Neutron Detection in MINERvA's Polystyrene Scintillator

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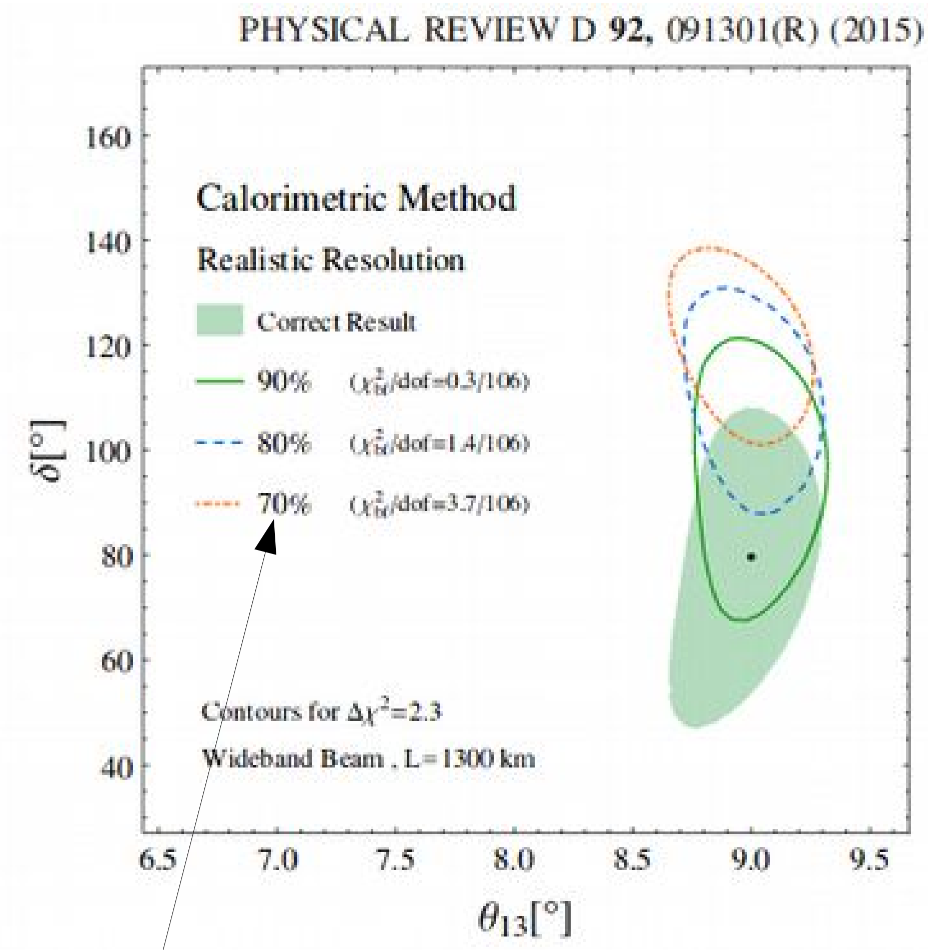
for the MINERvA Collaboration
TIPP 2021

