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Measurement of pion cross-section in ProtoDUNE SP detector at CERN

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Introduction

The study of pion absorption in nuclei remains a subject of considerable interest in medium-energy physics. All the measurements of pion absorption and charge exchange are below 300 MeV/c, as shown in figure 1. Besides the lack of cross-section measurements at high momentum (>300 MeV/c), there are still some opened questions related to pion absorptions. For example, Two-nucleon absorption has been observed to be important, but multi-nucleon absorption also plays an important role in pion nucleus reaction; Searching for the signature of Initial State interactions(ISI) Final State Interactions (FSI), Multi-nucleon process involved in pion absorptions have become an important topic in pion analysis.

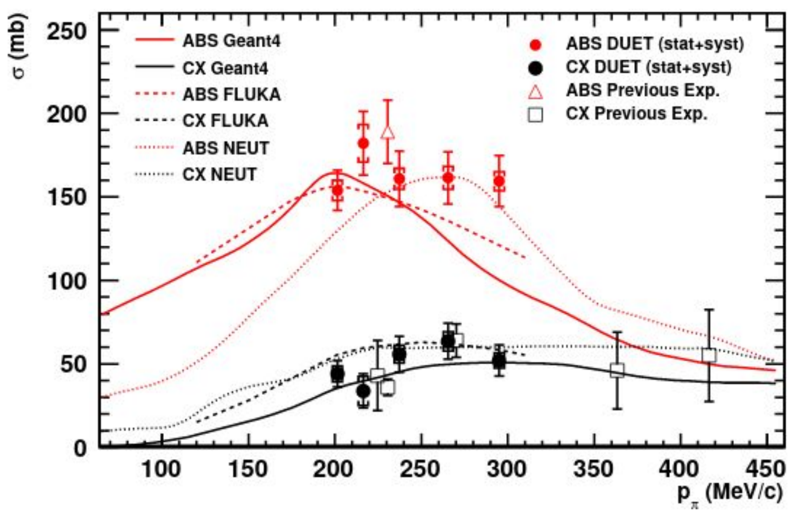


Figure 1. Pion cross section measurements in previous experiments [1].

Research Scheme of Pion Analysis Group with pion beam events (1 GeV/c)

- Shower and particle identification
- Cross section measurement of pion absorption and charge exchange processes
- Characterize the kinematic distributions of pion absorption including
  - Proton's momentum, kinetic energy and angular distribution
  - Missing energy and missing momentum distribution
- Nuclear effect study
  - Searching for signature of FSI, nucleon-nucleon correlations
  - Transverse Kinematic Imbalance study (TKI)

ProtoDUNE Single Phase (SP) Detector[2] (Shown in Figure 2)

- Active volume: 6m high, 7m wide and 7.2 m deep (along drift direction)
- Scientific goals of protoDUNE
  - Prototype the production and installation procedures for the signle phase far detector design.
  - Validate the design from the perspective of basic detector performance.
  - Accumulate test-beam data for the study of detector response, calibration, particle identification etc[3].

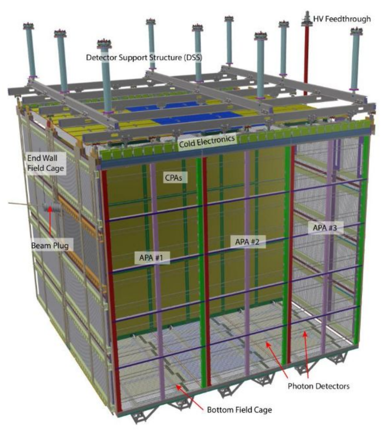


Figure 2. The major components of the protoDUNE-SP Time Projection Chamber (TPC)

H4-VLE Test Beam [2]

H4-VLE test beam comes from an extension of secondary 80 GeV/c pions beam line, coming in turn from a first extension of the 400 GeV/c primary beam from SPS. FIgure 3 shows the H4-VLE beam line of protoDUNE-SP

- It consits of tertiary e, p, μ, π, K beam with momenta range from a 0.5 to 7 GeV/c.
- Large amount of data to study hadron-Ar interactions (Over 4 million beam events collected).

