Analysis of the μ-2p Final State with SBND

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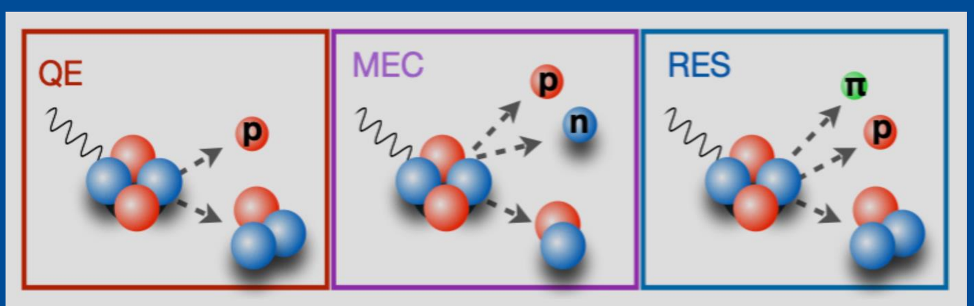

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Introduction

The neutrino remains an enigma within the Standard Model. The Short-Baseline Near Detector (SBND) at Fermilab aims to probe these peculiar particles by examining essential regions of neutrino research, including oscillation measurement and searches for sterile neutrinos.

As liquid Argon (LAr) neutrino detectors such as SBND gain relevancy, **it is necessary to understand neutrino interactions pertinent within LAr detectors**, namely ν-nucleon interactions, to reduce the substantial uncertainties from said interactions. This research intends to probe the ν interaction signature of one muon and two protons with SBND. **Few studies have examined the μ-2p final state**, among these are studies at ArgoNeuT[1], MicroBooNE[2], and ICARUS[3]. The lack of research on the μ-2p signature suggests the need for further examination.

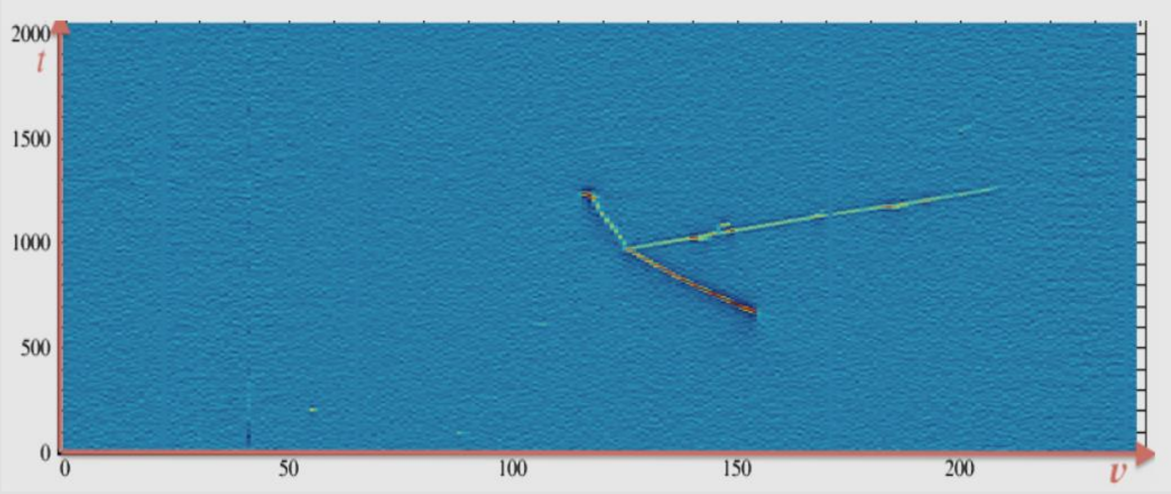


Figure 1:
One of four μ-2p detections by the ArgoNeuT detector[1]

SBND demonstrates strong potential to examine this final state as the detector's dense LAr nuclei enable numerous neutrino interactions, resulting in **sufficient μ-2p statistics.**

