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

Isabella Ginnetti\textsuperscript{a} advised by Minerba Betancourt\textsuperscript{a} and Bruce Howard\textsuperscript{a}
\textsuperscript{a}Fermi National Accelerator Laboratory, \textsuperscript{b}Michigan State University

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, \(Q_{\text{frac}} = \frac{Q_{\text{Gauss}} - Q_{\text{raw}}}{Q_{\text{raw}}}\). 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.

Absolute Energy Calibration Methodology

Utilizes samples of simulated muons in ICARUS and SBND that are well-confined and stopped in the detectors. Samples use the hybrid hit finder.

• The MicroBooNE technique [2] uses the relationship between \(dE/dx\) and \(dQ/dx\).
  
  \[
  \frac{dQ}{dx} \text{ calculated} = \exp\left(\frac{C}{dE/dx} - n\right)
  \]

  • Corrected \(dE/dx\) values are calculated and compared to theory using a \(\chi^2\) test, and the optimized constant is found by minimizing \(\chi^2/\text{ndf}\).
  
  • The LArIAT technique [3] also uses the relationship between \(dQ/dx\) and \(dE/dx\).

  \[
  \frac{dQ}{dx} = C_{\text{col}} \frac{dE/dx}{W_{\text{col}}} - R \left(\frac{dE}{dx}\right)^2
  \]

  • The \(dQ/dx\) vs. \(dE/dx\) curve is fit with the calibration constant as a fit parameter. The fit determines the optimized constant.

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


Acknowledgements

I would like to thank my advisors Minerba Betancourt and Bruce Howard for their guidance, the ICARUS collaboration for providing the data and tools for the analysis, Fermilab for hosting, and the Department of Energy for funding.

Table of calibration constants for ICARUS collection plane

<table>
<thead>
<tr>
<th>Methodology</th>
<th>MicroBooNE (ADC*tick/electron)</th>
<th>LArIAT (ADC*tick/electron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q_{\text{frac}})</td>
<td>0.0159016*</td>
<td>0.0159452*</td>
</tr>
</tbody>
</table>

* 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.