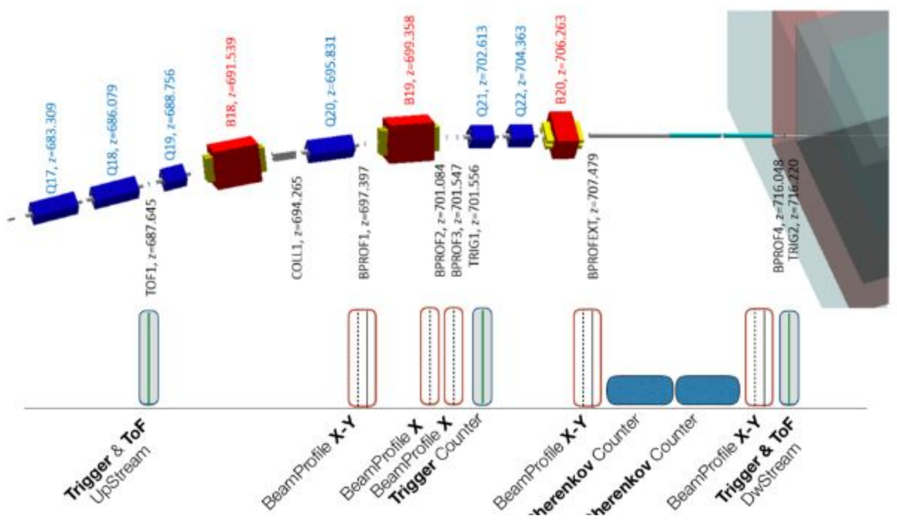


Figure 3. H4-VLE beam line for protoDUNE-SP.

Cross Section Measurement and Systematic Evaluation Scheme

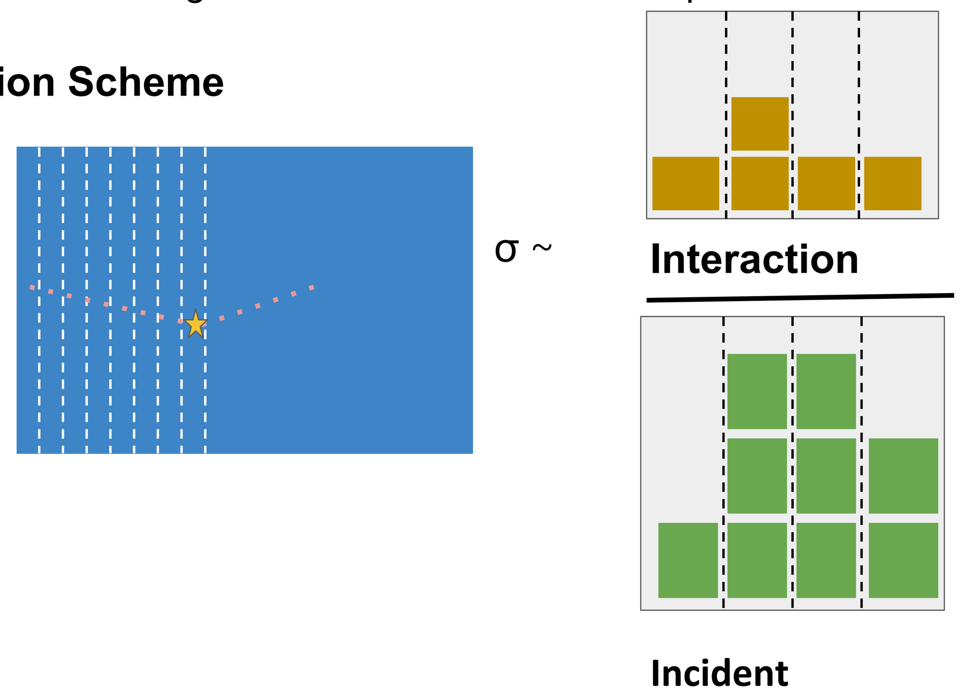
Cross section calculation based on Thin-Slice method developed by LArIAT[4]

