Measuring the proton-argon cross-section at ProtoDUNE-SP

- Outline
  - ProtoDUNE-SP experiment
  - Proton-argon cross-section measurement

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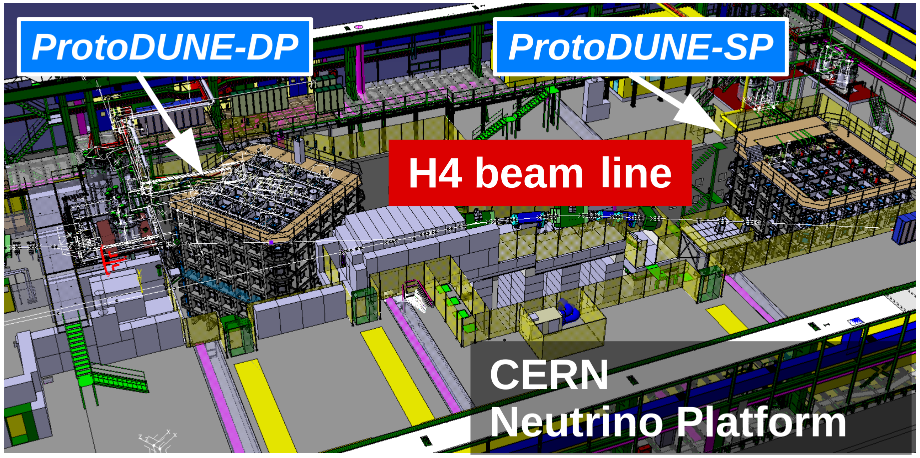
February 22, 2021

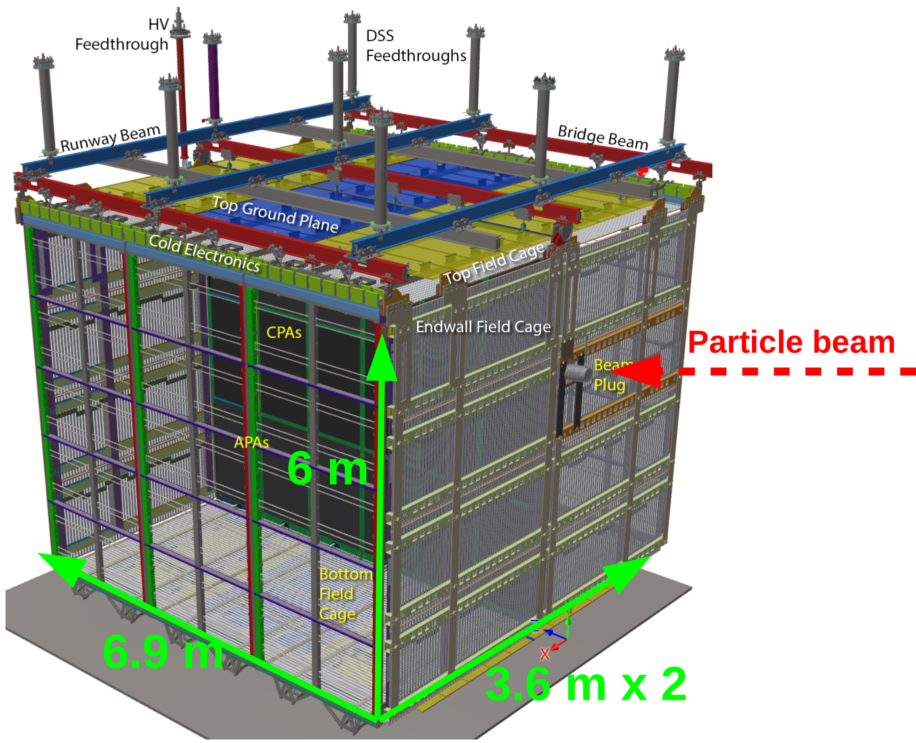
Introducing ProtoDUNE-SP

- **Primary physics goal: Measure hadron-argon cross sections**
  Results provide critical information on hadron scattering in LAr and help better understanding of FSI in neutrino-argon interactions



- **Controlled environment**
  CERN H4 beamline with known particle type (hadrons and electrons) & incident energies
- **A variety of test-beam particles in broad range of momenta**
  0.3-7 GeV/c (**π^+/p/K^+/μ^+/e^-**)
- **Rich data to study hadron-Ar interactions**
  Over 4 million beam events collected (all momenta)

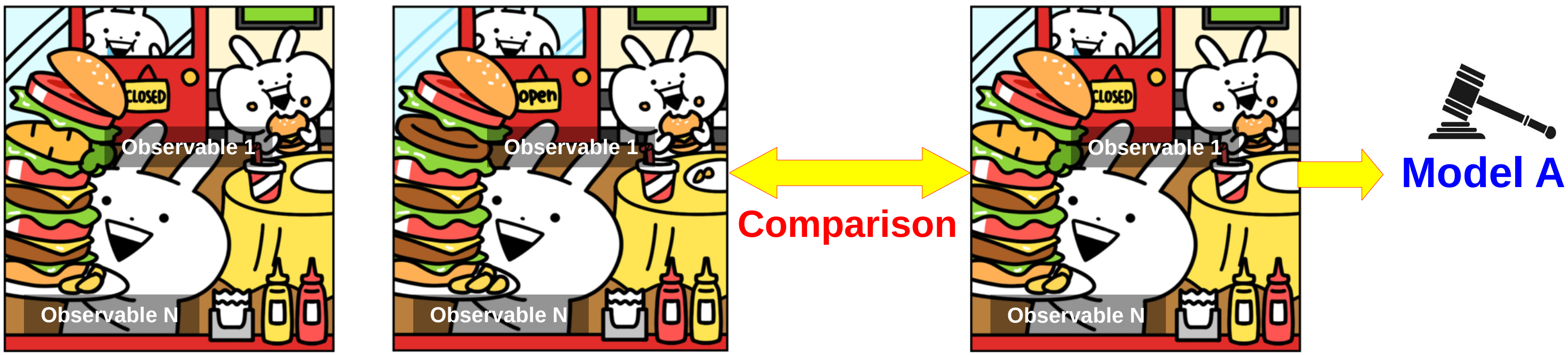
- **LArTPC** (main detector)
  Excellent tracking & calorimetric capabilities



