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Neutrino Induced Neutral Current Coherent π^0 Production in The NOvA Near Detector

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The NOvA experiment is a long-baseline neutrino oscillation experiment designed to measure the rate of electron neutrinos appearance in a muon neutrino beam. It consists of two finely segmented, liquid scintillator detectors at 14 mrad off-axis in the NuMI beam. The NOvA Near Detector, located at Fermilab, provides an excellent opportunity to study neutrino-nucleus interactions which are important for neutrino oscillation measurements. This presentation will present one of the first such measurements from NOvA: neutrino-induced coherent-π^0 production. Neutrinos can coherently interact with the target nucleus via neutral current exchange and produce a single, forward π^0 , which makes background to the ν_e appearance measurement. This analysis aims to measure the coherent-π^0 kinematics and cross-section and compare to model predictions, and thusly also provide a data constraint on π^0 production in the neutral current resonance and deep-inelastic interaction.

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1. Introduction

Neutrinos can coherently interact with the target nucleus and produce an outgoing pion via both neutral current (NC) interactions and produce a forward-going π^0, with no other particles or vertex activity. Coherent interaction involves a very small momentum transfer to the target nucleus and no exchange of quantum numbers. The coherent π^0 production contributes to the background of the ν_e appearance oscillation measurement. Furthermore, the coherent process provides insight into the structure of the weak hadronic current, and the Partially Conserved Axial Current (PCAC) hypothesis [1].

2. The NOvA Near Detector and Neutrino Flux

The NOvA near detector is a 300-ton, fine-grained, nearly fully active low-Z tracking calorimeter, constructed from liquid scintillator contained inside extruded PVC modules. The extrusions are assembled in alternating layers of vertical and horizontal planes, which are 0.15 radiation lengths in width, optimized for electromagnetic (EM) shower measurement. The detector is 14 mrad off-axis on the Main Injector (NuMI) neutrino beam so that it sees a narrow-band neutrino flux peaking at 2GeV, dominated by muon neutrinos (ν_μ, 94%).

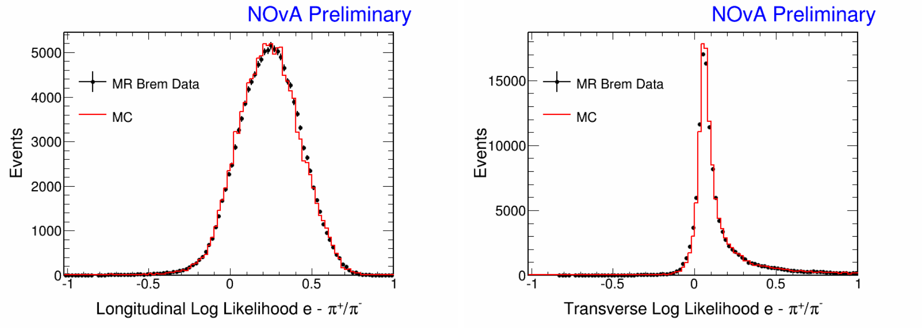

Figure 1: Performance of longitudinal (left) and transverse (right) dE/dx log-likelihood functions for EM shower identification, using Muon-Removed Brem showers. Those likelihood functions are built upon dE/dx information to separate EM showers from background particles (the example here shows charged pions only). Data (black points) and MC (red line) show good agreement.

We use the Muon-Removal (MR) technique to check the detector's response to EM shower particles [2]. This technique looks for bremsstrahlung (Brem) radiation showers induced by high energy rock muons and remove the muons to get a pure EM shower sample. This study shows good data/MC agreement, which demonstrates that the EM showers are correctly modeled in the MC and constrains the uncertainty from EM shower modeling and simulation of detector respond (Figure 1).

3. Coherent π^0 Analysis

In this analysis, we first select single π^0 events in the NC sample defined by the absence of a reconstructed muon in the final state. Both photons from π^0 decay should be reconstructed, and identified as EM-like by the log-likelihood functions. Figure 2 shows the invariant mass of the selected NC single π^0 sample. The π^0 mass peak is correctly reconstructed, which also serves as a constraint on the energy calibration. Next, using two variables, namely the ratio of the prong energy to total event energy ($E_{\gamma\gamma}/E_{Tot}$), and the vertex energy (E_{Vtx}) (Figure 3), we define a control sample, entirely dominated by non-coherent π^0, and a signal sample containing coherent and non-coherent events. The control sample is used to tune the normalization and shape of the background kinematics (energy and angle), which is then applied to the non-coherent background in the signal sample. Finally, the coherent signal is measured in the coherent signal sample as the data excess over non-coherent MC prediction. Data is still blinded in this sample at this stage of analysis.

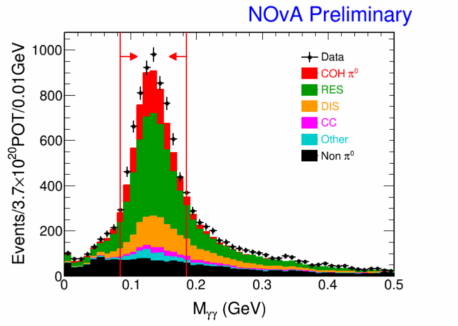

Figure 2: Invariant mass of the selected NC singal π^0 sample data (black points) and MC (colors).

