Waveform fitting algorithm for LoLX pulse data

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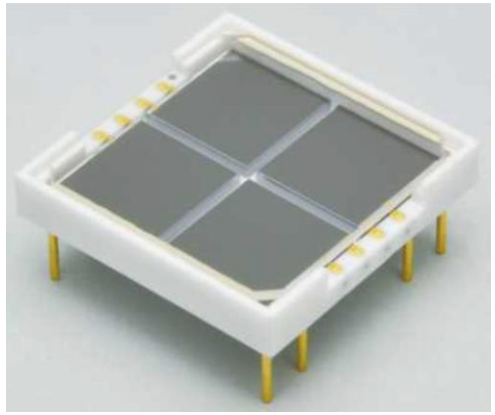
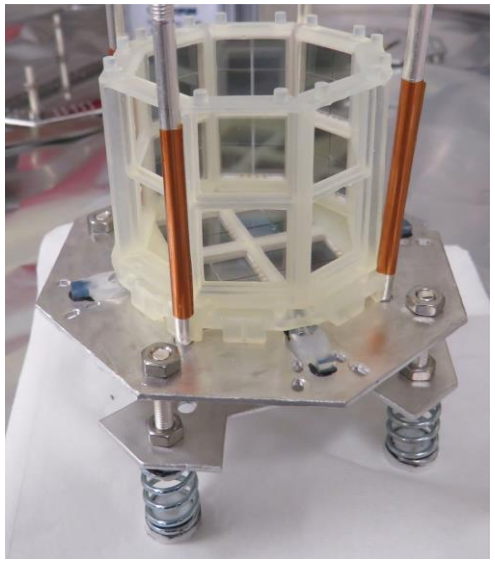
Light-only Liquid Xenon Experiment

- Study light emission, transport, and detection in liquid xenon (LXe)
- Cylindrical geometry lined with 96 Hamamatsu VUV4 Silicon Photomultipliers (SiPMs) submerged in Lxe

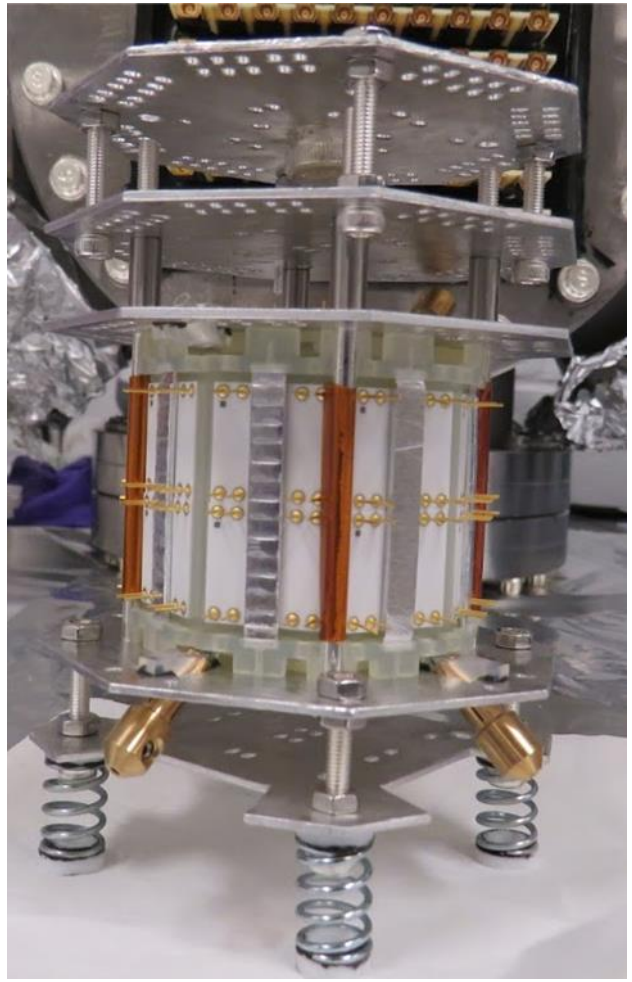
SiPM module



3D printer cage



LoLX detector



Figures: LoLX photo archive

Physics goals

- Measure Cherenkov and scintillation light yield in liquid xenon
- Characterize performance of multiple Silicon Photo Multipliers in liquid xenon
- Better understand SiPM external cross-talk

