Anode-Coupled Readout for Light Collection in Liquid Argon TPCs

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[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

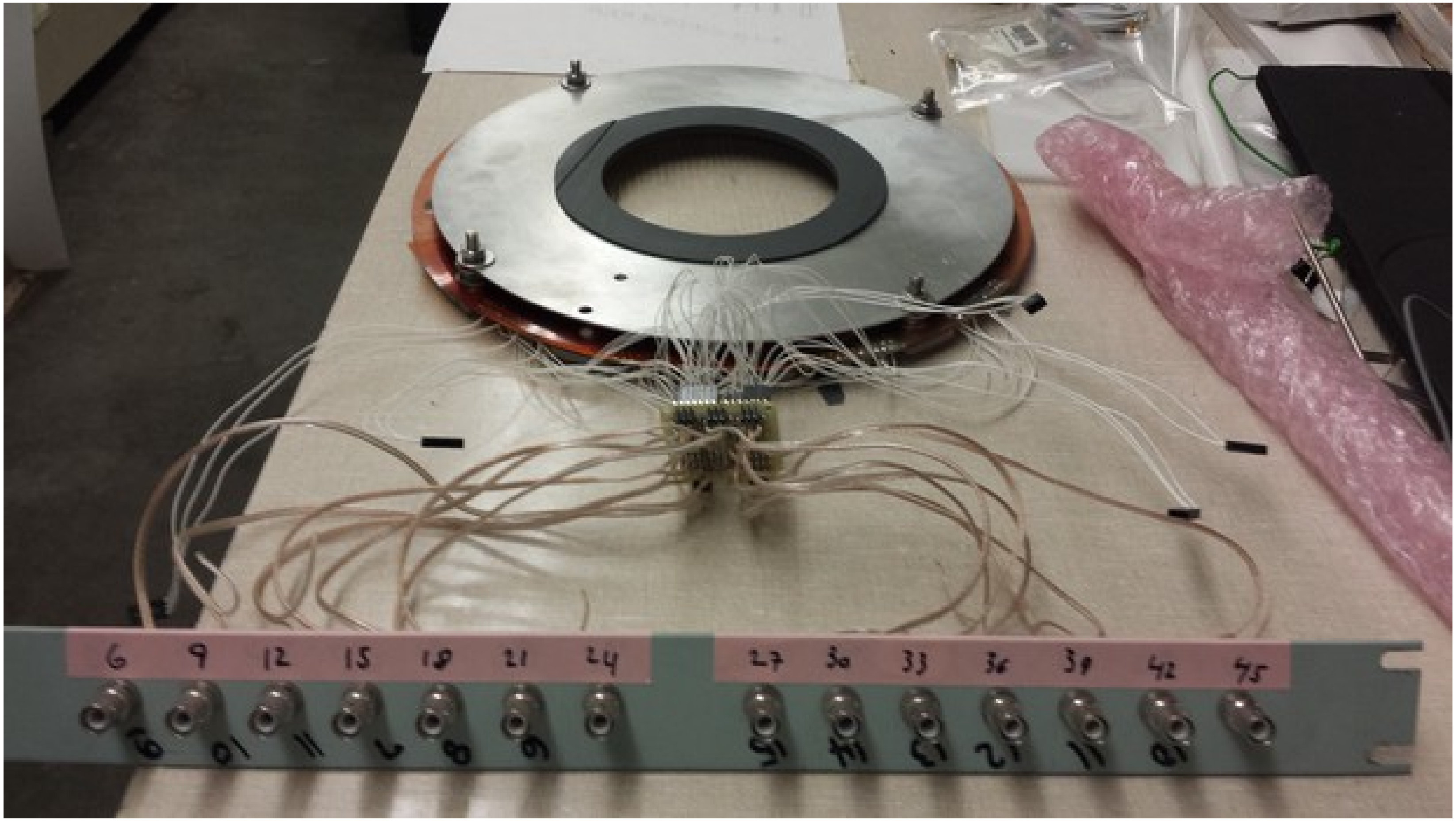
The Idea

- 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.

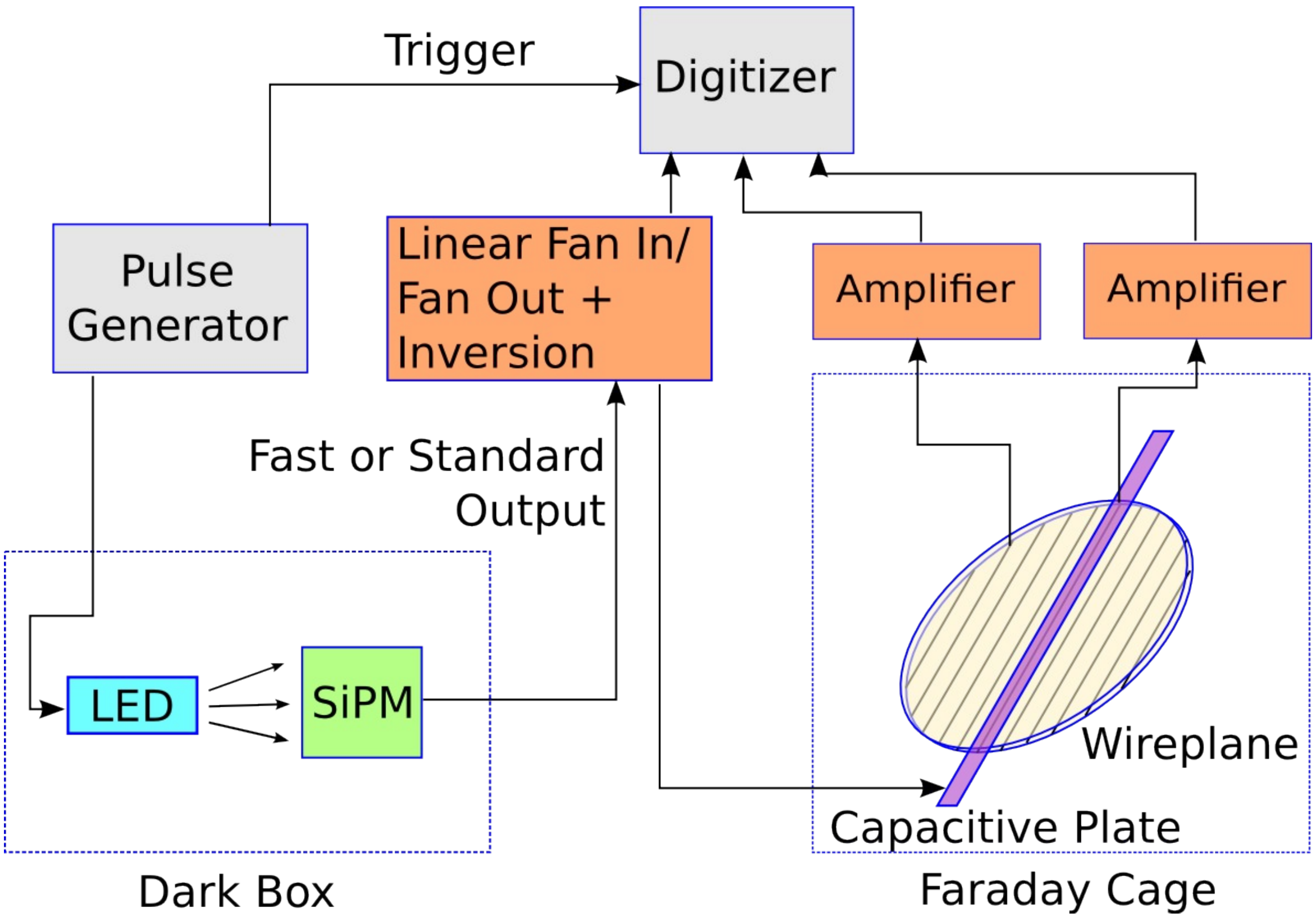
Potential Hurdles

- 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?

