Anode-Coupled Readout for Light Collection in Liquid Argon TPCs

Z. Moss, M. Toups, L. Bugel, G.H. Collin, J.M. Conrad

[arXiv:1507.01997]

The Current DUNE Design

- ~ 10k SiPMs → ~1k channels, depending on configuration.
- Readout cables are problematic: many feedthroughs required (heat leaks), potential impurities introduced to the ullage.
- Dedicated readout is expensive! Hundreds of $ /channel

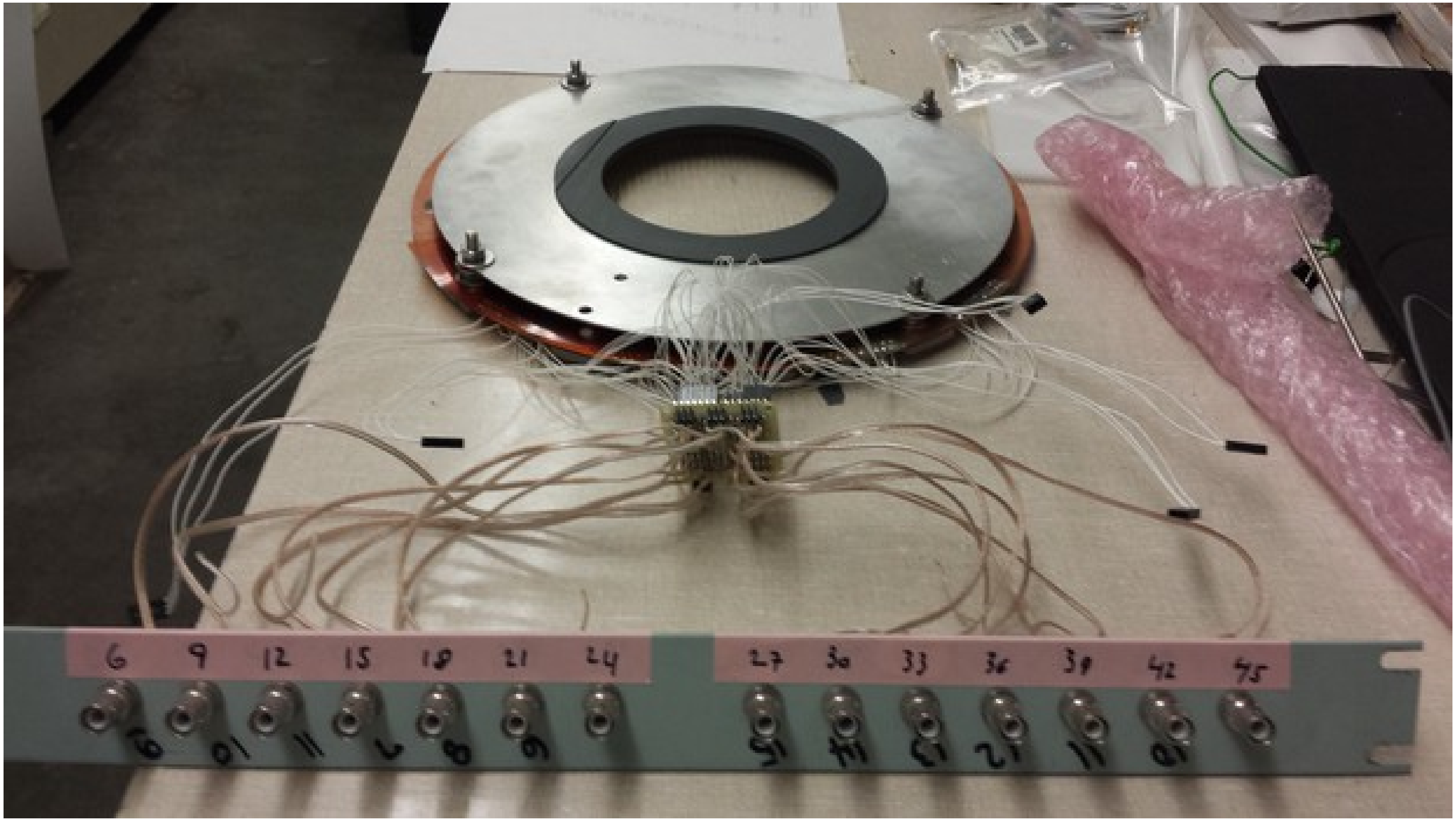
The Idea

- Argontube, Lariat, Icarus and MicroBooNE (preliminary) saw crosstalk on their wire-planes from PMT activity (see Gabriel Collin's study).
- Might it be possible to use this crosstalk as a readout, avoiding the complications of a dedicated system?
- Our proposal is to couple SiPM signal outputs to capacitive plates placed close to the collection plane, in an attempt to read the signals out using the wire-plane DAQ exclusively.
- This system is simple! It requires only a wire and a copper plate.

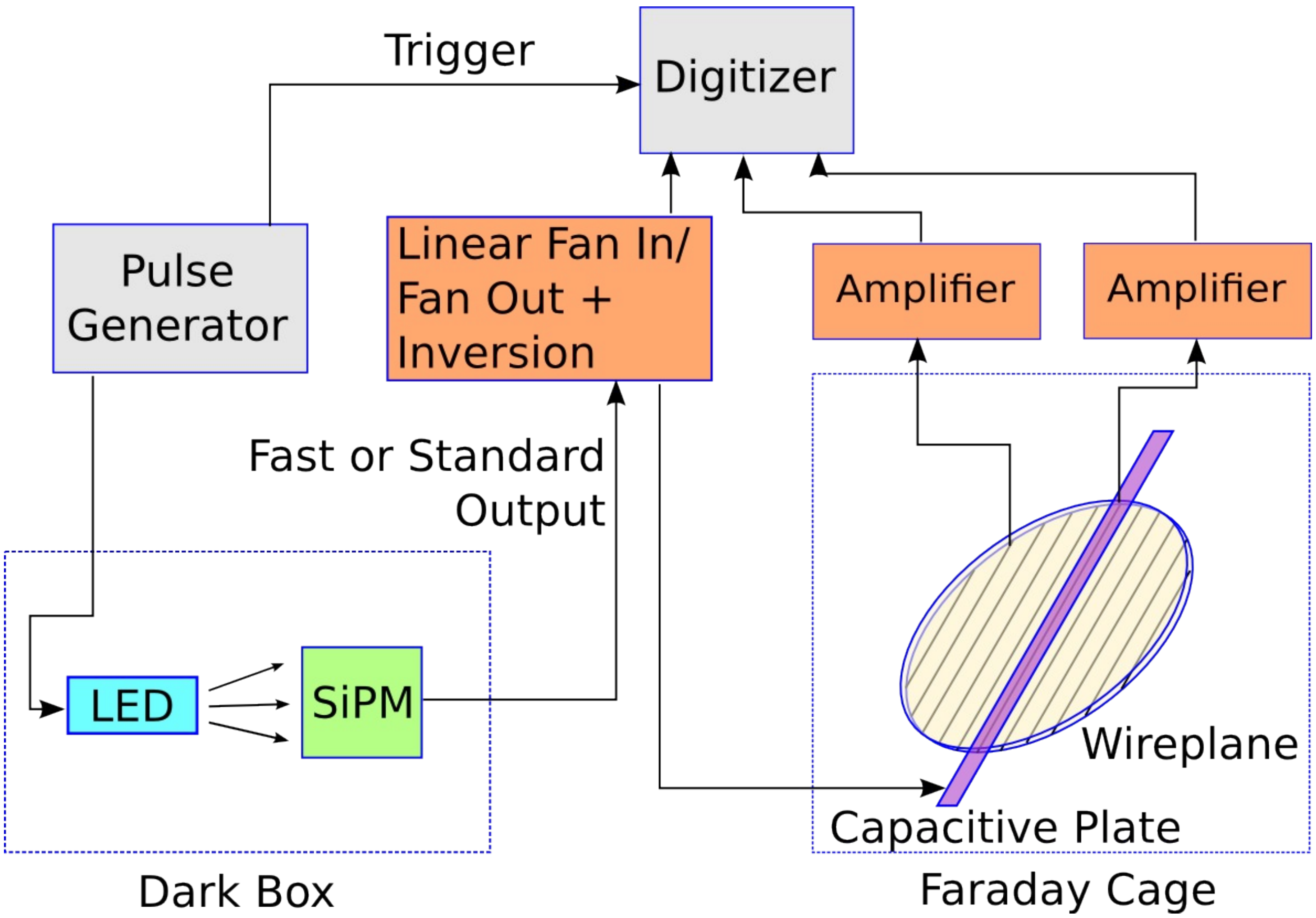
Potential Hurdles

- Will an unamplified SiPM produce a strong enough signal?
- Will the slow digitization and shaping times ruin our timing resolution?
- How good is our charge resolution? Can we see single PE?
- Will optical backgrounds swamp the charge readout?