- ~740 tons of liquid argon
- One of the 2 prototypes for DUNE at CERN Neutrino Platform

Determination Method of Cross-section Measurement

- Cross-section (XS) measurements using **XS reweighting**
- Working principle of XS reweighting:
  - → Observables served as representations of XS model(s)
  - → Validate XS models by comparing MC observables with those of data



MC: Model A   MC: Model B   Data

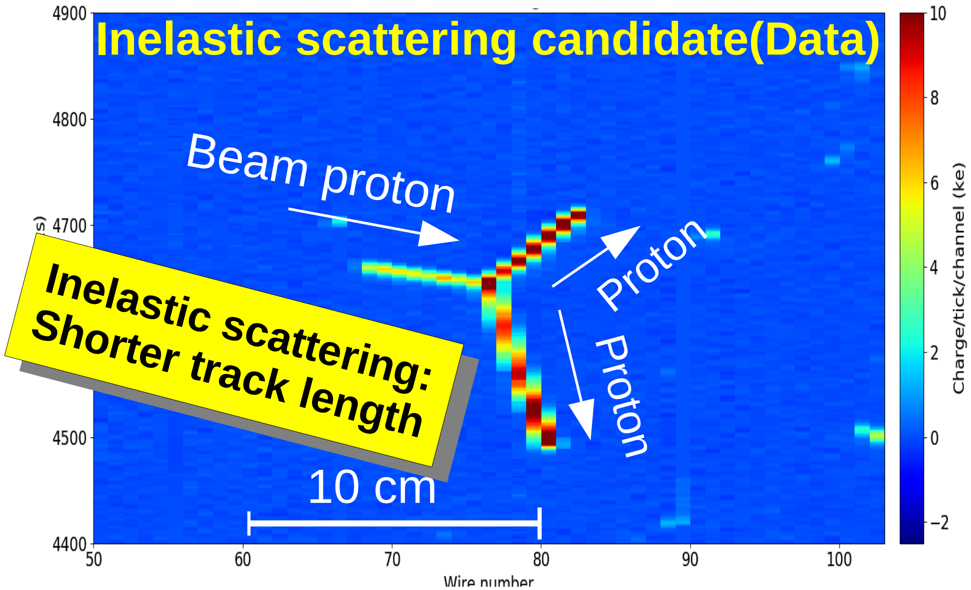
- Use **Geant4 Reweight** for XS reweighting
  - Geant4 version: v4_10_6_p01 (released on Feb. 14, 2020)

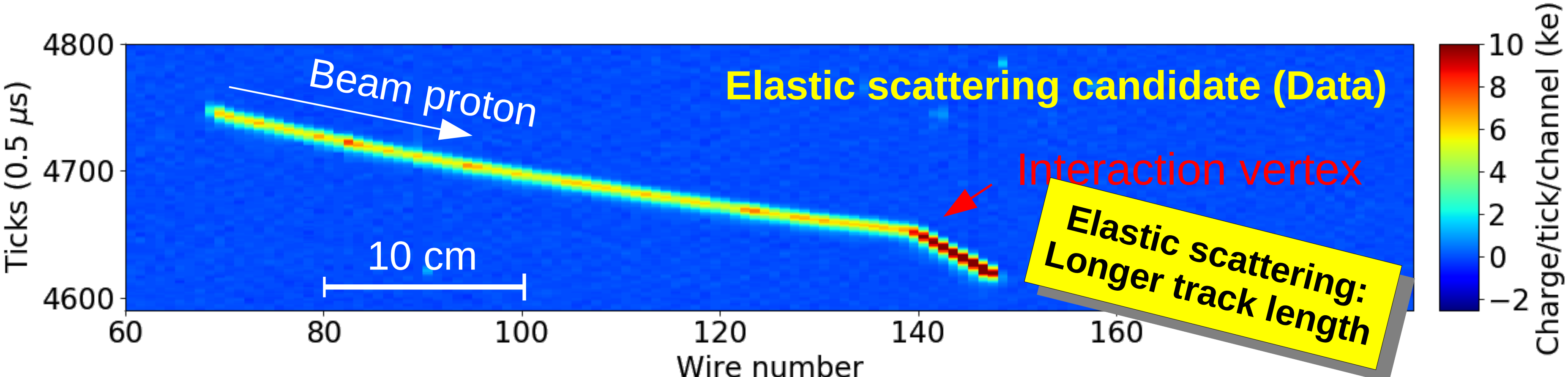
- Address & measure all detector systematics required

