FERMILAB-POSTER-22-008-V

Measuring the π^0 invariant mass in NOvA using Photon Identification

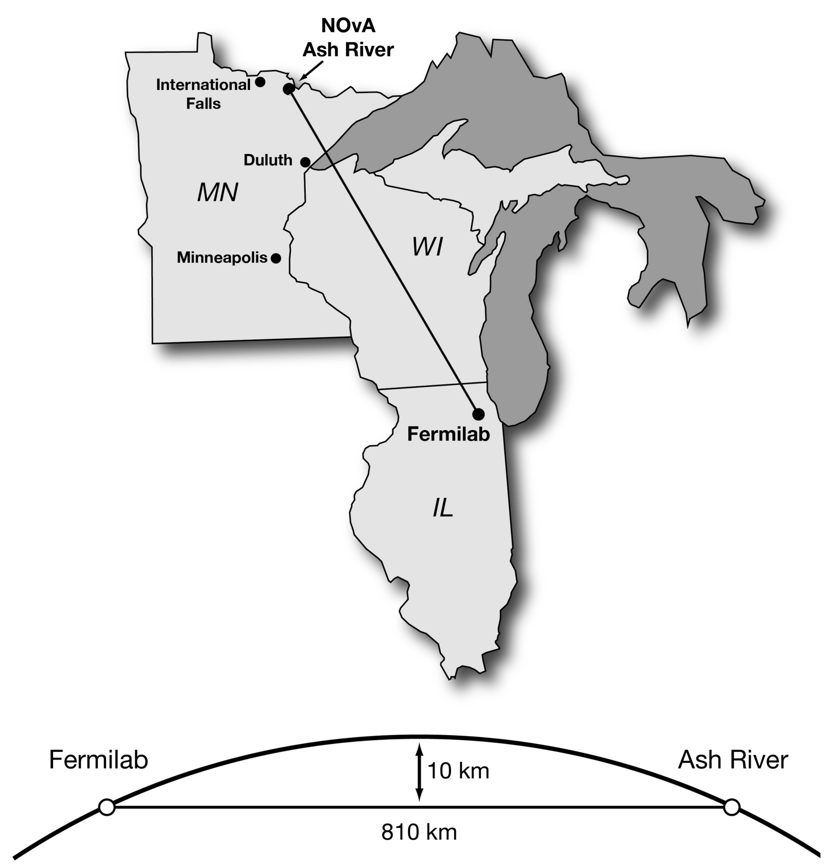
Maria Manrique Plata
Indiana University

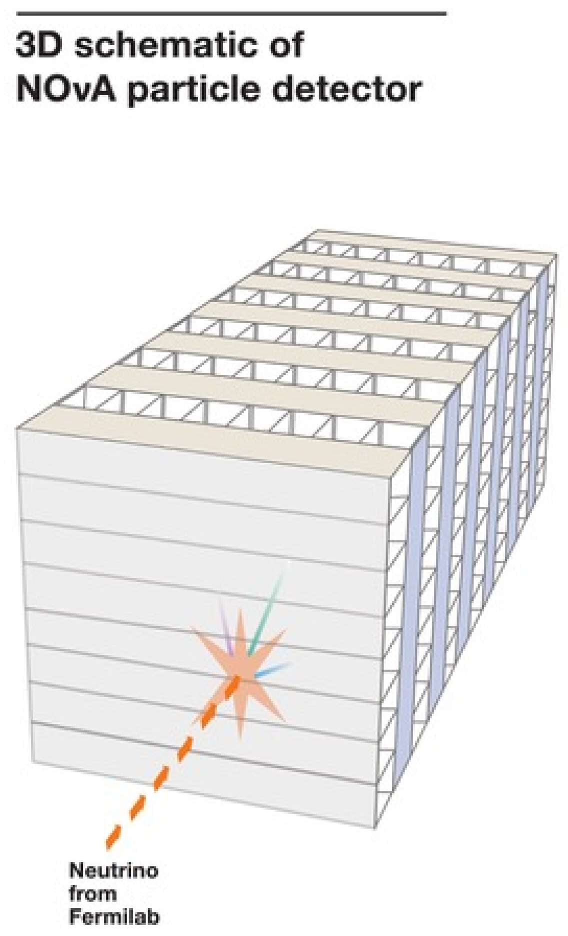
NOvA - NuMI Off-Axis ν_e Appearance

NOvA uses an established neutrino, or antineutrino, beam from Fermilab.

It is composed of two functionally equivalent detectors:
- The near detector located at Fermilab
- The far detector, a larger detector located in Ash River, Minnesota

By measuring neutrino and antineutrino rates at both detectors and comparing them, the neutrino mixing angles, CP phase, and mass ordering can be investigated.





