ProtoDUNE Pion Cross Section Analysis

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Introduction

Final State Interactions (FSI) and Secondary Interactions (SI) in the detectors will be large sources of uncertainty in DUNE

ProtoDUNE-SP provides pion data to help tune these models (S. Dolan's talk at the LBL workshop)

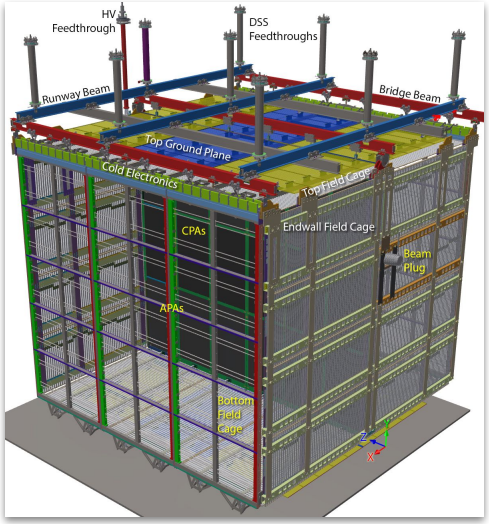
See previous work by T2K using DUET data

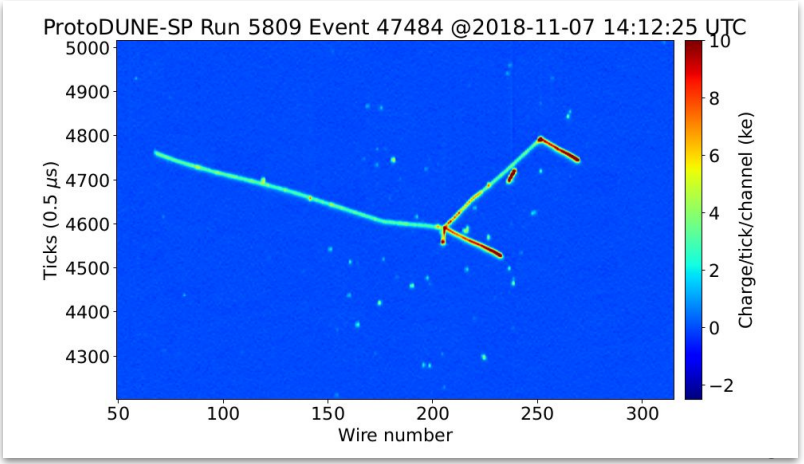
ProtoDUNE-SP Detector

400T active volume LArTPC at CERN

Fine-grained TPC allows tracking and energy reconstruction of charged particles within the argon

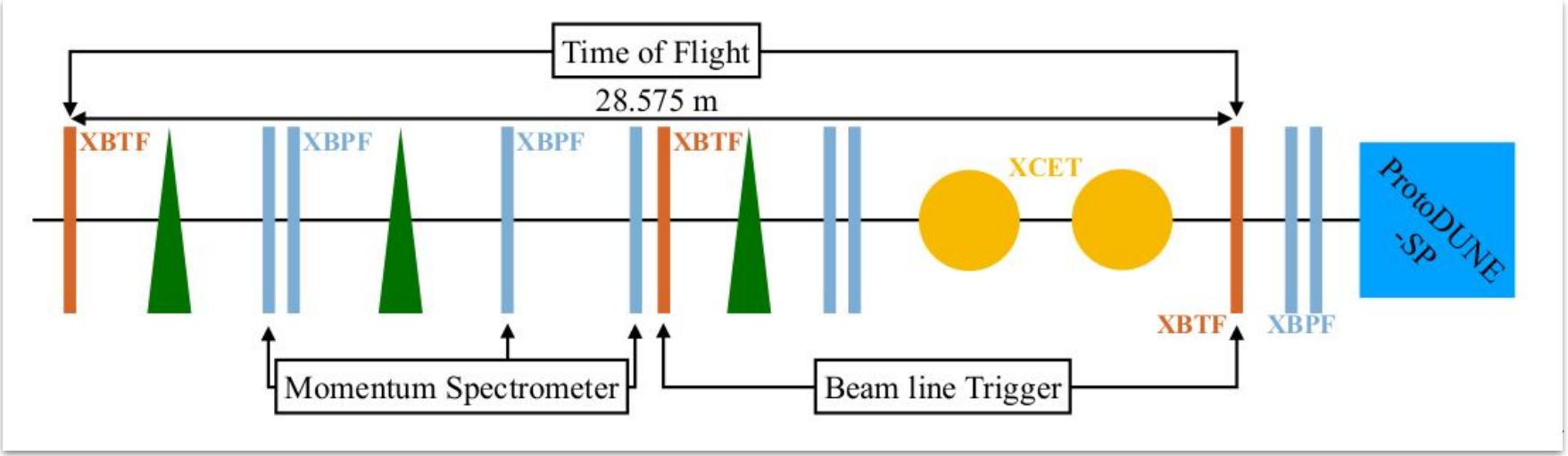
Charged particle test beam provided O(160k) pion-like triggers to study pion interactions within the argon





