PROCEEDINGS OF SCIENCE

Hadron-argon Cross Section Measurements in ProtoDUNE-SP

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Modern accelerator-based neutrino experiments use complex nuclei, such as argon, as neutrino targets that rely on nuclear models to unfold the reconstructed neutrino energy to the true neutrino energy. The nuclear effects complicate the neutrino oscillation measurements and are not well-understood, and there are very limited measurements of hadron cross sections on argon. ProtoDUNE-SP, a prototype liquid argon time projection chamber (LArTPC) for the Deep Underground Neutrino Experiment (DUNE) far detector, collected data from a hadronic test beam at CERN in 2018, including protons, pions, and kaons in the range 1 to 7 GeV/c. In this talk, we will present the status and results of the many hadron-argon cross section analyses.

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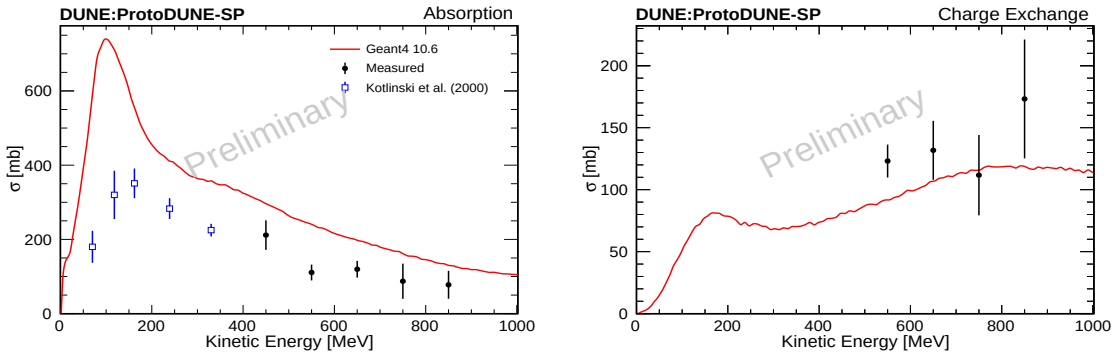
1. Introduction

The primary physics goals for ProtoDUNE-SP are the measurements of hadron interaction cross sections on liquid argon. Results will provide critical information on hadron scattering in liquid argon and improve understanding of final state interactions (FSI) in neutrino-argon interactions.

2. Hadron-argon Cross Section Measurements: Pions, Protons, Kaons, Neutrons

The 1 GeV/c pion-argon exclusive cross section consists of the absorption and the charge exchange interaction. The preliminary results [1, 2] are shown in Fig 1(a) and Fig 1(b). The measured absorption cross section shows lower values than the Geant4 prediction. Similar feature has been observed from the Large Acceptance Detector System (LADS) experiment [3].



(a) **(b)**

Figure 1: (a) The 1 GeV/c π^+-Ar absorption cross section measurements: ProtoDUNE-SP (black dots) and LADS [3] (blue circles). (b) ProtoDUNE-SP's 1 GeV/c π^+-Ar charge exchange cross section measurement. The Geant4 predictions (red curves) are shown for comparison.

The reconstructed 1 GeV/c π^+-Ar inelastic cross section, the 1 GeV/c p-Ar inelastic cross section, and the 2 GeV/c p-Ar inelastic cross section in MCs are shown in Fig 2(a), 2(b), and 2(c), respectively. All reconstructed inelastic cross sections show good consistencies with the Geant4 inputs. The theoretical predictions from different neutrino generators are available for the π^+-Ar and the p-Ar inelastic cross sections [4]. ProtoDUNE-SP's hadron-argon inelastic cross section measurements at low energies are sensitive to validate the model predictions.

The preliminary result of the 6 GeV/c K-Ar inelastic cross section [5] is shown in Fig 2(d). The measured cross section shows lower values than the Geant4 prediction. A new dE/dx measurement is performed using stopping kaons produced from 6 and 7 GeV/c primary interactions. Fig 3(a) shows the updated dE/dx measurements of the stopping kaons, muons, and protons. Good agreement between data and MC is observed.

