Calibration of Cold Electronics using CRP5 Data

Karla Téllez Girón Flores
Wenqiang Gu
Jay Hyun Jo
Xin Qian

05/17/2024 *ProtoDUNE VD Sim/Reco Meeting*

Outline

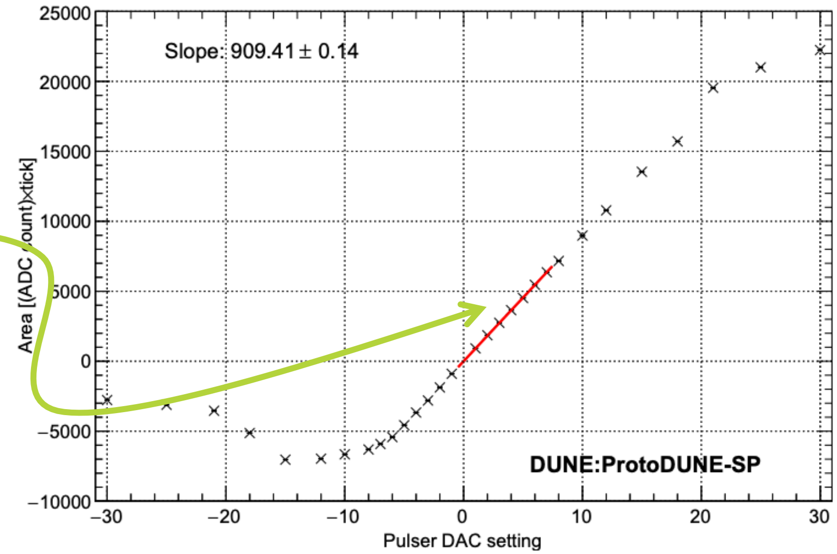
- **Introduction**
- **Imperfect pole-zero cancellation**
- **Calibration of PDVD Coldbox Data**
  - **Waveform fitting**
  - **Distributions of shaping time, amplitude, chi2, etc.**
  - **Calibration Results**

Introduction

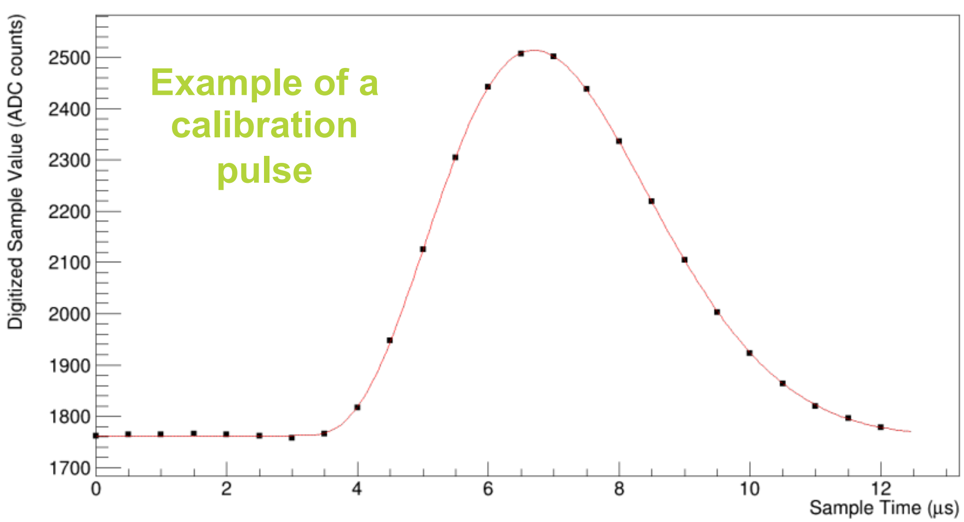
- In PDSP, the CE average gain is calibrated with pulse's charge area:

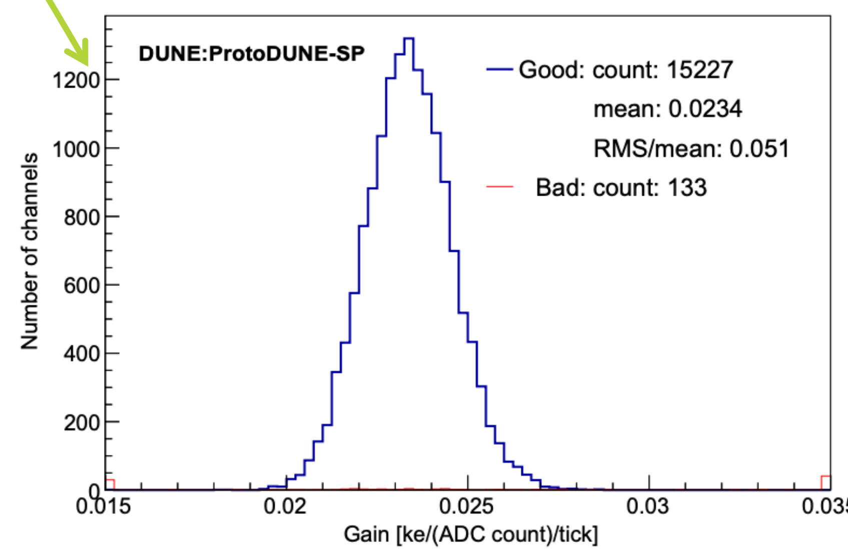
  ~23.5e/(ADC*tick)

- Pulser's step charge: 21.4ke (DAC = 0, 1, …, 63)
- Signal processing algorithm normalizes each readout channel's CE response amplitude (without shaping time correction).



