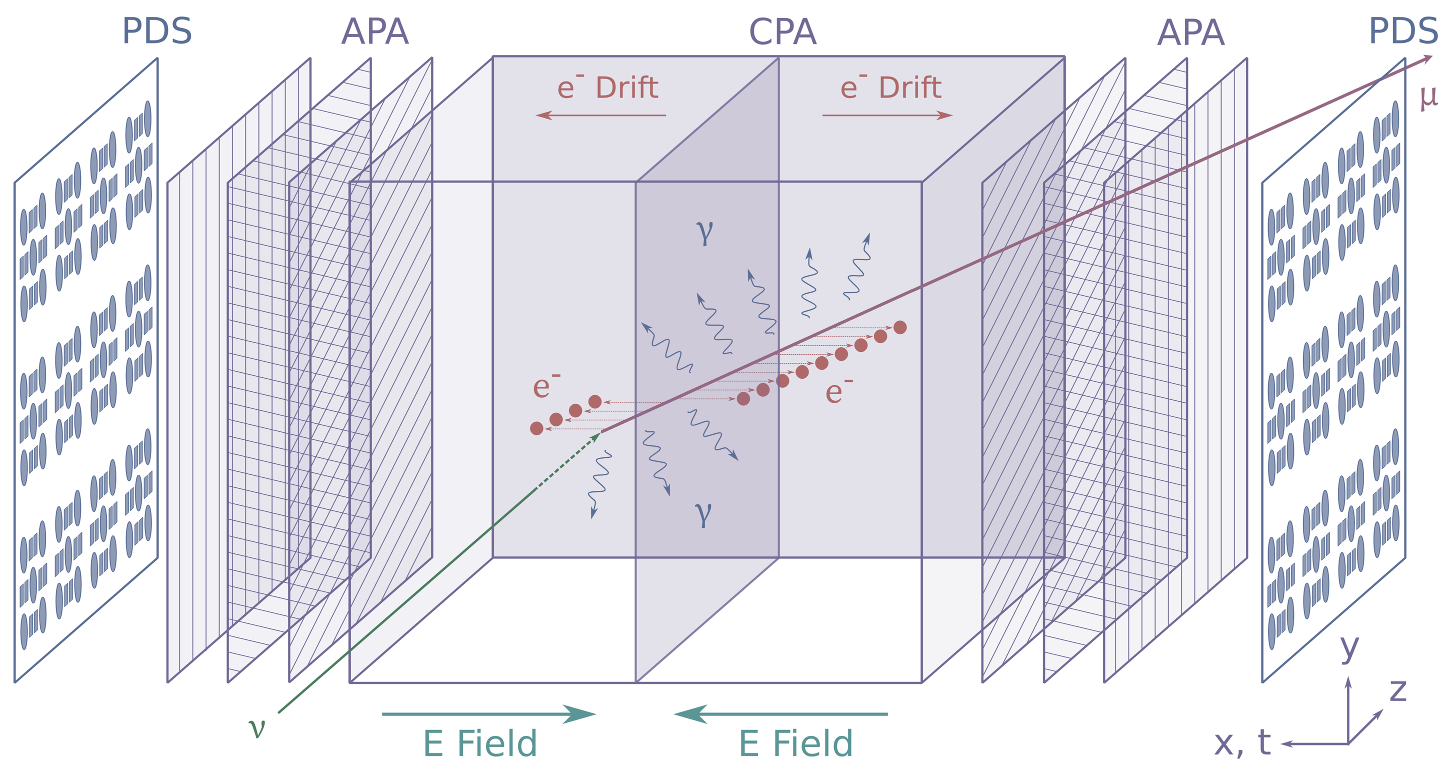
Data-driven Detector Systematics for Liquid Argon Time Projection Chambers

