Status of the muon neutrino charged-current zero mesons cross section measurement in the NOvA near detector

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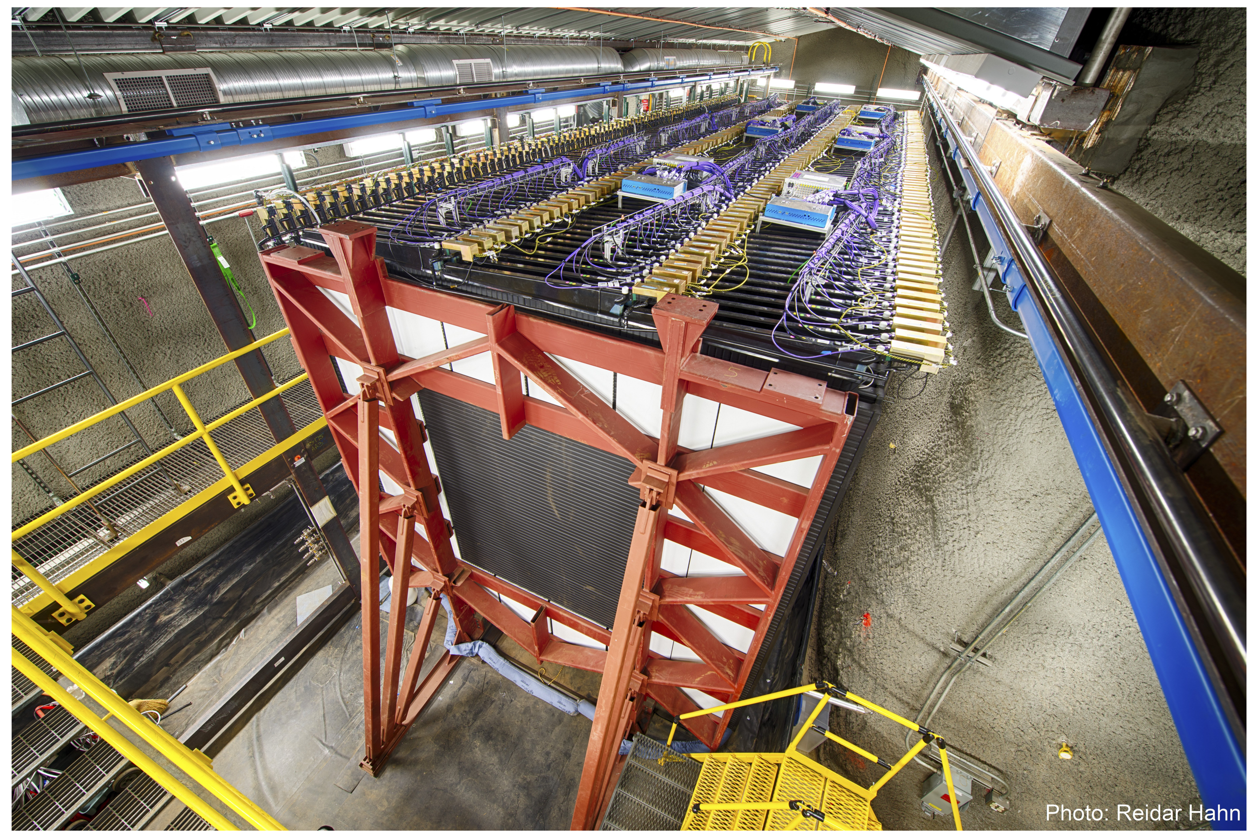


