

Update on Mesonless $\bar{\nu}_\mu$ CC Cross Section @ ProtoDUNE ND

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2x2 First Analysis Meeting

June 23, 2023

Outline

The analysis is lead by Elise Hinkle

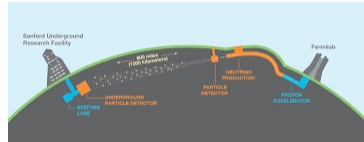
- Reminder of Motivation
- Reminder of the Signal Definition
- Technical Details
- Simulation Studies
- Plans for Systematic Uncertainties
- Summary

Reminder of Motivation

Collected data are on tape



Collect data at the end of the decade

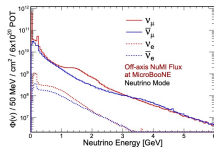


Collect data over the next 3 years

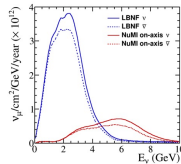


Anti-neutrino Energy (GeV)

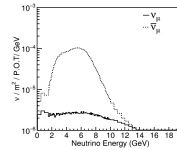
NuMI off axis : < 0.4 GeV



LBNF : 2.5 GeV



NuMI : 6 GeV



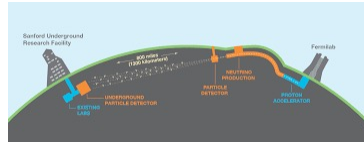
- The success of DUNE neutrino oscillation program depends heavily on minimizing systematic uncertainties associated with the neutrino cross-sections
- The short baseline neutrino program, along with ArgoNeut will contribute significantly for understanding neutrino-Argon interactions
- There exists no assessment of exclusive processes for antineutrino-Argon interactions
 - MicroBooNE collected NuMI off axis antineutrino data
 - Can produce cross-section measurements with antineutrino beam peaked at low energies
 - ProtoDUNE-ND will collect data from NuMI antineutrino beam with an energy peaked at medium energy
 - Both physics programs are essential for understanding neutrino-Argon interactions at DUNE

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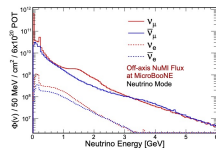


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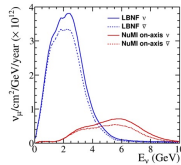


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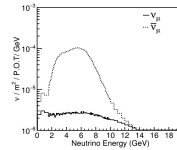
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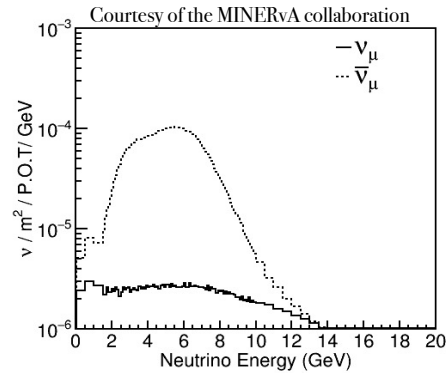
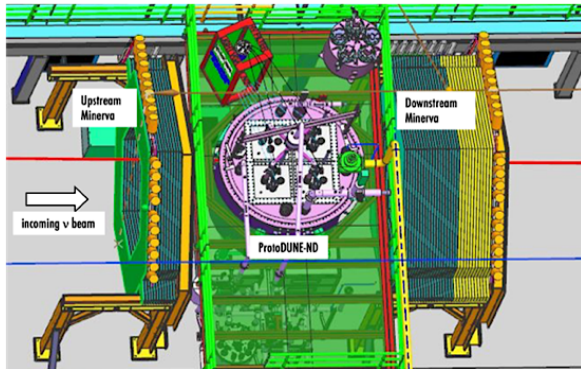
NuMI : 6 GeV



