Proton Inelastic Cross-section Analysis: Energy Reconstruction

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Hadron Analysis Meeting

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Kansas State University

Fermilab

DUNE

Outline

- Proton kinetic energy calculation

Energy Reconstruction

- KE at TPC front-face is critical when using Beth-Bloch-based energy reconstruction (link)
  - → We are able to measure KE_{ff} precisely for elastic-scattering protons*, but NOT for inelastic-scattering protons.
- Decide to use calorimetric-based energy calculation with constant E-loss assumption:

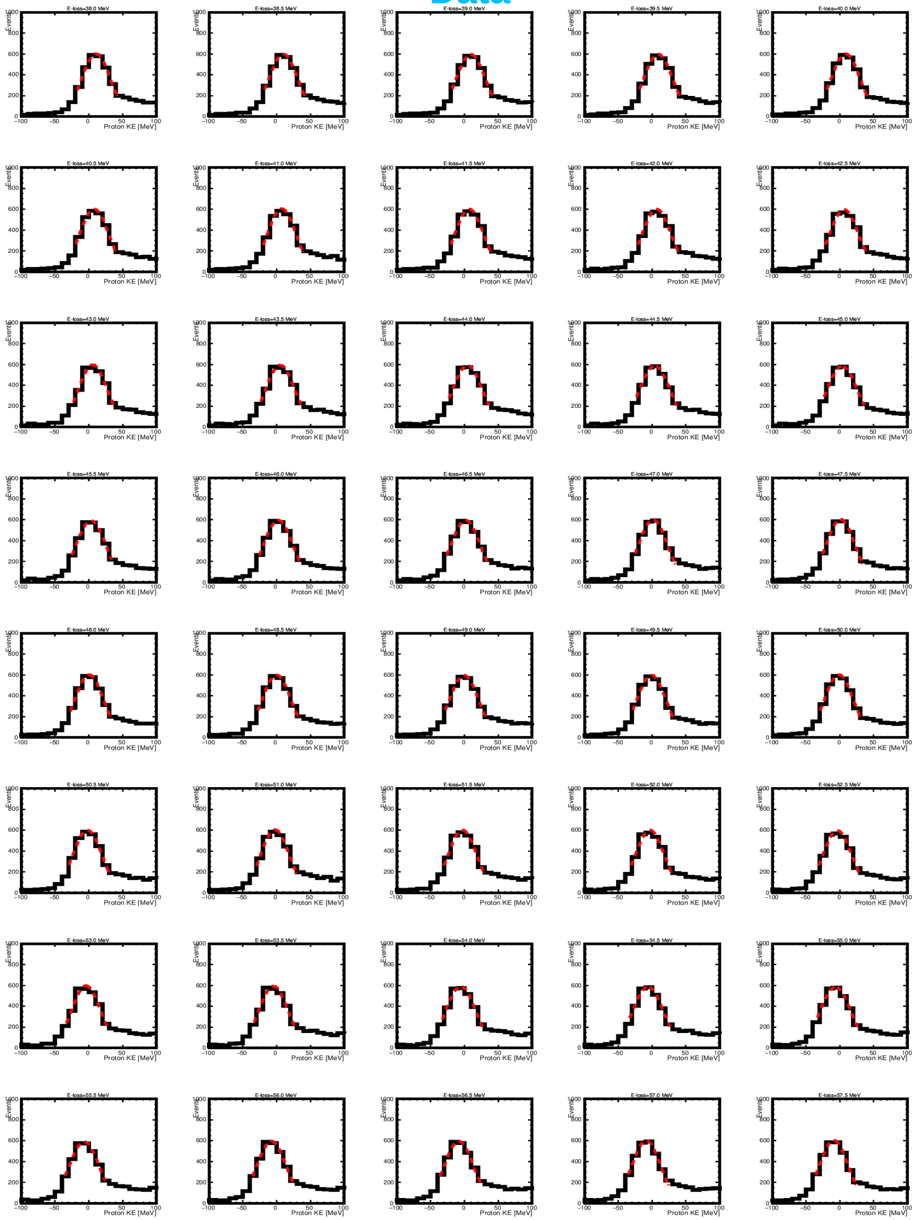
$$KE_{reco} = KE_{beam} - \underbrace{\langle \Delta E \rangle}_{\text{Upstream E-loss}} - \underbrace{\sum_j \frac{dE_j}{dx_j} dx_j}_{\text{Calorimetric reco (Not using the Bethe-Bloch formula)}}$$

- Upstream E-loss determination:
  - → Tune <ΔE> s.t. low energy elastic-scattering peak at 0 MeV

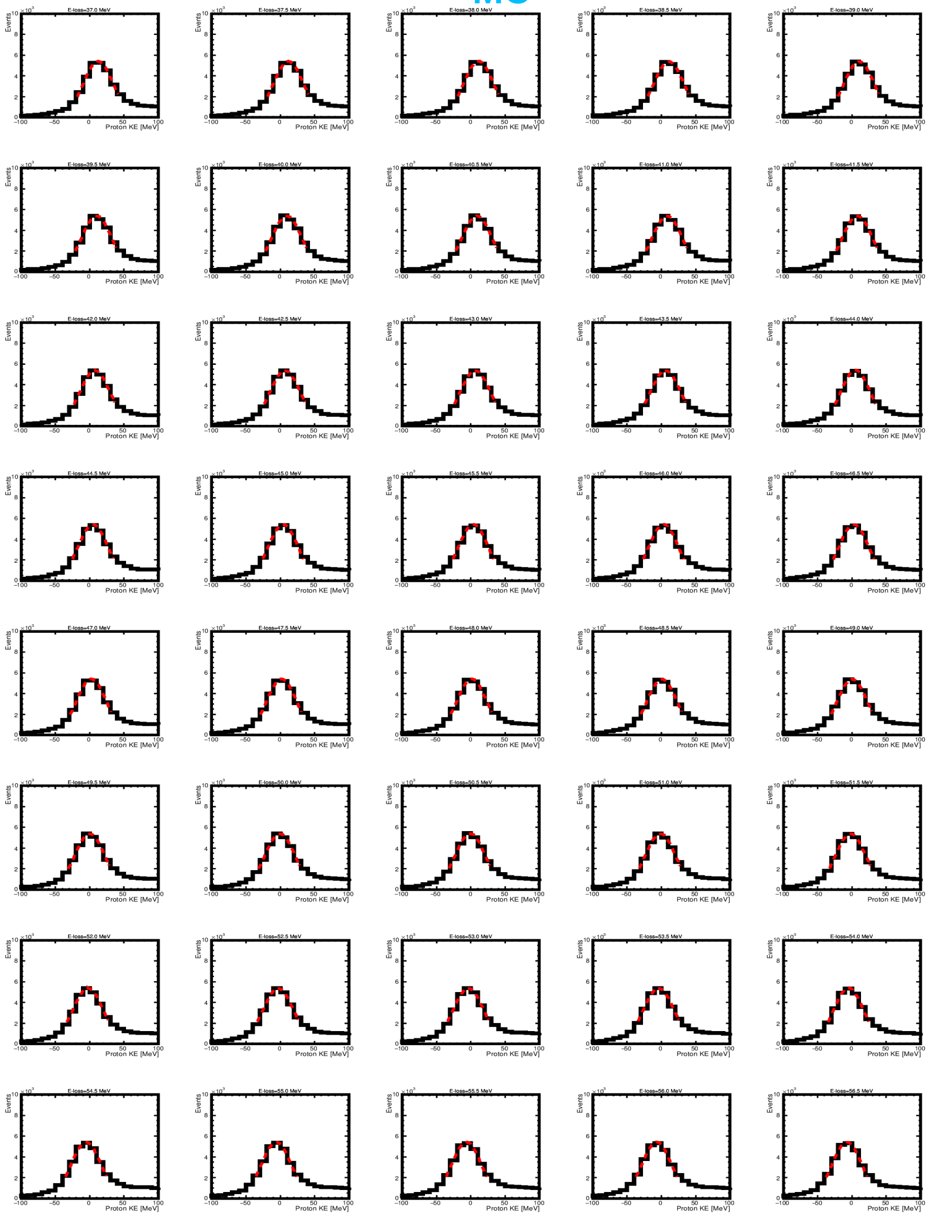
*See details in the backup slides (page 10-11)

