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Signal Processing with WireCell in SBND

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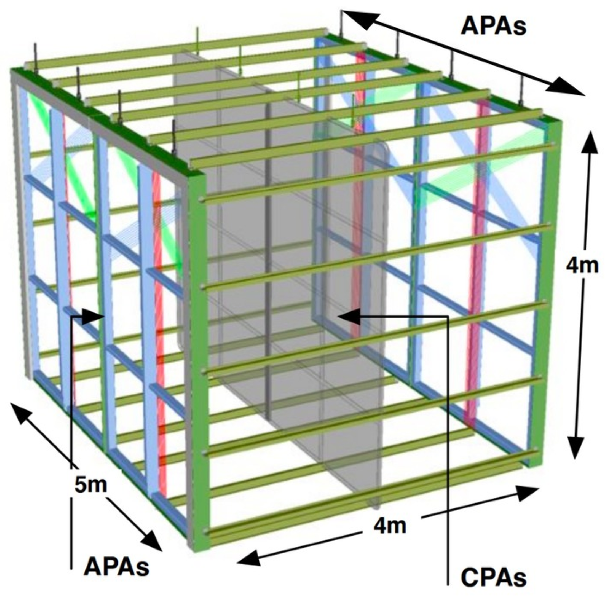
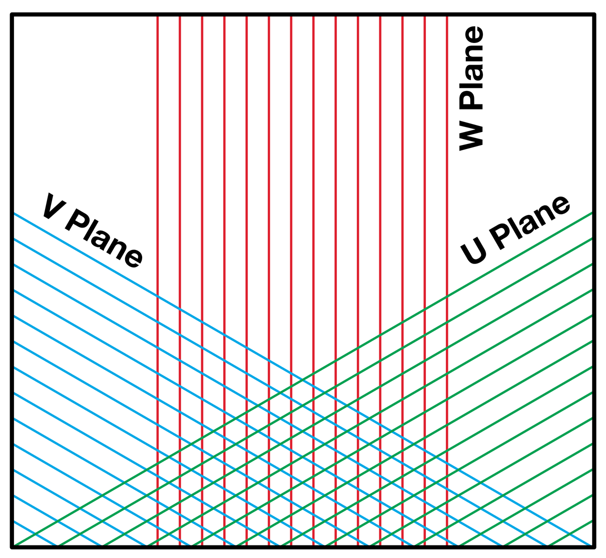
The Short Baseline Near Detector (SBND), a 112 ton liquid argon time projection chamber (LArTPC), is the near detector of the Short Baseline Neutrino Program [1]. In a LArTPC, ionization electrons from a charged particle interaction drift along electric field lines, inducing bipolar signals on induction wire planes and a unipolar signal on the collection wire plane. These measured signals must undergo noise filtering, deconvolution, and signal processing to recover the original ionization signal. WireCell, a software package developed for LArTPCs, implements 2D deconvolution (in time and wire dimensions) to correct for the inter-wire induction field effects inherent to LArTPC signals [2].



Model of the SBND detector [3], showing the positions of the anode plane and cathode plane assemblies (APAs and CPAs). Wires are located on the APAs.