Thomas Wester, University of Chicago

On behalf of the SBND Collaboration

Liquid Argon Time Projection Chambers

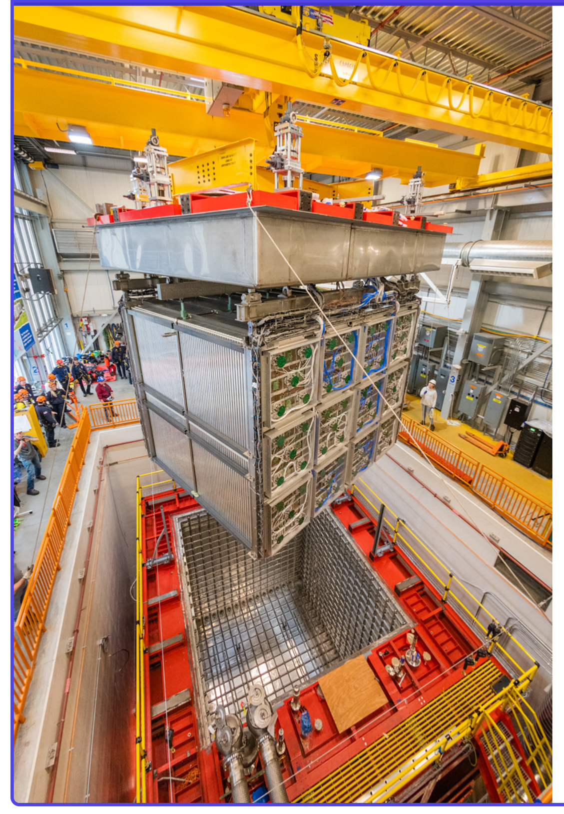


Liquid Argon Time Projection Chambers (LArTPCs) are high-resolution detectors for neutrino experiments.

Charged particles create ionization tracks that drift toward wire planes in a strong electric field. Readout electronics record wire waveforms as ionization drifts across the planes.

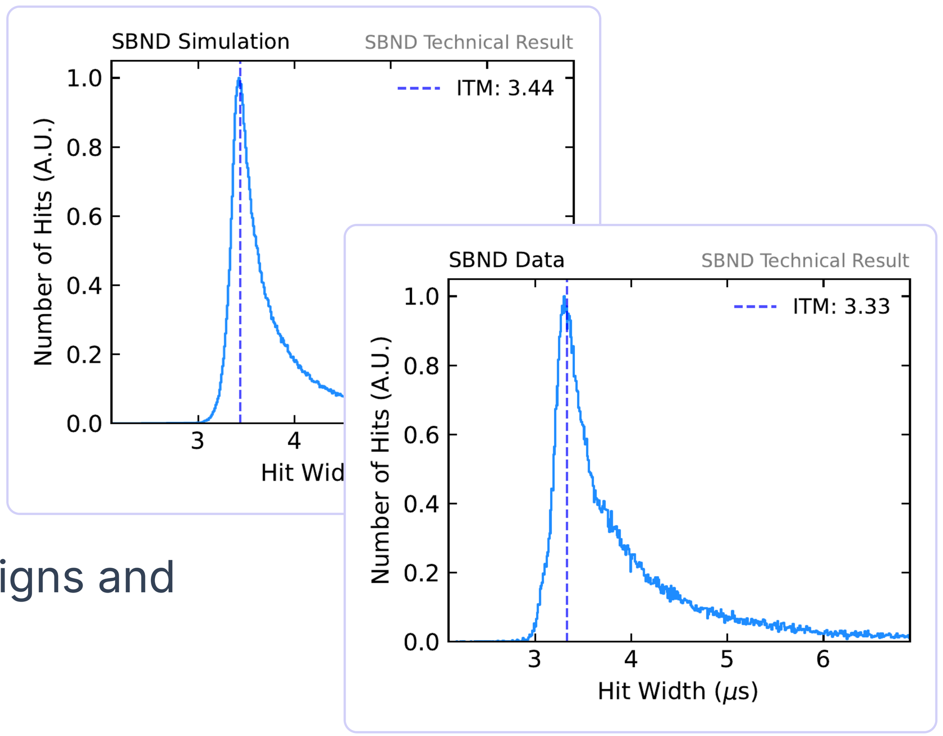
Hits are formed by deconvolving the electronics response from wire waveforms [1], leaving a Gaussian shape with a width and amplitude.