Low Energy Peak

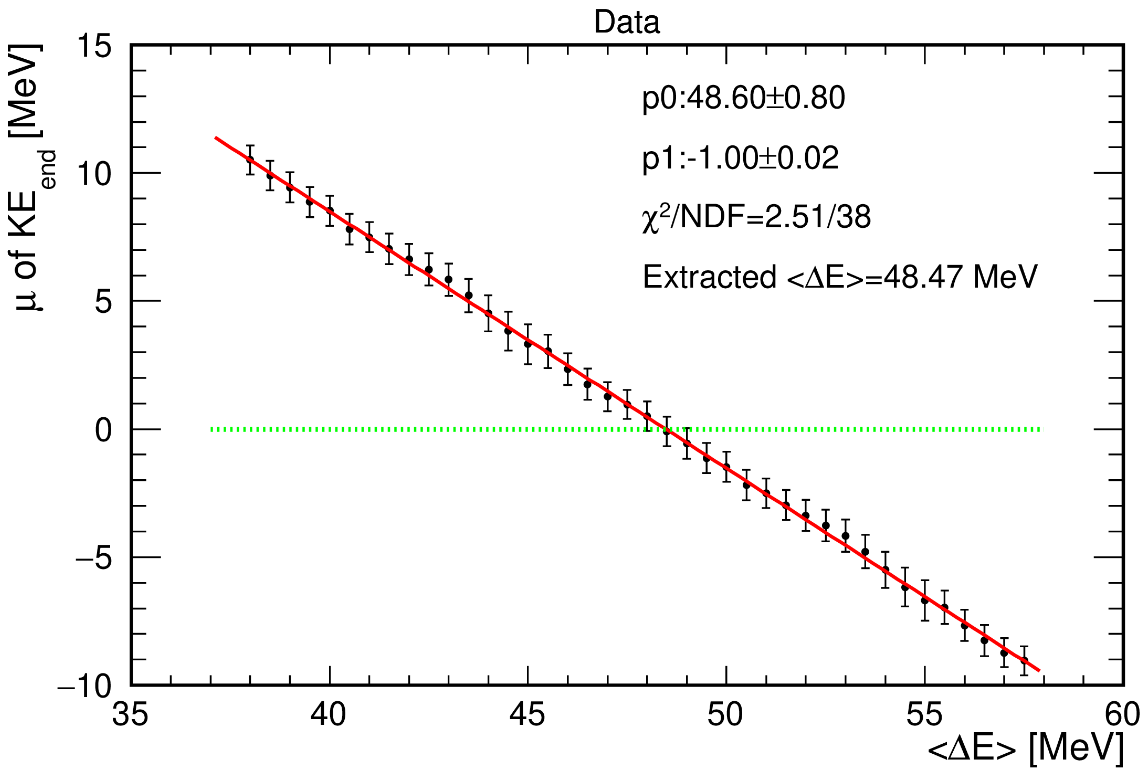
Data

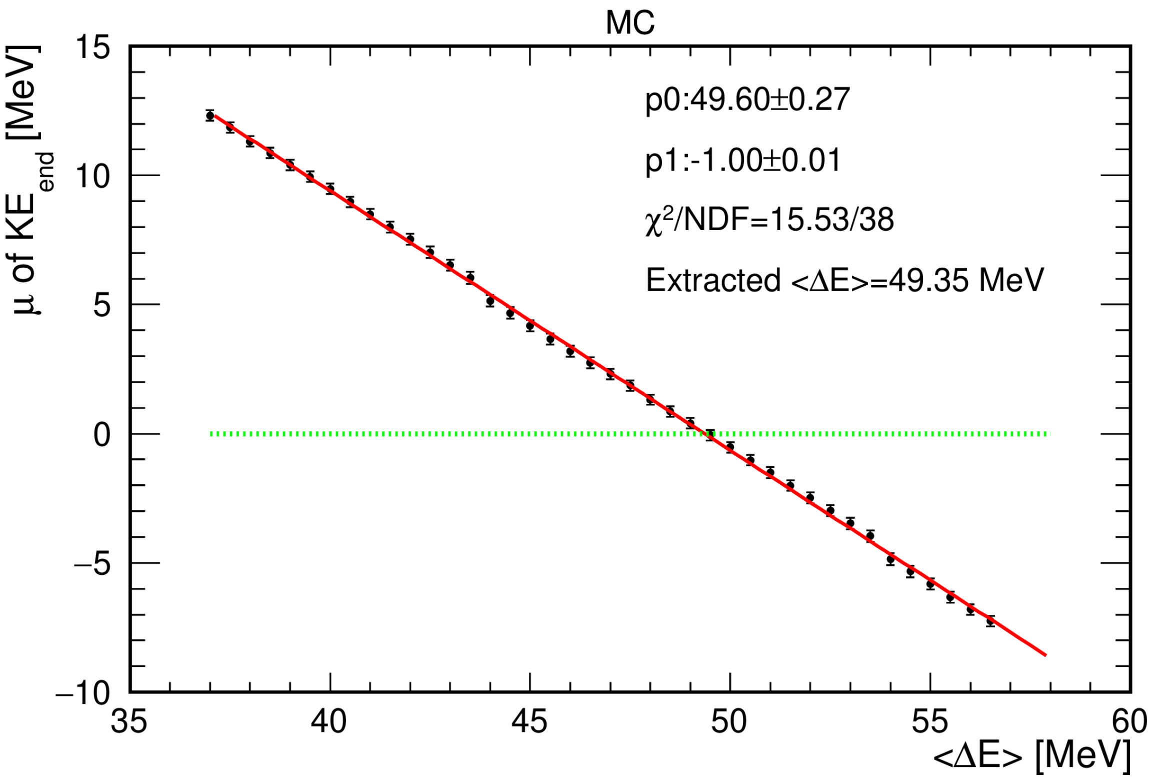


MC



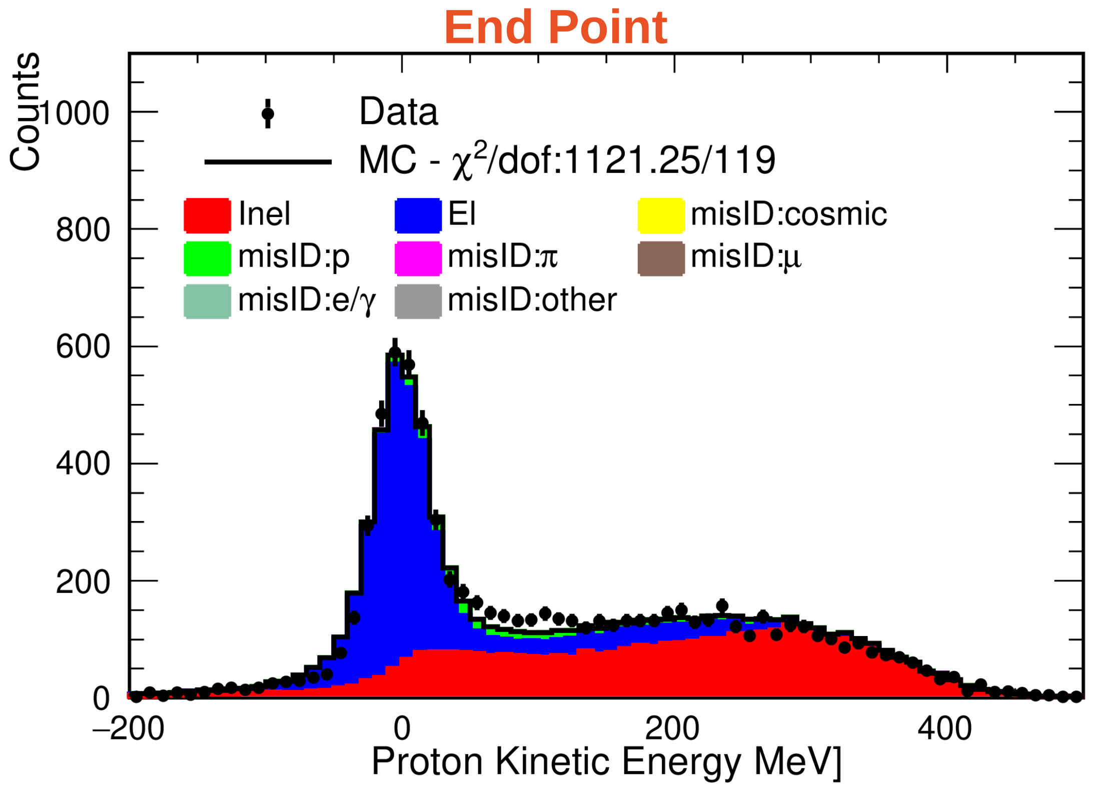
KE_{end} v.s. E-loss

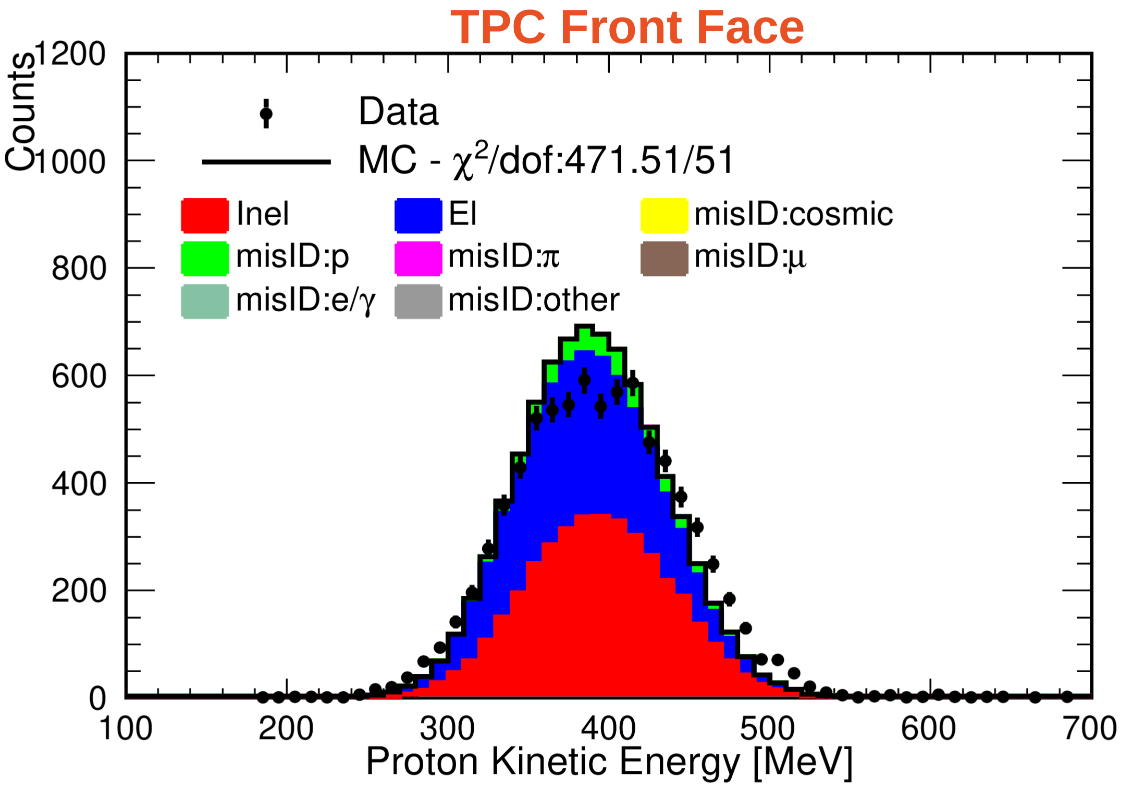