Pictures from https://quan-inc.jp/en/

Proton-argon Cross-section

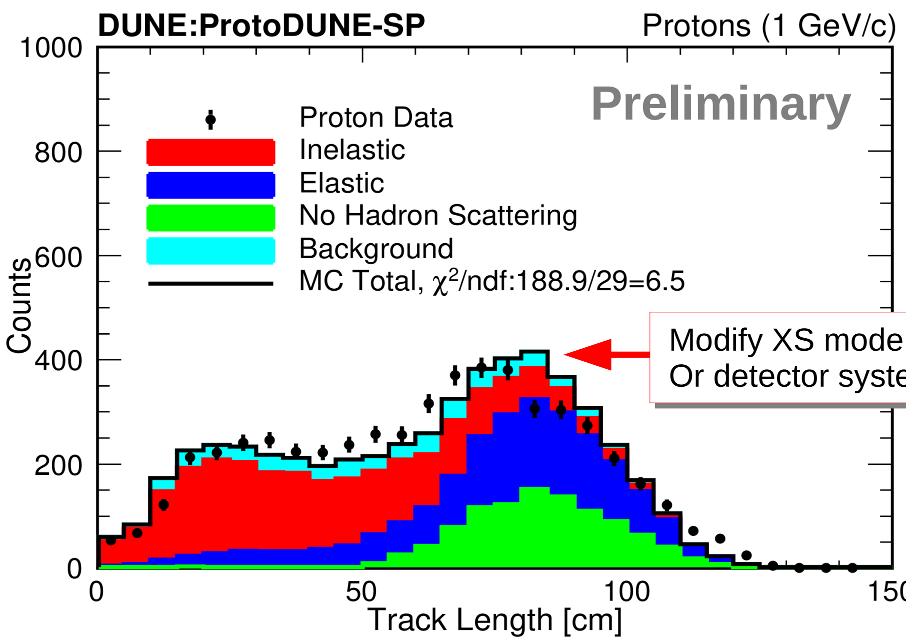
- Very limited proton-argon cross-section measurements made in the past
- **Inclusive Cross-section**
  - **Elastic**
    Nucleus is left in ground state
  - **Inelastic**
    Nucleus is left in an excited state and/or one or more nucleons are knocked out



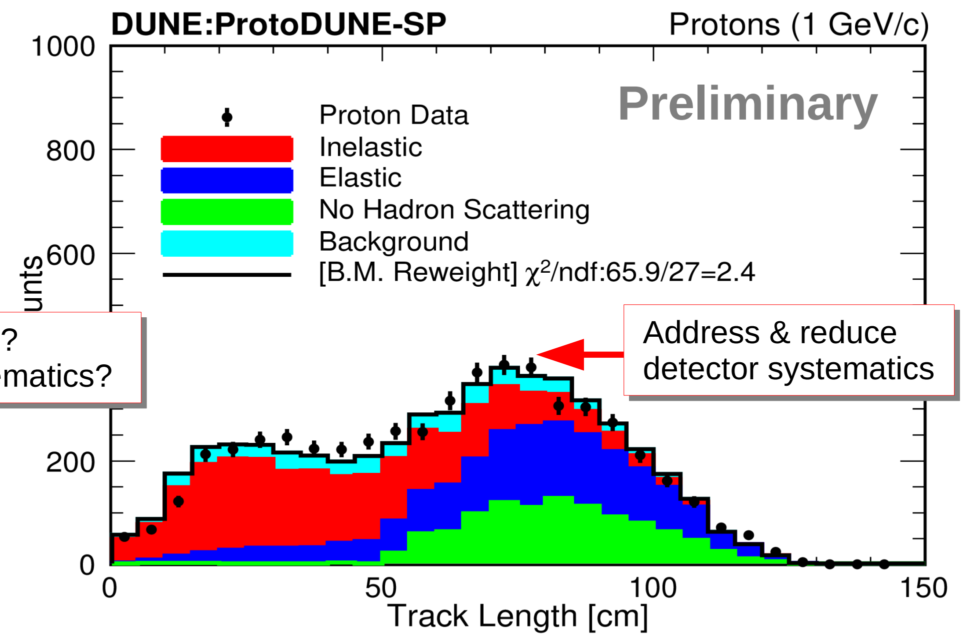


Track Length for Cross-section Measurement

Before reducing beam momentum systematics



After reducing beam momentum systematics



- Track length observable & beam momentum sensitive to XS
- Peak position difference between data & MC
  → Detector systematics due to beam momentum difference between data & MC
- Technique developed to reduce beam momentum systematics
- Data agree with Geant4 MC prediction

Summary & Outlook

- ProtoDUNE-SP measures hadron-argon cross-sections with great precision
  → Well-controlled environment + high resolution LAr TPC
- Measuring inclusive proton-argon cross-section using Geant4 cross-section reweighting
- Evaluating & reducing detector systematics on-going
- Working toward the proton-argon XS measurements, which will provide valuable information to DUNE & entire neutrino community

