ProtoDUNE-SP Proton Analysis

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APS April Meeting
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Introduction

- Neutrino oscillation experiments have ushered in a new era with precision measurements employed in the search for CP violation and mass hierarchy.
- Charged-current (CC) interactions are the primary detection channels for neutrino oscillation experiments. Protons are one of the final state particles in neutrino CC interactions such as CC quasi-elastic (CCQE) and CC resonance (CCRES) interactions, and hence they play an essential role in reconstructing the neutrino total energy in the interactions.
  → Must require precise cross section measurements
- Liquid argon time projection chambers (LArTPC) provide excellent tracking and calorimetric capabilities, enabling us to study neutrino-nucleus interactions in unprecedented detail.
- ProtoDUNE-SP experiment
  → Understand the detector responses of different particles interacting in a LArTPC
  → Prototype detector that form the building blocks for DUNE
- This talk will focus on the ProtoDUNE-SP beam proton analysis

ProtoDUNE-SP Experiment: Setup

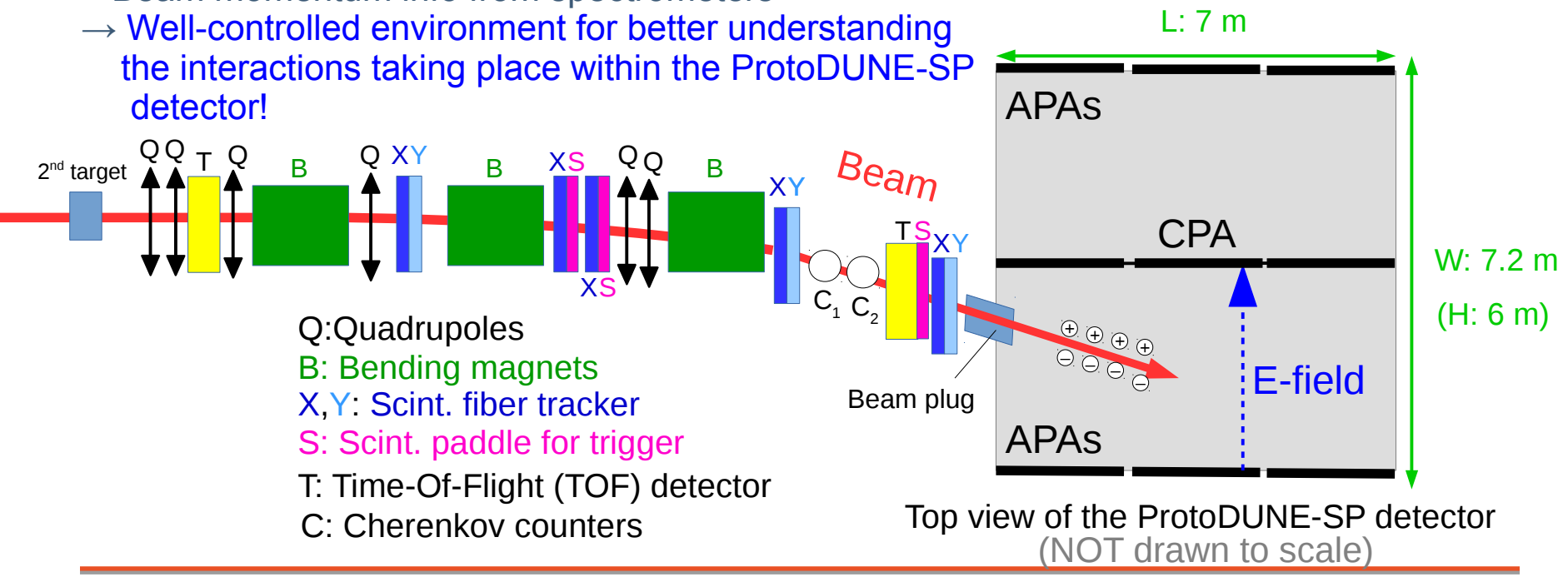
- ProtoDUNE-SP Detector*
  - LArTPC, 0.77 kt/ (7m x 7.2 m x 6 m)
  - 2 drift volumes divided by the cathode plane assemably (CPA)
  - 3 anode plane assemblies (APA) on each drift volume
    2 induction + 1 collection wire plane/APA
  - 60 photon detectors
  - Operation voltage: -180 kV on CPA / purity:~5.5 ms electron lifetime
- CERN H4 beamline & Beamline Instrumentation**
  - Known particle type ($p/e^-/\pi^+/\mu^+/K^+$ beam) & incident energies (0.5 – 7 GeV/c)
  + Particle ID info from high/low pressure Cherenkov counters & TOF
  + Beam momentum info from spectrometers

  → Well-controlled environment for better understanding the interactions taking place within the ProtoDUNE-SP detector!