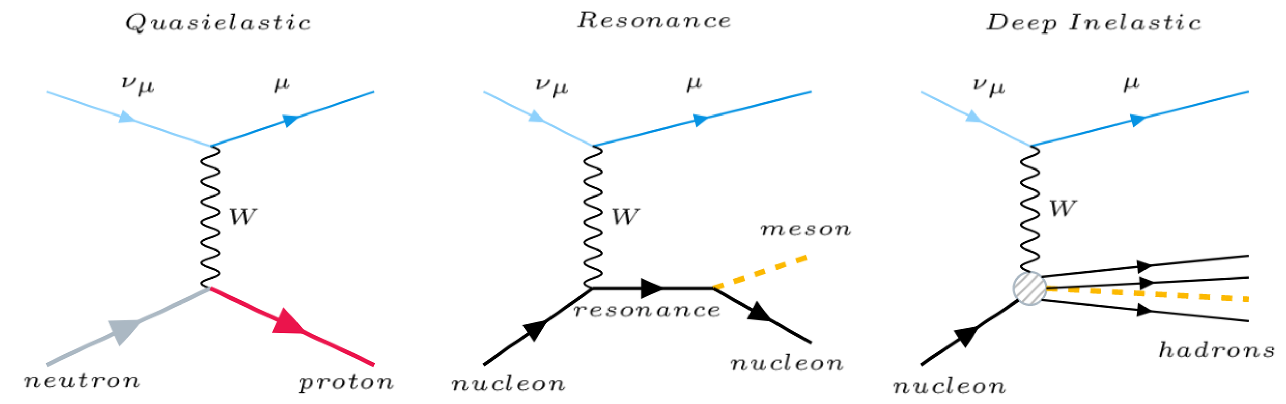
Neutrino Cross Sections at NOvA

NOvA is a long-baseline accelerator neutrino experiment at Fermilab. While it's mostly known for carrying out precision neutrino oscillation measurements, its near detector is an excellent environment to study and measure neutrino interaction cross sections.

Neutrinos don't make tracks in detectors, so we use the products of their interactions to reconstruct their energy and flavor. This is important:

- to understand the nature of the weak interaction inside nuclei. Neutrinos are the best probe for this type of physics
- to do precision oscillation measurements, as we need to reduce the uncertainties coming from neutrino interactions

In the near detector, muon neutrinos are the most abundant. These diagrams represent some of the charged-current (CC) interactions they can undergo, where a generally easy-to-identify muon (in blue) is produced:



The simplest case is the quasielastic interaction, where the neutrino can be reconstructed solely from studying the muon. But neutrino interactions are affected by the nuclear environment, because:

- the initial state of the nucleus is variable
- secondary particle production or absorption can occur
- neutrino interaction can happen on multiple particles simultaneously

This makes it impossible to exactly tell interaction modes apart from what we see in the detector. However, an alternative is to look for:

ν_μCC Zero Mesons

This signal is defined from what we see in the detector. It requires interactions with one muon and accepts other particles except for visible mesons (yellow lines in the previous diagrams), which are characteristic of inelastic interactions.

- **Especially sensitive to quasielastic**, as well as more subtle multiparticle interactions
- **Useful to reduce cross-section systematic uncertainties** in current and future oscillation experiments
- Handle for **constraining nuclear models**
- **The deliverable:** differential cross sections with respect to final state particle kinematics

Interaction Event Reconstruction

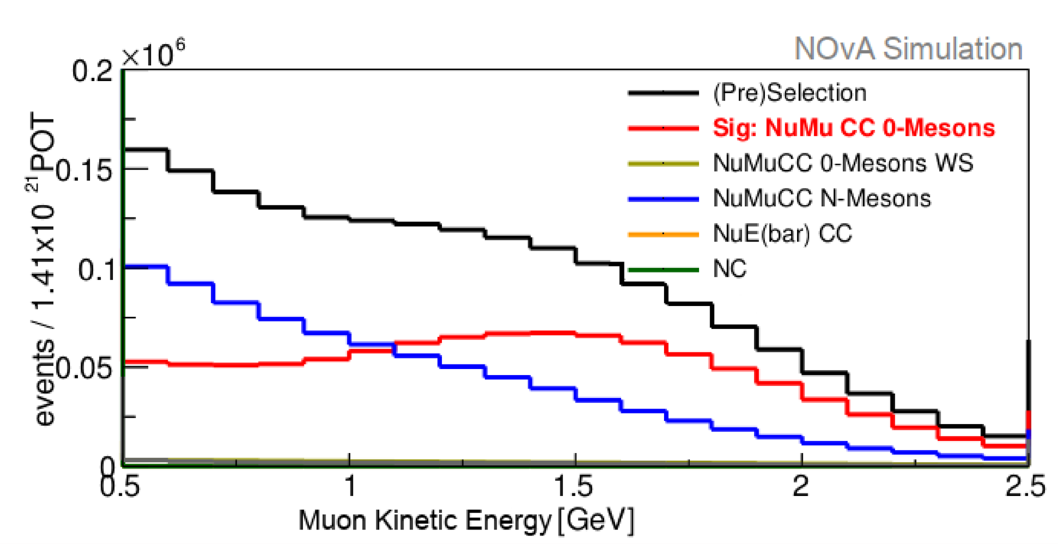
The NOvA near detector is optimized for detecting muon neutrino interactions. Thus it consists of a scintillator-based particle tracker (fully active) and a muon catcher (interleaved active and iron layers).