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Journal of Instrumentation

Our first paper on detector performance: JINST 15 (2020) P12004

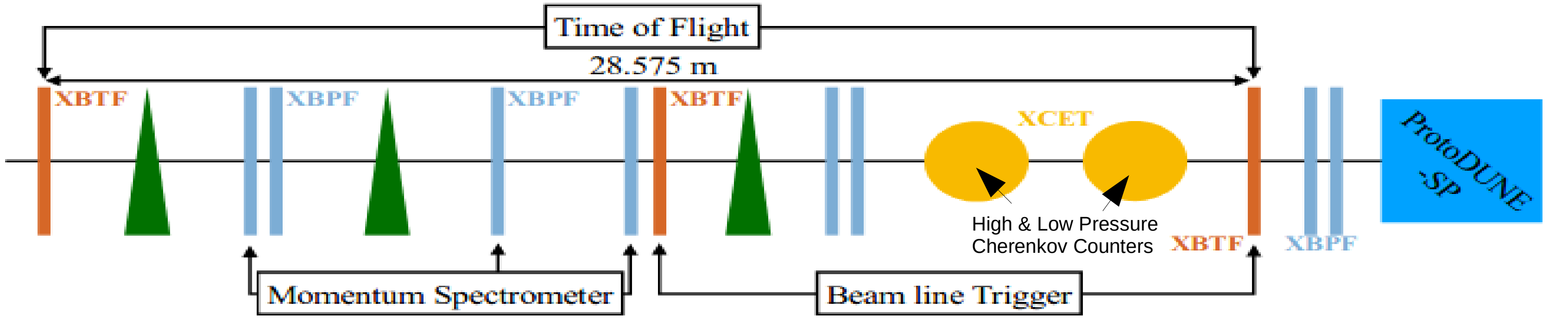
OPEN ACCESS

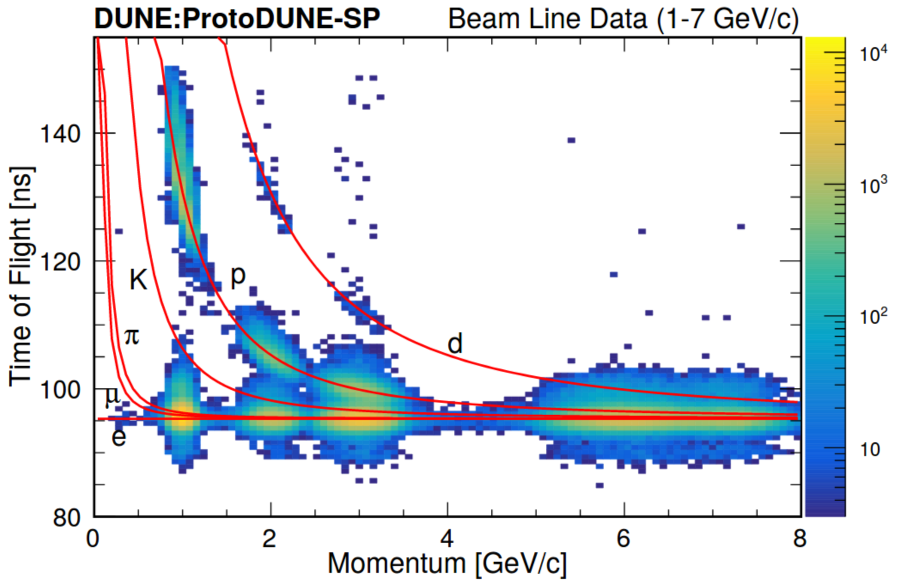
First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform

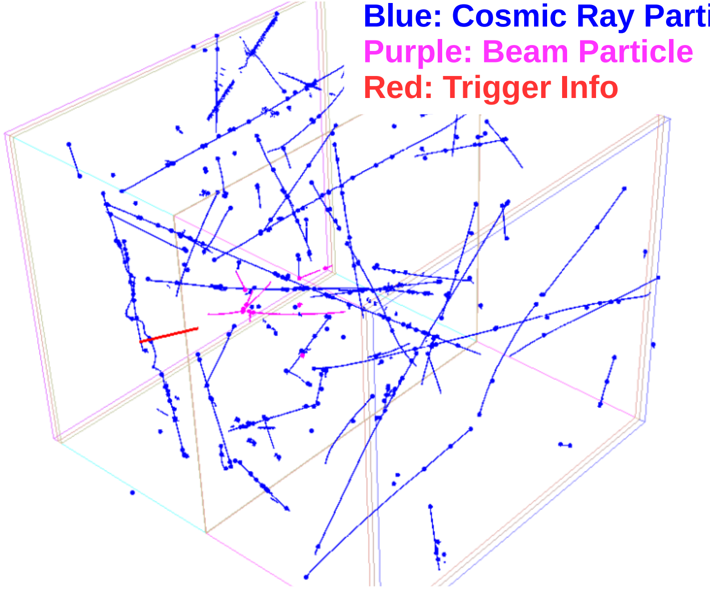
B. Abi[142], A. Abed Abud[21,118], R. Acciarri[61], M.A. Acero[8], G. Adamov[65], M. Adamowski[61], D. Adams[17], P. Adrien[21], M. Adinolfi[16], Z. Ahmad[182], J. Ahmed[185], T. Alion[171], S. Alonso Monsalve[21], C. Alt[53], J. Anderson[4], C. Andreopoulos[159,118], M.P. Andrews[61], F. Andrianala[2], S. Andringa[114], A. Ankowski[160], M. Antonova[77], S. Antusch[10], A. Aranda-Fernandez[39], A. Ariga[11], L.O. Arnold[42], M.A. Arroyave[52], J. Asaadi[175], A. Aurisano[37], V. Aushev[113], D. Autiero[90], F. Azfar[142], H. Back[143], J.J. Back[185], C. Backhouse[180], P. Baesso[16], L. Bagby[61], R. Bajou[145], S. Balasubramanian[189], P. Baldi[26], B. Bambah[75], F. Barao[114,92], G. Barenboim[77], G.J. Barker[185], W. Barkhouse[136], C. Barnes[125], G. Barr[142],