The Short-Baseline Near Detector



The Short-Baseline Near Detector (SBND) is a LArTPC located 110 m from the Booster Neutrino Beam (BNB) target at Fermilab. It is designed to perform precision neutrino-argon cross-section measurements and to act as the near detector in the Short-Baseline Neutrino (SBN) Program [2].

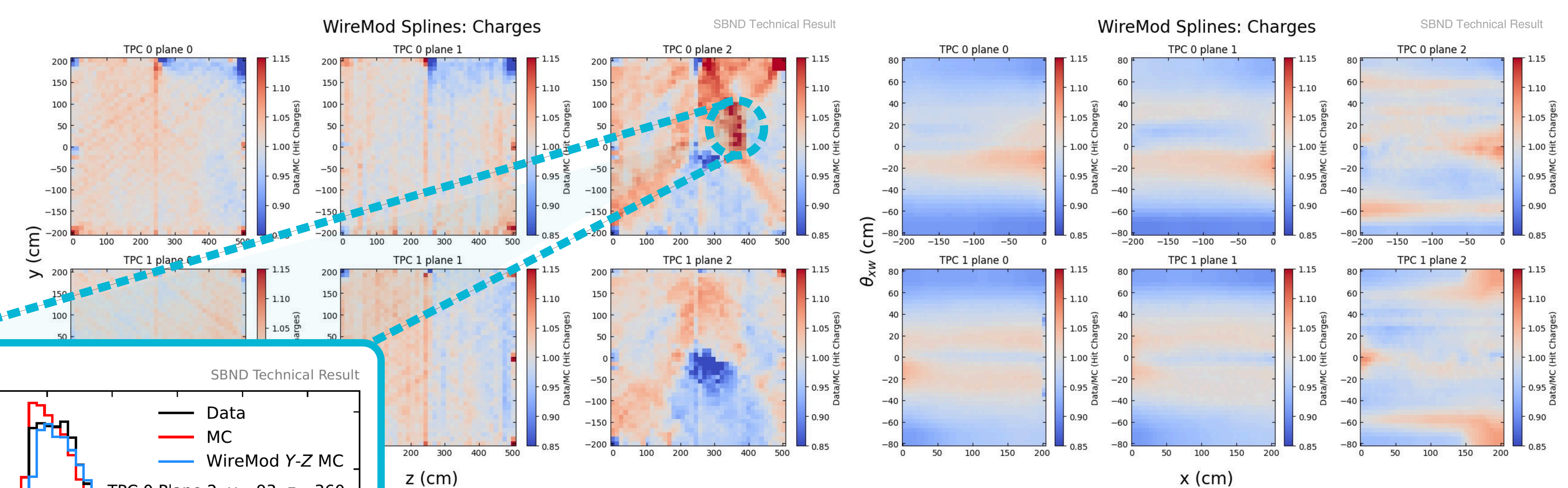
- 112-ton active mass, two drift volumes, each with three wire planes
- Cosmic muon triggers enable calibration campaigns and assessment of systematic uncertainties
- Data taking since 2024