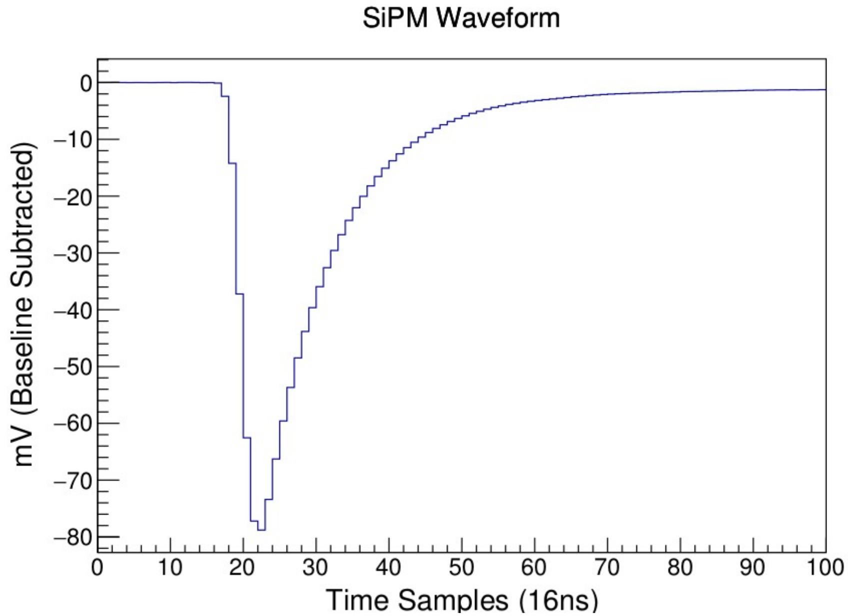
Wire-plane Experiments



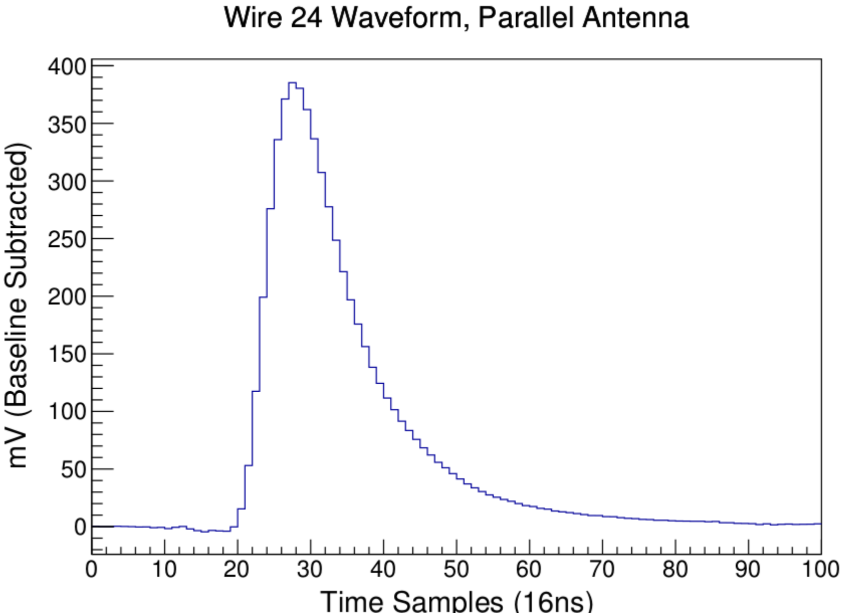
Wire-plane Experiments



Wire-plane Experiments



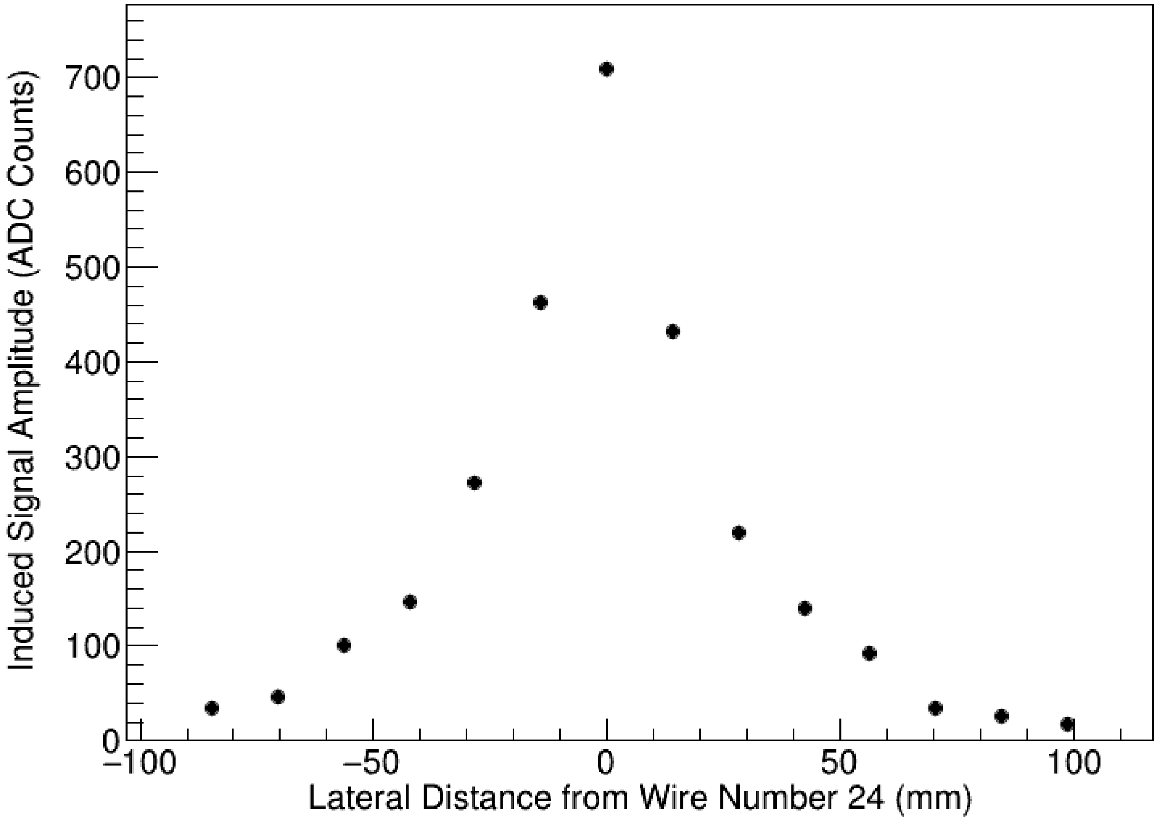
Raw SiPM Waveform



9.1 mV/fC

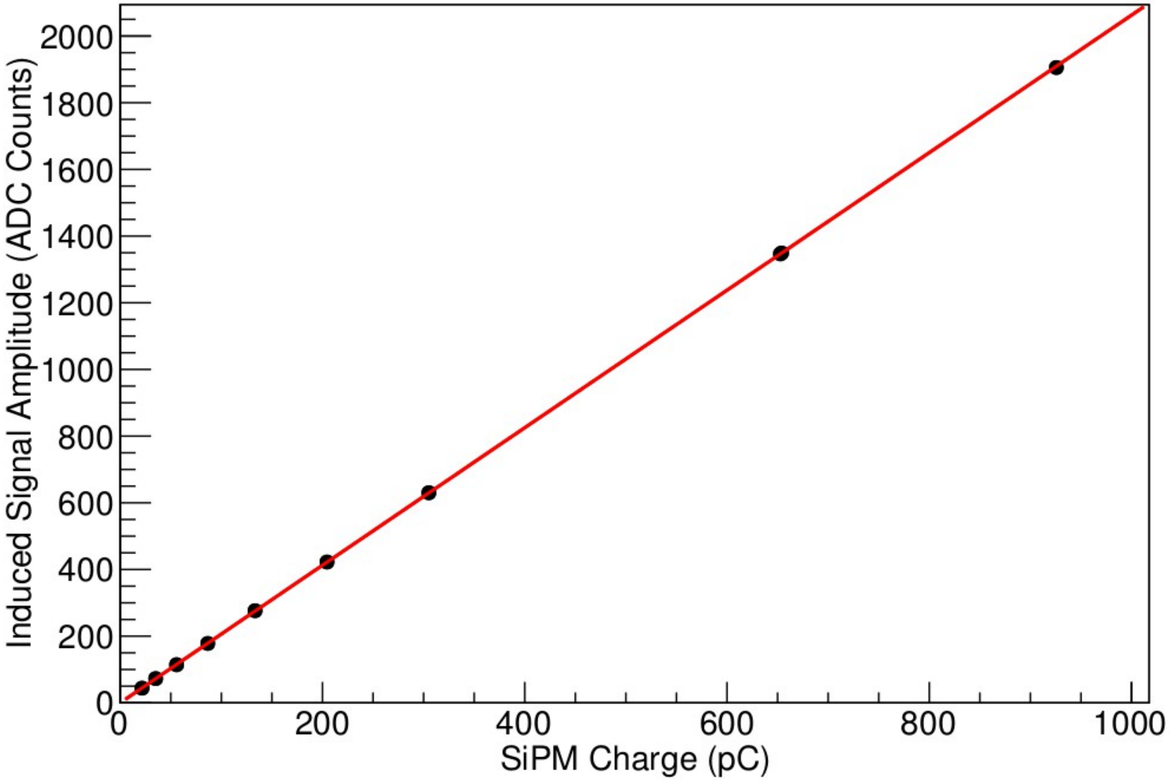
Digitized at 62.5 MHz, 12 bits.

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

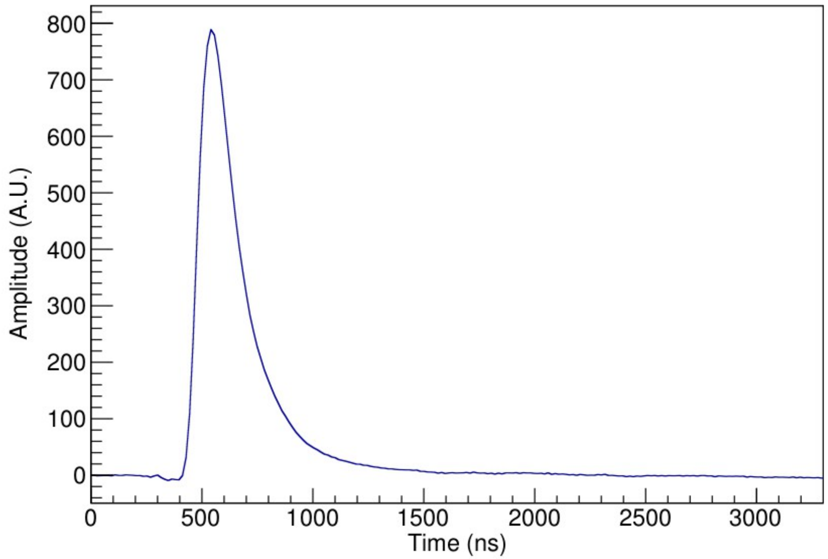
Charge Sensitivity

- 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.