1. Scintillator strips are grouped in planes of alternating orientations, providing two views of the detector
2. Energy deposits (hits) by particles are reconstructed using timing and spatial information, clustering them into trackable (tracks, prongs) and non-trackable (showers).
3. These are used to find interaction vertices
4. Particle identification is attempted via machine learning techniques based on energy deposition (dE/dX) and detector snapshots (convolutional visual networks)

Zero-Mesons Pre-Selection

This analysis uses the selection cuts of the parent ν_μCC Inclusive analysis as pre-selection:

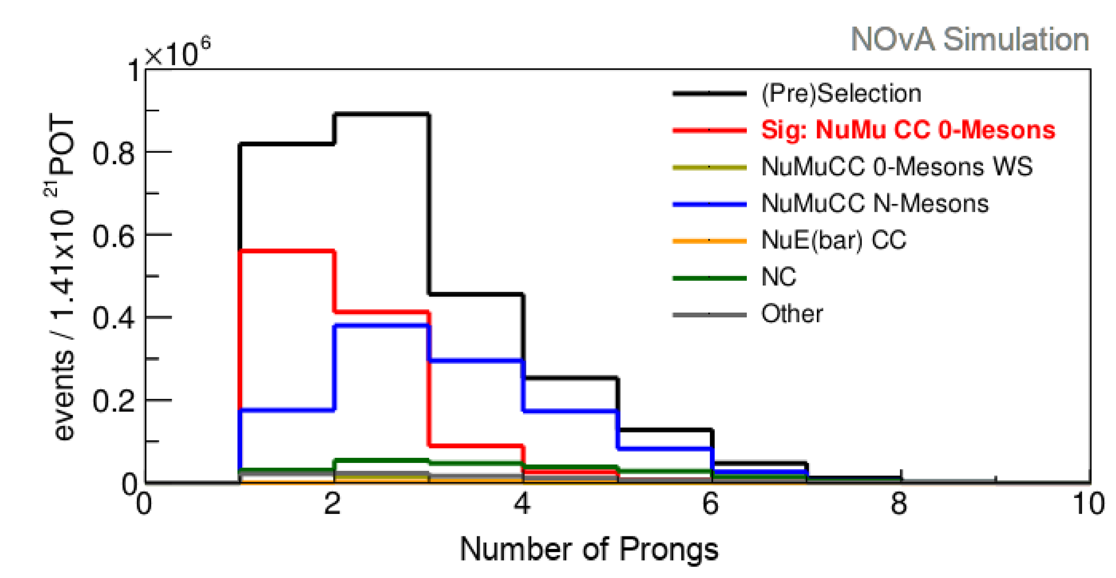
- Basic data quality cuts
- Full containment of all tracks and showers in the detector
- Interaction vertex in a fiducial volume
- Muon identification: Boosted Decision Tree based on dE/dX and scattering likelihood information of tracks