- Treat wire-to-wire spacing as a series of "thin-slab" targets
- Each thin-slab is an independent measurement
- Cross section (XS) formula:

$$XS(KE) = S_f \cdot \frac{N(KE)^{interacting}}{N(KE)^{incident}}$$

S_f ~100 barn for ProtoDUNE-SP

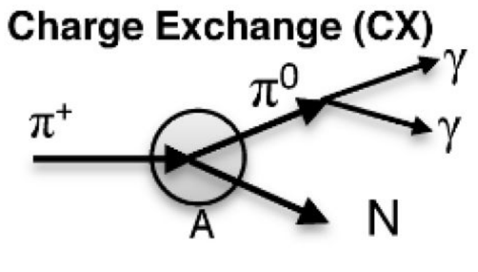
Is proportional to the ratio of number of interacting events to number of incident events as a function of energy.



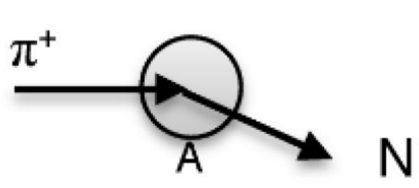
Signal & Background Definition

- Pion Absorption:
  - No neutral pions
  - No charged pions above **threshold**
- Charge Exchange:
  - No charged pions above **threshold**
  - 1 or more neutral pions
- Pion Reaction :
  - At least one charged pions above **threshold**
  - Any number of neutral pions

Charge Exchange (CX)



Absorption (ABS)



Low Momentum Threshold

Figure 4 shows the distribution of reconstructed efficiency of charged pions from pion events with beam momentum = 1 GeV/c

- Reconstructed efficiency is very low for true momentum fewer than 0.15 GeV
- A low momentum threshold to the pions in signal and background definition in analysis

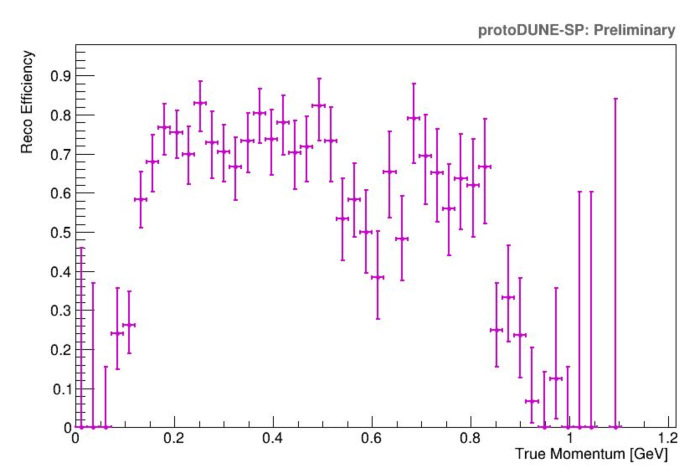


Figure 4. Reconstructed efficiency distribution of charged pions as a function of true momentum without any cuts.

Systematics evaluation analysis:

- in progress including systematics from beam flux,
- GEANT4 theoretical model and detector response.

References:
[1]E.S.Pinzon Guerra, et Al. "Measurement of σ_{ABS} and σ_{CX} of π on Carbon by DUEt. arXiv:1611.05612
[2] B. Abi, et Al. "The single-Phase ProtoDUNE Technical Design Report". arXiv:1706.07081, 2020
[3] B. Abi, et Al. "First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform". arXiv:2007.06722
[4] Nutini, Irene. (2017). The first pion-Ar Cross section measurement with the LArIAT experiment.

Shower Identification

Shower identification is performed to all the particle objects in TPC identified by pandora, which is a multi-algorithm pattern recognition software used in LArTPC experiments [2] . All the particle objects are identified as shower-like and track-like based on track score calculated by a convolutional neural network (CNN) and shower to interaction vertex distance.