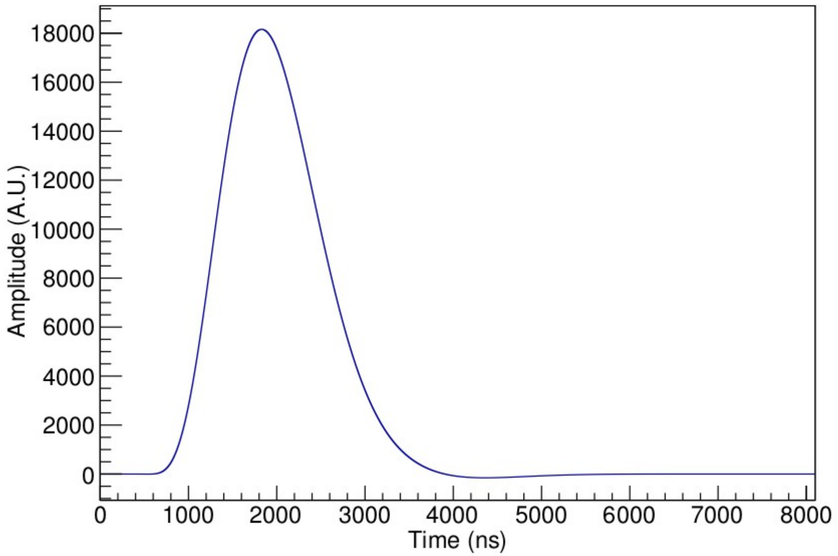
Timing Studies

- The MicroBooNE optical readout ADCs operate at 64MHz
- 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

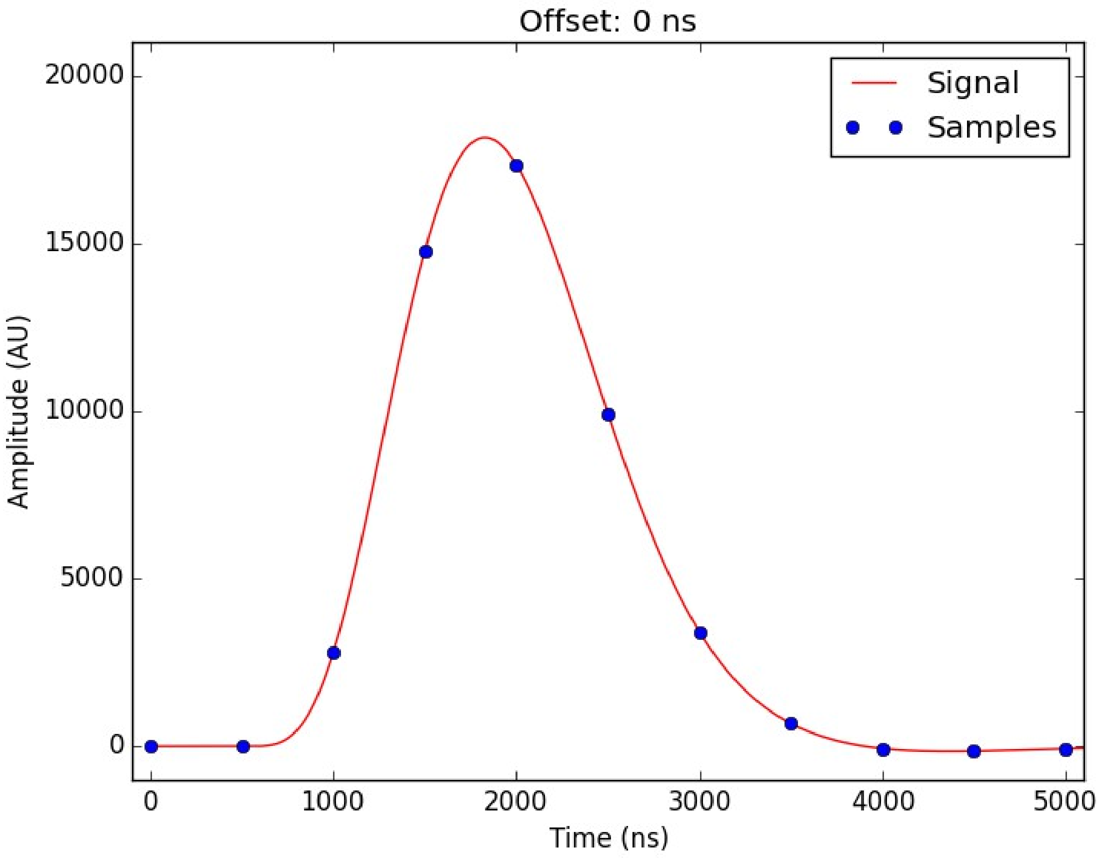


An averaged wire waveform from wire 24.

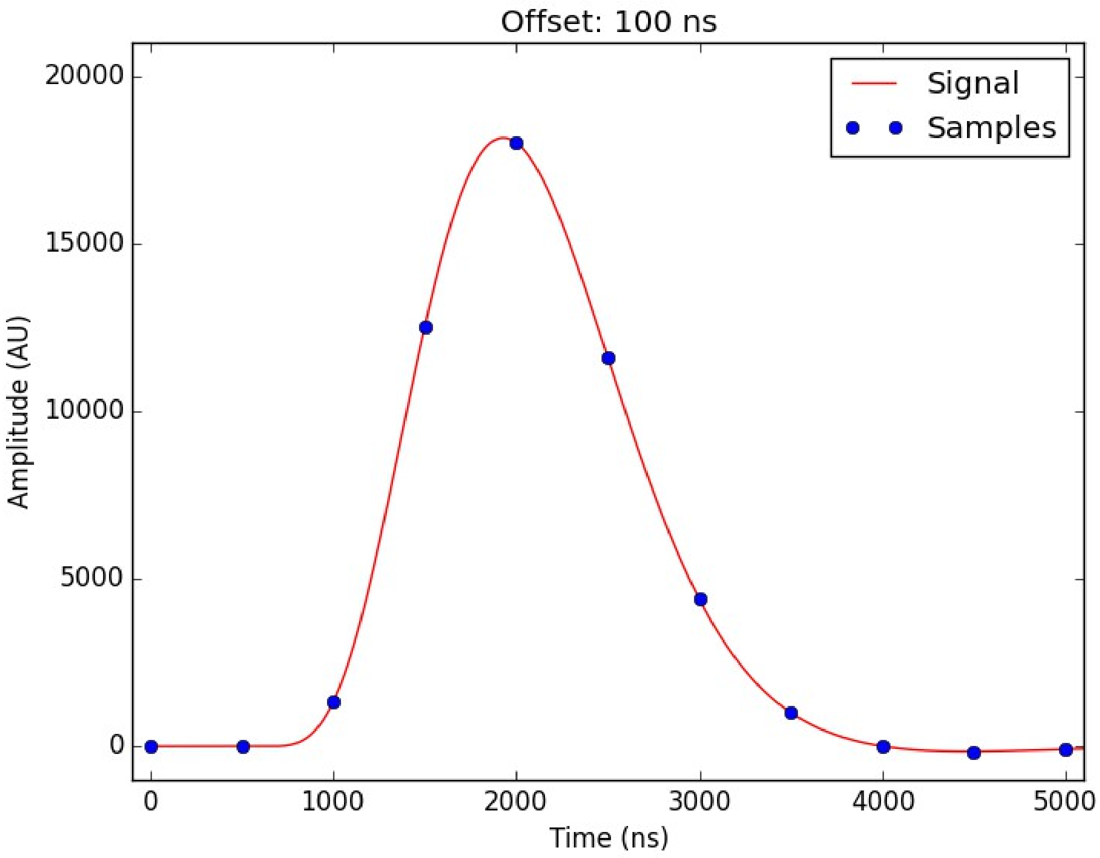


The same waveform, convolved with the 0.5 microsecond MicroBooNE kernel.