Backup

Particle Identification & Event Reconstruction





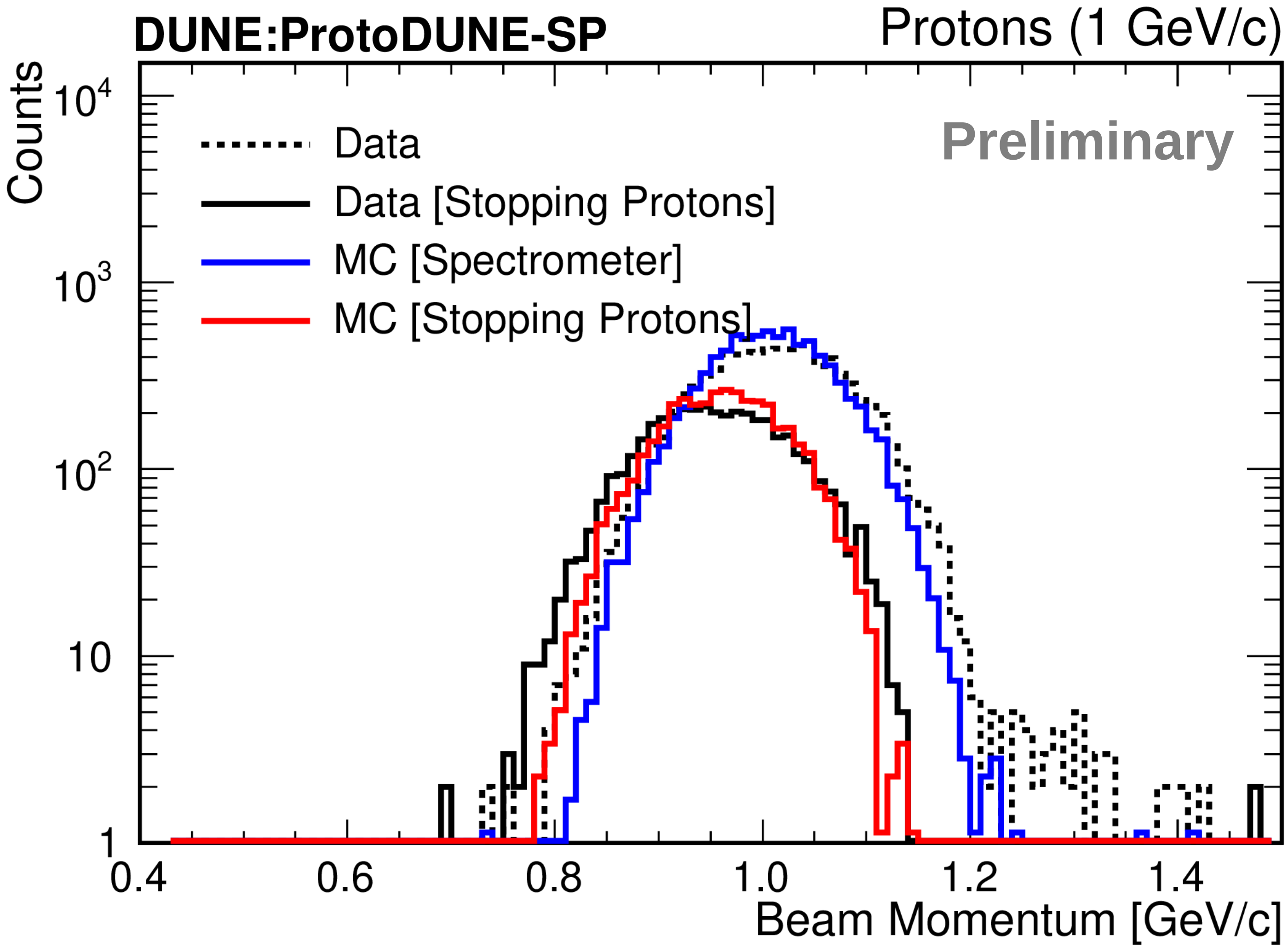


Pandora Event Display (Data)

- Particle identification:
  → Use the info from TOF & Cherenkov counters*
- Event reconstruction:
  → Use Pandora** multiple algorithms to reconstruct tracks/showers