Neutrons are of particular interest because they will be a source of missing energy for LArTPC-based neutrino experiments such as DUNE. The n-Ar inelastic cross section measurement presented is based on neutrons produced in the 1 GeV/c pion interaction. The preliminary result of the n-Ar inelastic cross section [6] is shown in Fig 3(b). Both ProtoDUNE-SP and MiniCAPTAIN [7] suggest that the n-Ar inelastic cross section is higher than the Geant4 nominal.

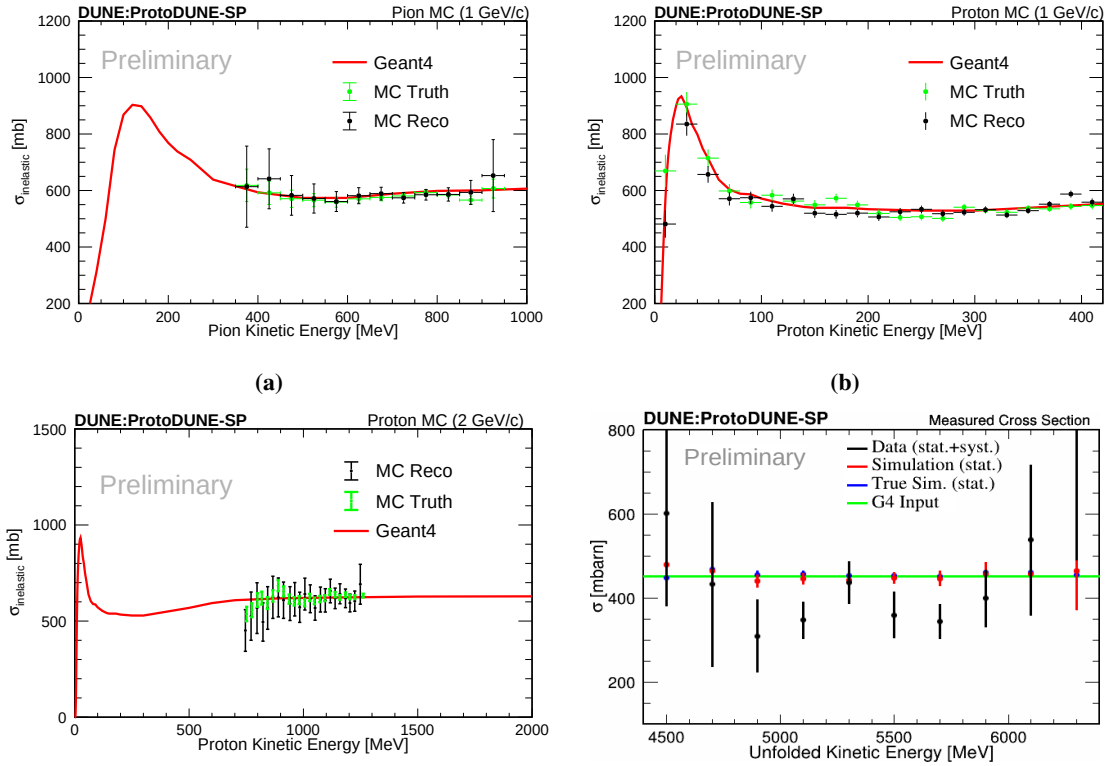


Figure 2: (a) The 1 GeV/c π^+-Ar inelastic cross section in MC. (b) The 1 GeV/c p-Ar inelastic cross section in MC. (c) The 2 GeV/c p-Ar inelastic cross section in MC. The Geant4 predictions are presented (red curves). (d) The 6 GeV/c K-Ar inelastic cross section measurement: data (black dots), MC reconstructed (red dots), MC truth (blue dots), and the Geant4 prediction (green line).