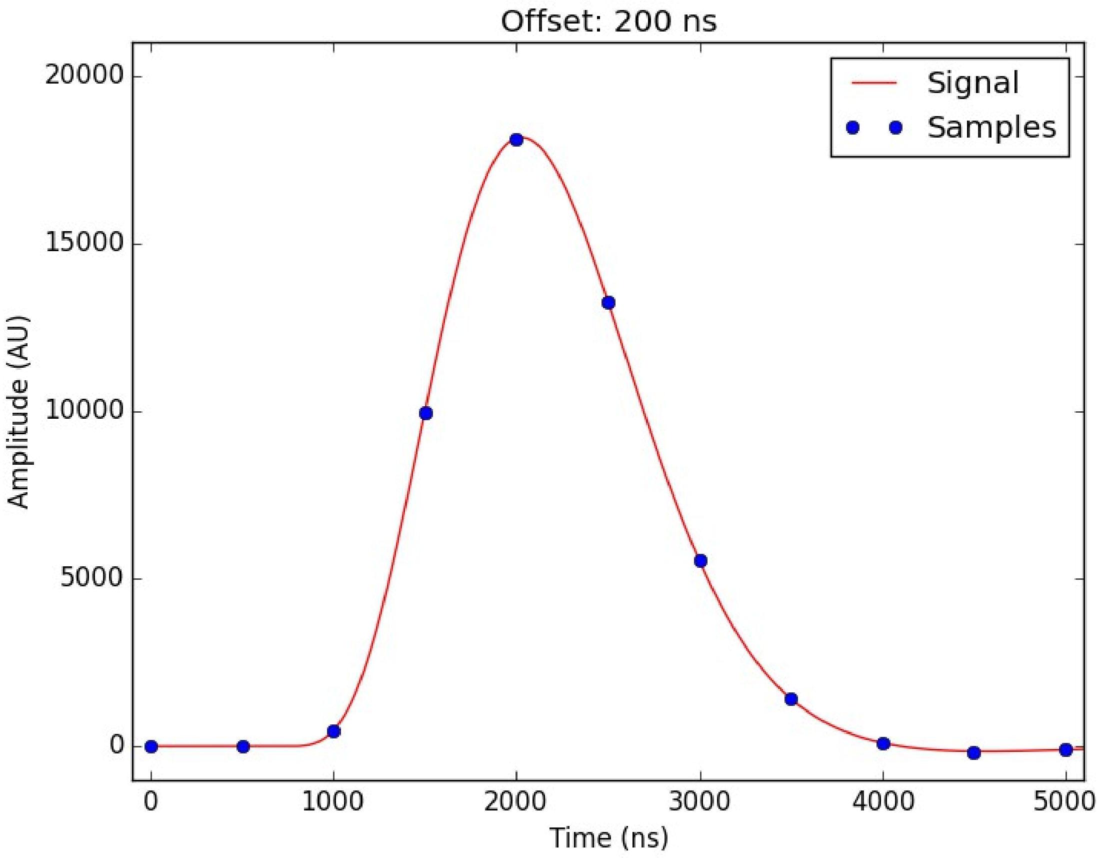
Timing Variation



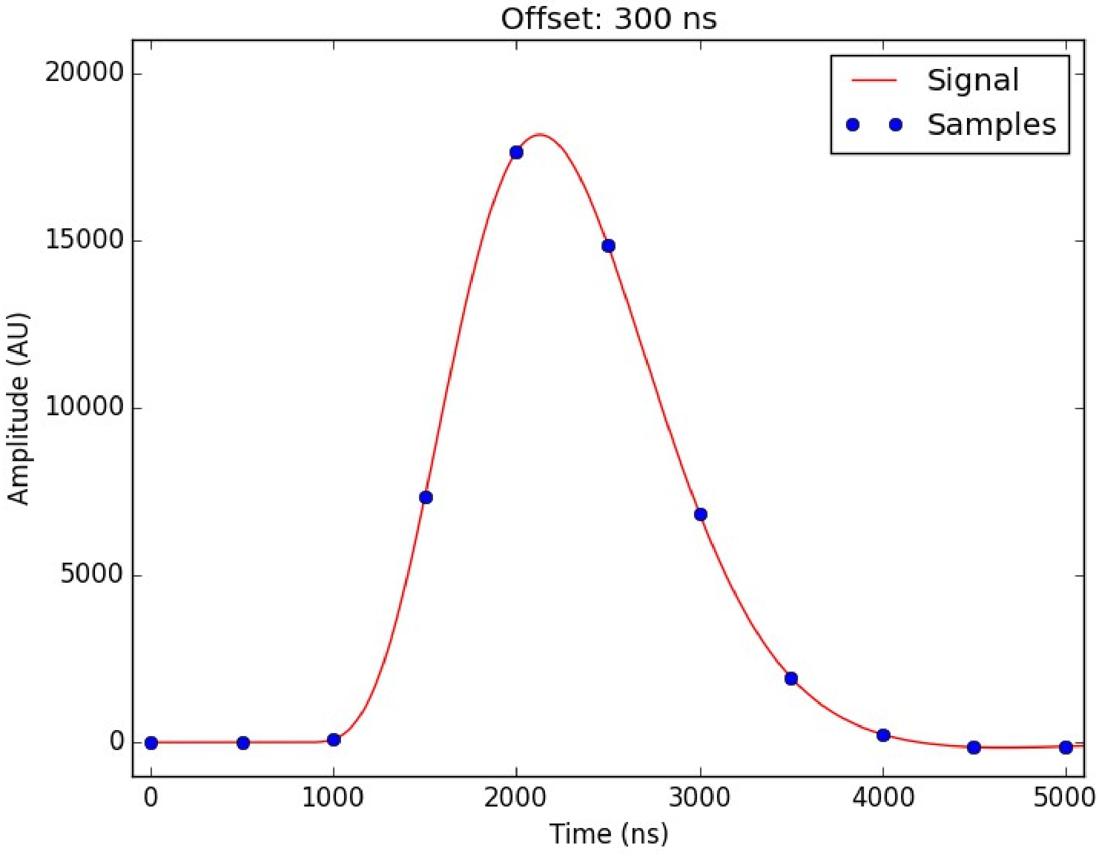
Timing Variation



Timing Variation



Timing Variation



Constant Fraction Discrimination

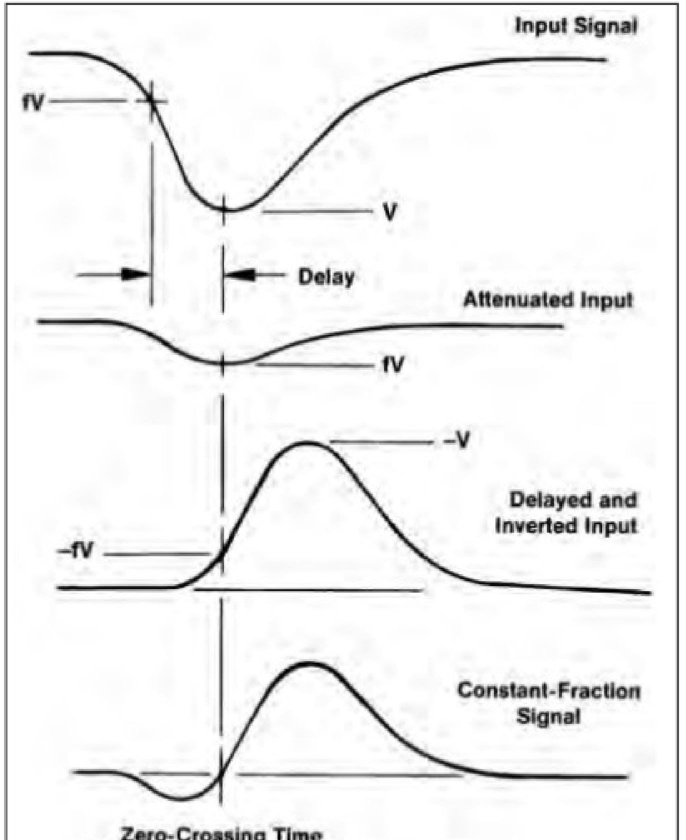
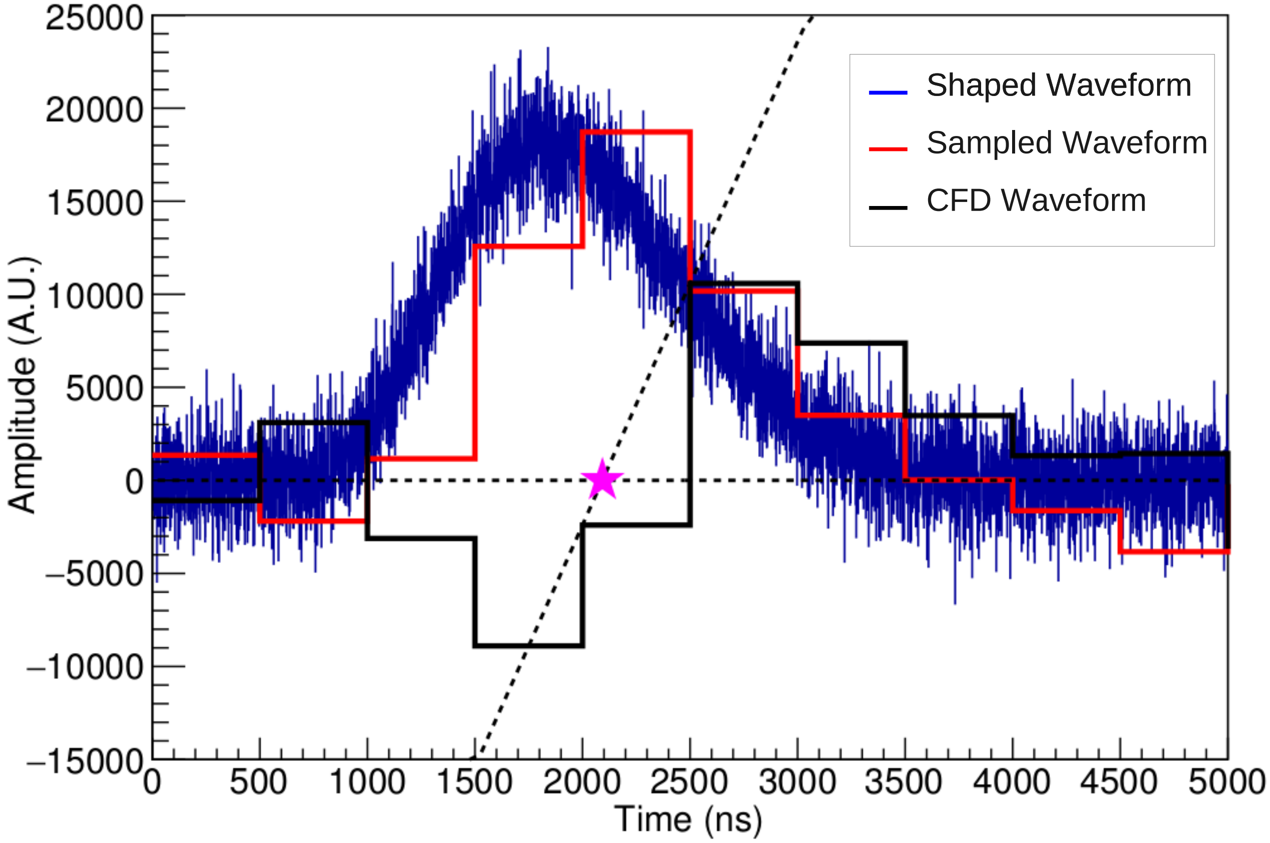


Fig. 3. Formation of the Constant-Fraction Signal.