SiPM technology

- Photodetector of choice for noble liquid detectors
- Fast, single-photon counters

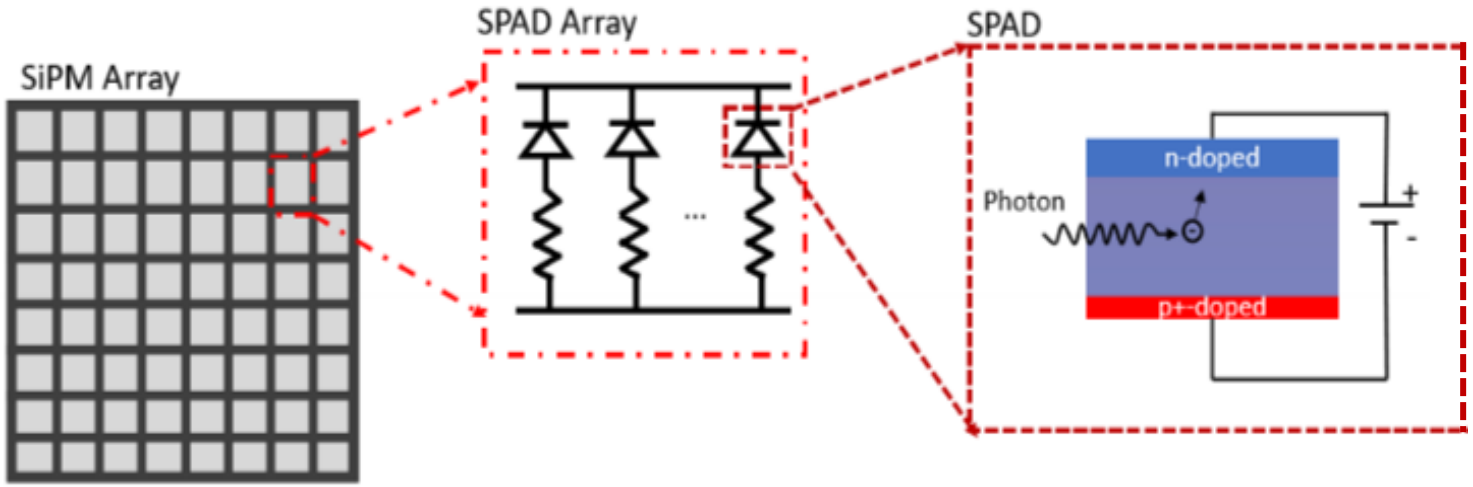


Figure: David Gallacher, MSc. Thesis Argon-1 at Carleton

- Array of single photon avalanche diodes (SPADs)

How do SiPMs work?

1. Photon is absorbed in SPAD depletion region
2. Charge carriers trigger avalanche
3. Produces analogue output signal

SiPM correlated noise

- During photon-detection process, secondary photons can be produced.
- Reach nearby SPADs