T12.00005, Hannah Elizabeth Rogers
Overview of ProtoDUNE-SP and Initial Study of Space Charge

L17.00004, Bryan J Ramson
The Photon Detection System (PDS) at ProtoDUNE

L17.00002, Wenqiang Gu
Signal Processing in the ProtoDUNE-SP LArTPC



Top view of the ProtoDUNE-SP detector
(NOT drawn to scale)

* See details in arXiv:1706.07081, "The Single-Phase ProtoDUNE Technical Design Report"

** PHYS. REV. ACCEL. BEAMS 20, 111001 (2017)

Beam Event Selection & Reconstruction

- Detector response of protons in the LArTPC
  → Deposited energy calibration & reconstruction
  → stopping protons
- Sample: Run 5387 [1 GeV/c] / 180 kV / ~5.5 msec
- Data analysis

  [1] Distinguish particle species based on the info from TOF & Cherenkov counters from the beanline instrumentation

  [2] Use Pandora* pattern recognition algorithms for track reconstruction

  [3] Event selection cuts:

  -Data cleaning cuts

  +Position cuts: start positions of primary proton tracks close to those of the beam track positions

  +Angle cut (direction cosine between beam and primary track)

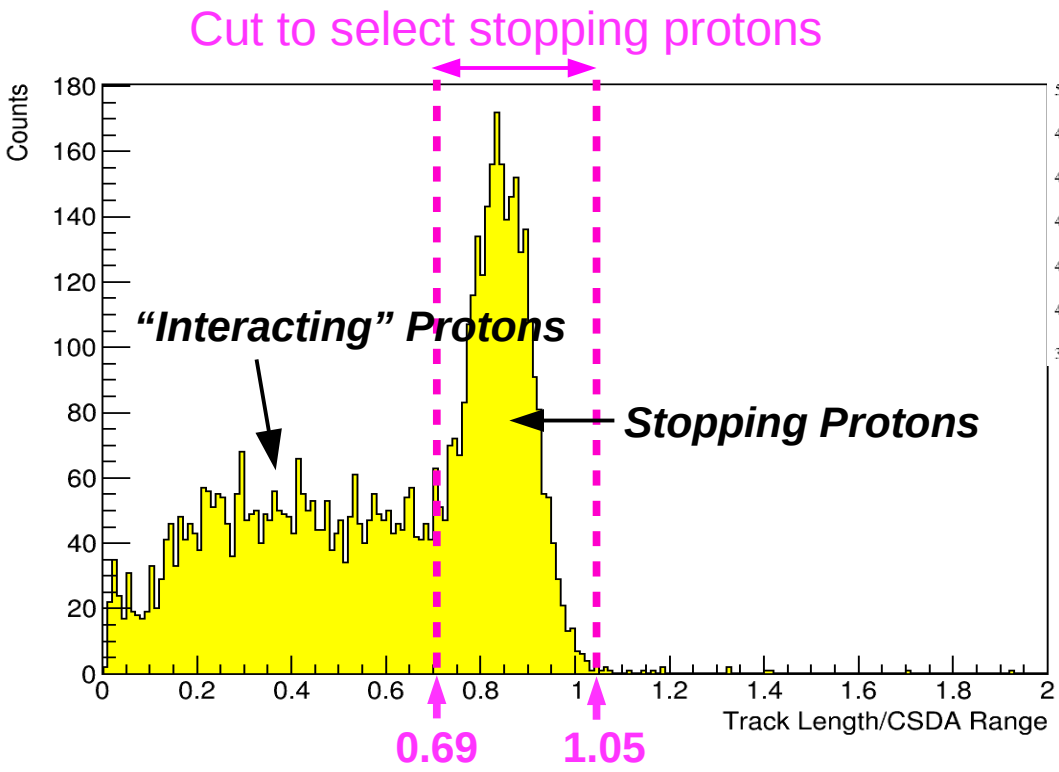
  -Stopping proton cut

  Use a ratio cut (track length/CSDA) to select the stopping protons

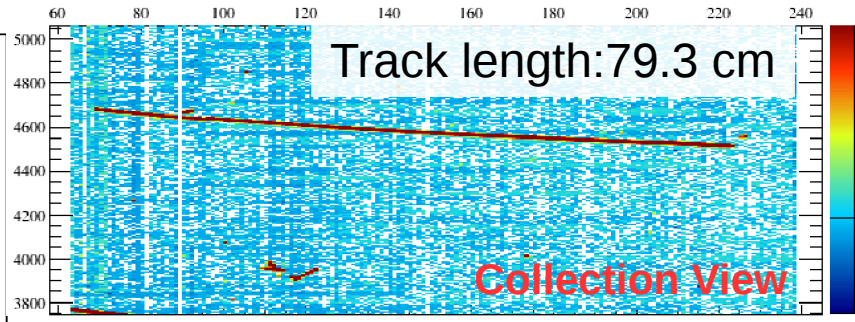
  [4] Calibration (translate charge deposition to energy deposition)