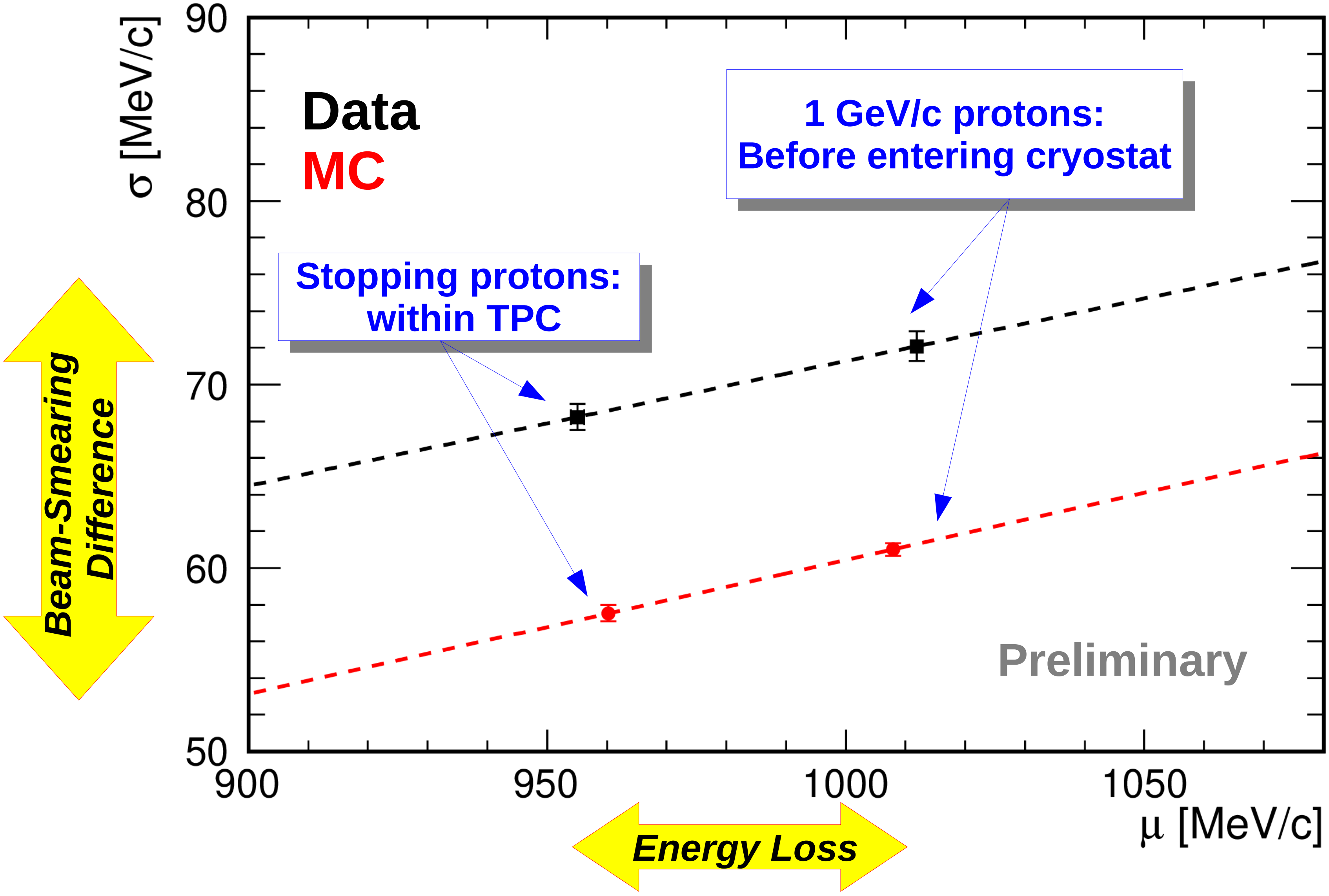
**Pandora reconstruction algorithms: https://link.springer.com/article/10.1140/epjc/s10052-017-5481-6

Data/MC Beam Momentum



- Data beam widths wider than those of MC
- Fit Gaussian on each sample and extract its mean & sigma to study systematics

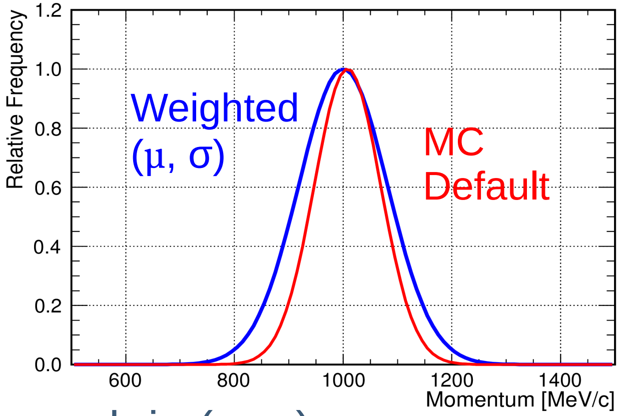
Beam Momenta – Control Samples

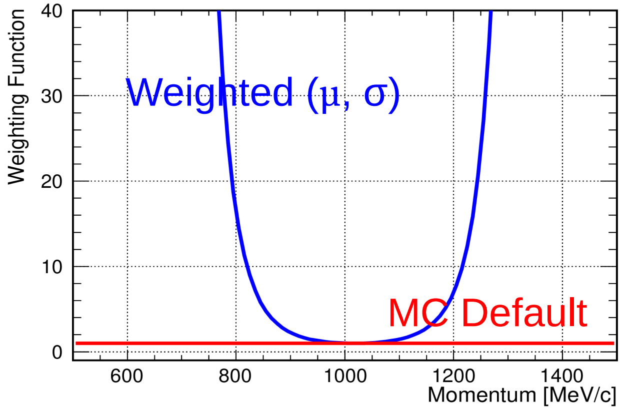


 * Mean (μ) & sigma(σ) of fitted Gaussian

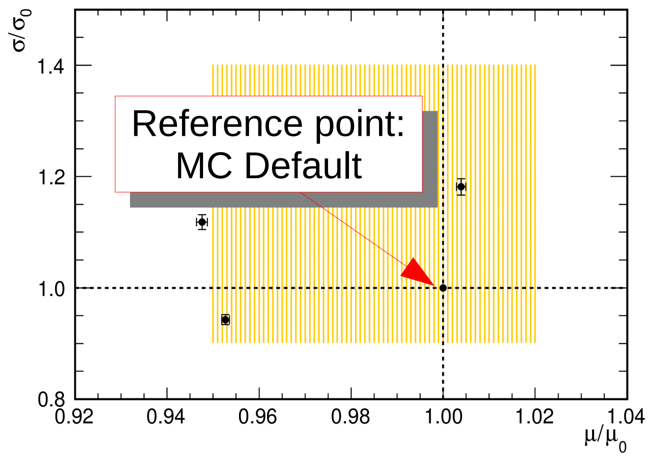
Mitigation of Beam Momentum Systematics

- ProtoDUNE-SP has developed two techniques to mitigate beam momentum systematics: (1) Jake's data-driven beam MC [link]   (2) Beam momentum reweighting
- Use beam momentum reweighting to mitigate beam momentum systematics
  - Weighting function definition: Gaussian with weighted μ & σ / Default Gaussian





- Grid search in (μ, σ) space



*Reference point for reweighting (no reweighting)