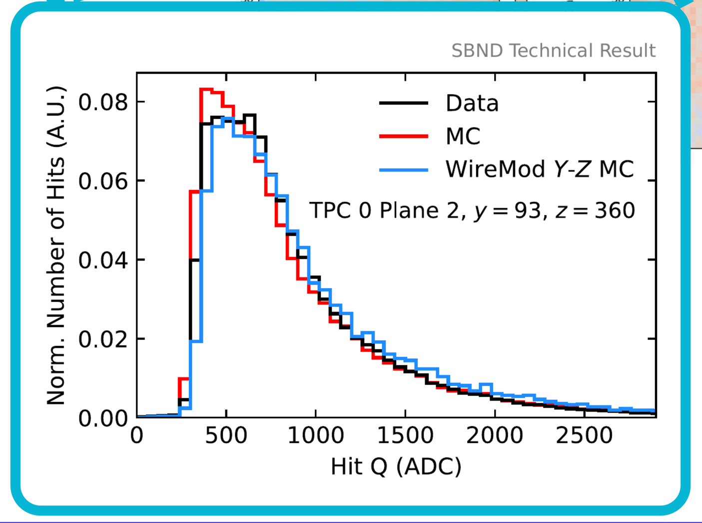


WireMod Technique

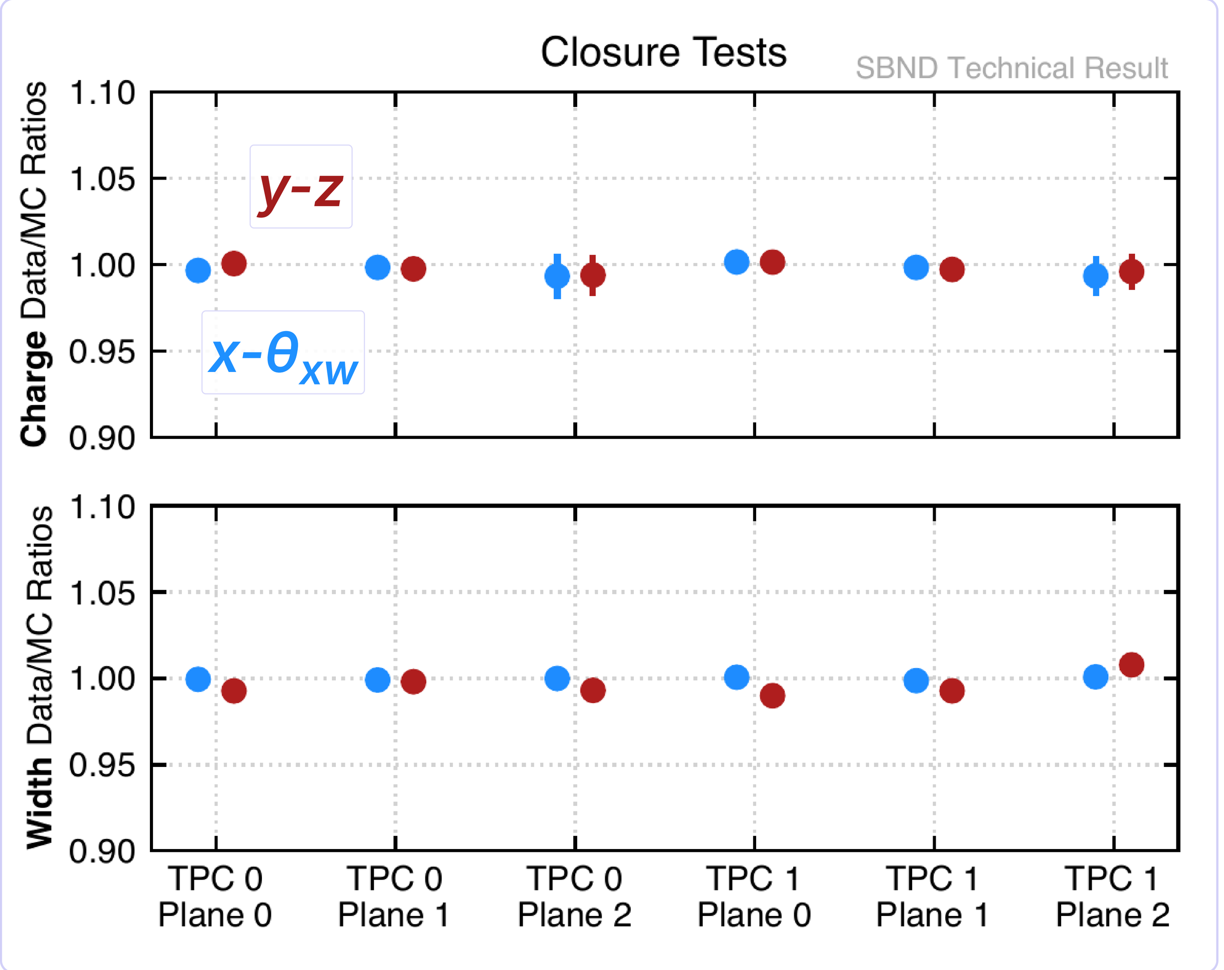
Residual discrepancies in wire waveforms between data and simulation after calibrations are a source of systematic uncertainty. For SBND, we use the **WireMod** technique [3] to quantify the impact of mismodeling.