- Shower-like: Track Score < 0.3 and Shower - Interaction vertex > 5 cm
- Track-like: Track Score > 0.3 or Shower - Interaction vertex distance < 5 cm

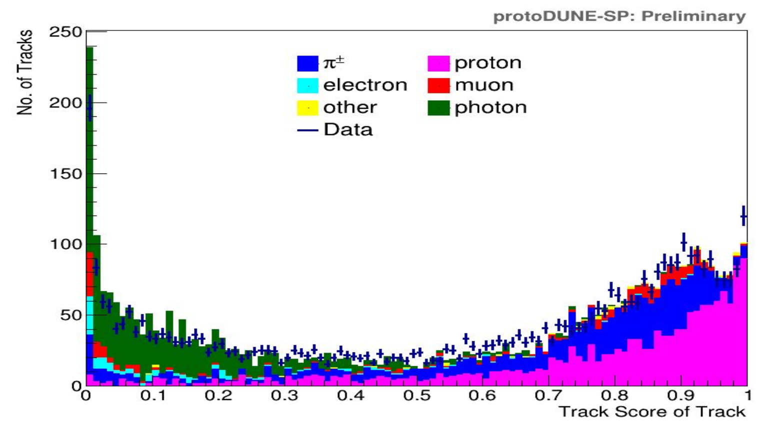


Figure 5. Track Score distribution of all particle flow objects in LArTPC.

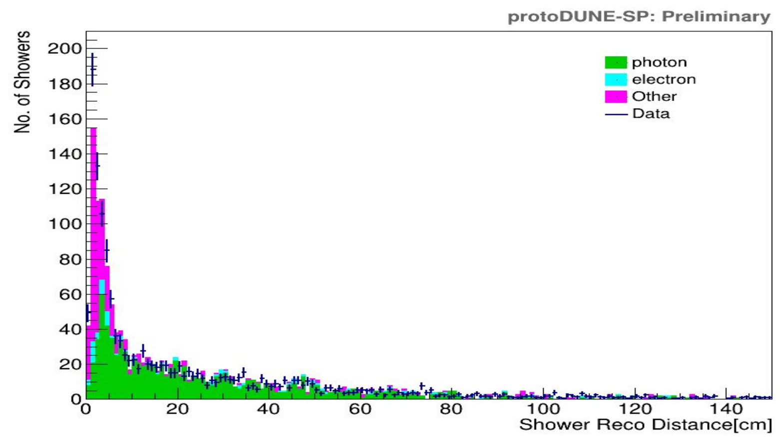


Figure 6. Distribution of Shower - Interaction distance.

Pion - Proton Separation

To select the pion absorption and charge exchange processes, protons needs to be identified and separated from all the track-like objects in TPC based on two calculated variables as a function of energy loss dE/dx

- Truncated Mean dE/dx (Figure 7)
  - Calculated from energy loss dE/dx in collection plane
  - Hits at the begining and end of the track excluded in calculation
  - Proton Region: Truncated Mean dEdx > 3.4; Pion Region: 0.6 < Truncated Mean dEdx < 2.8
    Transition Region: Truncated Mean dEdx < 0.6 and 2.8 < Truncated Mean dEdx < 3.4 -> Further proton-pion separation (chi2/ndof > 70) performed in transition region
- Chi2 per degree of freedom(Figure 8):

$$PID = \chi^2_{proton}/ndof = \sum_{hit}\left(\frac{dE/dx_{measured} - dE/dx_{theory}}{\sigma_{dE/dx}}\right)^2/ndof$$