Test beam and Instrumentation

The test beam was instrumented with various subdetectors to allow for triggering, momentum reconstruction (spectrometry around bending magnets in green), TOF measurement, and (along with TOF) PID using the Cerenkov detectors (in yellow)



Analysis Overview

Study rate of pion interactions in various channels

- Select pion/muon triggers with well-reconstructed beam tracks
- Separate muons from pions
    - Select three types of pion interactions

Use a likelihood-fit to unfold from reconstructed variables (combination of reconstructed energy at interaction point and depth into detector) into the number of true interactions of a given channel at a given energy

Extract cross section from varied MC truth information

Signal Definition

Absorption:

$$\pi^+ + \mathrm{Ar} \rightarrow \mathrm{N}' + \text{nucleons}$$

Charge Exchange:

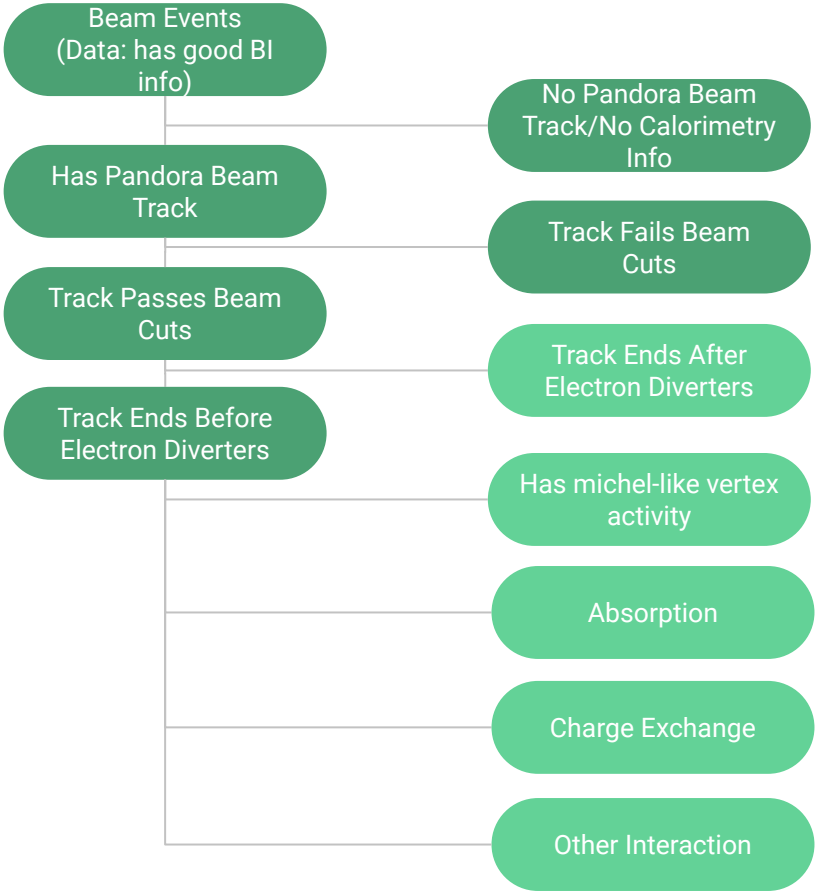
$$\pi^+ + \mathrm{Ar} \rightarrow \mathrm{N}' + \text{nucleons} + n\pi^0$$