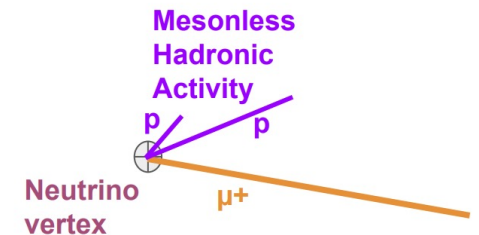
- DUNE would like to produce the first oscillation results before Phase II (middle of the next decade)
 - Primary competition is Hyper-K
 - DUNE near detector program will rely heavily on the development and knowledge obtain from measurements that are produced from SBN and ProtoDUNE-ND programs
 - Although ProtoDUNE-ND detector system has limitations, we can take advantage of producing the world first exclusive cross-section measurements
 - Cross-section measurements will be challenging

Reminder of the Signal Definition

Collect data over the next 3 years

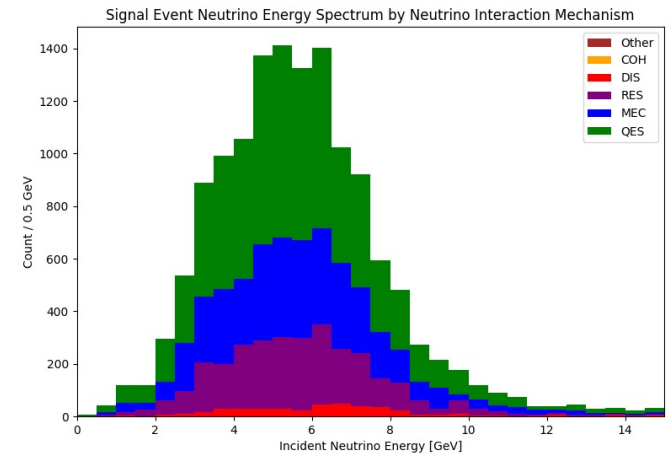


- The goal of the group is to start with an exclusive channel having a simple topology and realistic and practical measurements
 - Previous studies from ProtoDUNE-ND shows that majority of the neutrino-Argon produced muons will exit the downstream MINERvA detector
 - The signal topology includes an interaction event in the 2x2 that has the following characteristics:
 - a long track contained or exiting ProtoDUNE-ND, which is identify as the muon candidate
 - short track(s) contained in the 2x2 or MINERvA, which are not identify as mesons
 - The proposed measurements are:
 - Proton multiplicity in the vertex region
 - Leading proton momentum
 - Sub-leading proton momentum
 - Opening angle between the muon and leading proton
 - Opening angle between the leading and sub-leading protons

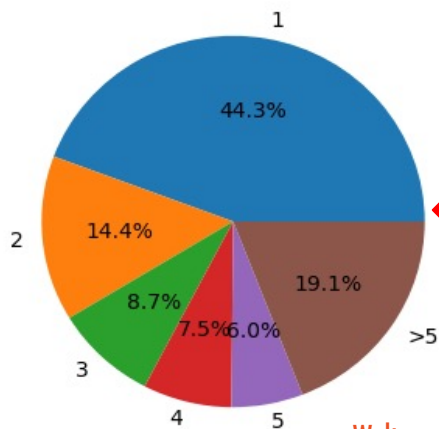


Technical Details

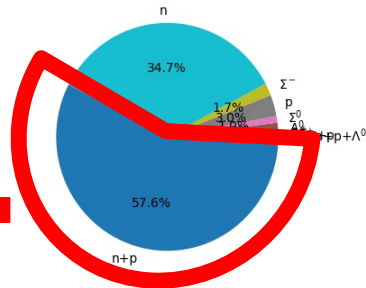
- Production: [MiniRun3 larnd v2 sample](#) : 1,023 files
- Analysis Code: [Mesonless Numubar CC - github](#)
- More Information on the Analysis
 - Signal events includes both ν_μ and $\bar{\nu}_\mu$ CC events
 - 91.4% ($\bar{\nu}_\mu$) and 8.6% (ν_μ)
 - Short track's threshold is 3 pixels = 1.2 cm
 - Scaled to 2.5e10 POT