The detectors are made of long, reflective, PVC cells. Each cell is filled with liquid scintillator and a fiber optic cable. Light inside the cell is redirected to an avalanche photodiode, then a front end board which registers the activity.

Cells have a rectangular cross-section of 3.6 cm x 5.6 cm. They are stacked to create panels with alternating cell directions, which allows for 3D track reconstruction.

Note on Resolution - The π^0 mass is reconstructed using photon energies and the opening angle between said photons. Our mass resolution is therefore affected by the energy and angular resolution of NOvA. The angular resolution of our detector is the main contributor to our mass peak resolution, as seen by the variance (σ) of the Gaussian fit when using combinations of true quantities and reconstructed quantities for neutrino (and antineutrino) mode.

	Reconstructed $\theta_{\gamma\gamma}$	True $\theta_{\gamma\gamma}$
Reconstructed E_γ	32.1 ± 0.6 (31.6 ± 0.6)	14.9 ± 0.3 (13.7 ± 0.3)
True E_γ	19.9 ± 0.4 (20.4 ± 0.6)	Delta Function

Variance (σ) of fit (MeV)

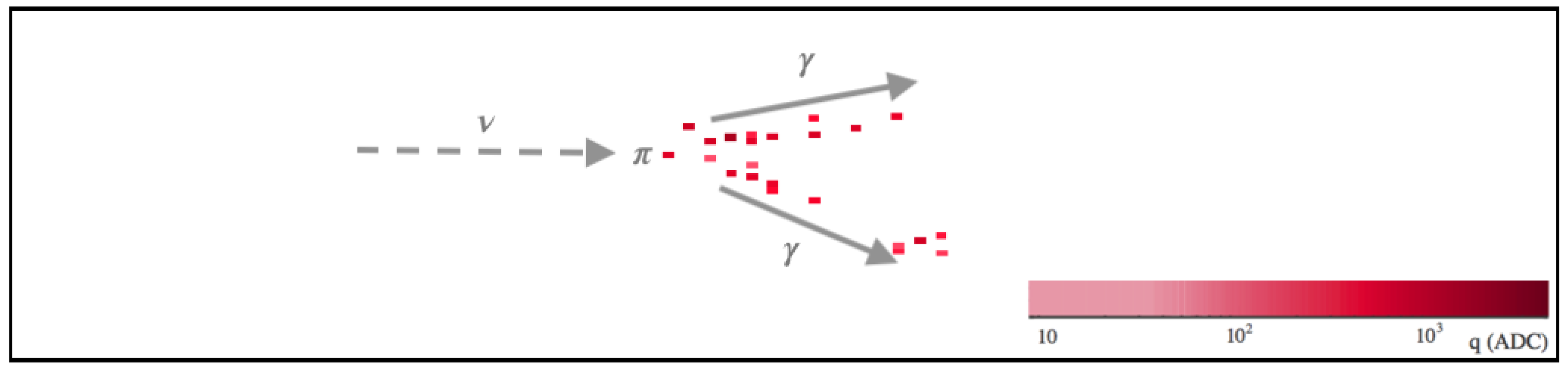
Importance of $\pi^0 s$

Neutrino oscillation measurements are sensitive to the energy calibration of a detector.

Using the $\pi^0 \rightarrow \gamma\gamma$ decay, the π^0 mass is directly connected to the energy scale, and can be used as a calibration crosscheck.

$$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1 - cos\theta_{\gamma\gamma})}$$

Mistakes in photon energy reconstruction could yield incorrect energy scale assumptions. Other particles near our π^0 will increase the likelihood of incorrect energy reconstruction. To minimize this, we take advantage of coherent pion production, which creates a single π^0 with no other particles [1].



A simulated neutral pion produced in a NC coherent interaction, immediately decaying into a pair of photons, as seen in the NOvA near detector.

Sample Identification

In order to isolate NC coherent π^0s we:

1. Use basic quality checks to remove poorly reconstructed events and events near the detector edge
2. Require events with only two tracks
3. Impose a photon ID minimum on each track
4. Limit the average energy deposition (dE/dx) of a track

Particle ID - NOvA reconstruction algorithms cluster events into slices with ideally one neutrino interaction per slice. Each slice then undergoes interaction vertex and track reconstruction. For each track present in an event, a convolutional network is used to identify the particle most likely responsible for said track [2]. Some of the information used for particle identification includes:
- Overall topology of event
- Separation between tracks
- Distance from interaction vertex to beginning of tracks
  - Photons travel some distance, characterized by the radiation length of the medium (~30cm in NOvA), before depositing energy. This is used to distinguish EM showers produced by electrons and photons.
- Energy deposition (dE/dx) profile