μ: Mean of Gaussian extracted from the fit

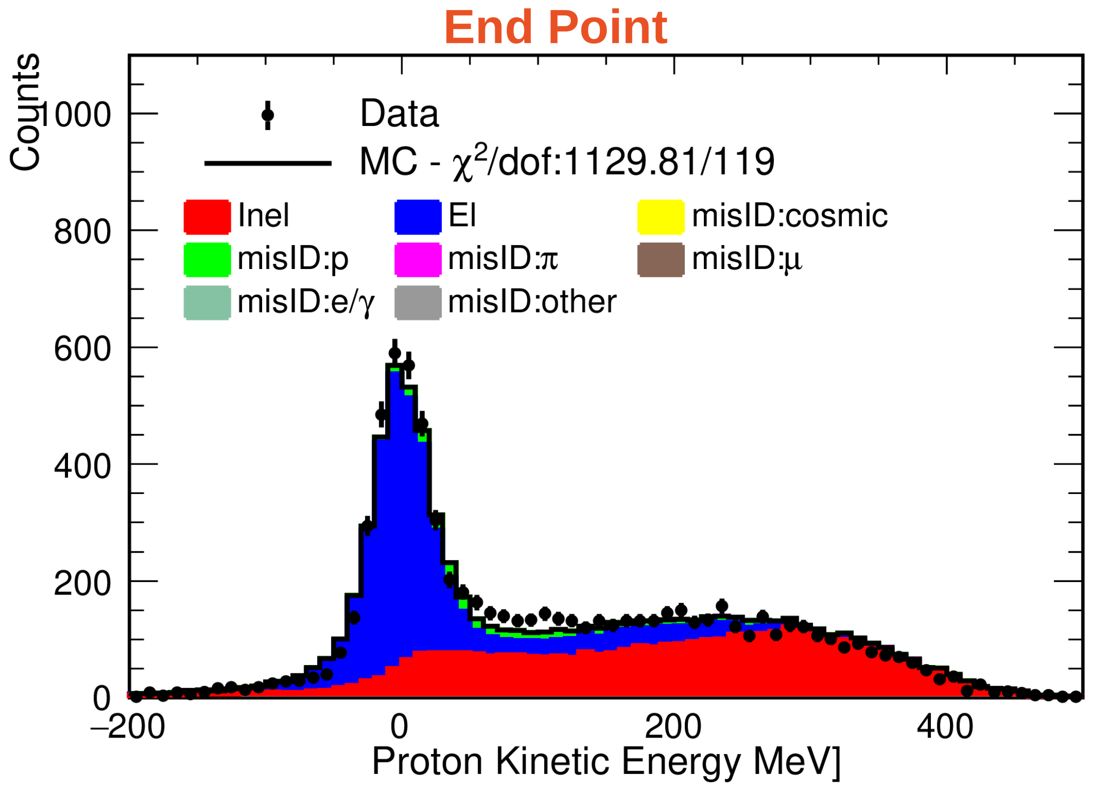
Data/MC Comparison

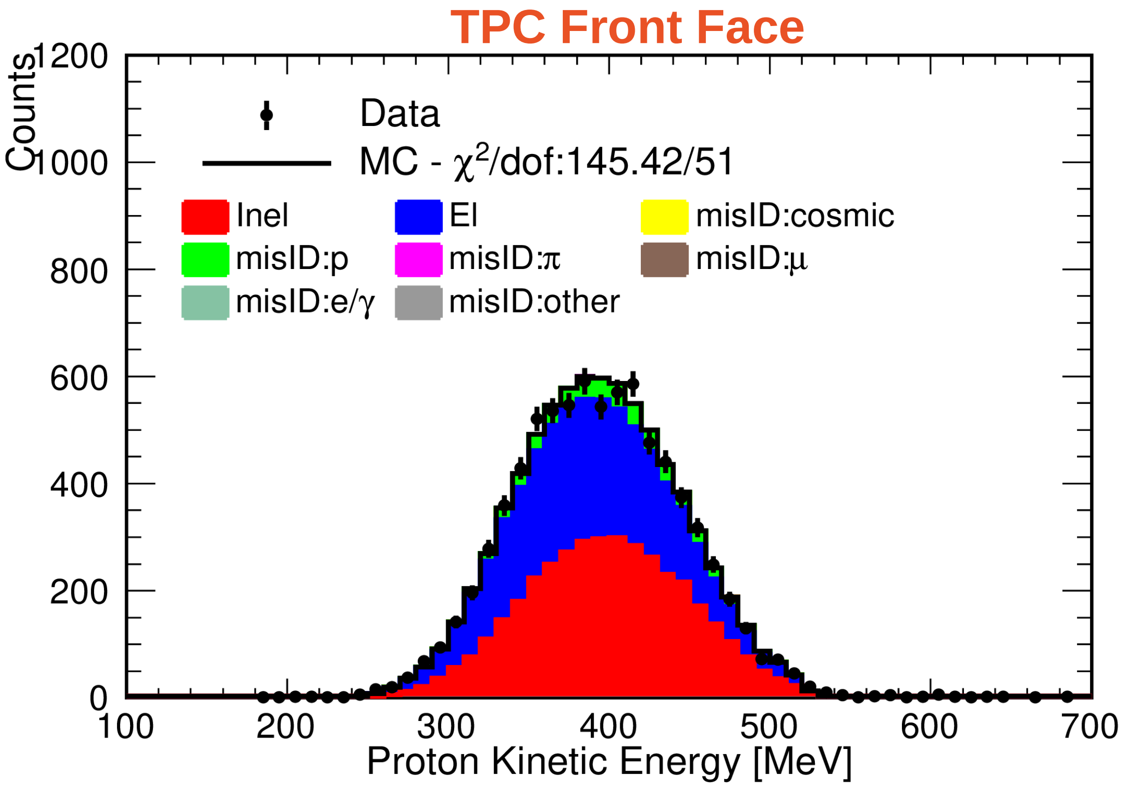




- Good to see low energy peak at zero MeV (as expected)
- Data/MC discrepancies observed