Primary Proton Multiplicity in Signal Events with Protons

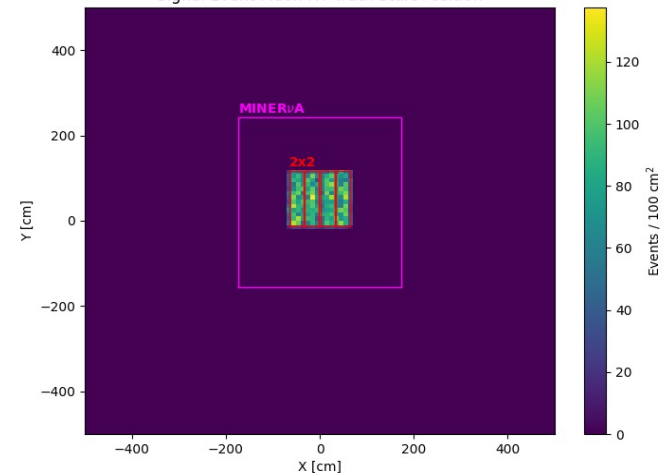


Final State Hadrons in Signal Events

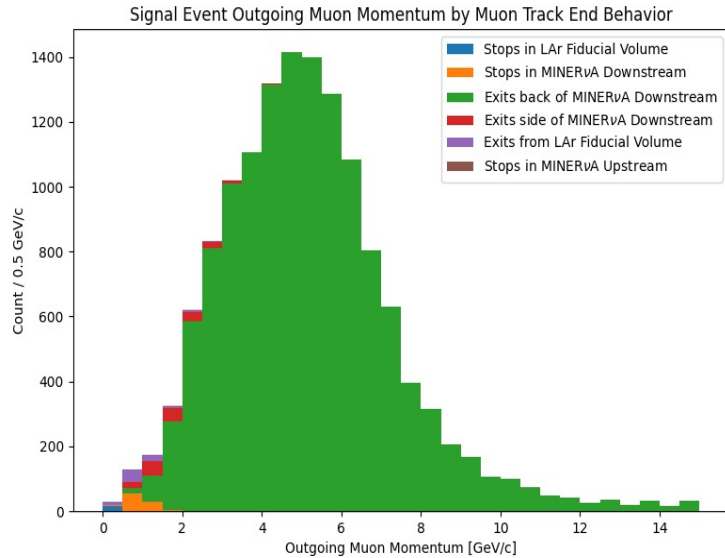
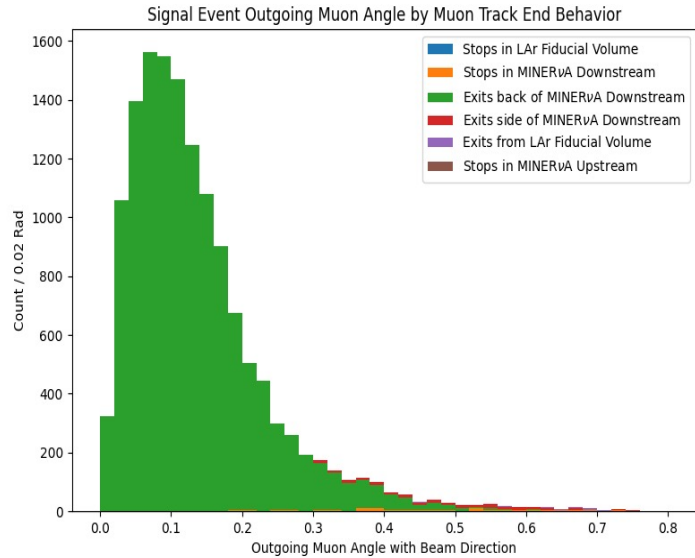
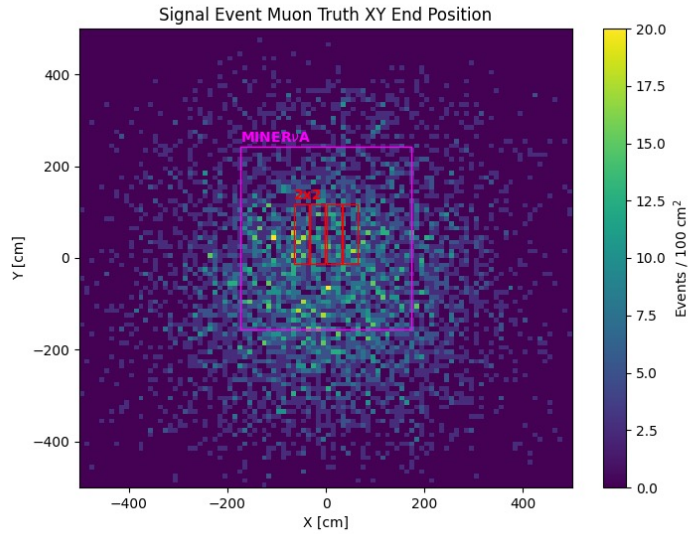
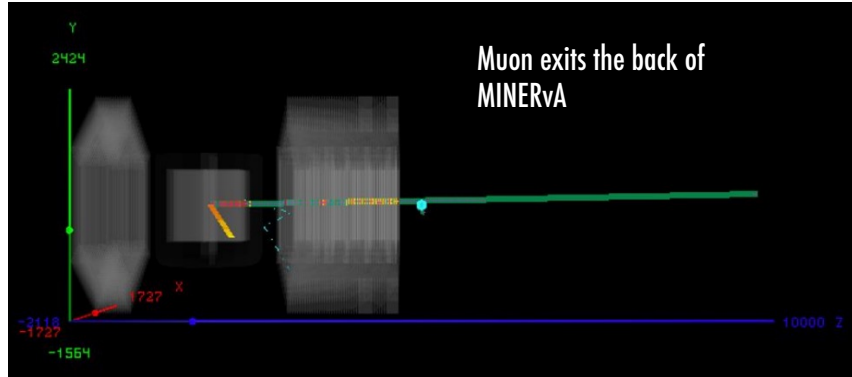