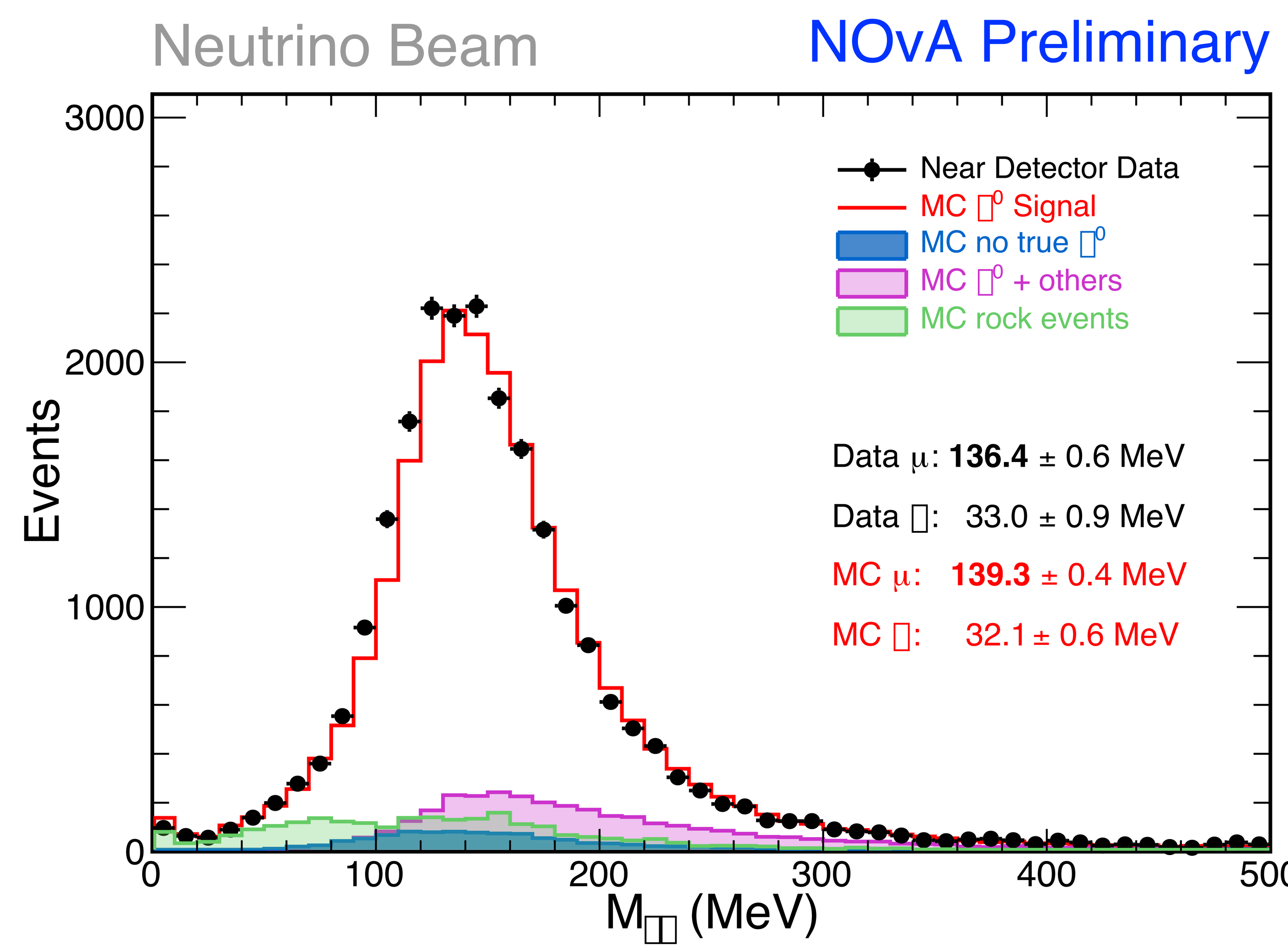
Energy deposition - Non-coherent pion production typically also produces hadrons. Occasionally, because of lack of separation, the particles are classified as one track. An energy deposition limit of 4 MeV/cm will decrease the *π^0+ others* background by 60% while having a small effect on the selection of NC coherent π^0s.