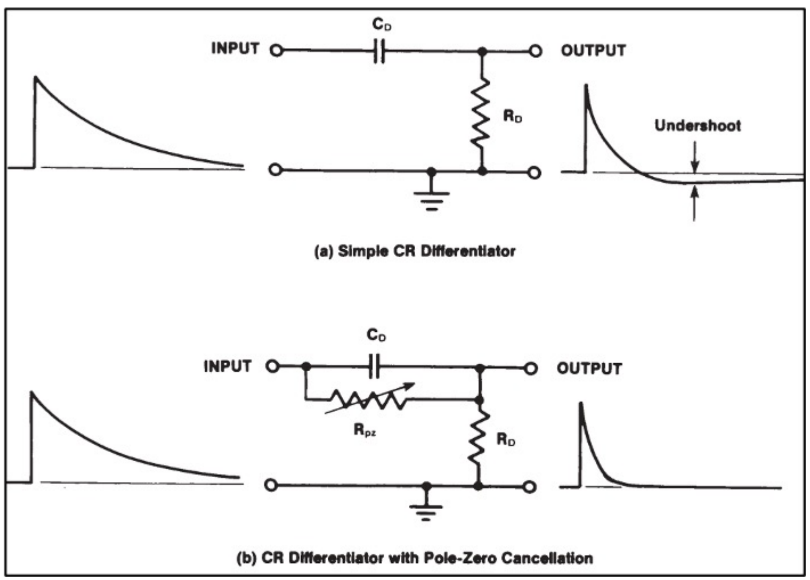
https://arxiv.org/pdf/2007.06722





Imperfect Pole-zero Cancelation

- In PDSP the calibration procedure doesn't consider
  - Variation in shaping time
  - **Imperfect pole-zero** cancellation of the pre-amplifier



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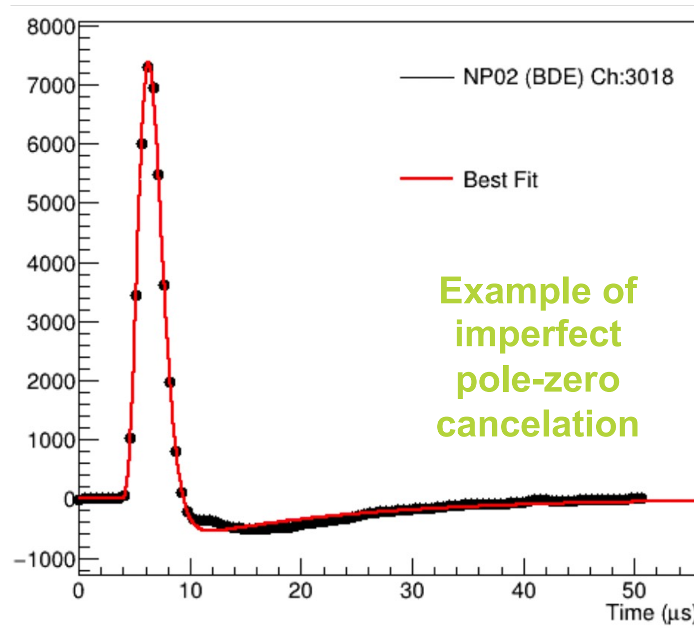


Imperfect Pole-zero Cancelation

- Taking MicroBooNE data as an example.
- Ideal Electronics Response can't describe all waveforms.
- For 2D signal processing, we need a uniform electronics response function.

distribution in the time domain. The impulse response function in the time domain is obtained from the inverse Laplace transformation of the transfer function for the network

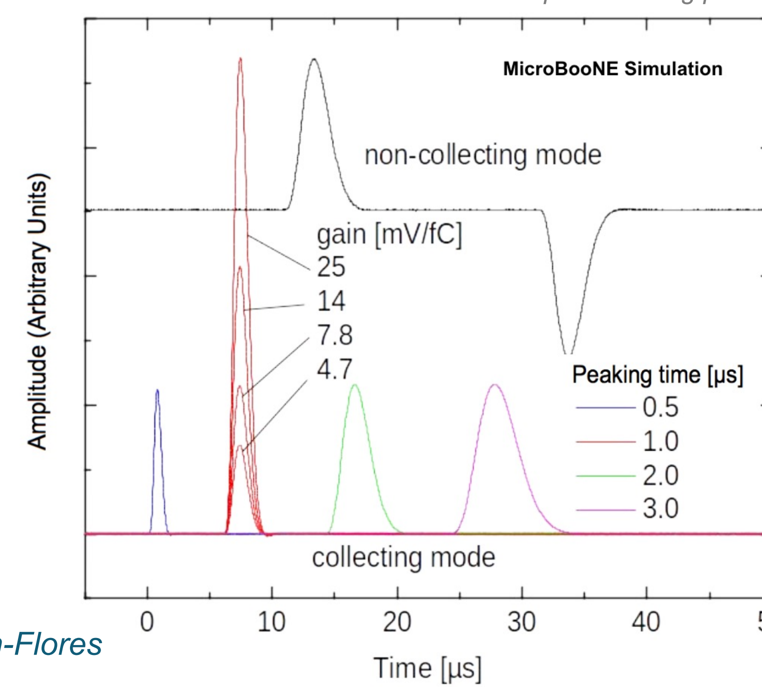
$$T(s) = \frac{A_0 \cdot C_A}{(p_0 + s) \cdot (p_{i1}^2 + (p_{r1} + s)^2) \cdot (p_{i2}^2 + (p_{r2} + s)^2)}, \tag{3.1}$$