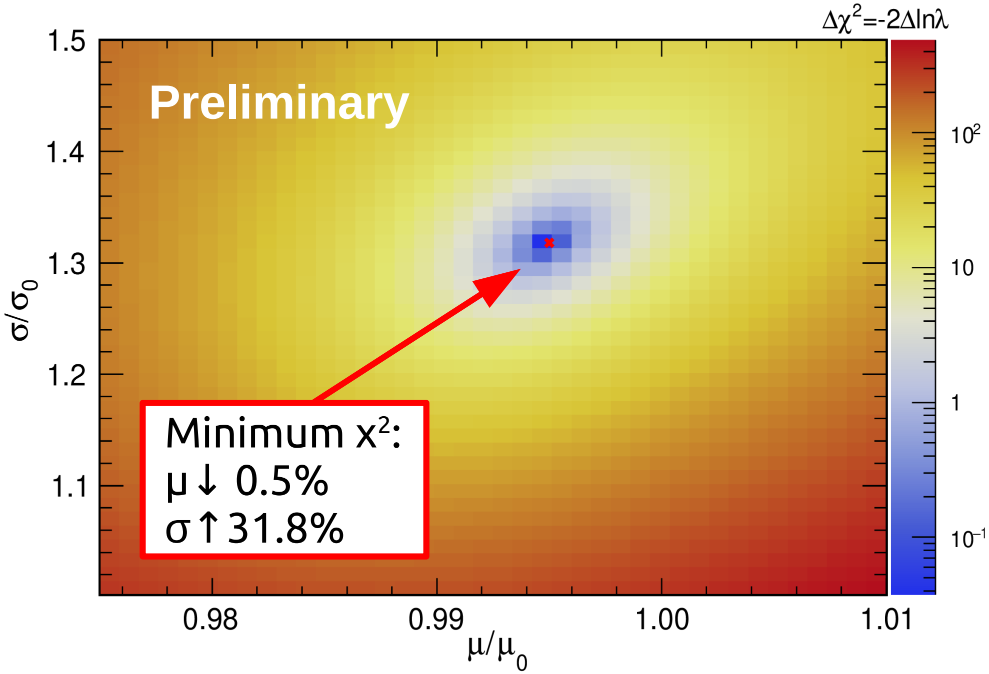
μ_0: Mean of beam momentum [MC default]

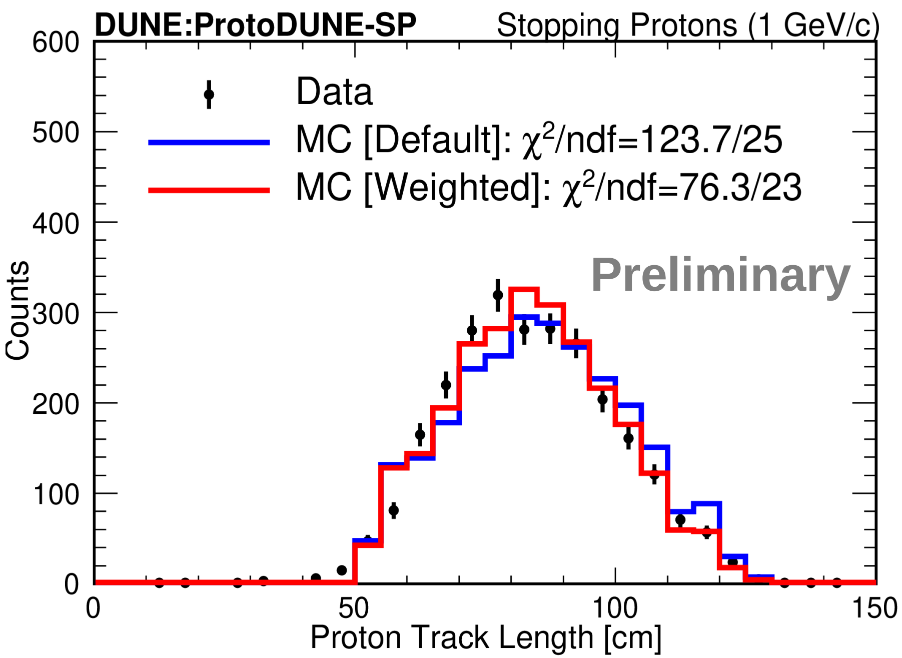
σ_0: Sigma of beam momentum [MC default]

* Grid setting
  - μ: 0.95 – 1.02, Δμ=0.001
  - σ: 0.90 – 1.40, Δσ=0.002

  (each orange dot represents for single grid point for beam momentum reweighting)