Why Neutrons Matter in Oscillation Experiments

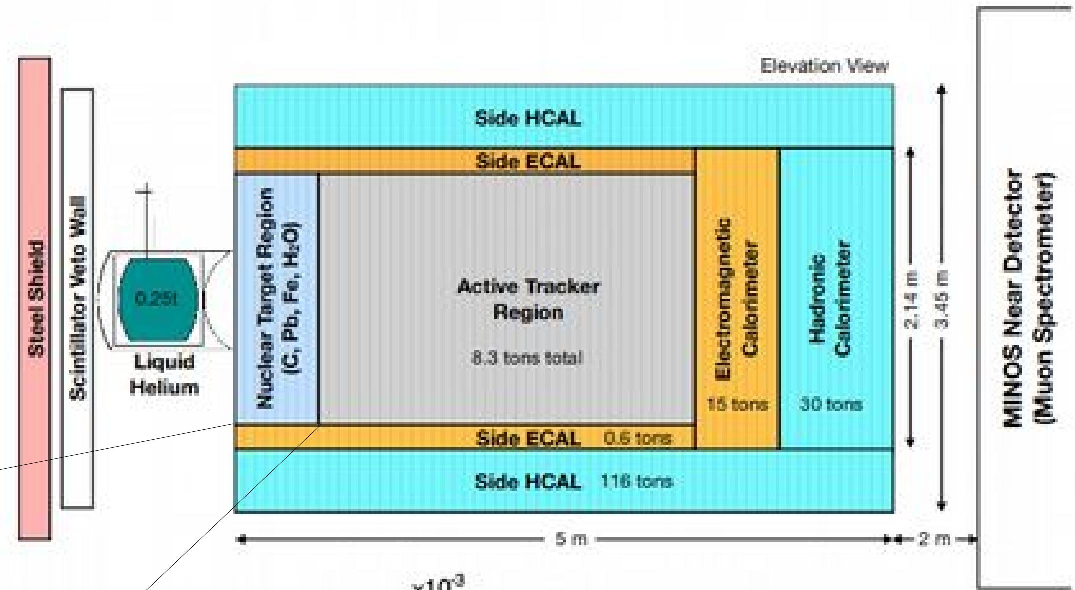


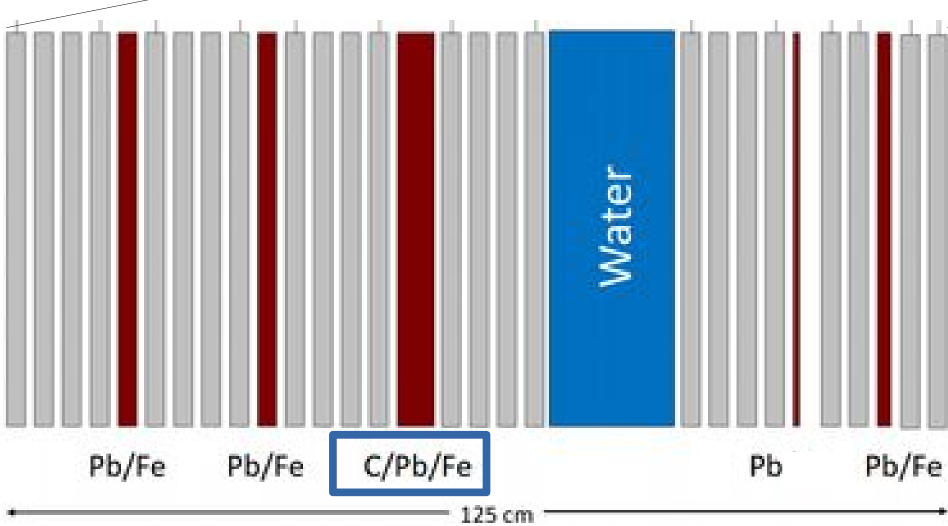
Percent missing energy Accounted for

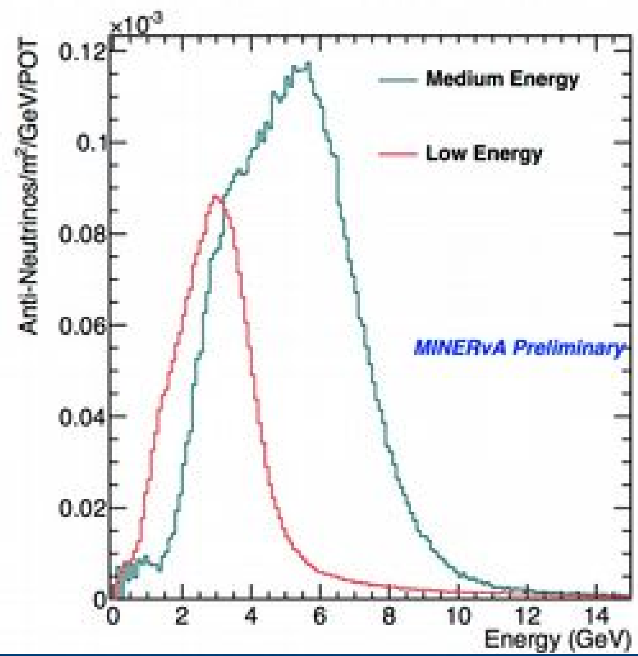
- Need to measure **E_ν**
  - Charged Current Quasi-Elastic: Just need muon
  - Calorimetric: Need all particles
- Neutrons disrupt both
  - Signal interaction on multiple nucleons
  - Missing energy
- Neutrons *associated* with lots of O(GeV) neutrino measurements, but measurements of neutrons *produced* by an interaction are rare

The MINERvA Detector

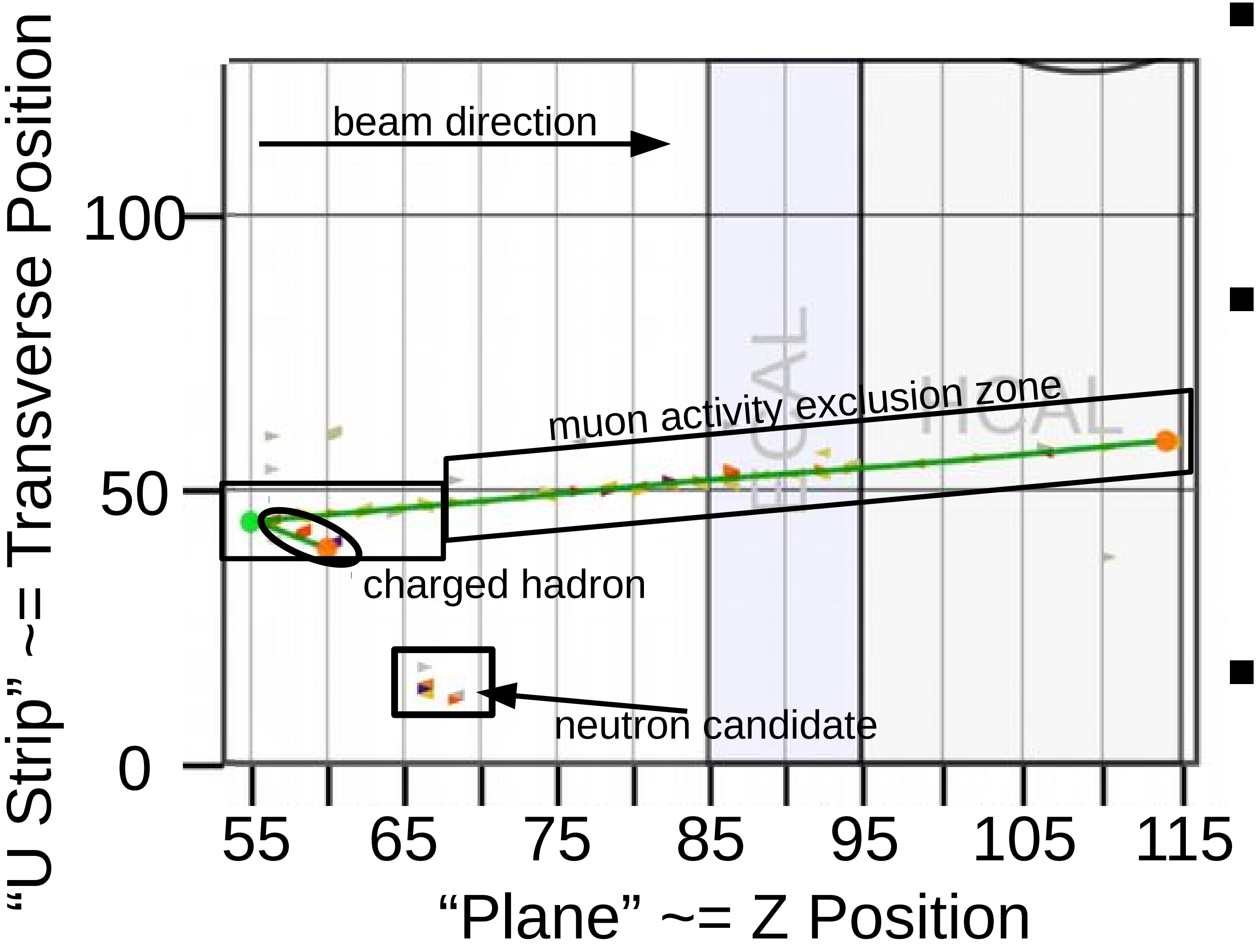
- Polystyrene scintillator (CH) → tracking, calorimetry
- Magnetized MINOS near detector → muons
- Sampling ECAL and HCAL
- NuMI beam at Fermilab
  - 2 flux eras: 2 GeV peak and 6 GeV peak
  - Each overlaps different part of DUNE flux





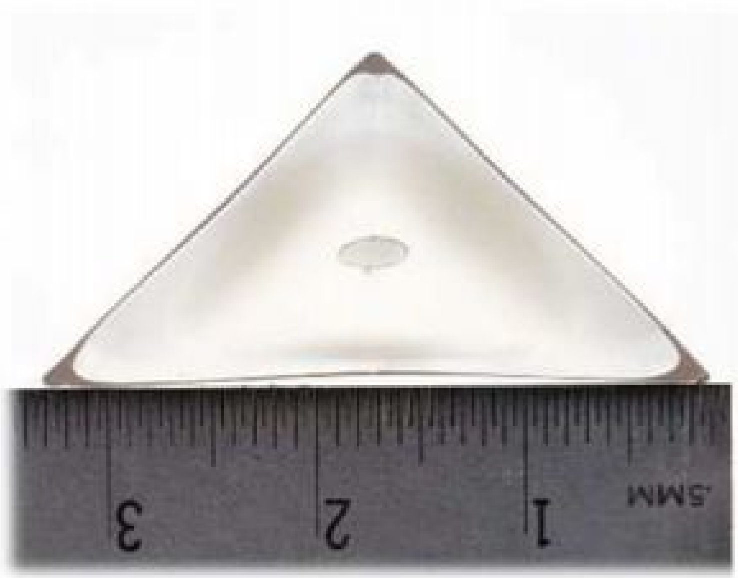


What do Neutrons Look Like?