*Pandora reconstruction algorithms: https://link.springer.com/article/10.1140/epjc/s10052-017-5481-6

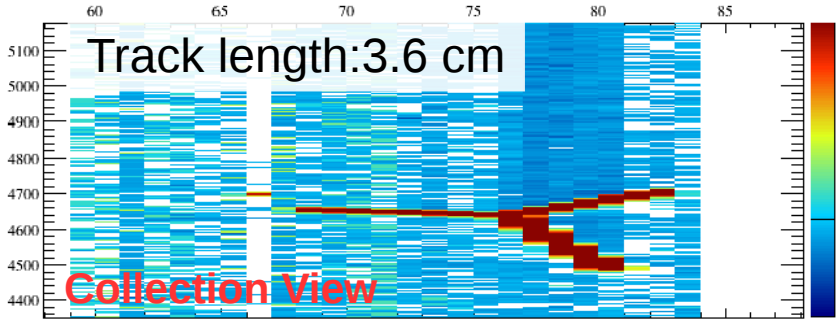
Beam Protons (Data)



Stopping Proton



Interacting Proton

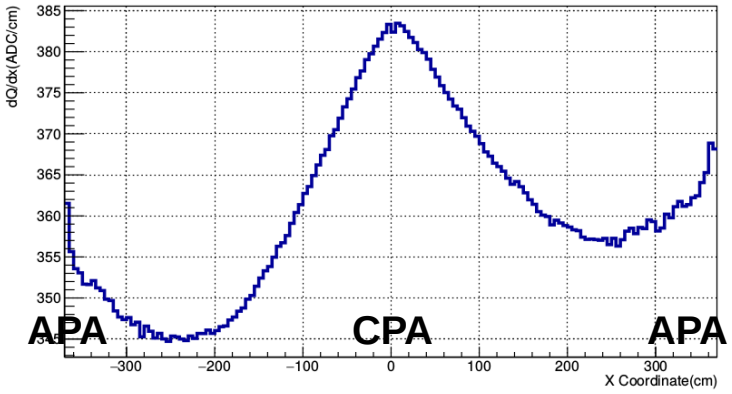


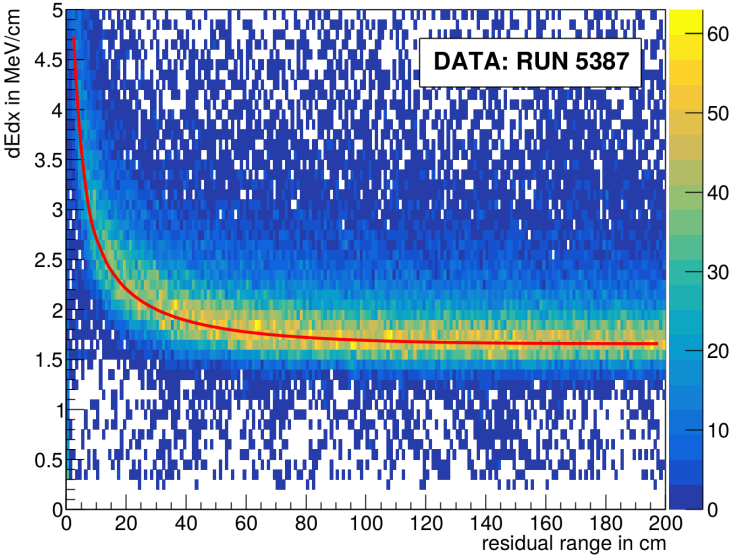
- Convert beam proton momentum to its CSDA range*
- Use the ratio cut (track length/CSDA range) to select the stopping protons

*CSDA range: Average path length traveled by a charged particle as it slows down to rest (continuous-slowing-down approximation)

