Mateus F. Carneiro

Oregon State University

NuFact 2018

August 15 2018

Recent Results from MINERvA

Outline

Challenges and motivation

The detector

Recent Results

Outline

Challenges and motivation

The detector

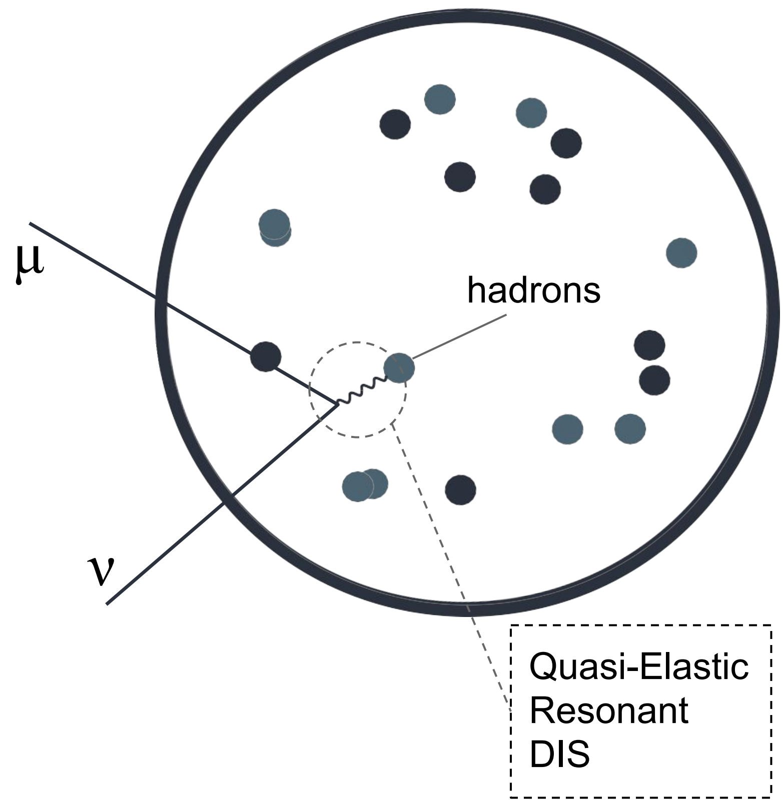
Recent Results

The Nucleus!

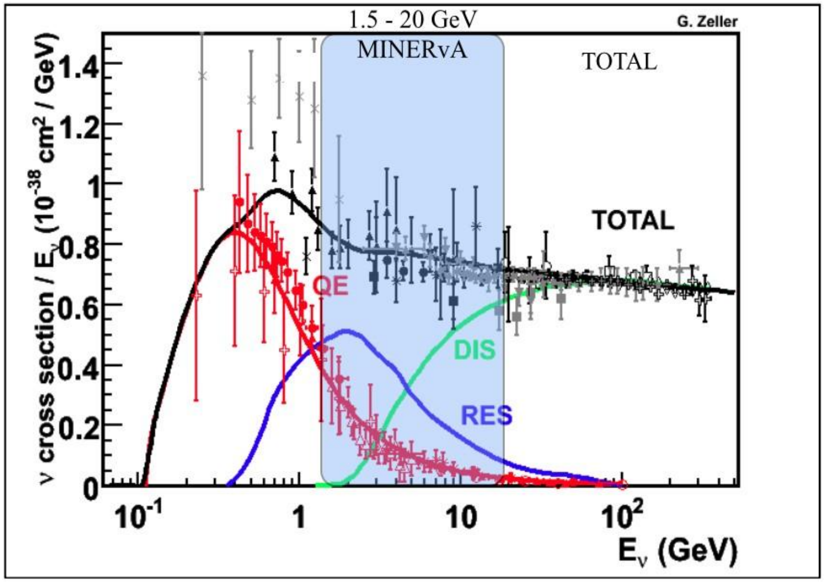
Initial State Interactions

Neutrinos can interact in a variety of channels:

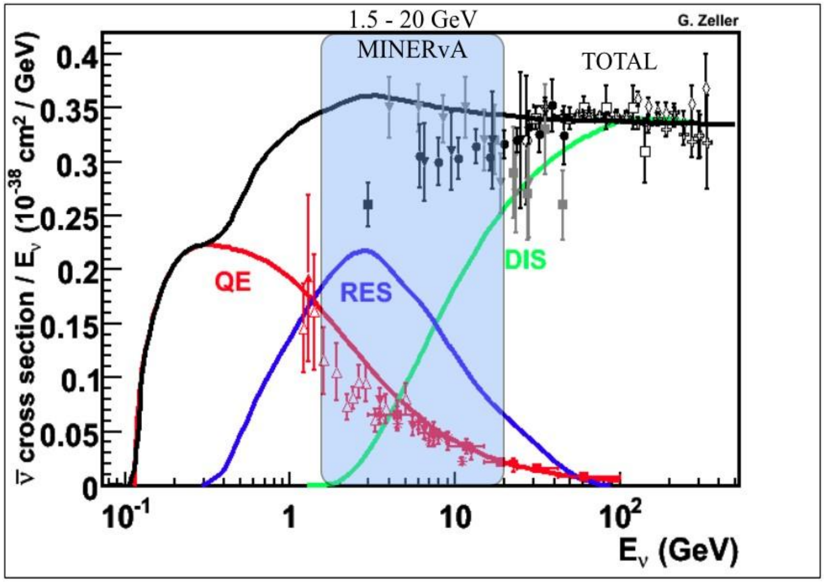
- Quasi-Elastic
- Resonance
- Deep Inelastic Scattering

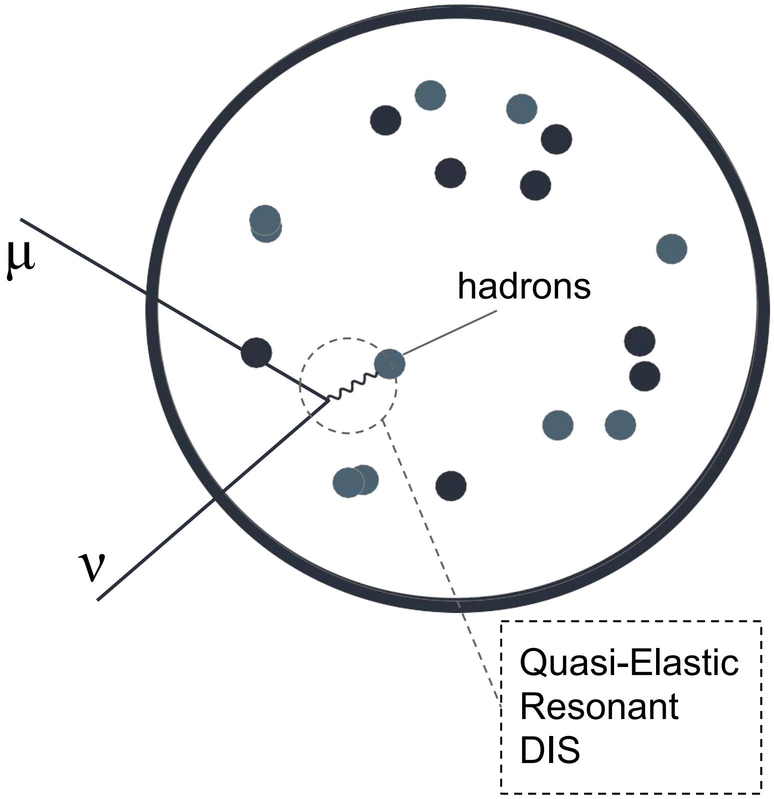


Neutrino



Antineutrino





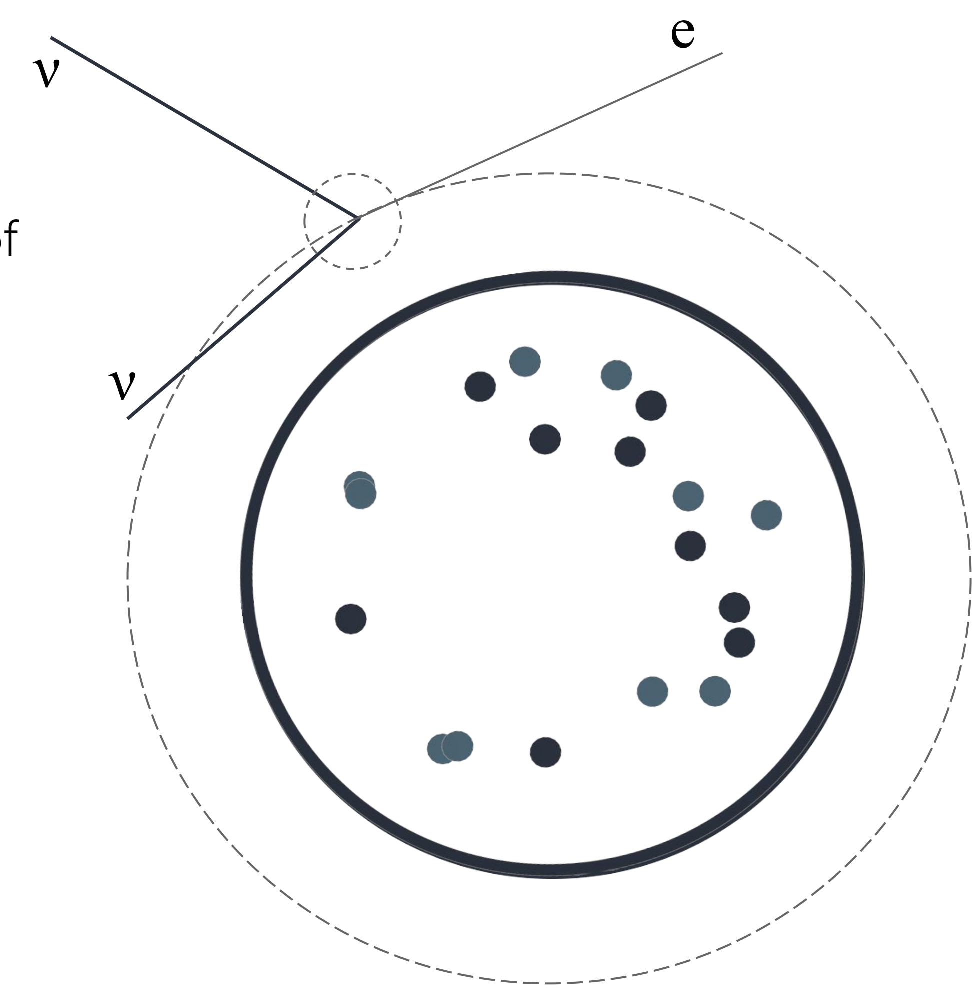
Rev. Mod. Phys. 84, 1307-1341 (2012)

The Nucleus!

Initial State Interactions

Neutrinos can interact in a variety of channels:

- Quasi-Elastic
- Resonance
- Deep Inelastic Scattering
- Neutrino - electron elastic scattering

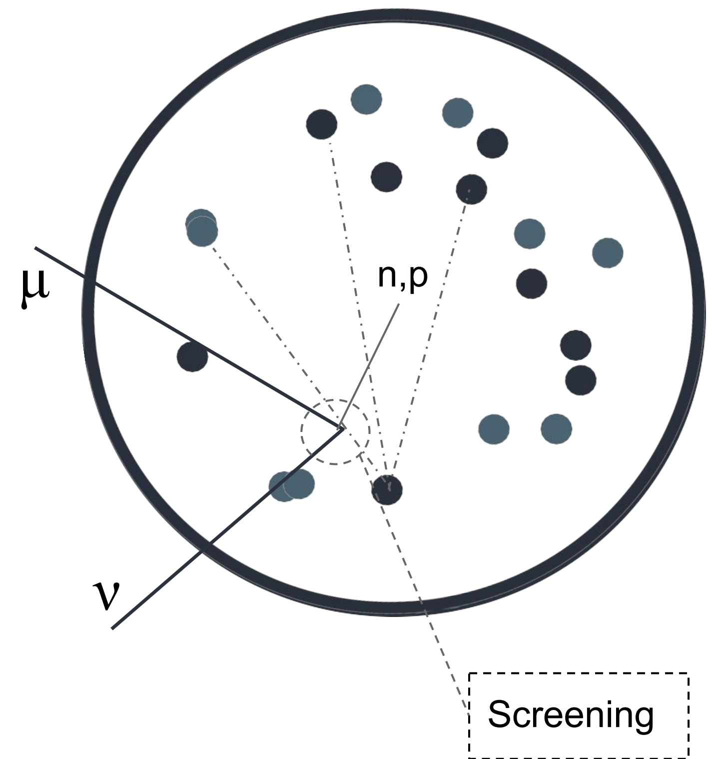


The Nucleus!