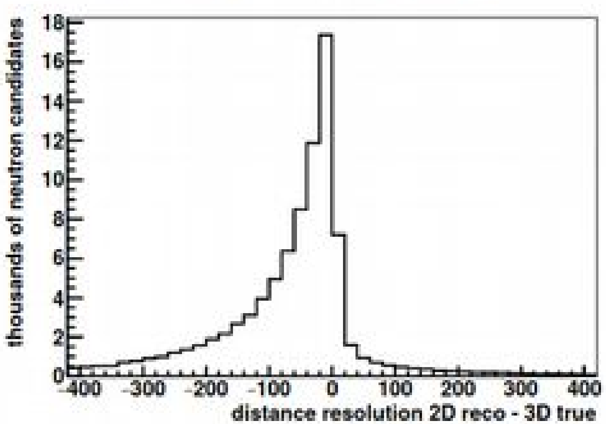
- Isolated energy deposits
- Not too close to charged particle activity
- Theshold: > 1.5 MeV deposited

MINERvA’s Tracker

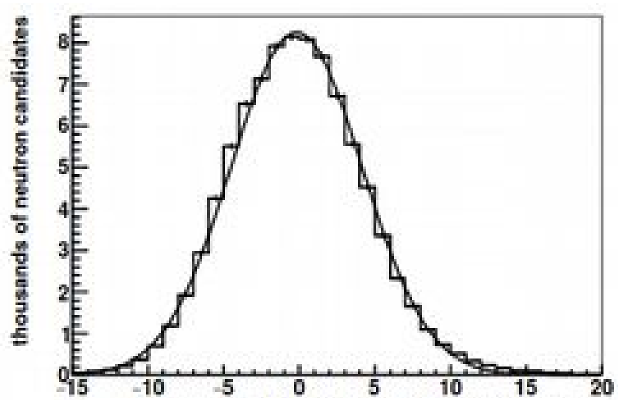


- Only read out on one end → timing resolution
- Modules have 4 planes → raises minimum proton energy for 3D reconstruction

