Overview of the CE Calibration Analysis using PDHD Pulser Data

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Dataset

- **NP04 TPC Electronics Studies Runs**.
- **Pulser Calibration Run 28286 from July of 2024.**
- **DAC = 30.**
- **7.8 mV/fC LArASIC gain.**
- **2 μs CE Shaping Time.**
- **LArASIC Output Mode: Single-ended.**

Waveform Fitting

1. A peak finding algorithm finds and isolates the positive and negative peaks for each channel in data.

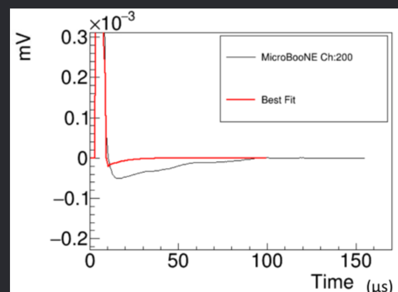
2. Averaging of all pulses for <u>each channel</u> effectively gets rid of most noisy tails.

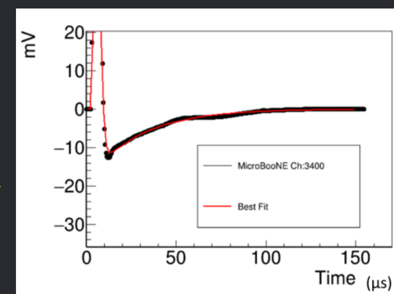
3. Fitting waveforms using a two-step process
   - Pre-fitting using Ideal Electronics Response Function from 0-10 μs.
   - Fit using *New* Electronics Response Function* from 0-50 μs.

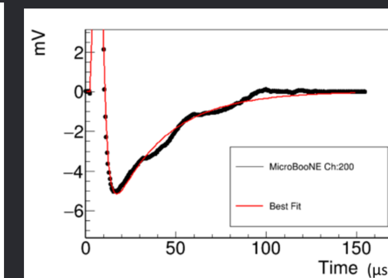
*New Electronics Response Function

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

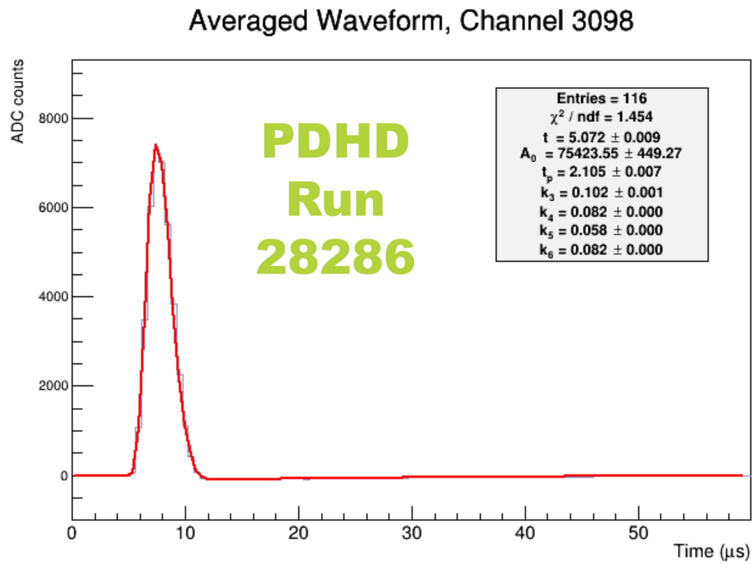
```
double response(double *x, double *par){
  Double_t t = x[0]-par[0];
  Double_t A0 = par[1];
  Double_t tp = par[2];
  Double_t CT = 1./1.996;
  Double_t A = A0 * 2.7433/pow(tp*CT,4);
  Double_t p0 = 1.477/tp/CT;
  Double_t pr1 = 1.417/tp/CT;
  Double_t pr2 = 1.204/tp/CT;
  Double_t pi1 = 0.598/tp/CT;
  Double_t pi2 = 1.299/tp/CT;


  double k3 = par[3];
  double k4 = par[4];
  double k5 = par[5];
  double k6 = par[6];

  double value = A*((-(k3*k4) + pow(k4,2) + k3*k5 - k4*k5)/(exp(k4*t)*(k4 - k6)*(k4 - p0)*(pow(k4,2) + pow(pi1,2) - 2*k4*pr1 + pow(pr1,2))*(pow(k4,2) + pow(pi2,2) -
      2*k4*pr2 + pow(pr2,2))) +
         (-(k3*k5) + k3*k6 + k5*k6 - pow(k6,2))/(exp(k6*t)*(k4 - k6)*(k6 - p0)*(pow(k6,2) + pow(pi1,2) - 2*k6*pr1 + pow(pr1,2))*(pow(k6,2) + pow(pi2,2) - 2*k6*pr2 +