Initial State Interactions

Neutrinos can interact in a variety of channels:

- Quasi-Elastic
- Resonance
- Deep Inelastic Scattering
- Neutrino - electron elastic scattering
- Screening

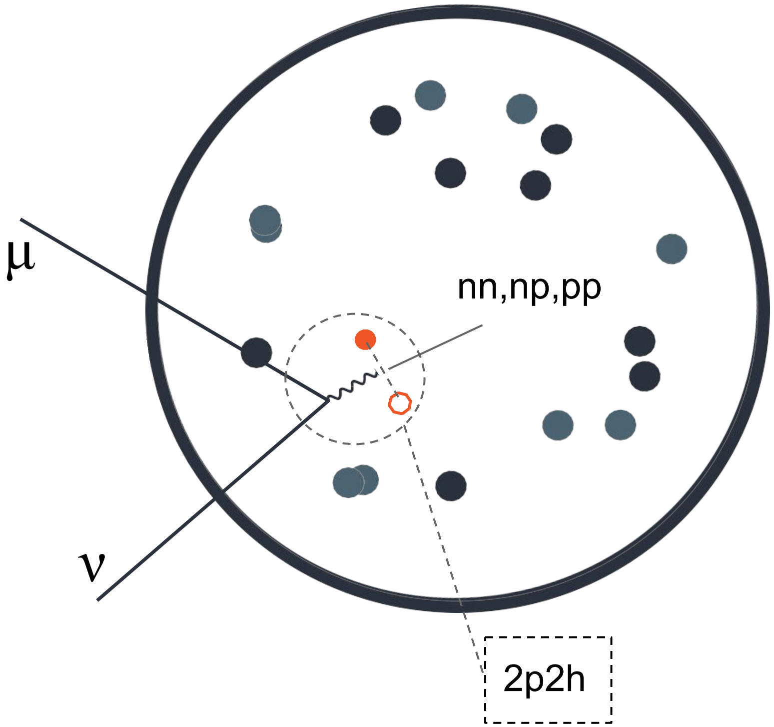


The Nucleus!

Initial State Interactions

Neutrinos can interact in a variety of channels:

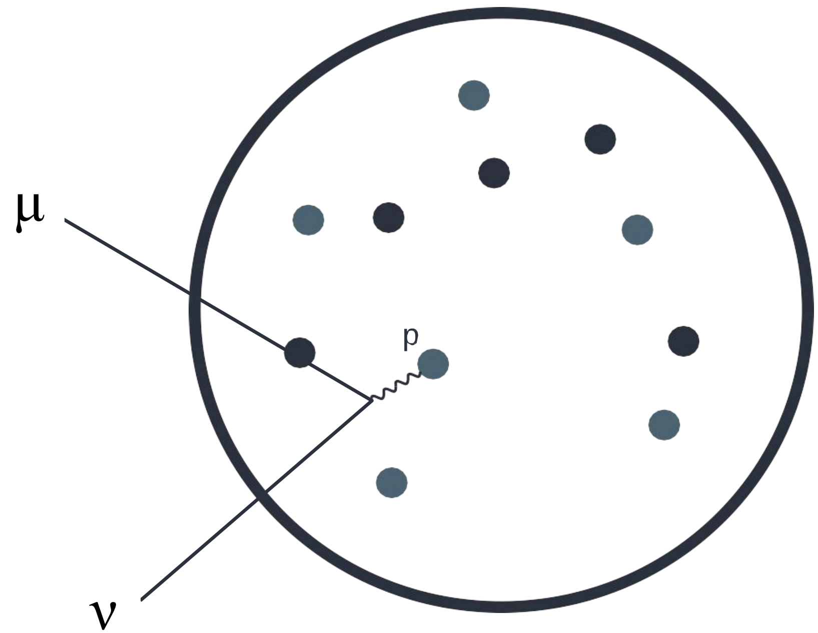
- Quasi-Elastic
- Resonance
- Deep Inelastic Scattering
- Neutrino - electron elastic scattering
- Screening
- Multi-nucleon Correlations
- ...



The Nucleus!

Final State Interactions (FSI)

The products of the Initial interaction undergo different process before leaving the nucleus



The Nucleus!

Final State Interactions (FSI)

The products of the Initial interaction undergo different process before leaving the nucleus

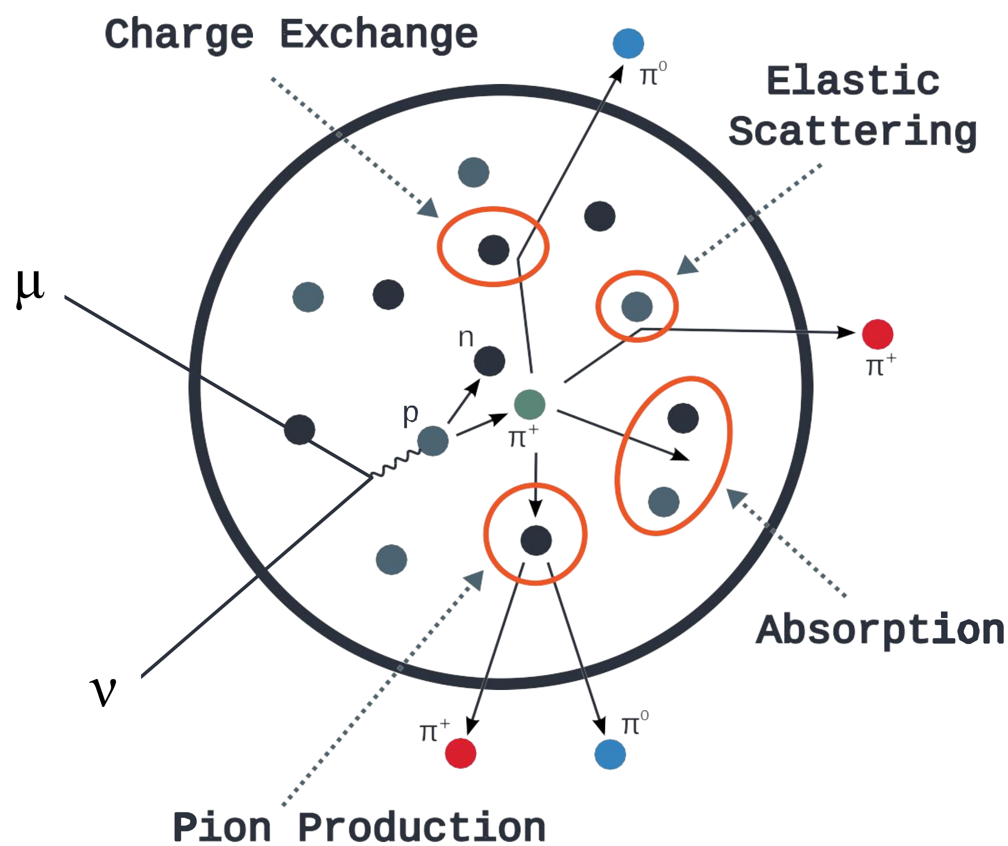


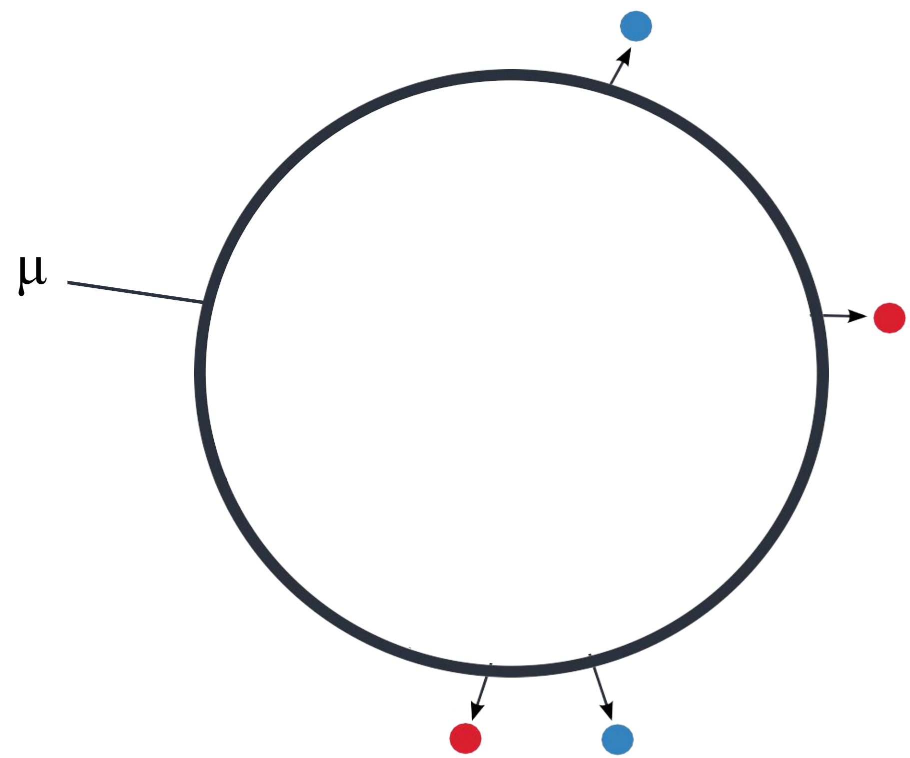
Illustration by Tomasz Golan

The Nucleus!

Final State

What is actually seen in the detector cannot be classified in terms of the Initial Interactions

We need to define our samples in terms of observed topologies



Outline

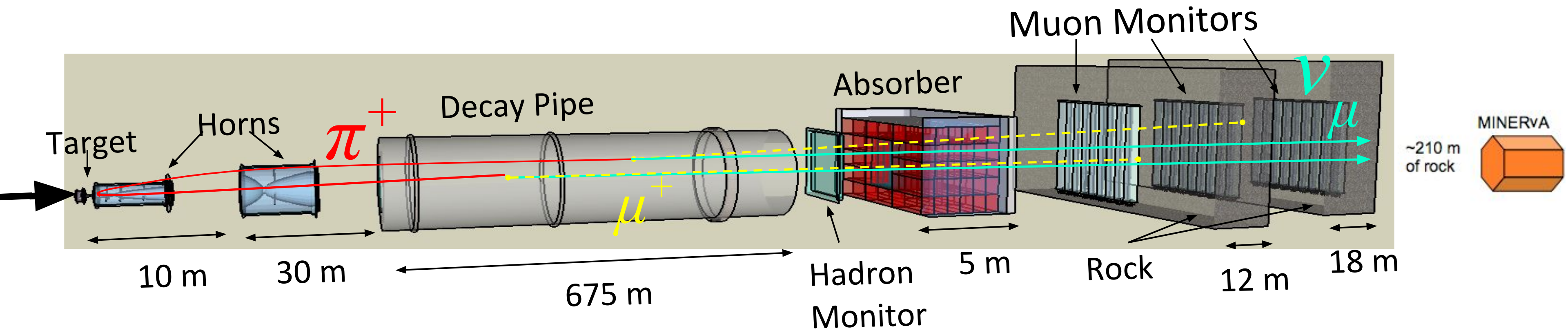
Challenges and motivation

The detector

Recent Results

The NuMI Beam

figure courtesy Ž. Pavlović

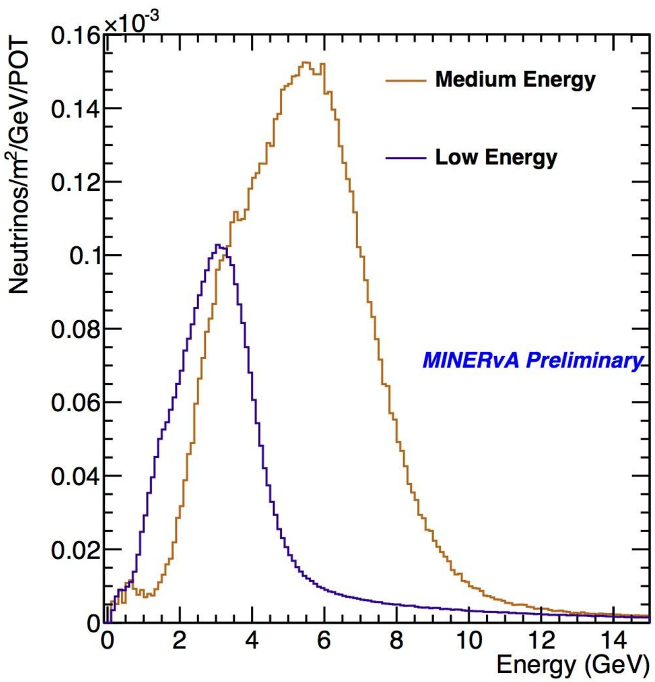


120 GeV/c protons on carbon target produce pions.

Pions and kaons decay into muons and neutrinos.

