Measuring the Proton-argon Cross Section at ProtoDUNE-SP

Heng-Ye Liao (liao@phys.ksu.edu) for the DUNE Collaboration

KANSAS STATE UNIVERSITY

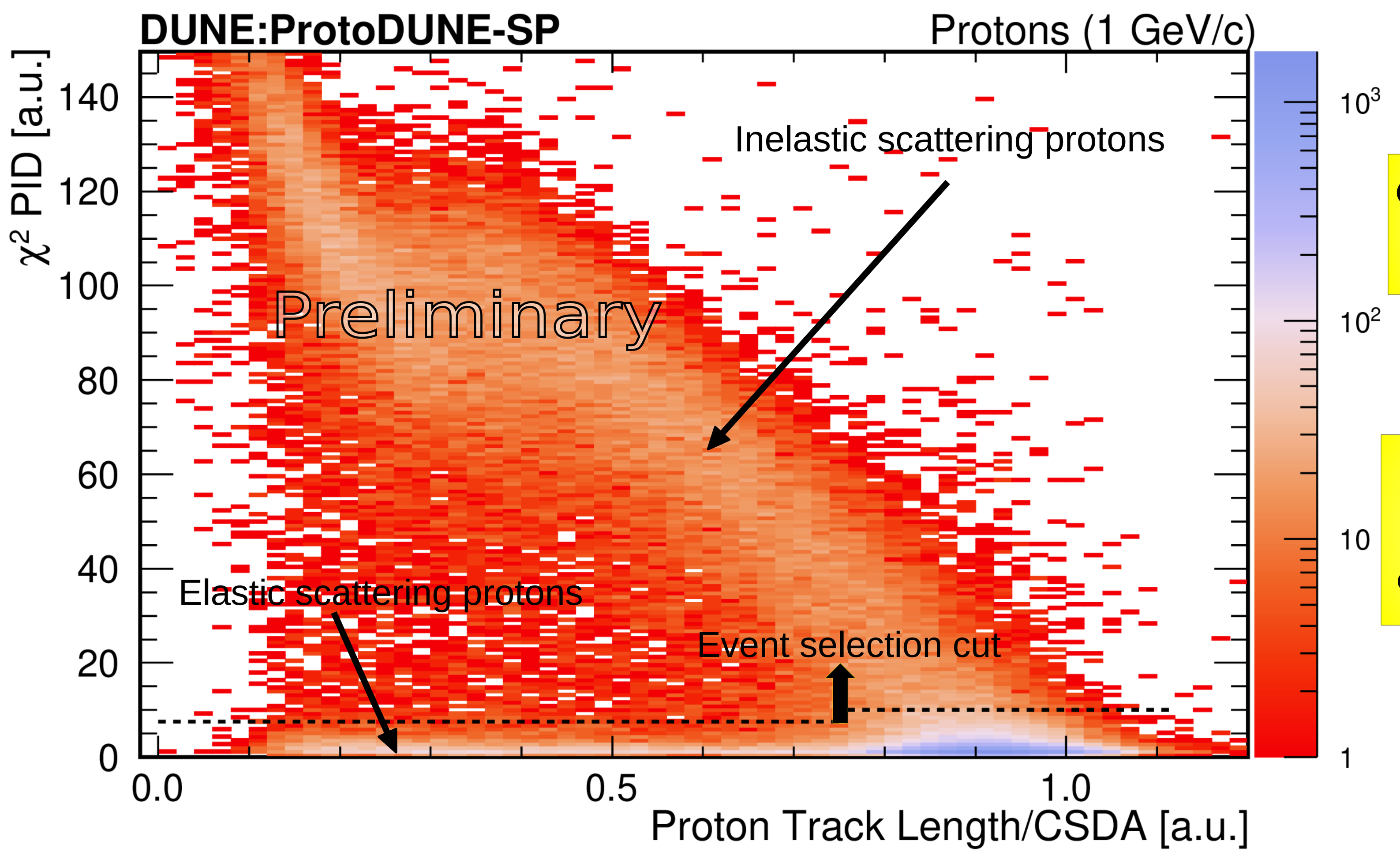
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