             pow(pr2,2))) +
         (-(k3*k5) + k3*p0 + k5*p0 - pow(p0,2))/(exp(p0*t)*(k4 - p0)*(-k6 + p0)*(pow(p0,2) + pow(pi1,2) - 2*p0*pr1 + pow(pr1,2))*(pow(p0,2) + pow(pi2,2) - 2*p0*pr2
             + pow(pr2,2))) +
     (pi1*((pow(pi1,2) + pow(pr1,2))*(2*k6*(pow(pi1,2) + pow(pr1,2))*(pr1 - pr2) + k6*p0*(-pow(pi1,2) + pow(pi2,2) - pow(pr1,2) + pow(pr2,2)) + (pow(pi1,2) +
         pow(pr1,2))*(pow(pi1,2) - pow(pi2,2) + (pr1 - pr2)*(2*p0 - 3*pr1 + pr2)) +
              k5*(2*pow(pi1,2)*(-2*pr1 + pr2) + p0*(pow(pi1,2) - pow(pi2,2) - 3*pow(pr1,2) + 4*pr1*pr2 - pow(pr2,2)) + 2*pr1*(pow(pi2,2) + 2*pow(pr1,2) - 3*pr1*pr2
                 + pow(pr2,2)) +
                 k6*(pow(pi1,2) - pow(pi2,2) + (pr1 - pr2)*(2*p0 - 3*pr1 + pr2)))) + k4*((pow(pi1,2) + pow(pr1,2))*(2*(pow(pi1,2) + pow(pr1,2))*(pr1 - pr2) +
                     p0*(-pow(pi1,2) + pow(pi2,2) - pow(pr1,2) + pow(pr2,2))) +
              k5*(2*k6*(pow(pi1,2) + pow(pr1,2))*(pr1 - pr2) - k6*p0*(pow(pi1,2) - pow(pi2,2) + pow(pr1,2) - pow(pr2,2)) + (pow(pi1,2) + pow(pr1,2))*(pow(pi1,2) -
                 pow(pi2,2) + (pr1 - pr2)*(2*p0 - 3*pr1 + pr2))) +
              k6*(-pow(pi1,4) + pow(pi1,2)*(pow(pi2,2) - 2*pow(pr1,2) + 2*p0*pr2 + pow(pr2,2)) + pr1*(pr1*(pow(pi2,2) - pow(pr1,2) + pow(pr2,2)) - 2*p0*(pow(pi2,2)
                 - pr1*pr2 + pow(pr2,2)))))) +
           k3*(-((pow(pi1,2) + pow(pr1,2))*(4*pow(pi1,2)*pr1 - 2*pow(pi2,2)*pr1 - 4*pow(pr1,3) - 2*pow(pi1,2)*pr2 + 6*pow(pr1,2)*pr2 - 2*pr1*pow(pr2,2) +
               p0*(-pow(pi1,2) + pow(pi2,2) + 3*pow(pr1,2) - 4*pr1*pr2 + pow(pr2,2)) +
                   k6*(-pow(pi1,2) + pow(pi2,2) - (pr1 - pr2)*(2*p0 - 3*pr1 + pr2)))) + k5*(-pow(pi1,4) + pow(pi1,2)*(pow(pi2,2) - 4*p0*pr1 + 10*pow(pr1,2) +
```