Walton on behalf of Hinkle et al.

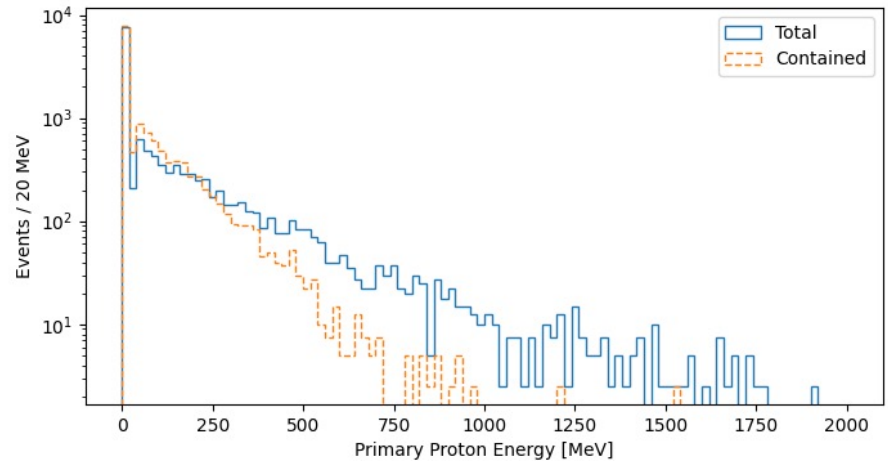
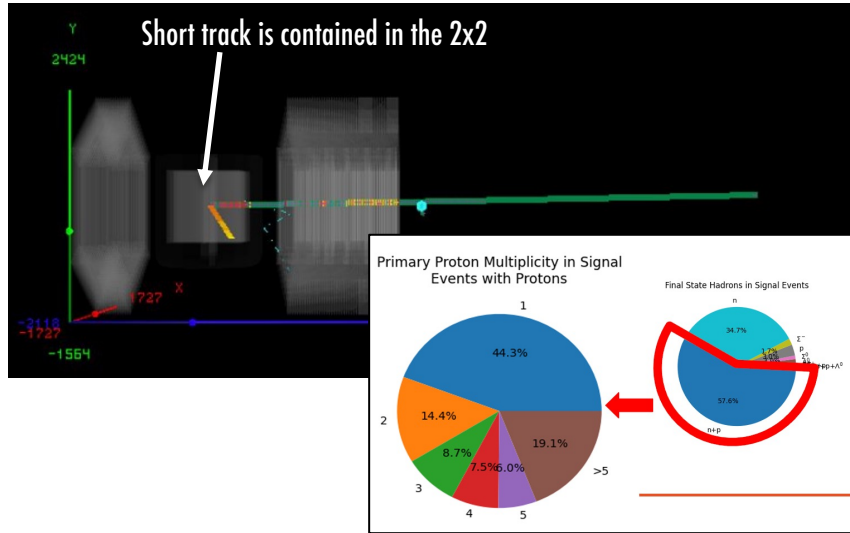
Signal Event Muon XY Truth Start Position