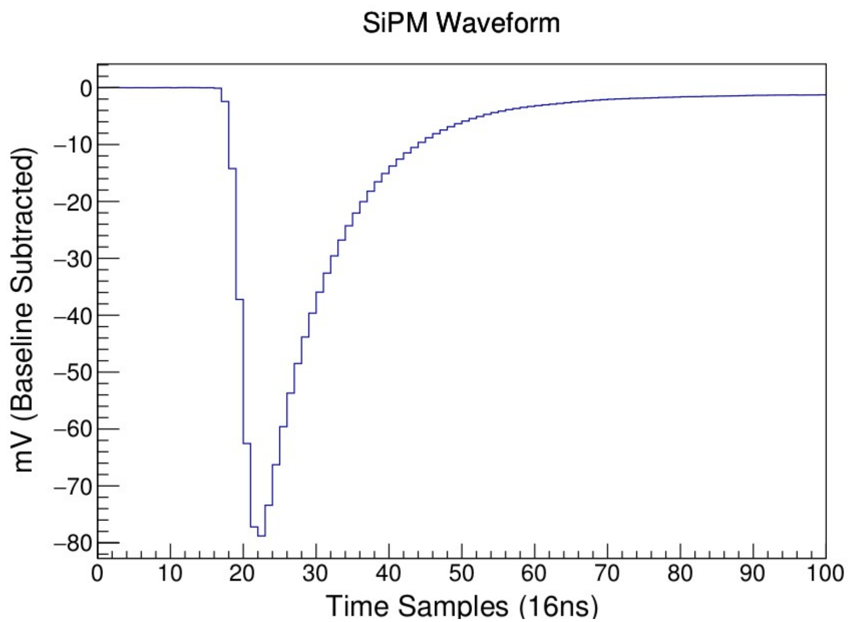
Wire-plane Experiments

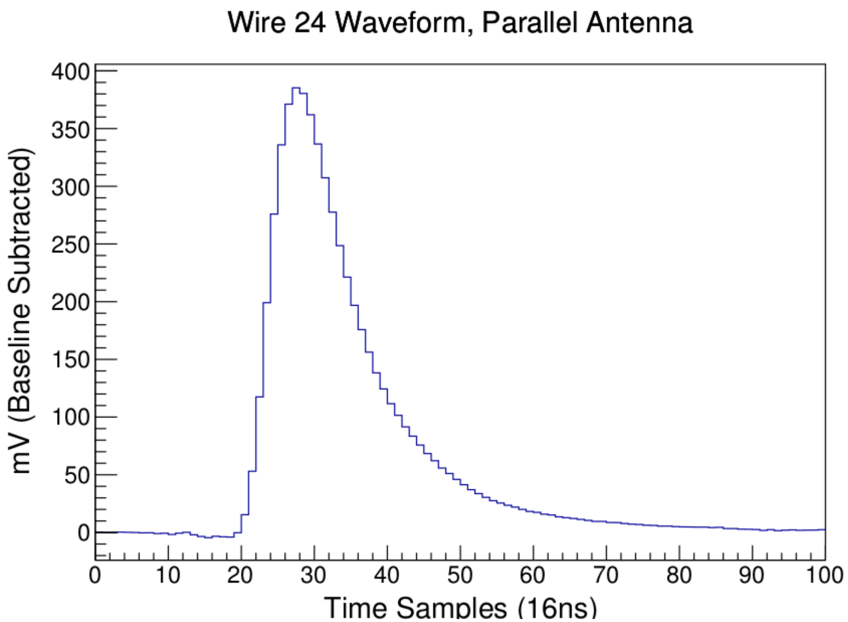


Wire-plane Experiments



Wire-plane Experiments



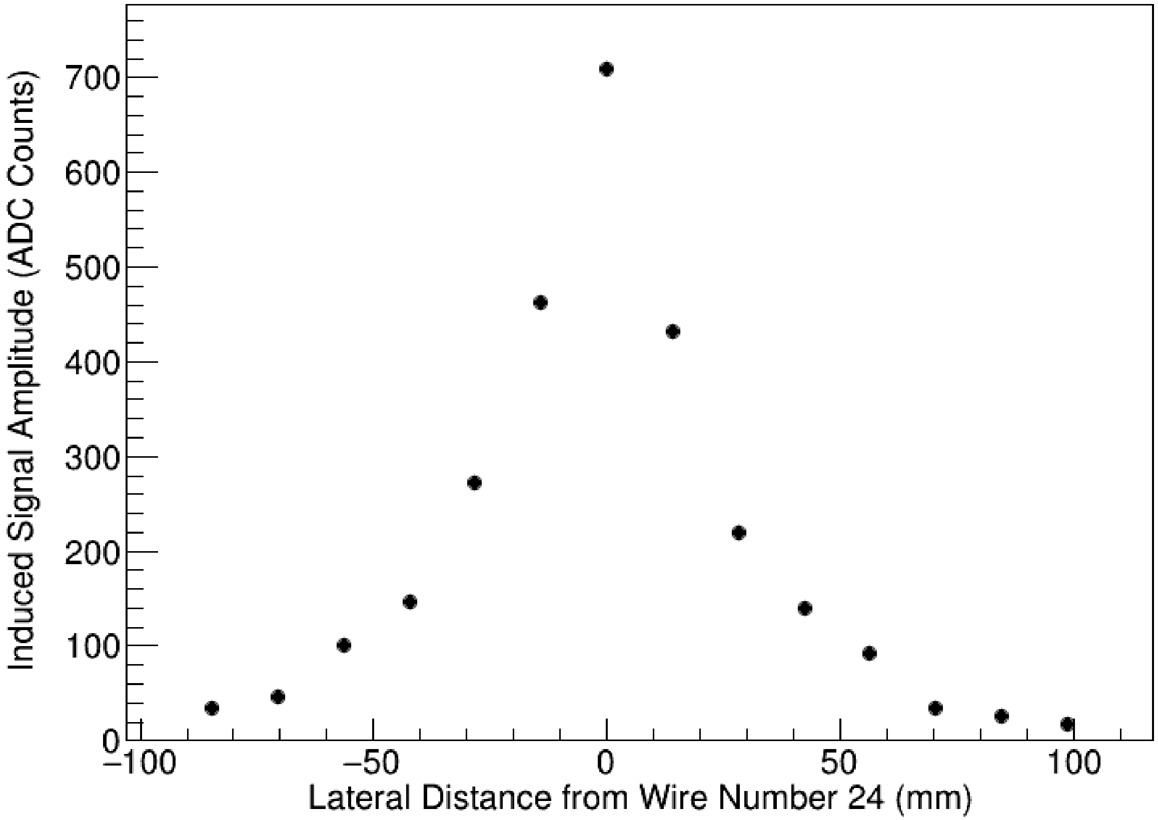


Raw SiPM Waveform

9.1 mV/fC

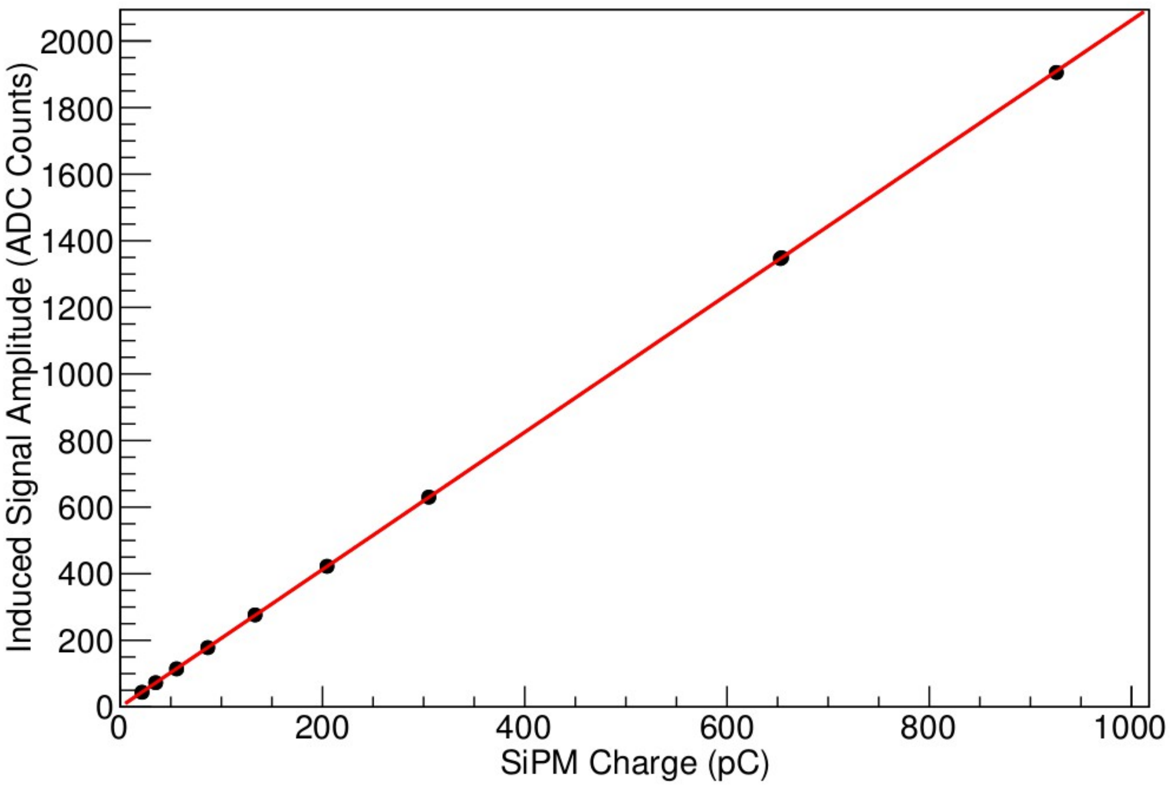
Digitized at 62.5 MHz, 12 bits.

Signal Distribution



Induced signal amplitude as a function of wire distance. The antenna is situated directly above and parallel to wire 24. The vertical distance is 1.3cm.