Other:

$$\pi^+ + \mathrm{Ar} \rightarrow \mathrm{N}' + \text{nucleons} + \text{charged pions}$$

Note: Considering a threshold of 150 MeV/c on the charged pions due to our inefficiency in identifying these ➔ Signal events can contain charged pions < 150 MeV/c

Event Selection

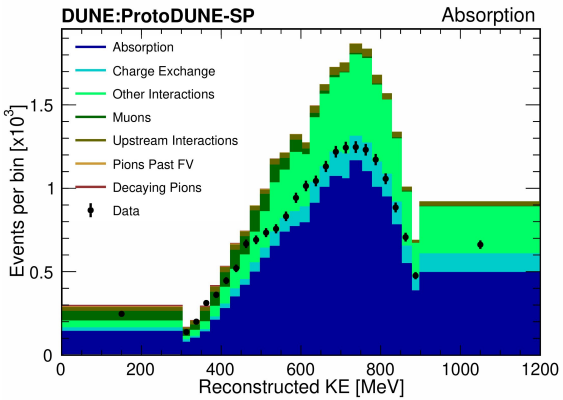


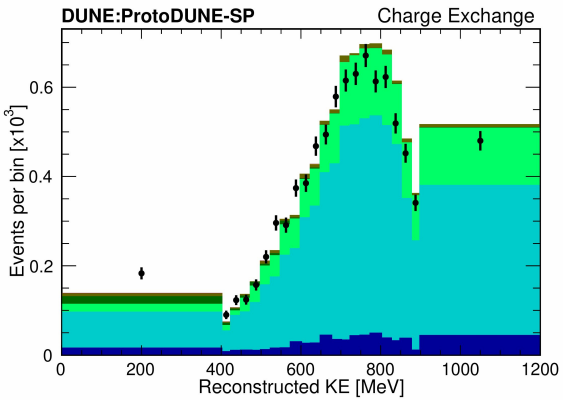
Categorize every π/μ-like event according to this flow chart

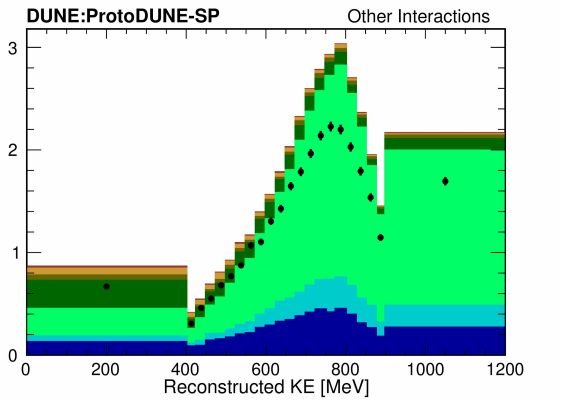
Last 5 categories enter into selection/fit

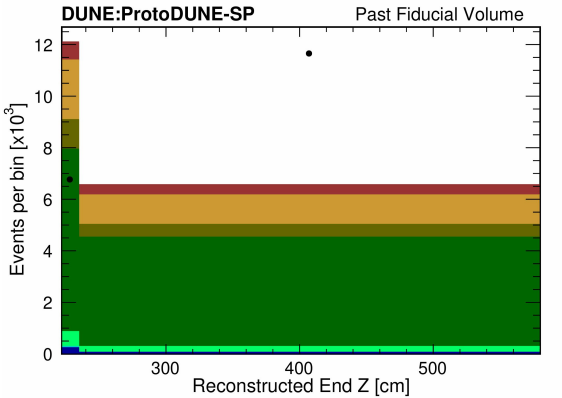
Attempts to separate pion interactions (last 3 categories) from stopping pions and muons