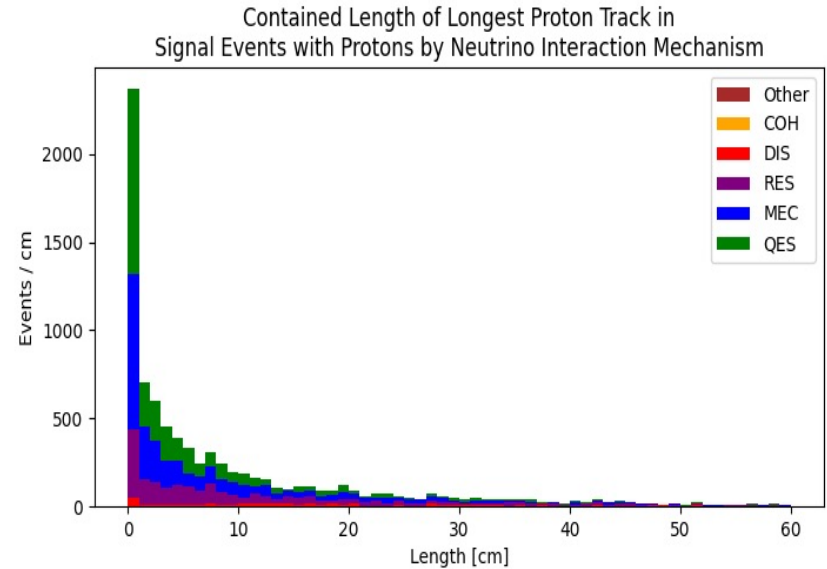
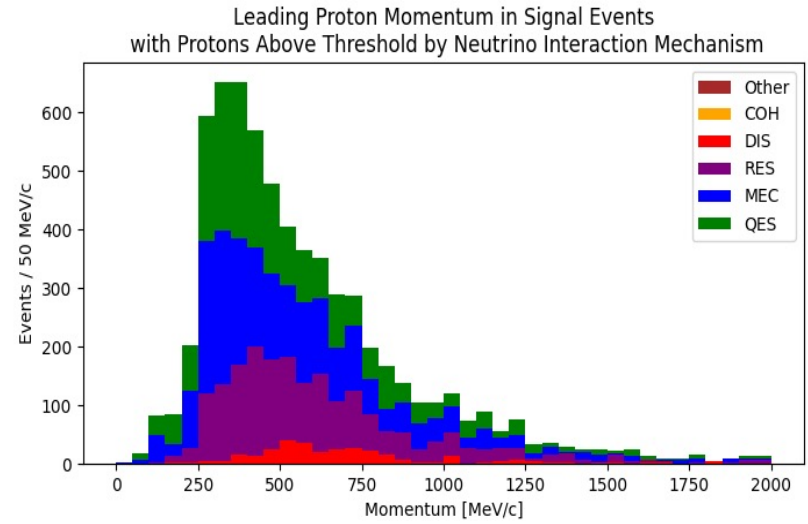
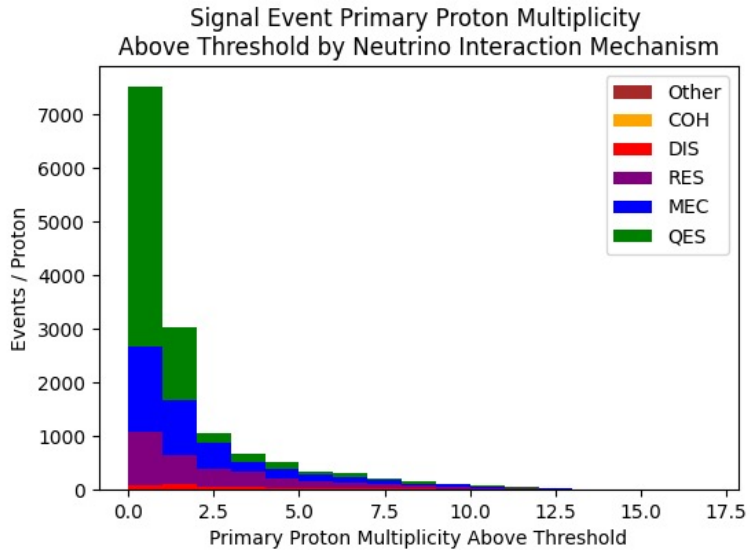
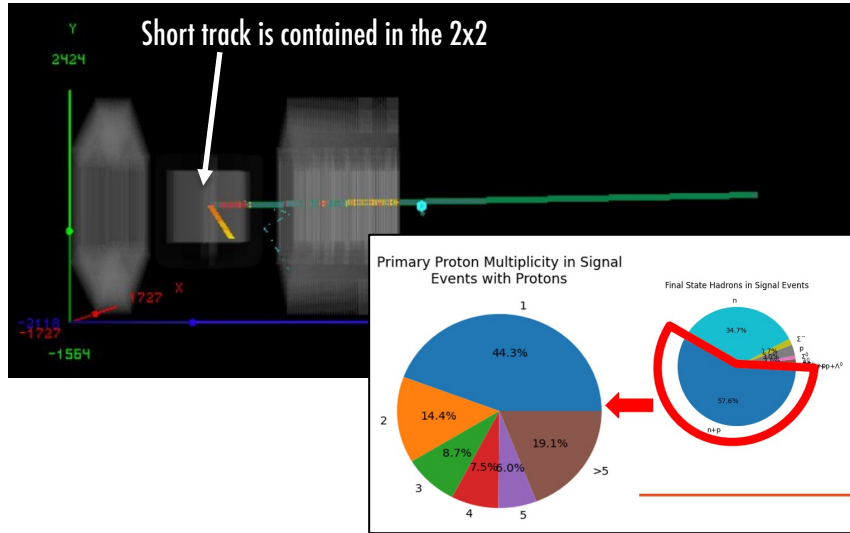
Simulation Studies