with s being a complex frequency variable. The parameters in equation 3.1 are obtained from a detailed simulation of the network design and are determined to be:

$$\begin{aligned} p_{r1} &= \frac{1.417}{t_p \cdot C_T}, \quad p_{r2} = \frac{1.204}{t_p \cdot C_T}, \\ p_{i1} &= \frac{0.598}{t_p \cdot C_T}, \quad p_{i2} = \frac{1.299}{t_p \cdot C_T}, \\ p_0 &= \frac{1.477}{t_p \cdot C_T}, \quad C_A = \frac{2.7433}{(t_p \cdot C_T)^4}, \\ C_T &= \frac{1}{1.996}; \end{aligned} \tag{3.2}$$

where A_0 is the gain parameter and t_p is the peaking time constant. $T(s)$ has units of $\frac{\text{V}}{\text{C}}\ (\text{Hz})^{-1}$.

https://arxiv.org/pdf/1804.02583



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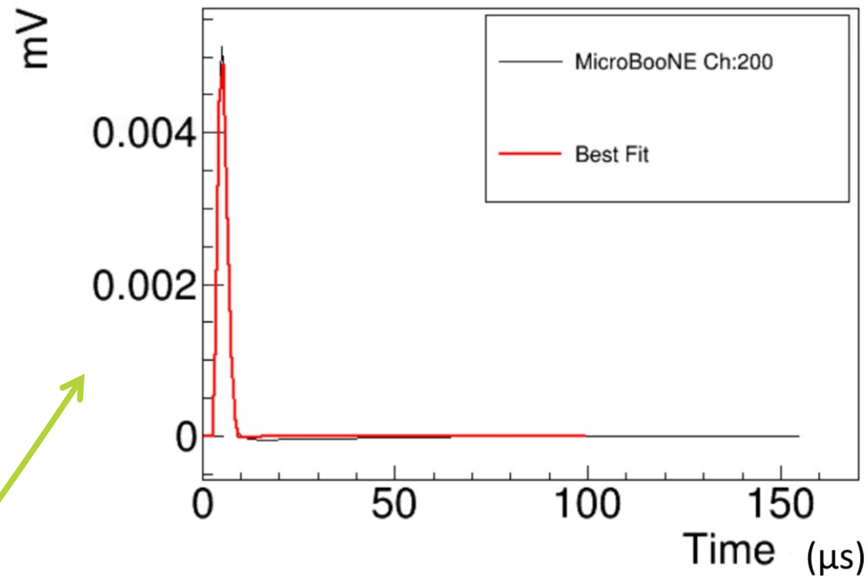
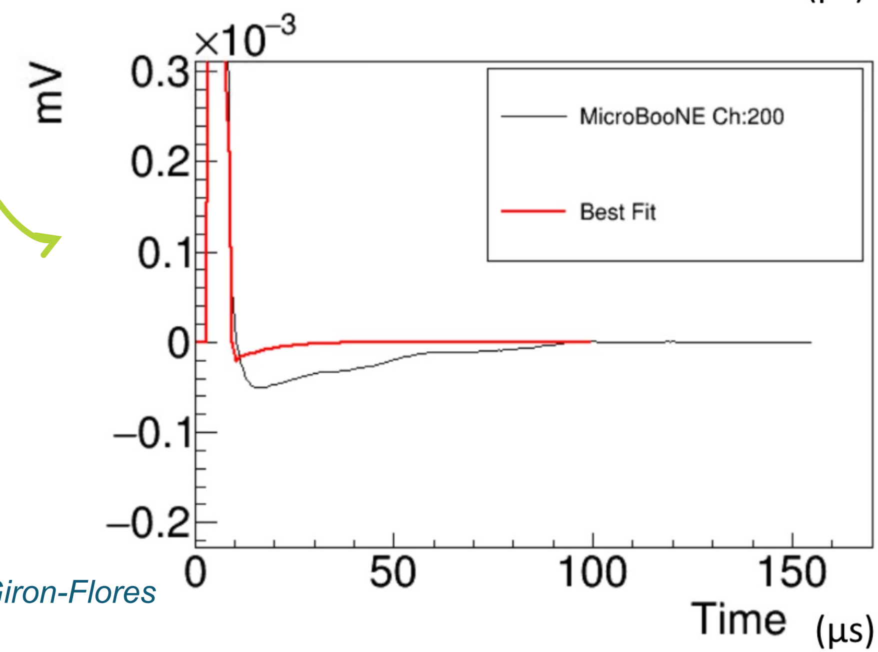
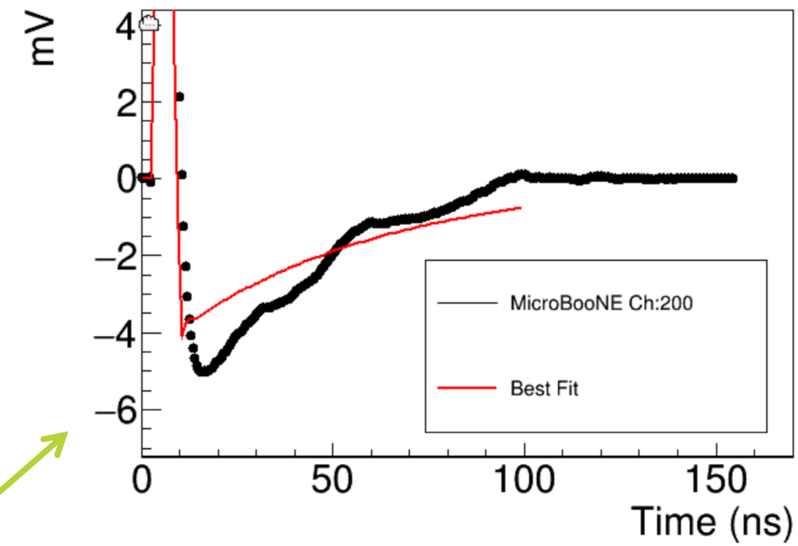




