Analysis of the Impact of Hit Finding on Charge and Energy Reconstruction for ICARUS

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Introduction

The ICARUS detector needs to accurately reconstruct particle interactions to study interesting neutrino phenomena. Data reconstruction starts by processing wire plane signals into hits using a hit finder. The hits are used to calculate charge displaced per unit length, dQ/dx. Using dQ/dx, a calibration constant, and a charge to energy conversion formula, energy lost per unit length, dE/dx, is reconstructed.

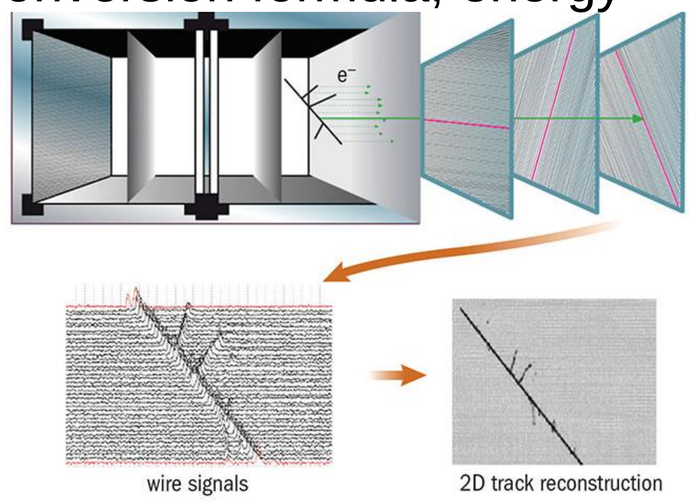


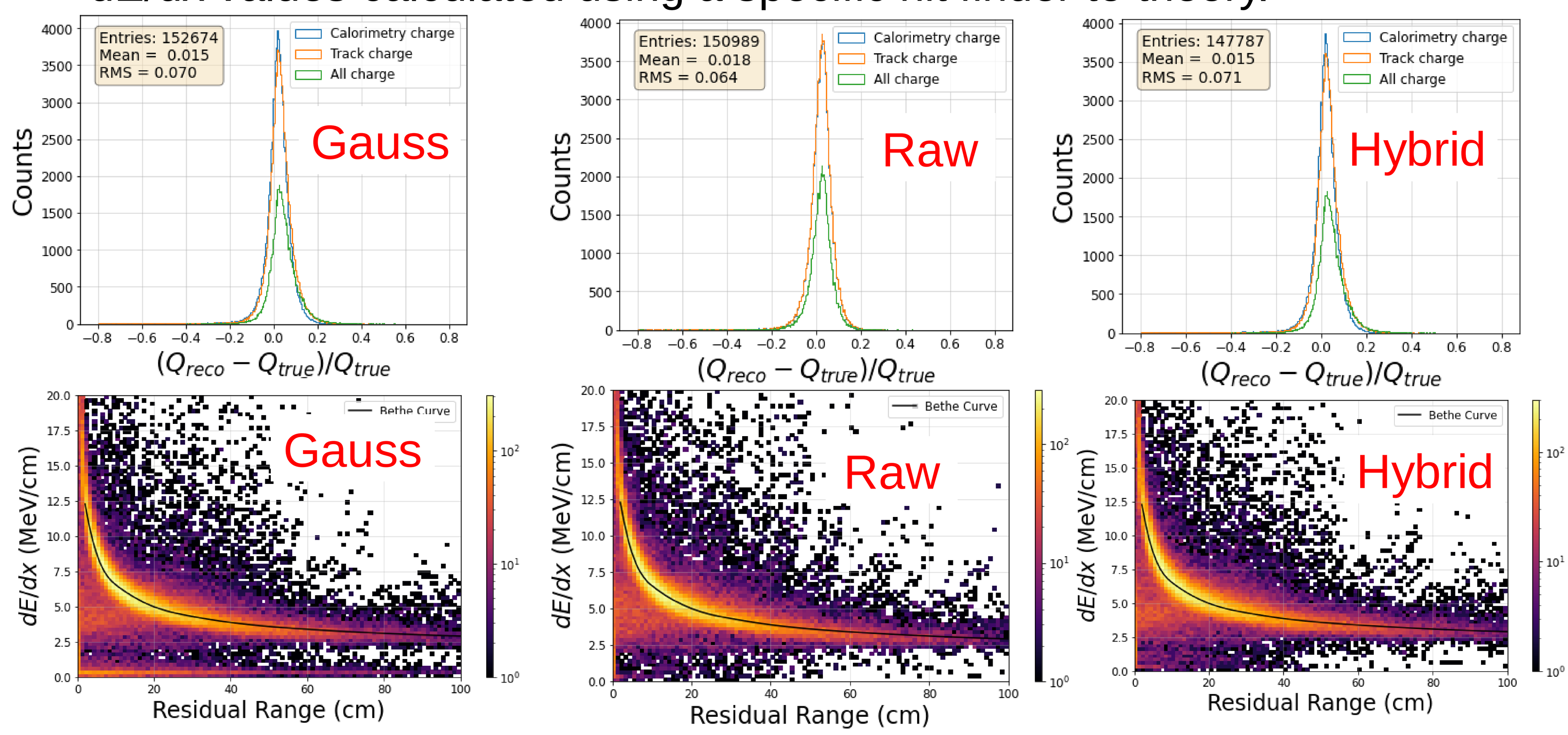
Diagram of event reconstruction process in ICARUS [1]. Signals are measured by each of the wire planes, converted into hits, and then used to calculate dQ/dx and dE/dx. Hits are also combined to construct tracks and showers.