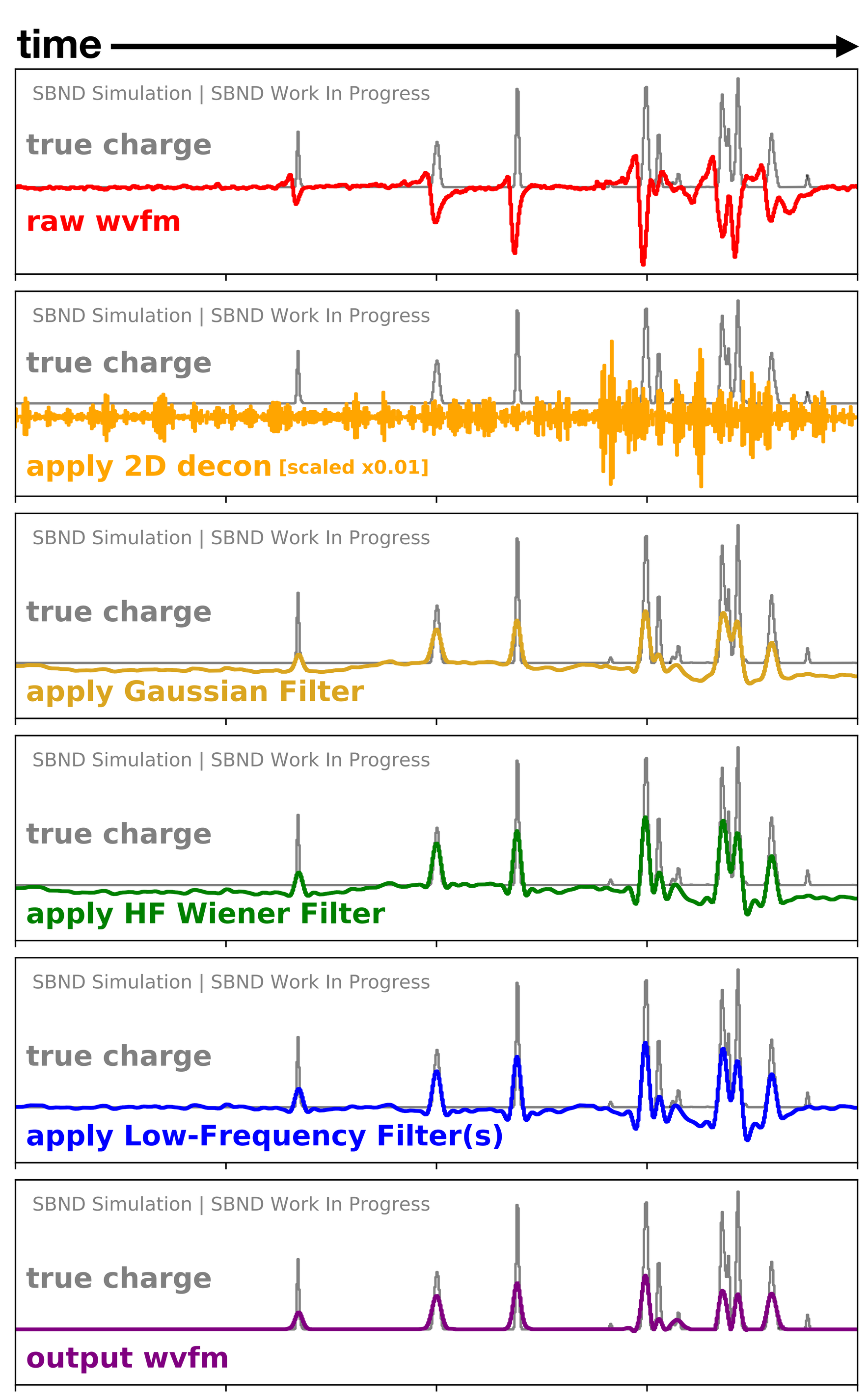


Layering of wires in SBND. U is the first induction plane, followed by V, and W is the collection plane. Wires are separated by 3 mm in each plane, and induction planes are rotated ±60° from W.

WireCell Signal Processing (SP) Chain

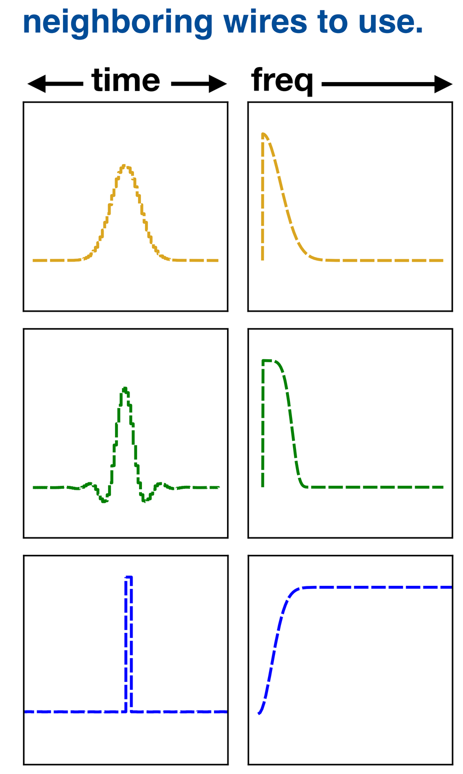
The main steps of SP are 2D deconvolution, high-frequency (HF) filters, low-frequency (LF) filters, and region-of-interest (ROI) finding. ROIs are implemented to limit LF noise and preserve charge extraction [2]. Filter functional shapes also shown in both the time and frequency domain.

Raw Waveform → **2D Deconvolution** → **Gaussian Filter** → **Wiener Filter** → **LF Filters (+ ROI)** → **Output Waveform**



Raw waveforms include noise, electric field response, electronics response, and signal.