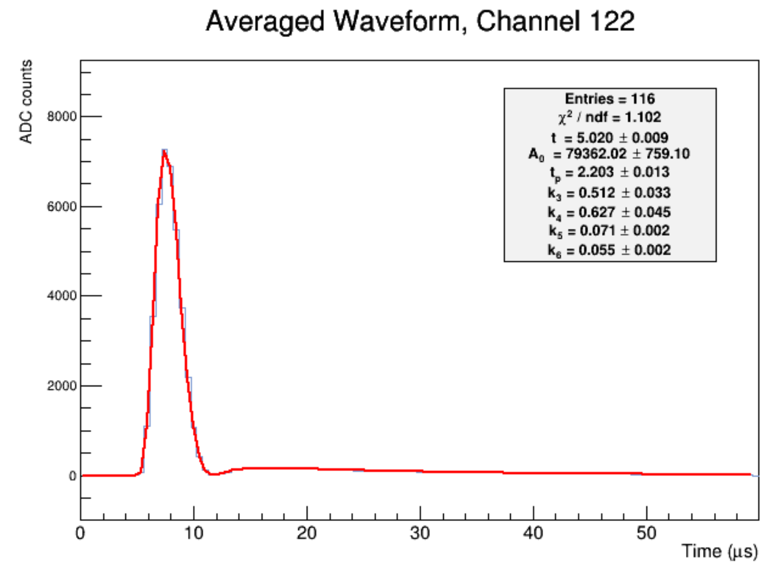


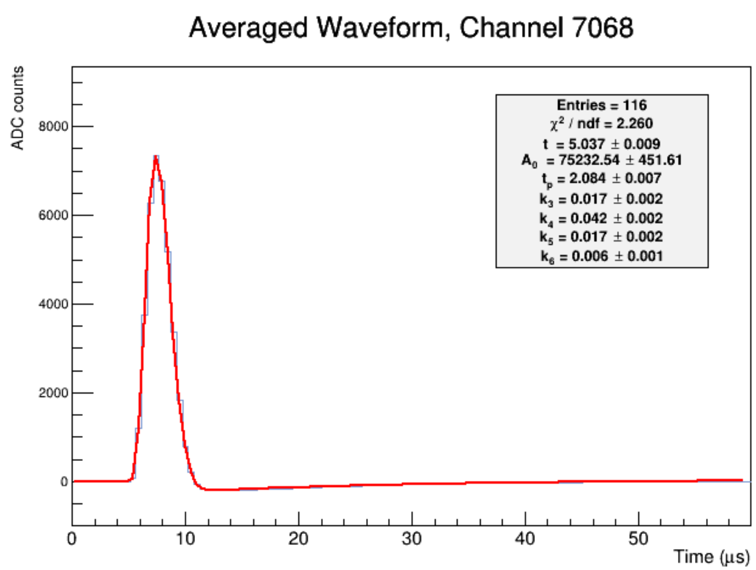


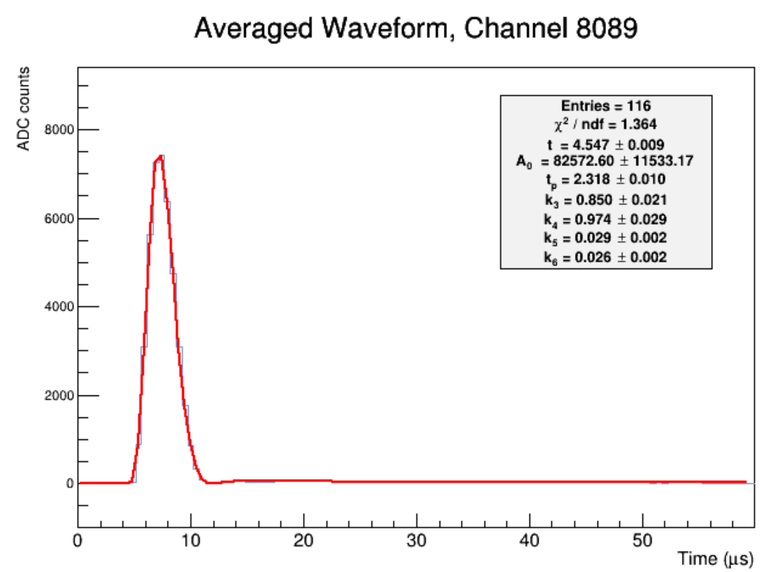


Examples of Fitted Waveforms



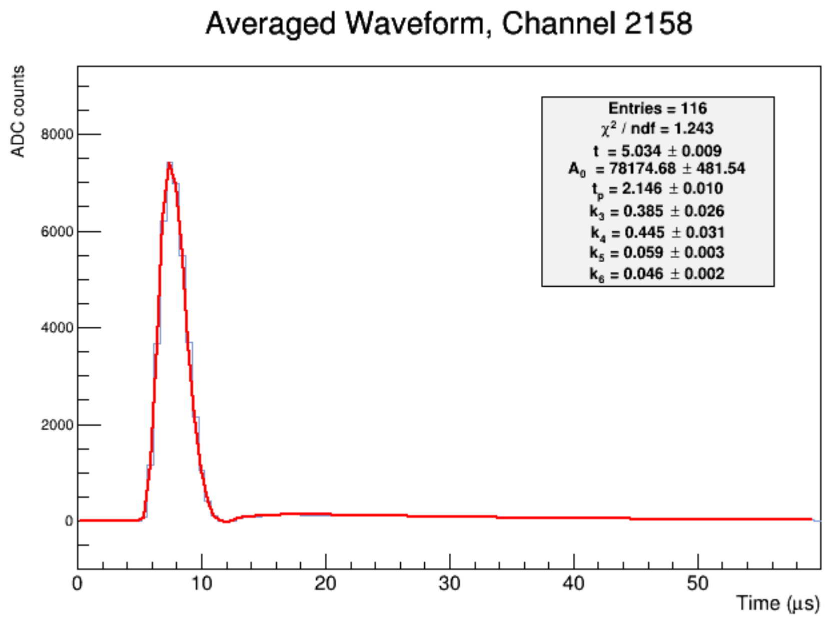


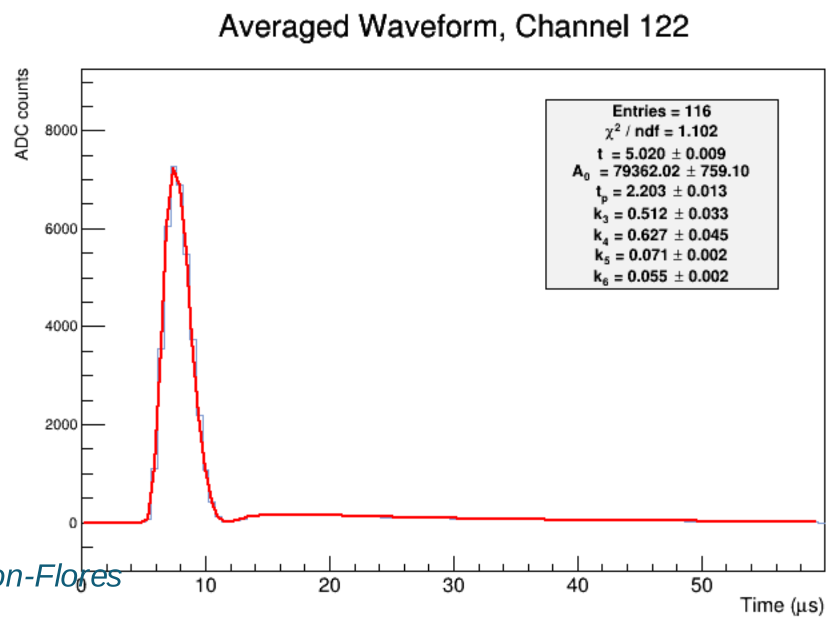




Waveform Correction

1. **Run the full fitter on our dataset.**
2. Extract fit parameters.
3. Run the waveform correction (Wire-Cell).
4. Fit corrected waveforms with Ideal Electronics Response Function.