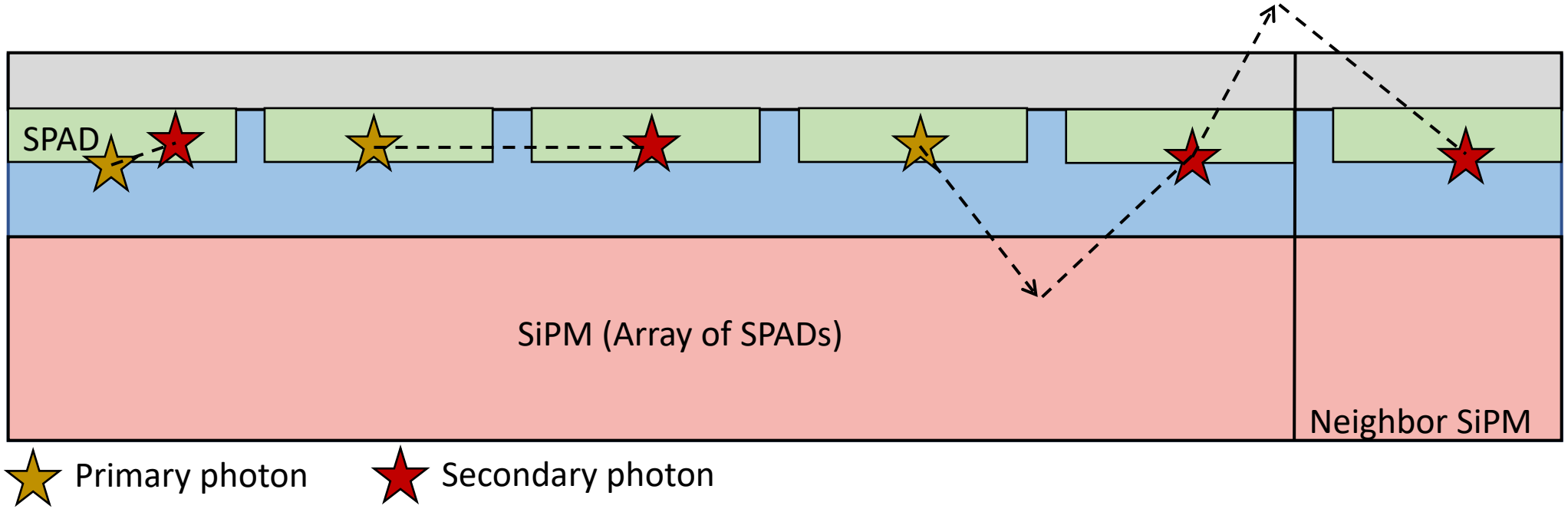


Figure: Reproduced from David Gallacher, MSc. Thesis Argon-1 at Carleton

SiPM correlated noise

- Time resolution of after-pulsing is key to characterizing correlated noise

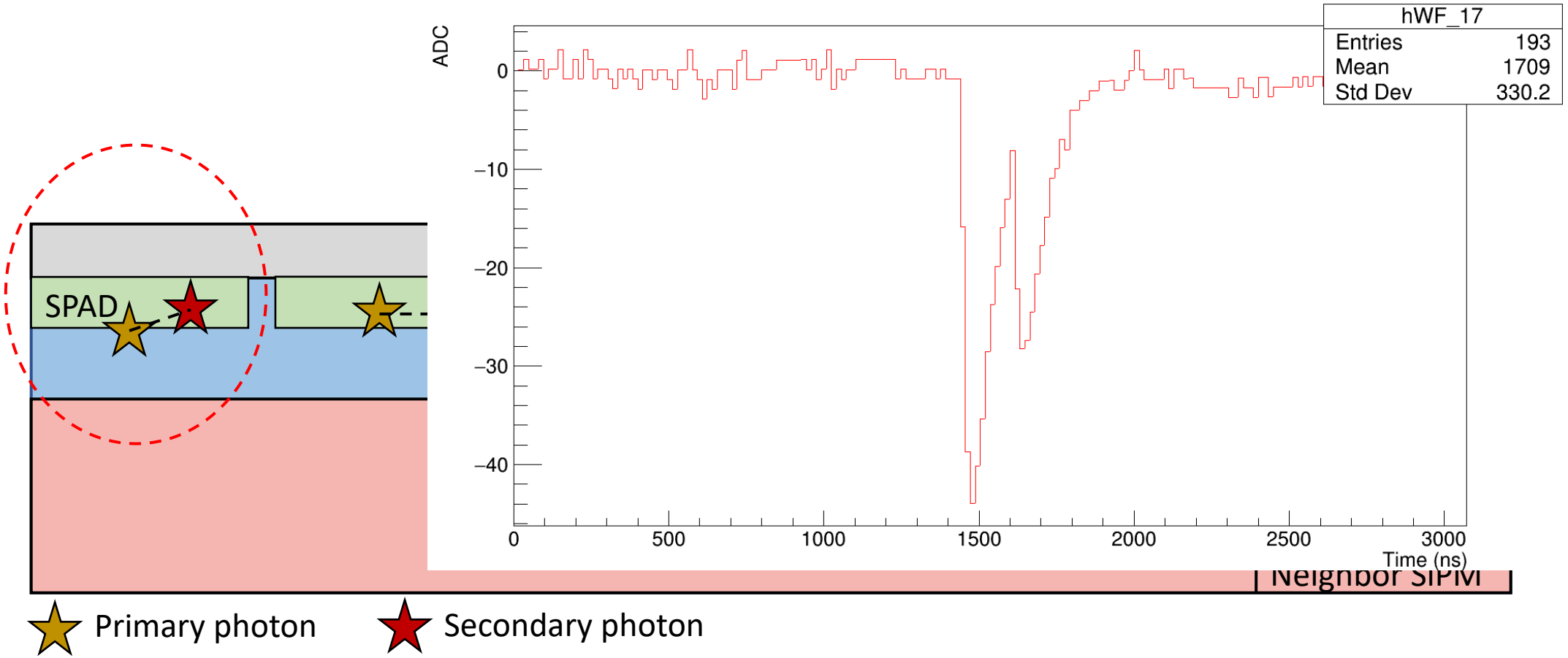


Figure: Reproduced from David Gallacher, MSc. Thesis Argon-1 at Carleton

Why a pulse fitter?

- Characterize SiPM pulse shape with reliable template

- Improve the energy and timing resolution of response model for photon detection

Pulse fitter structure

Single Avalanche Response Function (SARF)

Exponential/Gaussian

$$f_{short}(t) = e^{\left[\frac{\sigma^2}{2\tau_s^2} - \frac{t-t_0}{\tau_s}\right]} \times \operatorname{erfc}\left[\frac{\sigma}{\sqrt{2}\tau_s} - \frac{t-t_0}{\sqrt{2}\sigma}\right]$$

$$f_{long}(t) = e^{\left[\frac{\sigma^2}{2\tau_l^2} - \frac{t-t_0}{\tau_l}\right]} \times \operatorname{erfc}\left[\frac{\sigma}{\sqrt{2}\tau_l} - \frac{t-t_0}{\sqrt{2}\sigma}\right]$$

(Complementary) Error function

$$f_{fit}(t) = Amp \times \left[\frac{(1-k)}{2\tau_s} f_{short}(t) + \frac{k}{2\tau_l} f_{long}(t)\right]$$

- Photon counting signal reconstruction
- Functional template for LoLX pulse shape
- Estimate six parameters per pulse