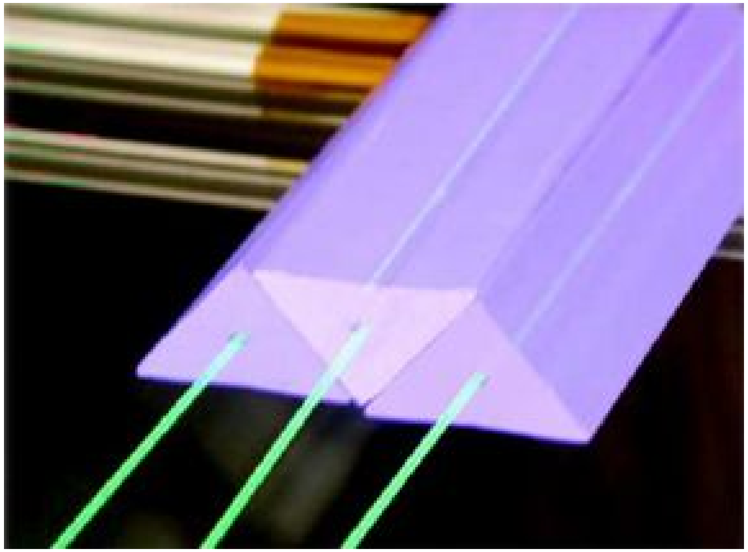
Distance from Vertex



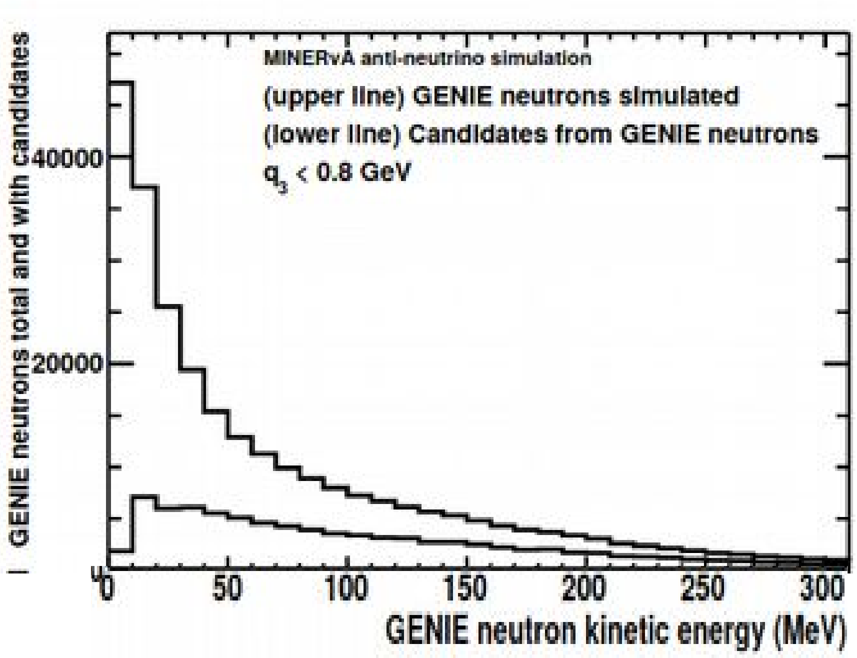
Timing

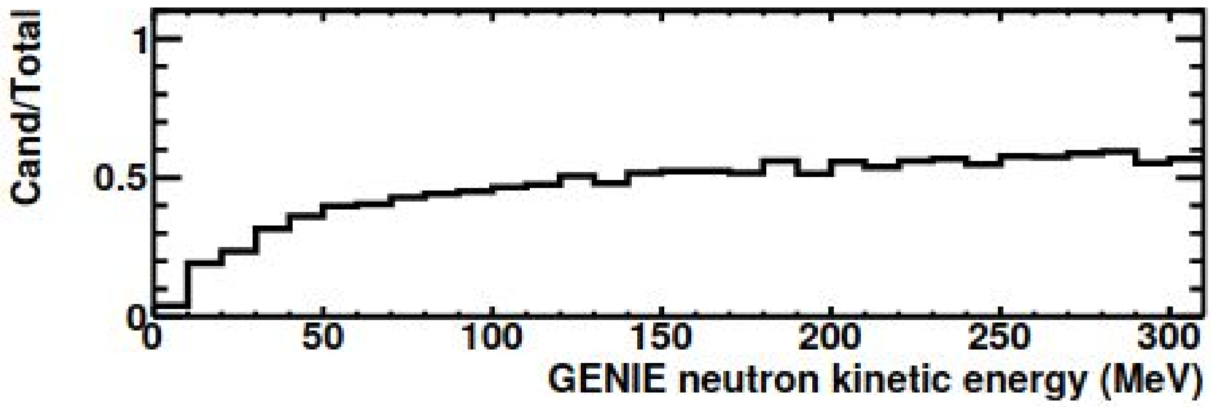


TOF Resolution [ns]



What Neutrons does MINERvA Detect?



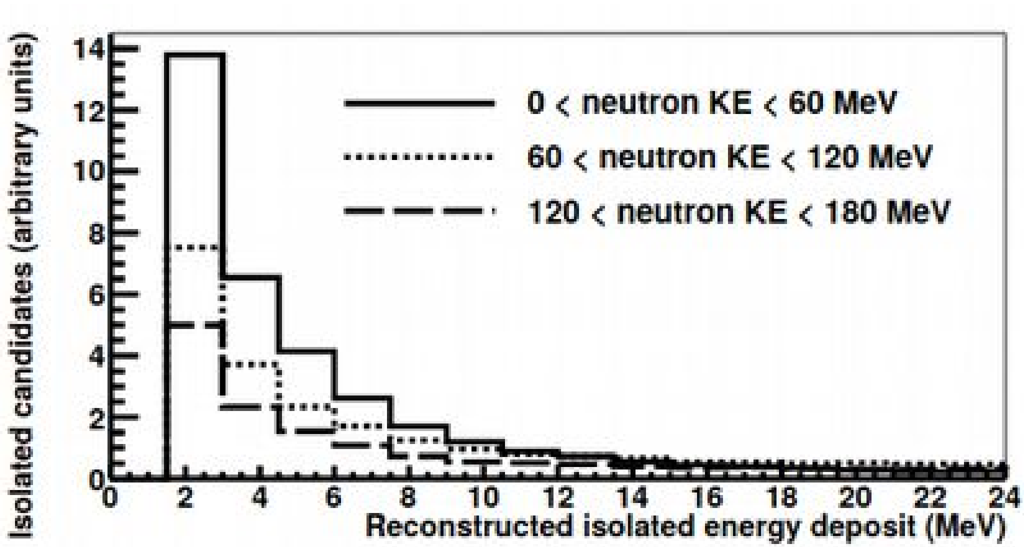


https://arxiv.org/pdf/1901.04892.pdf

- **Prompt** neutron energy deposits
- Predicted neutrons dominated by low KE
- But detection efficiency drops off rapidly

Neutron Reconstruction in MINERvA

q_3 = 3-momentum transfer
to hadronic system
~= low non-muon energy



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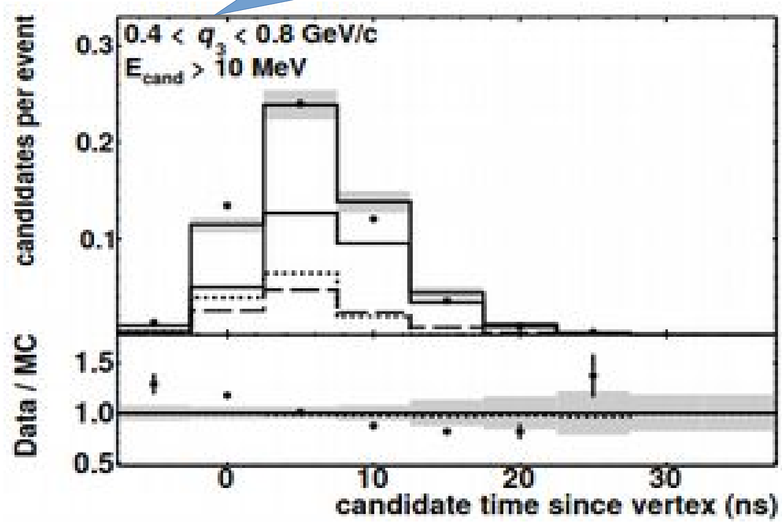
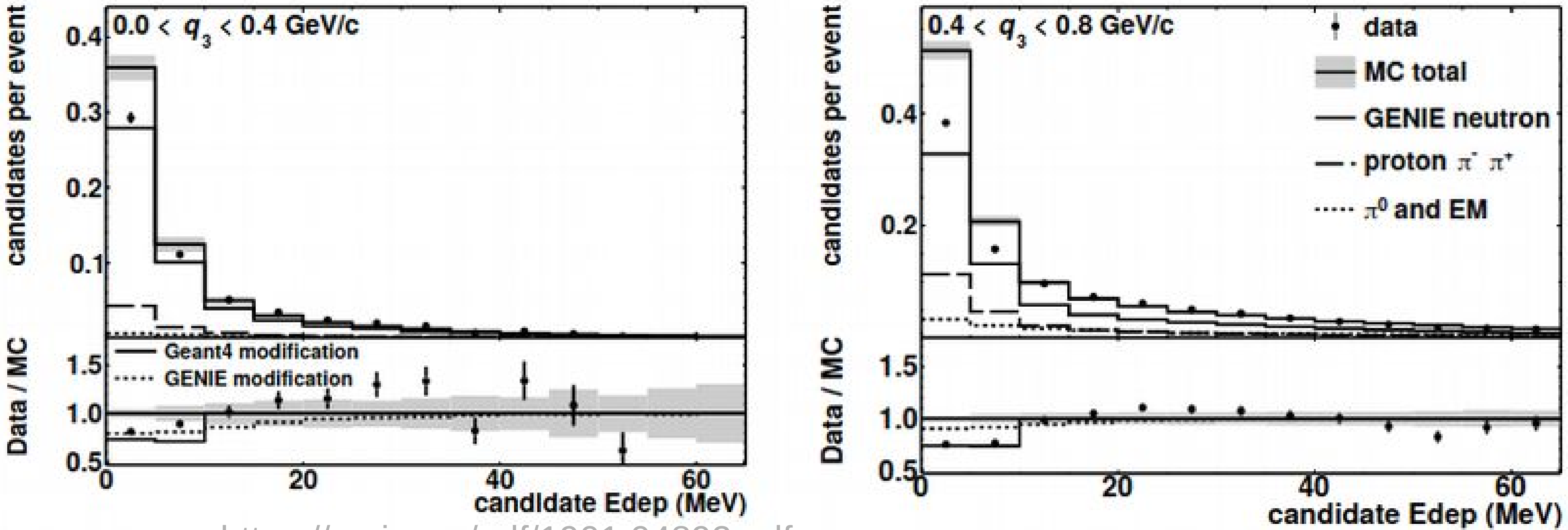


