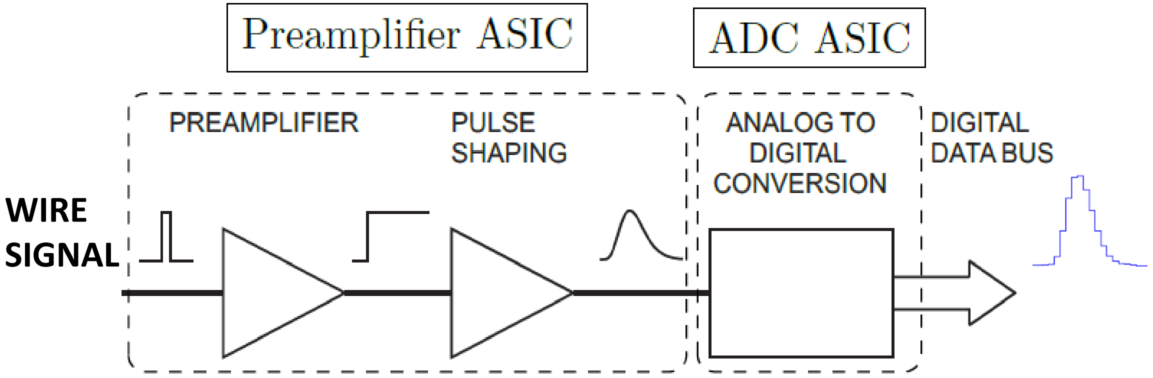

ADC Calibration in LArTPC

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for the DUNE collaboration

Workshop on Calibration and Reconstruction for LArTPCs
December 10th 2018

Evolution of ADC in LArTPC

μBooNE
- *Warm*
- *Commercial*
- *AD-9222*

→

protoDUNE
- *Cold*
- *Non-commercial*
- *“domino” P1*

→

SBND
- *Cold*
- *Commercial*
- *AD7274*

→

DUNE
- *Cold*
- *Non-commercial*
- *???*

?

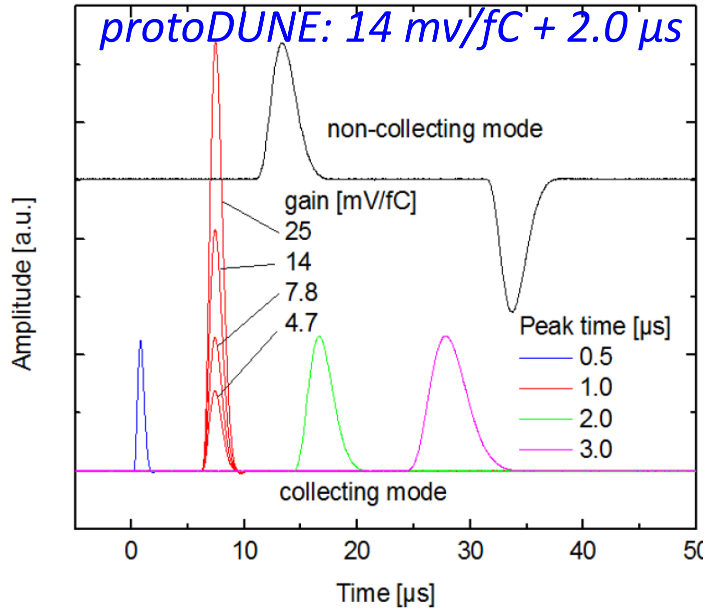
- Cold ADC is essential for DUNE

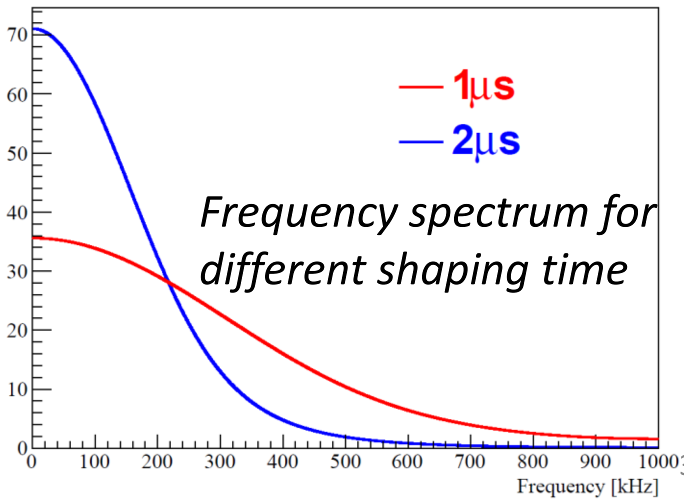
V. Radeka et al. ***Cold electronics for 'Giant' Liquid Argon Time Projection Chambers***, *J. Phys. Conf. Ser.* **308** (2011) 012021

How to choose an ADC?

- Dynamic range
  - 300 fC maximum ionized charge, 0.1 fC noise → 12-bit ADC
  - Preamp gain 4.7 mV/fC → ADC 0 ~ 1.6V

- Digitization frequency
  - Nyquist theorem: 1 MHz for 2us shaping
  - 2 MHz oversampling is helpful for improving resolution, sticky code mitigation, etc.



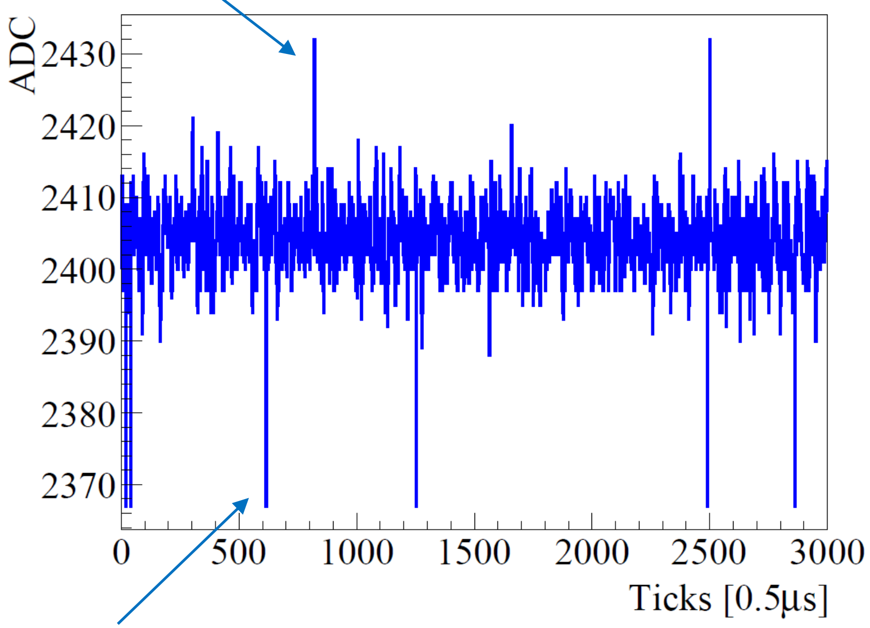


Precise ADC determination in protoDUNE

- However, given the cold environment in LAr, two problems occur for the precise determination of ADC