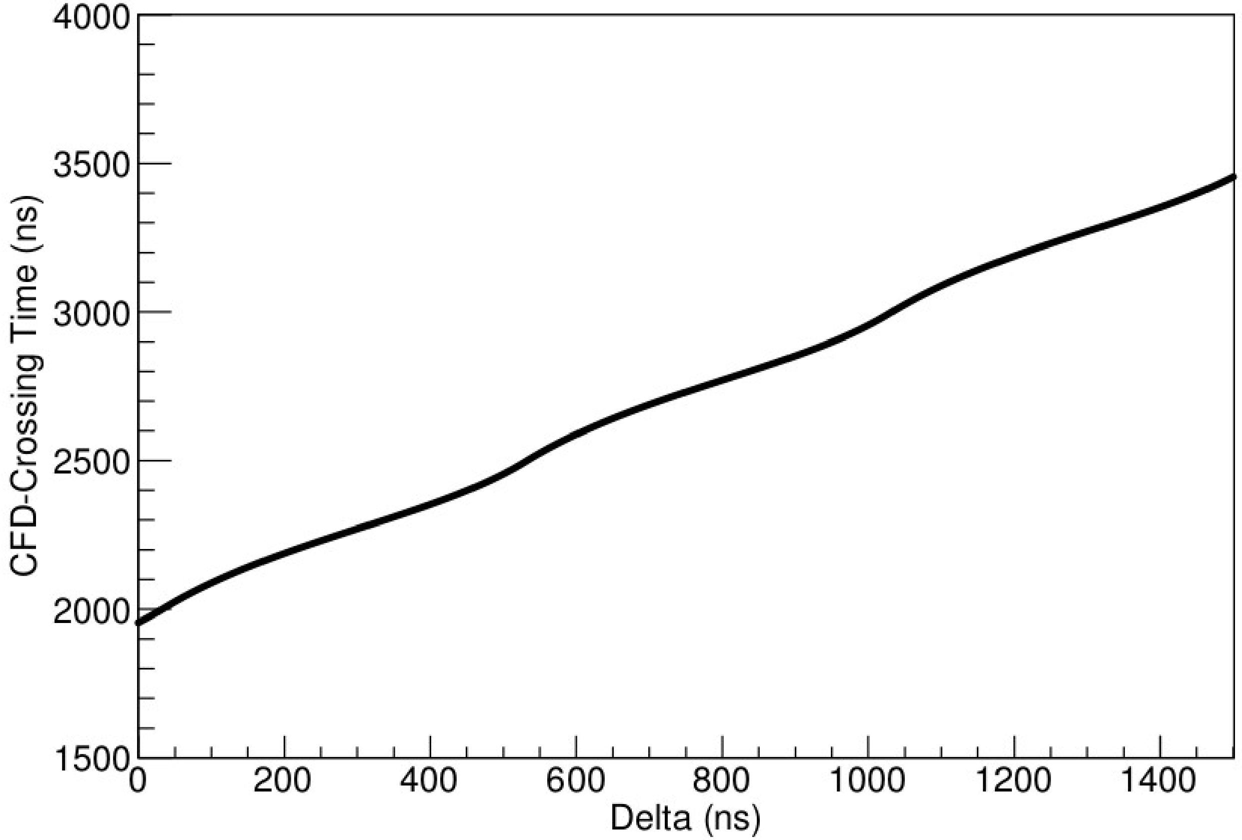
“*Introduction to Fast Timing Discriminators*”, Ortec**.**

Our CFD Implementation



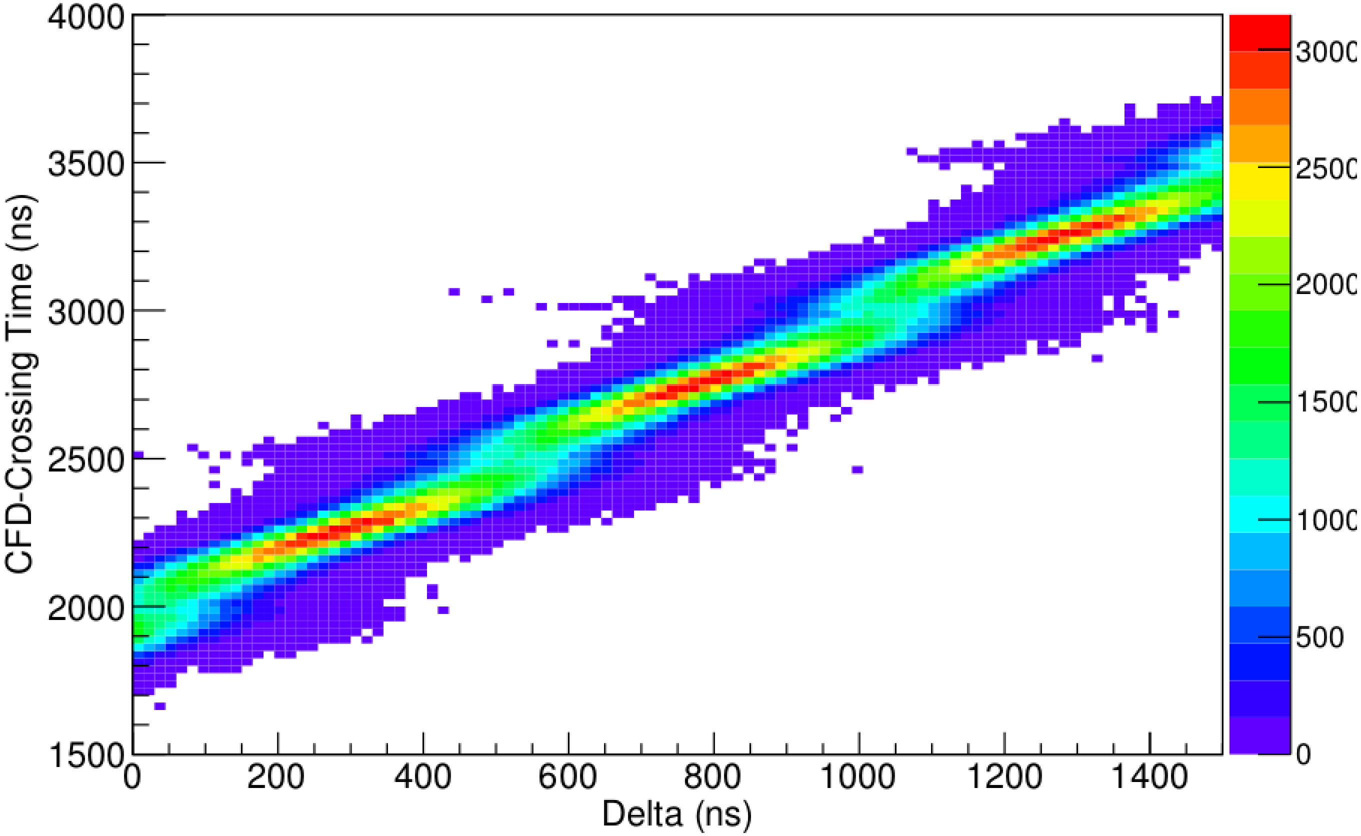
10% noise added to the shaped signal.

CFD Without Noise



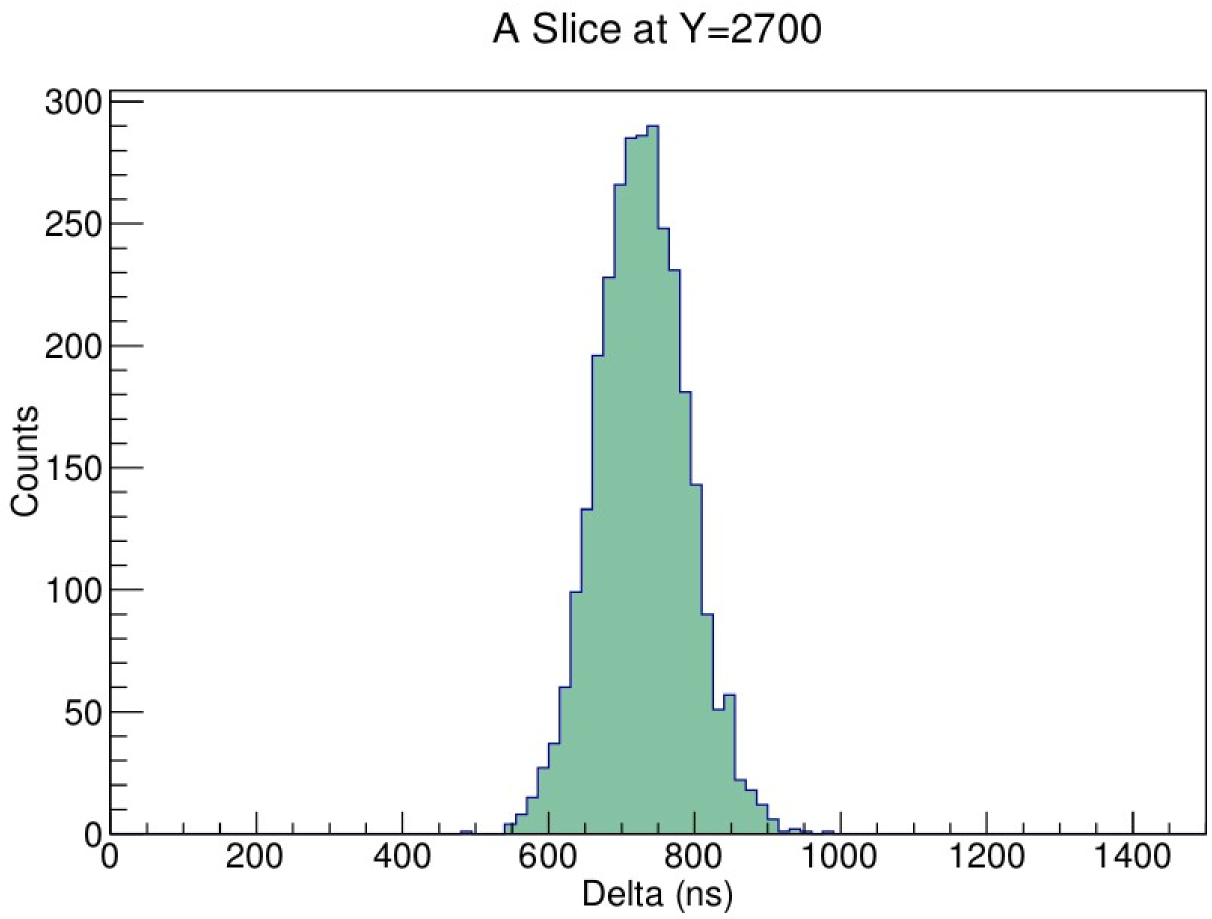
CFD Performance for noiseless waveforms.

