Novel Approach for Evaluating Detector Systematics in the MicroBooNE LArTPC

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Introduction

Detector systematics quantify uncertainties due to differences between the detector response in simulation and in data

To address uncertainties that can be described by changes in the amplitude and width of wire waveforms:

1) Compare waveform properties in data and simulation, then extract functions that measure the difference
2) Modify waveforms in simulated events according to the extracted data-to-simulation differences

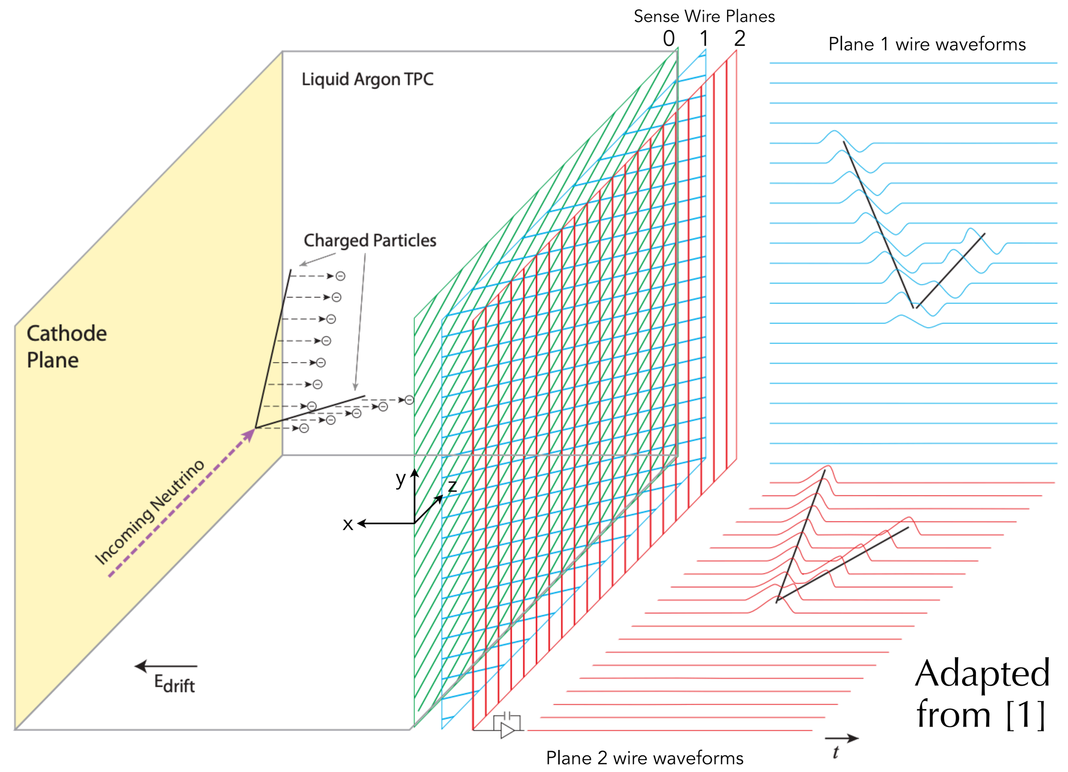
Differences between the nominal and modified simulations can be used to evaluate detector systematic uncertainties

This approach is data-driven and computationally efficient

Detector Response Parameters

The detector's response to an energy deposition from a charged particle varies as a function of:

- position in x, y, and z
- angular orientation of particle's trajectory, θ_{XZ} and θ_{YZ}
- amount of energy deposited, dE/dx



Adapted from [1]

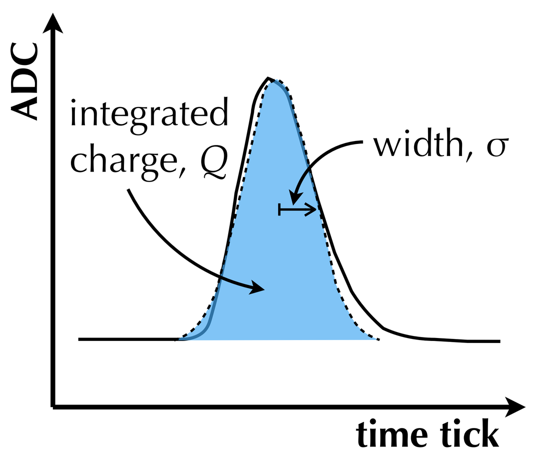
For a vector $\Delta\vec{x}$,

$$\theta_{XZ} = \arctan\left(\frac{\Delta x}{\Delta z}\right)$$

$$\theta_{YZ} = \arctan\left(\frac{\Delta y}{\Delta z}\right)$$

The variation in the deconvolved wire waveforms [2,3] can be described in terms of the properties of a Gaussian fit to the waveform, which is called a hit