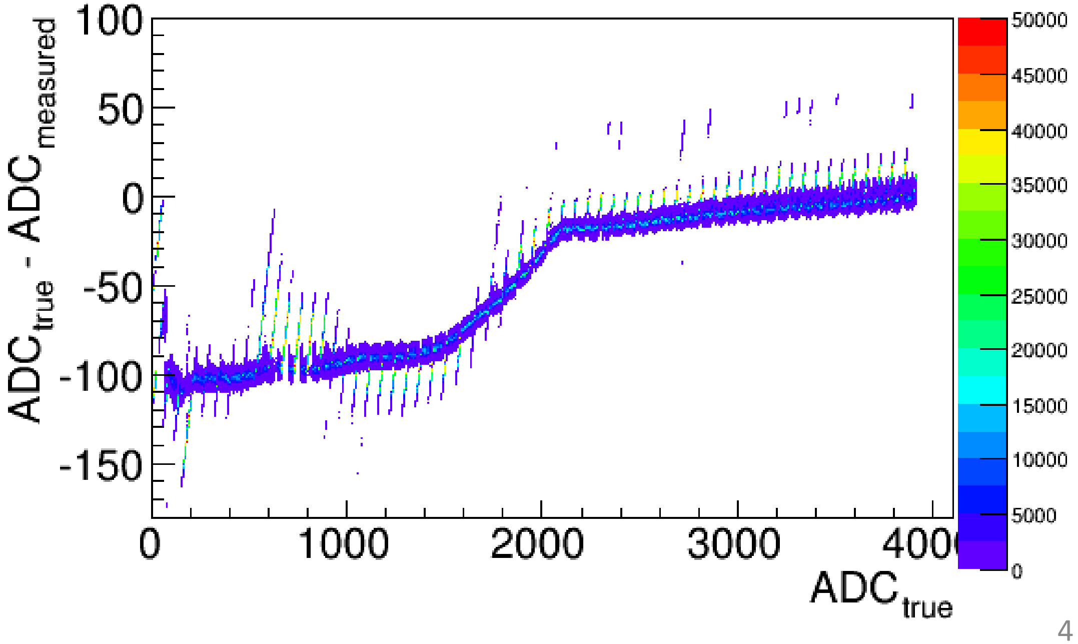
2432
= $(100110\ 000000)_2$

ADC Sticky Code



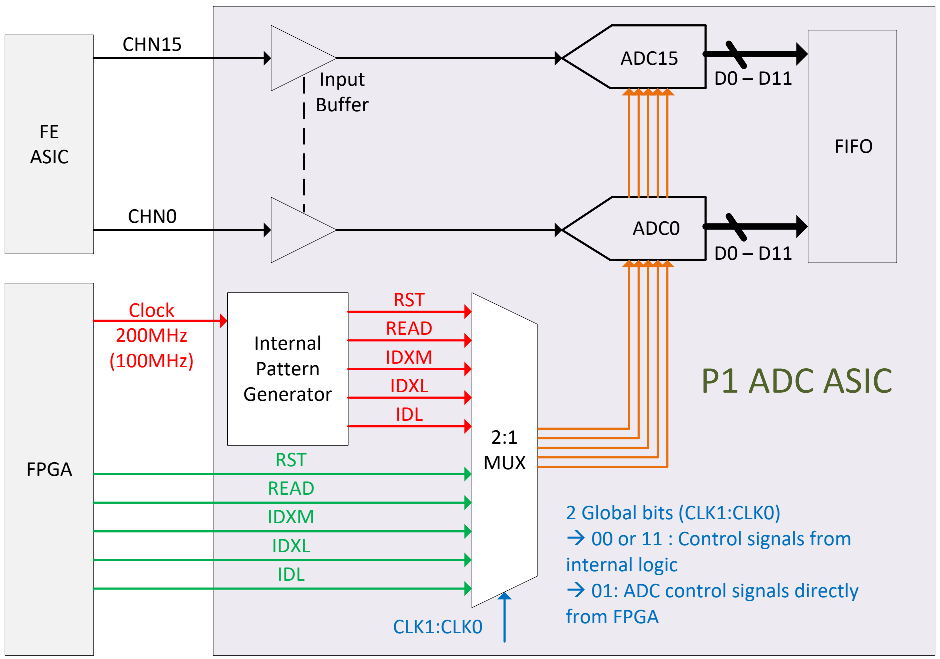
2367
= $(100100\ 111111)_2$

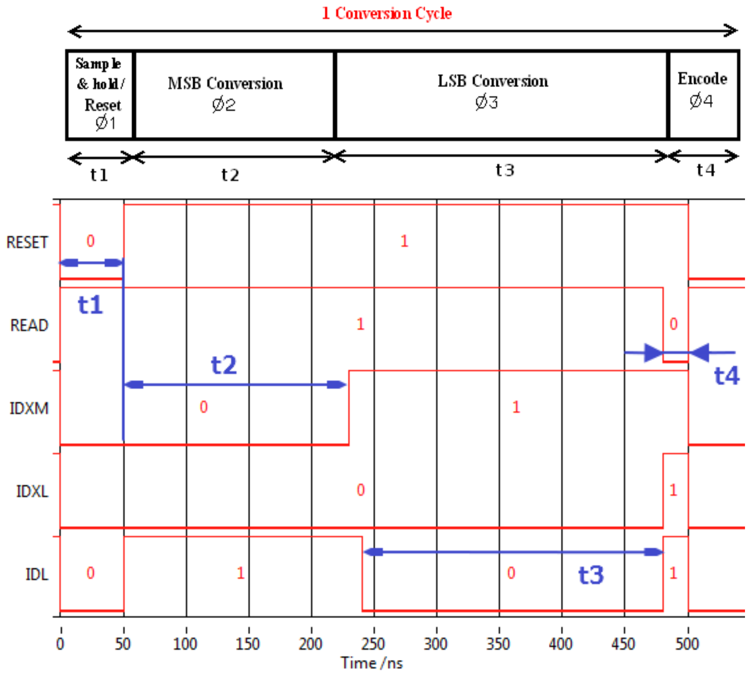
ADC Nonlinearity



ADC readout scheme in protoDUNE

- Read/write logic synchronized through five control signals
- In cold environment, an instability in bit conversion results in sticky code and nonlinearity



