FERMILAB-POSTER-20-053-E

High Statistics Anti-Neutrino nucleus CCQE Like cross-section measurements on CH Target with $<E_\nu>$ ~ 6 GeV

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Introduction

The MINERvA Experiment is a neutrino cross-section measurement experiment based in Fermilab that aims to study the neutrino cross-sections in different nuclei for neutrino energy ranging from 1 to 10 GeV to understand the nuclear effects on neutrino nucleus scattering and help the current and future oscillation experiments.

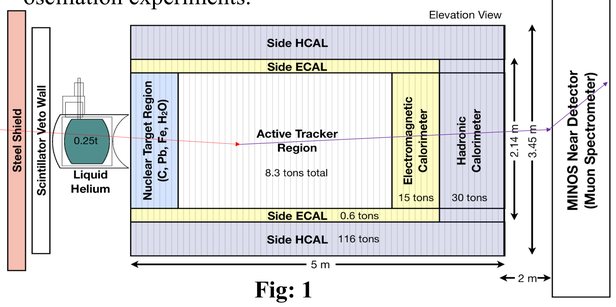


Fig: 1

Schematic diagram of MINERvA detector with MINOS near detector on the downstream end of the MINERvA detector

Motivation

- CCQELike interactions are one of the dominating interactions seen by current (NOvA, T2K) and future (DUNE, Hyper K) oscillation experiments.
- Muon kinematics alone to reconstruct incoming neutrino energy.
- Initial and final State interactions need to be understood in the complex nuclear environment.

Signal Definition

- True CCQE Event : Incoming antineutrino interacts with a proton inside target nucleus to produce a neutron by exchanging W boson, and a positive muon. ($\overline{\nu_\mu} + p \rightarrow \mu^+ + n$)
- Nuclear effect can change the final state particles faking a true CCQE event to look like non CCQE or vice versa.
- **Define Signal based on Final State Particles (CCQELike)**

Example of a true CCQE event faking a non CCQE event due to nuclear effects

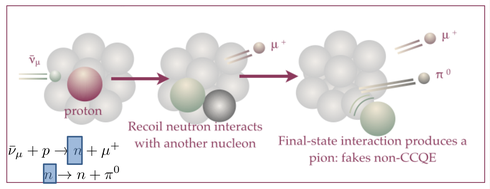


Fig: 2

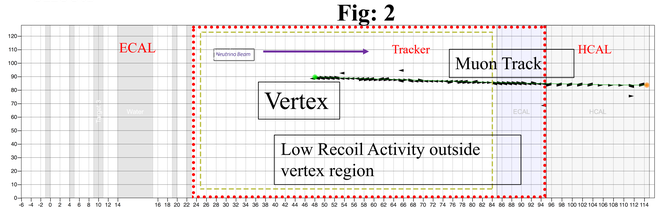


Fig: 3 Event display of a typical reconstructed CCQELike Event

True CCQELike Event:

- One Muon track
- Any number of neutrons
- Any number of protons with KE<120MeV
- No mesons or Baryons

Selection Cuts:

- Interaction vertex inside Tracker
- 1 MINOS matched muon with angle less than 20^0 w.r.t beam
- Low recoil activity outside the interaction vertex region

Signal Selection

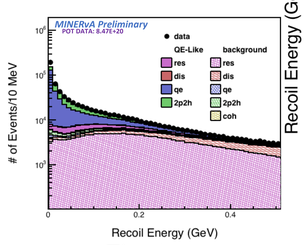


Fig: 4

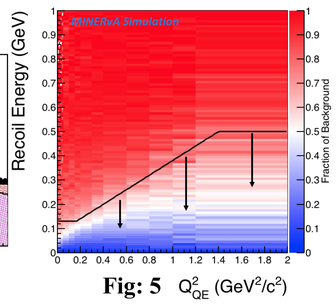


Fig: 5 Q^2_{QE} (GeV^2/c^2)

- Recoil energy (Fig: 4) to select signal events from the background
- Signal events are in the low recoil region
- Optimal Signal Selection cut varies with Q2 (black line in Fig: 5)
  - Based on Optimization of signal efficiency and purity

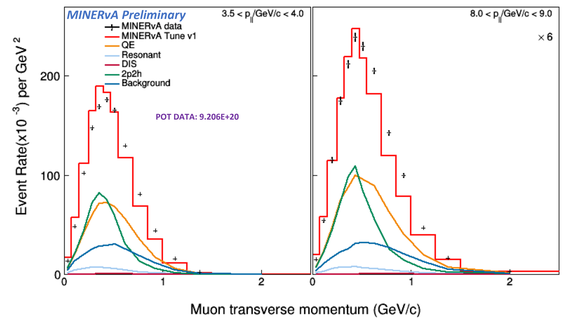


Fig: 6

- Reconstructed raw events as a function of p_T in the bins of $p_\parallel$. Two $p_\parallel$ bins from rising and falling part of $p_\parallel$ distribution to show the events passing reconstruction cuts
- Simulation MINERvA tune v1 : GENIE 2.12.6[1] +Nieves 2p2h[2] +Non Resonant Pion Reduction + Neutrino Low Recoil Fits + Valencia RPA applied to QE
- QE and 2p2h dominate the signal events.
- Low resonance contribution