I. Introduction

- **Main physics goal of ProtoDUNE-SP**:
  Precise hadron-Ar cross section measurements
  - Provide critical info. on hadron scattering in the LAr & aid better understanding of final state interactions (FSI) in ν-Ar interactions
  - Improved FSI model can reduce systematic uncertainties on ν energy reconstruction & ν signal selection
    → Crucial to achieve DUNE physics goals
- **Controlled environment, rich data, and excellent detector**
  - CERN H4 beamline with known particle type & incident energies
  - Test-beam particles from 0.3-7 GeV/c ($\pi^+/p/K^+/\mu^+/e^-$)
  - Over 4 million beam events collected
  - LArTPC has high resolution tracking & calorimetric capabilities
- **Successful demonstration of detector performance & operation**
  - ProtoDUNE-SP's first publication on detector performance [1]

II. Event Selection

- **Main focus: proton inelastic scattering**
  - Use ToF & Cherenkov counter info to select beam protons
  - Select inelastic scattering protons using normalized track length and χ^2 PID parameter
    + Normalized track length:=proton track length/CSDA range
    + CSDA range=Average path length as proton slows down to rest
    + χ^2 PID:= $\frac{1}{n_T}\sum_j \frac{\left[\left(\frac{dE}{dx}\right)_j(\text{Data}) - \left(\frac{dE}{dx}\right)_j(\text{MC Proton})\right]^2}{\sqrt{\left[\sigma\left(\frac{dE}{dx}\right)_j(\text{Data})\right]^2 + \left[\sigma\left(\frac{dE}{dx}\right)_j(\text{MC Proton})\right]^2}}$ (stopping proton hypothesis)



- **Event selection performance**
  - Signal: inelastic scattering protons (Inel.)
  - Main Backgrounds:
    Elastic scattering protons (El.) + secondary protons (misID:p)
  - Efficiency & purity after event selection cut

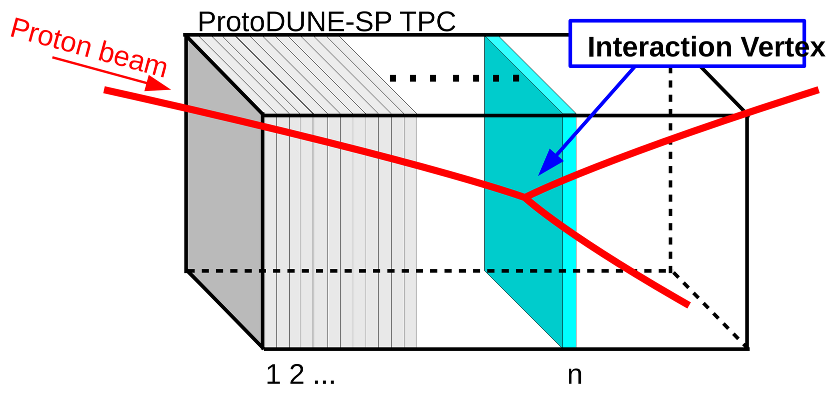
Signal		Background	
Purity	Efficiency	El.	misID:p
85.6%	47.7%	6.7%	7.3%