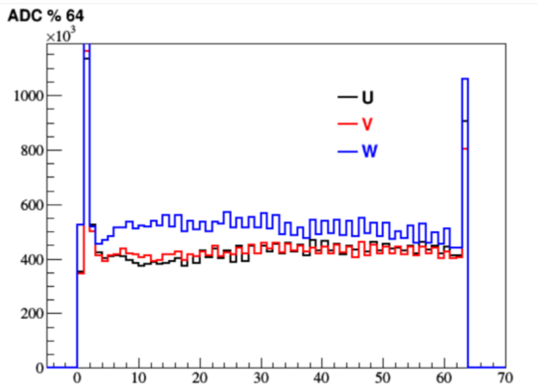


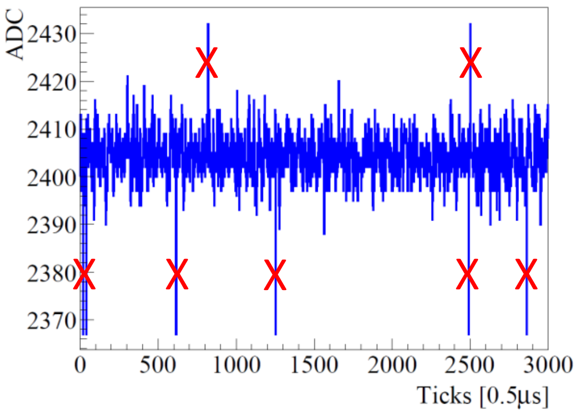
Procedure of sticky code mitigation

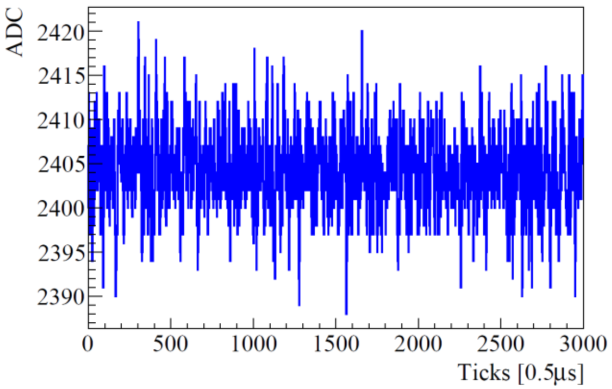
Identify sticky code:
ADC % 64 = 0, 1, 63, …

→ ***Veto sticky code candidates***

→ ***Interpolate the ticks with near-by "non-sticky" ticks***

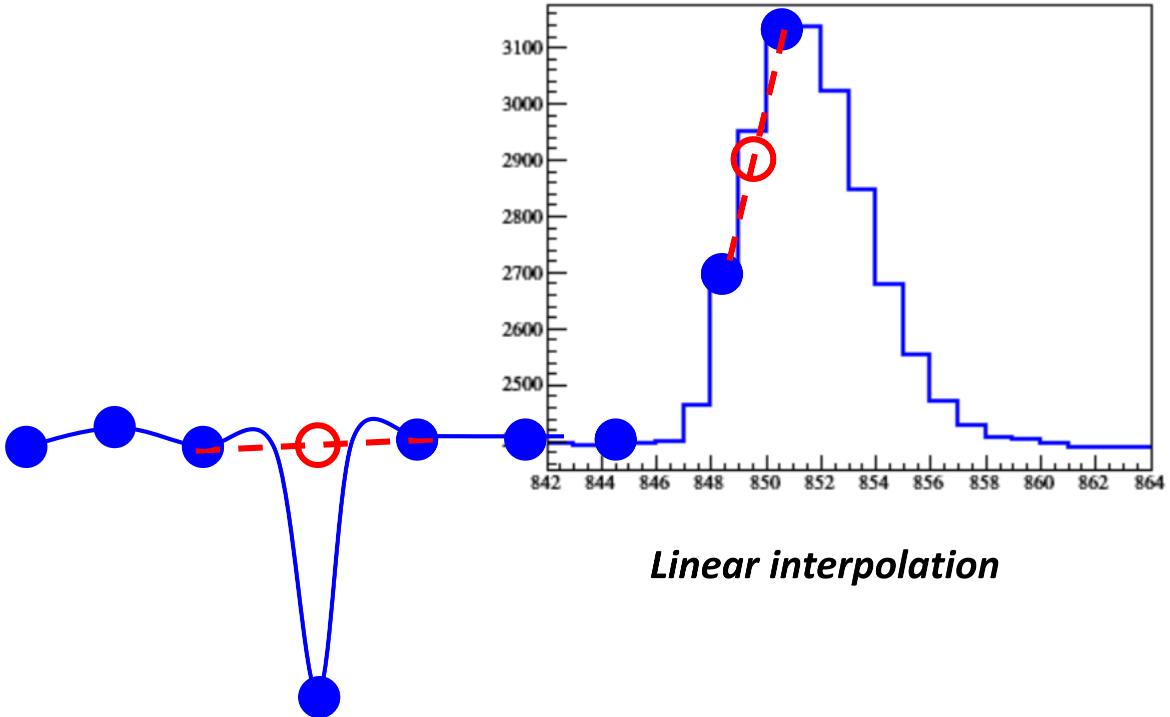




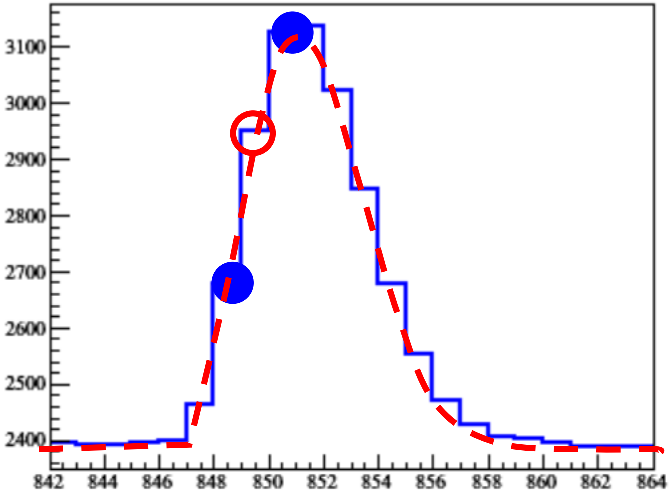


Sticky code interpolation

- Linear interpolation between “un-sticky” codes is a good first step
  - *2 MHz oversampling is helpful for interpolation*
- However, linear interpolation may not be sufficient for signal region
- A correction w.r.t. the electronics response function would be better