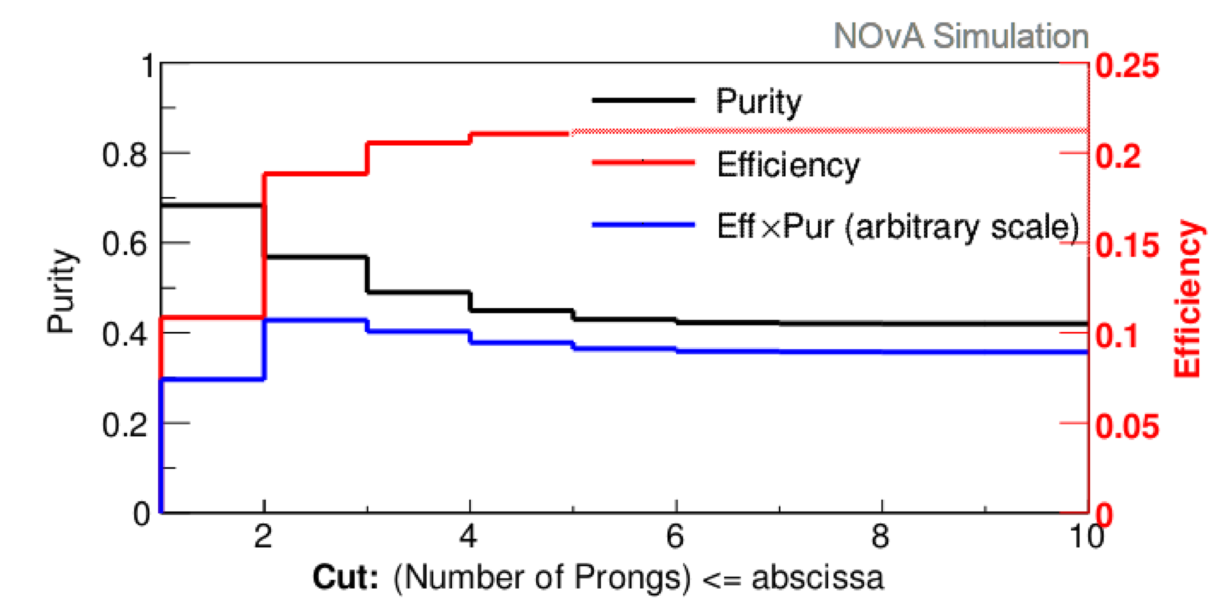


Exploring Selection Criteria

Multiplicity of prongs

In general, the presence of mesons is associated to more activity in the final state. Therefore, we can focus on a signal-richer sample by restricting to events with up to 4 prongs maximum:



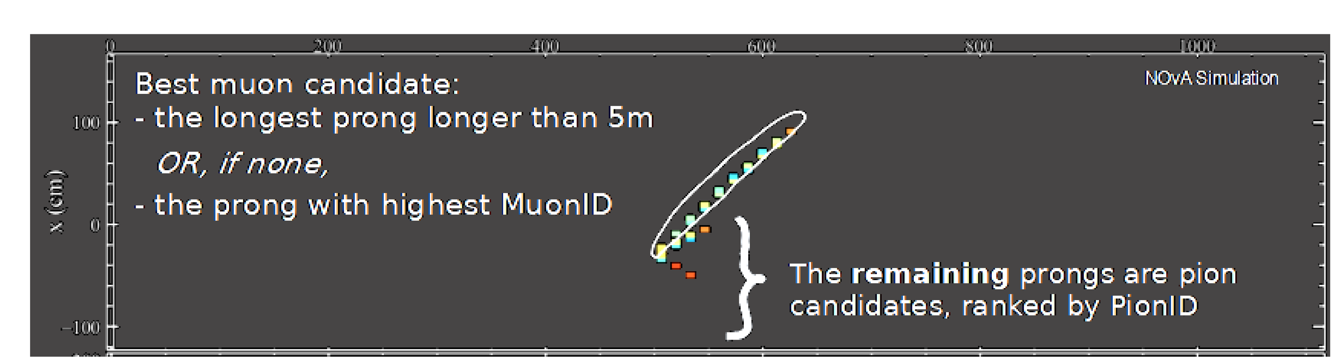


For particle identification, I explore using a convolutional visual network (CVN) trained on individual particles simulated in the NOvA near detector:

1. This aims to reduce potential bias from neutrino interaction modeling
2. For each prong, the network provides several particle scores which all add up to one.
3. I focus on the MuonID, ProtonID and PionID scores as I want to select a muon, preserve protons and reject mesons (which are usually pions)

Finding the best muon candidate

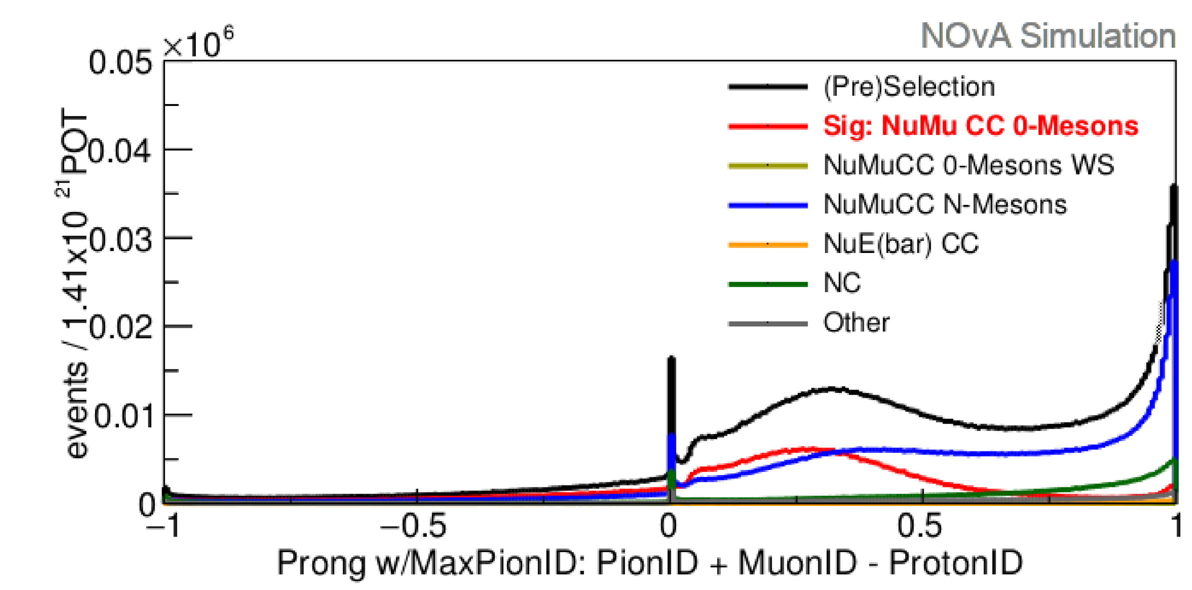
First, I use the MuonID score to decide which prong is the best muon candidate:

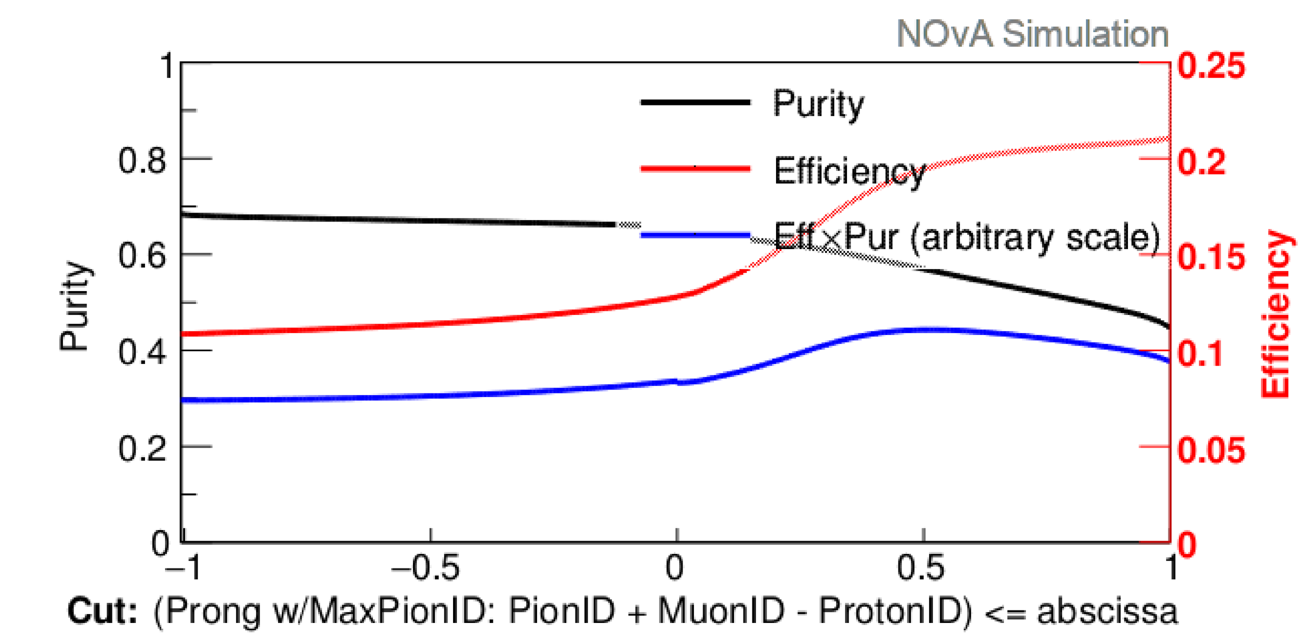


Finding meson candidates

Then, the remaining prongs are ranked by their PionID score and considered potential meson candidates. Using their scores, I want to construct an observable that enhances the separation between signal and background events.

A simple way to do this is with the ***PionID + MuonID - ProtonID of the leading pion candidate*** Pions and muons are likely to look alike in the detector. This combination of scores aims to enhance their separation from protons, which we want to preserve





I'm also studying ways to attempt the separation in a higher dimensional space, by e.g. training a Boosted Decision Tree on the available scores in the event.

Summary

- ν_μCC zero-mesons interactions is an **experimentally defined signal** that provides valuable handles for **tuning interaction models** and **reducing systematic uncertainties** in neutrino experiments
- I'm demonstrating promising advances in achieving an experimentally pure sample in NOvA by leveraging **particle-level identification tools** and **machine learning** methods
- Next steps:
  1. Refine the signal definition to include very low energy, difficult to reconstruct mesons
  2. Finalize the selection based on minimizing the expected uncertainty in the global cross section

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