Pion candidate selection from a 2 GeV/c momentum test beam sample with the ProtoDUNE Liquid Argon detector

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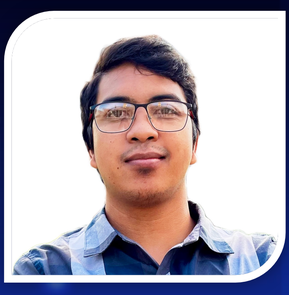


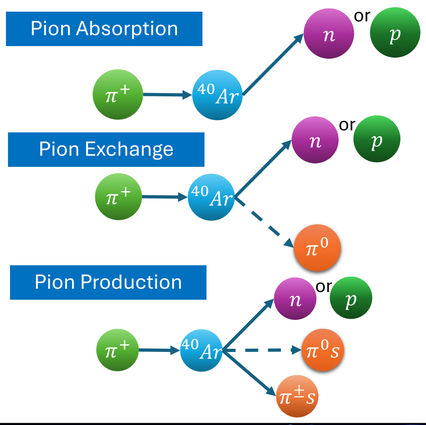
1 The ProtoDUNE Experiment

Overview of the ProtoDUNE Experiment

- To assess the performance of the DUNE Liquid Argon Far Detector (FD), the ProtoDUNE Single Phase Experiment, one of the prototypes of the DUNE detector modules, has been implemented at the CERN Neutrino Platform Facility.
- ProtoDUNE will define production and installation procedures for the DUNE FD and give the opportunity to measure the detector's response to different particles from CERN's H4-VLE Beam Line (e^-, p, μ, K^+ and π^+ beam between 0.3 GeV/c to 7 GeV/c)
- Measurements from these particles can be exploited to determine the cross-sections of charged particles in Liquid Argon.

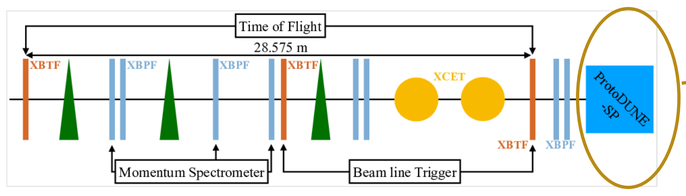
Objectives of the analysis

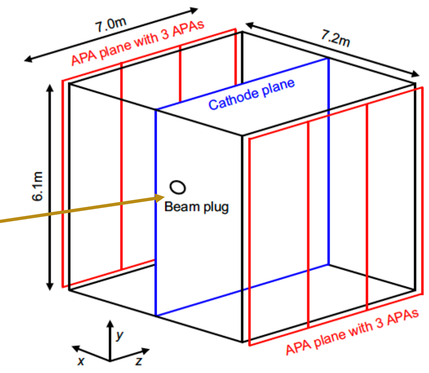
- Select 2 GeV/c pion beam sample from ProtoDUNE for a future π^+cross section measurements at 2 GeV/c.
- Pion interaction different topology :



2 Beamline instrumentation

Beamline Instrumentation (BI) : includes various components and devices that aid in monitoring and controlling the beam, ensuring the beam is aligned with the **beam plug**.





- The BI also plays a role in the measurement and identification of particles within the beamline.
- The Cherenkov counter from the BI distinguishes electrons from other particles, while the BI TOF distinguishes muons and pions from protons. However, it cannot further differentiate between muons and pions.