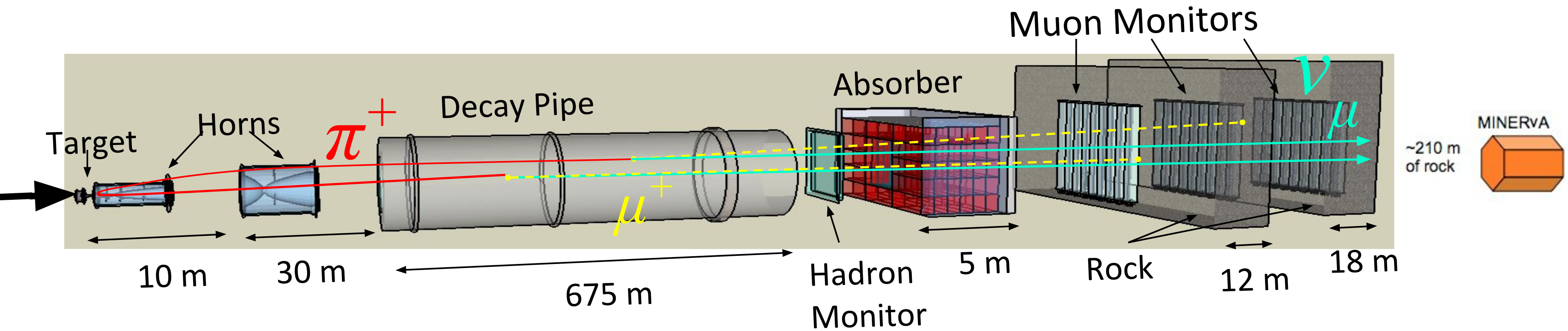
Horns focus positive or negative pions depending on their polarity

Neutrino beam energy increased by moving target and one horn



The NuMI Beam

figure courtesy Ž. Pavlović

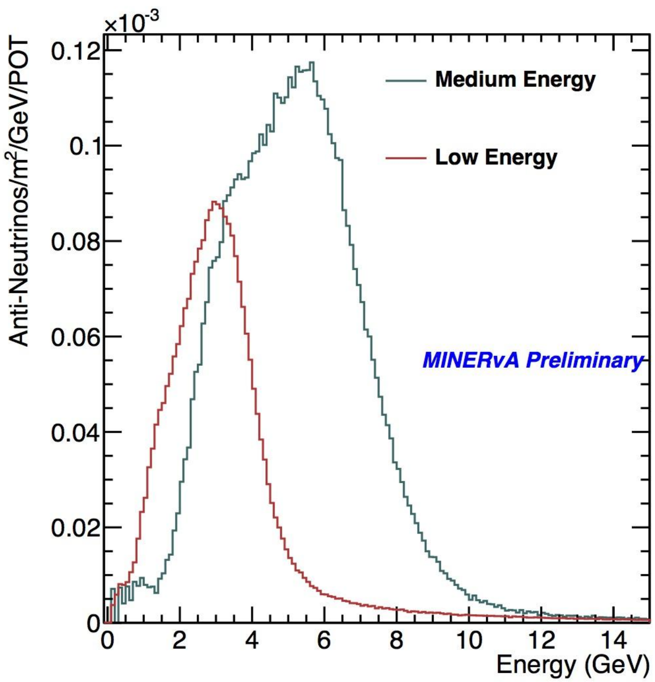


120 GeV/c protons on carbon target produce pions.

Pions and kaons decay into muons and neutrinos.

Horns focus positive or negative pions depending on their polarity

Neutrino beam energy increased by moving target and one horn



The Detectors

MINERvA + MINOS

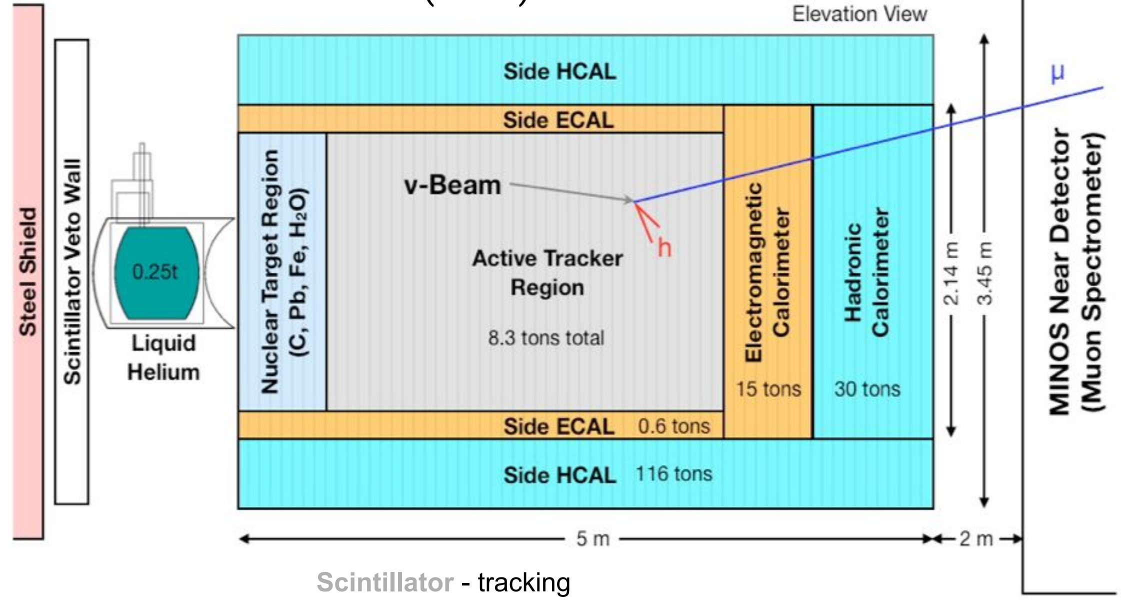
120 modules stacked along the beam line in three orientations

Fine-grained scintillator tracker surrounded by calorimeters

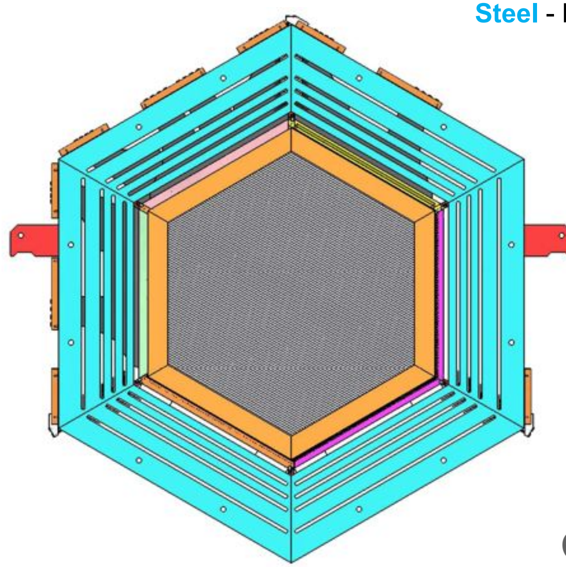
MINOS near detector as a muon spectrometer

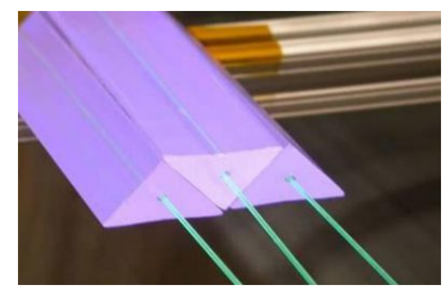
Upstream nuclear targets to measure A-dependence

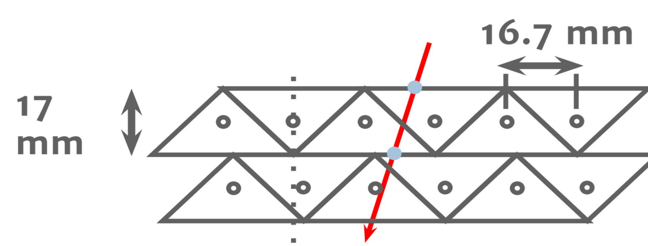
NIM A743 (2014) 130



Scintillator - tracking
Lead - EM calorimetry
Steel - hadronic calorimetry







Charge sharing for improved position resolution (~3 mm) and alignment

Outline

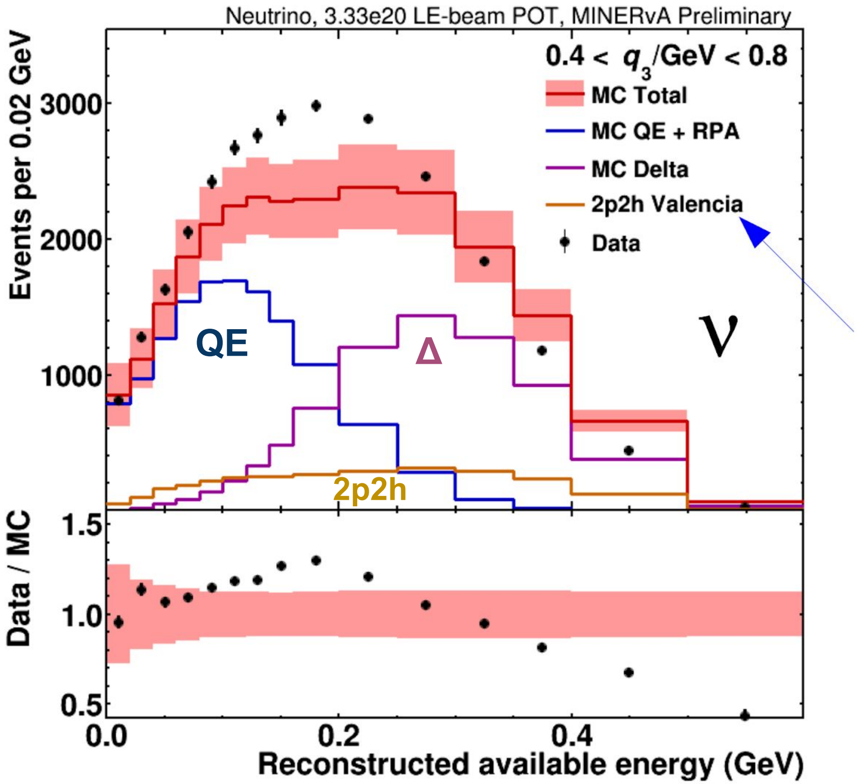
Challenges and motivation

The detector

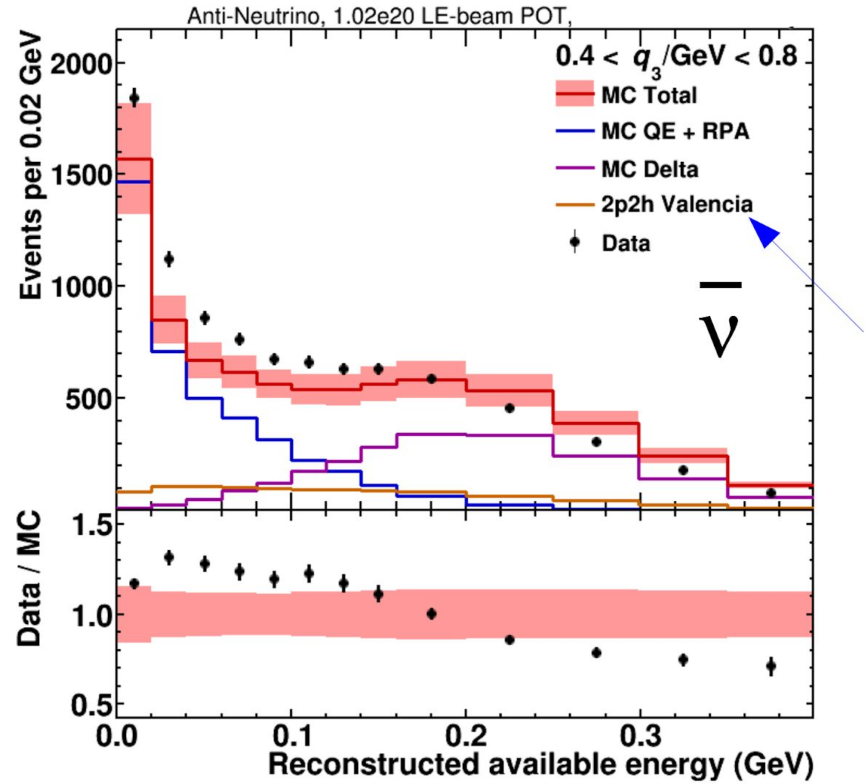
Recent Results

Look at inclusive scattering

[Phys.Rev.Lett. 116 (2016) 071802]



[Phys.Rev.Lett. 120 (2018) 221805]