Ndof: number of hits in collection plane

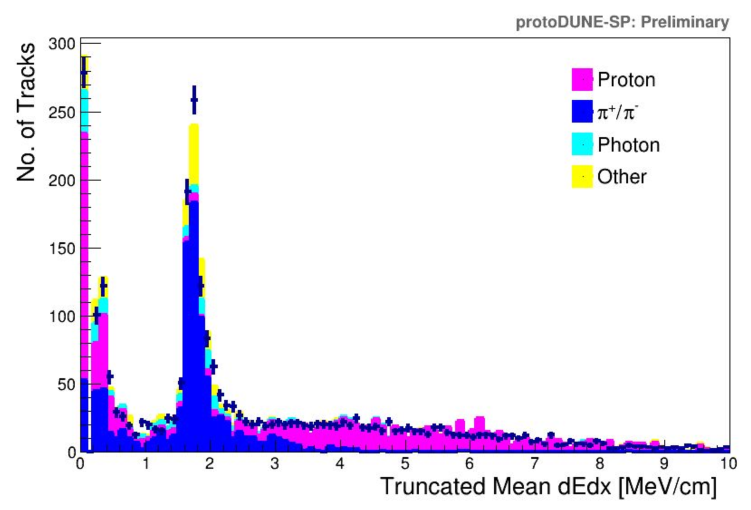


Figure 7. Distribution of truncated mean dEdx

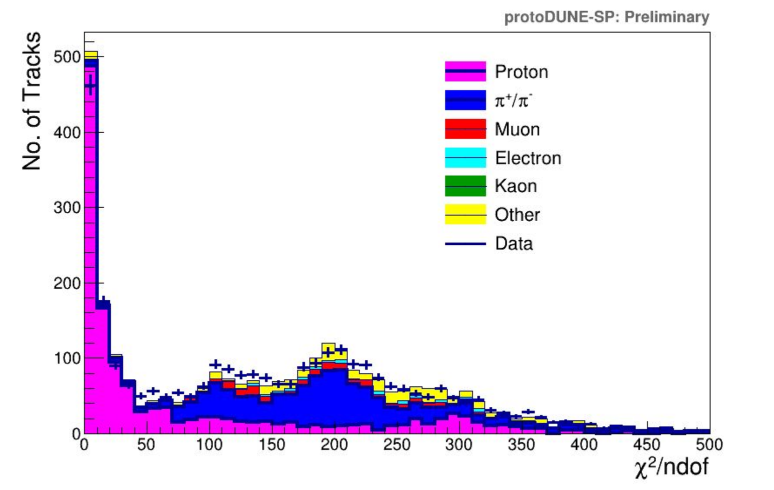


Figure 8. Distribution of chi2 calculated from dEdx on collection plane.

Particle Identification Purity

	Purity
Shower ID	90%
Proton ID	89%

Pion Absorption and Charge Exchange Event Selection

	Efficiency	Purity
Pion Absorption	63%	64%
Charge Exchange	49%	79%
Pion Absorption + Charge Exchange	70%	73%

Kinematic Distributions

Figure 9 shows the distribution of momentum and cosθ of all the proton candidates of all the selected pion absorption events

- Good agreement between data and MC
- Backgrounds are dominated by pion reactions