Hits are characterized by their peak position in time and two additional independent parameters: integrated charge, Q, and width, σ

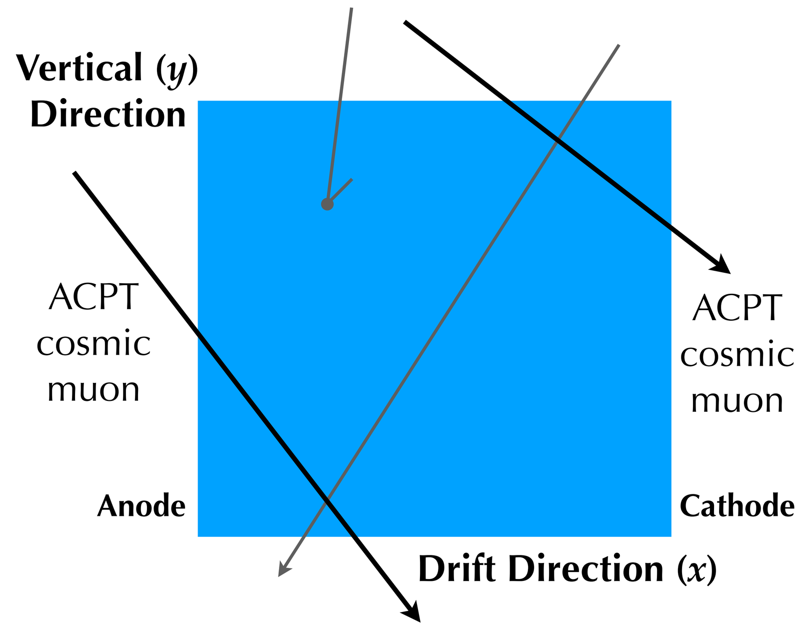


Data-to-Simulation Comparisons

Consider comparisons between data and simulation in the hit charges and widths vs. x, y, z, θ_{XZ}, θ_{YZ}, and dE/dx

Except for dE/dx, use in-time anode/cathode piercing tracks (ACPT) from cosmic ray muons in beam-off data

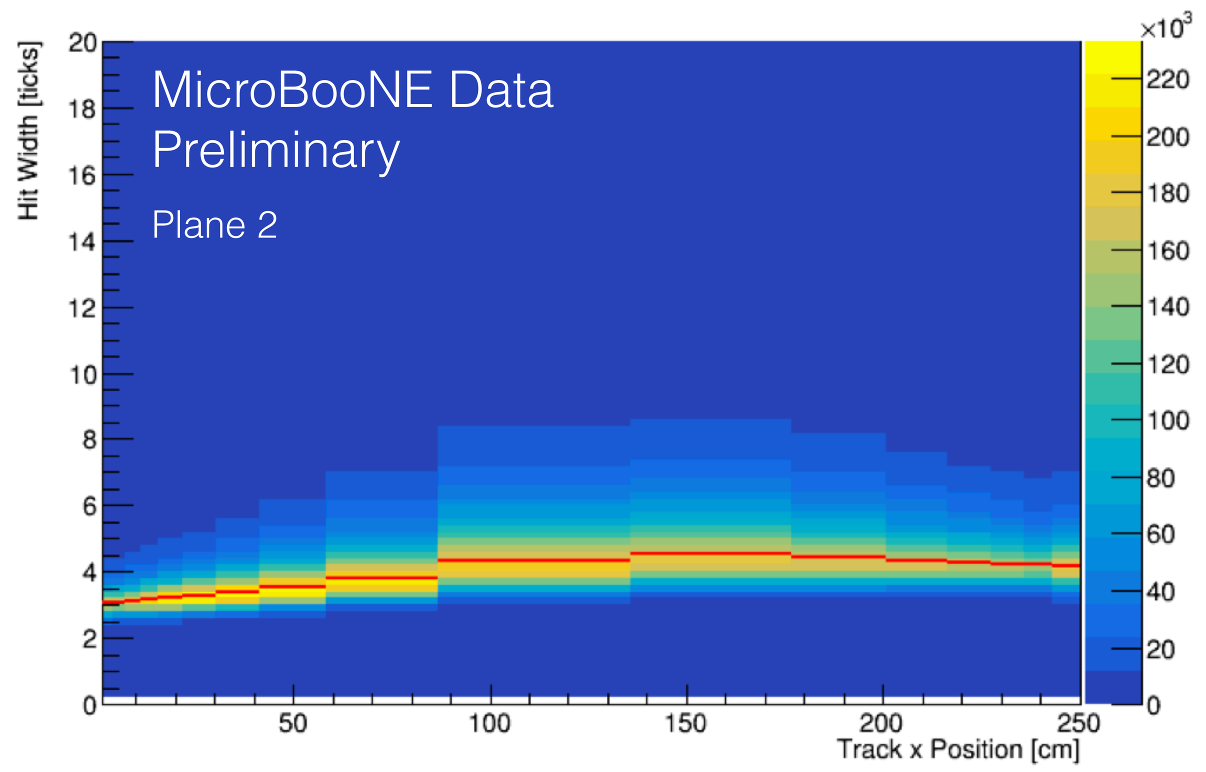
Also generate a comparable sample of simulated events