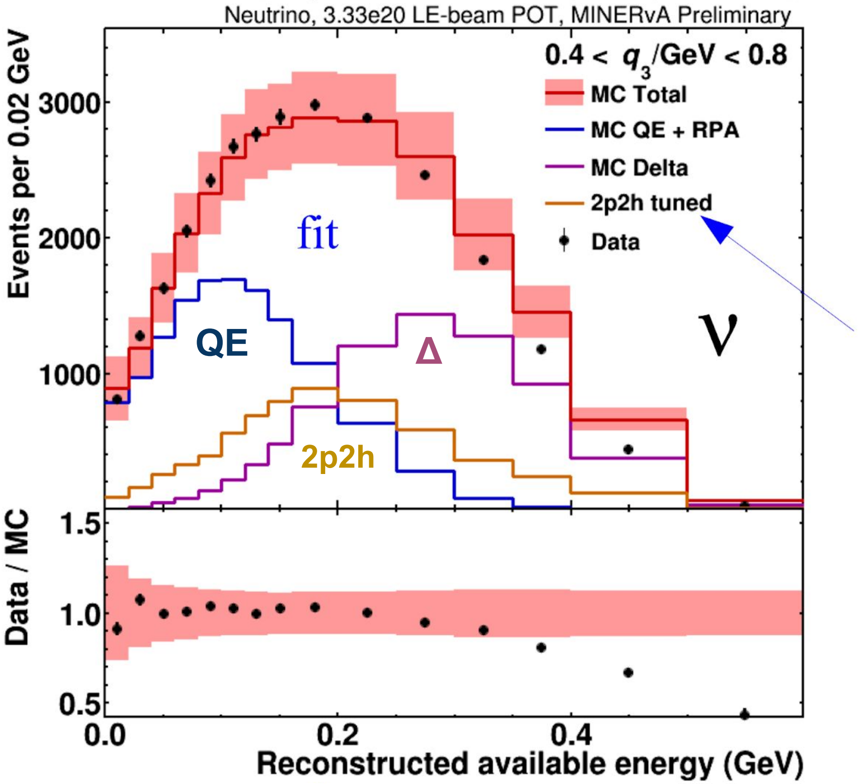


Monte Carlo = GENIE 2.8.4 + RPA + 2p2h Valencia model

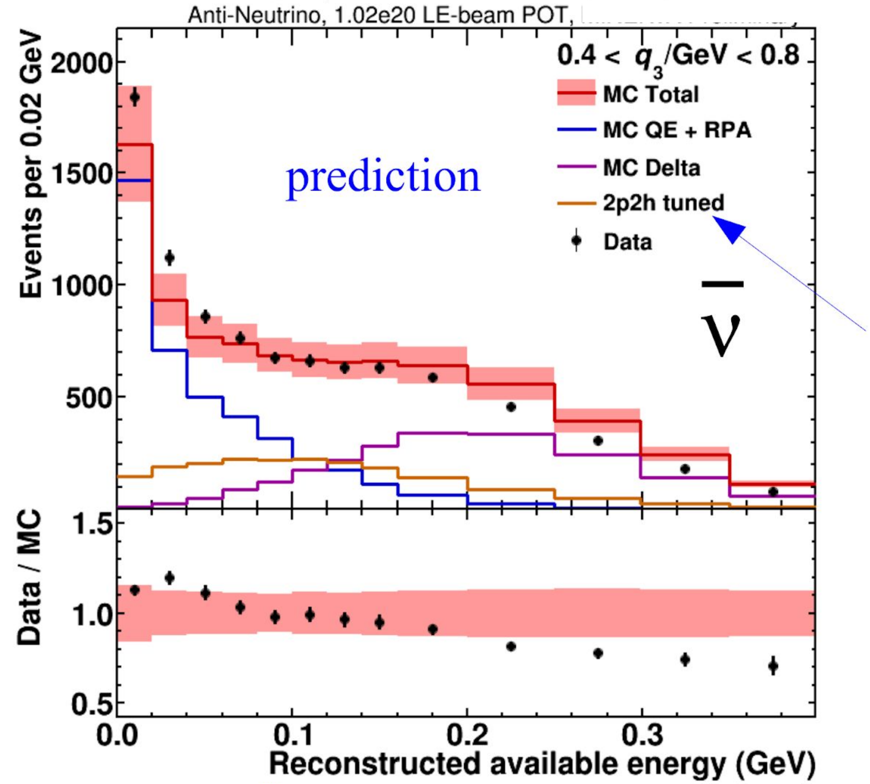
Added processes improves agreement, but not enough

The Low Energy Recoil Fit

[Phys.Rev.Lett. 116 (2016) 071802]



[Phys.Rev.Lett. 120 (2018) 221805]



Weighing up the 2p2h events with a 2D Gaussian weight

This tune designed to **empirically** “fill in” the dip region not whole kinematic range (**does not scale true QE or resonant production**)

CCQE-like (or CC0pi) sample selection

CC0pi in MINERvA

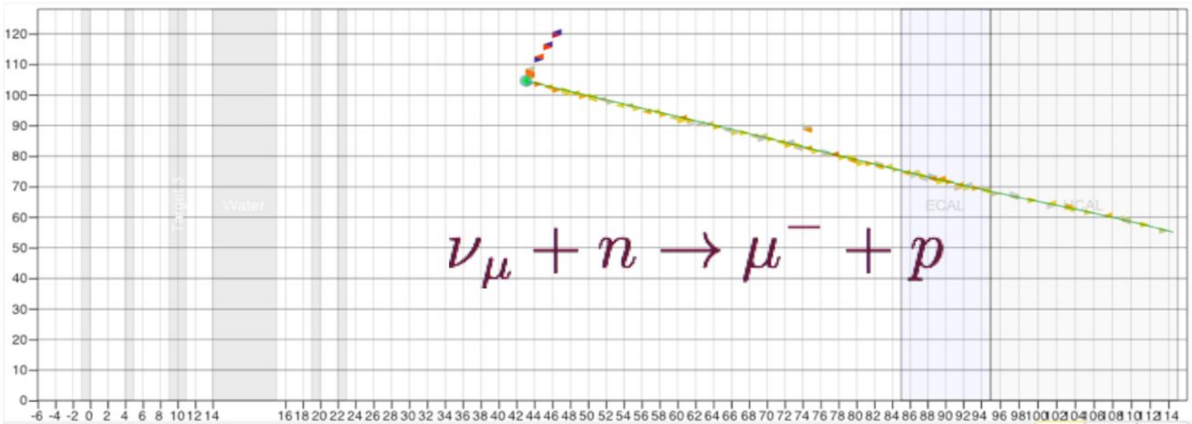
Scattering on CH (scintillator)

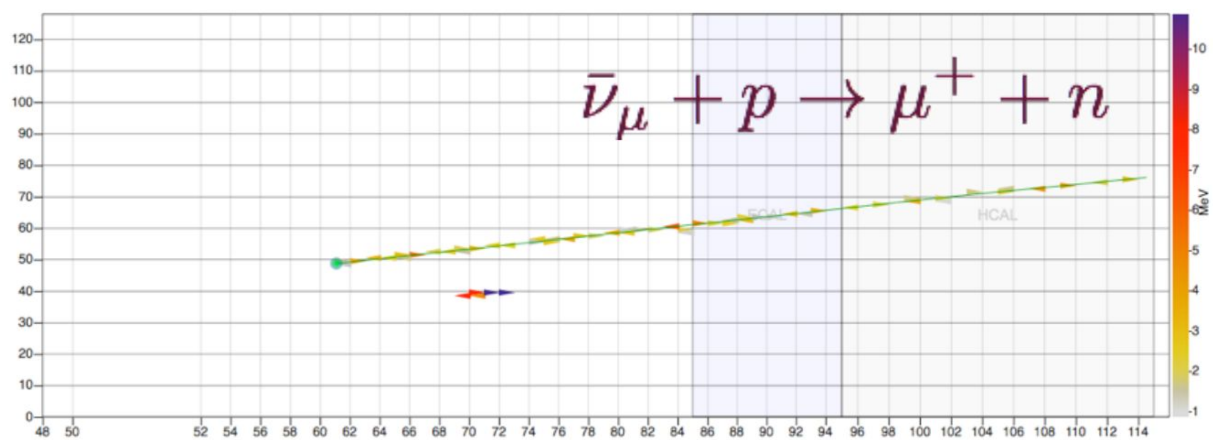
MINOS matched muons

Reconstructed Protons with > 120 MeV

Neutrons seem ~20% of the time

No Pions

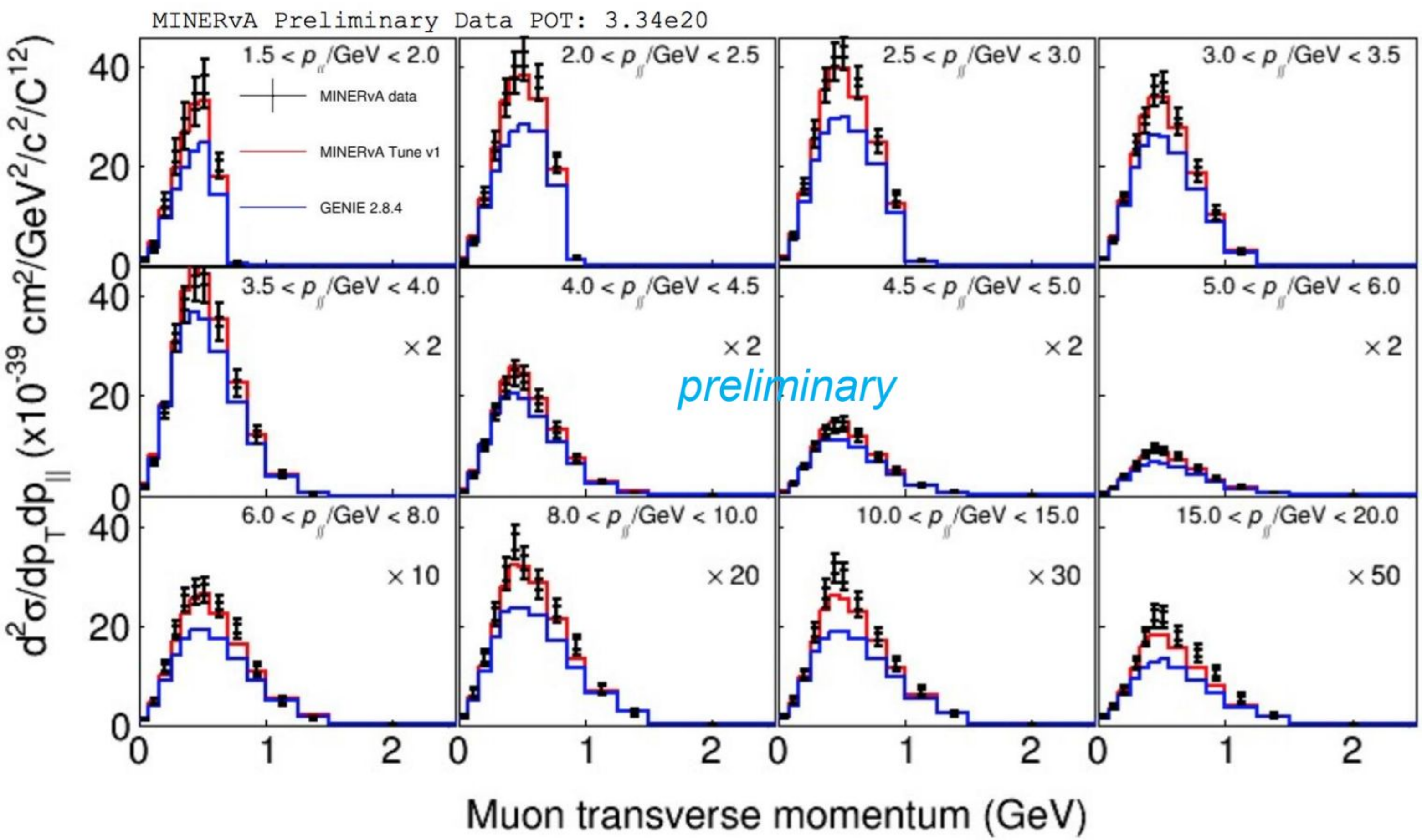




Neutrino CC0pi double differential cross section

Applying the inclusive fit into the exclusive data

Double differential Cross section in terms of muon parallel and transverse momentum