III. Thin-slice Method

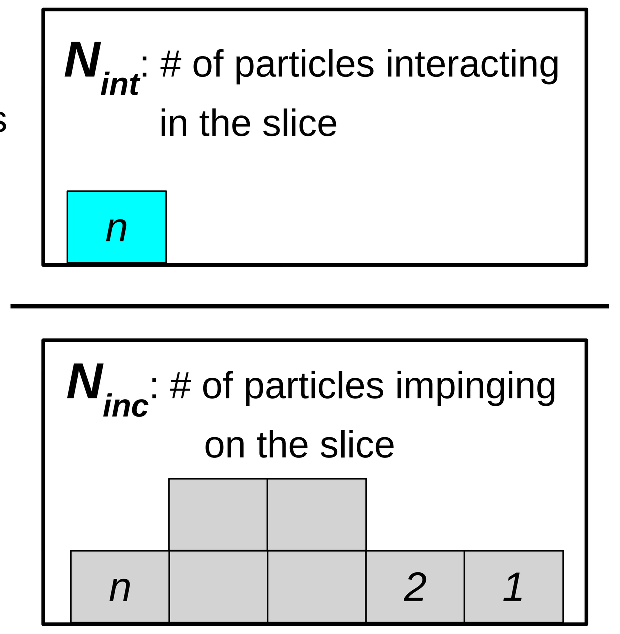
- **Cross section determination using thin-slice method**
  - Method first used for LArTPC analysis by the LArIAT experiment [2]
  - Treat wire-to-wire spacing as a series of "thin-slice" target, each slice is considered as an independent measurement
  - Cross section formula:

$$\sigma = \frac{M_{Ar}}{\rho t N_A} log\left(\frac{N_{inc}}{N_{inc} - N_{int}}\right)$$

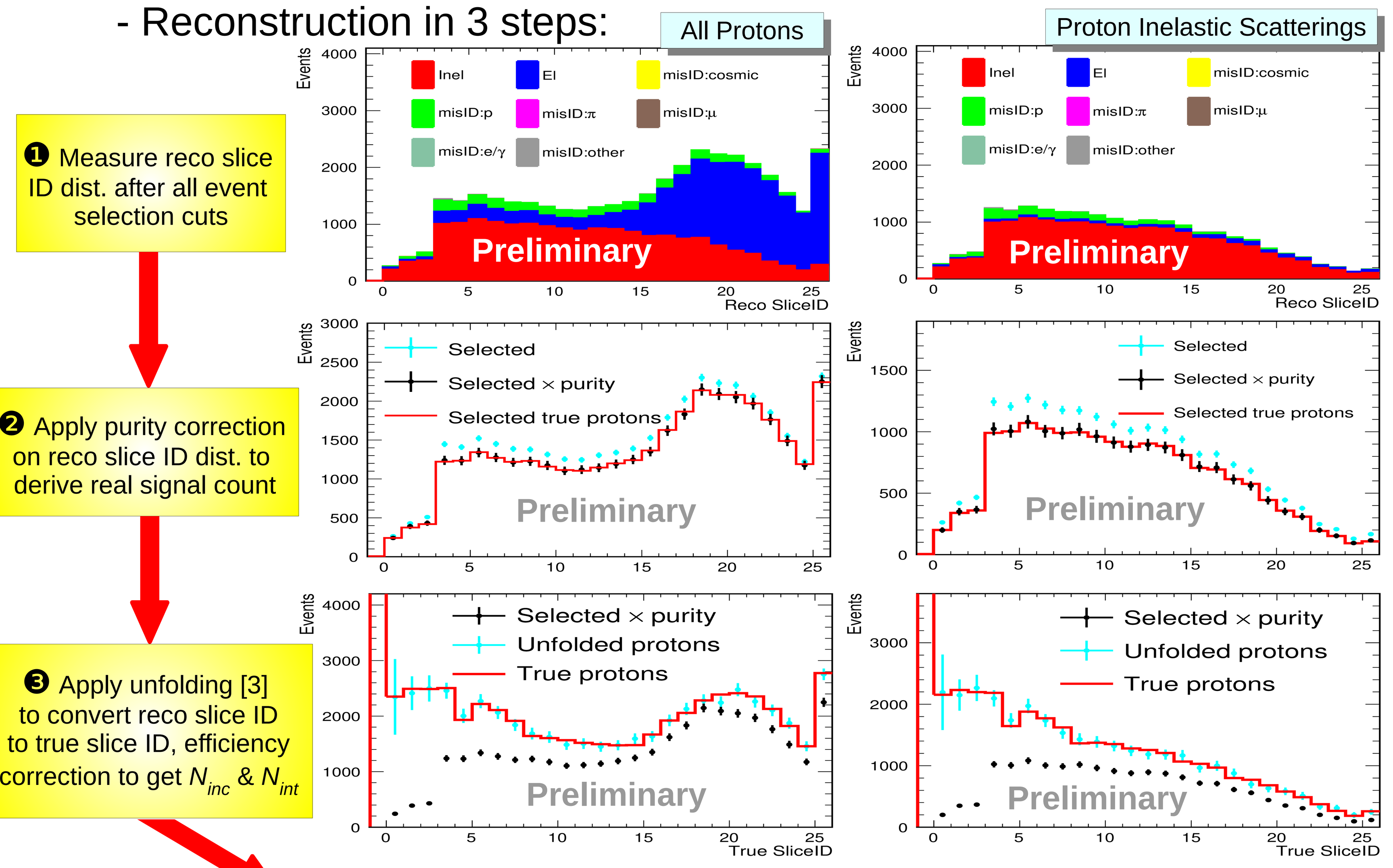
M_{Ar}: Ar mass
t: Slice thickness
ρ: Ar density