5. Retrieve Amplitude and Shaping Time.
6. Convert Amplitude to Gain.





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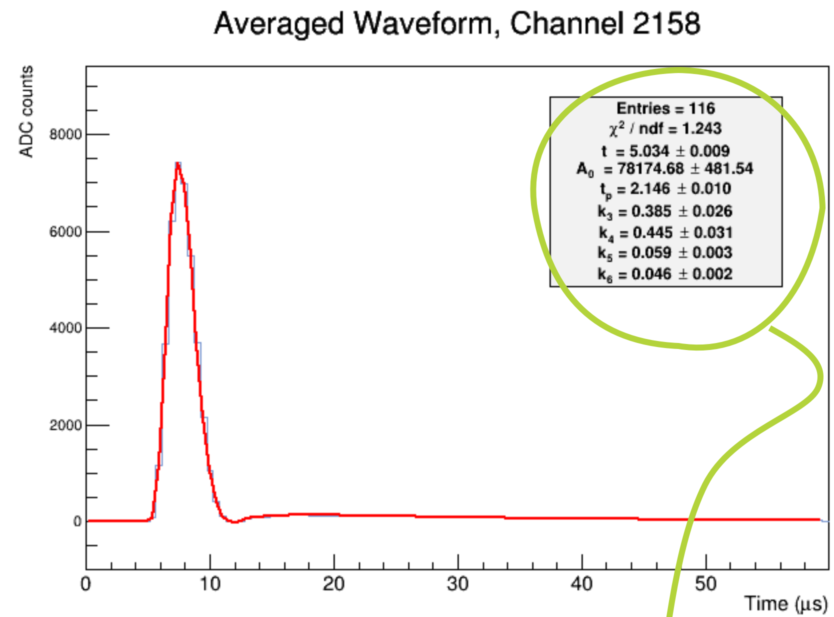

"channels": [
2158
],
"gain": 1.345697e-12,
"shaping": 2146.0,
"k3": 0.3846,
"k4": 0.4447,
"k5": 0.05915,
"k6": 0.04606
},

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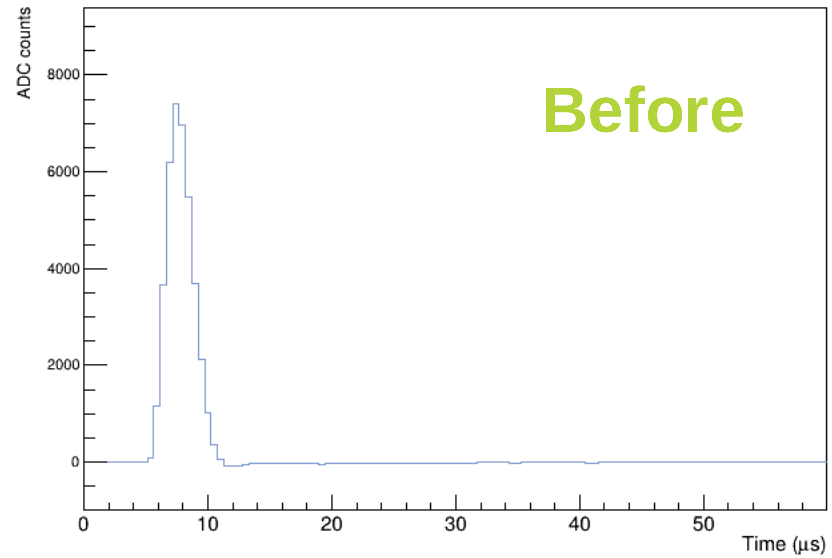