Linear interpolation



W.r.t response function

FFT interpolation w.r.t electronics response

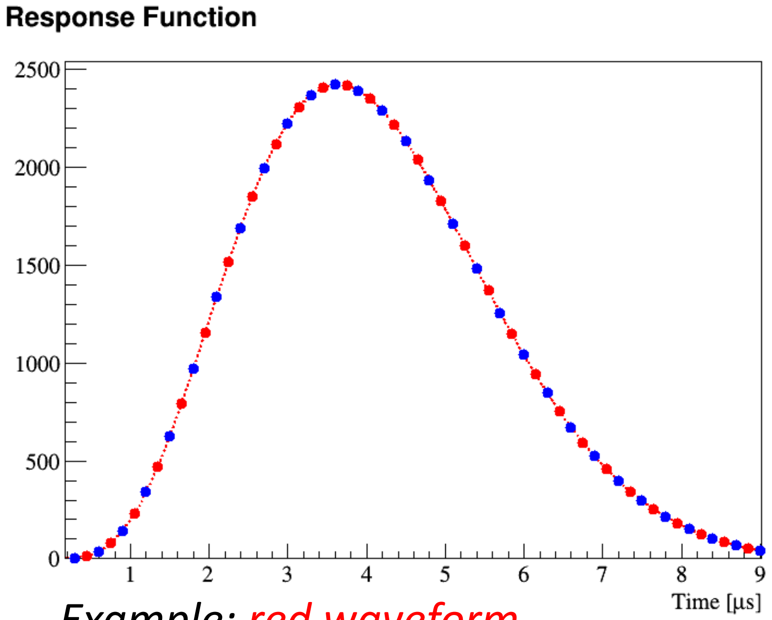
- However, some facts makes it difficult for using the response function
  - A few percent channel-to-channel variation in response function
  - Coupled with ADC nonlinearity (discussed shortly)

- Instead, a FFT interpolation is proposed by

  i) Linear interpolation as a base correction

  ii) Once a "sticky" code found in an even-binned tick, apply phase shift to odd-binned ticks to cover even-binned ticks, and *vice versa*

FT property	Time domain	Frequency domain
	$f(t)$	$F(\omega)$
Phase shift	$f(t-t_0)$	$F(\omega)e^{-j\omega t_0}$



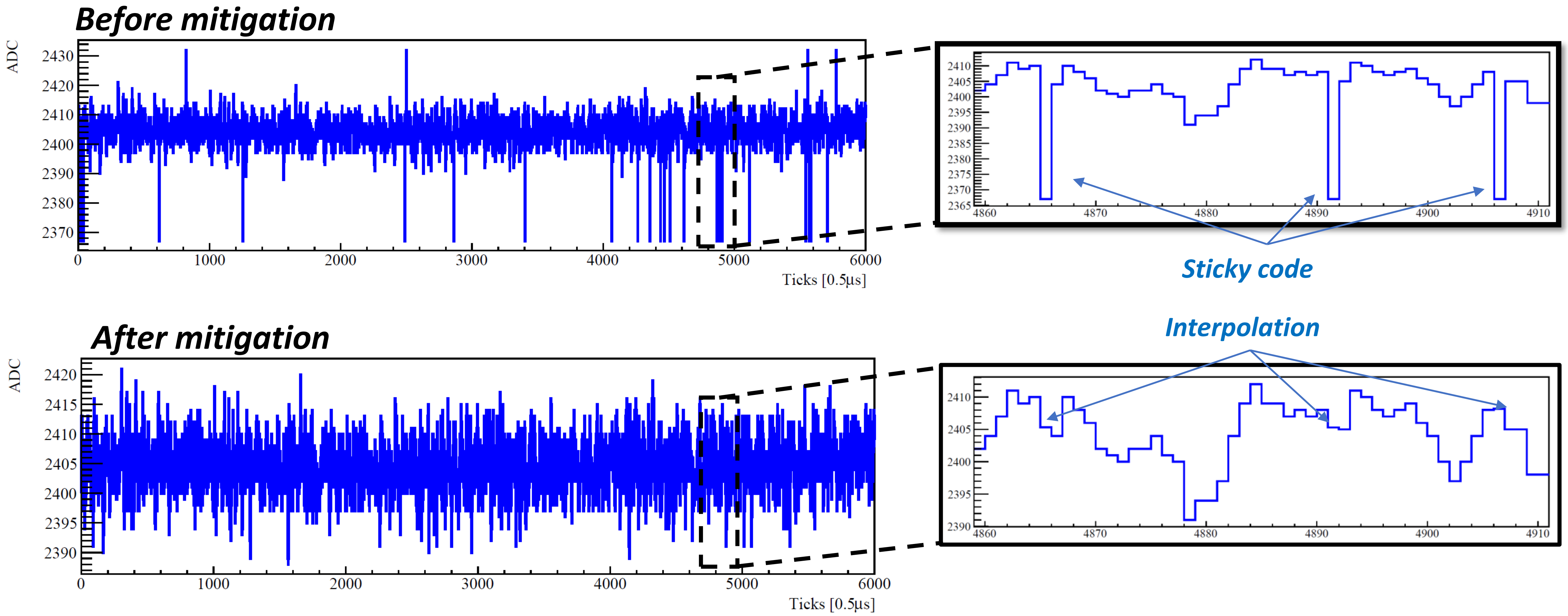
Example: red waveform interpolated from blue

Advantages of such FT interpolation

- Only the phase changed, while no changes of the magnitude in the frequency domain
  - Still respect the shape of the electronics response function

- Sometimes, good code tagged as “sticky”, the FT interpolation presumably minimize the biases
  - Balance of efficiency and accuracy for sticky code tagging