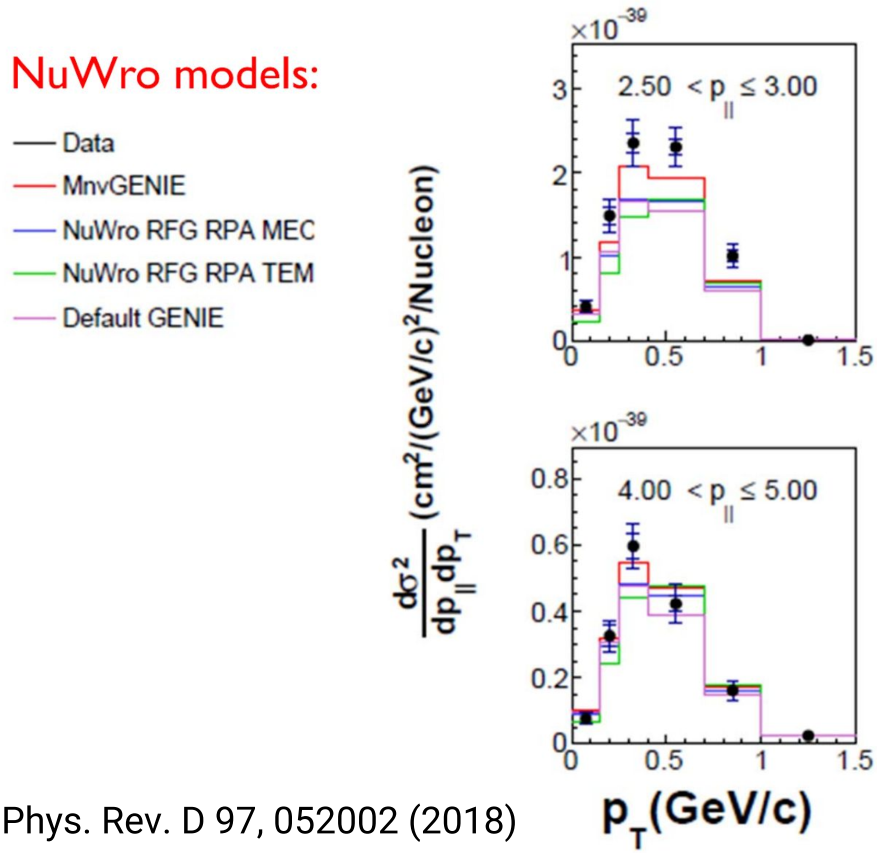


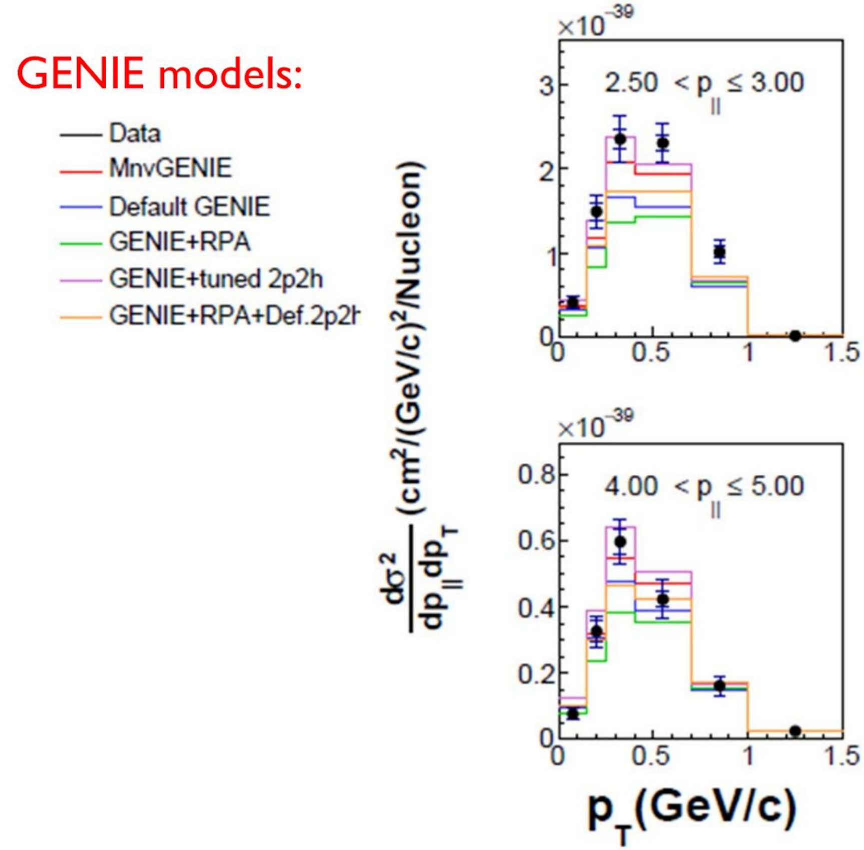
Oregon State University

Antineutrino CC0pi double differential cross section

Applying the inclusive fit into the exclusive data

Double differential Cross section in terms of muon parallel and transverse momentum





Phys. Rev. D 97, 052002 (2018)

Antineutrino Q^2 and E_ν

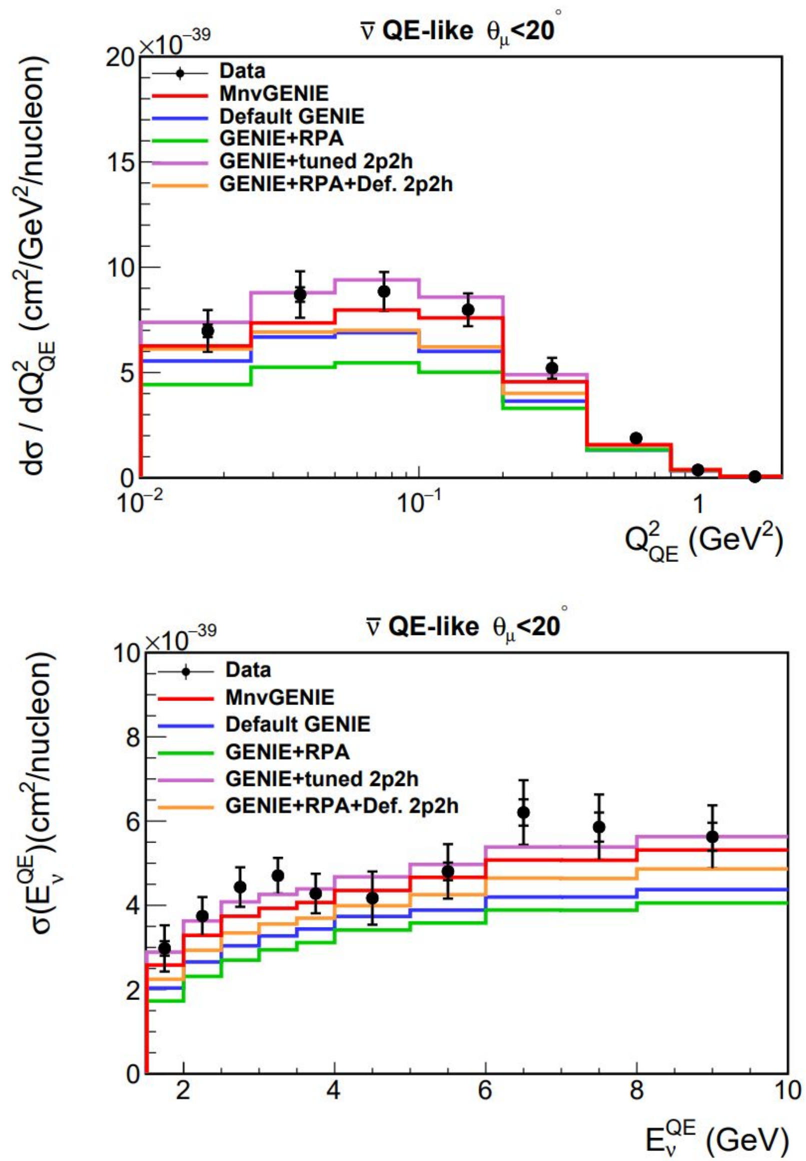
Cross Sections

Derived cross sections, inclusive for all data

GENIE comparisons show some 2p2h is essential

Full X^2 indicates a preference for models with RPA and 2p2h.

Theoretical models (orange) seem to not have enough strength



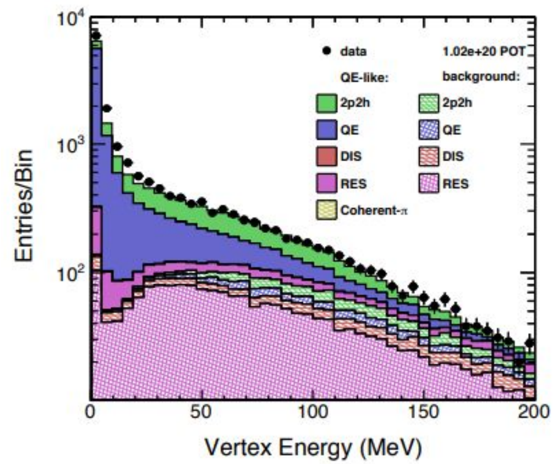
Phys. Rev. D 97, 052002 (2018)

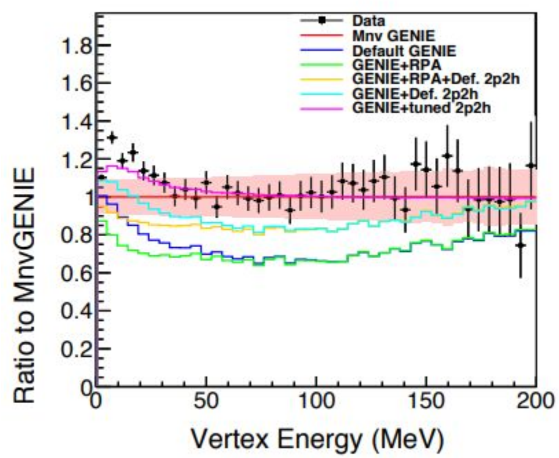
CC0pi Vertex Region Energy

Distribution not well predicted in our earlier results

The tuned GENIE does a much better job of modelling this distribution, but is there more we can learn?

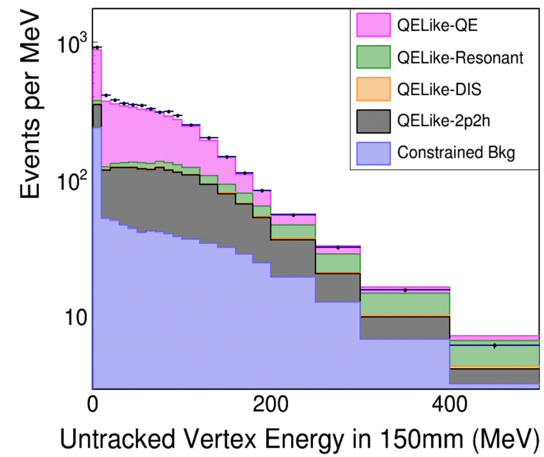
antineutrino

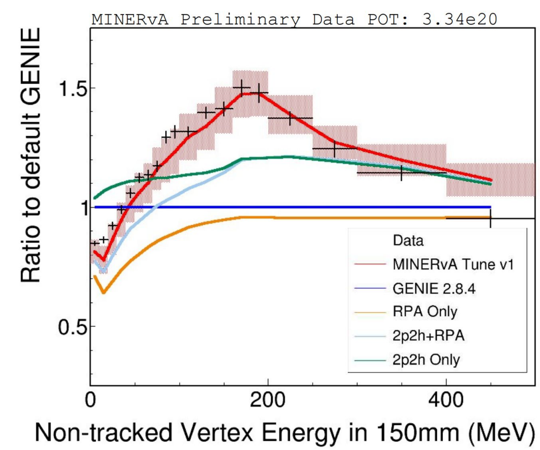




Phys. Rev. D 97, 052002 (2018)

neutrino





Publication in preparation

Neutrino CC0pi

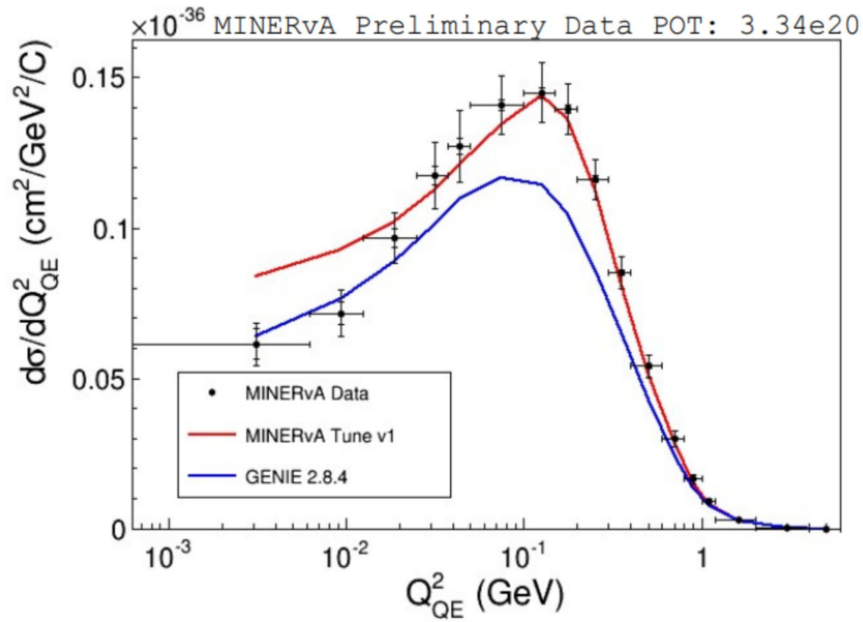
Perfect?