Calibration

- Calibration: *dQ/dx [ADC/cm] → dE/dx [MeV/cm]*





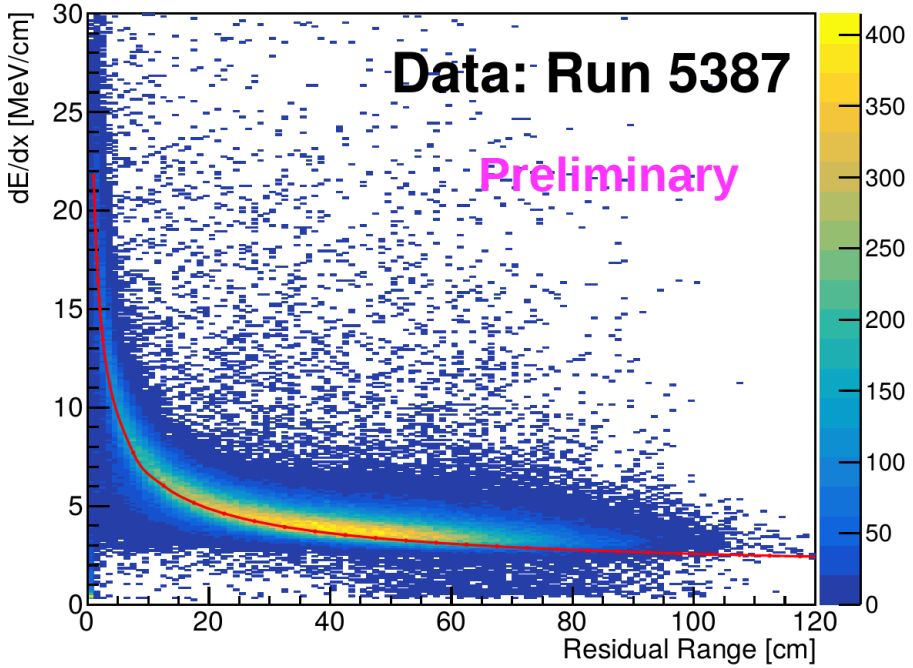
- Procedure
  - dQ/dx correction
    - Use TPC crossing muon tracks for the dQ/dx calibration
    - Correct the non-uniform dQ/dx distribution caused by both attenuation* and space charge effect (SCE)** to the uniform dQ/dx distribution
  - dE/dx calibration
    - Use the stopping muons† as a standard candle to translate dQ/dx [ADC/cm] to dQ/dx [fC/cm] (MIP region, 120-200 cm from the stoppping point)
    - Apply the modified box model□ to convert dQ/dx [fC/cm] to dE/dx [MeV/cm]
- It's a preliminary calibration scheme based on the over-all correction
- More dedicated SCE correction scheme is in development

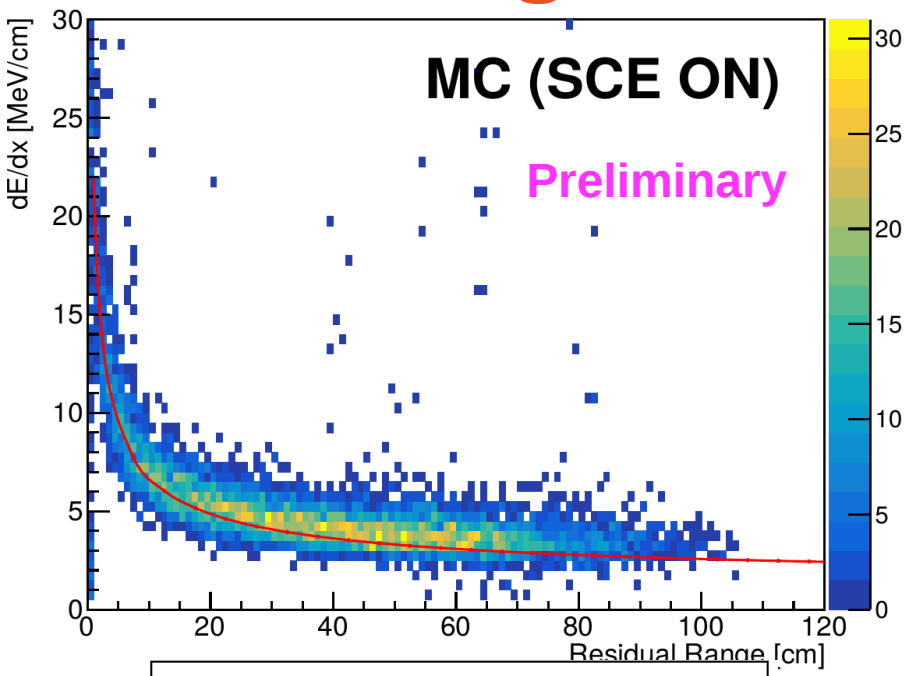
→ See Hannah Rogers' talk in: T12.00005 : "Overview of ProtoDUNE-SP and Initial Study of Space Charge" (04/15, Monday, 4:18 PM–4:30 PM)

□ "A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC" (https://arxiv.org/abs/1306.1712)