Neutrino experiments observe interactions from quasi-elastic production (**QE**), meson exchange current (**MEC**), resonant pion production (**RES**), neutral current (NC), deep inelastic scattering (DIS), & cosmic muons. μ-2p events should be produced by QE & MEC processes; however, RES may produce a similar topology with a μ-p-π final state. Consequently, the pion tracks may often be misidentified as protons. **This substantial source of uncertainty indicates the importance of studying the μ-2p final state.** To accurately identify the μ-2p signature, it is necessary to develop precise selection criteria, sensitive cuts, and a detailed analysis of kinematic variables. **Ultimately, this study aims to minimize misidentification & further the precision of neutrino analyses.**

Analysis

Throughout this analysis, multiple variables were examined in Monte Carlo data. By **comparing the contributions of certain production methods**, one can determine essential information about ν-nucleon interaction modeling. **To increase purity, event cuts from Jack Smedley were adapted to the following event selection criteria, informed by Fig. 2:**

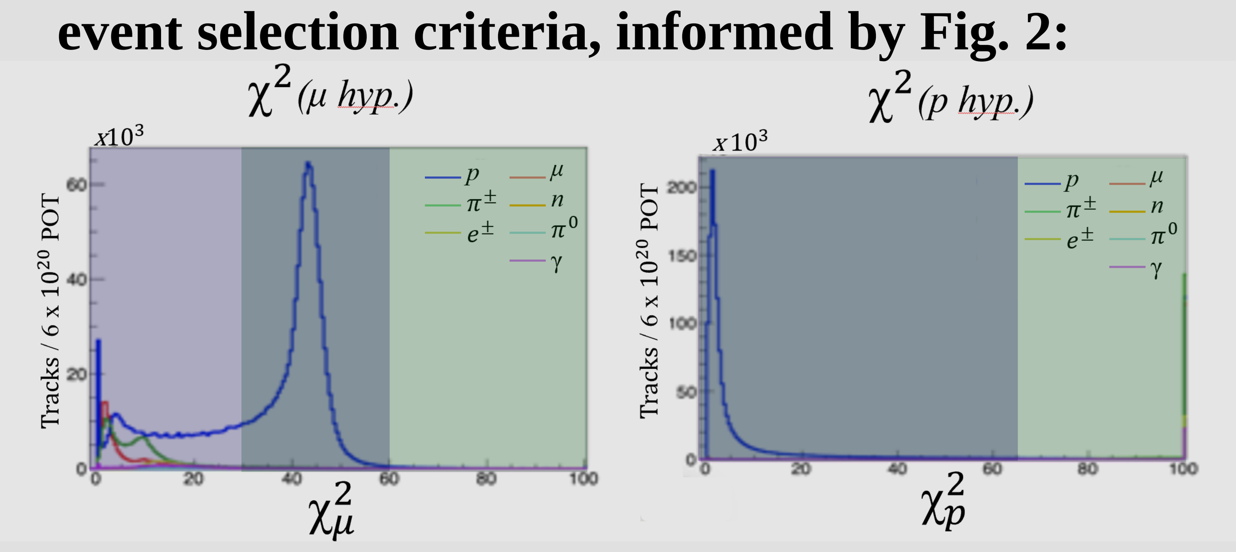


Figure 2:
Event yields generated by Shweta Yadav of χ^2 values for muon (left) & proton (right) hypotheses. The legend distinguishes the yields of each particle relative to each χ^2

- **Fiducial –** the interaction is contained
- **Muon** – $\chi^2_\mu > 30$ $\chi^2_p < 60$ Track length > 50 cm
- **Proton** – $\chi^2_\mu \neq 0$ $\chi^2_p < 65$ ($p_{leading}$ as the longest track)
- **Pion Cut** – $\chi^2_\mu \neq 0$ $\chi^2_p < 50$ $\chi^2_\pi < 30$ Track length < 10 cm