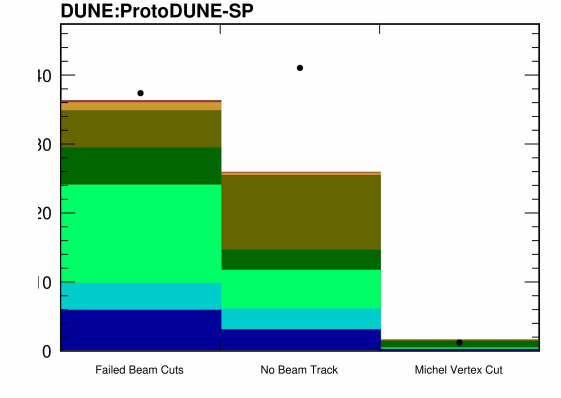
Event Distributions









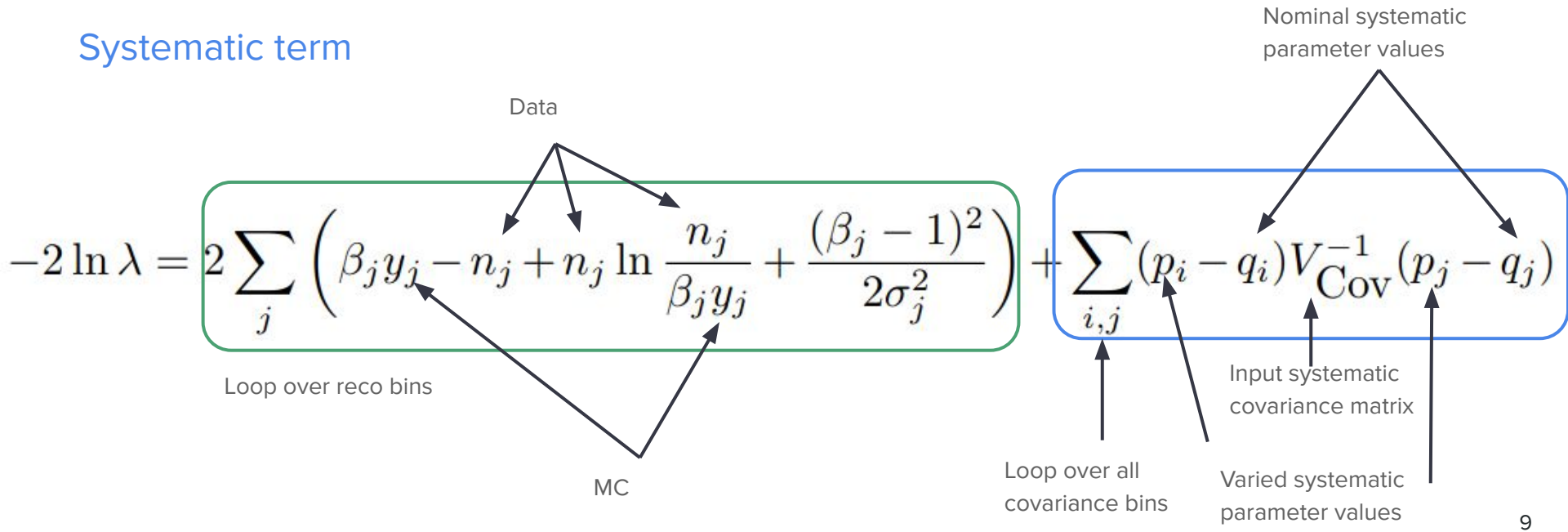


Fit Statistic

λ → Likelihood ratio

Statistical term (w/ Barlow Beeston scale factors β_j for MC stats)

Systematic term



Parameterization

Signal parameters – Scale number of events of signal interactions (absorption/charge exchange/other) in bins of true kinetic energy at interaction

- Absorption: 50-MeV-wide bins between 400 & 900, <400, >900
- Charge Exch./Other: 50-MeV-wide bins between 500 & 900, <500, >900

Muon parameter to scale the relative number of muons in the sample

Systematic parameters vary tracking efficiency, interaction rates of ‘downstream’ pions and protons, and a detector effect which breaks tracks near the region between APAs