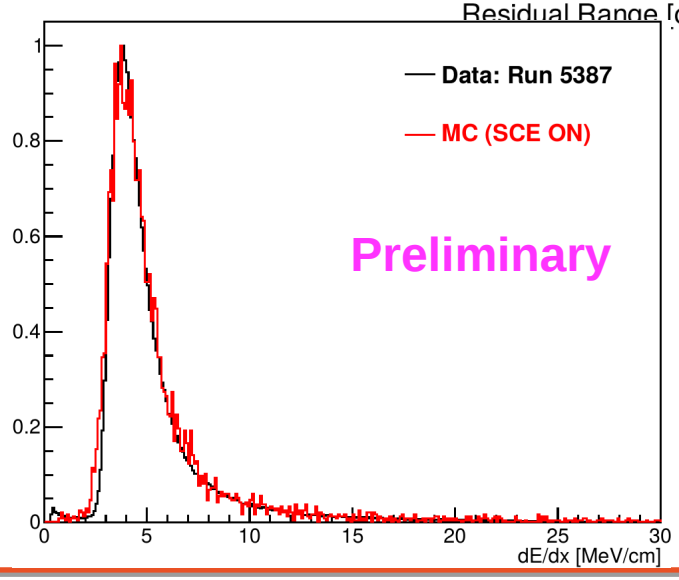
* Impurities absorb drifting electrons.
** The space-charge effect occurs as a result of a build up of slow moving ions in a region of the TPC which distorts the E-field.
† Cathode piercing tracks which start outside the TPC and end inside the TPC