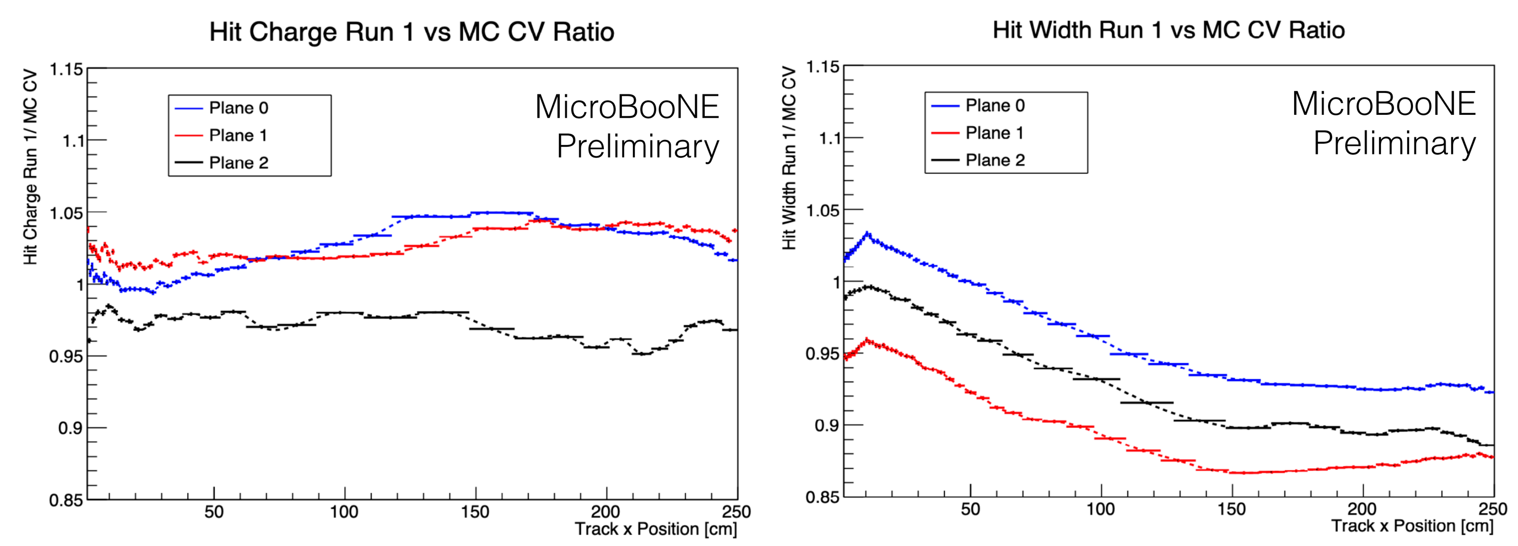
For each of the three wire planes, plot hit charge and width vs. reconstructed x position in data and simulation

Choose bins to obtain comparable track statistics in each

Find the peak of the hit properties in each x bin using an iterative truncated mean algorithm (red lines below)



Take the ratio of the data to the simulation in each bin, then fit ratio points with a spline to get a smooth function of x



Perform a similar measurement for the remaining variables, but using hit properties corrected based on x position

For dE/dx, use protons identified in neutrino interactions

Wire Waveform Modification

Each wire signal region is described by Gaussian function(s) with a position t_0, an integrated charge Q, and a width σ