Extracting Cross Section from Truth Info

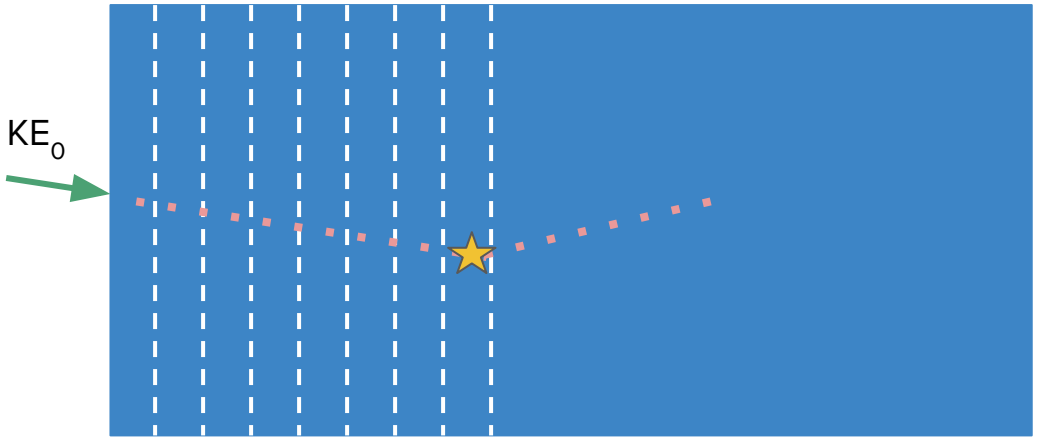
To calculate the cross section, ‘slice’ up the path of the simulated pion to create a sequence of thin target scattering experiments.

Using the true energy at the start of LAr, and the energy of the MC trajectory points: calculate the energy incident in each of the slices

Use these to build up a flux (Φ) as in a ‘classic’ thin target experiment

Count number of interactions (N_{Int}) at given energies

Cross sections are functions of N_{Int} and Φ



Extracting Post-Fit Cross Section

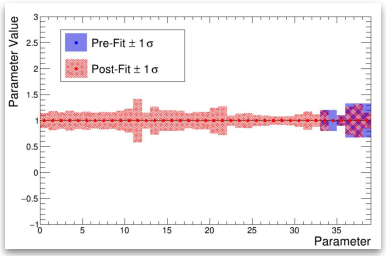
The MC is varied according to the best-fit parameters and the cross sections are extracted from this varied MC ensemble

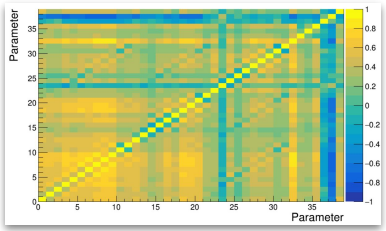
N_{Int} and Φ vary accordingly to give the correct cross sections

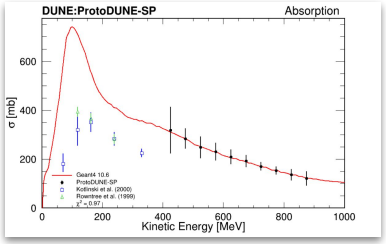
Uncertainty Propagation

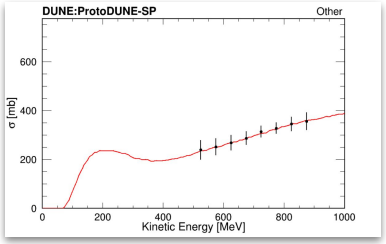
1000 ‘throws’ to the post-fit covariance matrix are performed to create 1000 MC ensembles representing the likelihood surface near the best-fit point

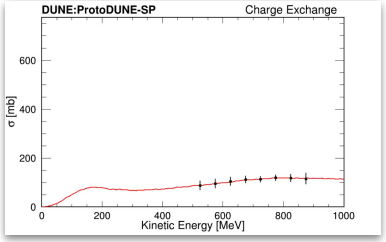
The cross sections are extracted from each of these and the covariance between each signal bin is found