Imperfect Pole-zero Cancelation

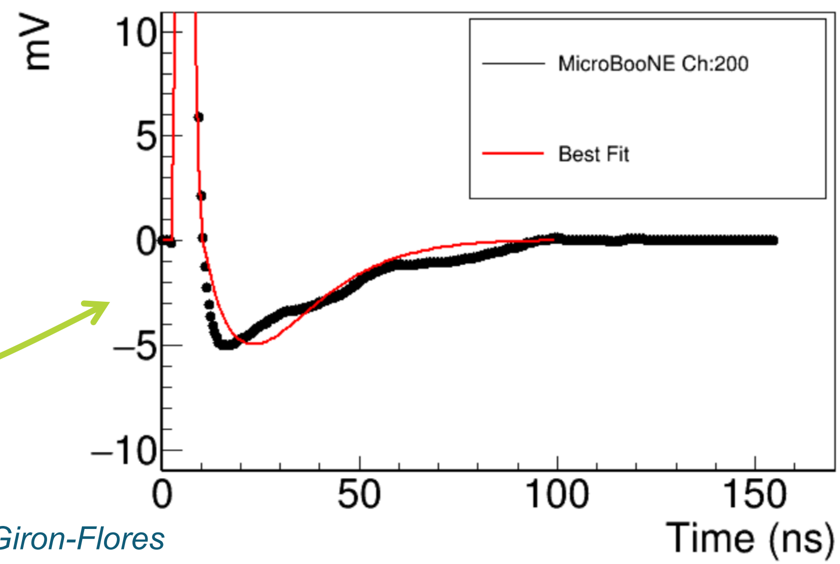
- Need a correction to the electronics response function:

T(s) multiplied by $\frac{s+p_3}{s+p_4}$



https://indico.fnal.gov/event/63116/

T(s) multiplied by $\frac{p_{i3}^2+(p_{r3}+s)^2}{p_{i4}^2+(p_{r4}+s)^2}$



Imperfect Pole-zero Cancelation

- From Prashansa Mukin (BNL ASIC designer):

$$T(s) = \frac{(s+k_3)(s+k_5)}{(s+k_4)(s+k_6)} \times \frac{A}{(s+p_0)(p_{1i}^2+(p_{1r}+s)^2)(p_{2i}^2+(p_{2r}+s)^2)}$$

- Adding a canceled pole can introduce a tail!
- Mismatch between (k_3, k_4) and (k_5,k_6) is the **imperfect pole-zero cancellation**.
- The case when k3=k4 and k5=k6, the transfer function recovers its ideal function form.

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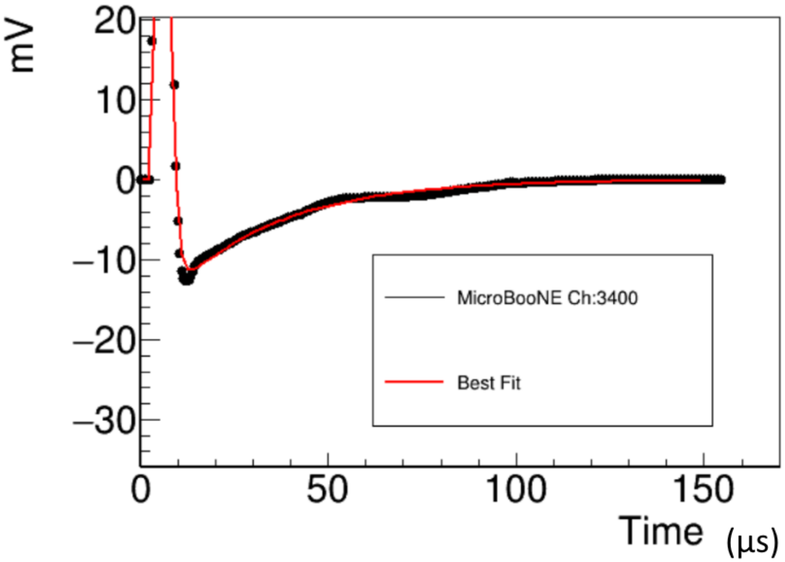
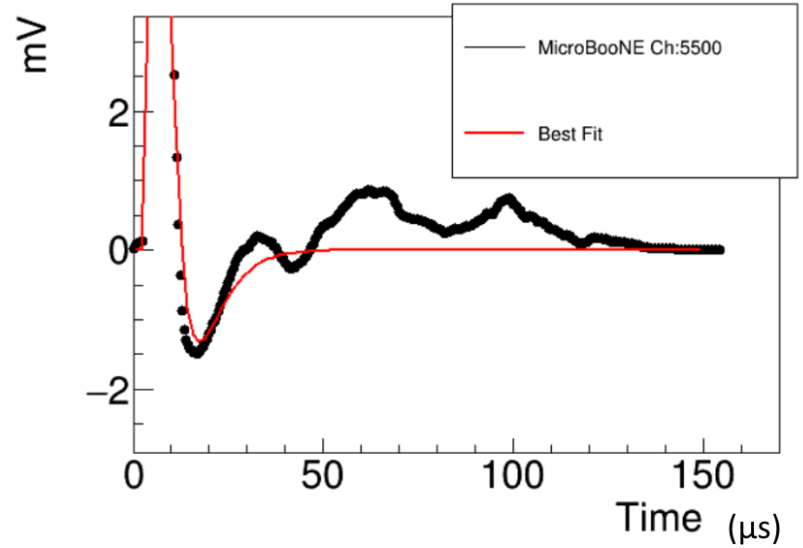
Imperfect Pole-zero Cancelation