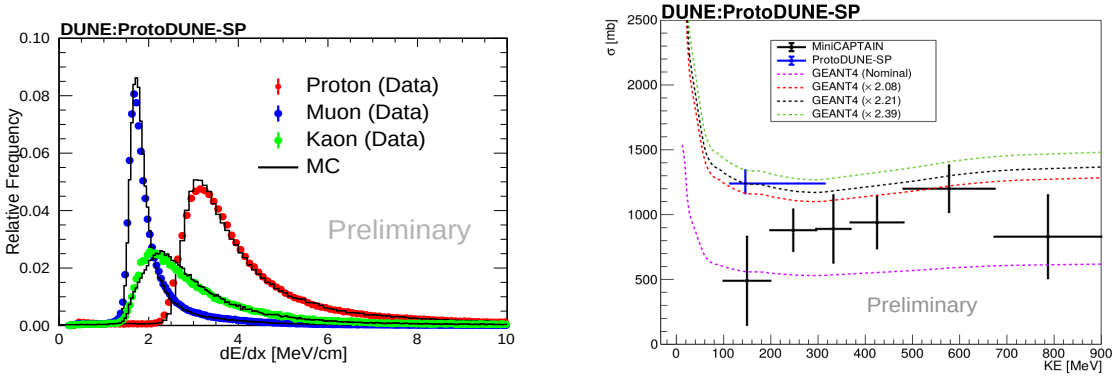
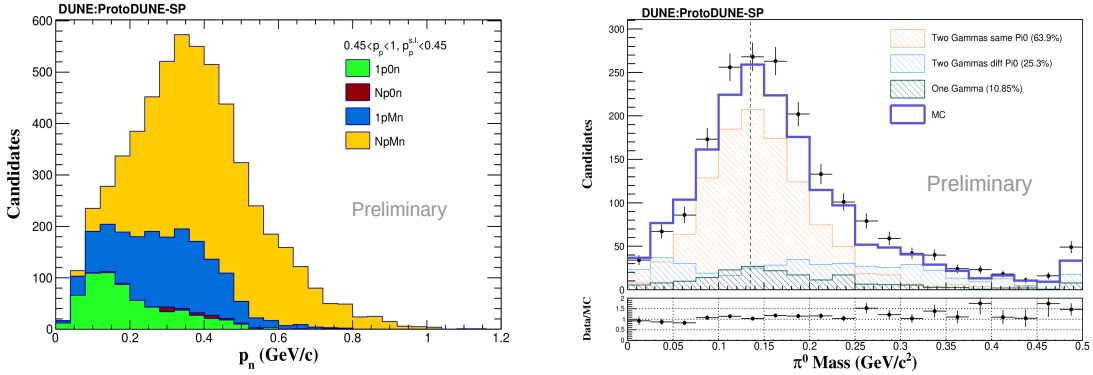


Figure 3: (a) The dE/dx measurements of the stopping kaons, protons, and muons. (b) The n-Ar inelastic cross section measurements: ProtoDUNE-SP (blue) and MiniCAPTAIN [7] (black). The Geant4 nominal (purple dashed line) and with different scaling factors are displayed.

The transverse kinematic imbalance has been measured in several neutrino experiments such as MINERνA and T2K to probe nuclear effects and FSI. Similar measurements are performed in ProtoDUNE-SP through the pion charge exchange interaction. The initial-state neutron momen-

tum, P_n, is used to measure the Fermi motion of nucleon inside argon nucleus. Fig 4(a) shows the reconstructed P_n in MC. The Fermi motion of the struck neutron (1p0n) in Ar is observed. Fig 4(b) shows the reconstructed π^0 mass peak, which served as a benchmark observable for the reconstruction. The reconstructed π^0 mass peak is well aligned with the theoretical prediction.

Measuring hadronic cross sections on argon aid better understanding of FSI in neutrino-argon interactions. ProtoDUNE-SP's measurements of the hadronic cross sections on argon have played a critical role in reducing systematic uncertainty for DUNE. Preliminary results for a number of hadronic cross section analyses have been reported and will be published.



(a) **(b)**

Figure 4: (a) The initial-state neutron momentum P_n in MC: Neutron Fermi motion in Ar (green) and backgrounds (other colors). (b) The reconstructed π^0 mass peak: Data (black dots) and MC (blue line). The theoretical π^0 mass is shown (dashed line).

References

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