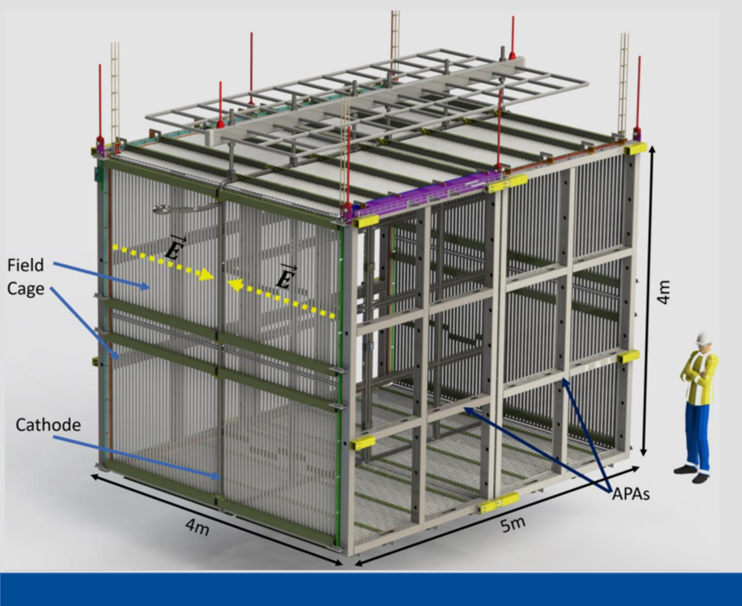


Figure 3: The Short-Baseline Near Detector

It was a common finding in each observable for QE processes to dominate until the second proton cut. At this point, RES production dominates, hinting **that an additional cut to eliminate pions may be essential** to optimize accurate event selection. Figure 4 demonstrates the results of such a cut.