- Energy deposit only a lower bound on KE
- Timing resolution not good enough for KE via TOF

First Neutron Result from MINERvA



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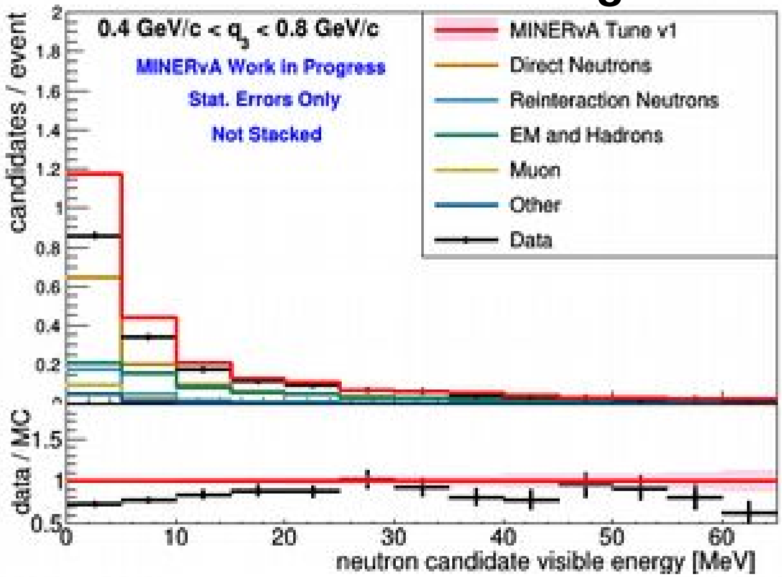
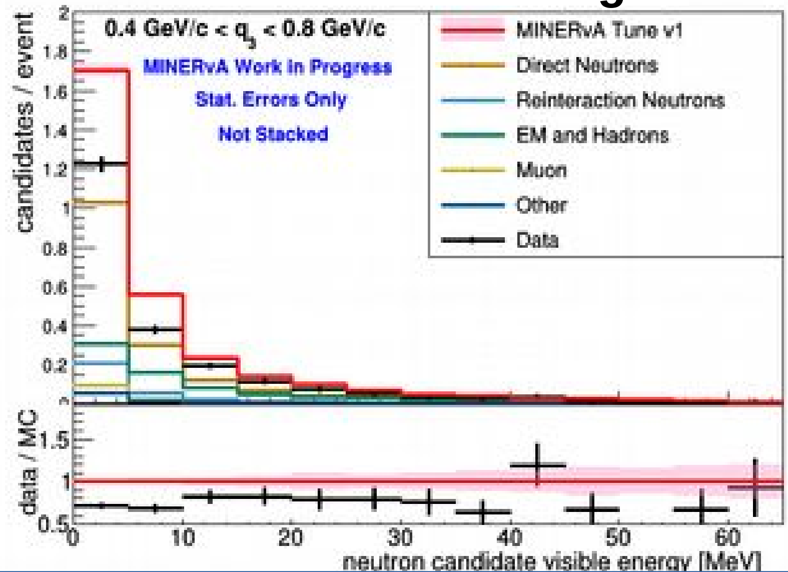
- Data/MC disagreement of undetermined origin at low energy deposit
- Candidate multiplicity has similar trend

Neutrons from Different Nuclei

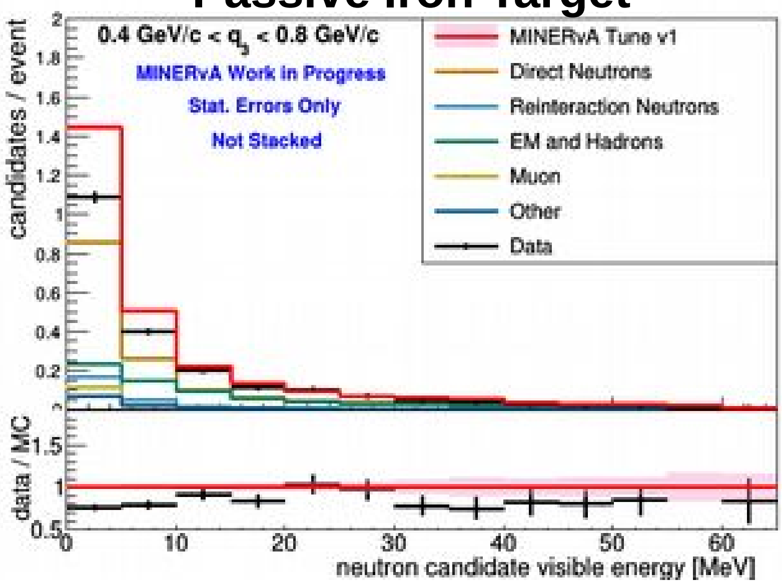
Passive Carbon Target



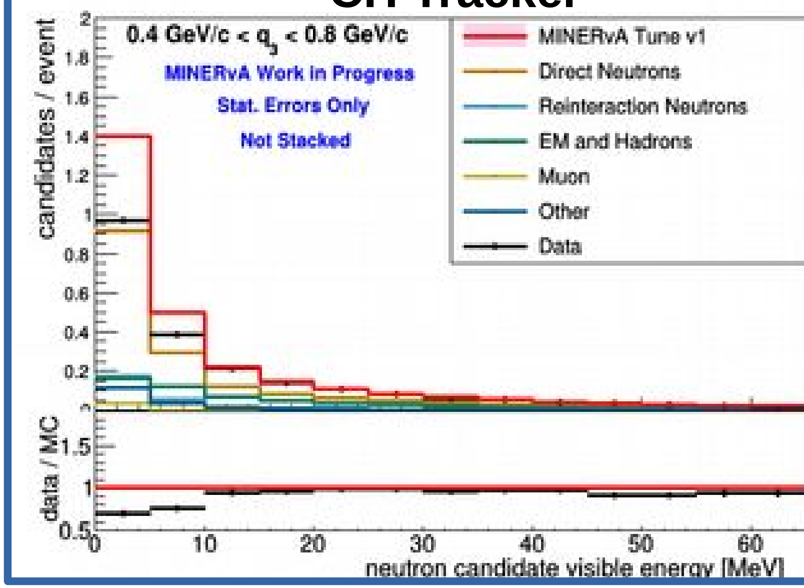
Passive Lead Target



Passive Iron Target



CH Tracker



- Backgrounds bigger but still manageable
- C similar to CH
- Lead ratio different
- 7.5x data in ME!