Linear Response



Slope: 2.063 +/- 0.002, Y-Intercept: -0.069 +/- 0.343 ADC
Chi^2/NDF = 7.17/9

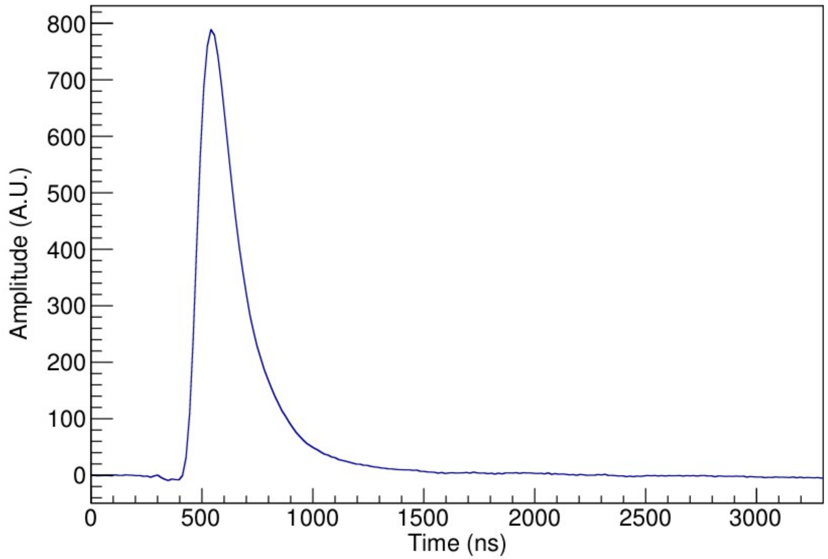
Charge Sensitivity

- Assuming the standard plate configuration used in these experiments (1.3cm vertical distance, parallel configuration) and a SiPM gain of 6x10^6, we estimate a ~3 ADC signal from a single PE at 14mV/fC wire gain.
- Overall gain can be tweaked by varying plate parameters, or through electronics modifications.
- We have not observed single PE signal due to enormous dark noise from warm SiPM.

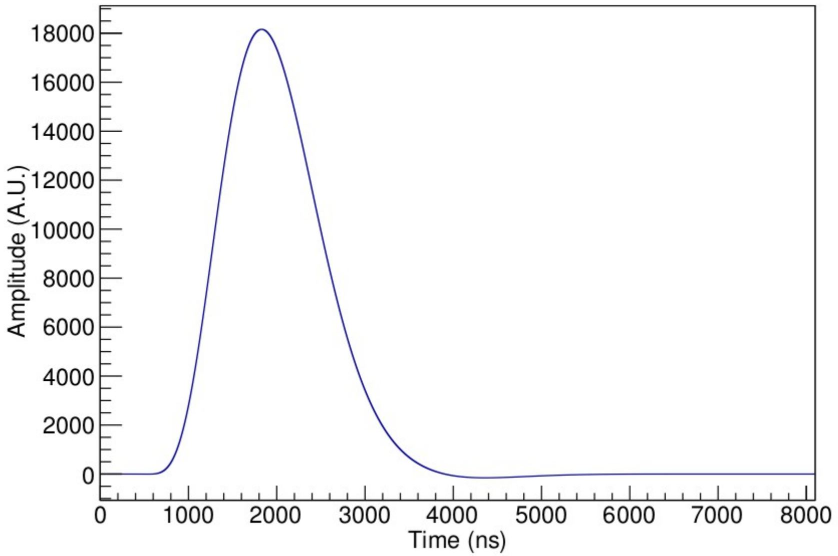
Timing Studies

- The MicroBooNE optical readout ADCs operate at ~62MHz
- The shaping time is 60ns.
- The wire-plane readout ADCs operate at 2MHz.
- Their shaping time is 0.5-3 microseconds.
- What happens to our timing resolution?
- Let's look at the effects of noise and sampling variation.

Timing Studies

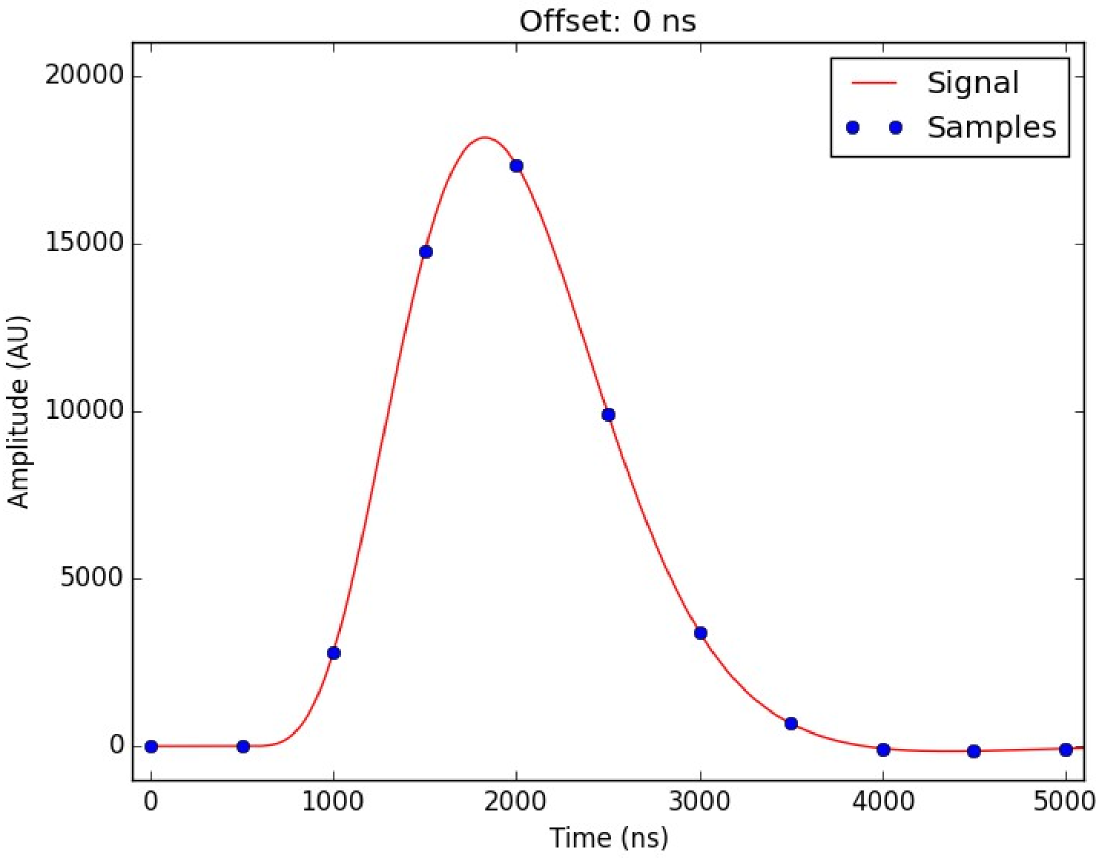


An averaged wire waveform from wire 24.

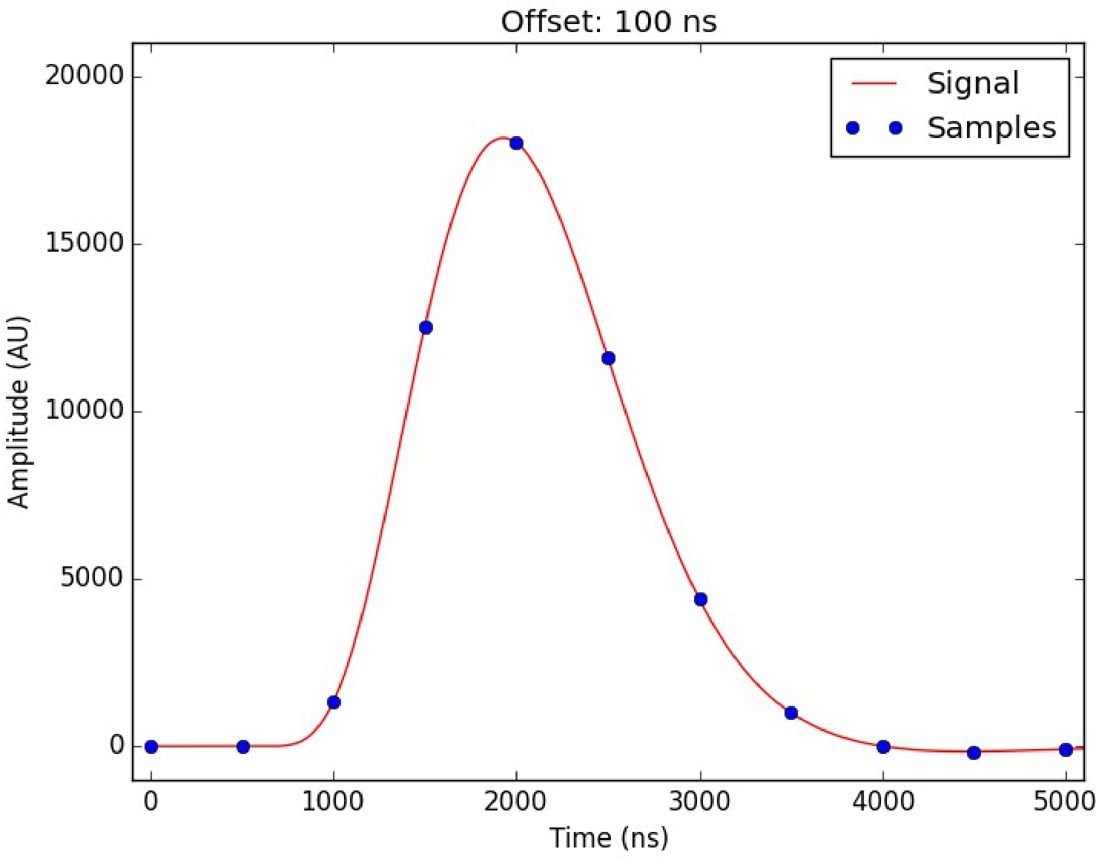


The same waveform, convolved with the 1 microsecond MicroBooNE kernel.