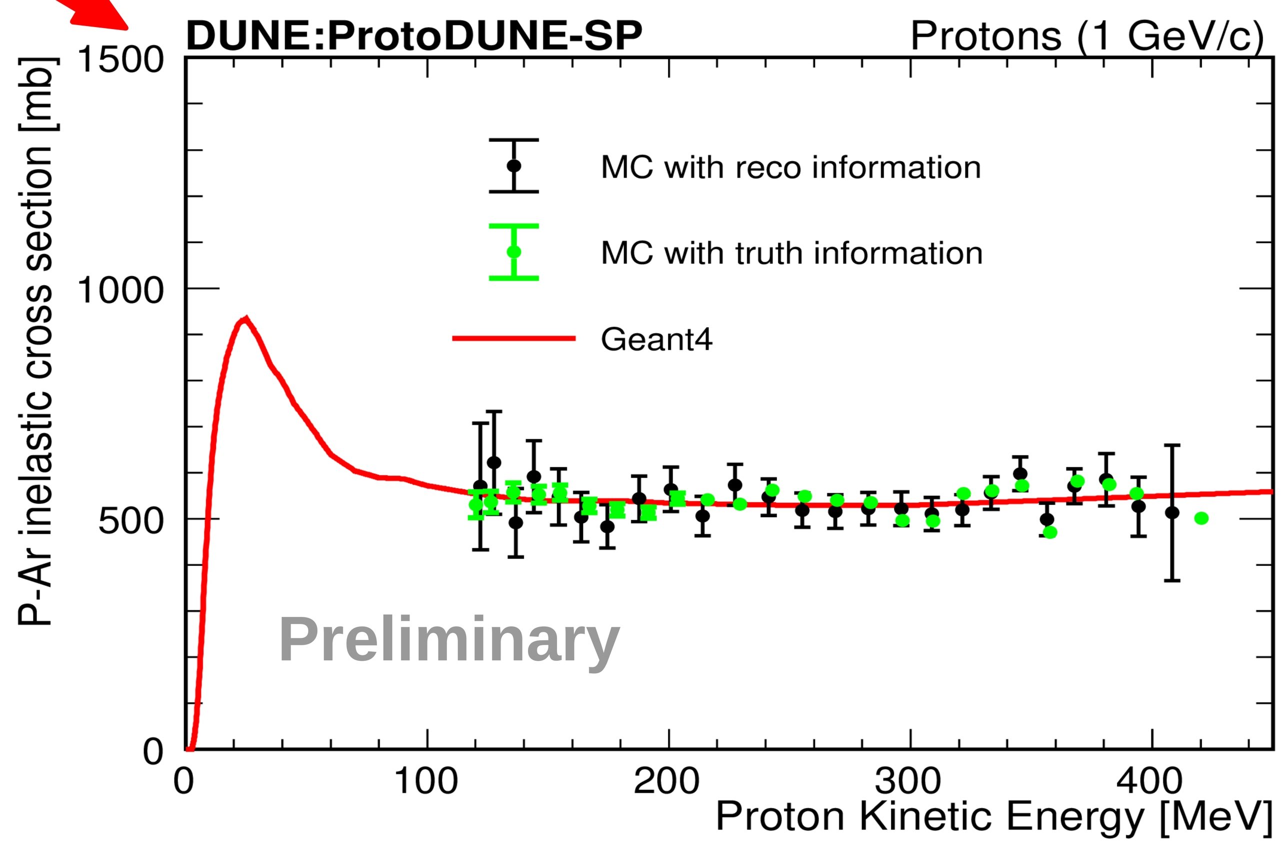


$$\sigma \propto \frac{N_{int}}{N_{inc}}$$



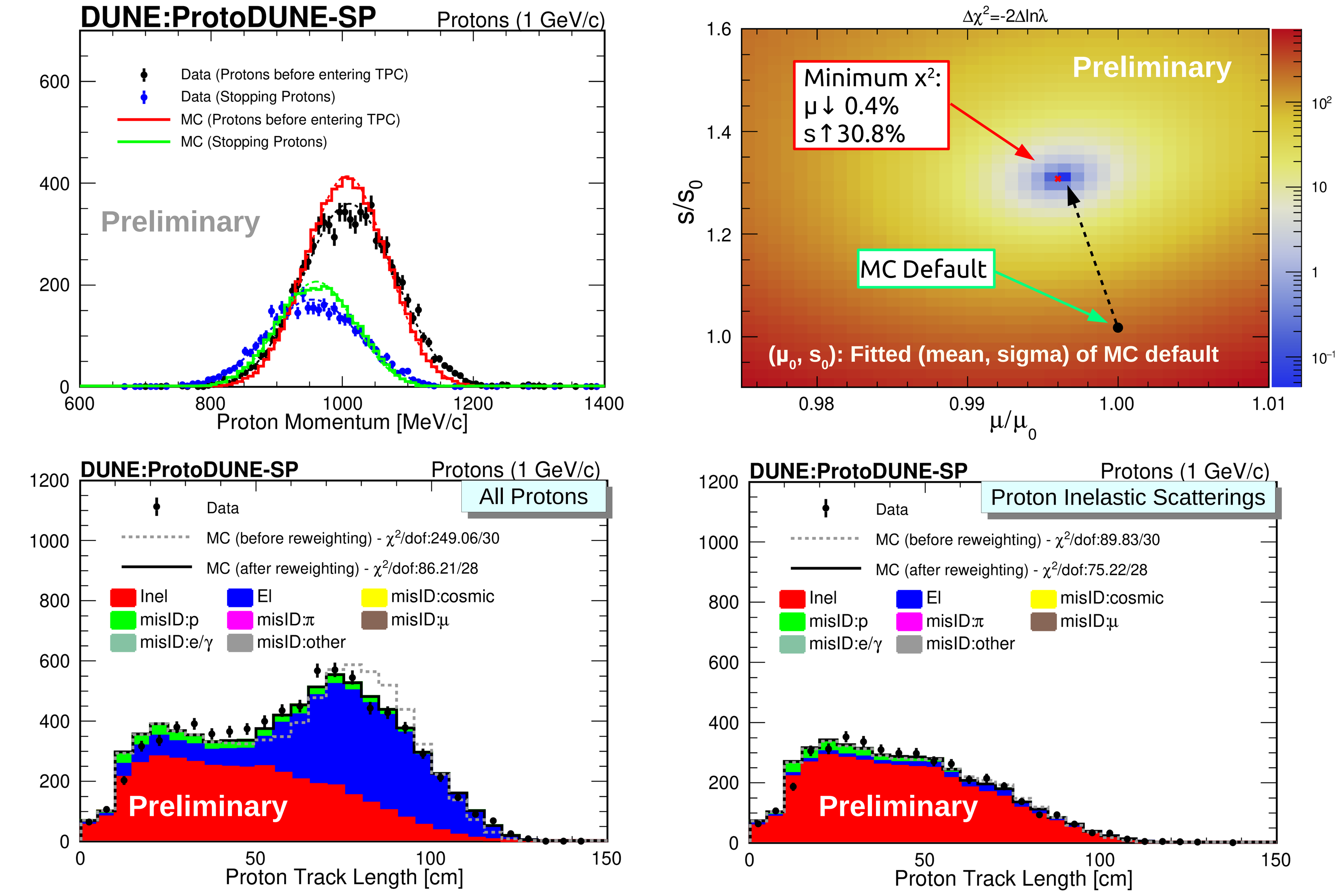
- **Proof of principle**
  - TPC is divided into thin slices (slice width=4 cm)
  - Measure N_{inc} & N_{int} independently
  - Slice ID:=track length/slice width for truth & reco (after space charge correction) → Slice ID=25 for overflow bin | ID=-1 for underflow bin
  - MC sample: ½ Test sample + ½ Validation sample (truth)
  - Reconstruction in 3 steps:





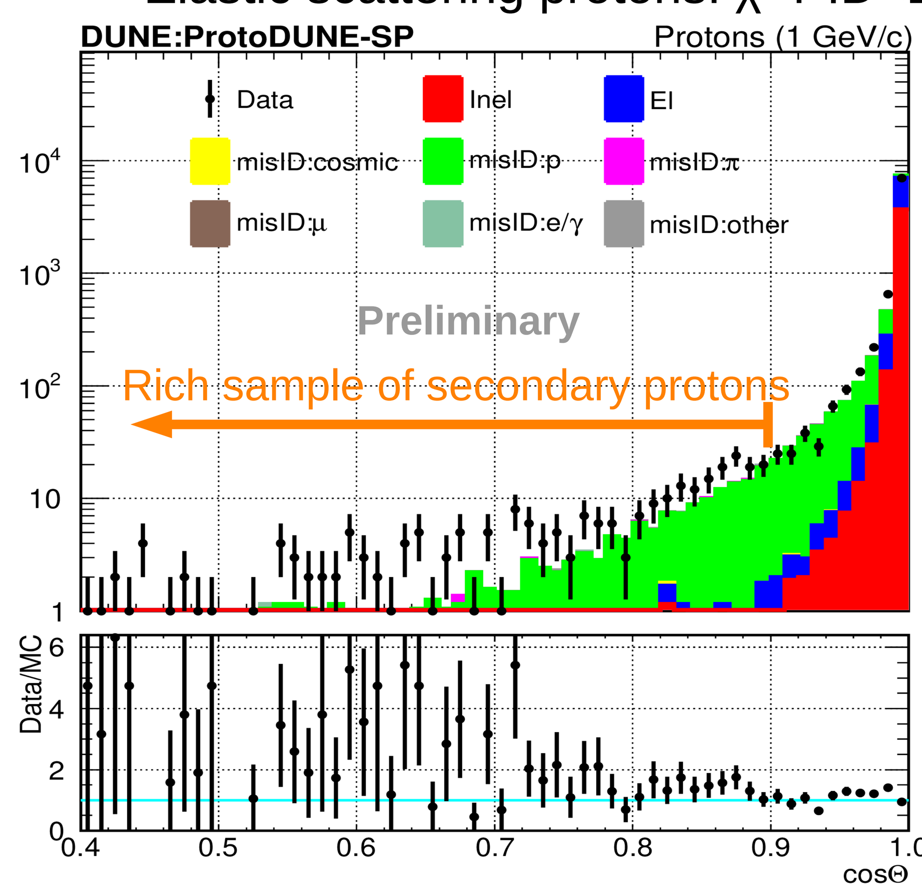
IV. Systematics

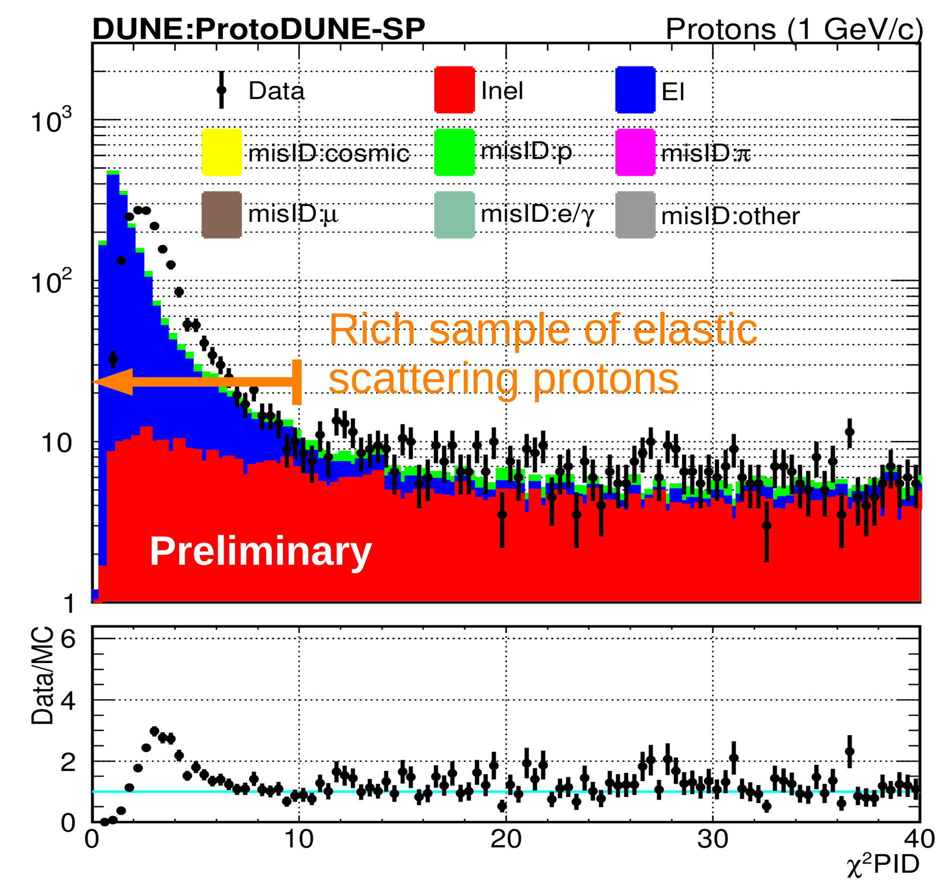
- **Main systematics of track length distributions**
  - Different (1) beam profile (2) material budget between data & MC
- **Mitigate beam momentum systematics using stopping protons**
  - Better agreement between data & MC after beam momentum reweighting



V. Background Measurement & Suppression

- **Data-driven method to constrain main backgrounds**
- **Select background-rich samples for the measurements**
  - Secondary protons: cosΘ<0.9 (Θ: angle between TPC & beam track)
  - Elastic scattering protons: χ^2 PID<10





VI. Summary & Outlook

- **Demonstration of proton inelastic cross section using thin-slice method**
- **Main backgrounds & systematics addressed**
- **Work in progress / future plan**
  - **More detailed background measurements**
  - **Estimation on systematic uncertainties**

References
[1] DUNE Collaboration, "First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform", JINST 15 P12004 (2020) (link)
[2] LArIAT Collaboration, "The Liquid Argon In A Testbeam (LArIAT) experiment", JINST 15 P04026 (2020) (link)
[3] RooUnfold: https://gitlab.cern.ch/RooUnfold/RooUnfold