ProtoDUNE SP Time Projection Chamber (TPC)

3 Beam Pion selection

Different Cuts used to select pion candidates in the 2 GeV/c beam

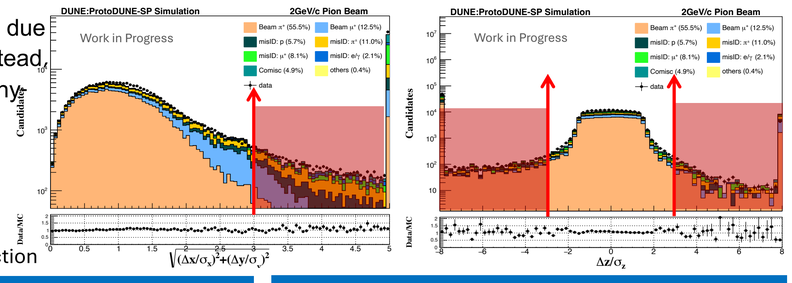
Cuts	
1. **Beam Particle ID Cut**	Select beam particles that passes the Pion and Muon trigger
2. **Track-like events Cut**	Differentiate track-like and shower-like events
3. **Beam Quality Cut**	Select π^+candidates with initial position and directions consistent with the primary beam
4. **Interaction position Cut**	Select particles that interact within the detector fiducial volume
5. **Michel Electron Cut**	Differentiate Michel electron and muons using CNN (to reduce muon background)
6. **Proton Cut**	Select protons using dE/dx information to reduce misidentified secondary proton background
7. **Beam Scraper Cut**	Ensure that events are aligned with beam plug, ie, reject events that lose energy before entering the detector (beam traversing additional material before entering the TPC)

4 Beam Quality Cuts

- **Primary background source**: misID secondary daughter particles, but cuts on position and direction is effective at reducing them.
- Cuts not applied directly on position due to potential beam mismodelling. Instead, MC and Data are fitted with a Cauchy-Lorentz function.

$$\sqrt{\left(\frac{\Delta x}{\sigma_x}\right)^2 + \left(\frac{\Delta y}{\sigma_y}\right)^2} < 3 \text{ and } \left|\frac{\Delta z}{\sigma_z}\right| < 3$$

- $\Delta x = x - \mu_x$
- μ_x : Mean value of fitted distribution function

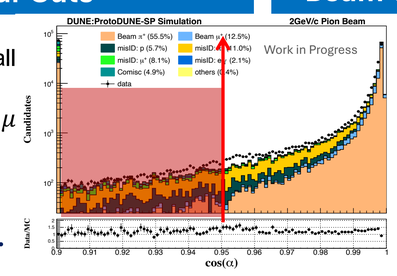


Beam Quality Angular Cuts

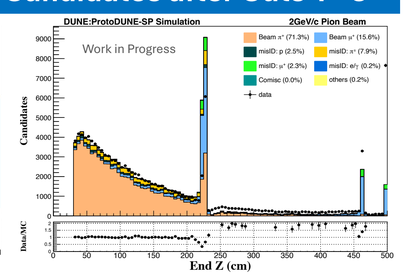
- Cuts on the angle between track direction and fitted mean angle of all tracks.

$$\cos\alpha = \cos\theta_x \cos\mu_{\theta_x} + \cos\theta_y \cos\mu + \cos\theta_z \cos\mu_{\theta_z} > 0.95$$

The cuts up to the Beam Quality increase beam purity to be 71.3%.