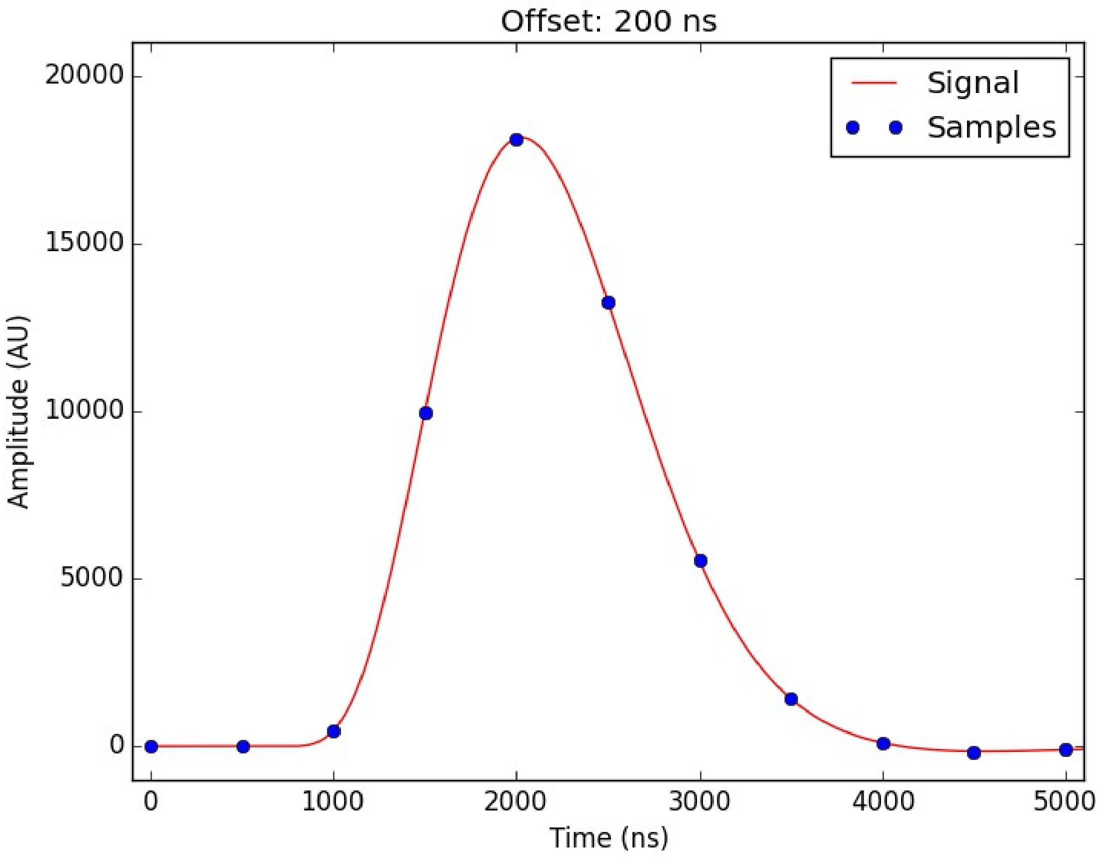
Timing Variation



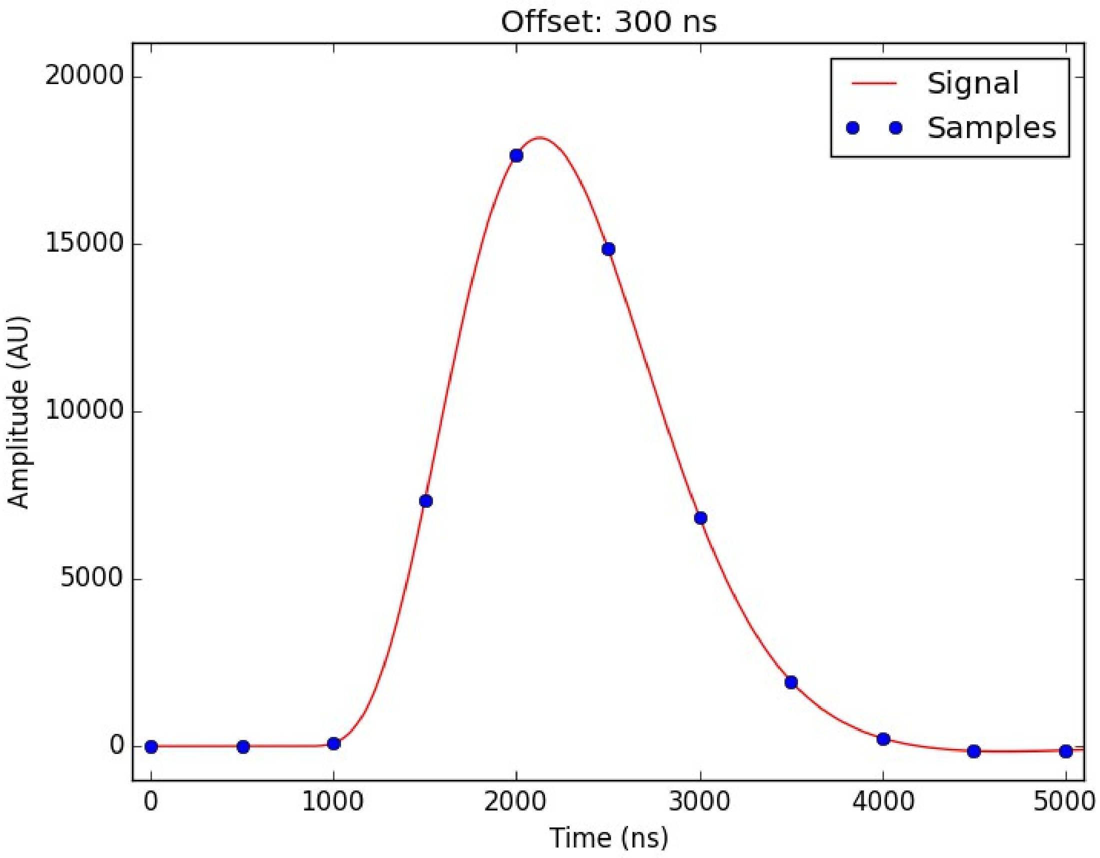
Timing Variation



Timing Variation



Timing Variation



Constant Fraction Discrimination

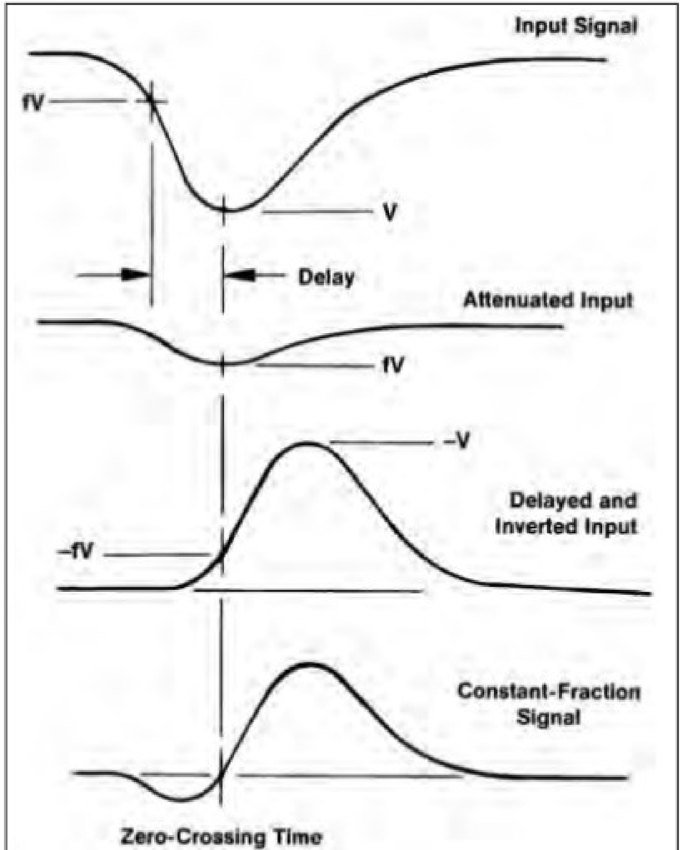
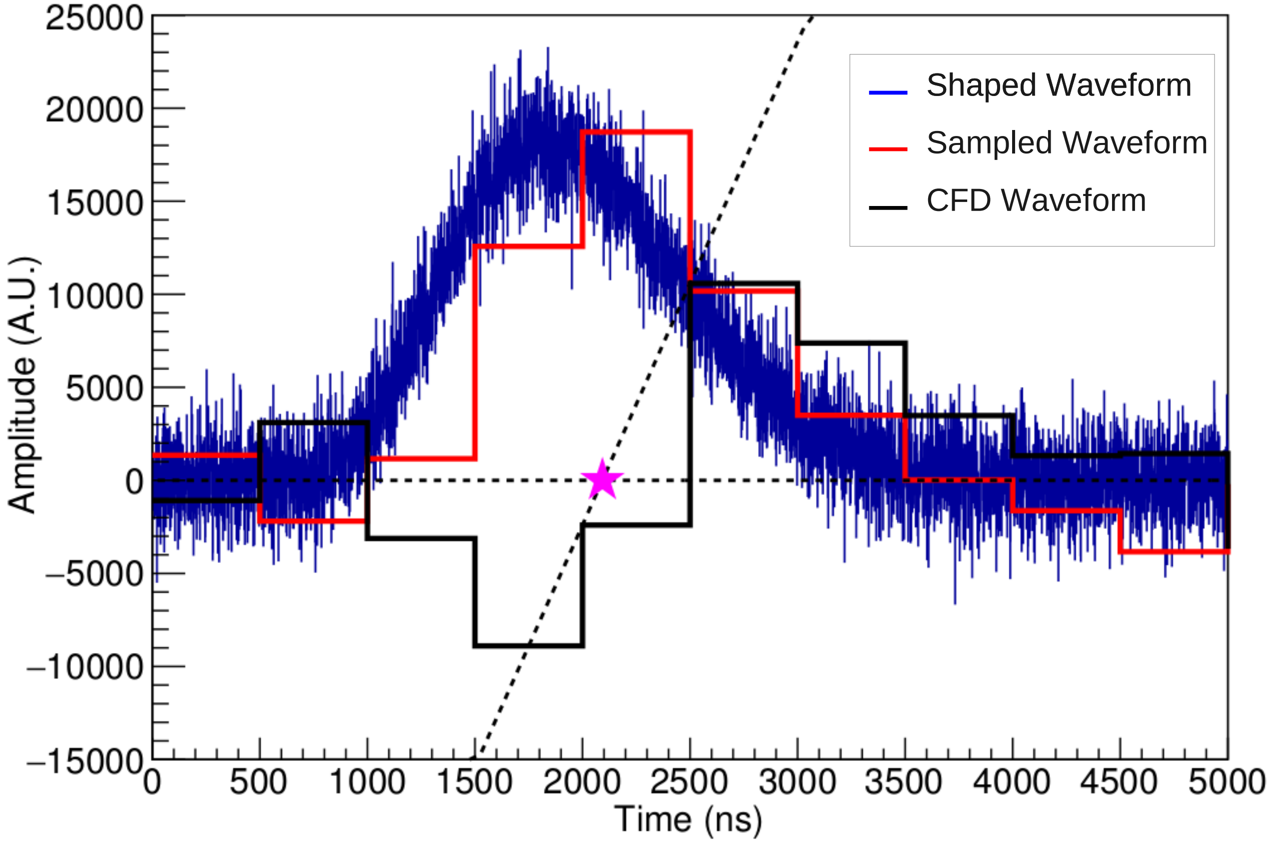