Data/MC Comparison after KE Reweighting





- KE reweight using KE_{ff} → Improve data/MC agreement on KE_{ff}
- Data/MC discrepancy at low KE still exist after reweighting
  → Implication that the issue may not be related to beam momentum/energy

Summary

- Fix the energy estimation using calorimetric-based energy reconstruction
- with constant E-loss assumption

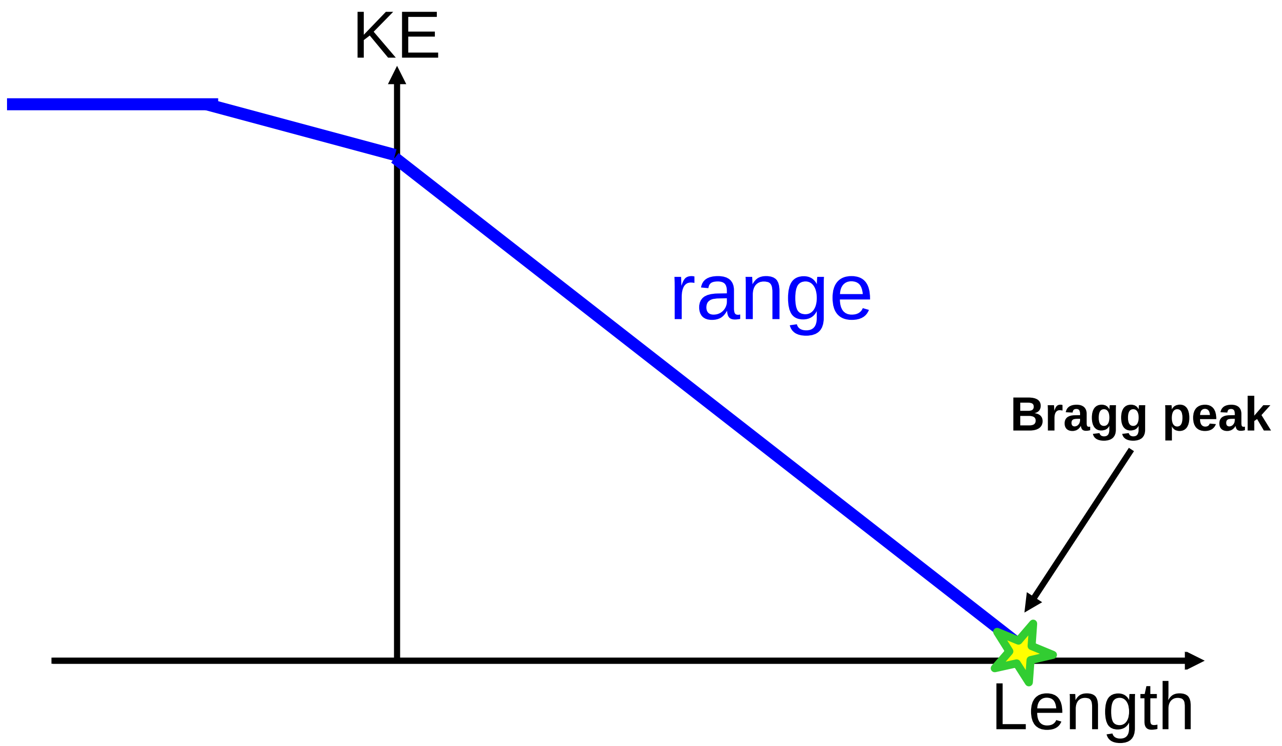
Next

- Data-driven background measurement using E-slice method
- Unblinding

Backup:

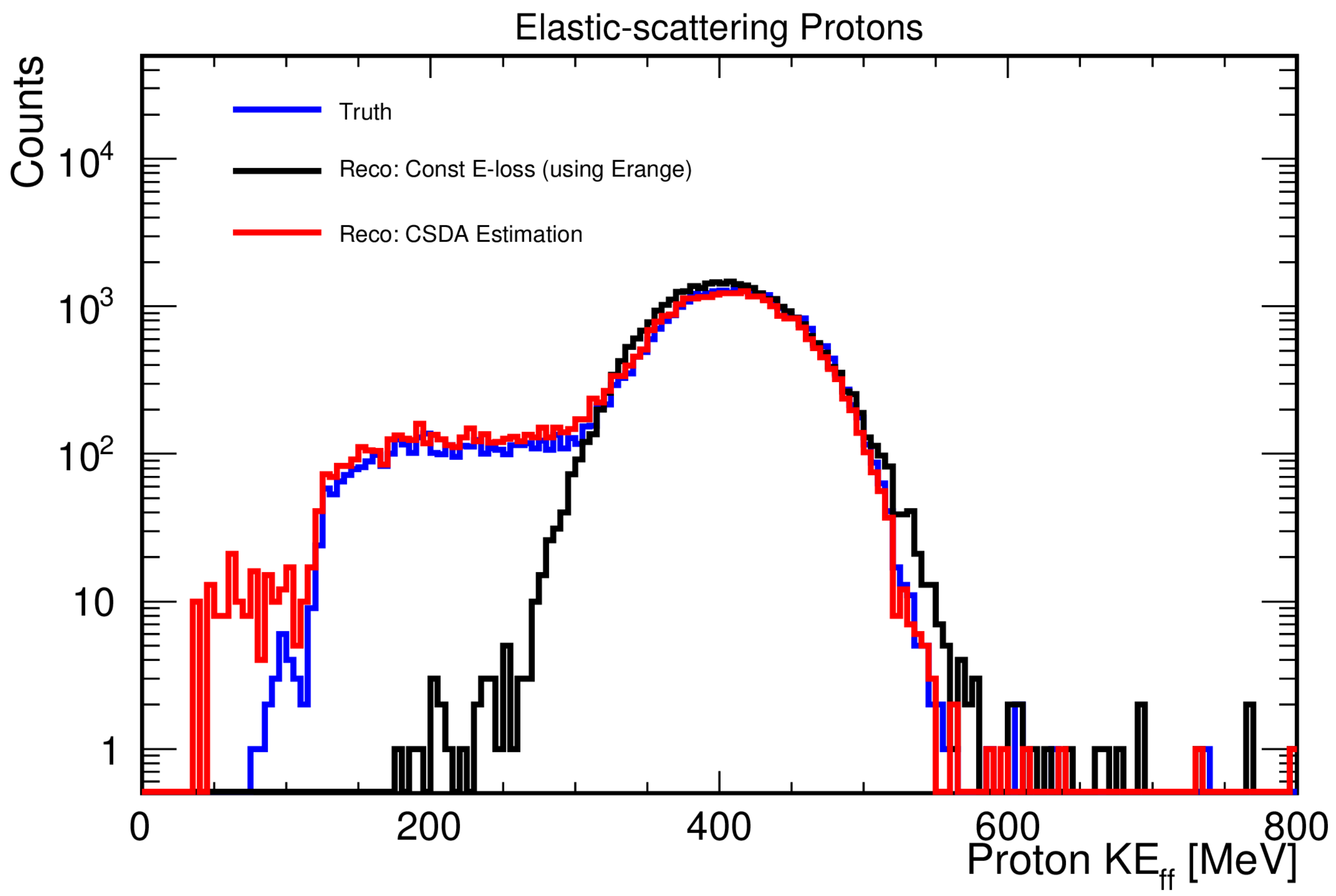
Other studies to improve energy estimation using Bethe-Bloch formula