Results

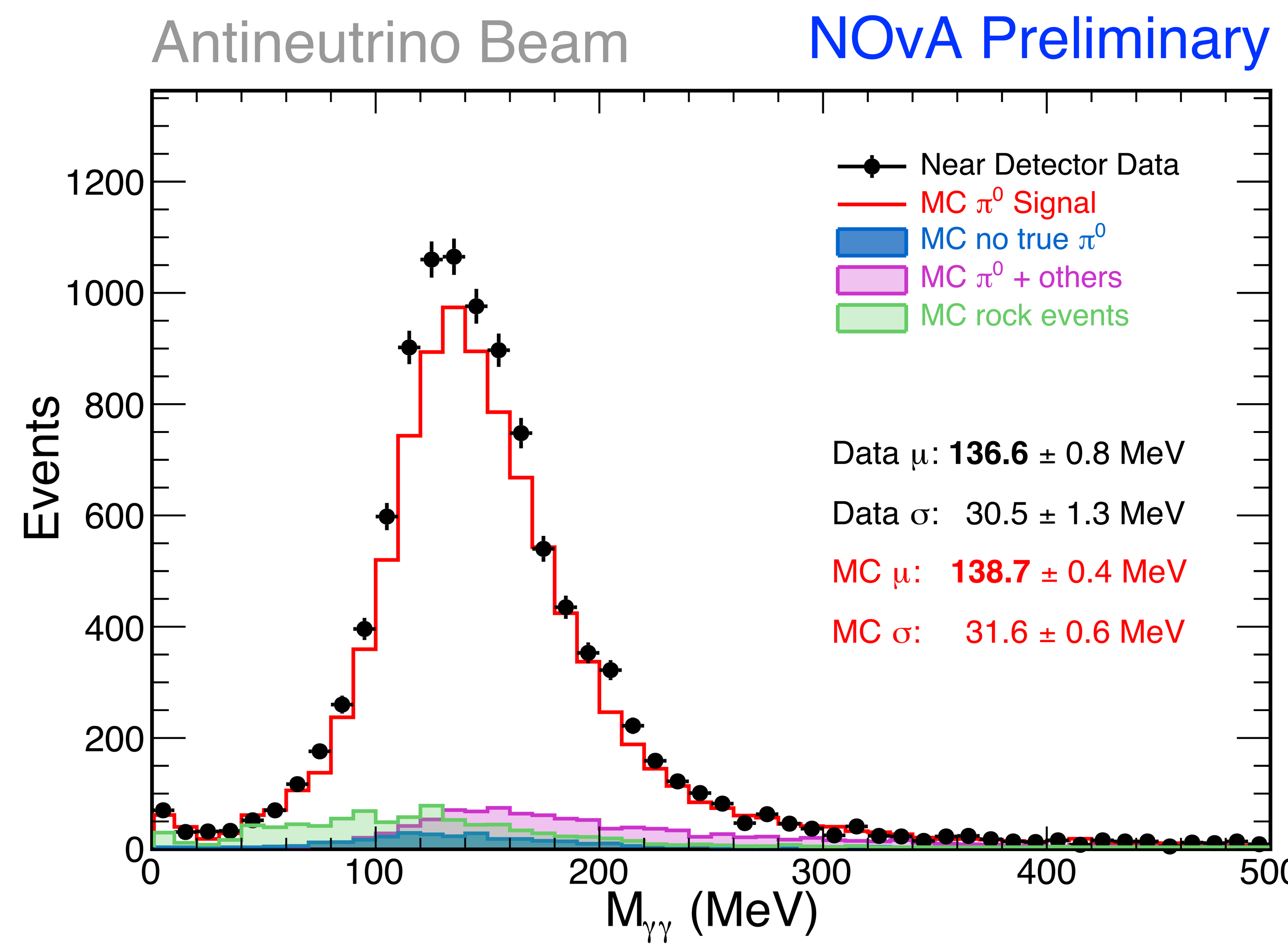
For both neutrino and antineutrino mode our mass reconstruction yields ~136 MeV, compared to a true π^0 mass of 135 MeV.

- There is a difference of 2.1% between the mass peak in simulations and data in neutrino mode, and 1.8% difference in antineutrino mode. For both modes, the difference is less than our allotted detector calibration uncertainty of 5%.

Note on fitting mechanism – The mean and variance of the π^0 invariant mass comes from a Gaussian fit around the FWHM of the background removed sample.



Figures: The reconstructed π^0 mass for neutrino and antineutrino mode using data and simulated events. MC is POT normalized.



Note on Backgrounds
- **No true pi0 –** Events with two photon-like tracks but no true π^0.
- **π^0 and others –** Events with one π^0 and other energy depositing particles.
- **Rock events –** Events with an interaction vertex outside of the detector.

References
1. The NOvA Collaboration. **Measurement of Neutrino-Induced Neutral-Current Coherent π^0 Production in the NOvA Near Detector.** Physical Review D, vol. 102, no. 1, 2020, doi.org/10.1103/physrevd.102.012004.
2. Psihas, F., et al. **Context-Enriched Identification of Particles with a Convolutional Network for Neutrino Events.** Physical Review D, vol. 100, no. 7, 2019, doi.org/10.1103/physrevd.100.073005.