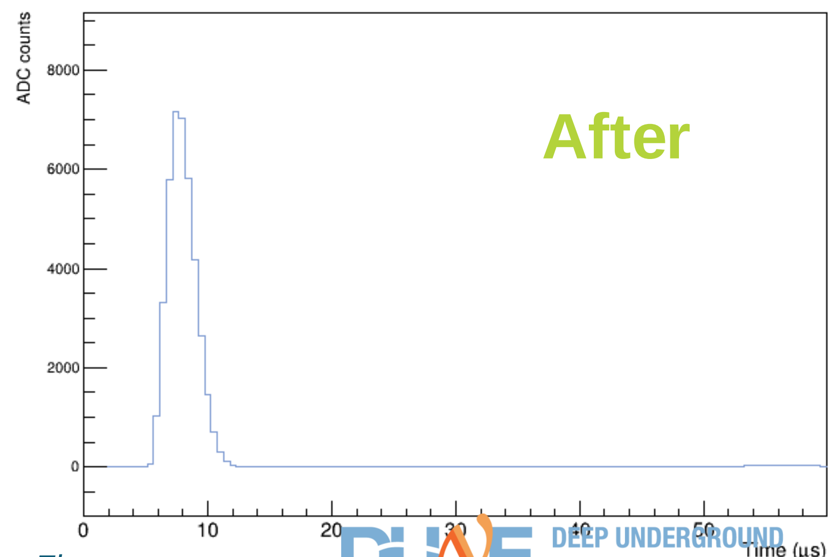

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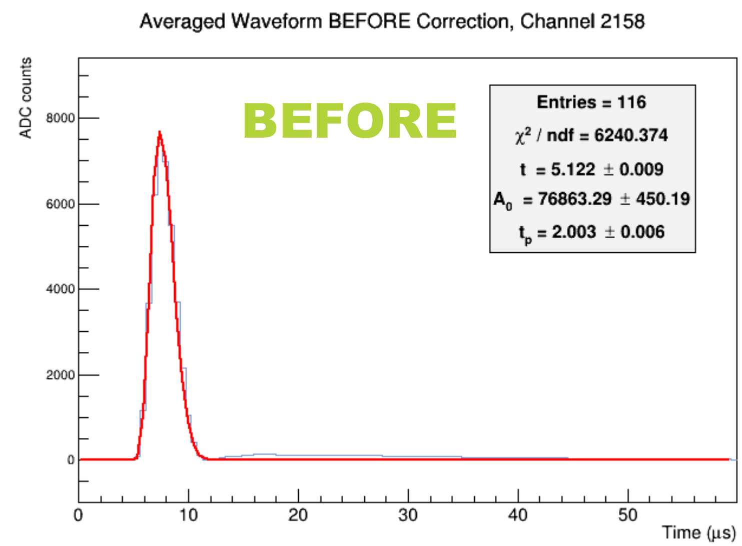

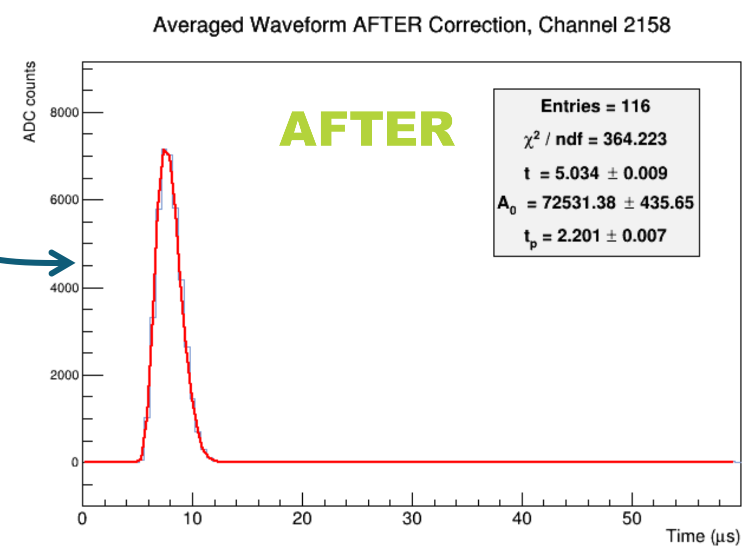

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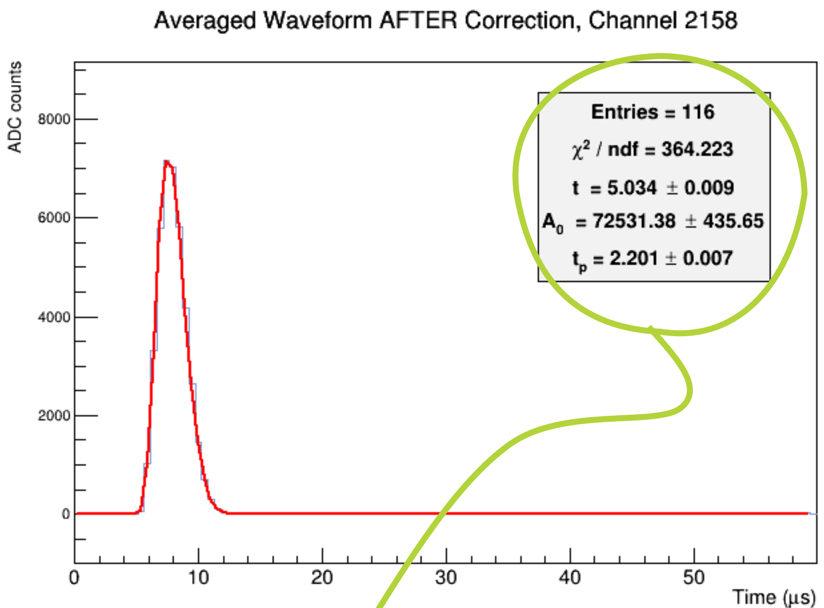