CFD With 10% Noise



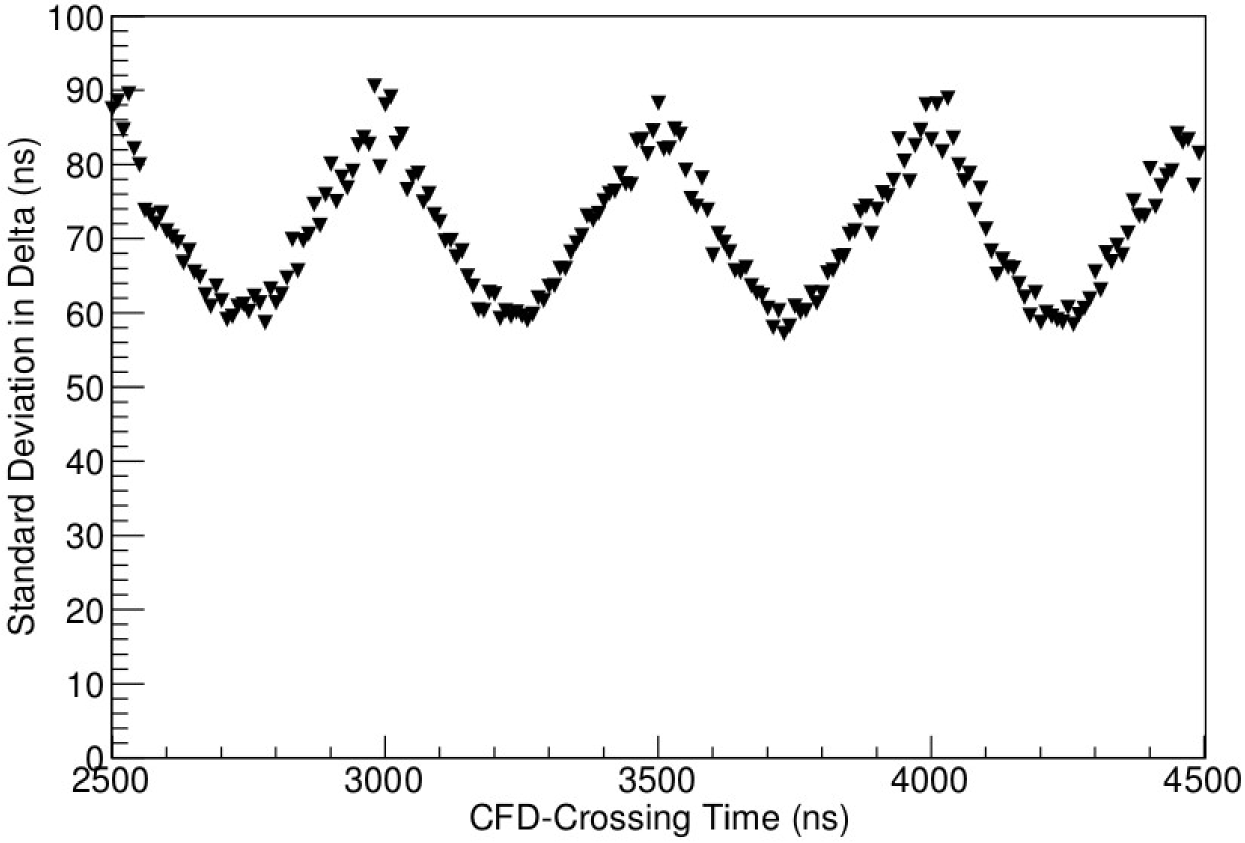
CFD Performance for 1000 noised waveforms per delta value.

Slice RMS



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

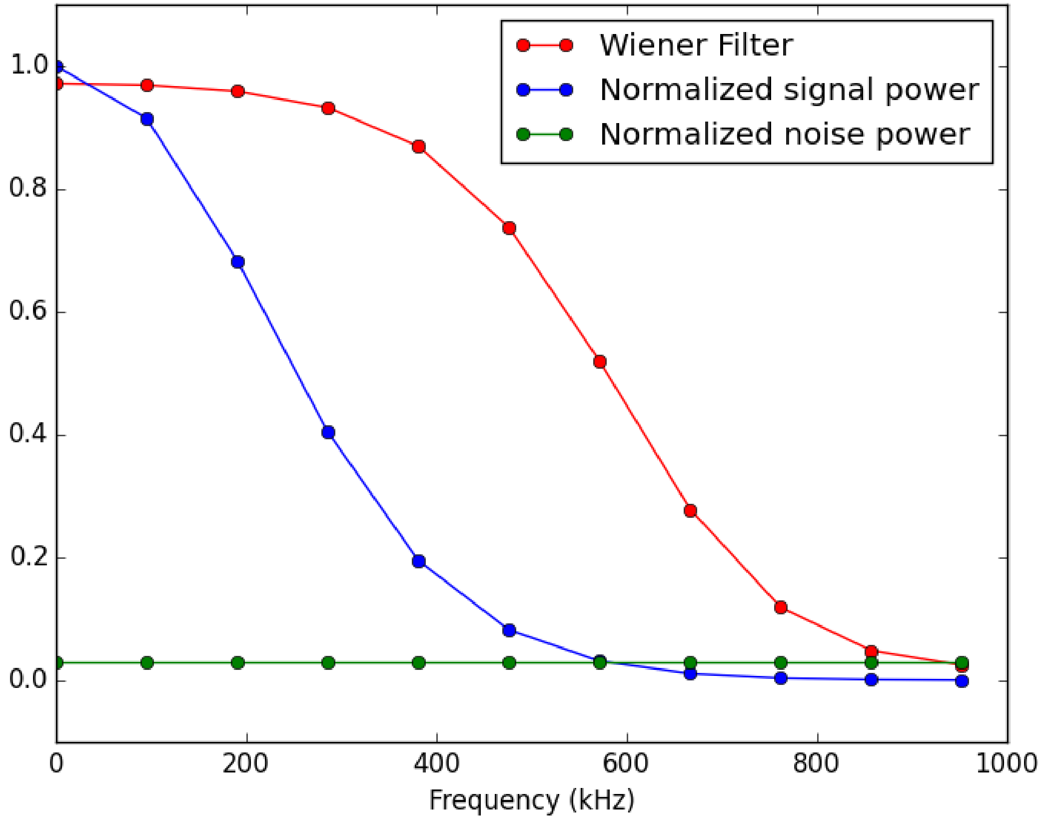
RMS vs CFD Crossing Time



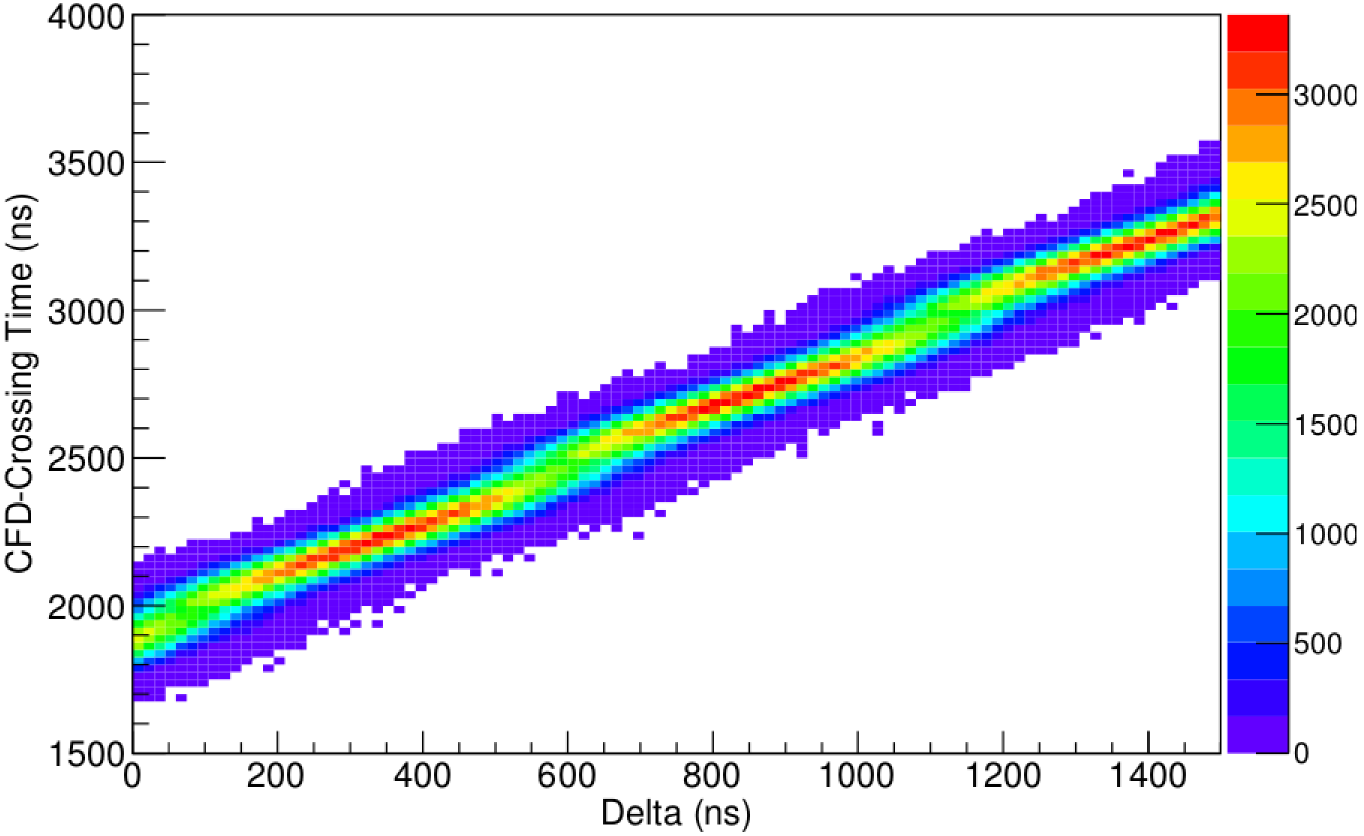
Wiener Filtering

- 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.