1. Correction factors, or *splines*, are computed via data-MC ratios between the most probable values (MPVs) of hit charge or width distributions as a function of coordinates and trajectory angles, x, y, z, θ_{xw} (w refers to the direction perpendicular to the wire orientation).
2. Simulated wire waveforms are scaled via the splines to approximate the data waveforms.
3. Validation via *closure tests* (right-most figure) by computing the ratios after applying the WireMod corrections to the wire waveforms. We see convergence to 1 in SBND for all closure tests.





The panels above show how the y, z, and x-θ_{xw} splines capture residual data-MC differences. The inset figure shows an example hit charge distribution from a region of the collection plane with a large spline value. We see the data and MC distribution shapes differ in peak position and the agreement is improved after WireMod.

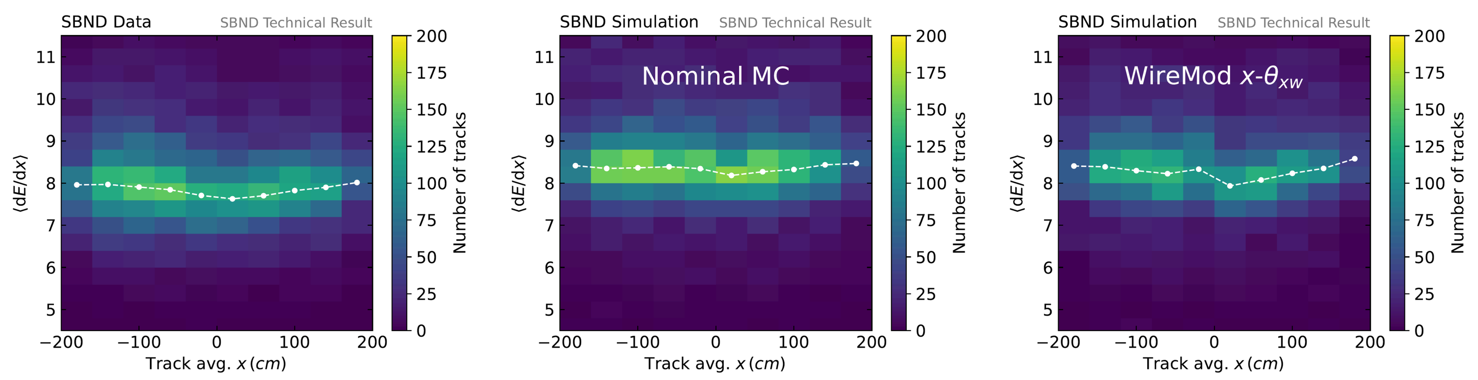


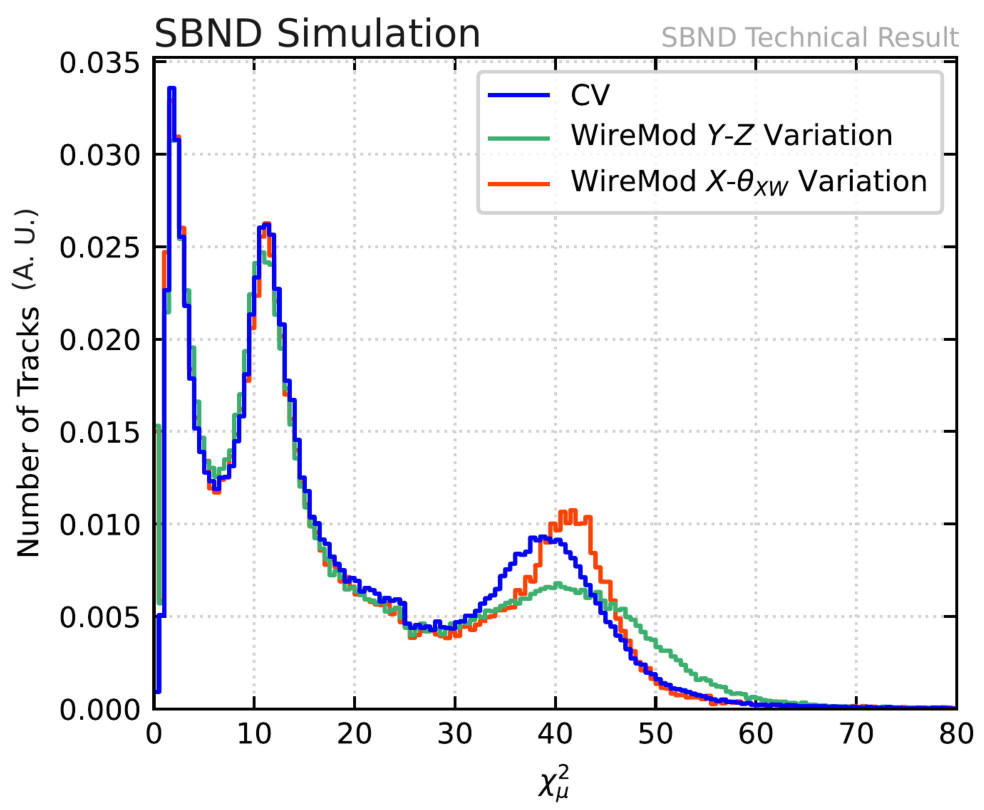
Systematic Uncertainties

Systematic uncertainties are evaluated by rerunning reconstruction algorithms on the modified waveforms. Low-level hit modifications propagate to high-level variables used in physics analyses.