Proton dE/dx vs Residual Range

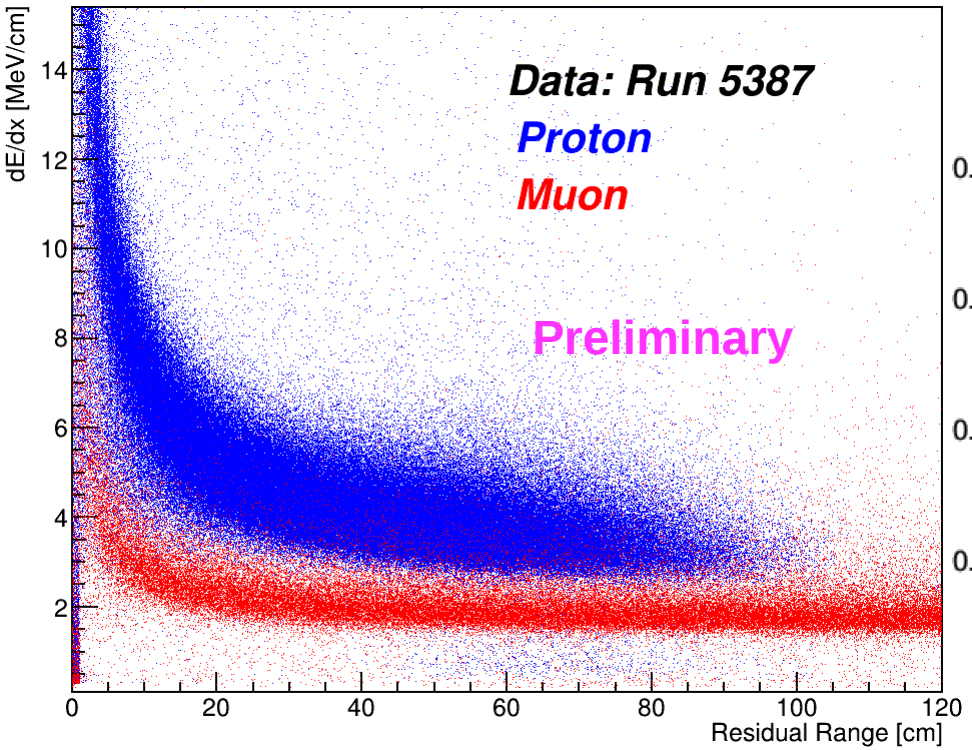


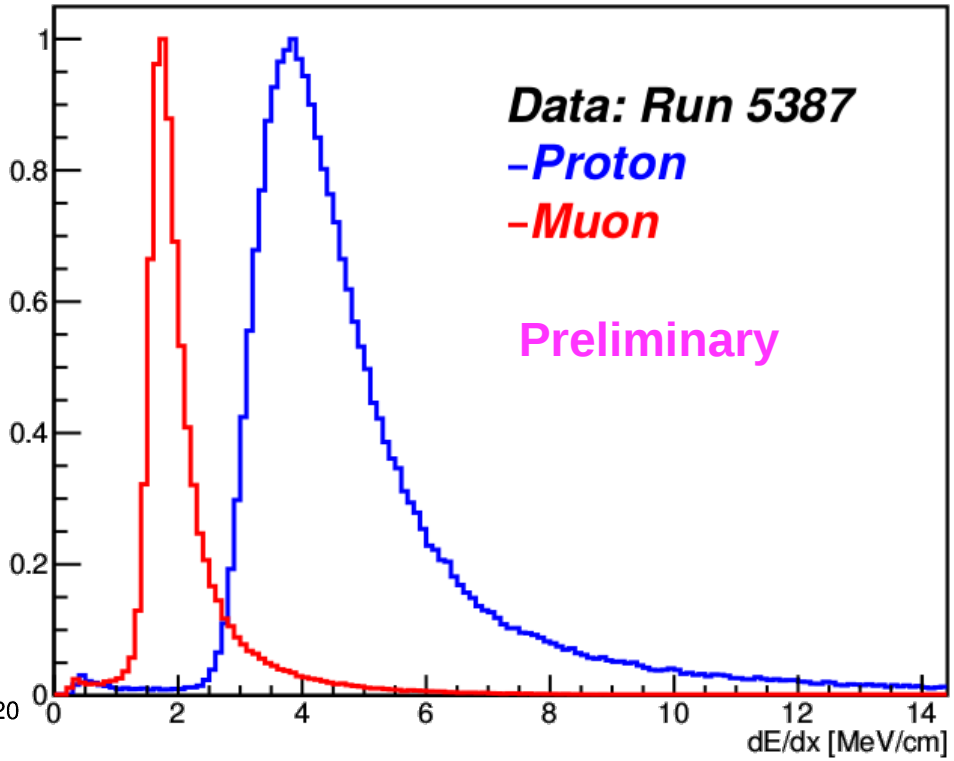


- Very good agreement between data and MC
- Discrepency between the data and the theoretical predicted curve (Landau-Vavilov)
  → Residual SCE not completely accounted for in the preliminary correction procedure



Particle Identification (Data)





- dE/dx as a function of residual range for stopping particles offers a robust method for particle identification in a LArTPC.
- ProtoDUNE-SP particle identification: clear μ/p separation

Summary & Outlook

- Preliminary result of the ProtoDUNE proton analysis
  - Track reconstruction
  - Event selection
  - Calibration scheme
  - Particle ID cabability

- More analyses on the way
  - Kinetic energy reconstructions
  - Proton-Argon cross section

Backup

Modified Box Model

$$\frac{dE}{dx} = \frac{\rho\,\varepsilon}{\beta}\left\{ Exp\left[\frac{\beta\, W_{ion}\, \frac{dQ}{dx}}{c\,\rho\,\varepsilon} \right] - \alpha \right\}$$

c: calibration const. [ADC/ion]
($c=6.155\times10^{-3}$ for run #5387)

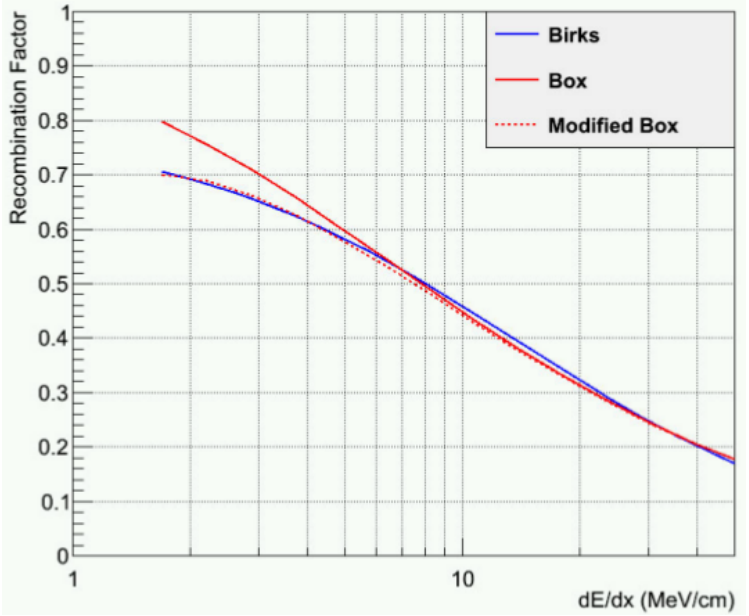
W_{ion}: 23.6 [eV/ion]

ε: 0.5 [kV/cm]

ρ: 1.38 [g/cm^3]