Study Objectives

- To investigate how different hit finders impact charge and dE/dx reconstruction.
- To compare two absolute energy calibration techniques to determine the constants used to convert from the charge measured by the detector to displaced electrons.

Hit Finder Study Methodology

- Utilizes samples of simulated muons and protons and three different hit finders, the Gauss, ICARUS raw, and hybrid hit finders.
  - Gauss: deconvolve signals and fit to Gaussians.
  - Raw: use raw wire plane signals and fit to an analytical function.
  - Hybrid: input deconvolved signals into raw hit finder.
- Hit finders are compared using plots of charge fractional difference, $Q_{frac} = \frac{Q_{reco}-Q_{true}}{Q_{true}}$. Checks for agreement between true and reconstructed charge
- Plots of dE/dx versus the residual range are created to compare the dE/dx values calculated using a specific hit finder to theory.



Charge fractional difference plots (top) and dE/dx vs. residual range plots (bottom) for a proton sample on the collection plane of ICARUS

Absolute Energy Calibration Methodology

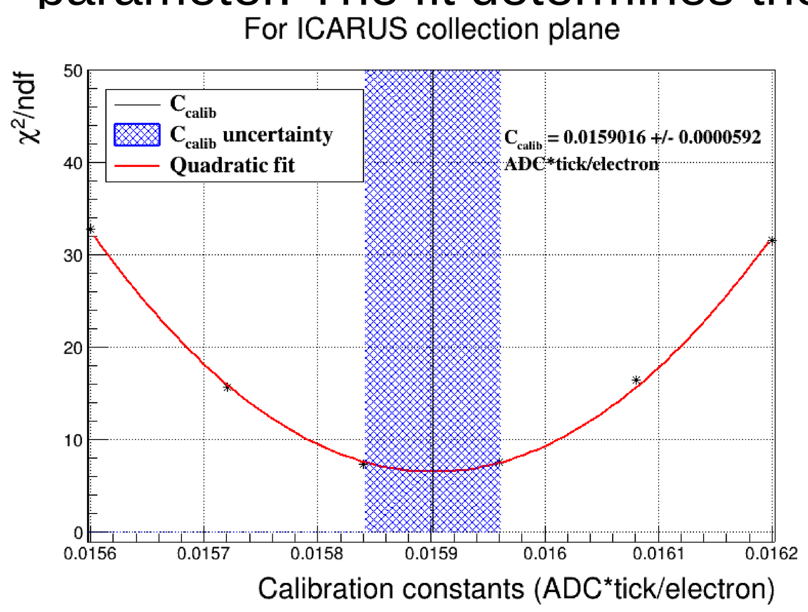
- Utilizes samples of simulated muons in ICARUS and SBND that are well-confined and stopping in the detectors. Samples use the hybrid hit finder.
- The MicroBooNE technique [2] uses the relationship between dE/dx and dQ/dx.