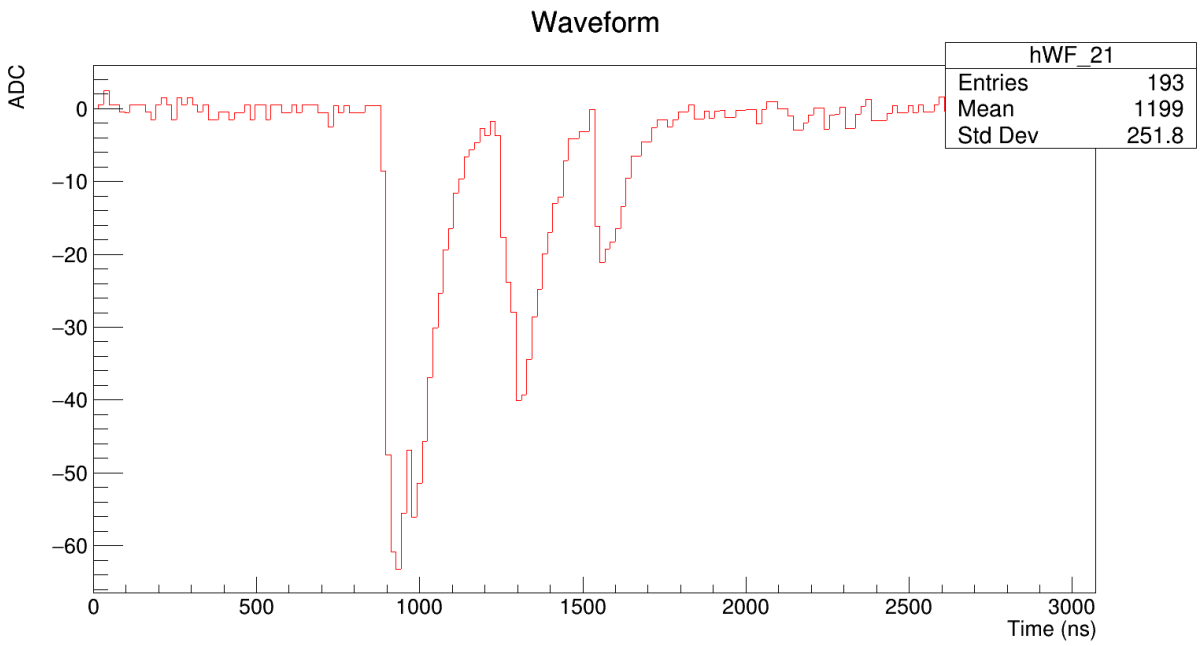
$$\sigma, \tau_s, \tau_l, t_0, A, k$$

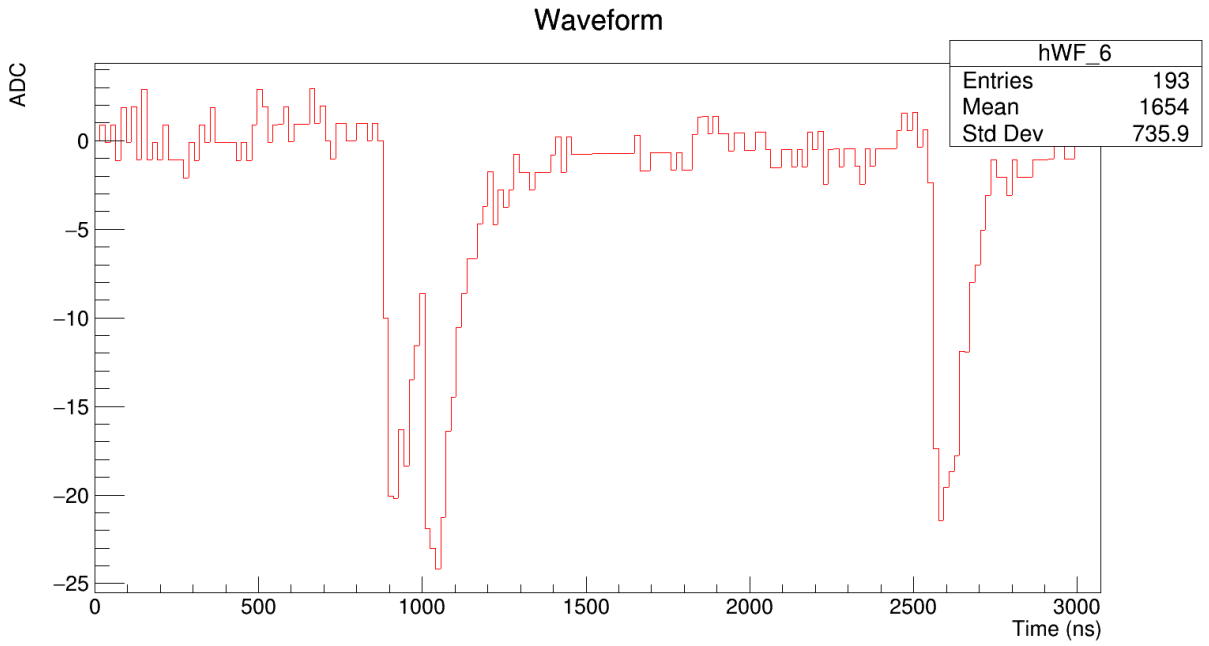
- Initial guess for t_0 and A from pulse finder

G. Gallina et al. Characterization of the Hamamatsu VUV4 MPPCs for nEXO, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, Volume 940, 2019, Pages 371-379, ISSN 0168-9002, https://doi.org/10.1016/j.nima.2019.05.096.