A_0 = 72531.38 ± 435.65 ADCs
t_p = 2.201 ± 0.007 µs

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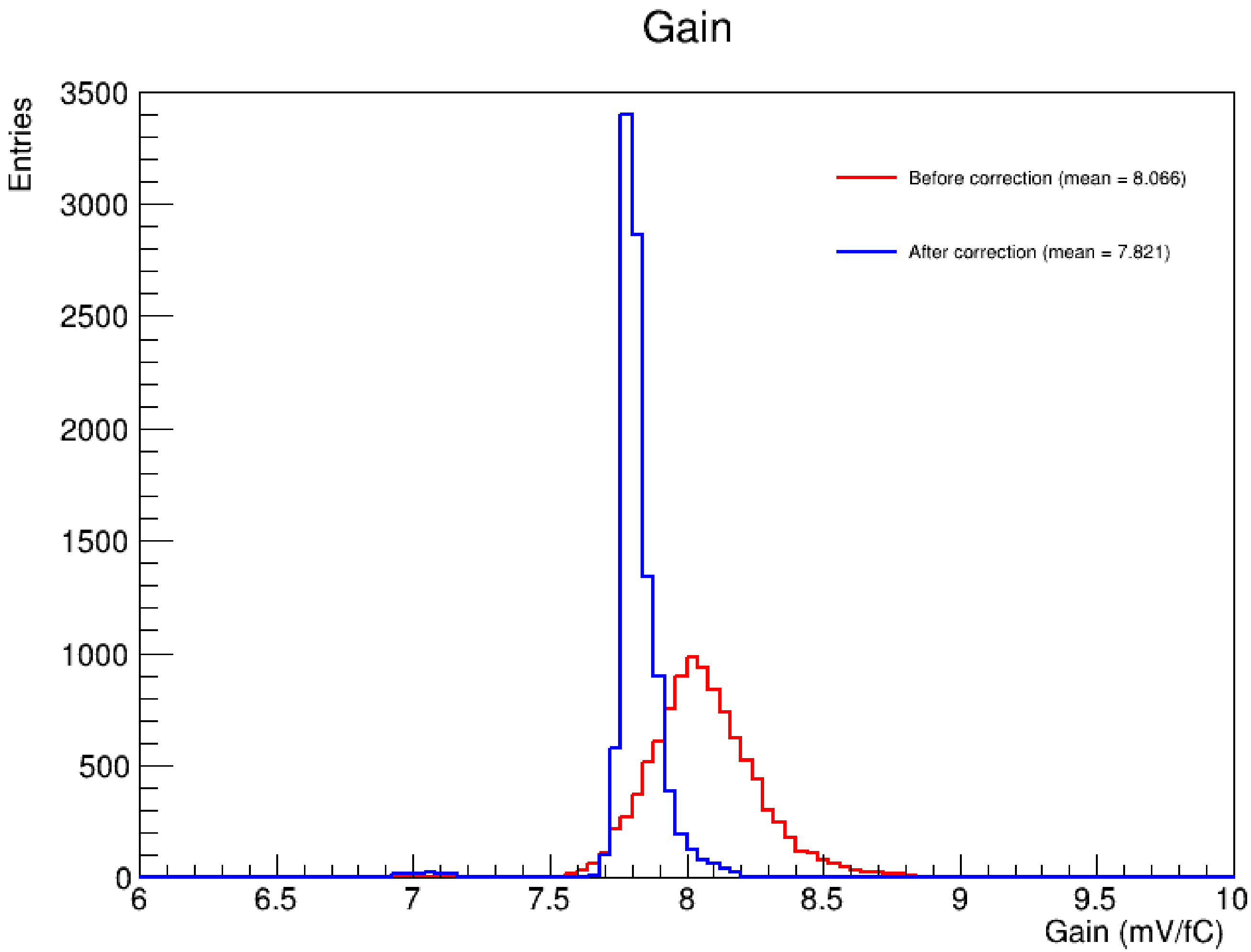
6. **Convert Amplitude to Gain.**

$$\mathbf{gain} = \frac{\mathbf{1400\ mV} * \mathbf{A_0}}{\mathbf{79.5315\ fC} * \mathbf{16384} * \mathbf{10}}$$

- **1400 mV is the maximum voltage in our voltage range.**
- **79.5315 fC is the injected charge**
    - **0.185 pF: test capacitance**
    - **14.33 mV/bit : DAC-to-voltage conversion factor for our LArASIC gain setting.**
    - **30 DAC: DAC setting.**
- **16384 : 14-bit ADC resolution (2^{14})**