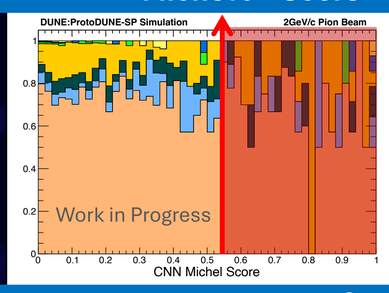


Beam Candidates after Cuts 1 - 3



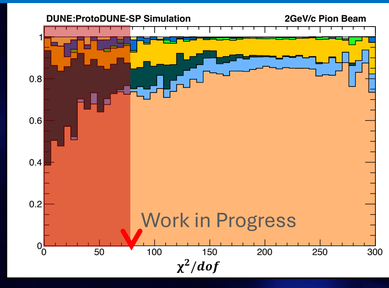
5 Michel Score & Proton Cuts

Michel e^- Score < 0.55



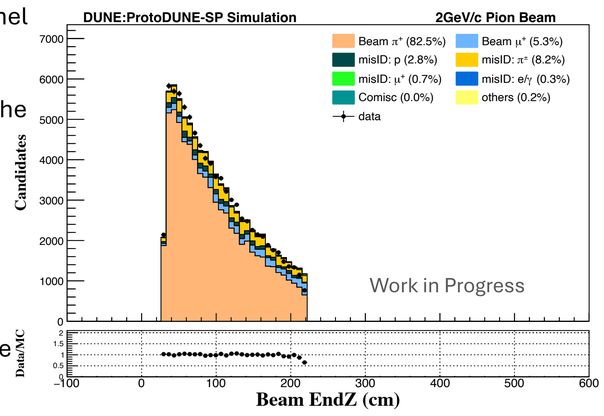
Michel Score Cut
Gets rid of all Michel electrons (hence reduce muon background with the identification of Michel electrons)

Proton Rejection : $\chi^2/dof > 80$



Proton Cut
Cut used to reduce misidentified secondary proton background.

Beam Candidates after Cuts 1 - 6



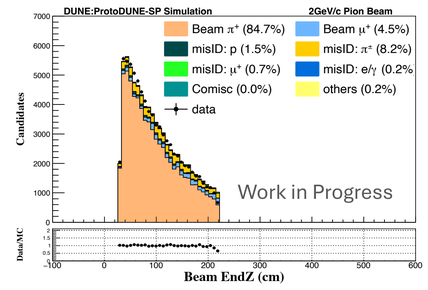
The Michel and Proton cuts increase purity to be 82.5% (while maintaining about the same level of efficiency).

6 Beam Scraper Cut

Beam Scraper Cut
Requires the beam particles to be aligned with the beam plug

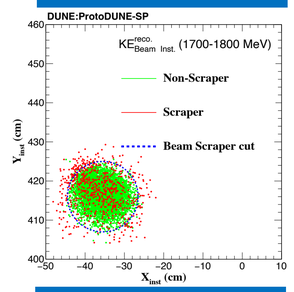
$$\text{Radius } r = \sqrt{\sigma_x^2 + \sigma_y^2}$$

	x (cm)	y (cm)	r (cm)
MC	-35.5	416	6
Data	-36	415.5	6

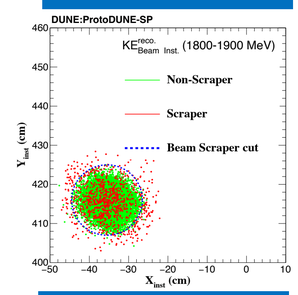


After all the cuts, we have a pion sample with 84.7% purity (with 57.4% efficiency).

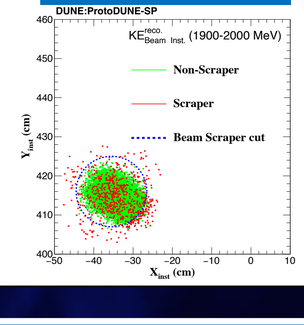
1700 – 1800 MeV



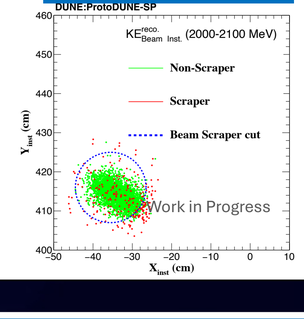
1800 – 1900 MeV



1900 – 2000 MeV



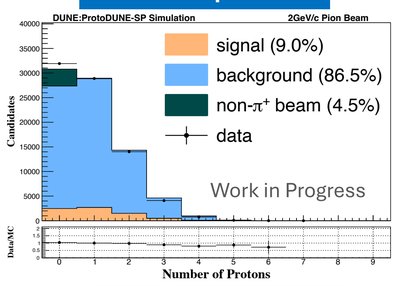
2000 – 2100 MeV



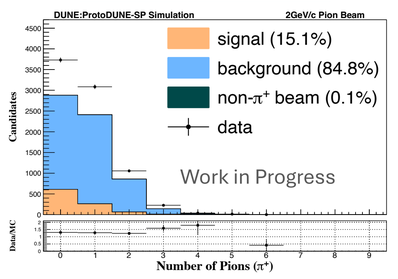
7 Daughter Particles Selection

Daughter Particles selection : additional cuts are applied to identify daughter particles.