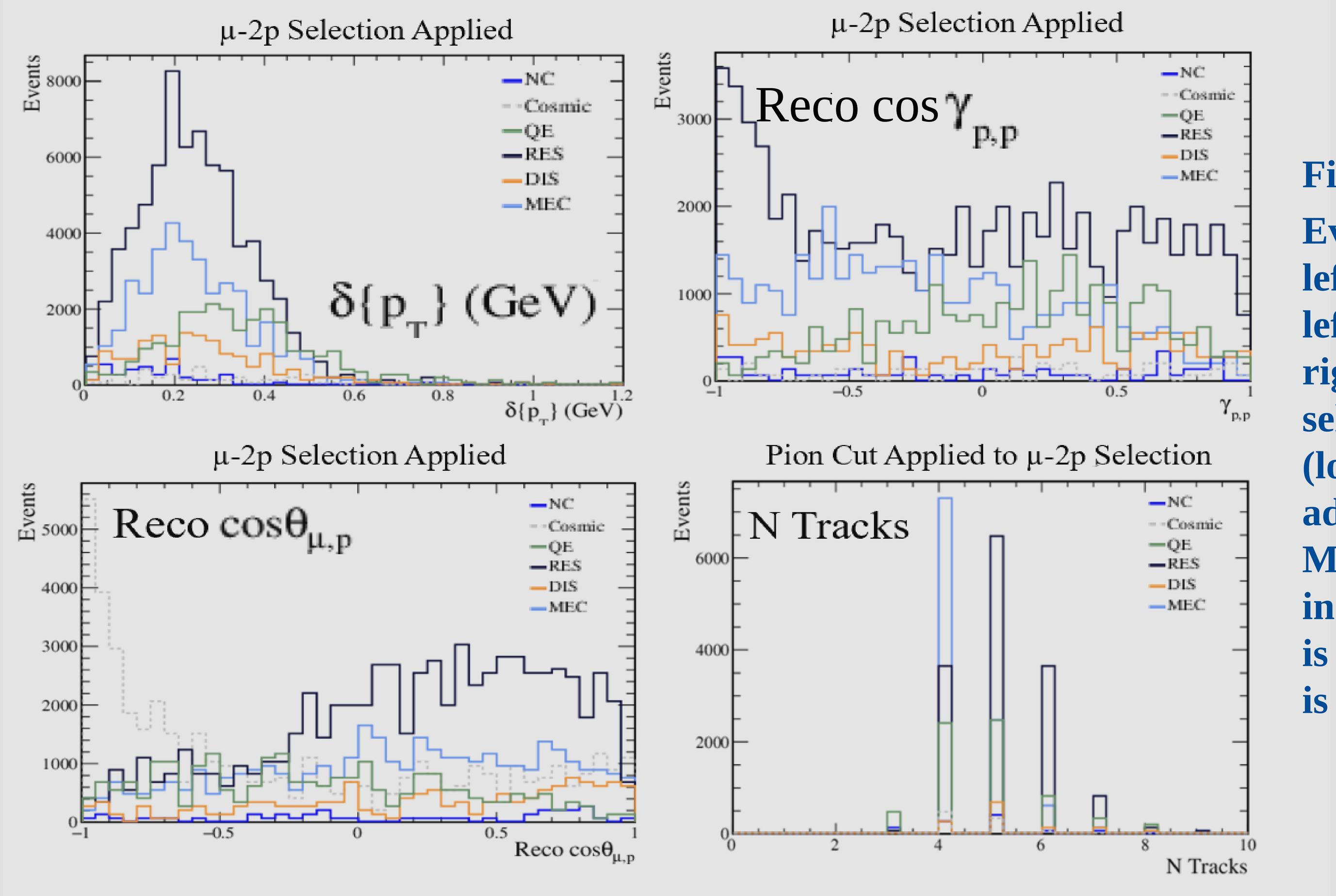


Figure 4:
Event yields of δp_T (upper left), reco. cos$\Theta_{\mu,p}$ (lower left), reco. cos $\gamma_{p,p}$ (upper right) following the μ-2p selection, and N Tracks (lower right) with an additional pion cut. The MEC & QE contribution in the fourth N Track bin is favorable once the π cut is applied.

Yields in True E_ν *(per year)*

6e20	RES	QE	MEC	DIS	NC	Total
No Cut	2053020	2990000	772450	469420	934777	7219667
Proton	295316	497519	162258	48897	24311	1028301
Two Protons	69490	25137	36432	10743	3099	144901
Pion Cut	14807	6749	10537	1033	826	33952