Conclusions

- MINERvA can count neutrons in a **flux relevant to DUNE**
- Observables available with **CH tracker** technology:
  - Energy deposited
  - Distance from vertex
  - Some timing information
- Low Energy data suggests neutron production **tuning needed**
- Capable of studying neutron production in **carbon**, **iron**, and **lead** with same detector
- Neutrons in upcoming publications
  - Antineutrino QE interactions on H $\rightarrow$ axial form factor
  - Multi-neutron low recoil $\rightarrow$ 2p2h and FSI
  - Neutrons in planned data preservation effort

Thank You

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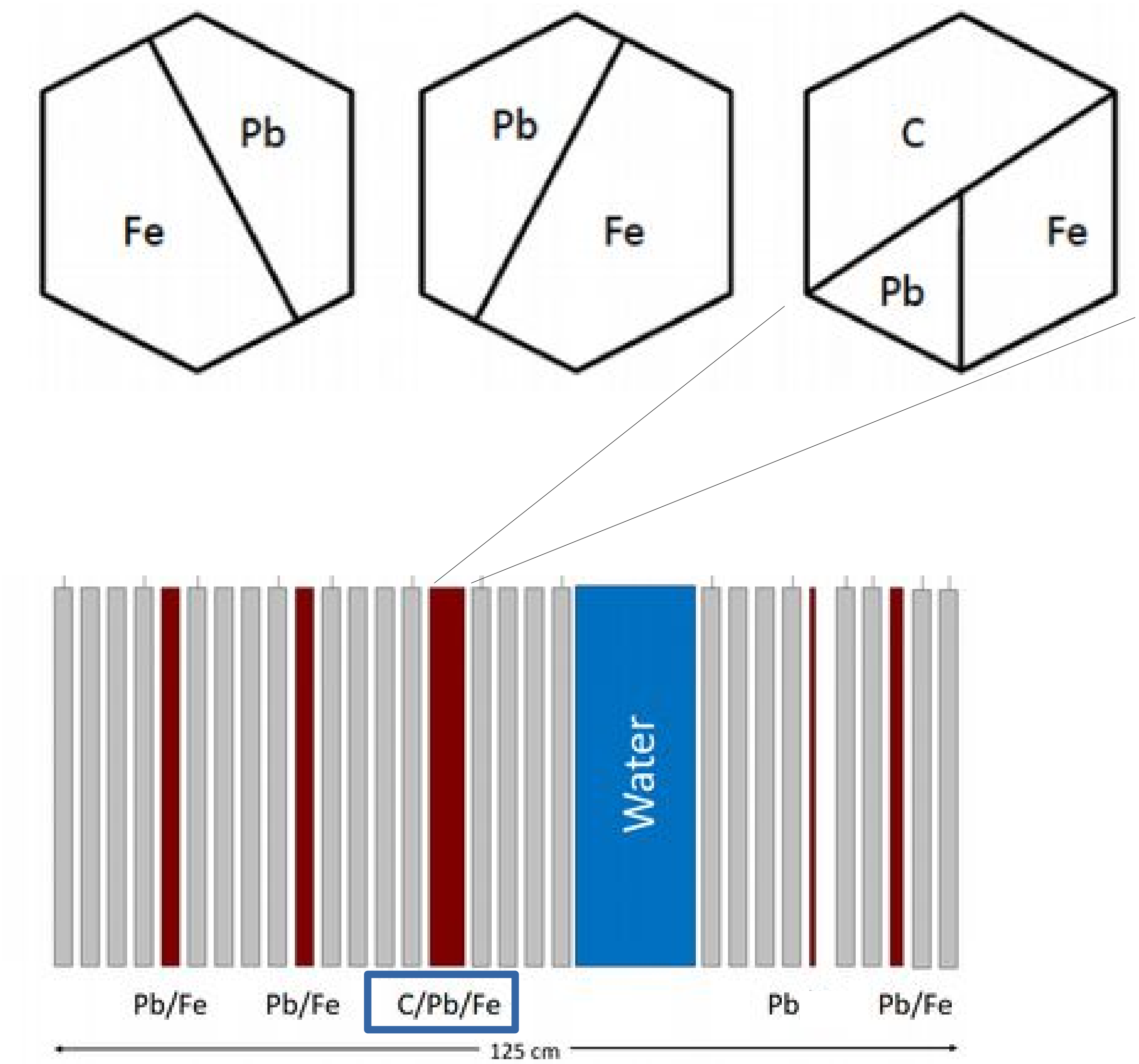
Backup Slides Follow