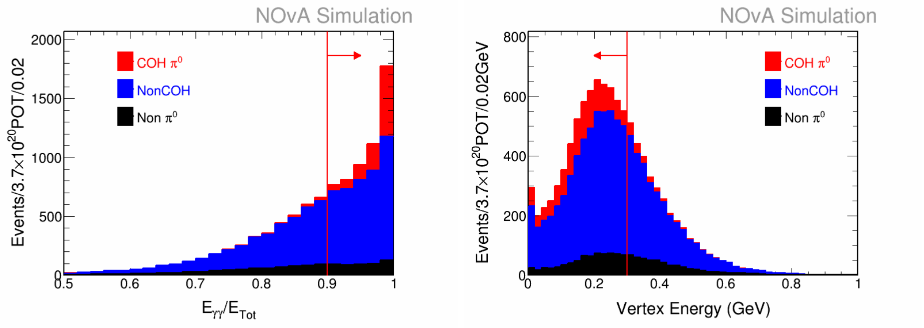

Figure 3: $E_{\gamma\gamma}/E_{Tot}$ (left) and E_{Vtx} (right) cuts used to define the signal sample and control sample. Signal sample is defined by $E_{\gamma\gamma}/E_{Tot} \geq 0.90$ AND $E_{Vtx} \leq 0.30$ GeV, and control sample by $E_{\gamma\gamma}/E_{Tot} < 0.90$ OR $E_{Vtx} > 0.30$ GeV

The cross-section of coherent π^0 production will be calculated as:

$$\sigma = \frac{N_{Data,selected} - N_{Bkg,norm}}{\varepsilon \times N_{Target} \times \phi} \tag{3.1}$$

where $N_{Data,selected}$ and $N_{Bkg,norm}$ are the number of data and normalized MC background in the selected coherent region of the signal sample, ε is the efficiency of coherent signal selection calculated by MC, N_{Target} is the number of target nucleus in the fiducial volume, and ϕ is the muon neutrino flux.

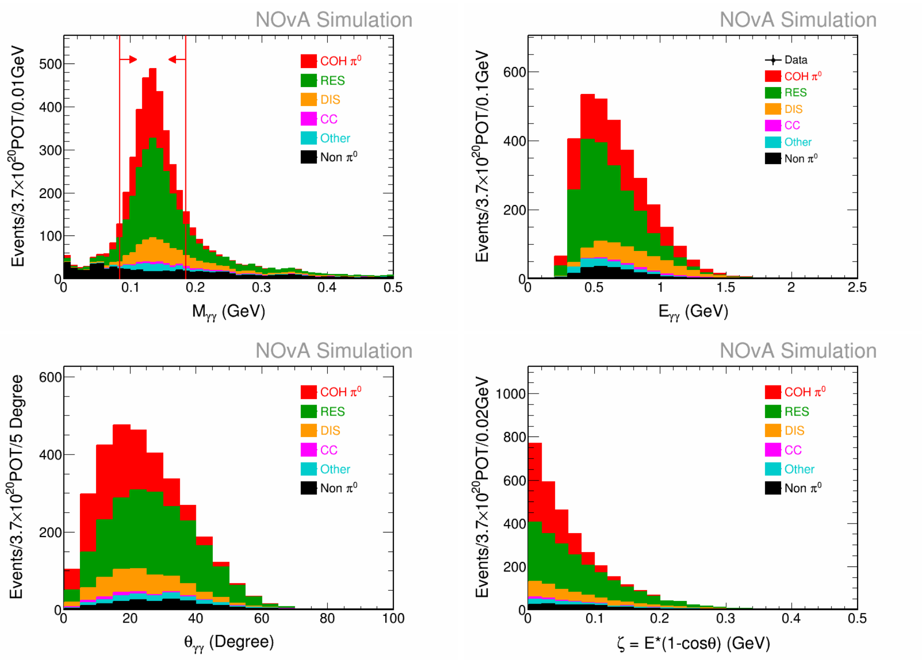

Figure 4: Kinematic variables of the control sample events, including the invariant mass ($M_{\gamma\gamma}$, top left), π^0 energy ($E_{\gamma\gamma}$, top right) and angle ($\theta_{\gamma\gamma}$, bottom left), and $\zeta = E_{\gamma\gamma} \times (1 - \cos\theta_{\gamma\gamma})$ (bottom right). Data is blinded for now in this sample.

4. Statistical and Systematic Uncertainties

With the current NOvA dataset (3.7×10^{20}POT) we expect ~8% statistical uncertainty. The systematic uncertainty from background normalization is constrained by the control sample which is estimated to be ~5% by changing the background constraining method and control sample definition. External data are used to constrain the flux uncertainty to ~11%. The coherent signal simluation uncertainty is estimated to be ~4% by comparing models. The simulation and detector response to EM showers are constrained by MR Brem showers to ~1%. Finally we have another ~2% uncertainty from the detector simulation. Overall we expect ~15% total uncertainty, which will make this analysis very competitive.

5. Summary

We are working on a measurement of neutrino-induced coherent π^0 production using high statistics NOvA data. Data-driven method are being developed to constrain the dominant systematic uncertainties. We expect to report a cross-section result soon.

References

[1] S. Adler, Phys. Rev. B **135**, 963 (1964).

[2] H. Duyang, Proceedings, Meeting of the APS Division of Particles and Fields (DPF 2015), arXiv:hep-ex/1511.0035.