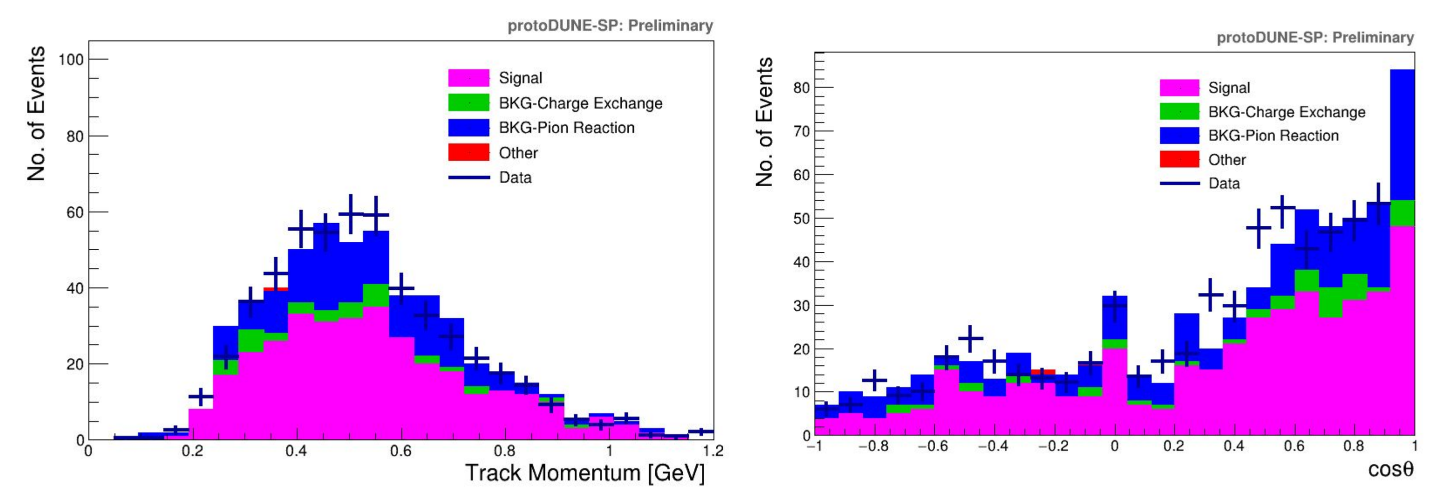


Figure 9. Distributions of momentum (Left) and cosθ (Right) of all the proton candidates of selected pion absorption events.

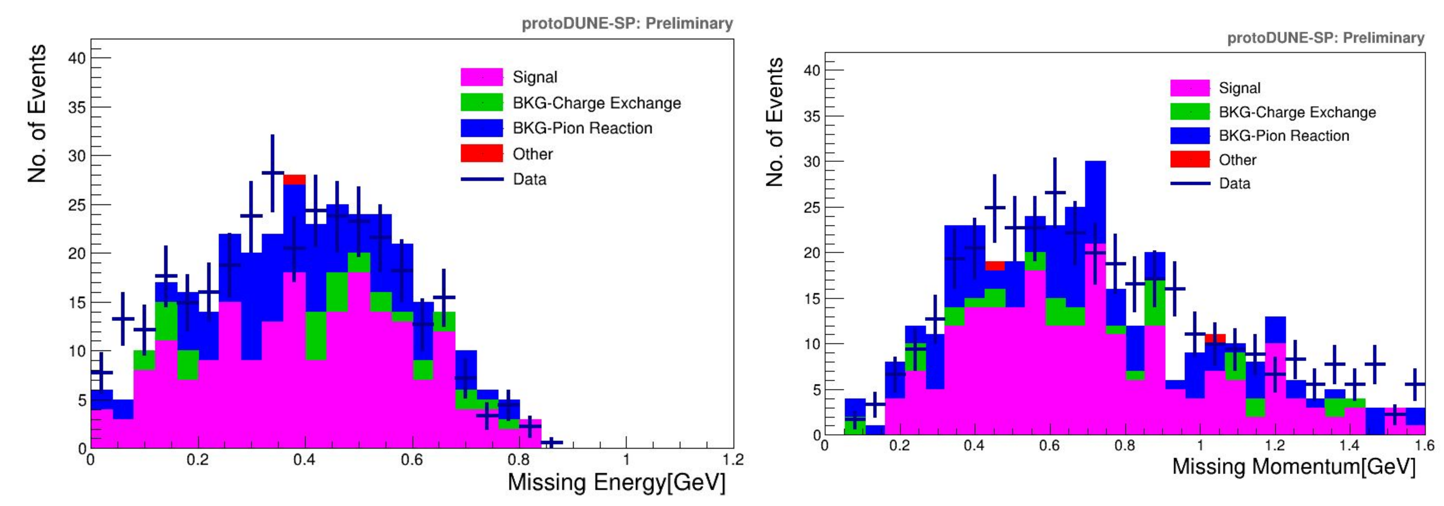


Figure 10. Distributions of missing energy (Left) and missing momentum (Right).