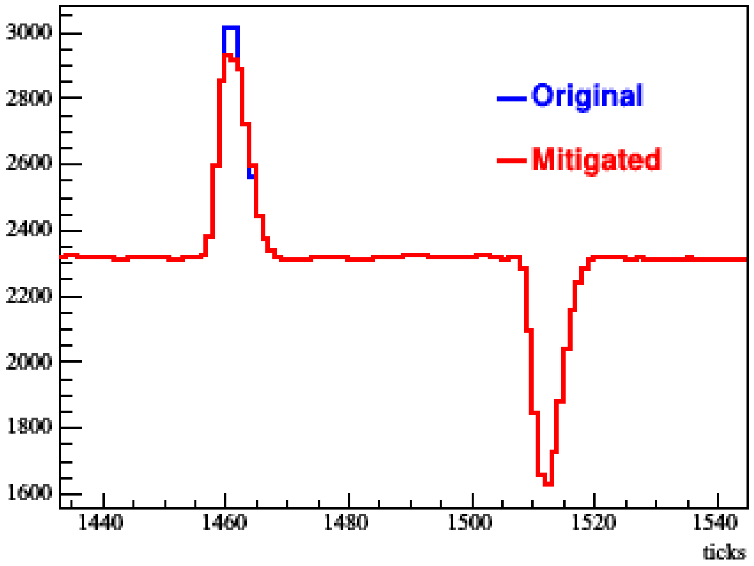
Performance of the ADC mitigation



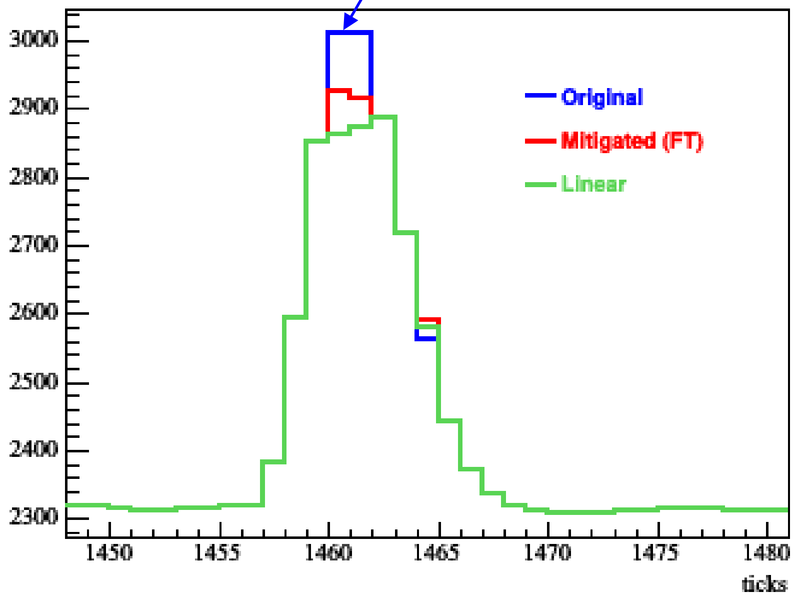
A special case

Sticky at 3008 = $(101111\ 000000)_2$

Preamp pulser waveform



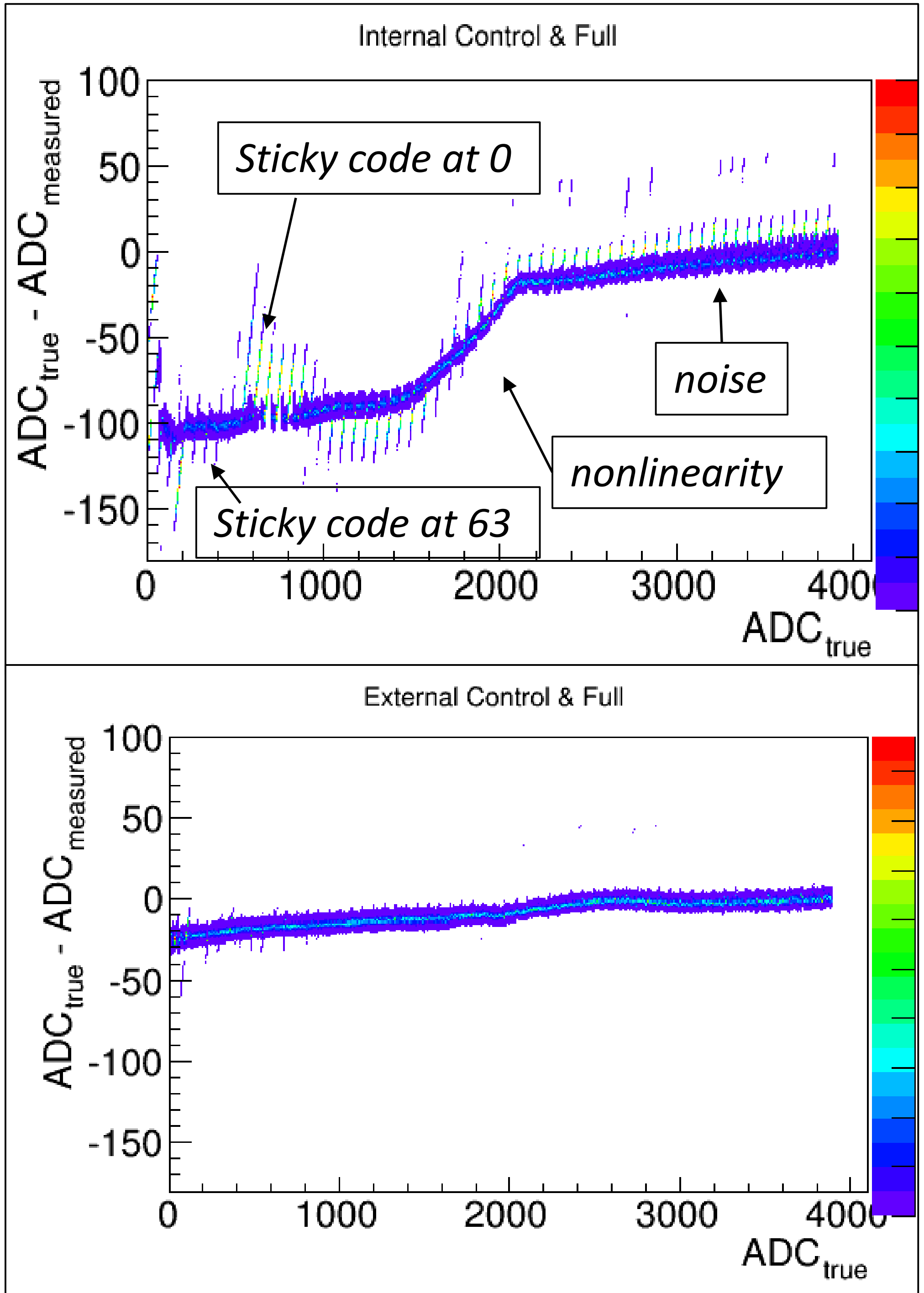
Zoom-in



- However, when two adjacent sticky codes happens on the peak region, the mitigation does not work well
- Need to improve this special case
  - Maybe ignore the base correction from linear interpolation