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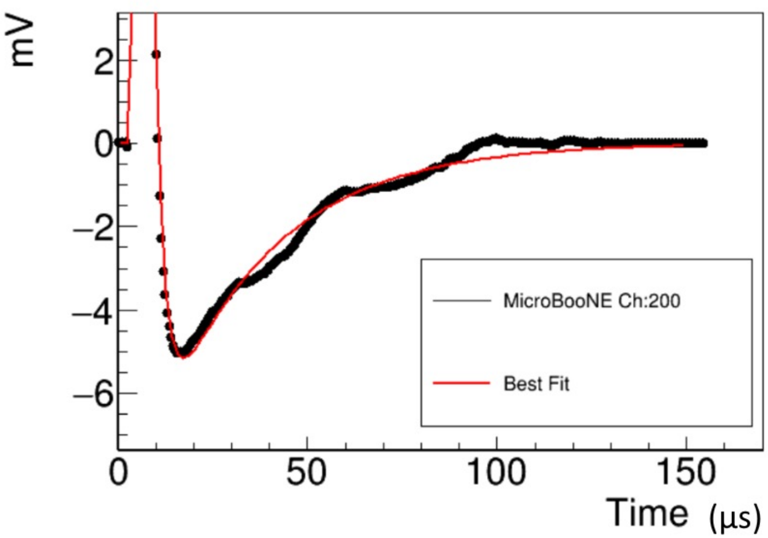
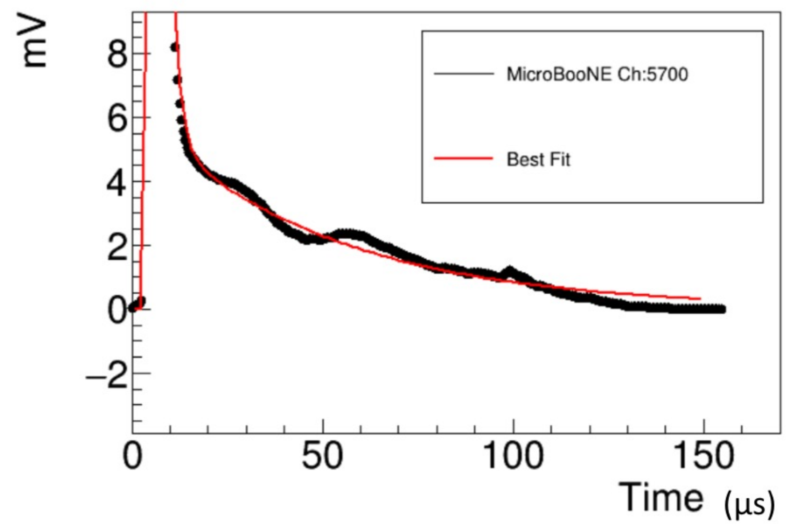




Calibration of CE Response with New Formula

* See lots of great studies ran by Alexander Shtov and Roger Huang! Particularly https://indico.fnal.gov/event/61231/

Calibration: The Setup

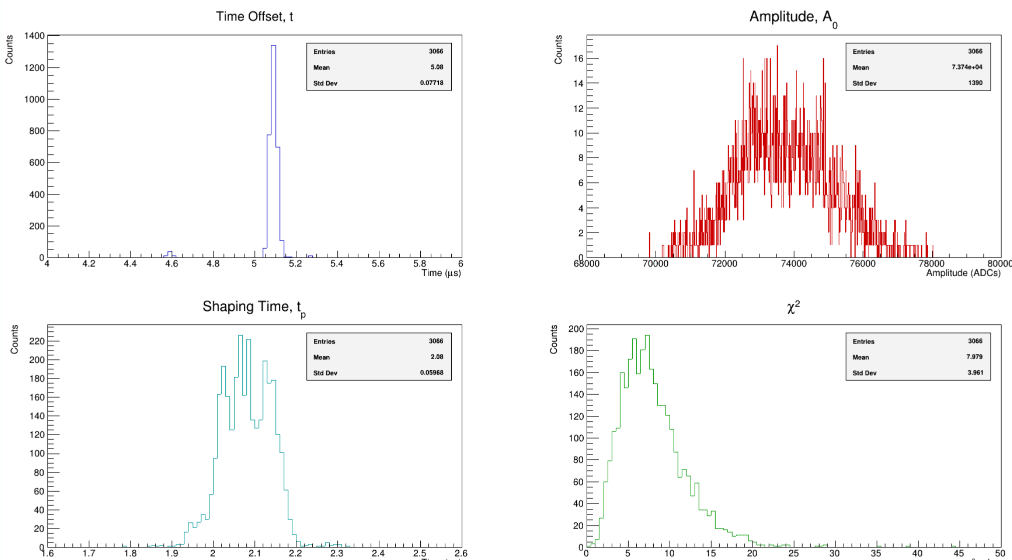
- **The Dataset:** NP02 Second Coldbox pulser calibration runs for CRP5.
- **Run:** 21040 (April 28, 2023).
- 14 mV/fC gain and 2 μs nominal shaping time.
- DAC setting: 30.