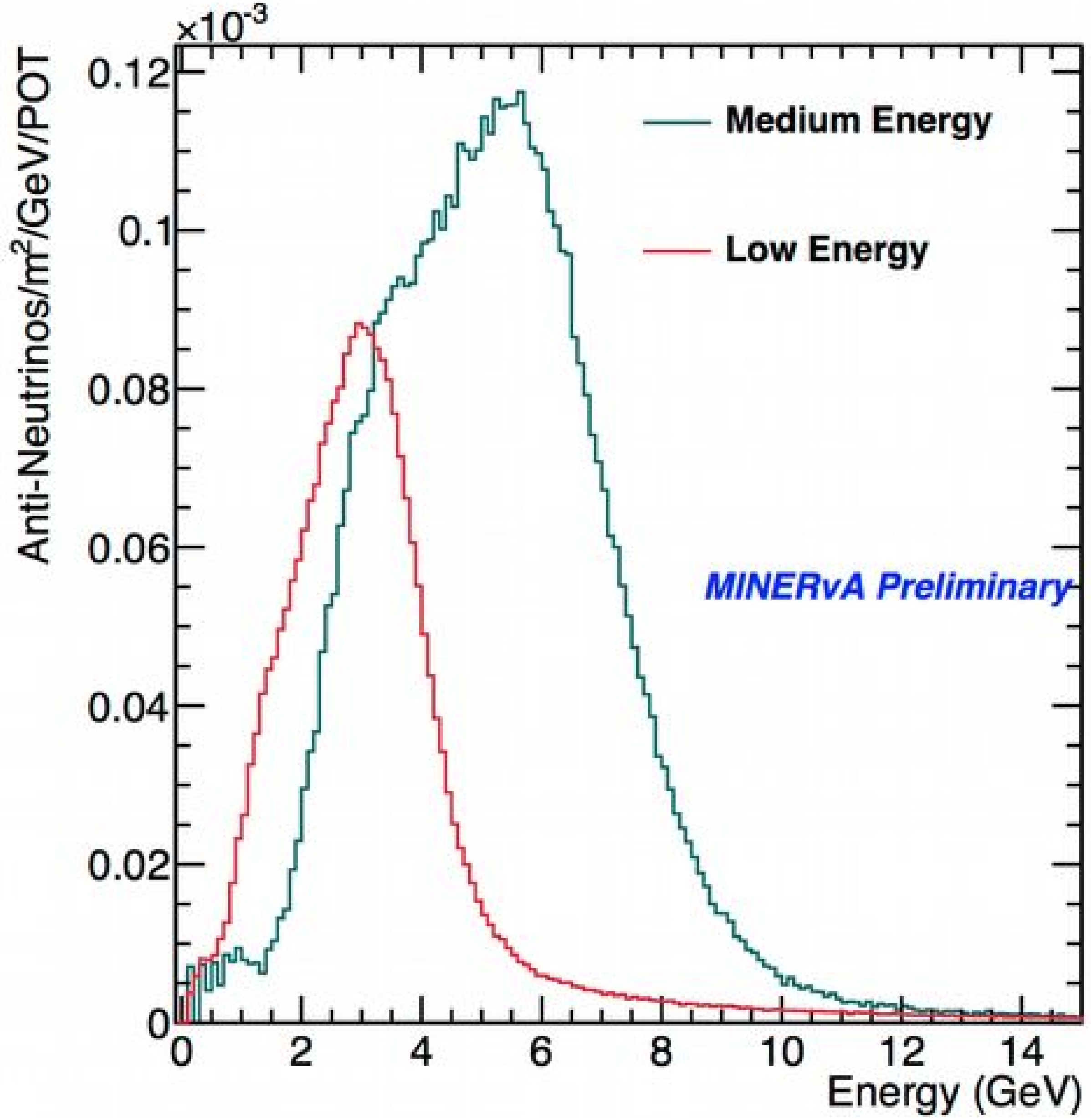
MINERvA's Nuclear Targets



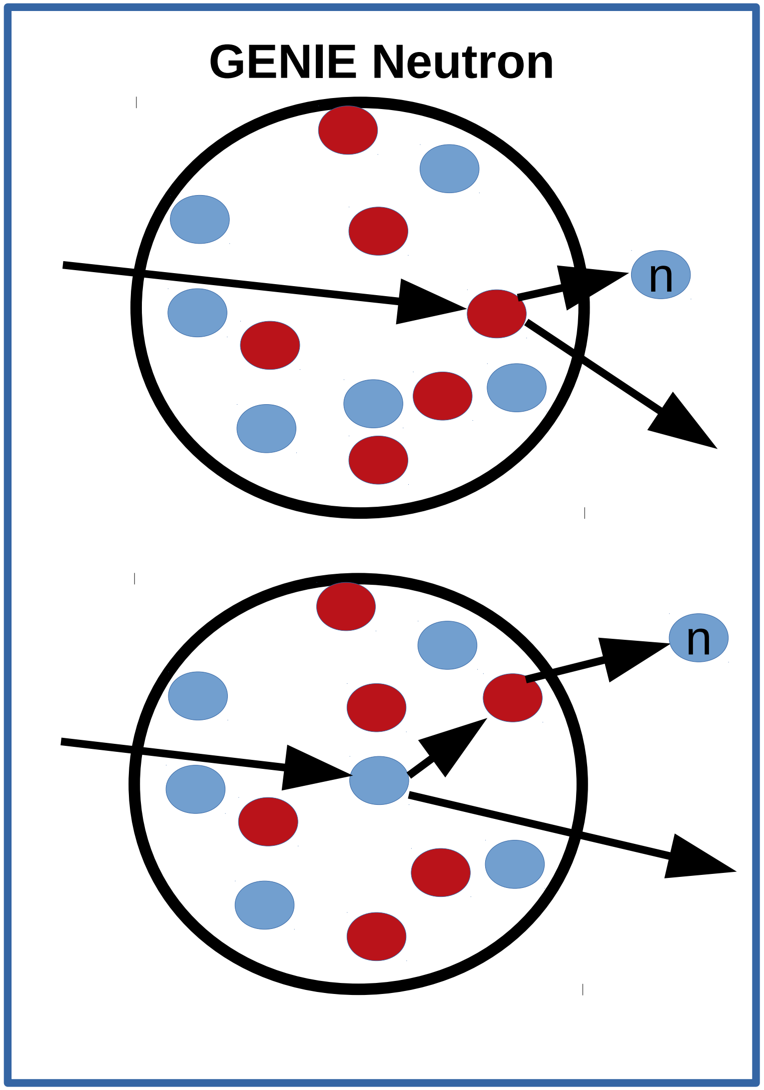
- Passive nuclear targets upstream of tracker
- Let us study A-dependence of neutrino cross sections
- Determine interaction material by x, y coordinates

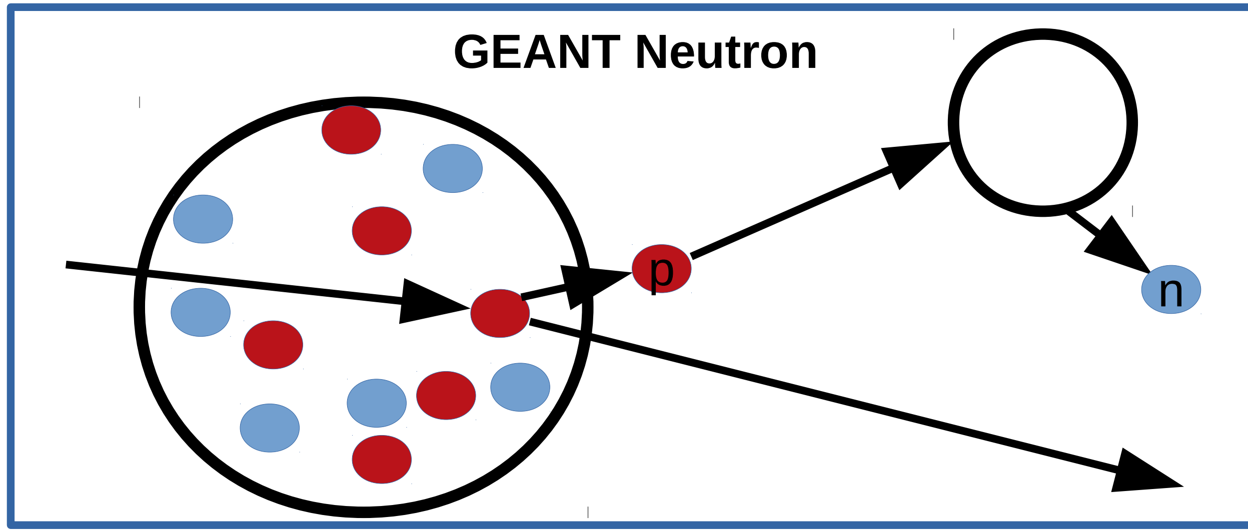
MINERvA's Datasets

- Low Energy
  - ~3 GeV beam
  - 1e20 POT
  - MINOS era
- Medium Energy
  - ~6 GeV beam
  - 12e20 POT
  - NOvA era
- More statistics in ME → more target analyses!