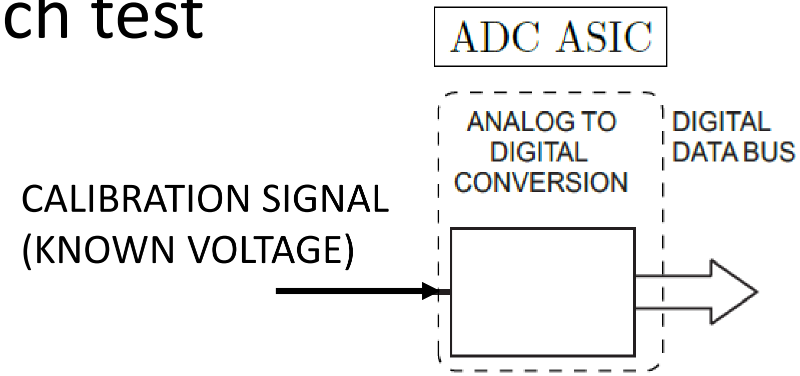
ADC nonlinearity (NL)

- Low temperature degrades the electronics and read/write logics
- External clock eases NL as well as sticky code
- NL is sensitive to clock settings
- A precise determination of ADC NL is very important for the extraction of ionized electrons



Difficulties from a bench test to protoDUNE

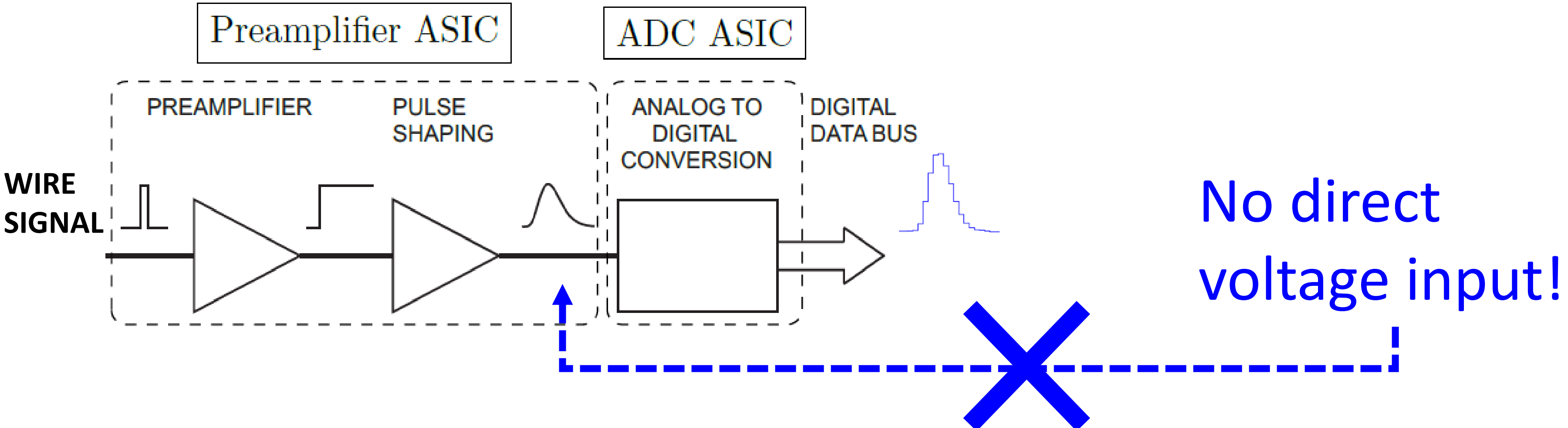
- Bench test



NL is sensitive to clock settings

- (bench test) clock is tuned for each ADC
- (protoDUNE) one clock shared by four ADC circuits

- ProtoDUNE



C. Adams et al., *Ionization Electron Signal Processing in Single Phase LArTPCs II. Data/Simulation Comparison and Performance in MicroBooNE*
arXiv:1804.02583