Fig. 3. Formation of the Constant-Fraction Signal.

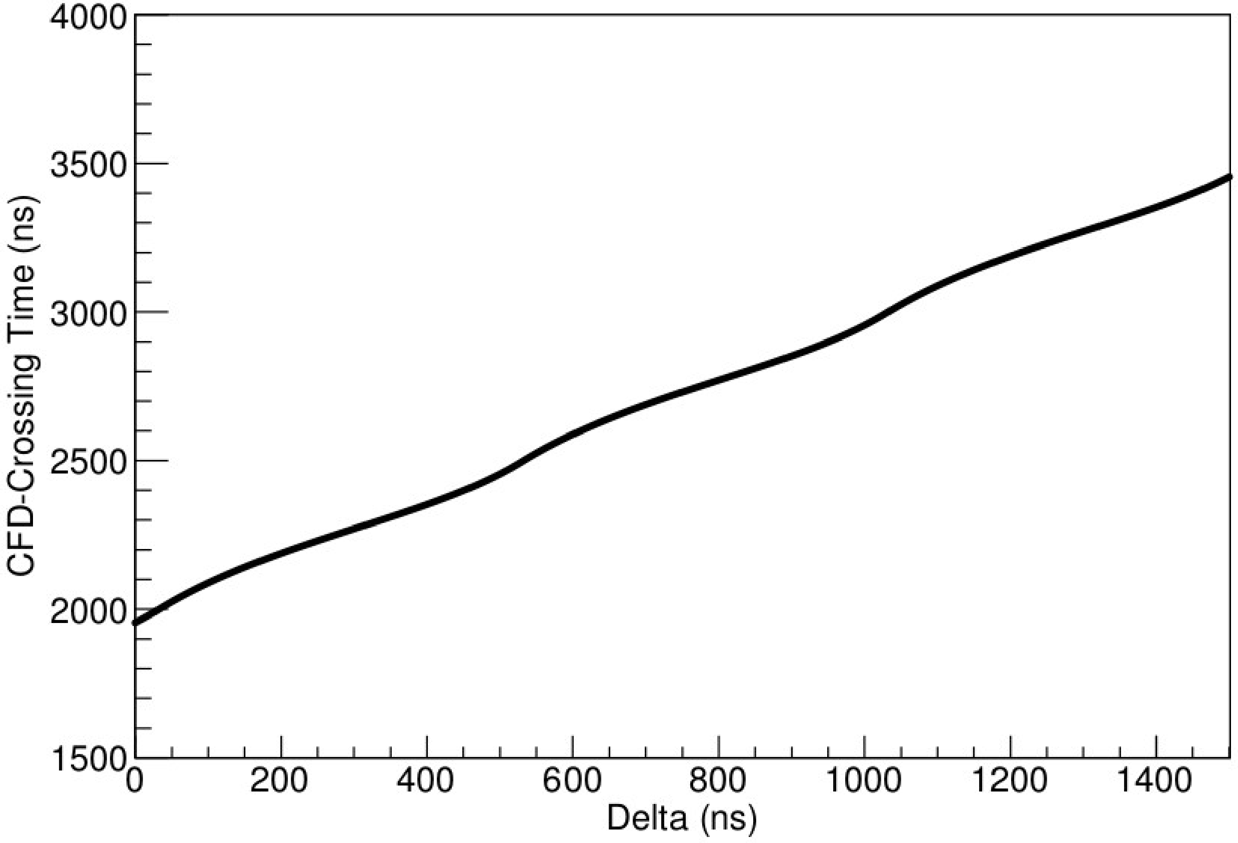
"*Introduction to Fast Timing Discriminators*", Ortec.

Our CFD Implementation



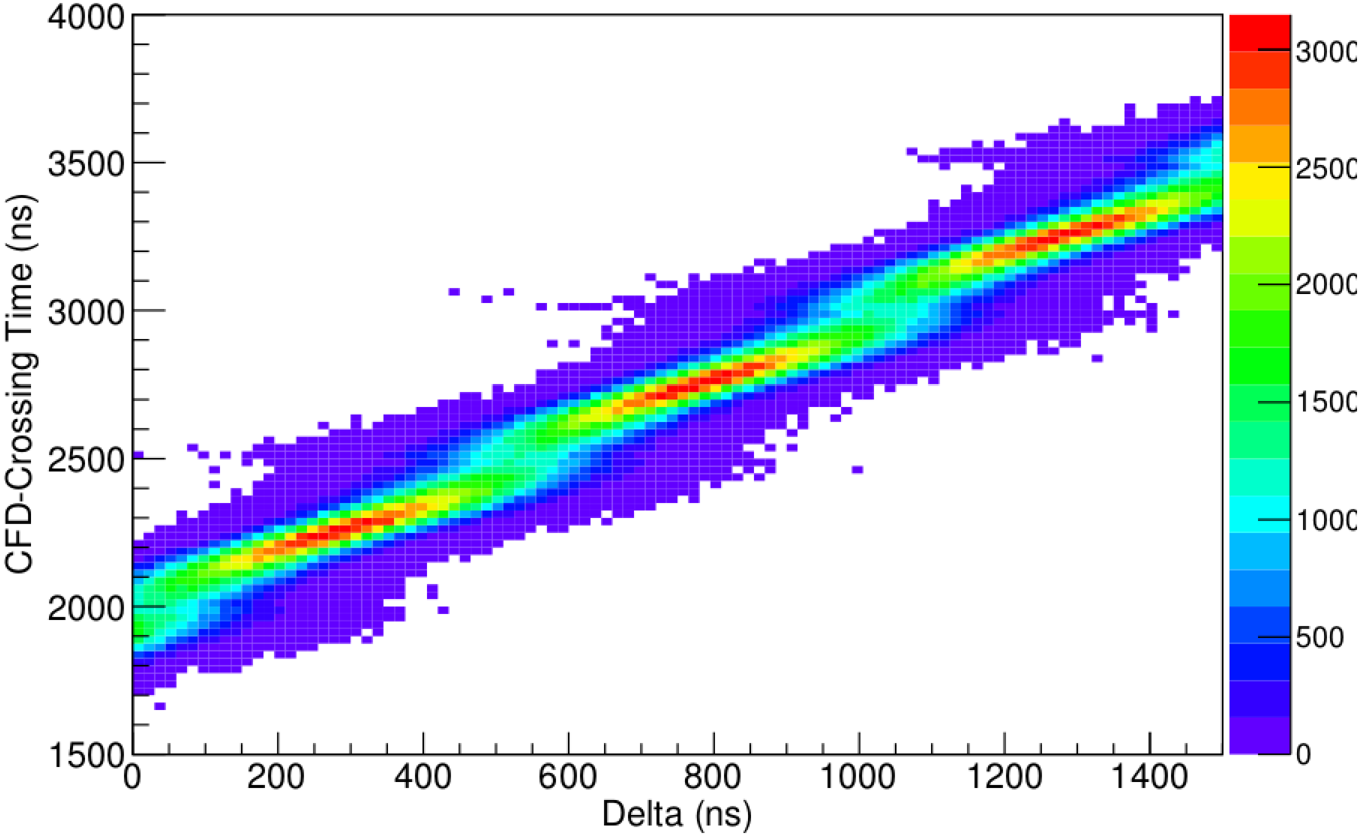
10% noise added to the shaped signal.