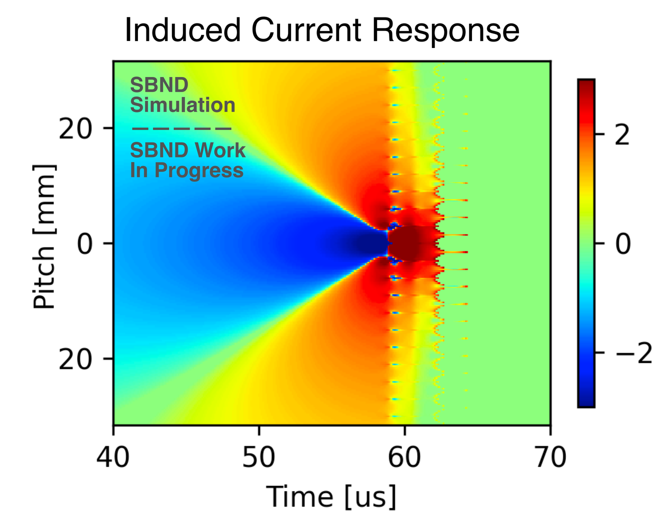
2D deco. includes a *wire* filter, which determines the # of neighboring wires to use.



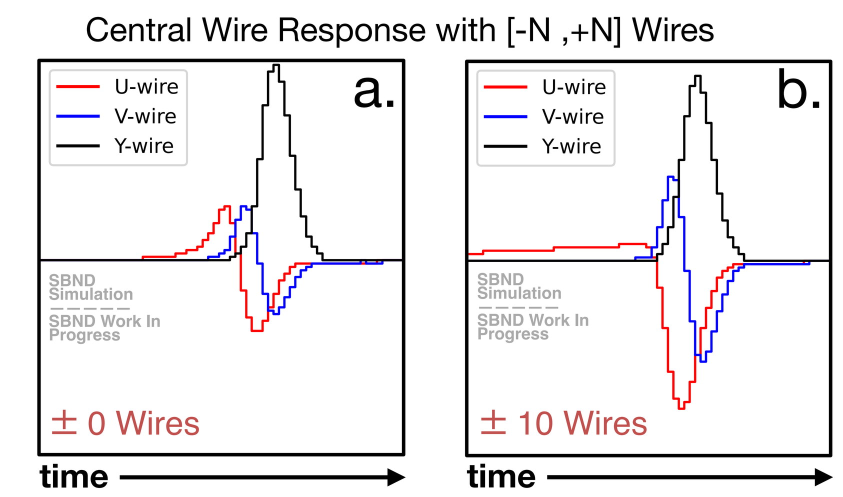
The timing of the signal peaks is clearly resolved in the output waveform.

2D Detector Response: Time & Wire Dimensions

The raw digitized TPC signal is a convolution of the arriving ionization electron distribution (time dimension), the field response describing the induced current on wires from moving charge (wire dimension), and the overall electronics response [2].



The position-averaged convolved field and electronics response for the U plane in SBND.



Central wire response function for a single electron including (a) no neighboring wires or (b) [-10, +10] neighboring wires.

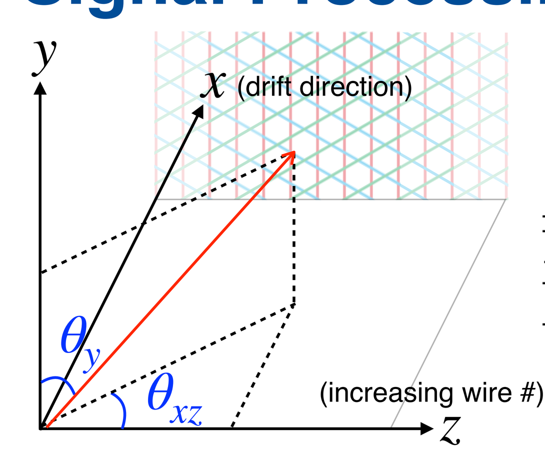
$$M_i(\omega) = \ldots + R_1(\omega)S_{i-1}(\omega) + R_0(\omega)S_i(\omega) + R_1(\omega)S_{i+1}(\omega) + \ldots$$