ADC calibration setup

Pulser
- Voltage * 64
- 0 ~ 1.4V

→

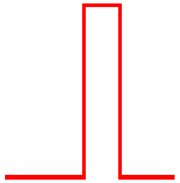
Preamplifier
- Gain *4
- Shaping *4

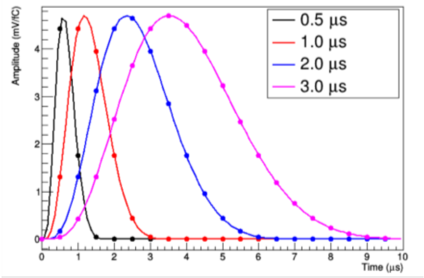
→

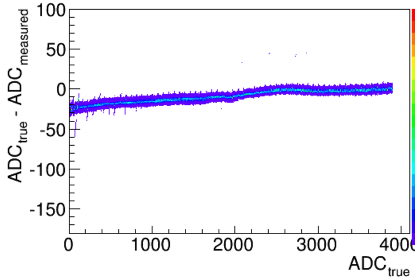
ADC nonlinearity

→

Waveform measurement



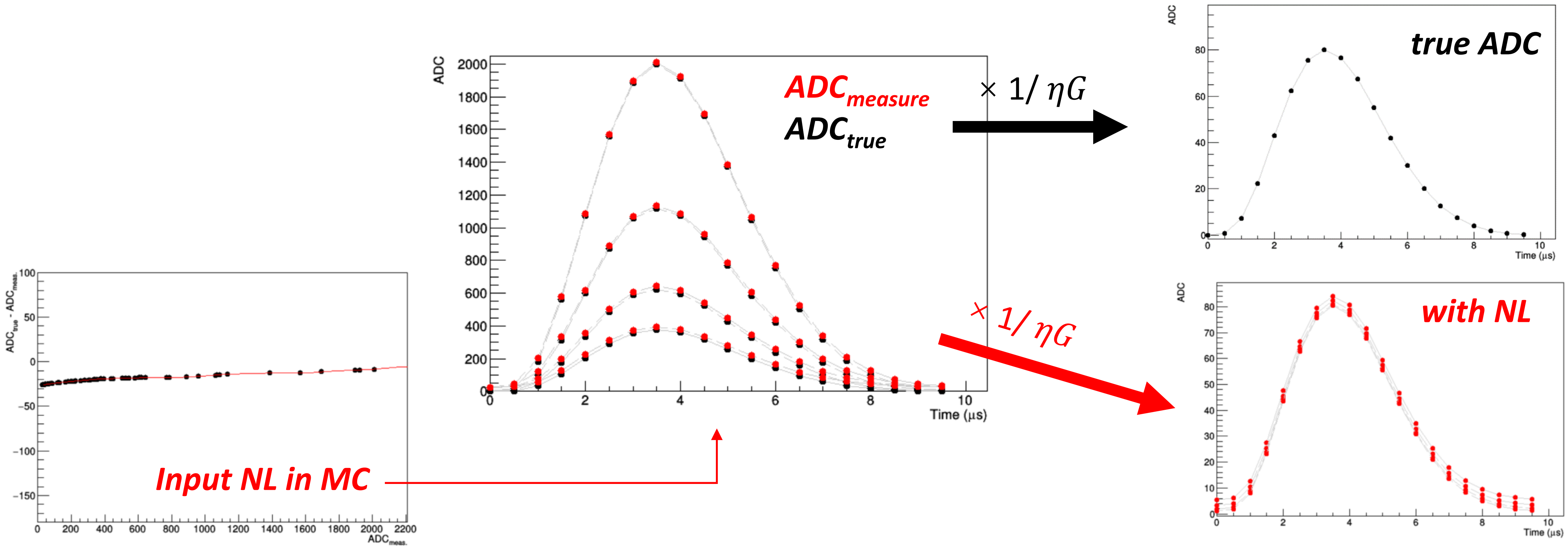




- Similar setup as in MicroBooNE electronics calibration

Calibration scheme independent of the shape of response function

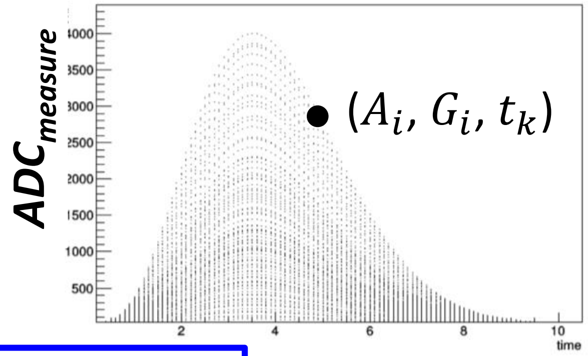
- Assume pulse voltage (η) and preamp gain (G) do not change the shape of electronics response
- NL distorts the shape differently for high ADC and low ADC



Waveforms match perfectly in shape

A spread in shapes
- Minimize it!

χ^2 minimization



$$\chi^{2(\alpha)} = \sum_i \left(A_i + f^{(\alpha)}(A_i) - R^{(\alpha-1)}(t_k)G_i\right)^2$$

index of the α-th iteration

G_i = pulse voltage × preamp gain
(A normalization of charge input)

Time tick for A_i

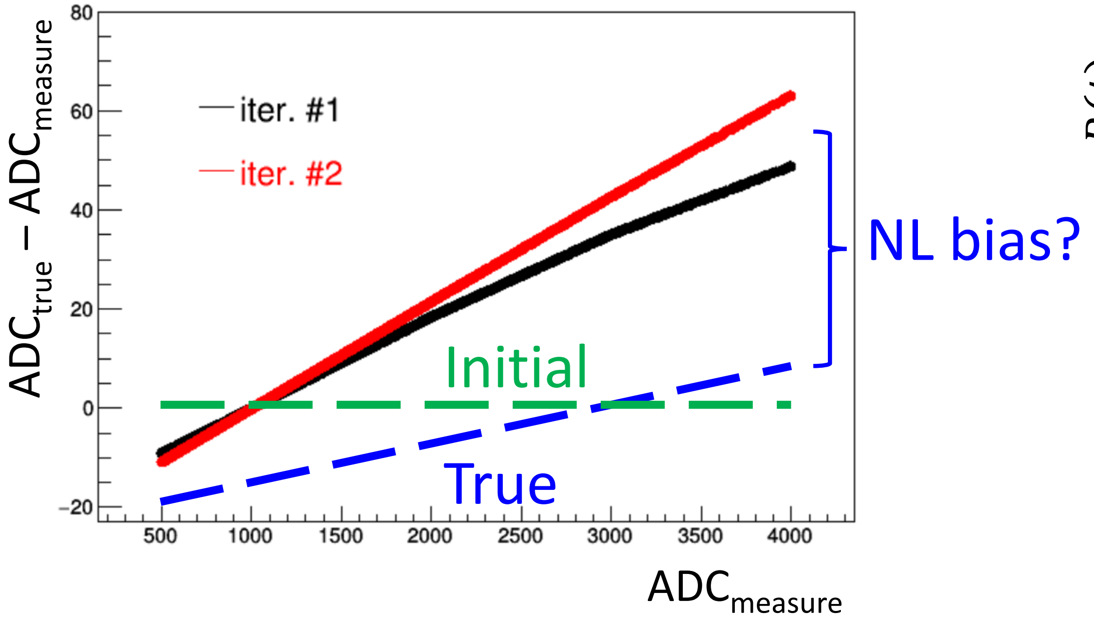
i-th data point

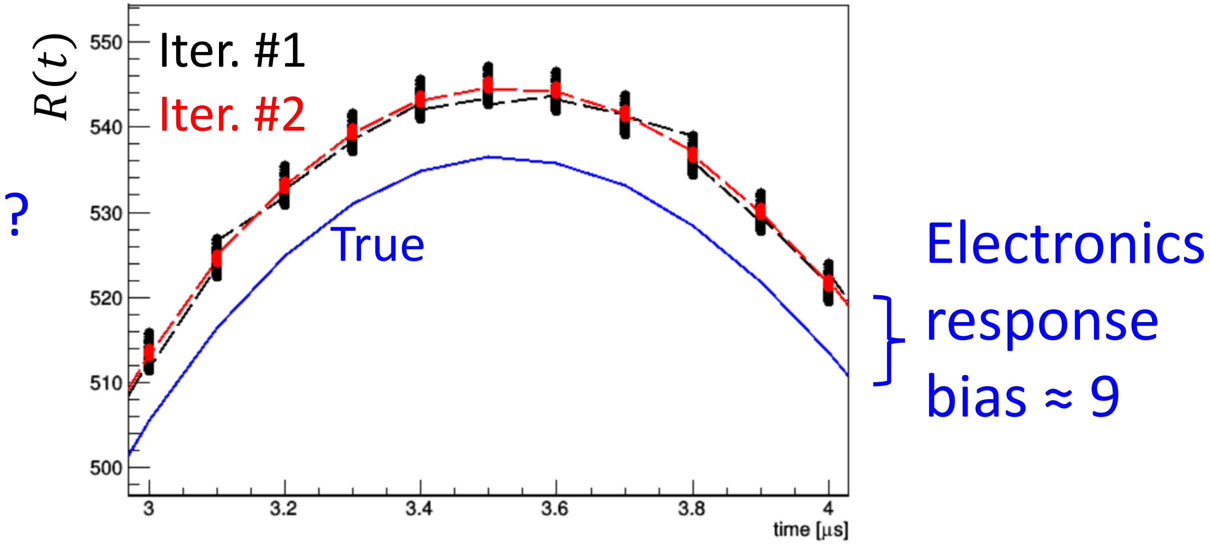
NL correction function
(To be fitted out)