CFD Without Noise



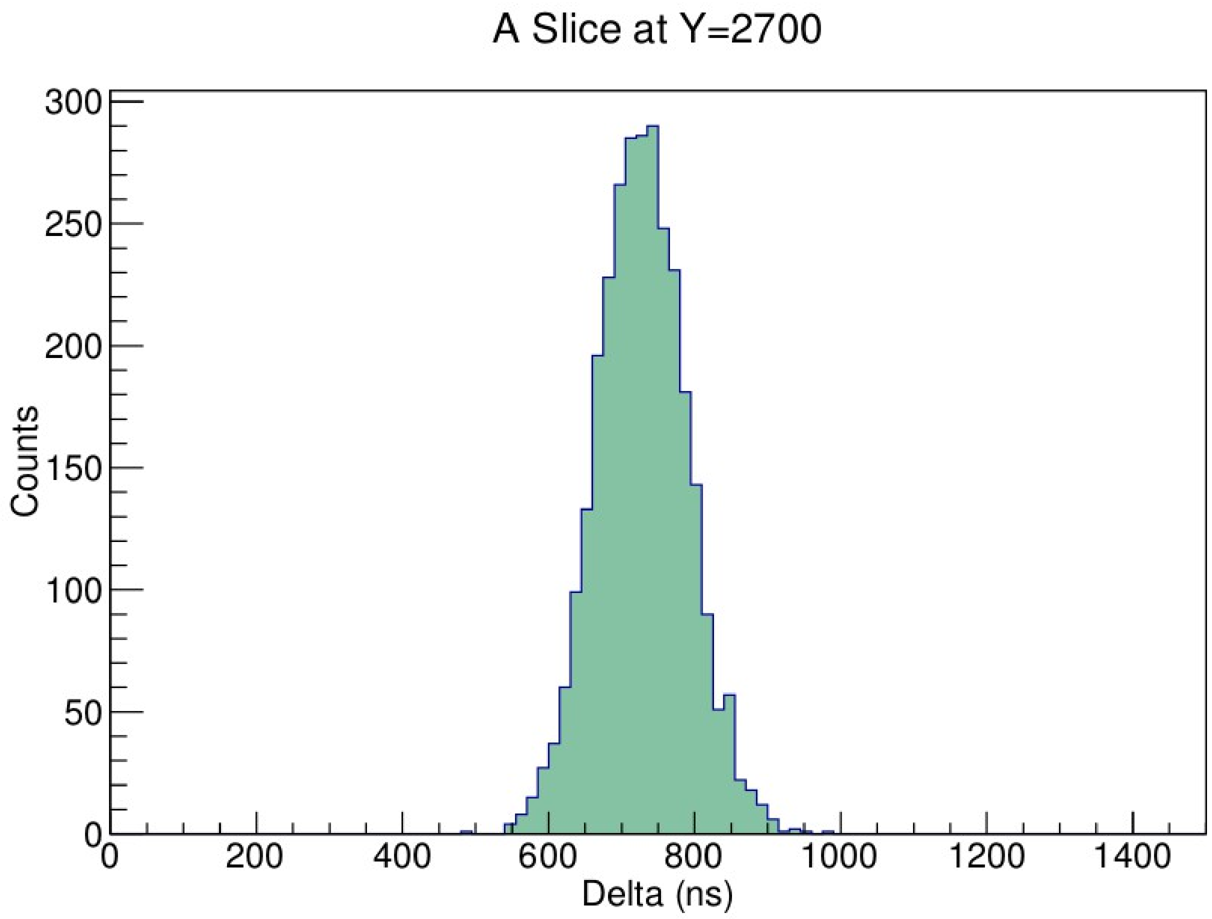
CFD Performance for noiseless waveforms.

CFD With 10% Noise



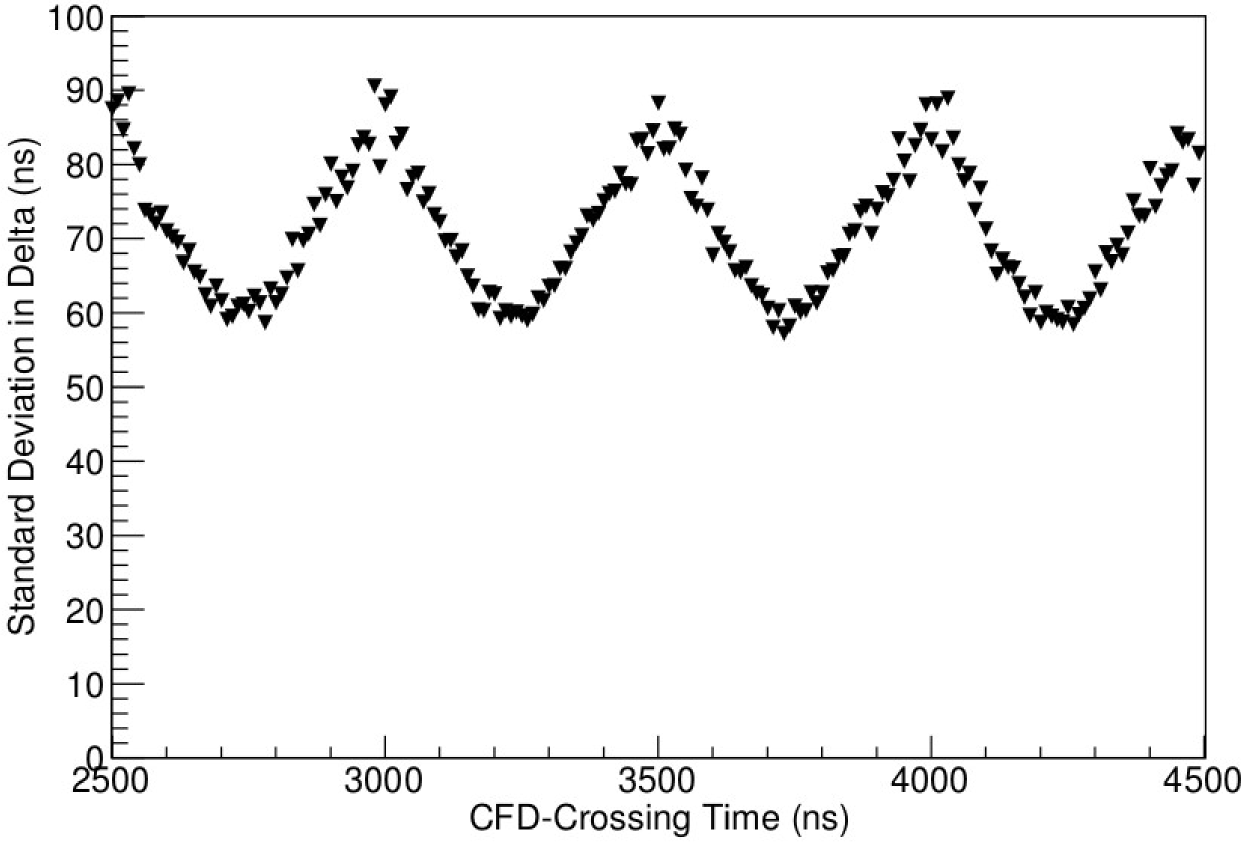
CFD Performance for 1000 noised waveforms per delta value.

Slice RMS



A Projection of the distribution onto the delta axis.
The RMS width is our figure of merit for t_0 reconstruction.