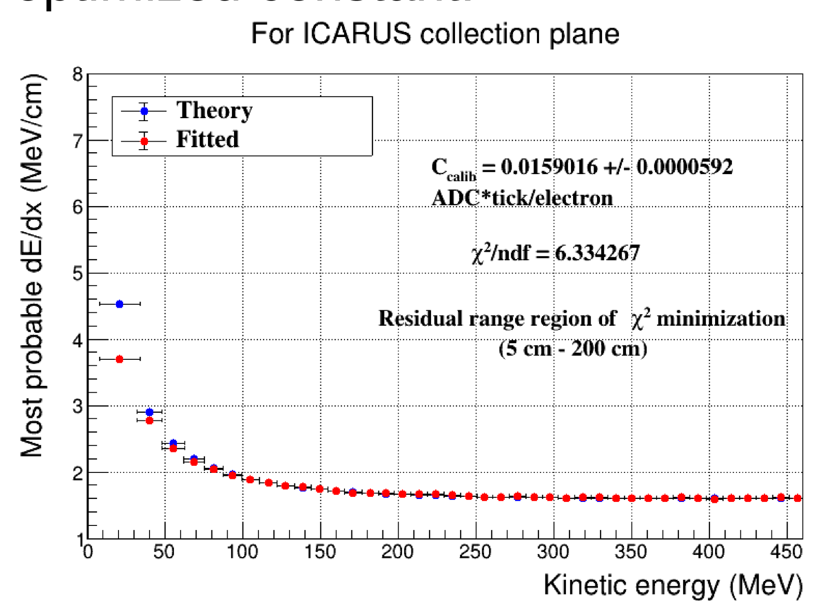
$$\left(\frac{dE}{dx}\right)_{calibrated} = \frac{\exp\left(\frac{\left(\frac{dQ}{dx}\right)_{calibrated}}{C_{cal}}\frac{\beta' W_{ion}}{\rho\mathcal{E}}\right)-\alpha}{\frac{\beta'}{\rho\mathcal{E}}}$$

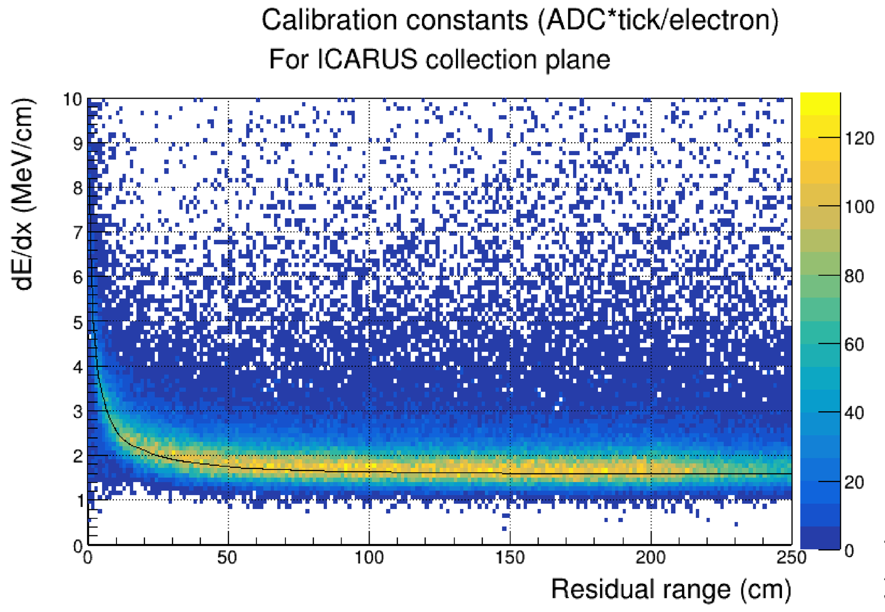
- Corrected dE/dx values are calculated and compared to theory using a χ^2 test, and the optimized constant is found by minimizing χ^2/ndf.
- The LArIAT technique [3] also uses the relationship between dQ/dx and dE/dx.