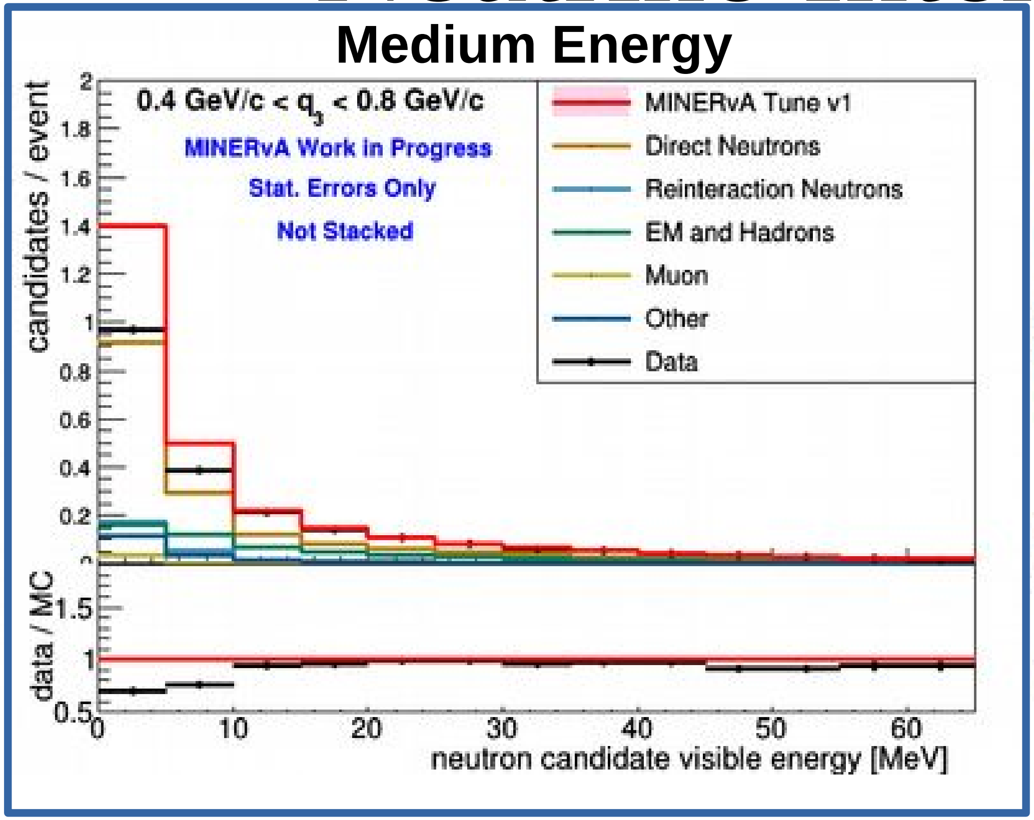
What are GEANT Neutrons?

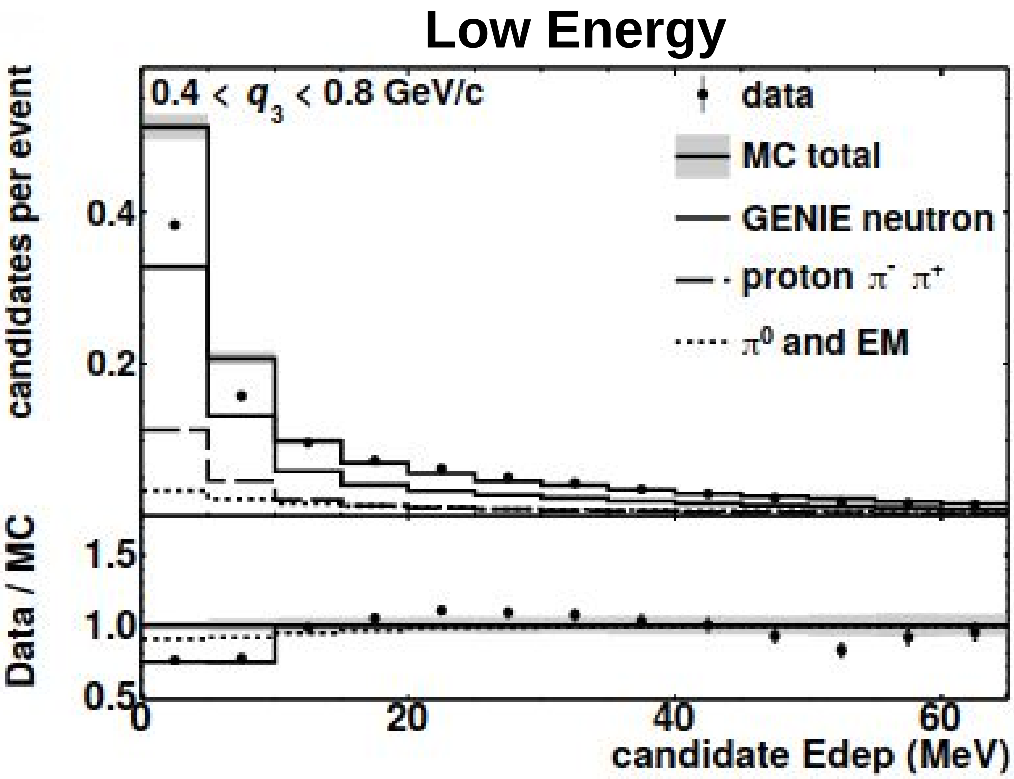




- GENIE neutrons probe neutrino kinematics
- GEANT neutrons irreducible background
- Other particles can be mis-reconstructed as neutrons
  - π^0s
  - Brehmstrahlung from muon
  - Low momentum charged pions
  - NC interactions

Many More Neutrons Near the Neutrino Interaction Vertex





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- Precise charged hadron removal replaces vertex box
- Can see candidates within 17cm of vertex!

- Same data/MC trend
- Same ratio of backgrounds to FS neutrons