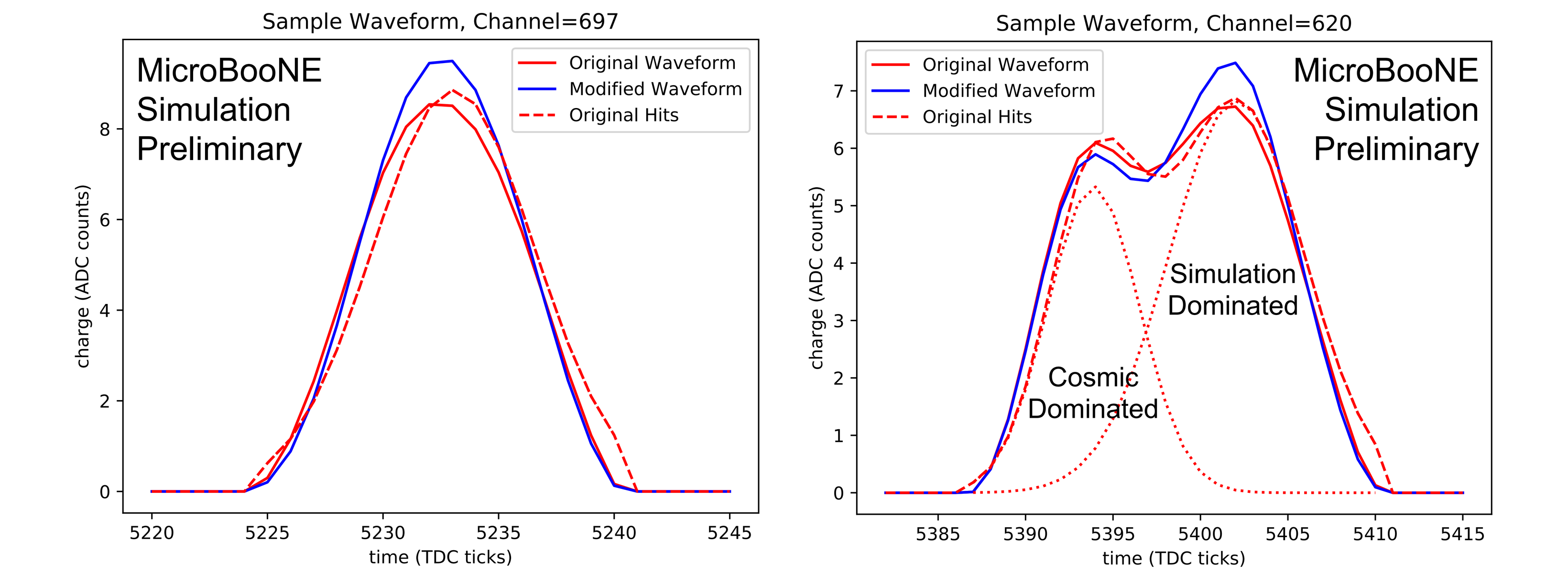
Simulated energy deposits are matched to the Gaussian that best matches their projected position on each wire plane

A modified charge Q' and width σ' are computed for each Gaussian based on truth properties of matched simulated energy deposits and the data/simulation ratios

At each time tick, the waveform is scaled by:

$$\text{scale}(t) = \frac{\sum_i \text{Gaus}(t; t_i, Q'_i, \sigma'_i)}{\sum_i \text{Gaus}(t; t_i, Q_i, \sigma_i)} \quad \text{where } \text{Gaus}(t; t_0, Q, \sigma) = \frac{Q}{\sqrt{2\pi}\,\sigma}\exp\left(-\frac{(t-t_0)^2}{2\sigma^2}\right)$$

Cosmic-dominated portions of waveforms are not modified



Summary and Conclusions

This is a novel, data-driven method for assessing systematics in MicroBooNE and could be applied to other LArTPCs

Since the publication of MicroBooNE's first physics results, have engaged in an extensive campaign to improve detector modeling [2,3,4,5] and better quantify related uncertainties

The combination yields reduced uncertainties: from 16.2% in our first measurement of the inclusive ν_μ charged current cross section [6], down to 3.3% in the most recent one [7]

References

[1] JINST 12, P02017 (2017)
[2] JINST 13, P07006 (2018)
[3] JINST 13, P07007 (2018)
[4] JINST 15, P03022 (2020)
[5] arXiv:1910.01430 [physics.ins-det]
[6] PRL 123, 131801 (2019)
[7] MICROBOONE-NOTE-1069-PUB

See also: MICROBOONE-NOTE-1075-PUB

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