Algorithm to Improve KE_{ff} of Elastic-scattering Protons



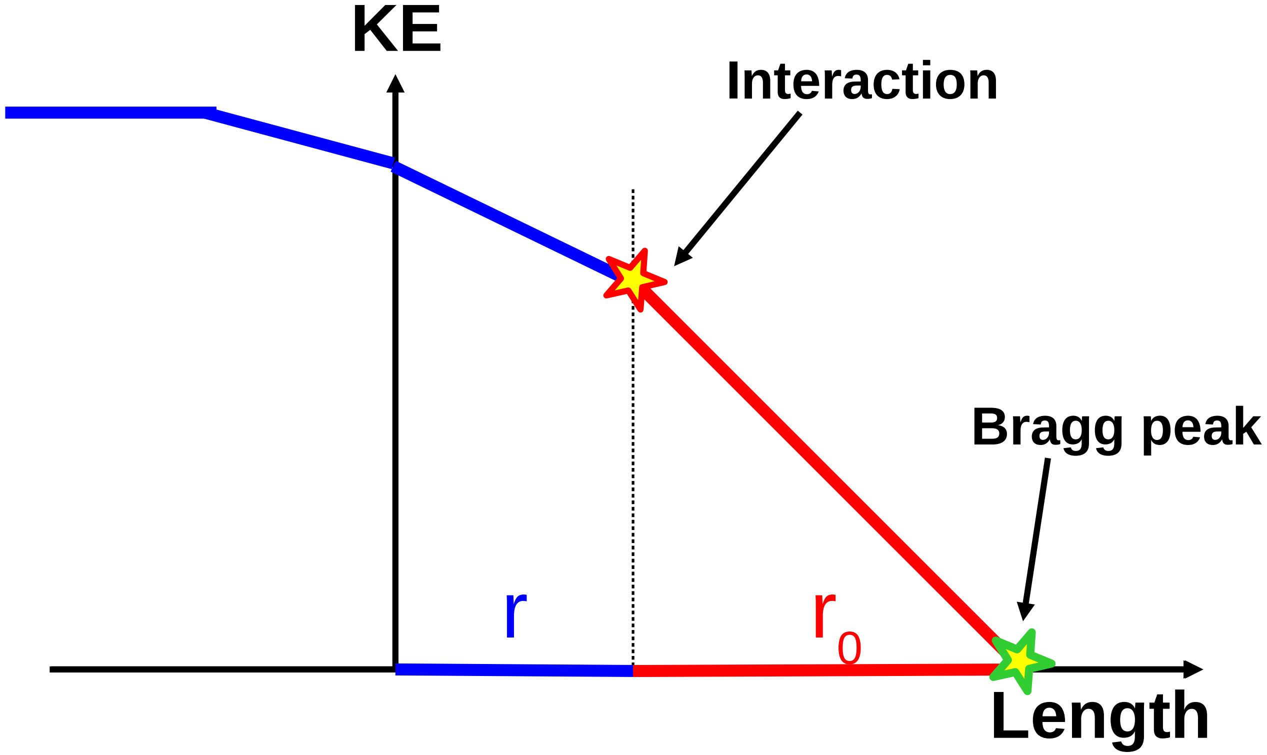
- For elastic-scattering protons, KE_{ff} estimation is critical, const. E-loss assumption can be improved
  → Use KE_{ff}=Length2E(range)

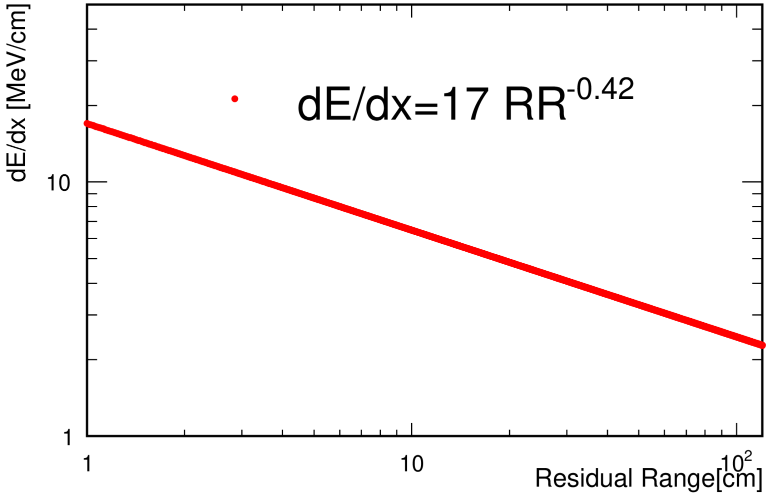
Algorithm to Improve KE_{ff} of Elastic-scattering Protons



- Range-based KE_{ff} estimation works well

Algorithm to Improve KE_{ff} of Inelastic-scattering Protons





$$\frac{dE}{dx} = 17 \cdot (r + r_0)^{-0.42}$$

$$r_0 = \left(\frac{17}{dE/dx}\right)^{\frac{1}{0.42}} - r$$

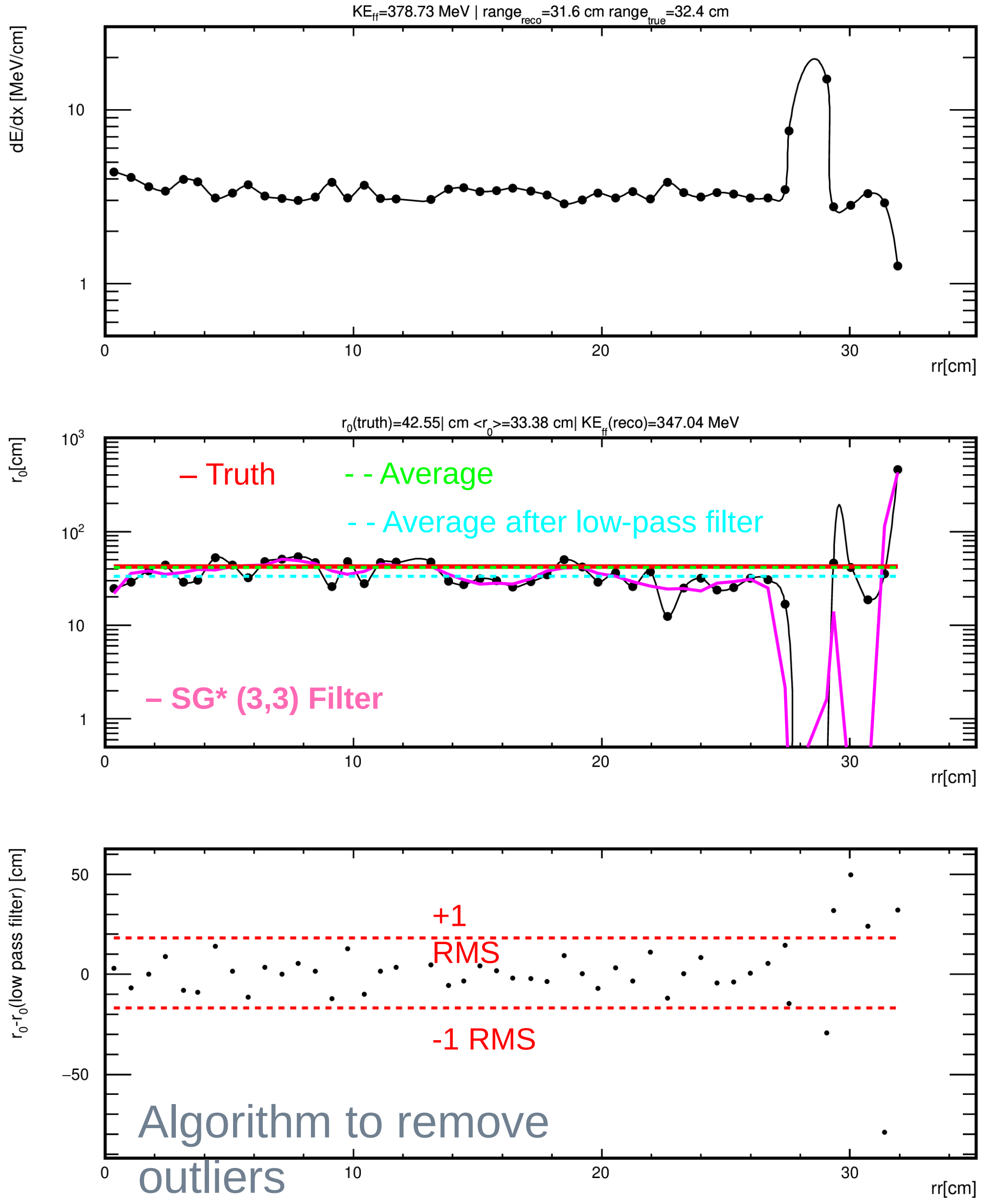
- Assume every proton will **STOP**
- Use **dE/dx & residual range** to predict $\mathbf{r_0}$

  r_0: Distance between interaction vertex and the point for Bragg peak

  r: Residual range of interacting protons

*Valid range using empirical formula: 0.1 – 30 cm

R_0 Calculations



Algorithm to remove outliers

- KE_{ff} (truth)=378.7 MeV, r_0 (truth)=42.6 cm
- KE_{ff}(reco)=Length2E(r_0+range(reco))
- r_0 calculations:

  [1] $<r_0>$=33.4 cm (low pass filter to remove outliers)

  → KE_{ff}(reco)=347.0 MeV

  [2] $<r_0>$=39.5 cm (all hits)

  → KE_{ff}(reco)=372.3 MeV

  [3] r_0=25.1 cm (last hit, track end)

  → KE_{ff}(reco)=318.7 MeV

*https://en.wikipedia.org/wiki/Savitzky%E2%80%93Golay_filter
SG(window size, poly. order)