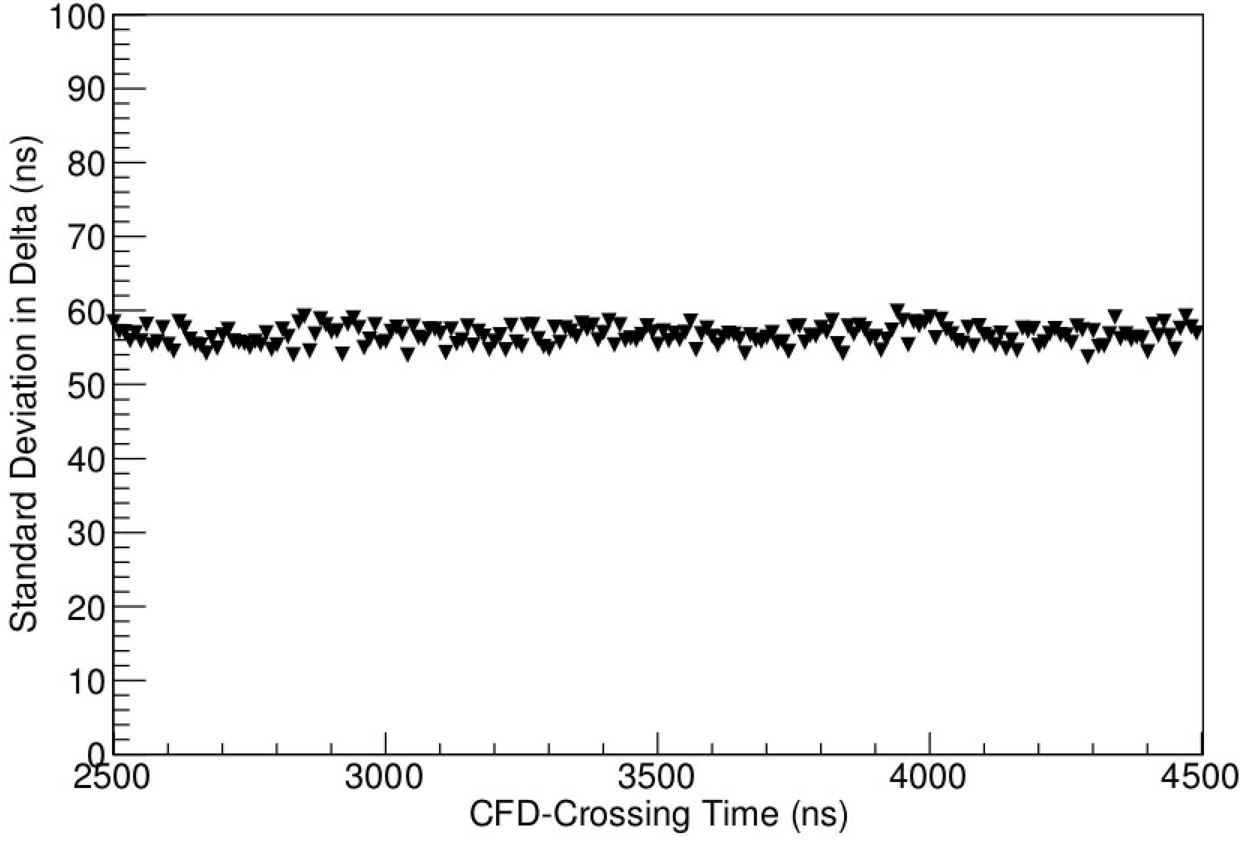
Wiener Filtering



CFD with Wiener Filtering



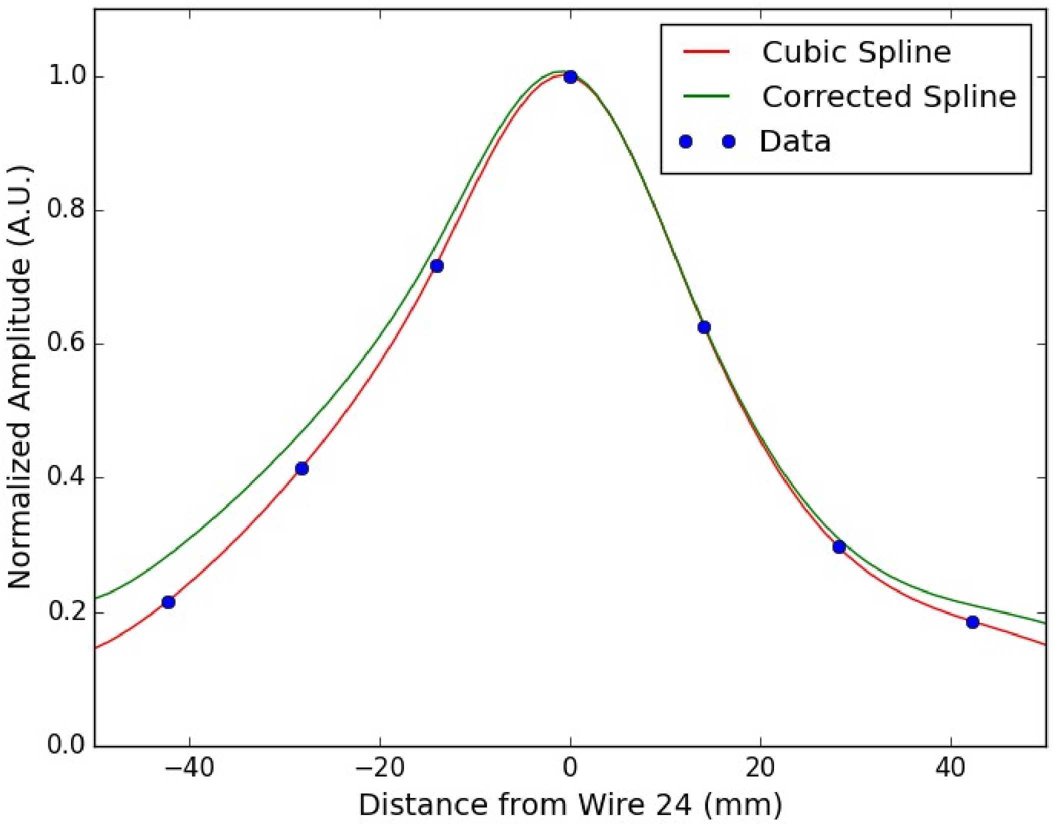
RMS with Wiener Filtering



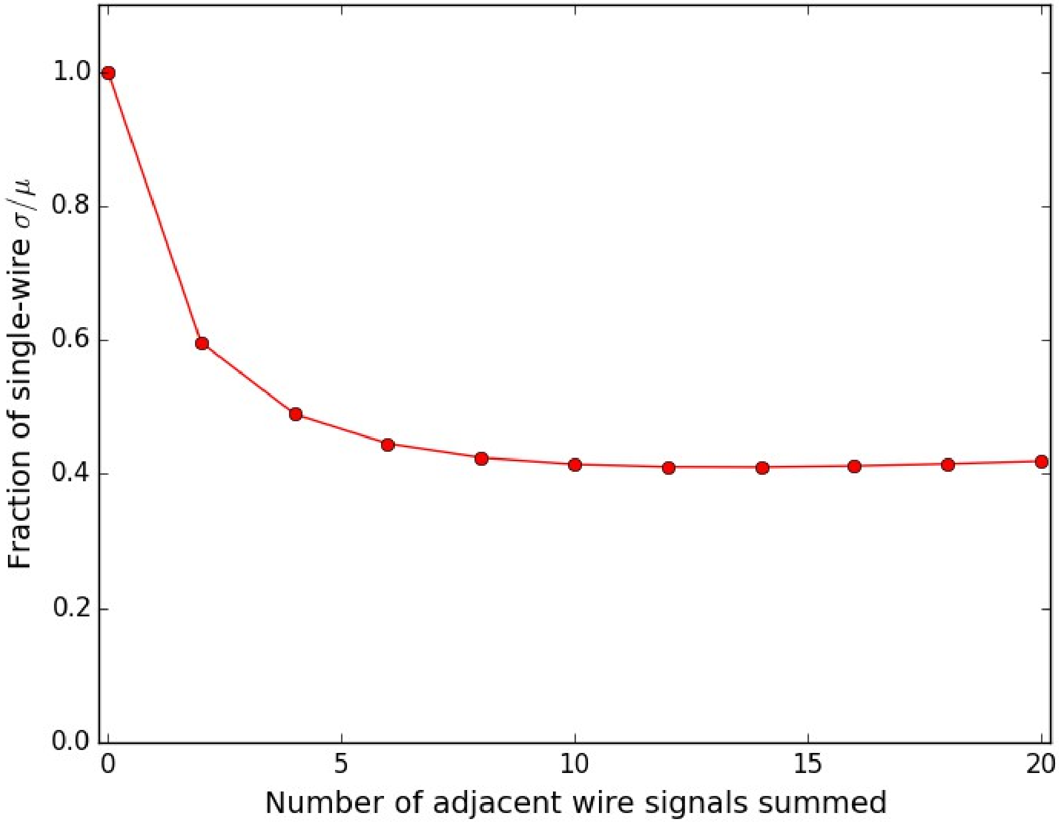
Exploiting Signal from Multiple Wires

- 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

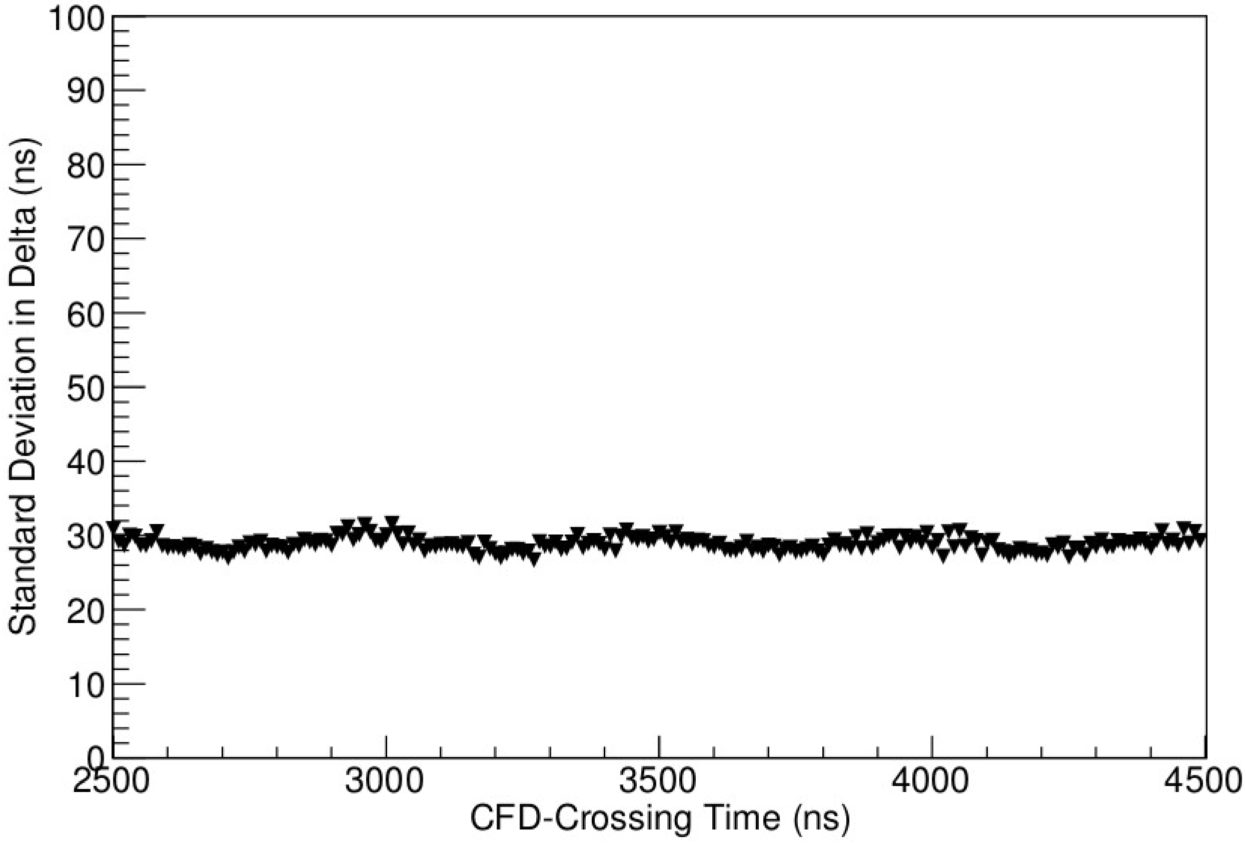


SNR Advantage



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

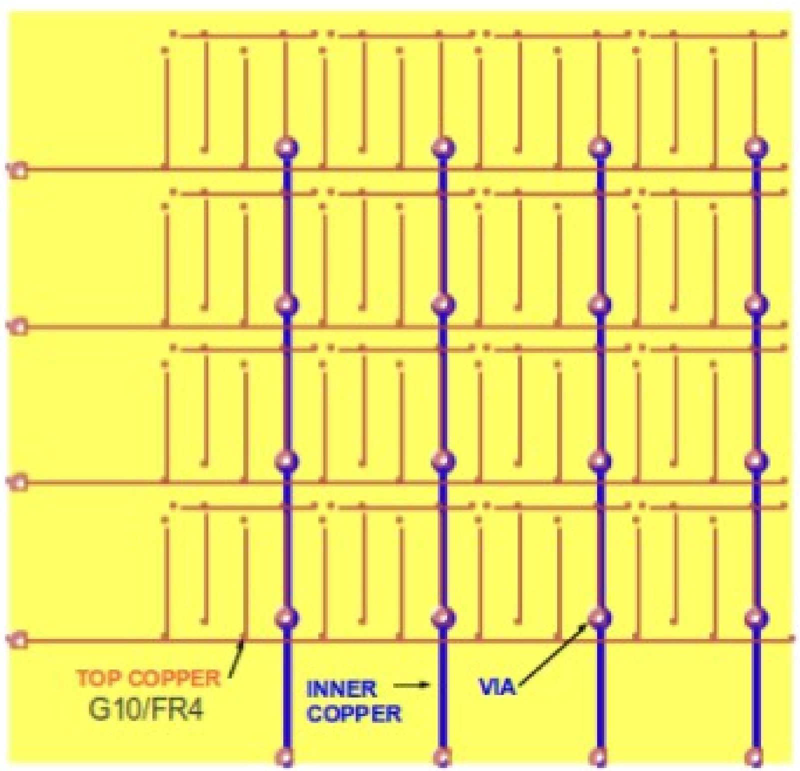
- We don't expect significant overlap between light and charge signal due to long drift times.
- Deep underground, the cosmic rate is low (DUNE CDR says 0.26 Hz), and is extremely unlikely to cause overlap with real charge signals.
- The SiPM dark rate at cryogenic temperatures is ~10Hz
- Ar39 seems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

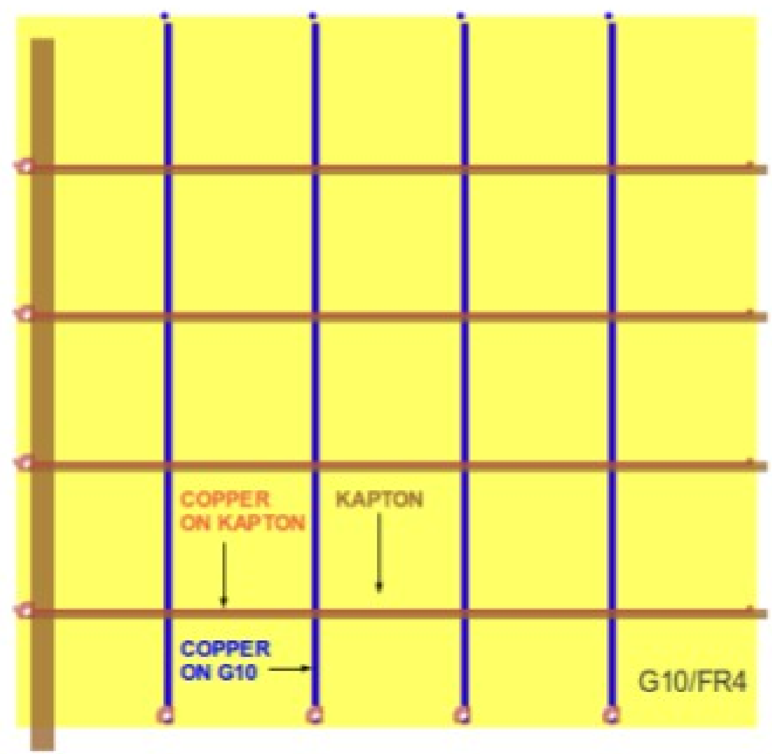
Potential Implementations

- Wireplane: SiPMs can be ganged together in clusters and connected to a capacitive plate in the dead area. Alternatively, multi-lightguide systems can couple SiPMs capacitively.