Simulation Studies



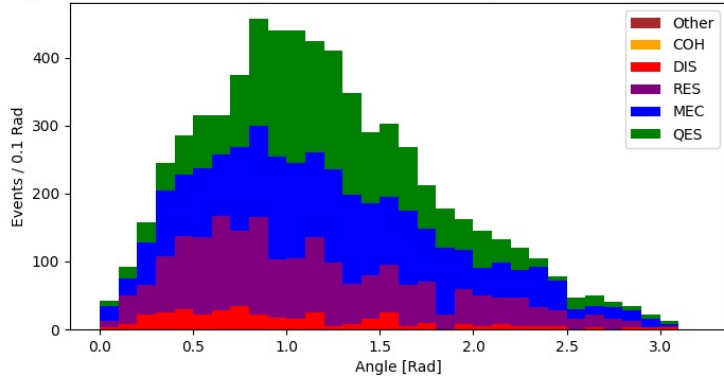
Simulation Studies



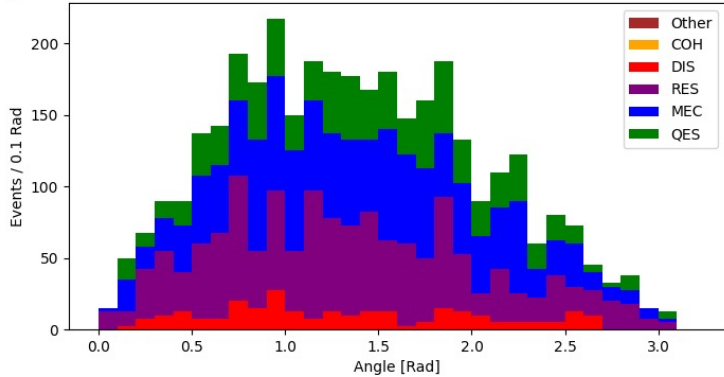
Simulation Studies

Snapshot of the proposed cross section observables

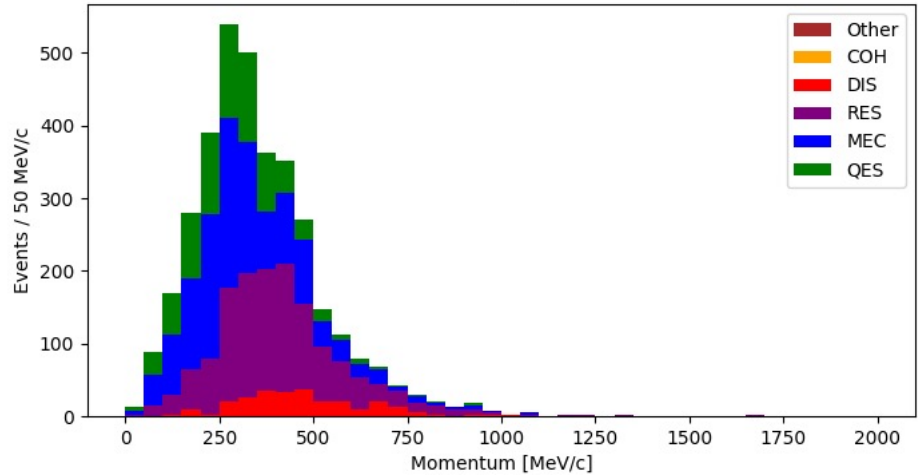
Leading Proton Angle with respect to Beam Direction in Signal Events with Protons Above Threshold Stacked by Neutrino Interaction Mechanism



Subleading Proton Angle with respect to Beam Direction in Signal Events with 2+ Protons Above Threshold Stacked by Neutrino Interaction Mechanism



Subleading Proton Momentum in Signal Events with 2+ Protons Above Threshold by Neutrino Interaction Mechanism



Plans for Systematic Uncertainties

- Detector systematic uncertainties

Systematic Error	Sample
TPC-TPC matching efficiency	Rock muons [data], Beam-off [data]
TPC-MINERvA matching efficiency	Rock muons [data], Beam-off [data]
TPC tracking efficiency	Beam-on [data], Beam-on [MC]
MINERvA tracking efficiency	Beam-on [data], Beam-on [MC]
Pixel hit efficiency	Beam-on [data], Beam-on [MC]
MINERvA hit efficiency	Beam-on [data], Beam-on [MC]
TPC momentum resolution	Beam-on [data], Beam-on [MC]
TPC momentum scale	Beam-on [data], Beam-on [MC]
TPC PID	Beam-on [data], Beam-on [MC]
Pileup background	Beam-on [data], Beam-on [MC]
Rock background	Beam-on [data], Beam-on [MC]
Cosmic-ray background	Beam-off [data]