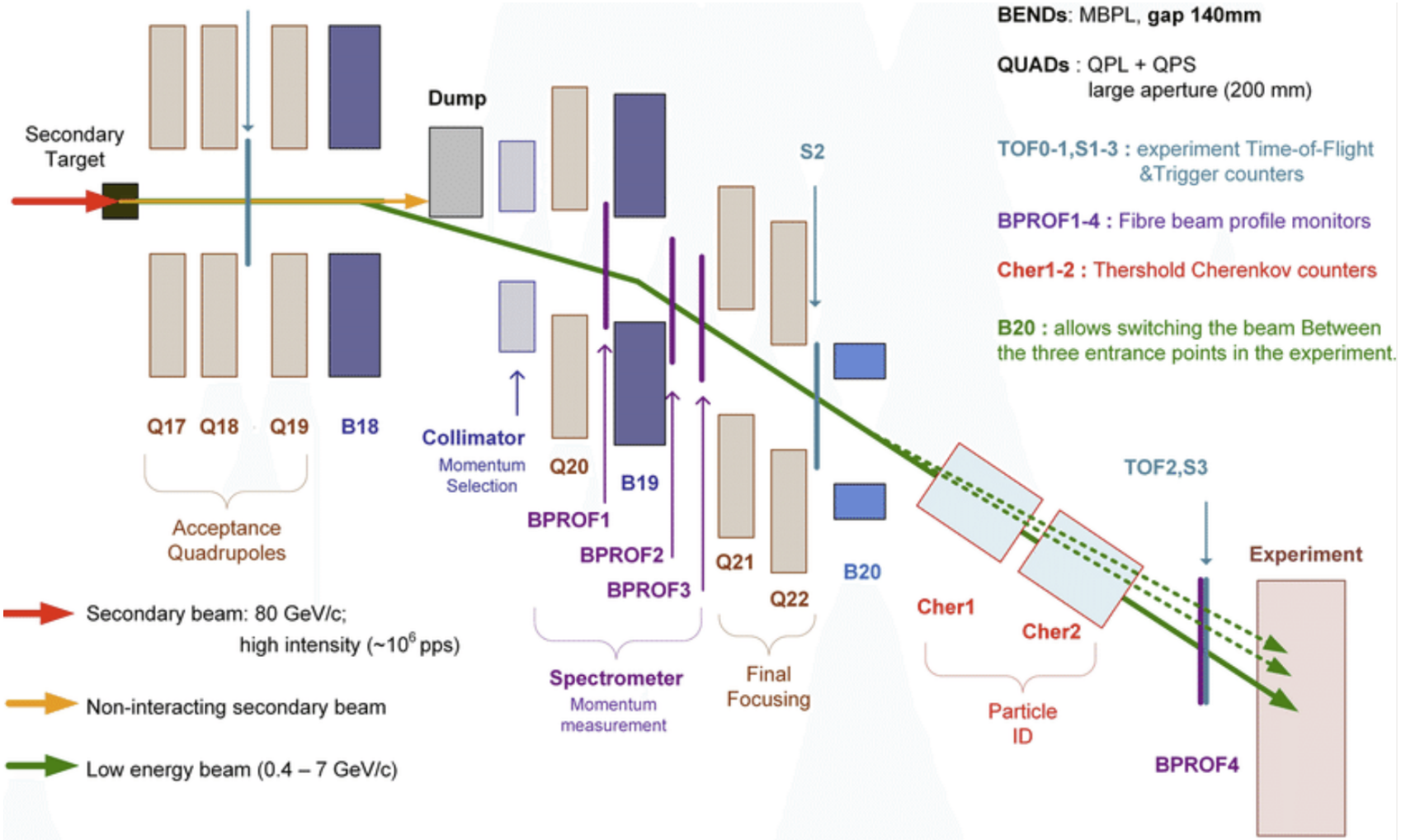
β: 0.212 [(keV/cm)(g/cm^2)/MeV]