Hybrid approach to fits

- Complex waveforms
- Discriminate between simple and compound pulses



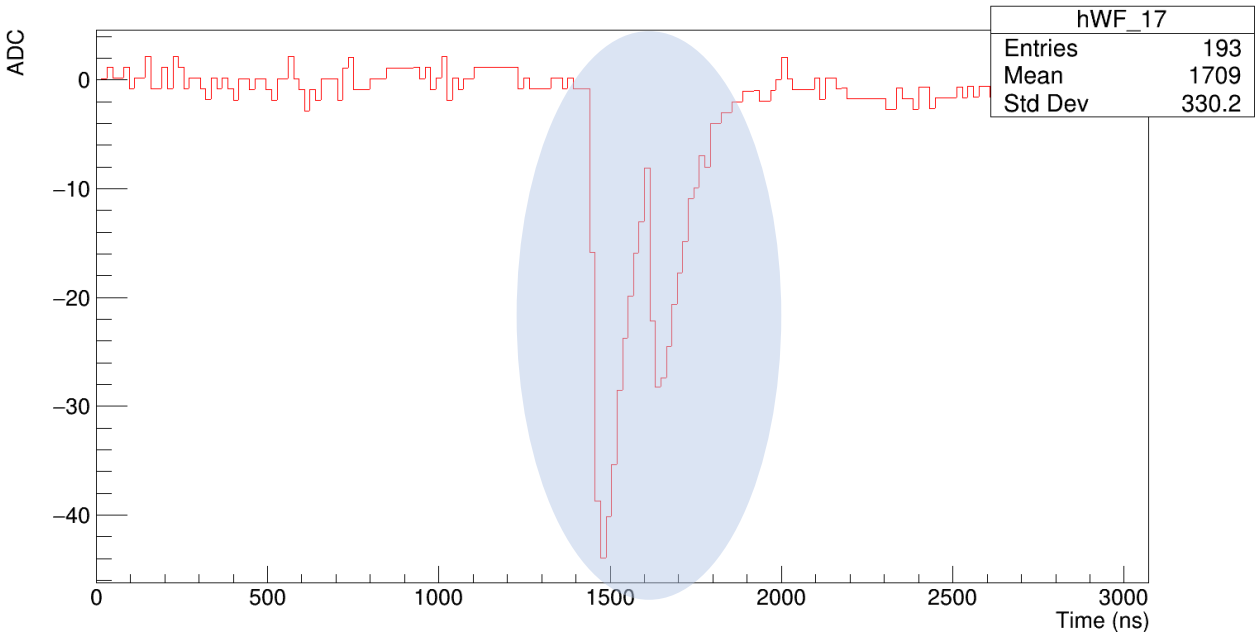


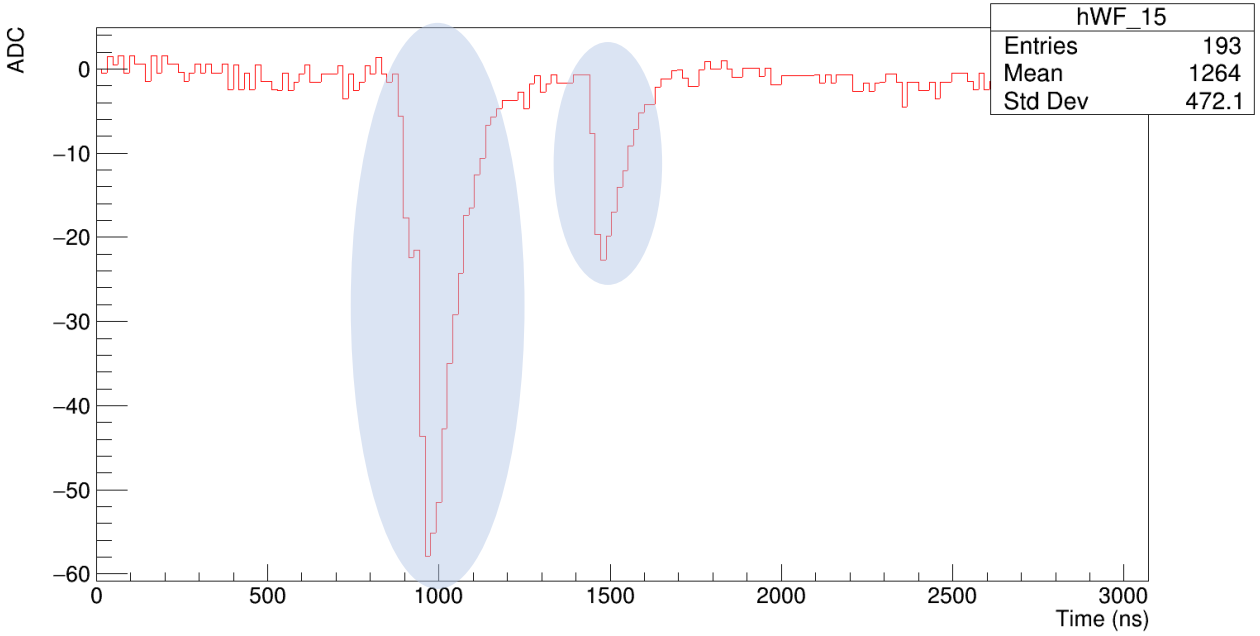
Hybrid approach to fits

- Discriminate between simple and compound pulses

1. Find number of main pulses

Does pulse return to baseline?