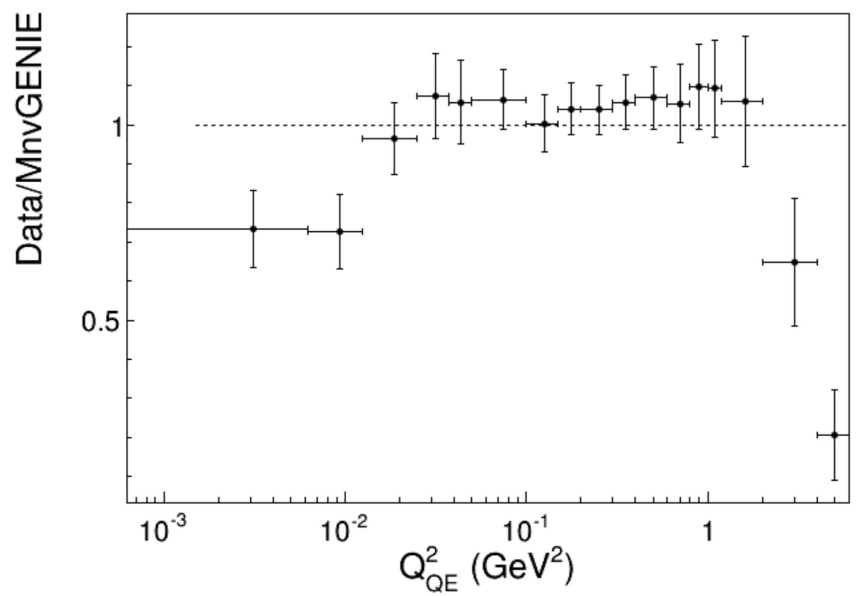
High Q^2

is a region where we are pushing the extent of the dipole approximation

Low Q^2

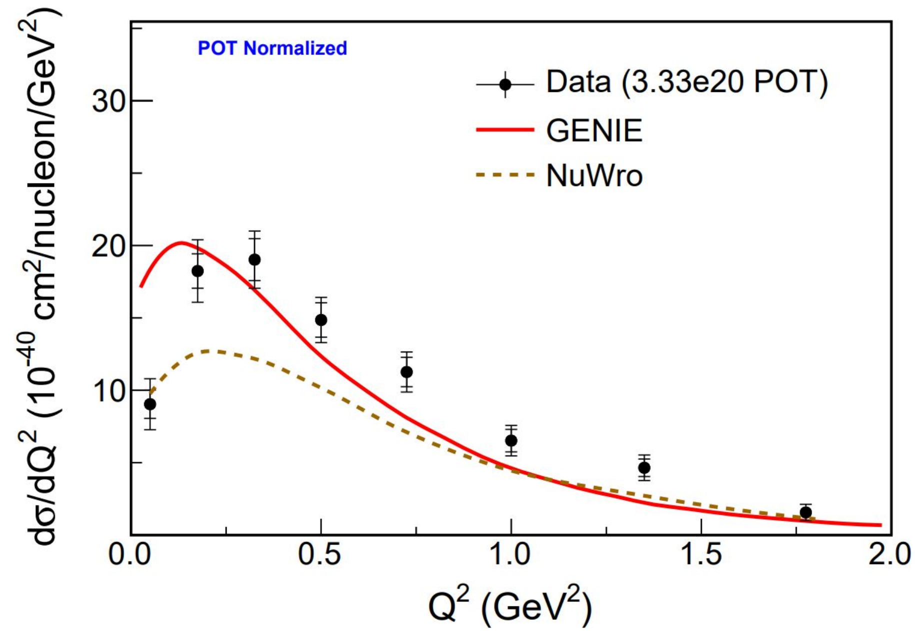
is a region of phase space where the fraction of events has an increased population of resonant pion qe-like events





CCp0 Cross Section

Phys. Rev. D 96, 072003 (2017)

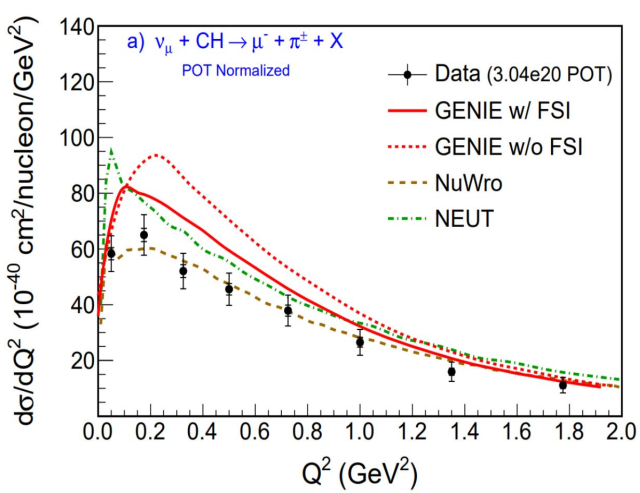


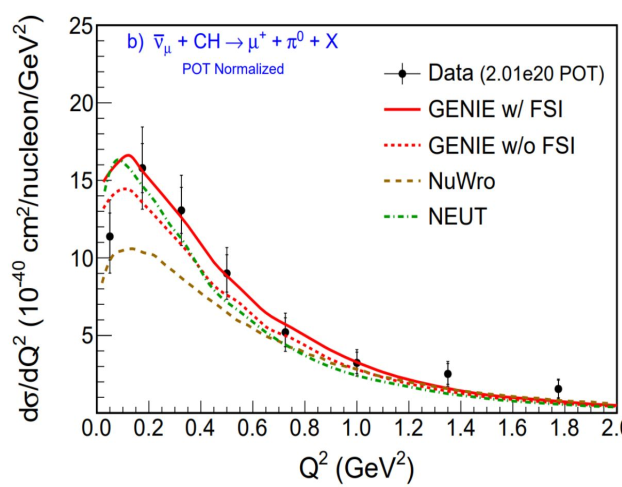
Perfect?

Recent CCp0 result wants a low Q2 reduction

So does the anti-neutrino result CCp0 result

Not as strongly in the CCp+ result





Phys. Rev. D 94, 052005 (2016)

Proton Muon Correlations in CC0π

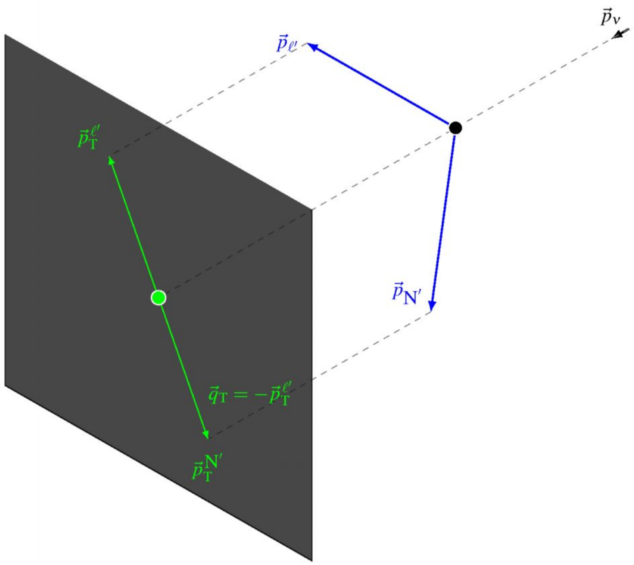
Transverse kinematic imbalances

– Bonus entertainment: Neutrino Shadow Play

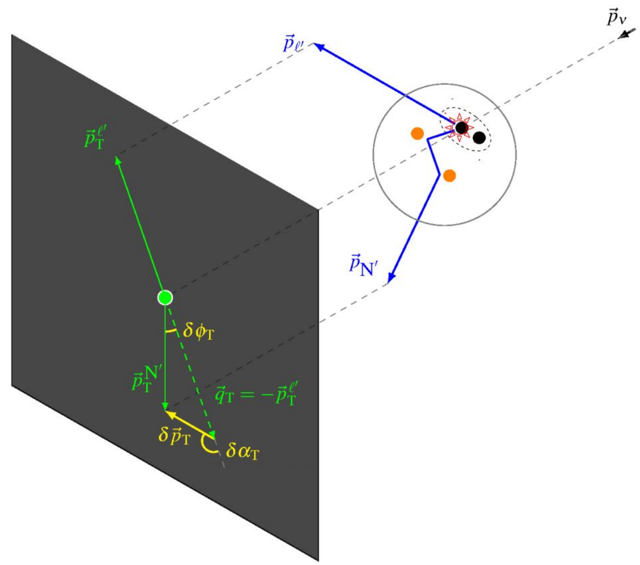
http://vms.fnal.gov/asset/detail?recid=1953173 from 00:08:50

$$\delta\vec{p}_{\mathrm{T}} = \vec{p}_{\mathrm{T}}^{\,\mathrm{N}} - \Delta\vec{p}_{\mathrm{T}}$$

Convolution of Fermi motion and intra-nuclear momentum transfer (IMT) due to FSI, resonance production, 2p2h etc.



Stationary nucleon target



Nuclear target

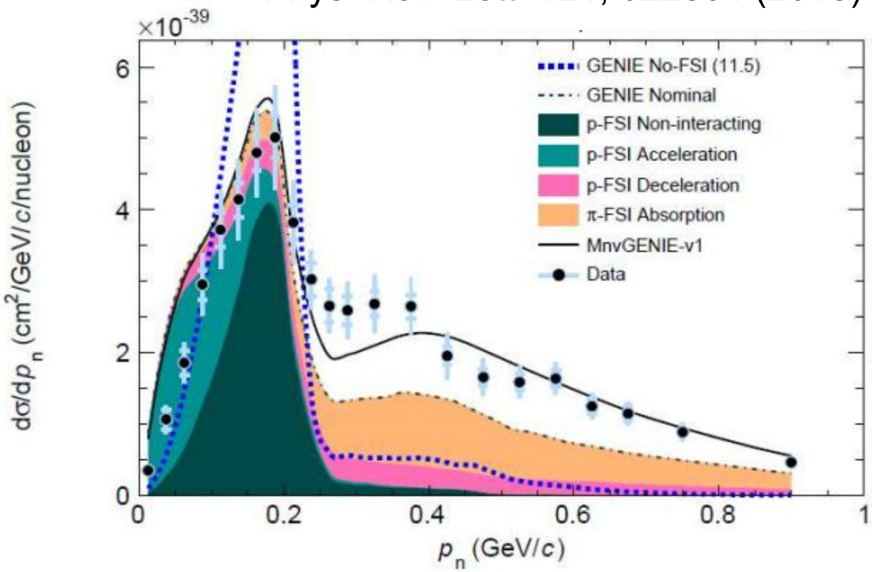
Xianguo Lu, Oxford 12

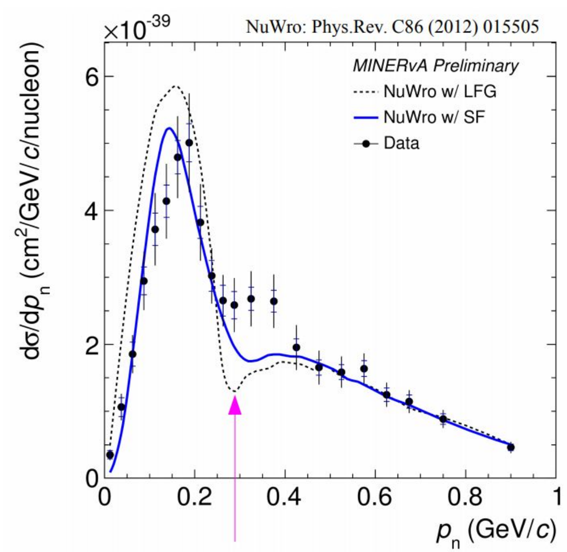
Proton Muon Correlations in CC0π

The results compared with generators show quite different expectations for the distributions

This analysis can tell us about Fermi motion, 2p2h and help nuclear effect isolation

Phys. Rev. Lett. 121, 022504 (2018)