α: 0.93

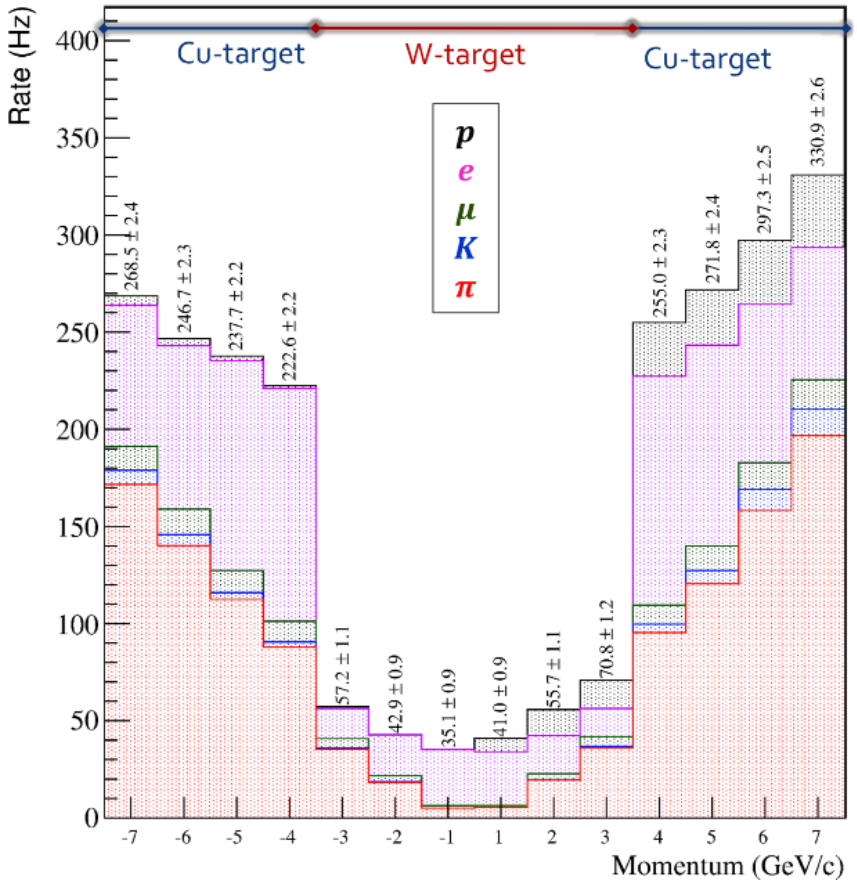


Reference: "A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC" (https://arxiv.org/abs/1306.1712)

Beamline Instrumentation

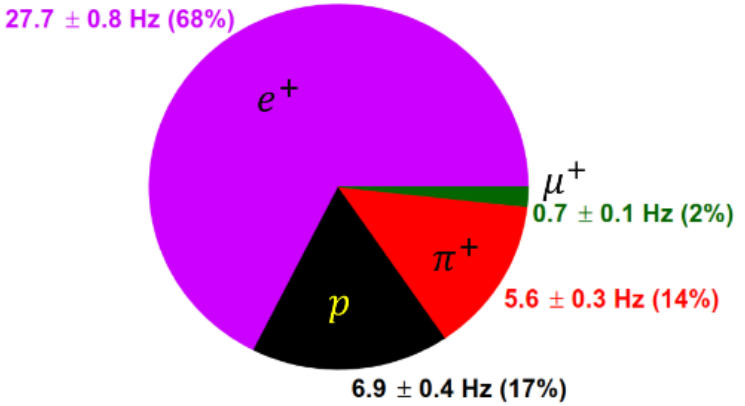


Beamline Instrumentation



Rates at 1 GeV/c

Rate with Collimator



APS April Meeting 2019

Saturday–Tuesday, April 13–16, 2019; Denver, Colorado

Session Index

Session T17: Neutrinos III

Show Abstracts

Sponsoring Units: DPF
Chair: Young-Kee Kim
Room: *Sheraton Grand Ballroom II*

Monday, April 15, 2019 3:30PM - 3:42PM	T17.00001: Status of the Short-Baseline Near Detector at Fermilab Michael R Mooney, Ryan LaZur
Monday, April 15, 2019 3:42PM - 3:54PM	T17.00002: Charged and neutral pion production in the MINERvA experiment Gonzalo A Diaz Bautista
Monday, April 15, 2019 3:54PM - 4:06PM	T17.00003: Initial study of the Neutral Current Single π^0 production in muon anti-neutrino interaction on water with the P0D Detector at T2K Shilin Liu
Monday, April 15, 2019 4:06PM - 4:18PM	T17.00004: First Oscillation Results Using Neutrinos and Antineutrinos from the NOvA Experiment Erica S Smith
Monday, April 15, 2019 4:18PM - 4:30PM	T17.00005: ν_e signal selection and cross-checks performed using muon removed simulations and cosmic muon brem showers in NOvA Reddy Pratap Gandrajula
Monday, April 15, 2019 4:30PM - 4:42PM	T17.00006: Systematic Uncertainties for the NOvA Oscillation Analyses Micah Groh
Monday, April 15, 2019 4:42PM - 4:54PM	T17.00007: ProtoDUNE Proton Analysis Heng-Ye Liao, Glenn Horton-Smith, Tingjun Yang
Monday, April 15, 2019 4:54PM - 5:06PM	T17.00008: Measurement of ^{8}B Solar Neutrino Flux in the SNO+ Water Phase Eric Marzec
Monday, April 15, 2019 5:06PM - 5:18PM	T17.00009: Reconstruction Techniques used in the NOvA Experiment Nitish Nayak