First Results



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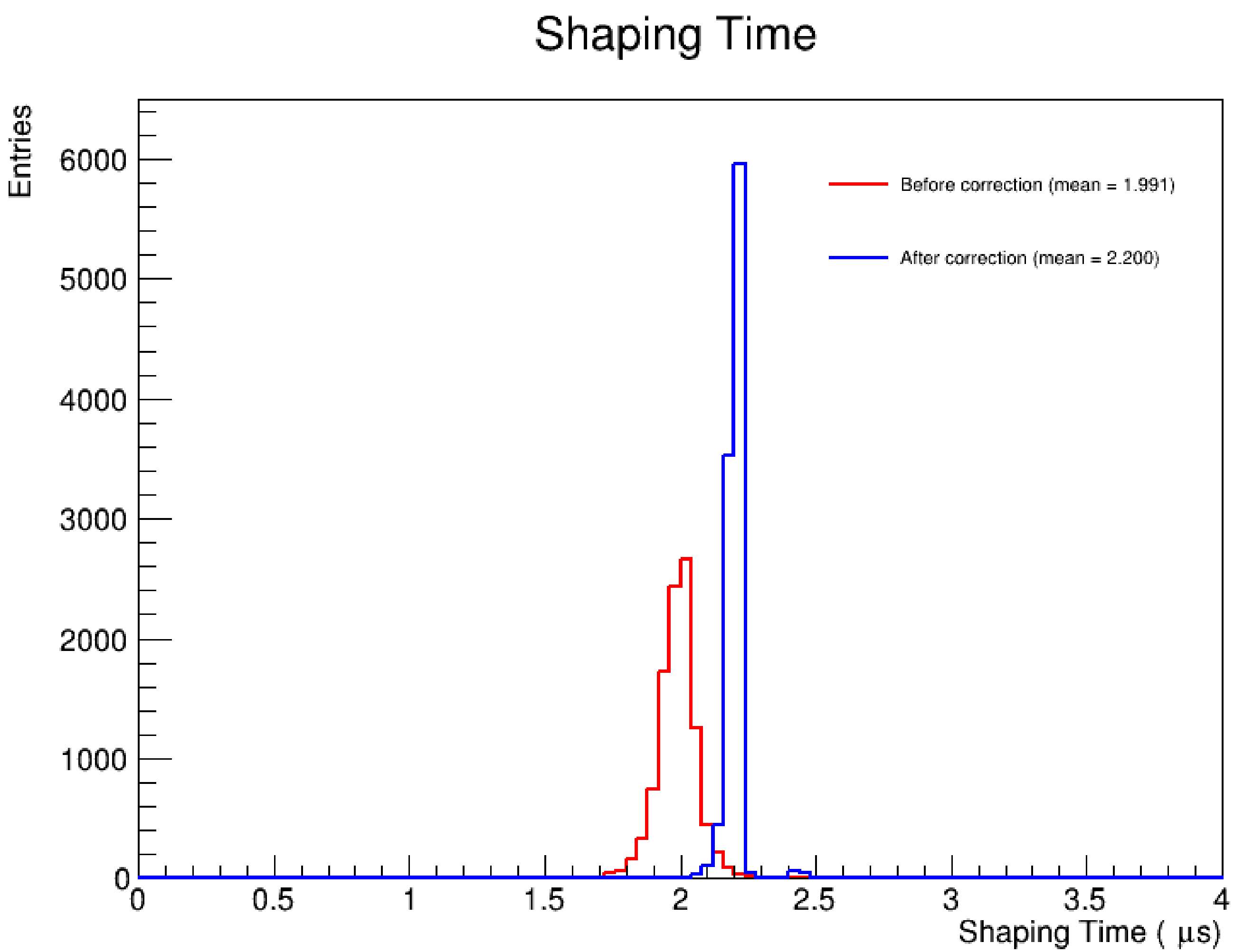