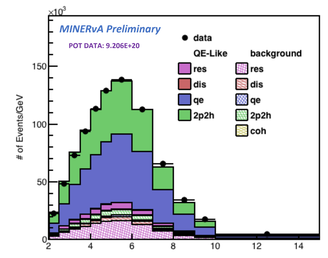


Fig: 7

Reconstructed incoming neutrino energy based on CCQE hypothesis (using muon kinematics only)

$$E_\nu^{QE} = \frac{m_p^2 - (m_n - E_b)^2 - m_\mu^2 + 2(m_n - E_b)E_\mu}{2(m_n - E_b - E_\mu + p_\mu \cos\theta_\mu)}$$

$$Q^2_{QE} = 2E_\nu^{QE}(E_\mu - p_\mu \cos\theta_\mu) - m_\mu^2$$

θ_μ Angle between incoming neutrino and outgoing muon

$Q^2_{QE} = -q^2$ Four Momentum Transfer Squared from lepton to hadron system

m_p and m_n are rest mass of proton and neutron and E_b is binding energy

Selection Efficiency and Purity

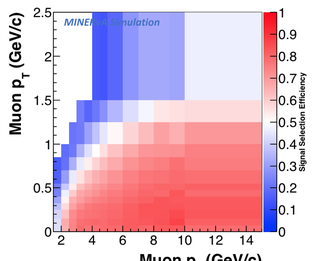


Fig: 8

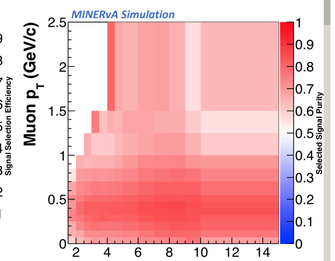


Fig: 9

Signal Selection Efficiency :

$$\frac{\#\ of\ True\ Signal\ Events\ passing\ cuts}{\#\ of\ True\ Signal\ Events}$$

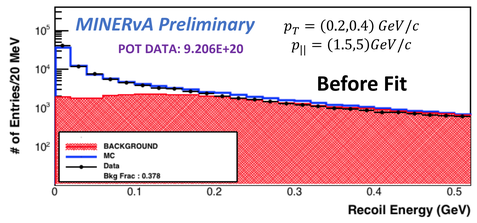
Purity

$$\frac{\#\ of\ True\ \ Signal\ Events\ passing\ cuts}{\#\ of\ \ Events\ passing\ Cuts}$$

- 0 Efficiency/Purity at low $p_\parallel$ and high p_T due to 20 degree angle cut requirement on selection cut.
- 70 to 80% pure sample with high selection efficiency

Background Subtraction

- Data driven fit in 14 different bins of p_T $p_\parallel$
- Fit to a recoil energy side band (100 to 500 MeV) that overlaps in some signal sideband regions
- Normalize the overall background using the fit



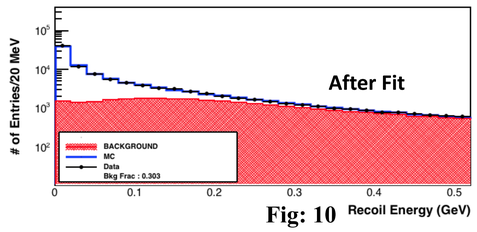


Fig: 10

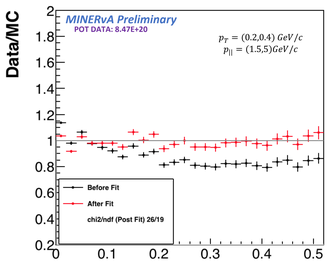


Fig: 11

Recoil energy distribution before and after fit (Fig 10) Ratio of Data and MC before and after fit (Fig 11)

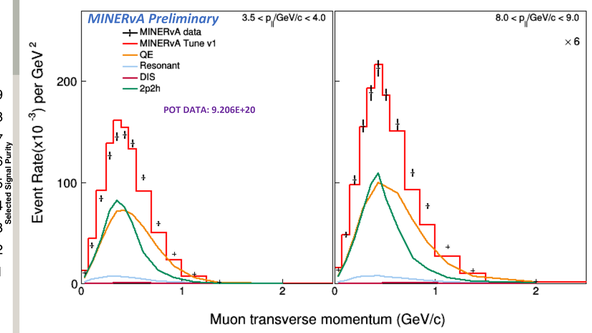


Fig: 12

- Figure 12 shows the background subtracted distribution along with the signal components of the MC.
- Dominated by true QE and 2p2h events.

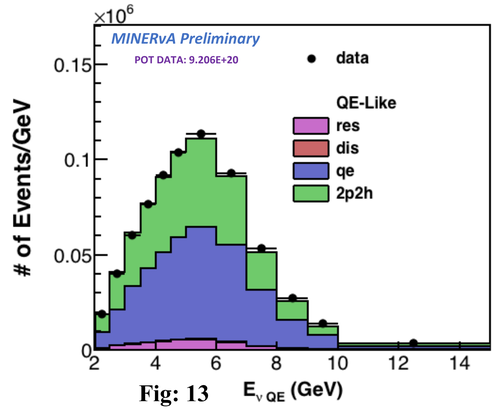


Fig: 13

- Neutrino energy (based on CCQE hypothesis) after background subtraction

Conclusion

- Demonstrates that event selection to background subtraction procedure is robust.
- Ongoing work on cross-section extraction.
- The cross-section measurements in 2 different phase spaces (p_T vs p|| and $E_{\nu\,QE}$ vs Q^2_{QE}) will have the advantage of much higher statistics compared to the measurement with neutrino flux of average energy 3.5 GeV
- Complements the neutrino mode side of CCQELike cross-section measurements with same beam that was recently published[3] .
- **Stay Tuned for Cross-section results!!**

References

1. C. Andreopoulos et al., Nuclear Instrumental Methods, A 614,87 (2010) arXiv: 0905.2517
2. J Nieves, I.R. Simo, and MIJ.V Vacas, Phys. Rev. C83, 045501 (2011)
3. Mateus Carnerio et. al, Phys. Rev. Lett. 124,121801 (2020)

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