Leverage existing data to formulate systematics evaluation tools

- High-purity through-going muon sample from Bern data
- Spring '23 NuMI data
- High-purity through-going muon sample from Bern data
- Spring '23 NuMI data
- High-purity proton sample from Bern data

Plans for Systematic Uncertainties

- **Detector systematic uncertainties**

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Roadmap for evaluation Minerva-related systematic uncertainties

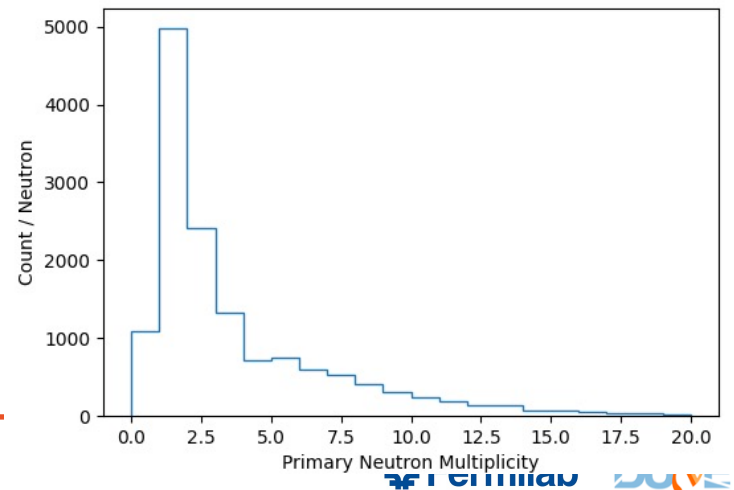
- Plan is to present preliminary results by the end of fall 2023
- **Action Items**
 - Process the raw data
 - Re-automate calibration production
 - Produce a selection of rock muons
 - Produce preliminary calibration results
 - Recovering calibration tools and scripts
 - Understand how to proceed with the hadron-based systematic uncertainties

Plans for Systematic Uncertainties

- Cross section systematic uncertainties
 - Interfacing with NIUWG/DIRT II conveners
 - Interest in data-driven studies and/or analysis infrastructure to address cross section systematics
 - Are there tools we should incorporate into the larger 2x2 analysis toolkit infrastructure to comprehensively evaluate cross section uncertainties
 - Laura Munteanu central to current work on zero meson systematics
 - Laura scheduled for presentation on July 20th analysis working group meeting on:
 - Introduction to nusystematics reweighting package
 - Description of existing dials
 - Highlight room for improvement

Meeting Announcements

- Weekly meetings on Thursdays:
 - @ 12pm CT on weeks with ND-LAr Consortium meetings
 - @ 10am CT on weeks with ND Prototype Analysis meetings
 - Connection info: <https://lbnl.zoom.us/j/6886635629>
 - Informal, technical discussions
- All welcome to participate
 - Need analyzers to assist with evaluating detector systematic uncertainties
 - Help bring Minerva offline software fully back online
 - Confirm Minerva software is working as expected for ProtoDUNE-ND needs
- Analyzers can evaluate and focus other qualities for this selection
 - Produce neutron-related analyses
 - Understanding neutrons is essential



Summary

- The analysis has improved the signal definition
 - Study different fiducial volumes
- Working on understanding containment and detector effects.
 - Next steps involve using geometric information
 - Quantify the electric field behavior on the characteristics of particles
- Continue to develop the analysis framework
 - Framework to produce a cross-section measurement using truth information
 - Including the systematic uncertainty infrastructure
 - Processing offline and simulated data
 - Develop a timeline to achieve analysis milestones
- Work with other analysis groups with related systematic uncertainties