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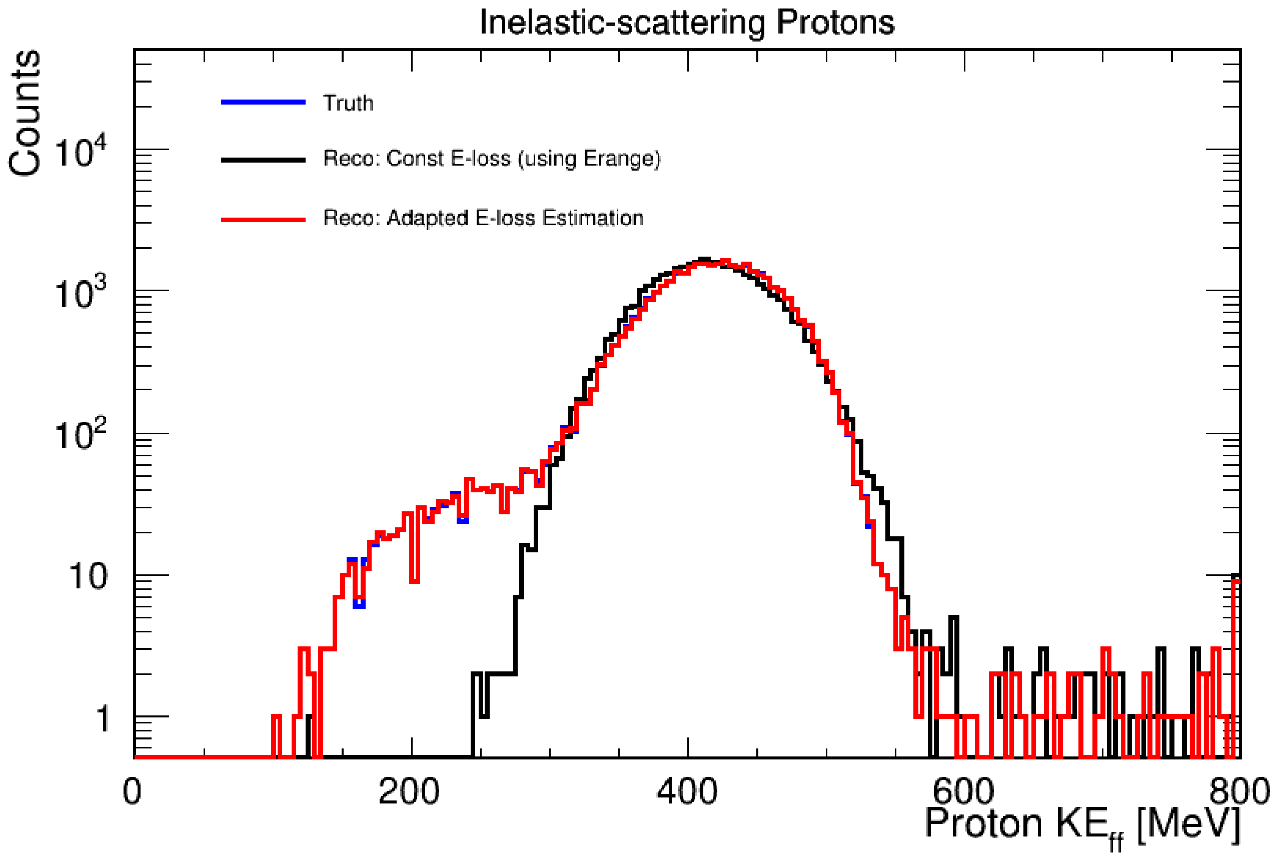
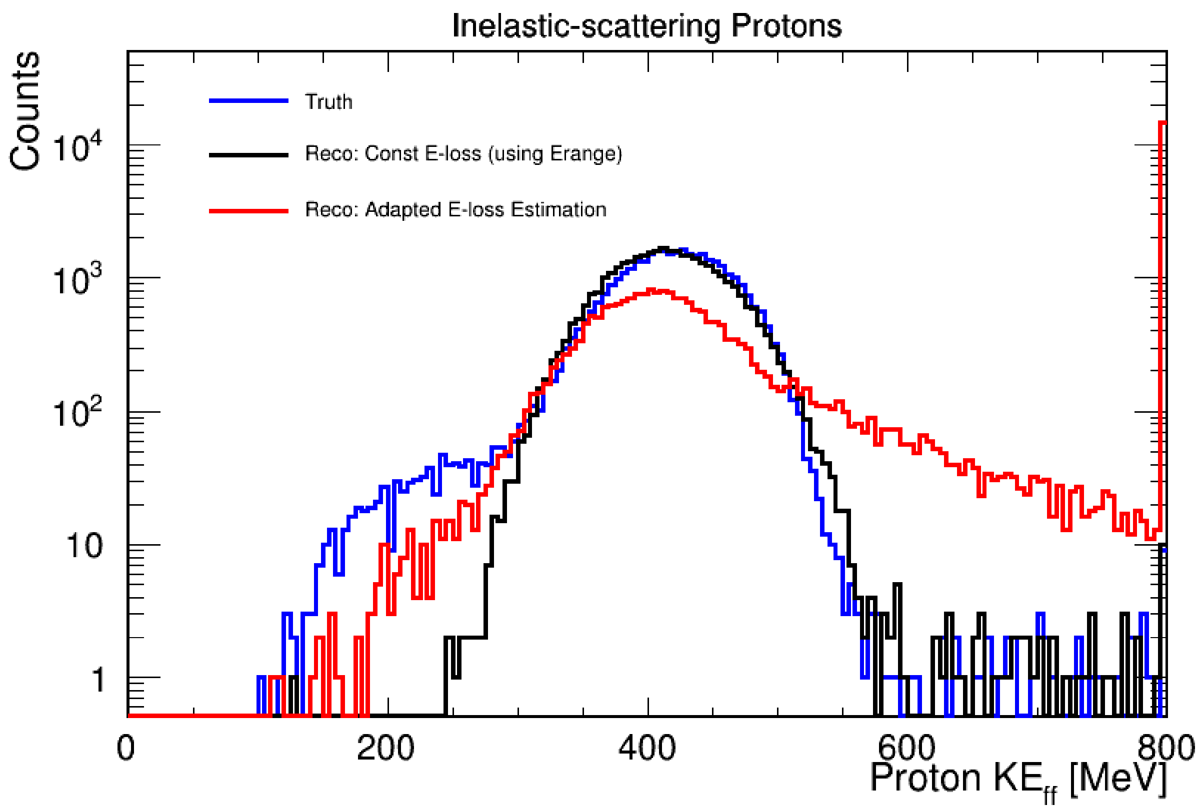
KE_{ff} of Inelastic-scattering Protons: Precise KE_{ff}

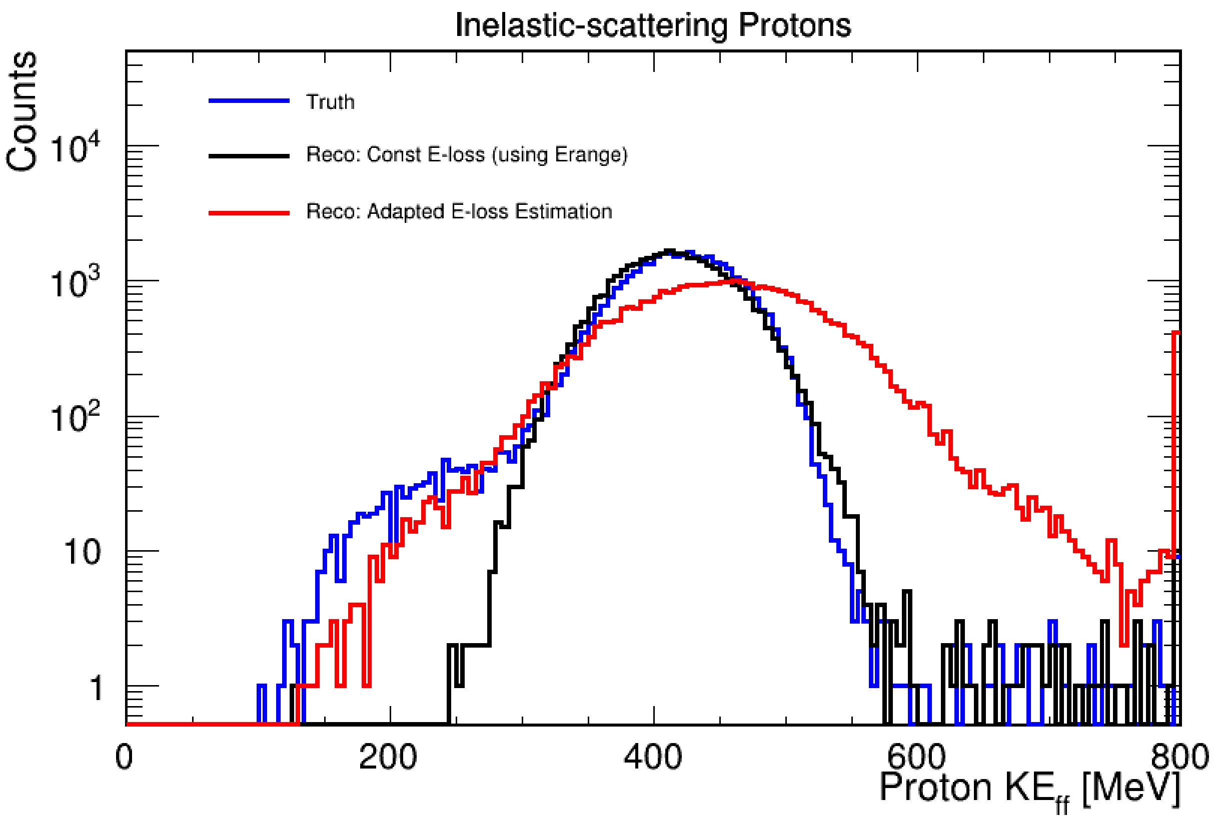


- Sanity check to see if the idea works
→ KE_{ff}(reco)=Length2E(CSDA(KE_{ff}(truth)))