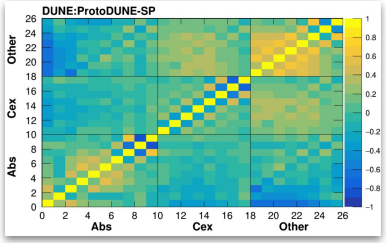












Other Systematics

Two additional sources of uncertainty are added in after the fit to data

- Energy-scale calibration (energy deposited by beam pion)
- Reconstructed beam line momentum (used to calculate initial energy before reaching TPC)

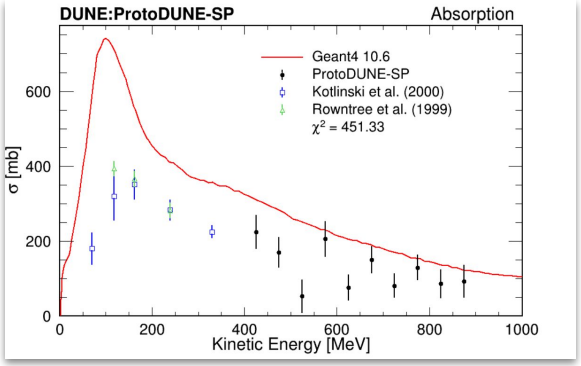
The data is varied according to the uncertainty (±1σ) on each source and the fit is reran

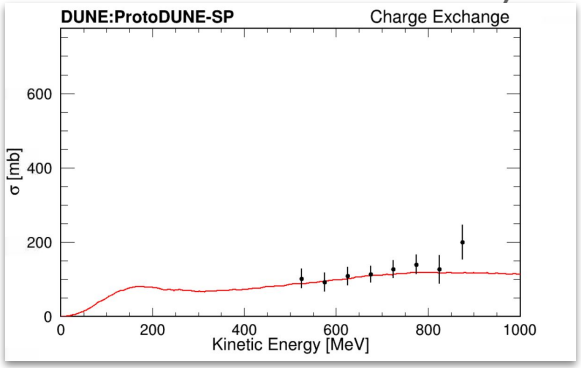
- Covariances are determined from differences in cross sections to nominal fit and added in quadrature to the post-fit cross section covariance

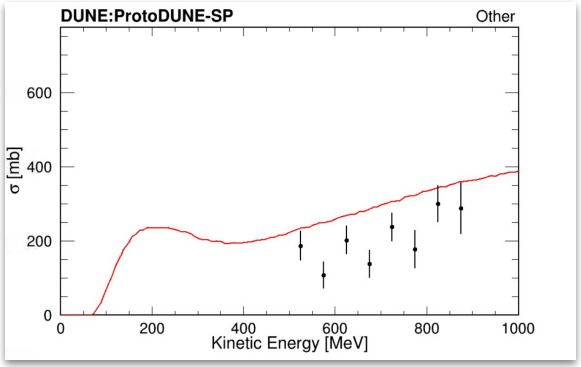
One remaining systematic: Space Charge Effect (in the works)

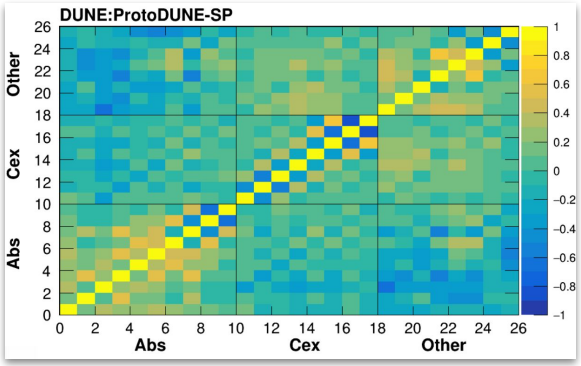
Preliminary Results

Fit to all 1 GeV/c beam data (no external uncertainties added in here)









Conclusions

Developed likelihood-fit based analysis to study exclusive pion interactions

1 GeV pion analysis is mature and nearing completion

Will provide useful data for DUNE’s FSI and SI model constraints

Thanks for Listening