↓

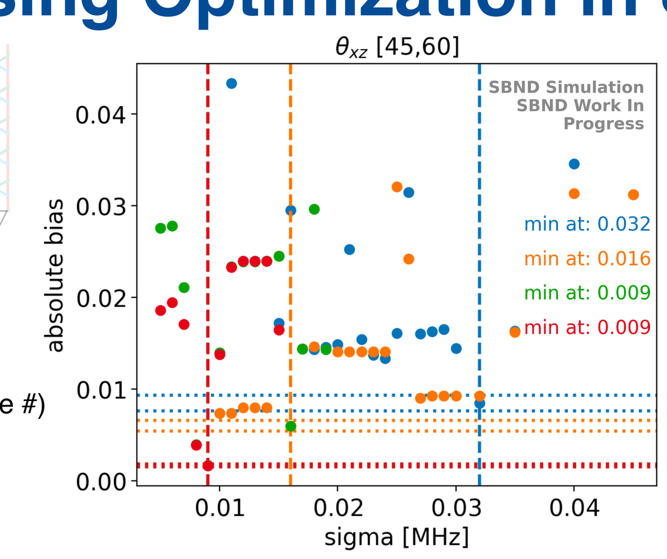
$$\begin{pmatrix} M_1(\omega) \\ M_2(\omega) \\ \vdots \\ M_{n-1}(\omega) \\ M_n(\omega) \end{pmatrix} = \begin{pmatrix} R_0(\omega) & R_1(\omega) & \ldots & R_{n-2}(\omega) & R_{n-1}(\omega) \\ R_1(\omega) & R_0(\omega) & \ldots & R_{n-3}(\omega) & R_{n-2}(\omega) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R_{n-2}(\omega) & R_{n-3}(\omega) & \ldots & R_0(\omega) & R_1(\omega) \\ R_{n-1}(\omega) & R_{n-2}(\omega) & \ldots & R_1(\omega) & R_0(\omega) \end{pmatrix} \cdot \begin{pmatrix} S_1(\omega) \\ S_2(\omega) \\ \vdots \\ S_{n-1}(\omega) \\ S_n(\omega) \end{pmatrix}$$

2D deconvolution: To extract the true signal S_i from the measured signal M_i, one applies the inverse of the response matrix R using Fourier transform techniques.

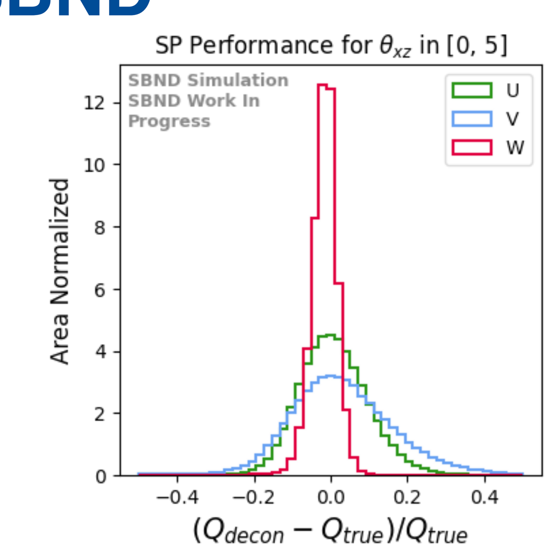
Signal Processing Optimization in SBND



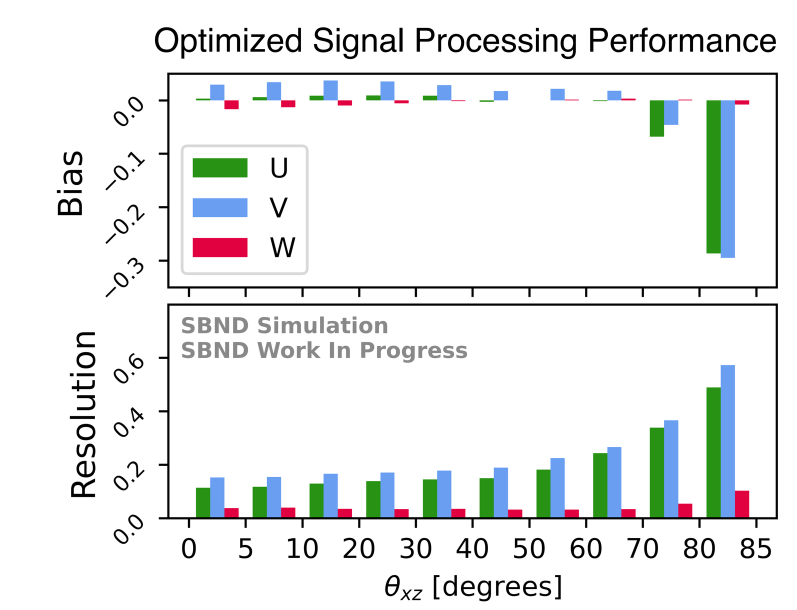
Geometric coordinates and angles. The θ_{xz} angle of the ionization affects the signal shape on the wires.