Right: An example for the χ^2_μ particle ID score.

Bottom: An example for PID scores from proton-like tracks vs. x, used in the WireMod x-θ_{xw} variation. Simulated particle ID scores show an x-dependent trend similar to the data after modification.

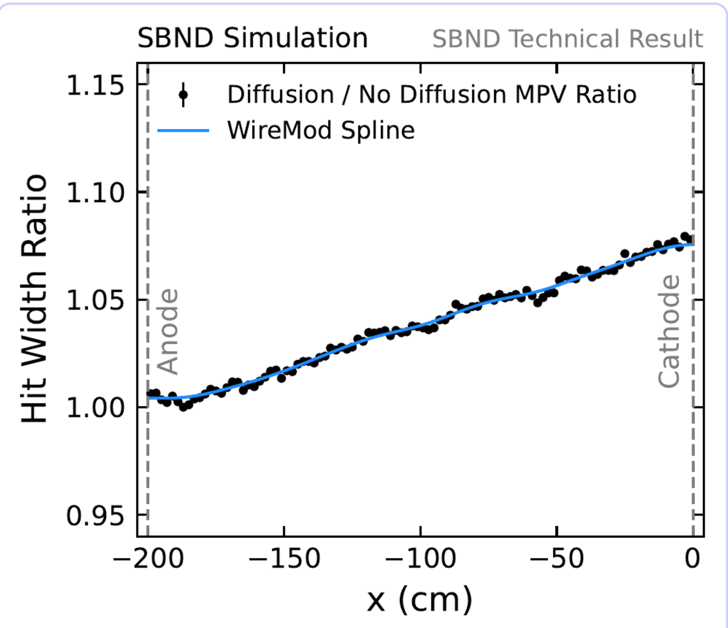




Outlook

Detector Modeling: WireMod enables rapid detector modeling studies. WireMod splines created from simulation with and without longitudinal diffusion capture increasing hit widths as a function of the drift coordinate. Such splines could reduce the need for dedicated simulations to capture these uncertainties.

Future Developments: We plan to extend the spline parameterization to higher dimensions to capture 3D effects within a single spline and extend the spline sample selection to include protons for cross-checks. Implementing WireMod corrections into the simulation model itself can further reduce uncertainty.



References: [1] C. Adams et al. (MicroBooNE Collaboration), JINST **13** (2018) P07007, [2] R. Acciarri et al. (SBND Collaboration), arXiv:1503.01520 (2015), [3] P. Abratenko et al. (MicroBooNE Collaboration), EPJC **82** 454 (2022).