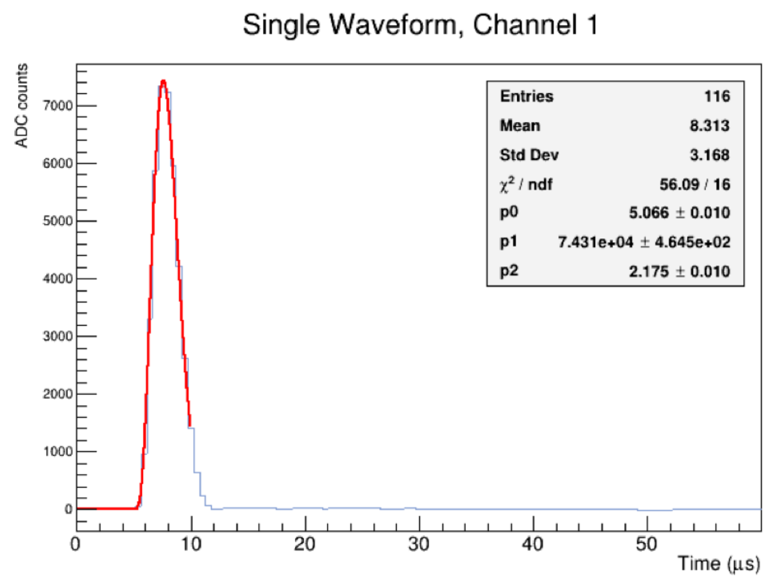
Calibration: The Method

- A **peak finding** algorithm finds the positive and negative peaks for each channel in data.
- Finds noisy channels and skips them.
- Fitting waveforms using a two-step process
  - Pre-fitting using Ideal Electronics Response Function from 0-10 μs.
  - Fit using New Electronics Response Function from 0-50 μs.

Calibration: Pre-Fit

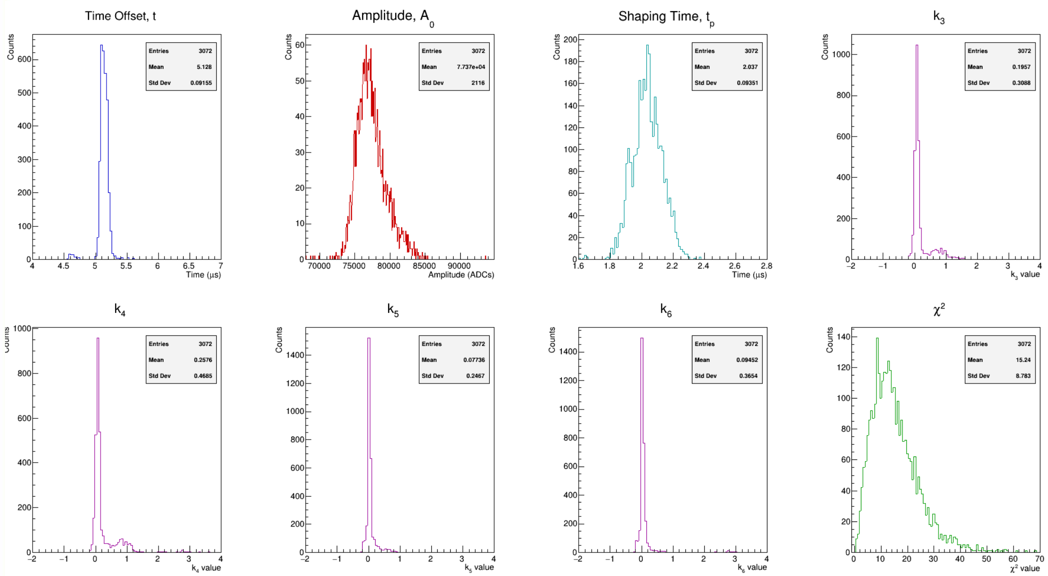
- Fitting peak with Ideal Electronics Response

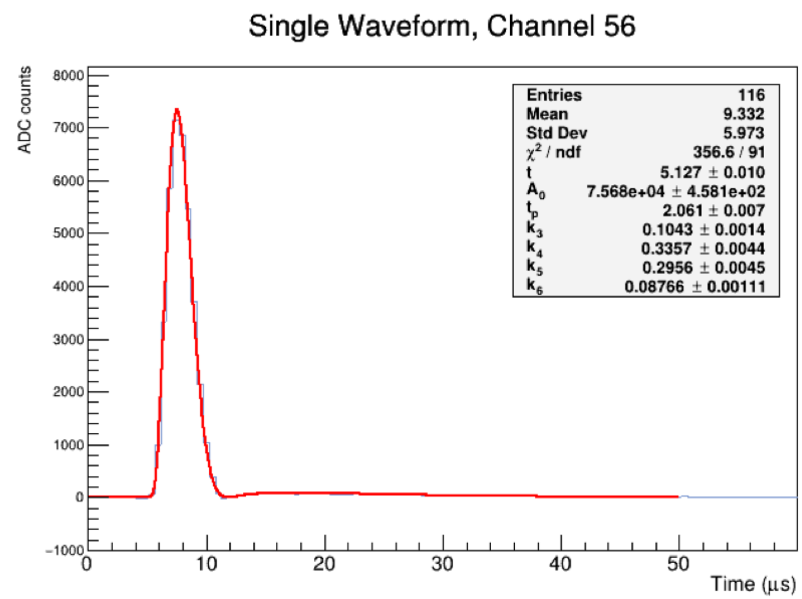




Calibration: Fit

- Retrieved parameters from Pre-Fit and fed them to New Electronics Response Function