$R^{(\alpha-1)}(t_k) = \frac{1}{N}\sum \frac{A_i + f^{(\alpha-1)}(A_i)}{G_i}$ is the **effective response function**
(Calculated with the NL function from best fit of previous iteration)

"Best-fit" $f(A_i)$ and $R(t)$ from simulation

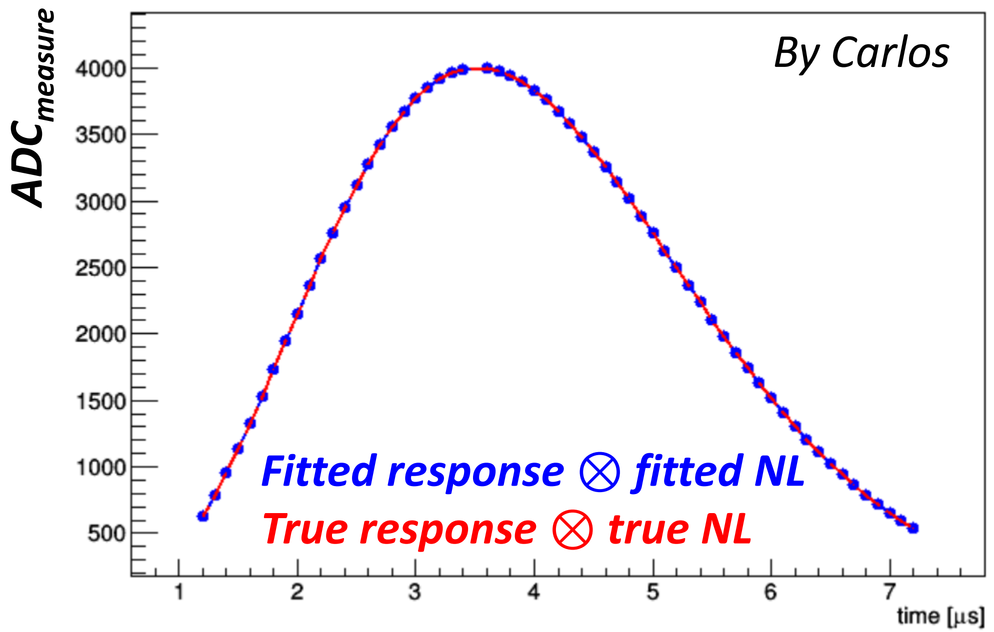
- Given an initial value of NL correction function $f(A_i)$
- After a few iterations, "best-fit" NL $f(A_i)$ and effective response $R(t)$ tends to be stable
- The spread in $R(t)$ significantly shrinks after minimization





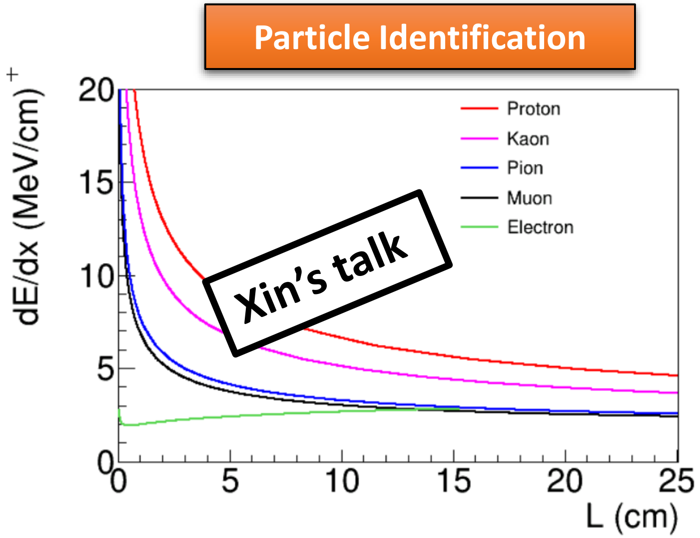
MC validation of the degeneracy

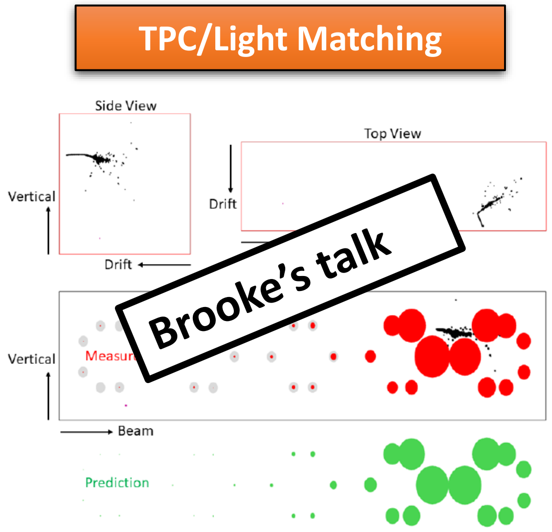
- Given a same charge input, the waveform predictions are close (<1 ADC) for
  - True response and NL
  - A “best-fit” effective response and NL
- NL bias in “best-fit” is not a problem!



Discussion: ADC impact on physics analysis

- ADC nonlinearity calibration is necessary for a precise extraction of ionized electrons
- Presumably, an important input for any analysis related with energy/charge
  - e.g., particle identification, TPC/light matching





Summary

- Cold electronics is essential for LArTPC experiments

- Sticky code mitigation
  - An interpolation approach through FT is proposed and studied in protoDUNE

- ADC nonlinearity
  - A calibration strategy was proposed and preliminarily studied in simulation