$$\frac{dQ}{dx} = C_{cal}\cdot\frac{dE/dx}{W_{ion}}\cdot R\left(\frac{dE}{dx},\mathcal{E}\right)$$

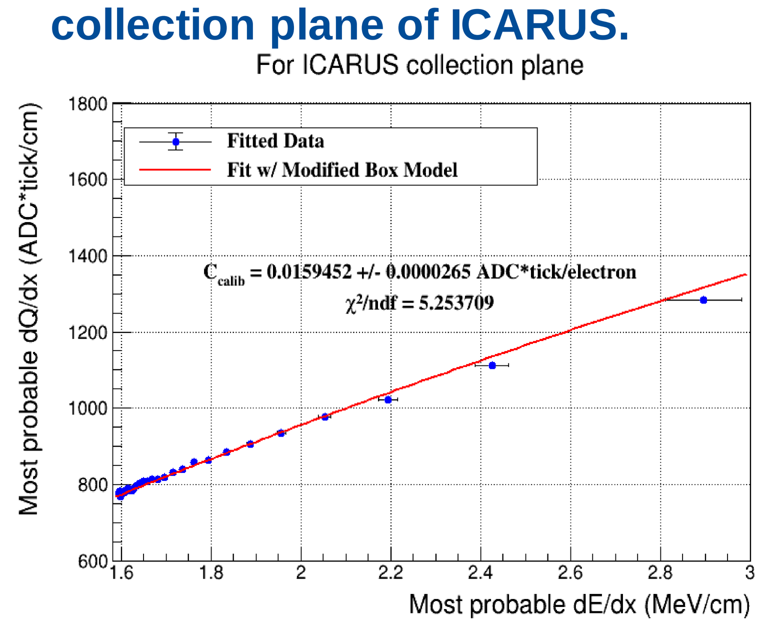
- The dQ/dx vs. dE/dx curve is fit with the calibration constant as a fit parameter. The fit determines the optimized constant.







Top left: χ^2/ndf versus calibration constants for MicroBooNE procedure. Top right: dE/dx vs. kinetic energy for MicroBooNE procedure. Bottom left: dE/dx vs. residual range for MicroBooNE procedure. All plots are for the collection plane of ICARUS.



Right: dQ/dx vs. dE/dx for LArIAT procedure. This plot is only for the collection plane of ICARUS.

Table of calibration constants for ICARUS collection plane

MicroBooNE (ADC*tick/electron)	LArIAT (ADC*tick/electron)
0.0159016*	0.0159452*

*** Error bounds are dominated by systematic uncertainties, which should be between 1-3% from previous work. Error bounds have not been robustly quantified in this study.**

Discussion of Results

- All the charge fractional different plots are roughly centered at zero with a narrow distribution.
- The Gauss hit finder produced an excess of low dE/dx values. This is from the Gauss hit finder being aggressive and splitting up long signals into many, small hits.
- Overall, the raw and hybrid hit finders perform better, but more work is needed to differentiate these two.
- The constants outputted from both techniques are similar and calibrate the data to correspond with theoretical expectations well.
- Next steps: use a cosmic muon sample to further test calibration procedure, use a proton sample to check if there is agreement between the corrected data and theory, and better quantify uncertainties.

References

[1] R. Acciarri et al. "A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam", arXiv:1503.01520, (2015).

[2] C. Adams et al. (The MicroBooNE Collaboration), "Calibration of the charge and energy loss per unit length of the MicroBooNE liquid argon time projection chamber using muons and protons", arXiv:1907.11736, JINST **15**, P03022 (2020).

[3] R. Acciarri et al. (The LArIAT Collaboration), "The Liquid Argon In A Testbeam (LArIAT) Experiment", arXiv:1911.10379, JINST **15**, P04026 (2020).

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