Offline correction of imperfect pole-zero cancellation

Electronics Response in Waveform Data

$$M_i(t_0) = \int_{-\infty}^{\infty} R_i(t - t_0) \cdot I(t) \cdot dt$$

Digitized Waveform ($M_i(t_0)$) — Channel "i" Elec. Response (R_i) — Induced Current ($I(t)$)

Frequency Domain

$$M_i(\omega) = R_i(\omega) \cdot I(\omega)$$

Electronics Response Correction

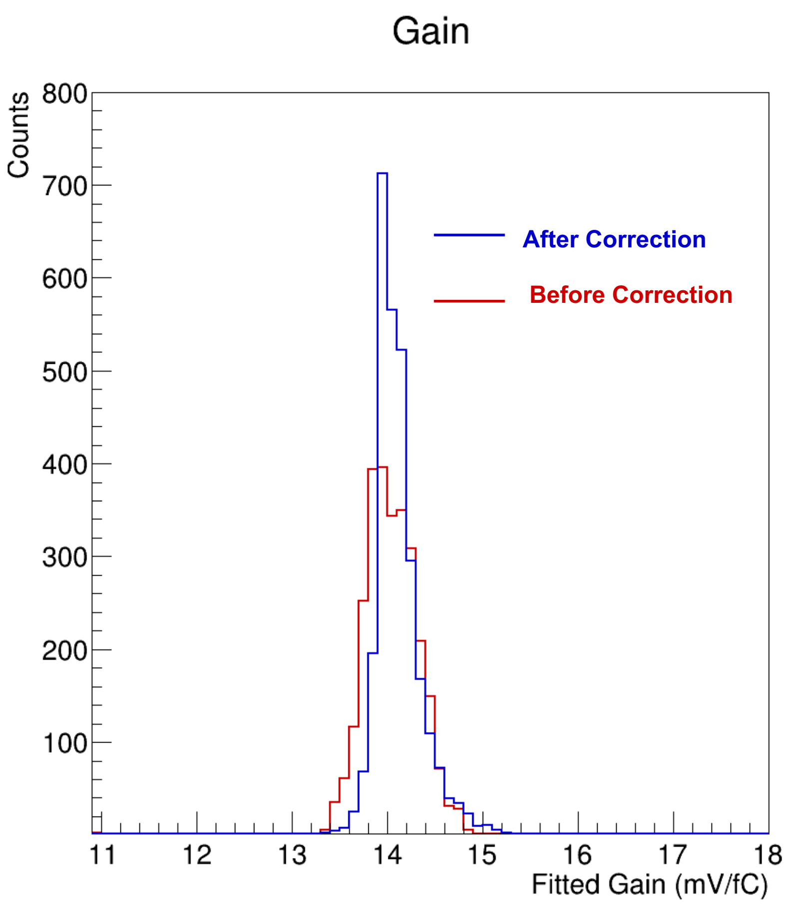
$$M_i^{Corr}(\omega) = M_i(\omega) \cdot \frac{R_{nominal}(\omega)}{R_i(\omega)}$$

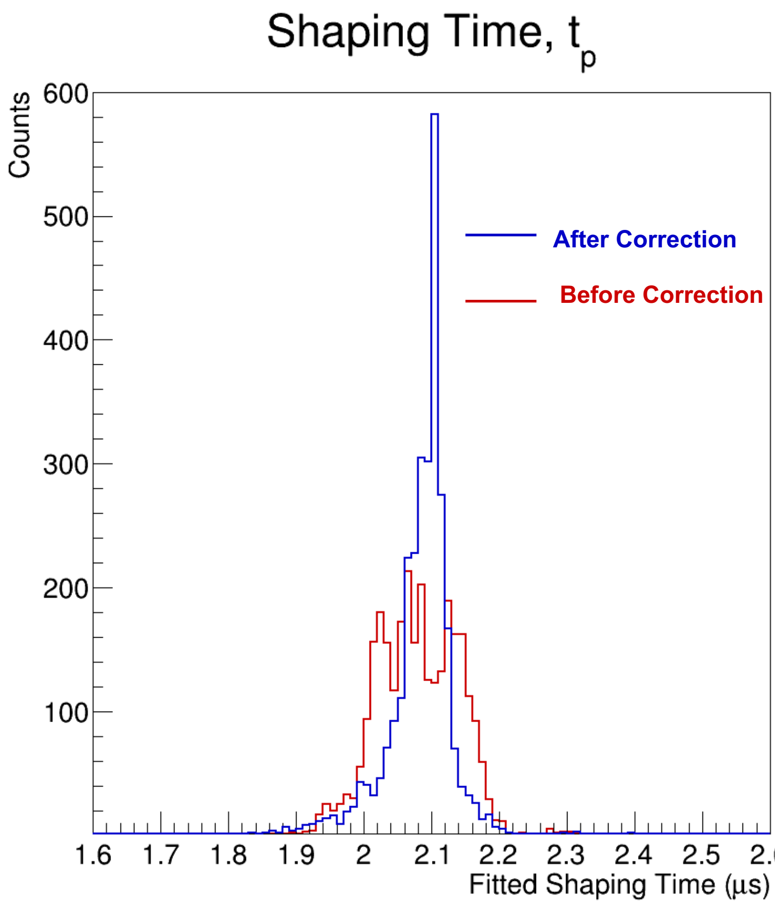
Channel "i" measured response FFT ($R_i(\omega)$)

Taken from Brian Kirby's slides for the LArTPC Calibration Workshop

Defined a correction based on the measured response.