Algorithm to Improve KE_{ff} of Inelastic-scattering Protons



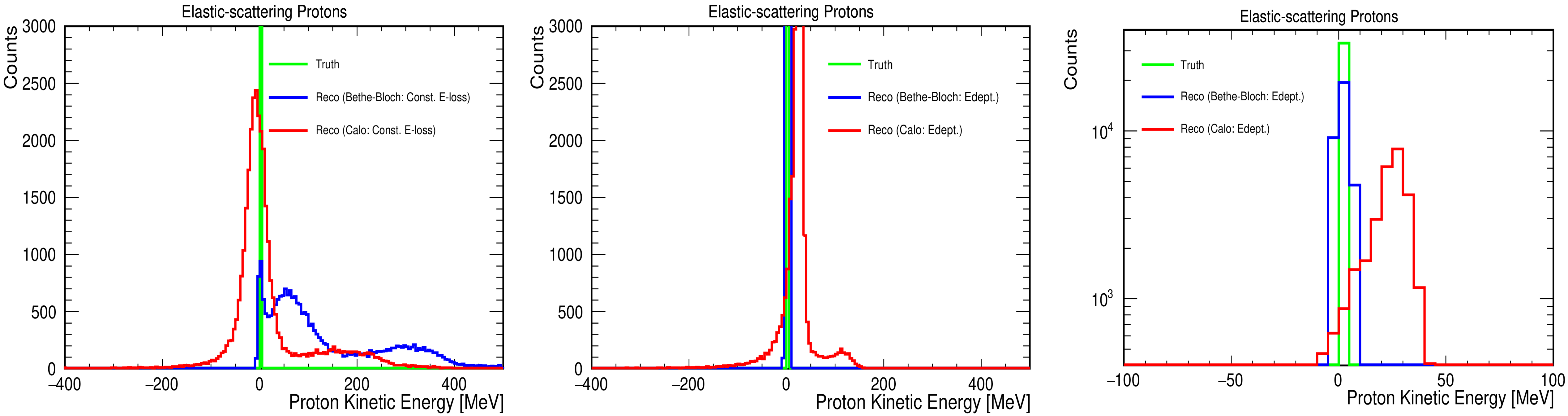
r_0 calculation using all hits



r_0 calculation removing outliers

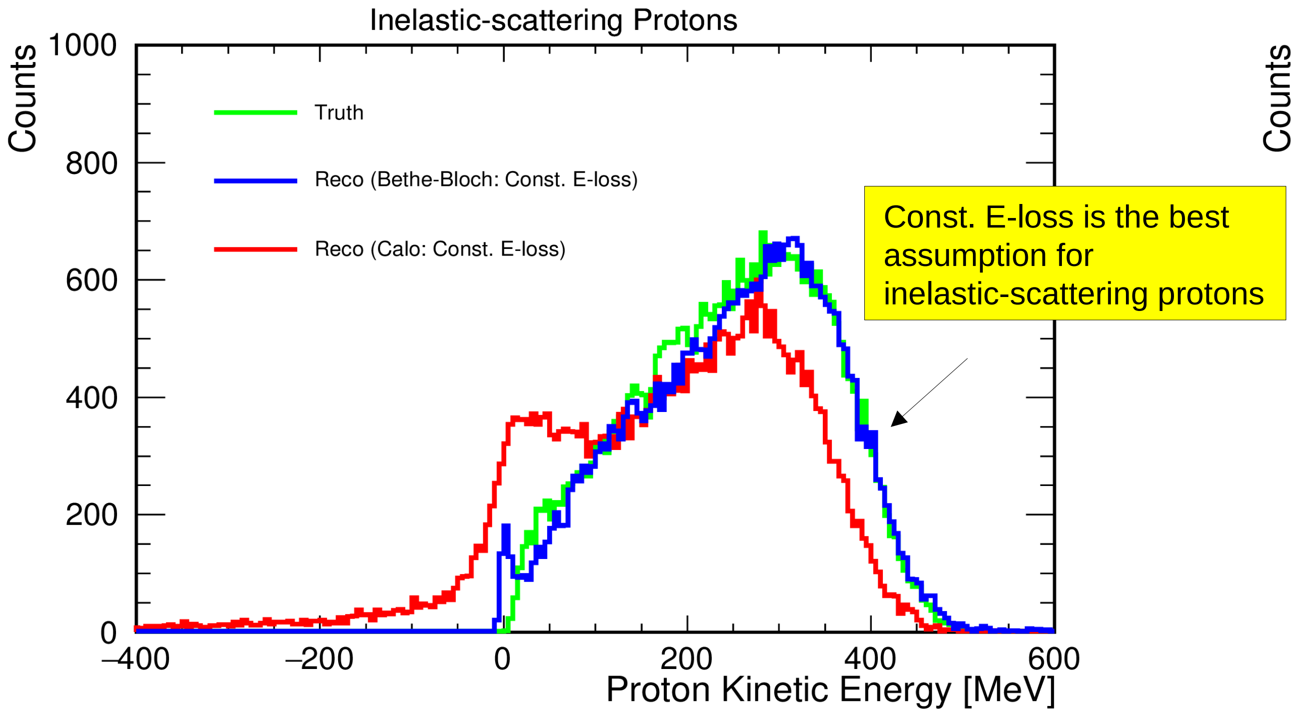
- Const. E-loss assumption is still the best assumption

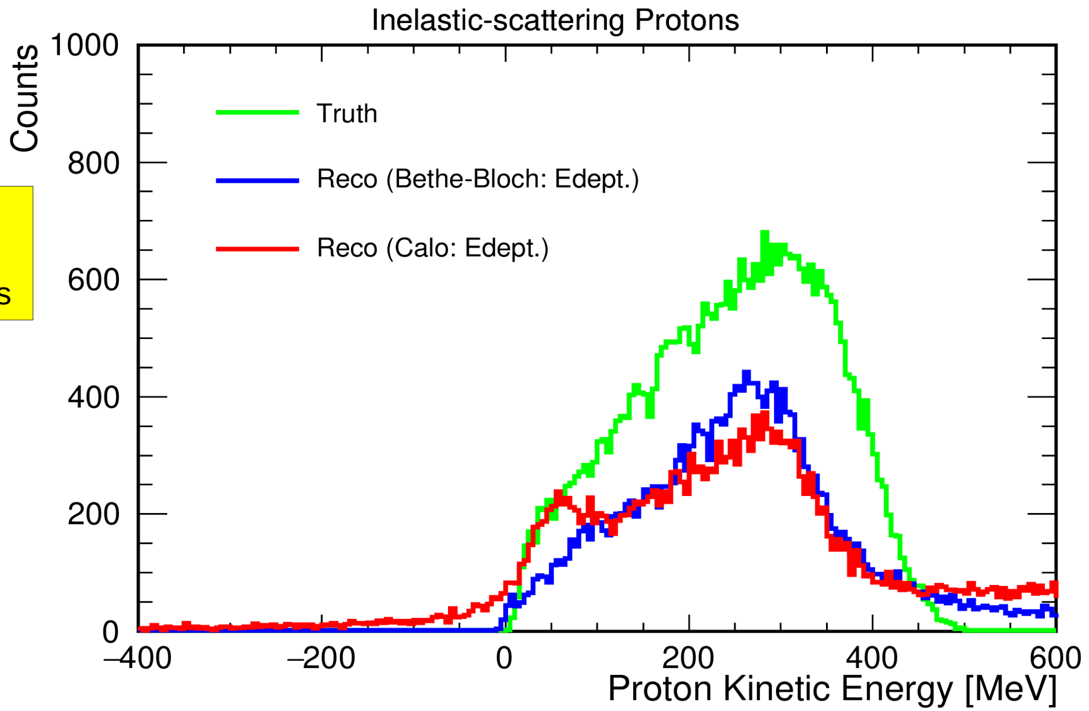
KE_{end}: Elastic-Scattering Protons



- Great energy reconstruction for elastic scattering protons using ranged-based energy calculation (Bethe-Bolch)
- Best KE_{ff} calculation: KE_{ff}=Length2(E)