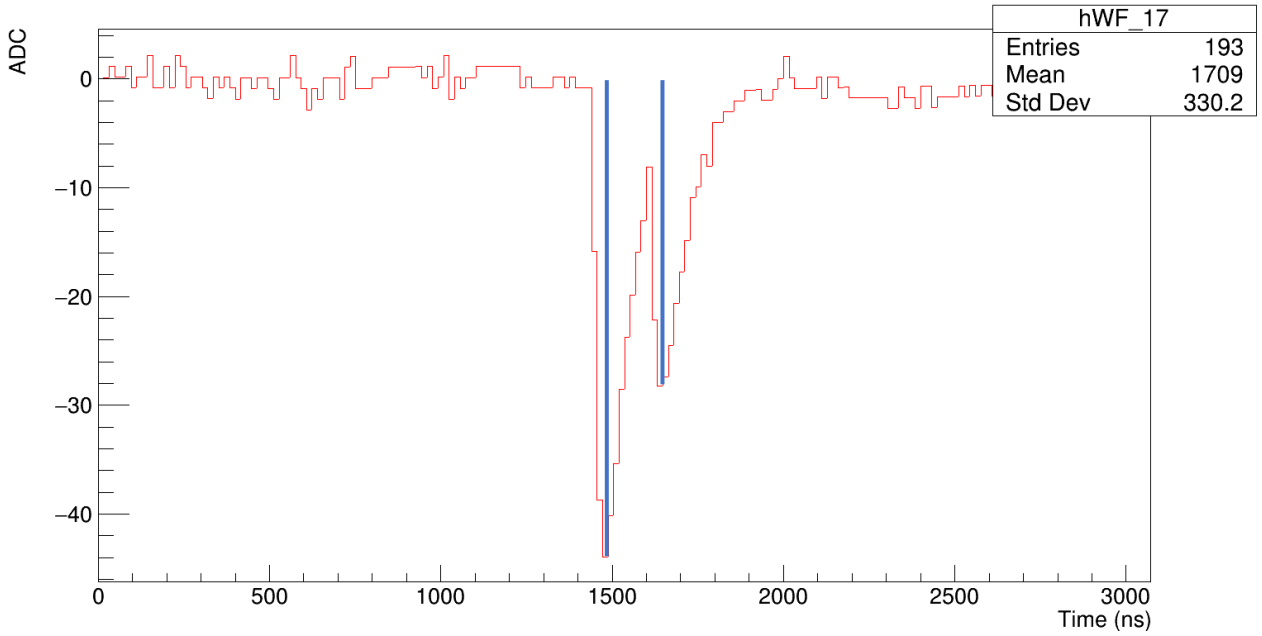


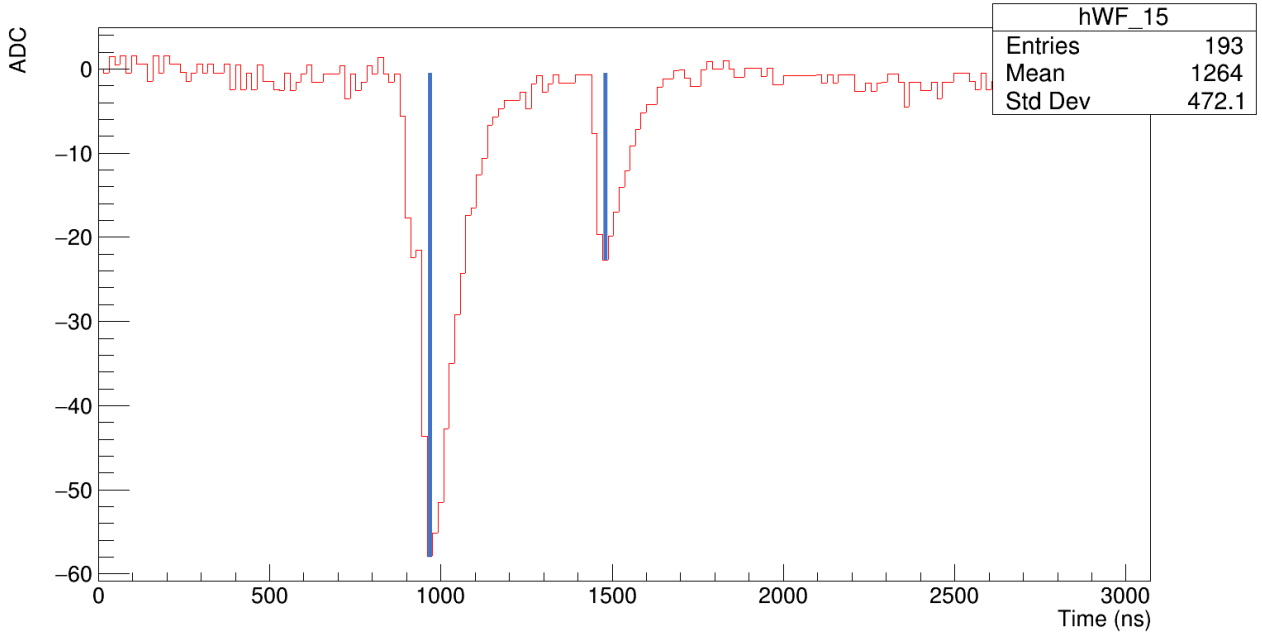


Hybrid approach to fits

- Discriminate between simple and compound pulses