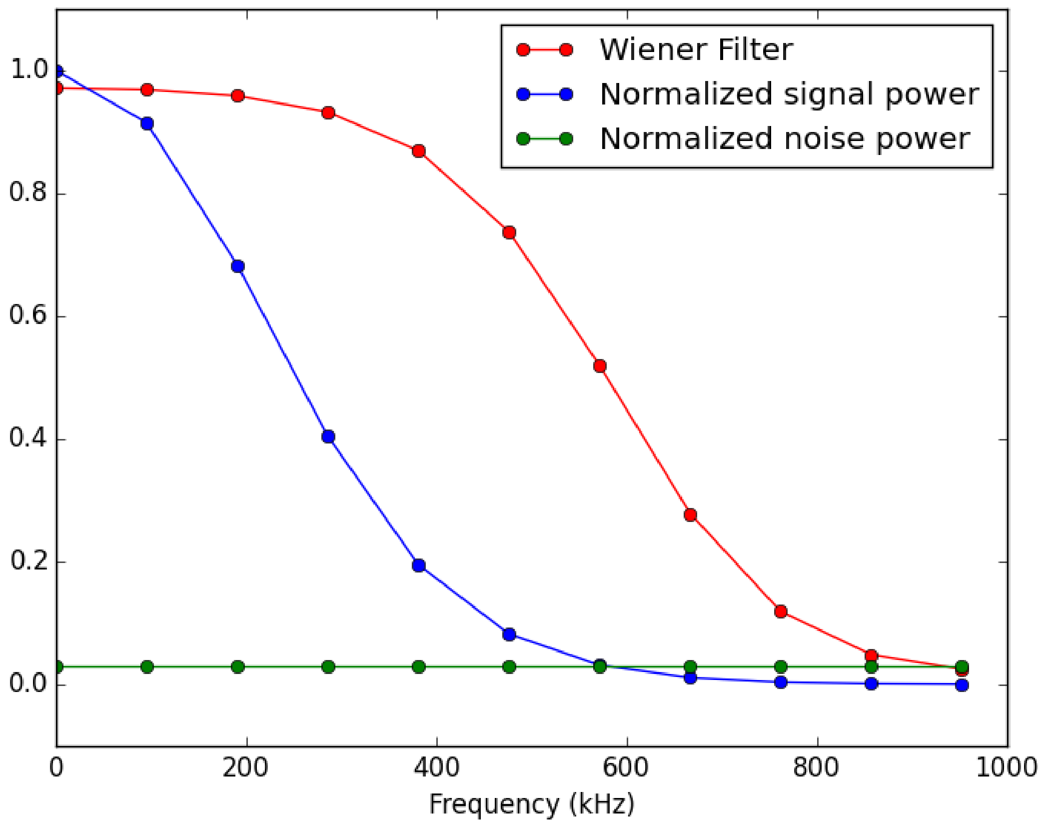
RMS vs CFD Crossing Time



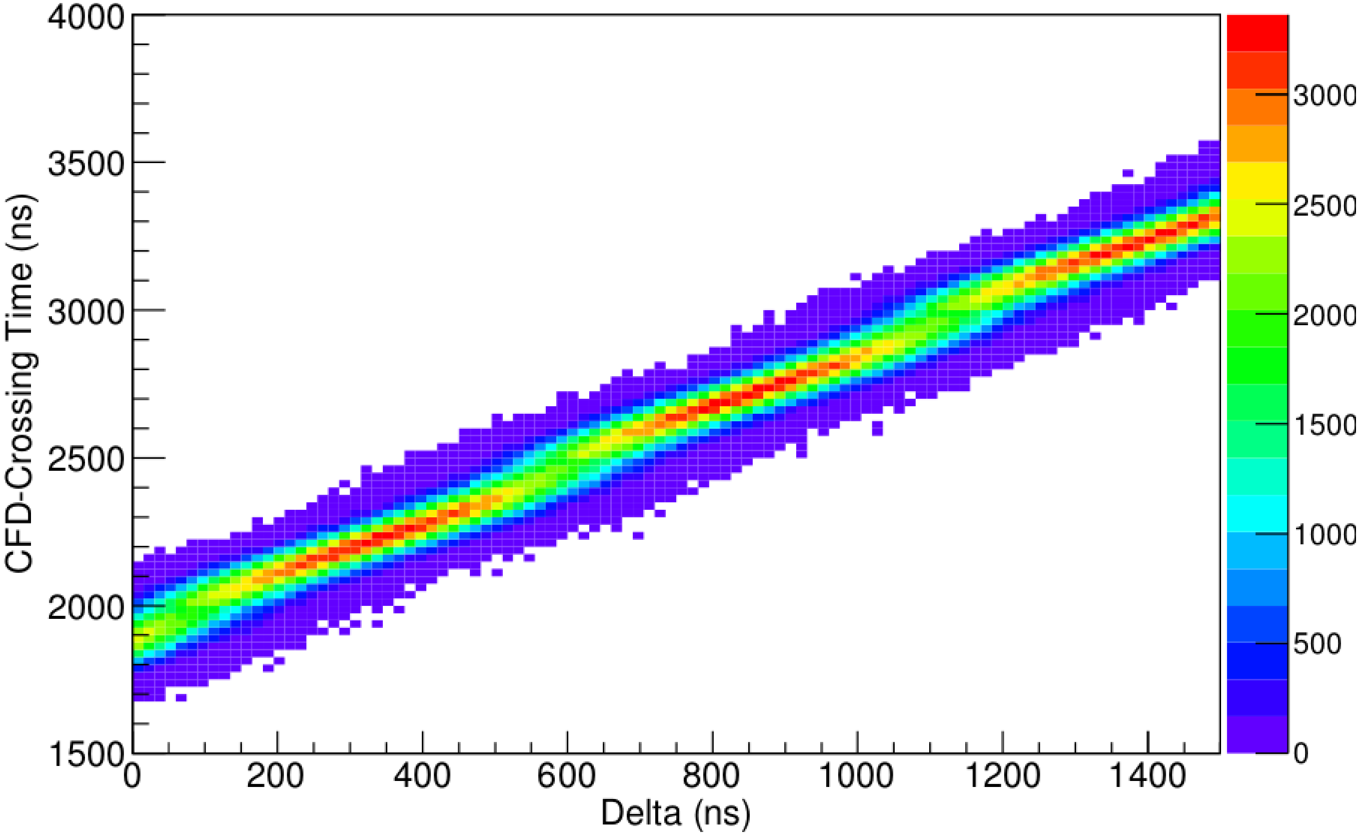
Wiener Filtering

- MicroBooNE will use Wiener filtering on its wire signals.
- We estimated power spectra for our applied noise (white noise: the spectrum is flat) and for our shaped and sampled signals.