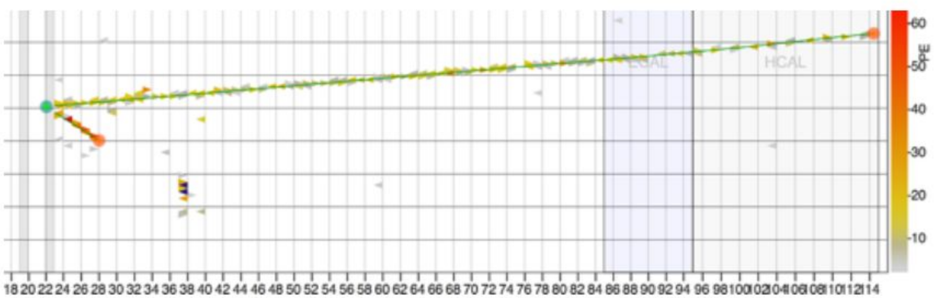


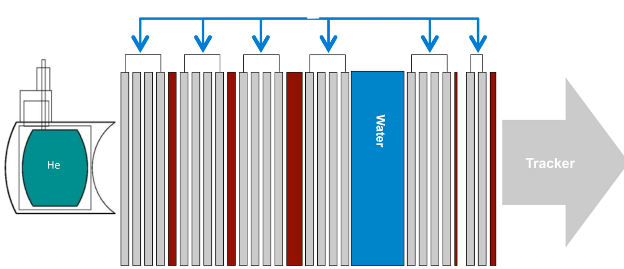


FSI Effects in the passive targets

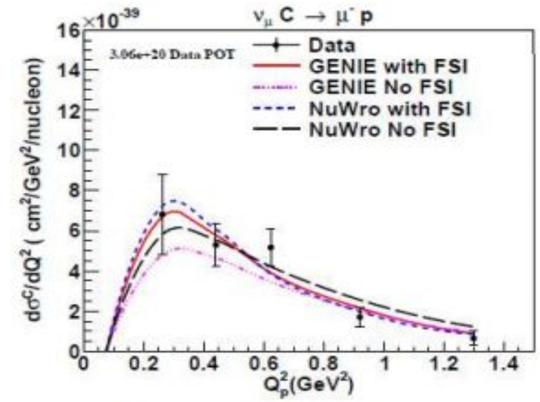
Analyses require a proton track to be well reconstructed

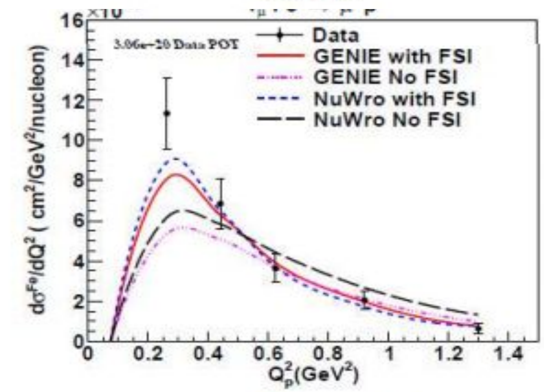
Uses passive targets, tracking determines target

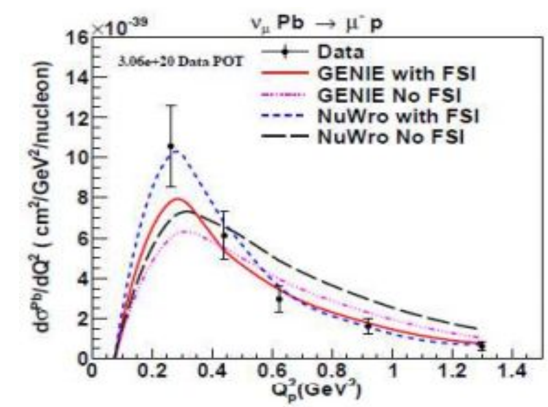




Phys. Rev. Lett. 119, 082001 (2017)





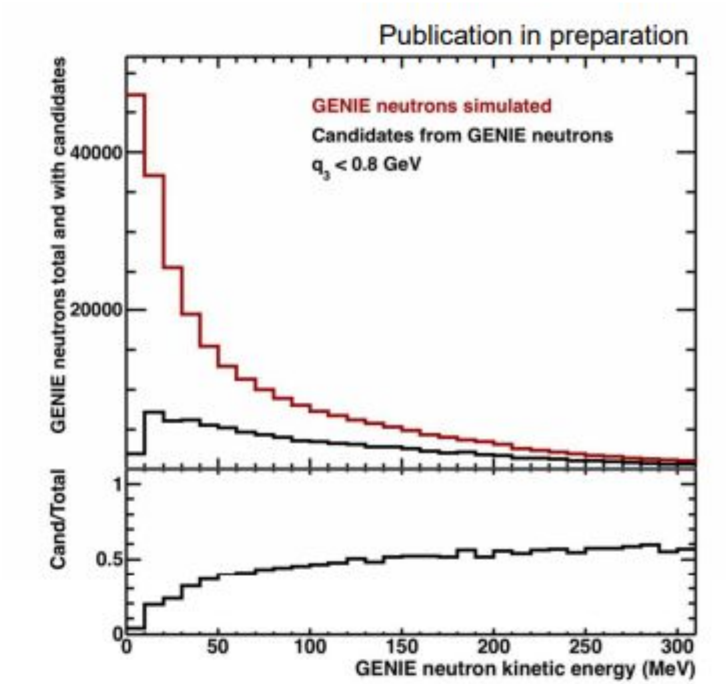


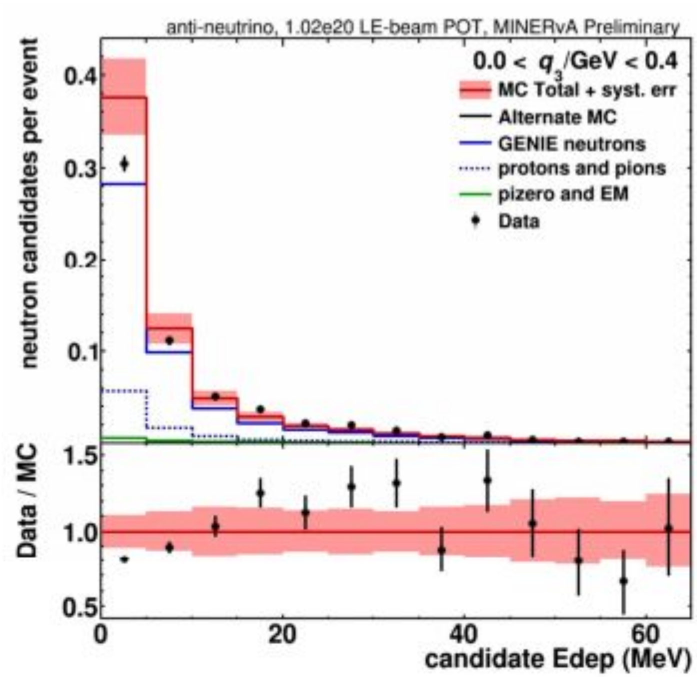
Future Results!

Neutron counting

Using the anti-neutrino low recoil sample we have started counting neutron candidates

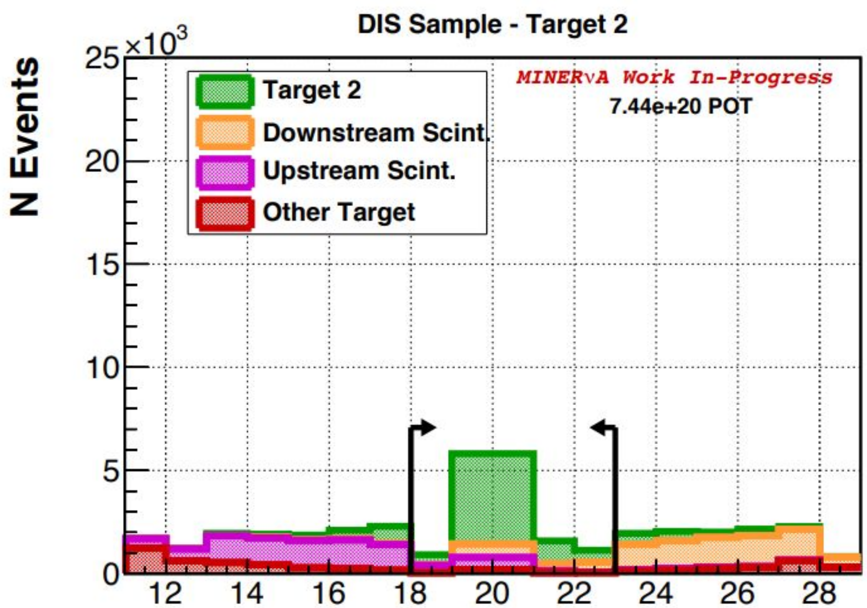
We can measure the time, position (2D or 3D) and energy deposited.



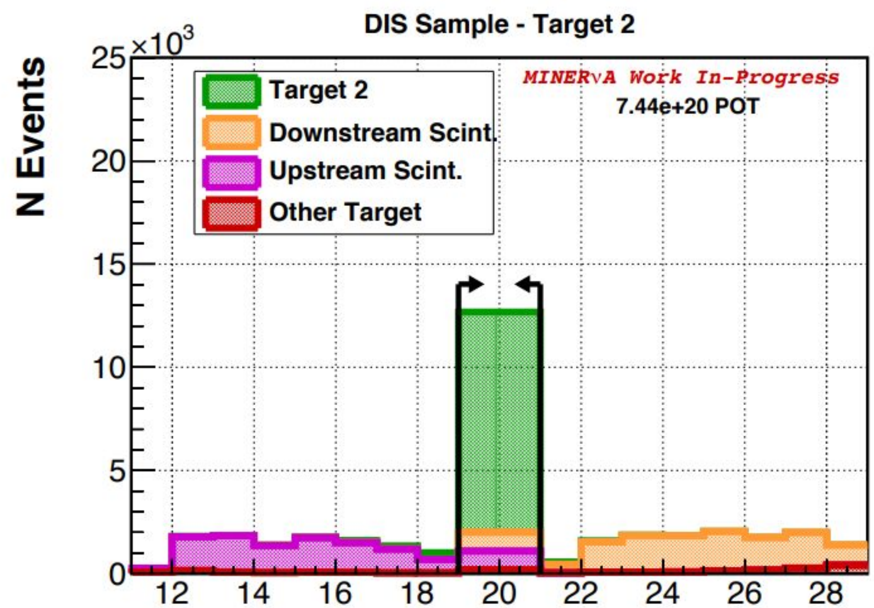


Future Results!

Machine learning for vertex id



Track Based Vertexing



Machine Learning Vertexing

By using image based Machine Learning, we can improve the vertex reconstruction.

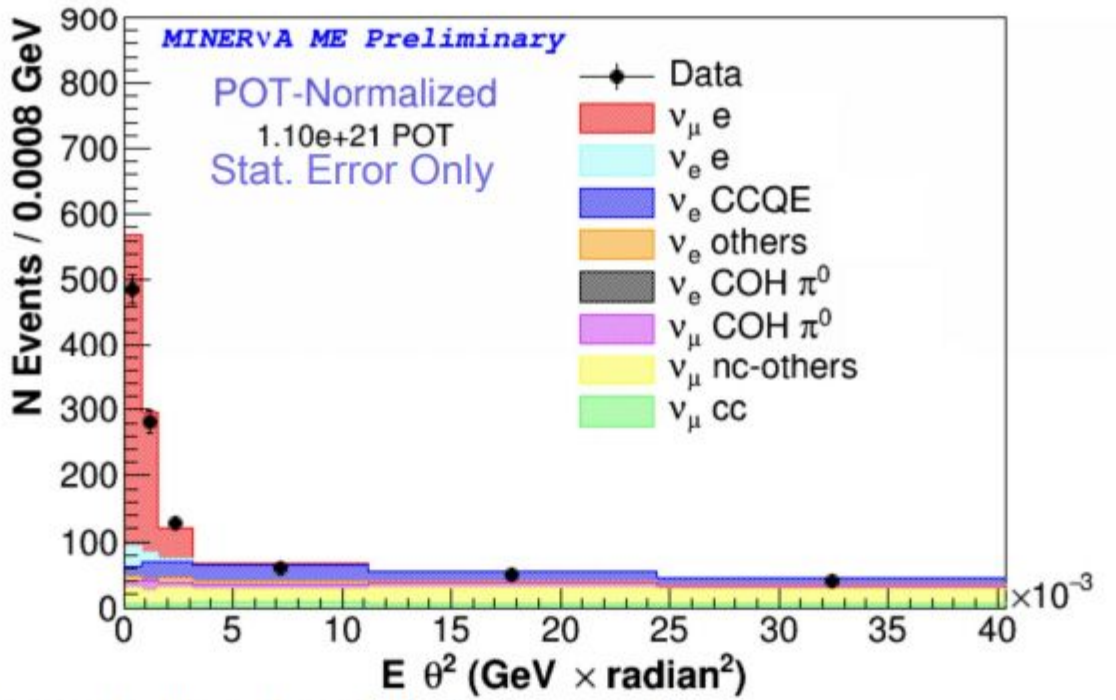
Future Results!

Using electrons to constrain the flux

Selected sample has about 800 n+e events

In the process of finalizing systematics

Flux constraint changes flux uncertainty from about 8% to 6% in the focusing peak



Conclusions

By combining many analyses with different focuses MINERvA is creating a vision of what neutrino interactions in nuclei look like at a few GeV

- RPA, 2p2h seem to be necessary in a Fermi Gas model
- Need more! Works for anti-nu pretty well
- FSI is needed and has issues with A-dependence
- Nuclear model has issues we should focus on
- Neutrons interact in hydrocarbons

Will continue to develop new analysis variables and tunes

The next dataset of MINERvA is starting to produce results.