- This system would be similar to the DUNE proposal, and can exploit fringe field coincidence.

Potential Implementations

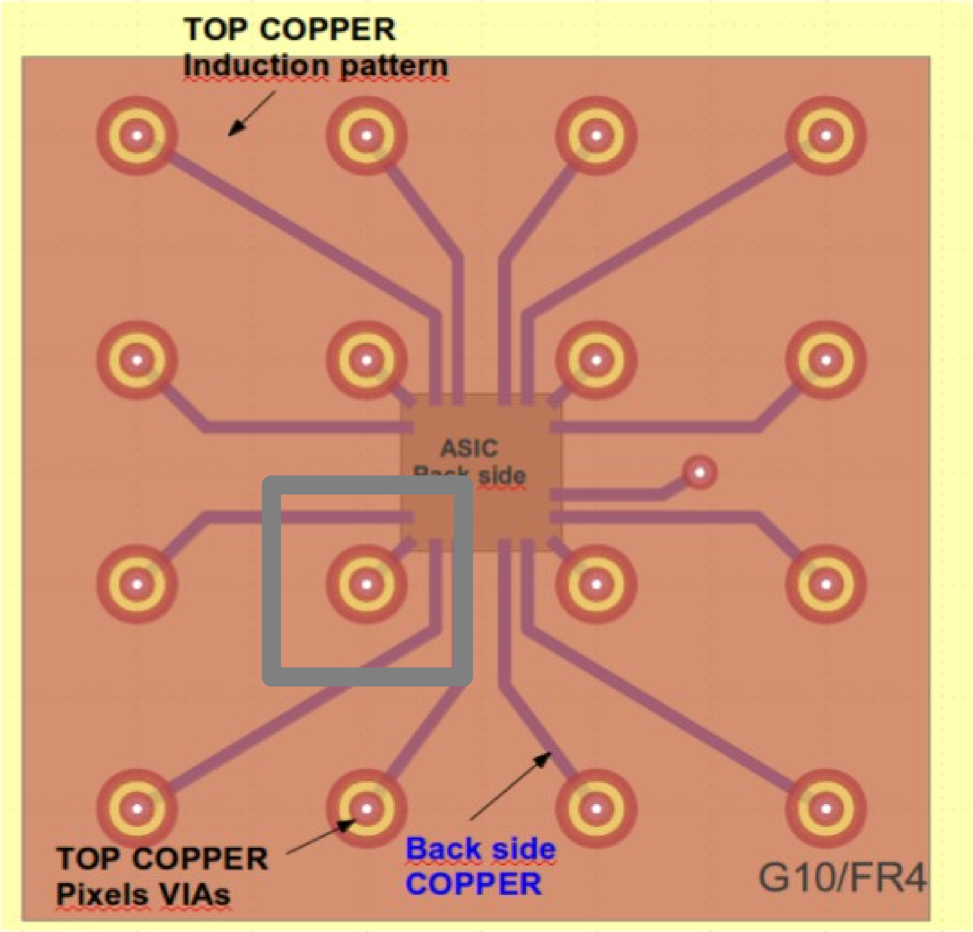
- Copper Crossbar: Plate on back, via to front SiPM (6x6mm^2)? Power traces?





Potential Implementation

- Pixels: Intersperse SiPMs among pixel banks, sacrificing the occasional pixel?



Potential Implementations

- To estimate coverage, assume the 2x2x10m^3 from the ArCube letter of intent. DUNE specifies a coverage of 0.5% total surface area. Covered area: 0.44m^2
- This requires ~10k SiPMs
- An estimate of ~100k pixels was given for a single anode surface (2m^2). Dividing between two surfaces requires roughly 5% pixel-SiPM replacement. Couple directly to the ASIC input?
- Use SiPMs as readout triggers? Is heating problem local or global? I don't think this is an issue for either the crossbar or the wireplane: only for the pixels.

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.