Beam Momentum Reweighting

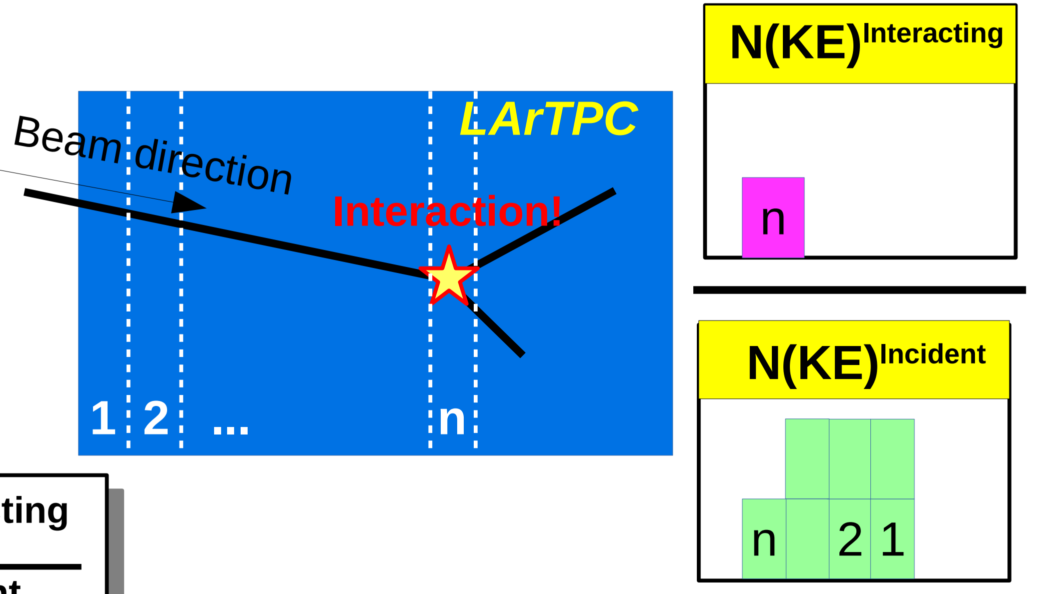




- Use control sample for beam momentum reweighting
  → Control sample = stopping protons
- Prod. 4 MC needs to reduce μ by 0.5% & increase σ by 31.8%

Thin Slice Method

- Developed by LArIAT experiment*
- Treat wire-to-wire spacing as a series of “thin-slab” targets
- Each thin-slab is an independent measurement



- XS formula:

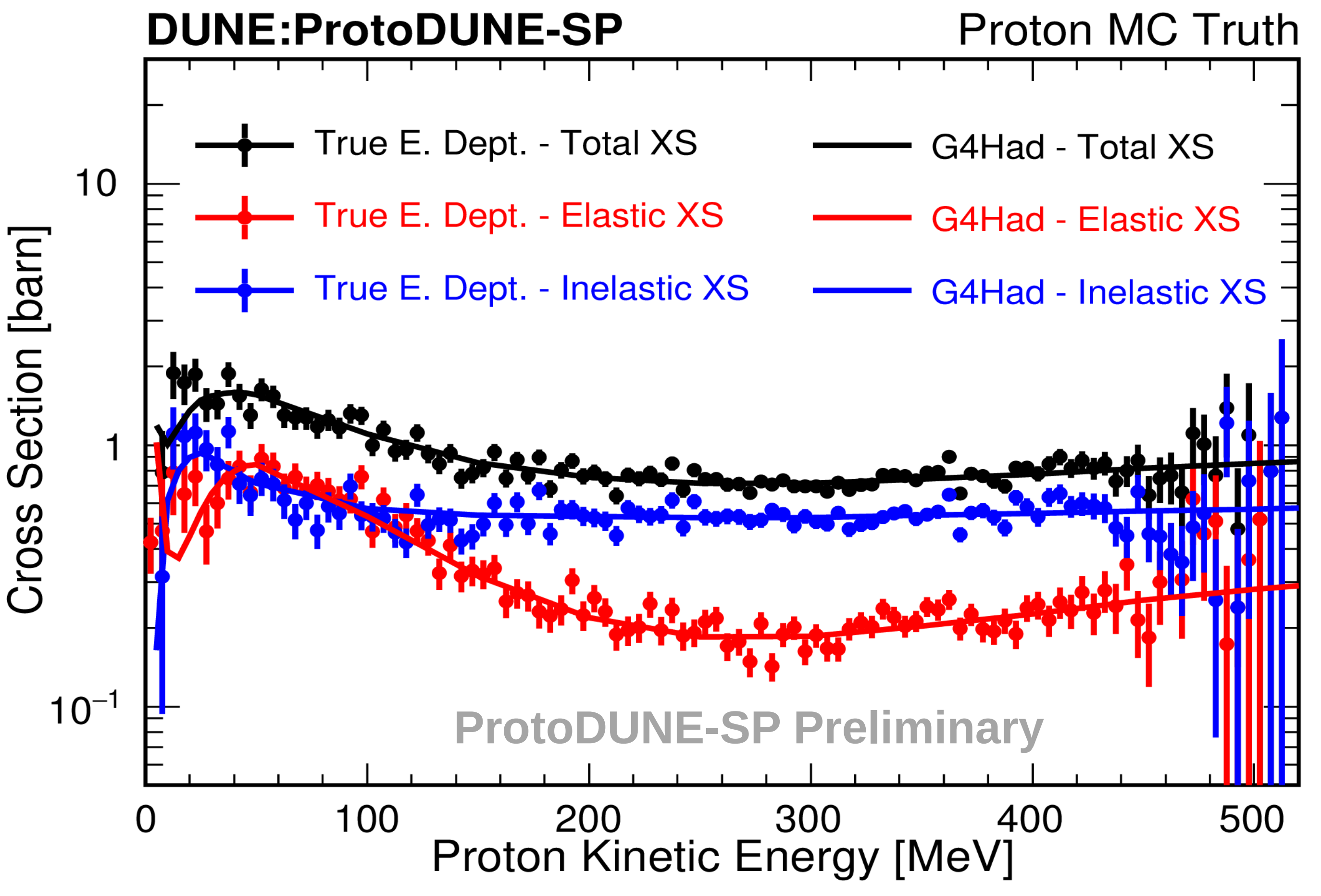
$$XS(KE) = S_f \cdot \frac{N(KE)^{interacting}}{N(KE)^{incident}}$$

S_f ~100 barn for ProtoDUNE-SP

*Reference: arXiv:1611.00821

Thin Slice Method: Proof-of-Principle

- Verification of the thin slice method using stand-along Geant4 application (G4HadStudies*)



* Hans Wenzel's package: https://github.com/hanswenzel/G4HadStudies