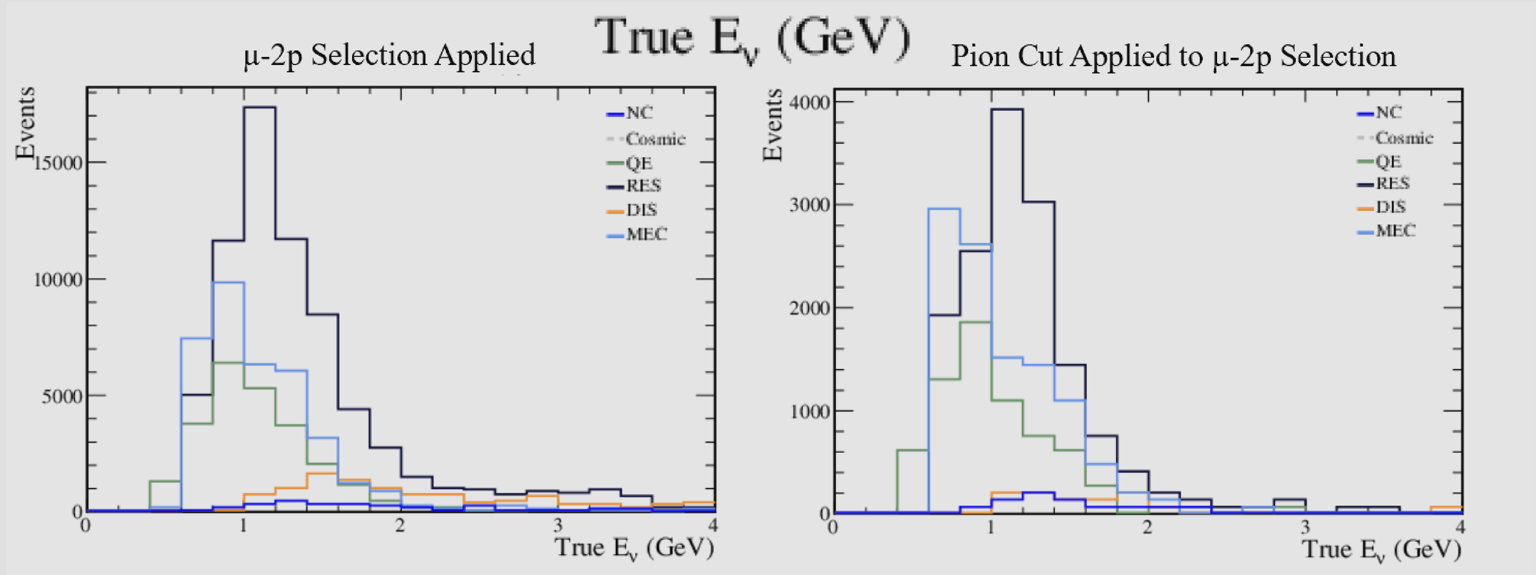
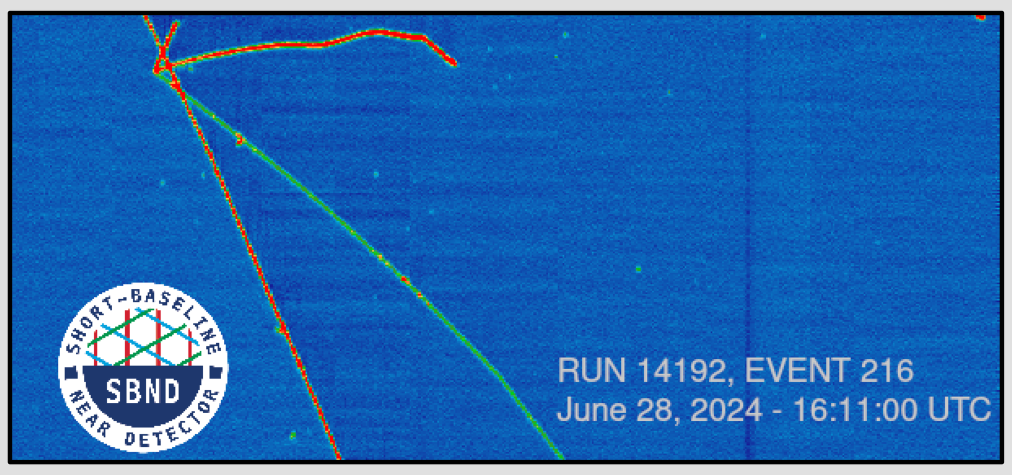


Figure 5: An estimated progression of event yields after each cut in True E_ν

An interesting feature among this cut progression in True E_ν is the **improved ratio** of $\frac{QE+MEC}{RES}$ following the added π cut. This ratio goes from 0.886 with the μ-2p selection to 1.17 with the additional cut on pions. Despite improved purity, one must acknowledge the significant decrease in statistics following the π cut. The future of μ-2p analysis will focus on **examining real SBND data** and comparing the results to our simulation. As data collection commenced, I have scanned several μ-2p candidate events with SBND such as Fig. 6.

Figure 6:
μ-2p candidate among the first data collected by SBND



Conclusion

The μ-2p final state is a promising site to study neutrino interactions within LAr detectors. Within simulation, the μ-2p final state demonstrates a surplus of resonant pion events, implying the need for further cuts to improve data purity. **Refining μ-2p criteria will increase precision of neutrino studies** from oscillation measurements to sterile ν searches.

Acknowledgements

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References

[1]Acciarri et al. *The detection of back-to-back proton pairs in CC neutrino interactions with the ArgoNeuT detector*
[2]Abratenko et al. *First Measurements of Differential Cross Sections for... in the MicroBooNE Detector*
[3]Howard et al. *Charged Current Mesonless Analysis with the off-axis NuMI beam at ICARUS*

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