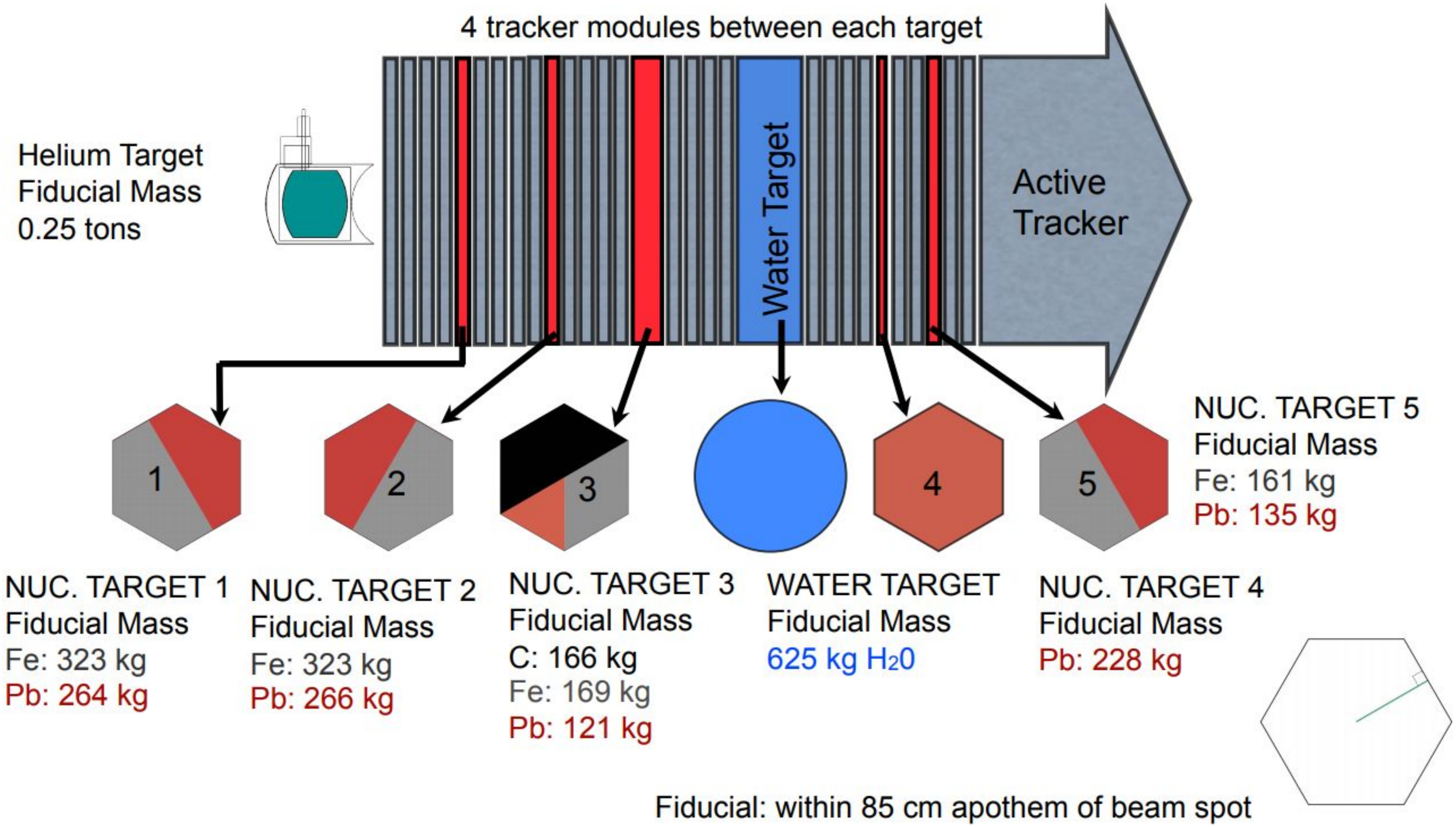
Stay tuned!


Thank You

BACKUPS

Nuclear Targets

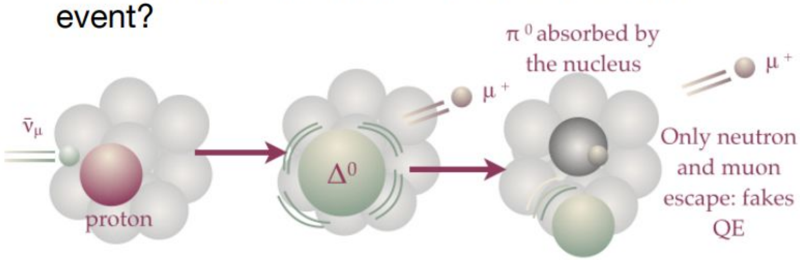
- Different targets built with combinations of different materials



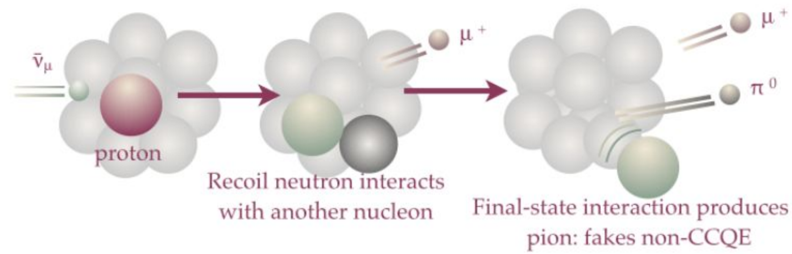
Why CCQE-like instead of CCQE?

We know that a true CCQE event produces a muon and single nucleon, but what about…?

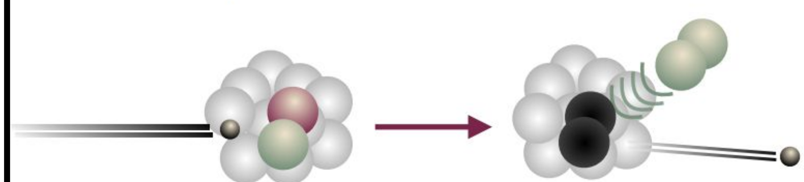
Resonant events where pion is absorbed in FSI, leaving a final state identical to a CCQE event?



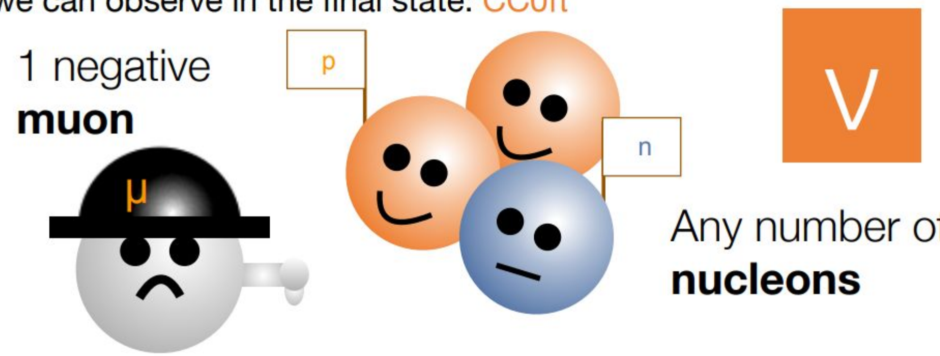
CCQE events where FSI produces pions in the final state?



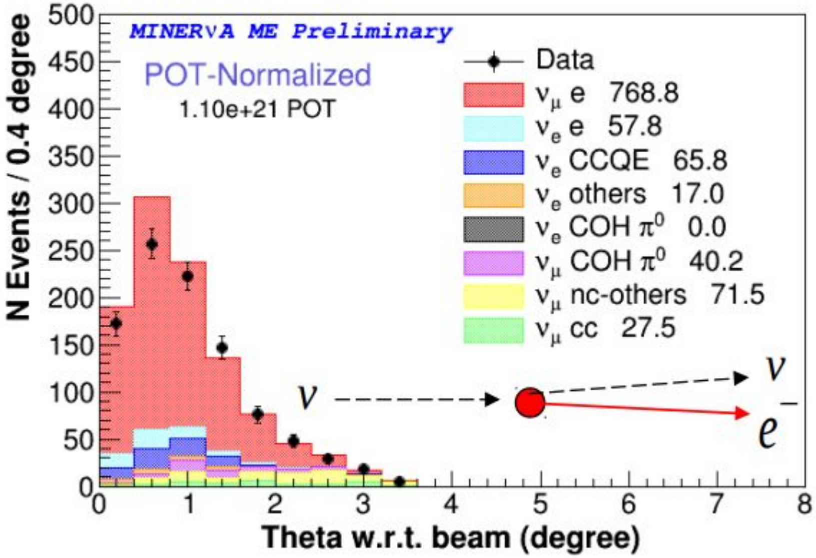
2p2h events with CCQE scattering from a correlated pair of nucleons?

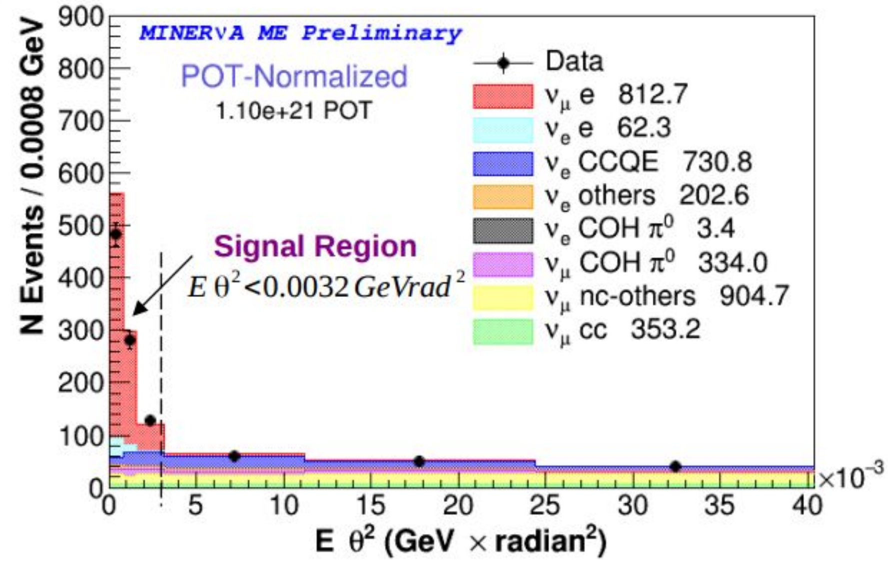


To reduce model dependence, and follow the lead of other experiments, we choose a signal definition that is based on what we can observe in the final state: CC0π



Signal definition for neutrino "QE-like"





- **Kinematic limit $E\theta^2 < 2m_e$; where E: Electron energy and θ: Electron angle with respect to the neutrino.**

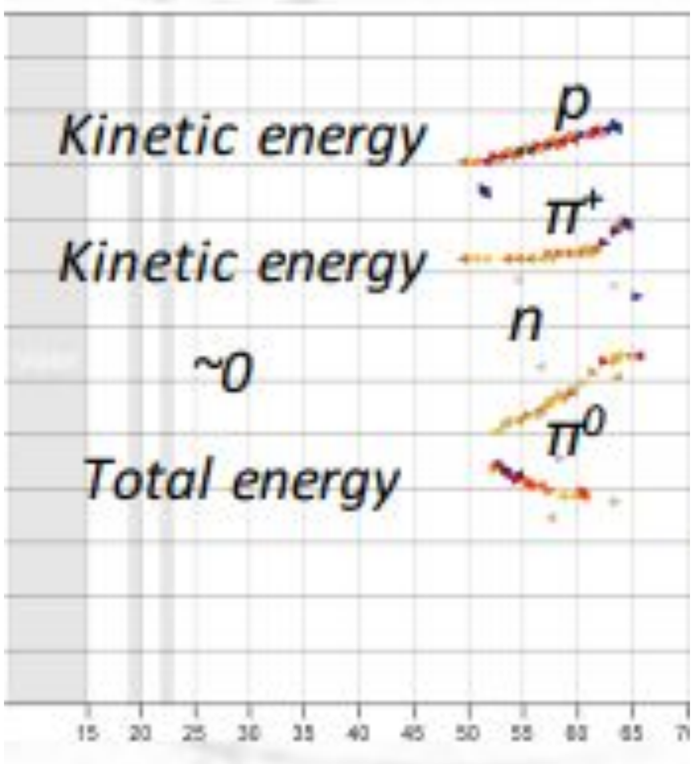
Clean separation of signal using cut.
Good angular resolution (0.4°) is critical to use $E\theta^2$ cut.

Back to neutrino Energy reconstruction

MINERvA's approach to reconstruct Neutrino Energy is to use calorimetry for all but the final state lepton.

Looking at inclusive charged current events in bins of energy transfer and momentum transfer defining quantity dependent on the details of the final state:

E_{avail} ***≡ (Proton and π± KE) + (E of other particles except neutrons)***



this technique is inspired by electron scattering experiments