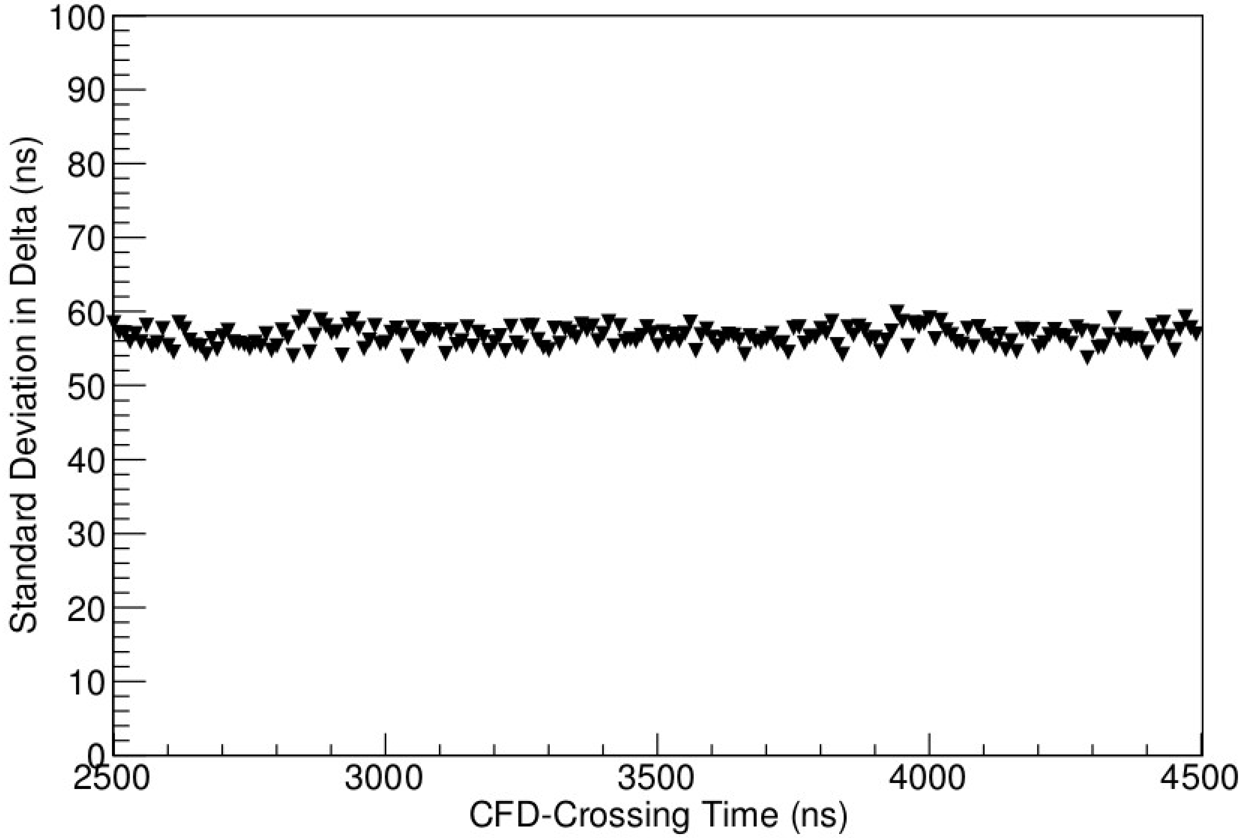
Wiener Filtering



CFD with Wiener Filtering



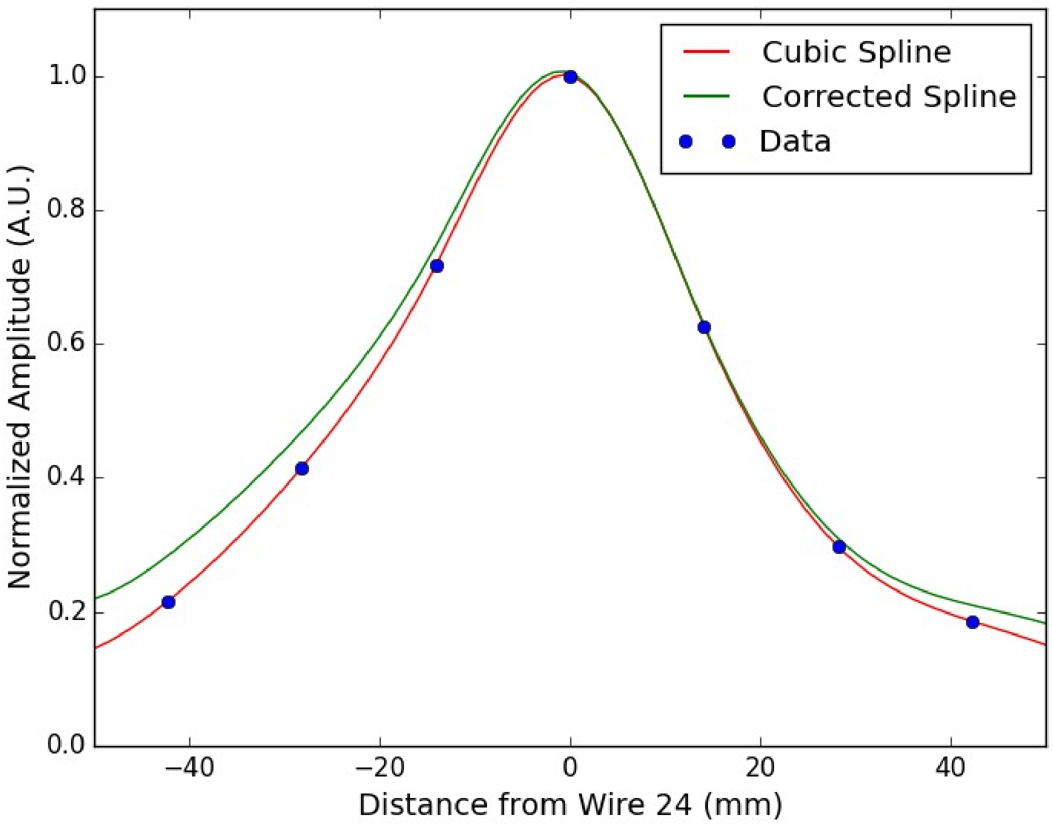
RMS with Wiener Filtering



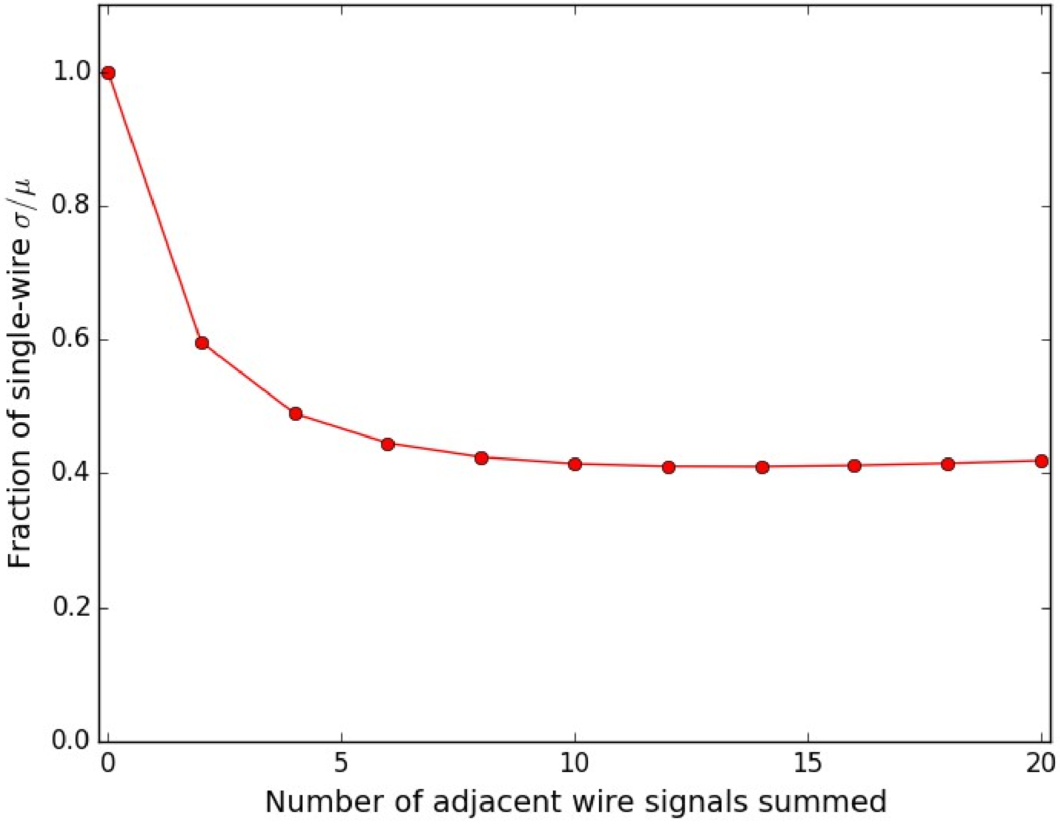
Exploiting Signal from Multiple Wires

- Judging by the induced signal pattern on slide 8, the wires adjacent to the maximal wire carry significant signal.
- Summing these signals may provide an advantageous signal to noise ratio (SNR), provided the signal drops off slowly, and that the noise is uncorrelated wire-to-wire.

Interpolated Signal Strength

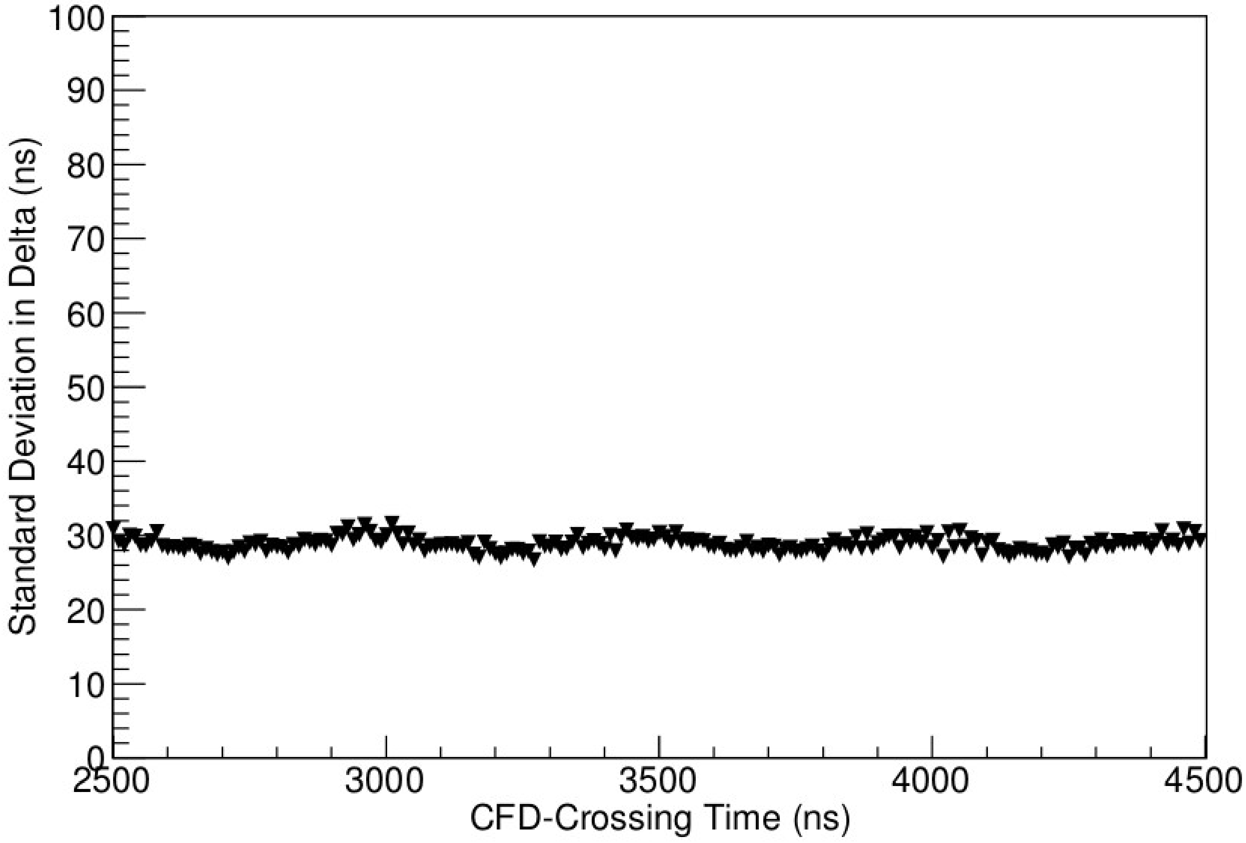


SNR Advantage



Using only 4 adjacent wires, we find a reduction in fractional noise RMS of over 2.

Expected RMS After Noise Reduction



30 ns RMS timing resolution!

Potential Hurdles

- Will an un-amplified SiPM produce a strong enough signal? Yes!
- Will the slow digitization and shaping times ruin our timing resolution? No!
- How good is our charge resolution? Can we see single PE? → Planned Bo run in fall.
- Will optical backgrounds swamp the charge readout?

Optical Backgrounds

- We don't expect significant overlap between light and charge signal due to long drift times.
- Deep underground, the cosmic rate is low (DUNE CDR says 0.26 Hz), and is extremely unlikely to cause overlap with real charge signals.
- The SiPM dark rate at cryogenic temperatures is ~10Hz
- Ar39 seems to be the biggest question.
- Can we fit for signal distribution and denoise?
- We can examine the possibilities this fall with a Bo run!

Thank you!

Potential Implementation

- Consider an array of 16 SiPMs, each coated with wavelength shifter.
- Loss in area, gain in efficiency.
- Dune continuously digitizes.
- 0.2% coverage: no trouble with plate occlusion.
- 4x4 plate has ~30% probability of inducing signal every 2.3ms, but the signal is small.
- Stagger plates to associate signal with TPC.