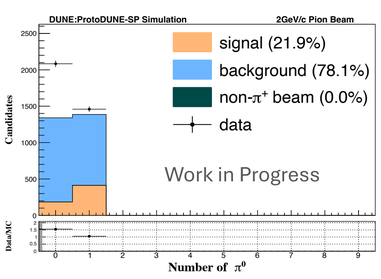
Selected protons



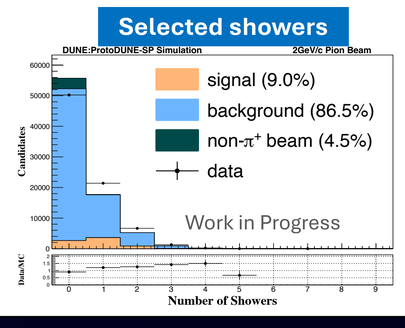
Selected π^+



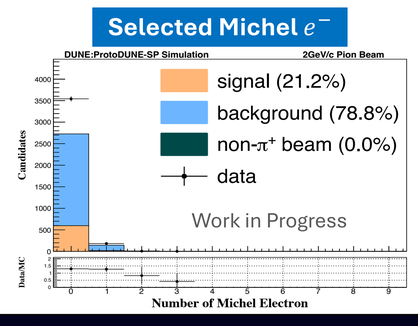
Selected π^0



Selected showers



Selected Michel e^-

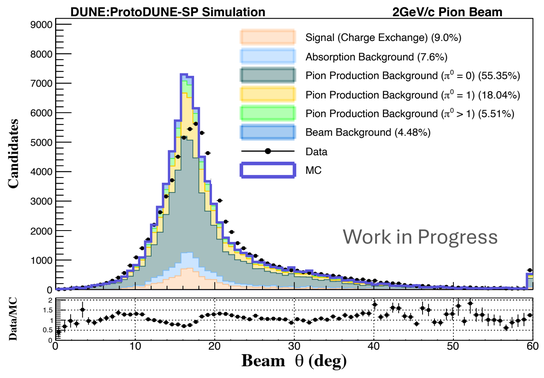


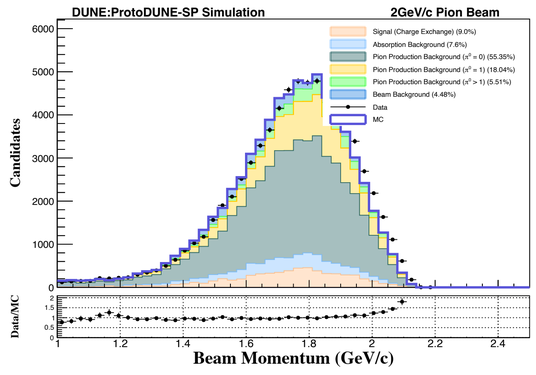
Signal definition:
Pion incoming beam with only one π^0 in the final state, does not contain charged pions, and no requirement on the number of final states nucleons **(charge exchange)**

8 Selected Pion Beam Event Topology

Selected Pion Events

- Charge Exchange (Signal) ~ **9.0%**
- Absorption Background ~ **7.6%**
- Pion Production Background (π^0= 0) ~ **55.35%**
- Pion Production Background (π^0= 1) ~ **18.04%**
- Pion Production Background (π^0> 1) ~ **5.51%**
- Beam Background ~ **4.48%**





Next Step

Cross section analysis using the selected 2 GeV/c Pion Beam sample from the first run of ProtoDUNE-SP