiv.org/pdf/2209.07852.pdf>



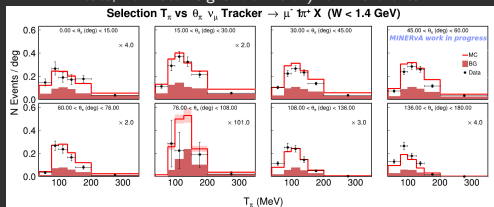
What's coming next for the ME era?

- Cross section $CC\ 1\pi^+$ production in the MINERvA tracker analysis in ME era.
- Other analyses:
 - Tracked and trackless $CC\ 1\pi^+$ in the MINERvA tracker.
 - 2D cross section $CC\ 1\pi^+$ production in the MINERvA tracker analysis.
- And more ...

Event selection for the $CC1\pi^\pm$ in MINERvA tracker for the ME era analyses.



Signal (Match cuts, match signal definition) and background (Match cuts, no Match signal definition) for MC events.



Data Selection for 2D analysis.

Conclusions



- More MINERvA analyses are coming!!
- CC $1 \pi^+$ are very important to:
 - Improve nuclear models.
 - Reduce uncertainties
 - And more ...
- The MINERvA Collaboration has a large data set to be analyzed.
- A lot things to be discovered ...



Thank you!!