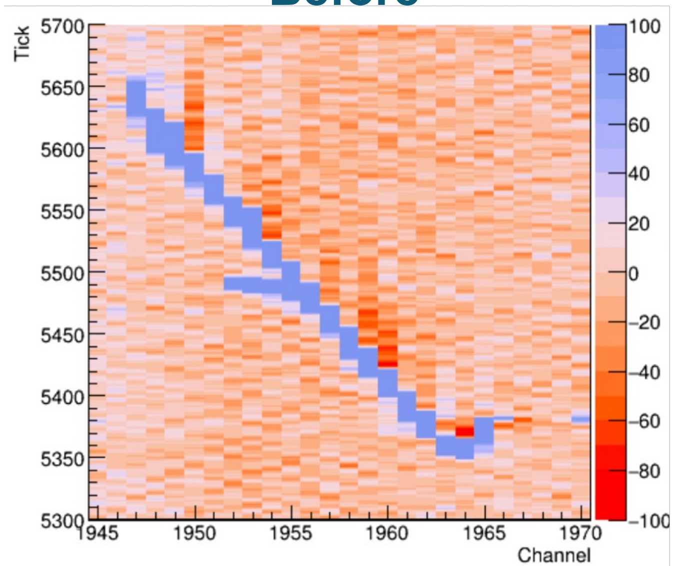
Offline correction of imperfect pole-zero cancellation



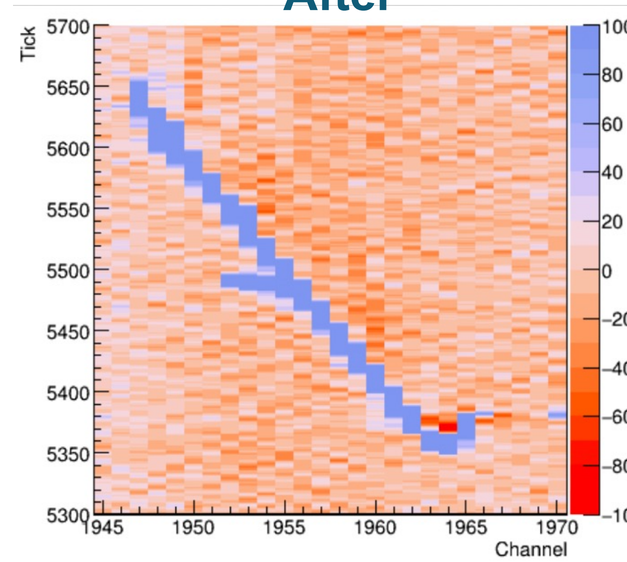


Performance of the Correction

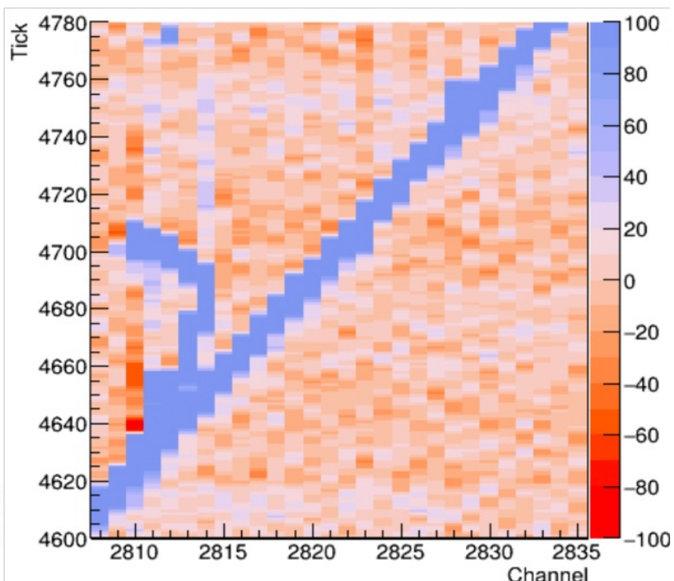
Before

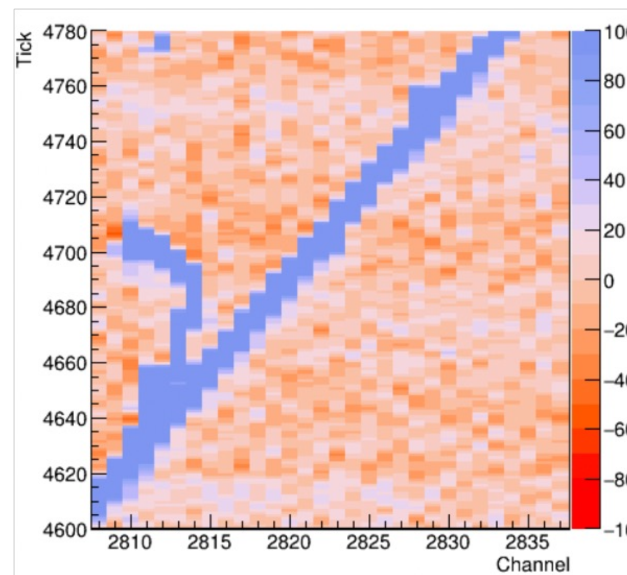


After



Run 21445, event 16472





Takeaways

- **An analytical formula is proposed to describe the imperfect pole-zero cancellation (undershoot/overshoot) in the CE response function.**
- **A calibration is done with the new formula using ProtoDUNE VD Coldbox data (and can be applied to HD right now!).**
- **Further work is needed to improve the calibration e.g. averaging waveforms.**
- **Expect to reduce the remaining variation in shaping time and long tail and further improve the reconstruction.**