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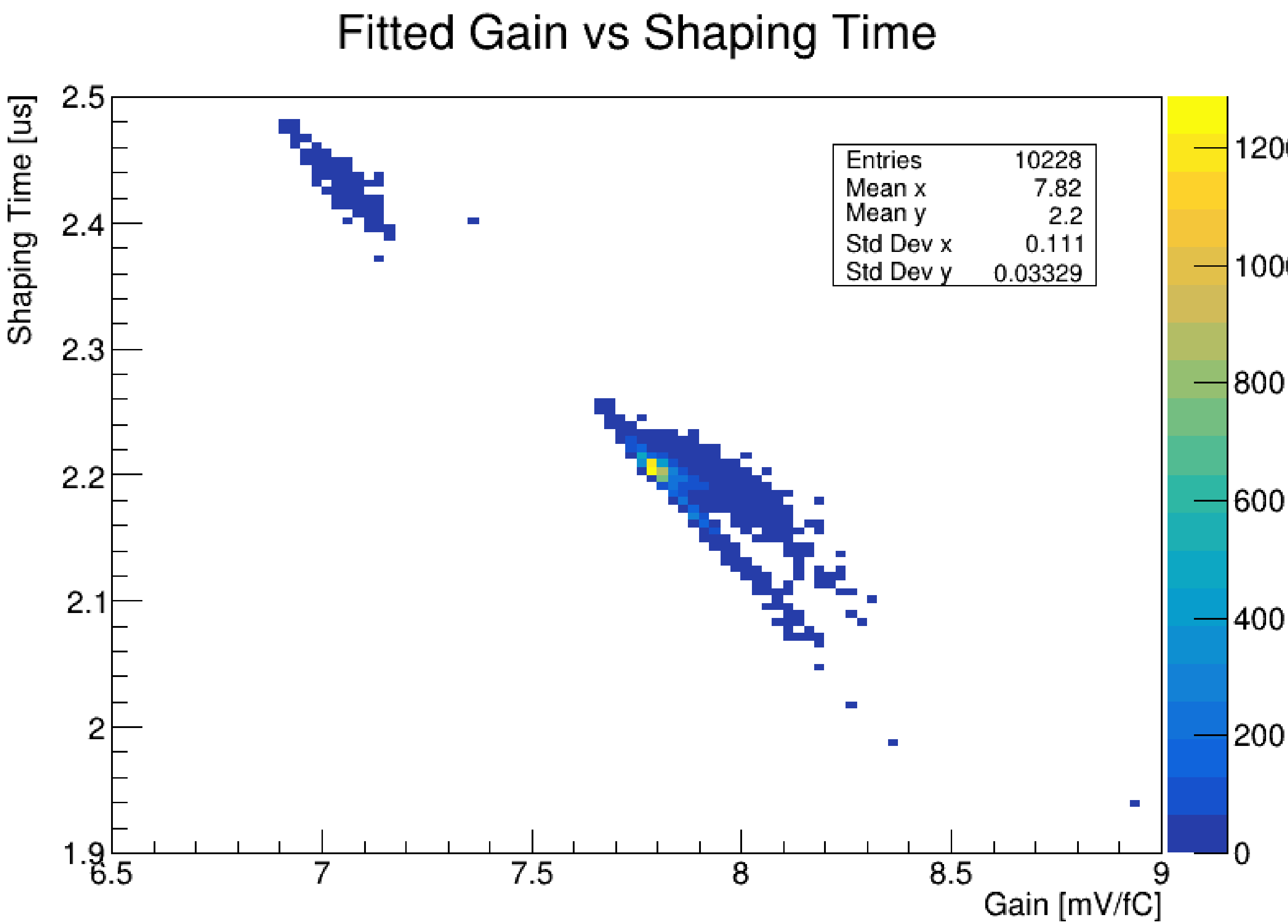
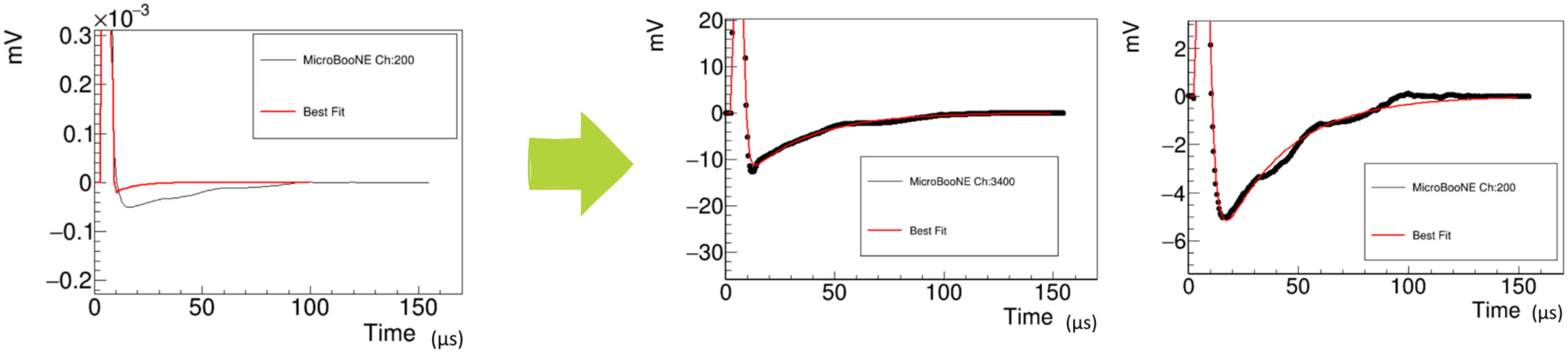


What's Next?

1. **Fix any remaining problems.**
2. **Gather all the components of the analysis and place them in a single place for the public to access.**
3. **Build a toolbox for CE performance analysis and troubleshooting.**

Backup Slides

Imperfect Pole-zero Cancelation



- From Prashansa Mukin (BNL ASIC designer):

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

Gain (A); Frequency (s); $\propto 1/t_p$

- 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**.
- When $k_3=k_4$ and $k_5=k_6$, the transfer function recovers its **ideal function** form.
- When $k_3 > k_4$ we have a **positive tail**.
- When $k_5 > k_6$ we have a **negative tail**.
- **Length** of tail is controlled by k_4.

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Electronics Response in Waveform Data

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

Digitized Waveform — Channel "i" Elec. Response — Induced Current

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

https://arxiv.org/pdf/1804.02583