Absolute bias as a function of tight LF filter parameters in $\theta_{xz} \in [45,60]$.



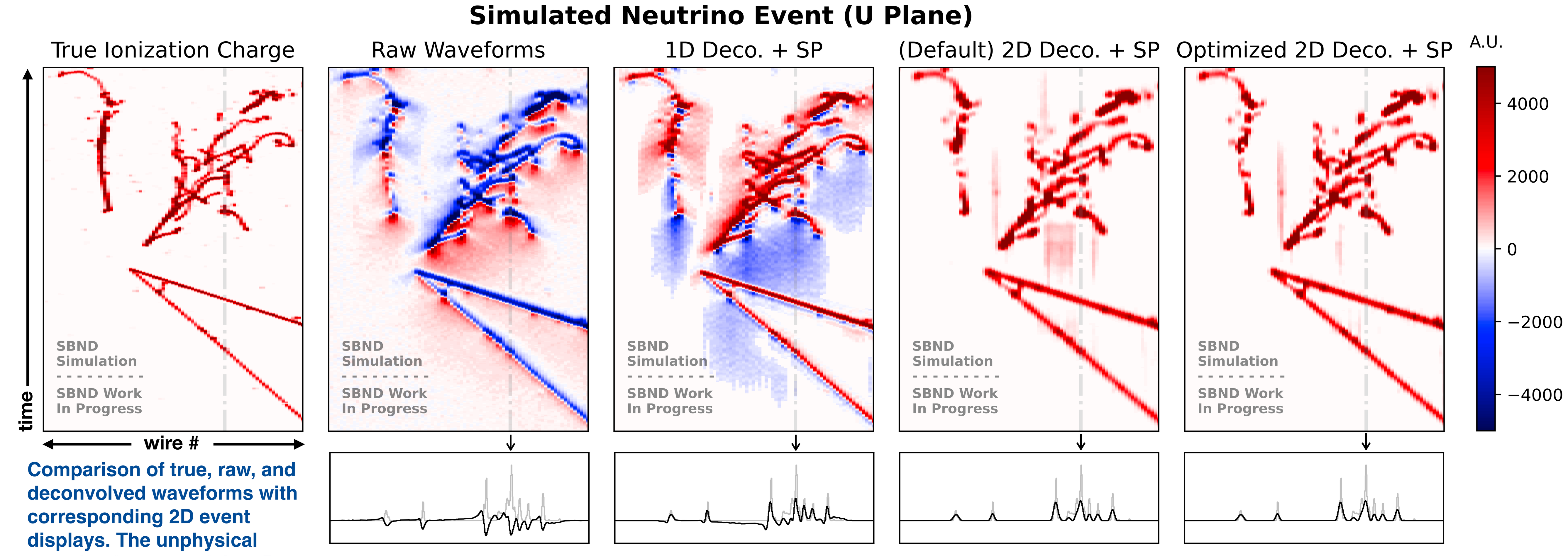
Fractional charge difference distribution for $\theta_{xz} \in [0,5]$.



Bias and resolution of charge extraction using optimal SP filter values for all angular bins.

To optimize the SP chain in SBND, we simulated minimum-ionizing particles in known θ_{xz} bins to maximize the charge extraction performance (bias, resolution, failure rate). We performed coordinate descent over SP filter (e.g. HF Wiener, LF, wire filters, etc.) values to determine optimum parameters.

Simulated Neutrino Event (U Plane)



Comparison of true, raw, and deconvolved waveforms with corresponding 2D event displays. The unphysical negative features of the 1D deco. are visible, as well as the improved "shadow" removal of the optimized 2D deco.

[1] Machado, P. A., Palamara, O., & Schmitz, D. W. (2019). The short-baseline neutrino program at Fermilab. *Annual Review of Nuclear and Particle Science*, *69*, 363-387.
[2] Adams, C., R. An, J. Anthony, J. Asaadi, M. Auger, L. Bagby, S. Balasubramanian et al. "Ionization electron signal processing in single phase LArTPCs. Part I. Algorithm Description and quantitative evaluation with MicroBooNE simulation." *Journal of Instrumentation* 13, no. 07 (2018): P07006.
[3] Acciarri, R., C. Adams, C. Andreopoulos, J. Asaadi, M. Babicz, et al. "Construction of precision wire readout planes for the Short-Baseline Near Detector (SBND)." *Journal of instrumentation* 15, no. 06 (2020): P06033.