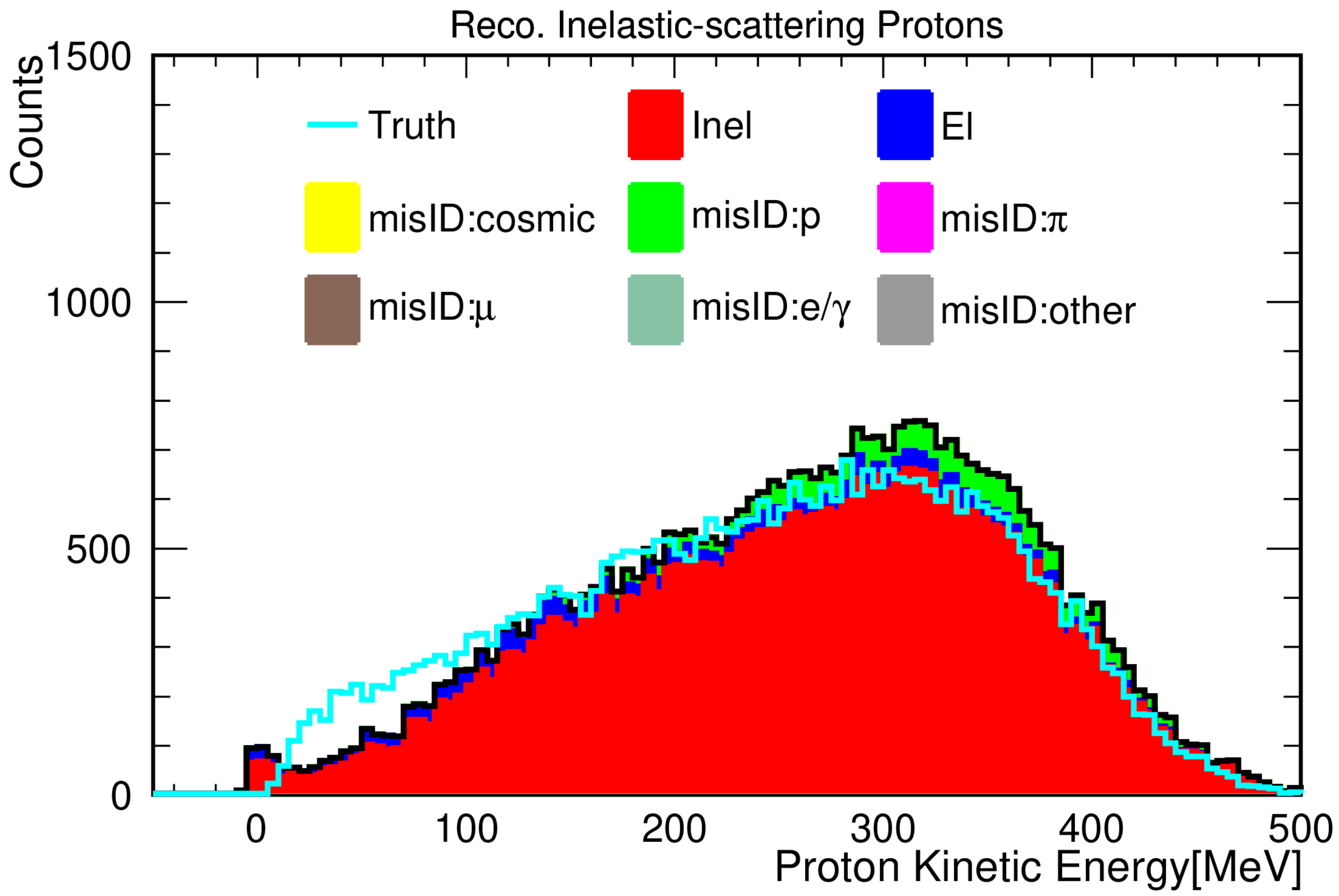
KE_{end}: Inelastic-Scattering Protons





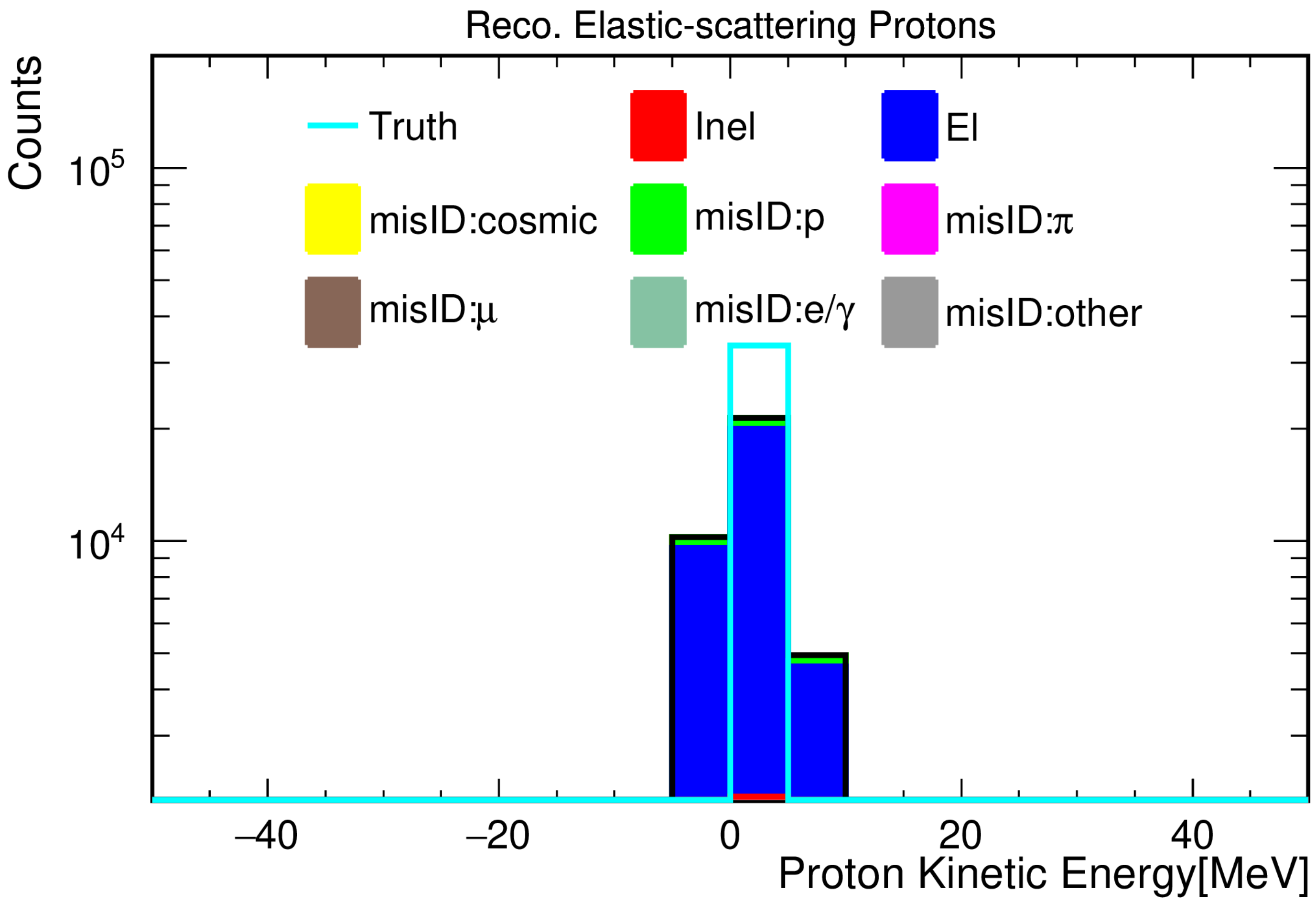
- Good energy reconstruction for inelastic scattering protons using ranged-based energy calculation (Bethe-Bolch)
- KE_{ff}=KE_{beam}-<ΔE>

KE_{end}: Reco. Inelastic-scattering Protons



- Proton KE after event selection of inelastic-scattering protons

KE_{end}: Reco. Elastic-scattering Protons



- Proton KE after event selection of elastic-scattering protons

KE_{end}: All Protons