1. Find number of main pulses
2. Number of peaks inside each pulse





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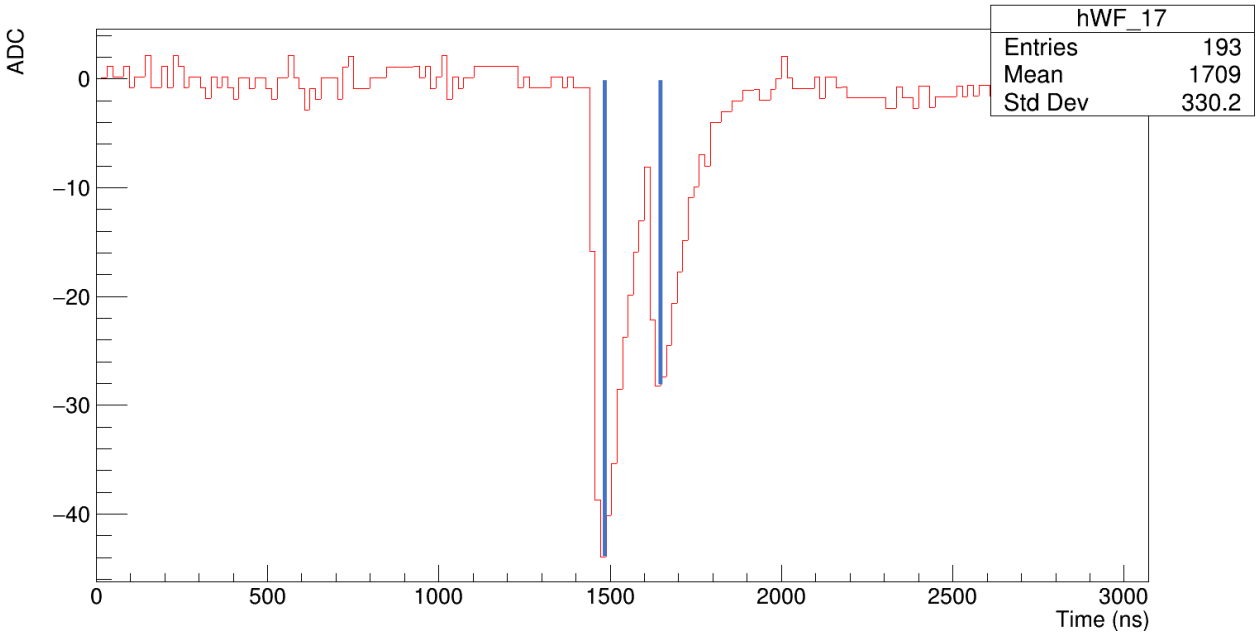

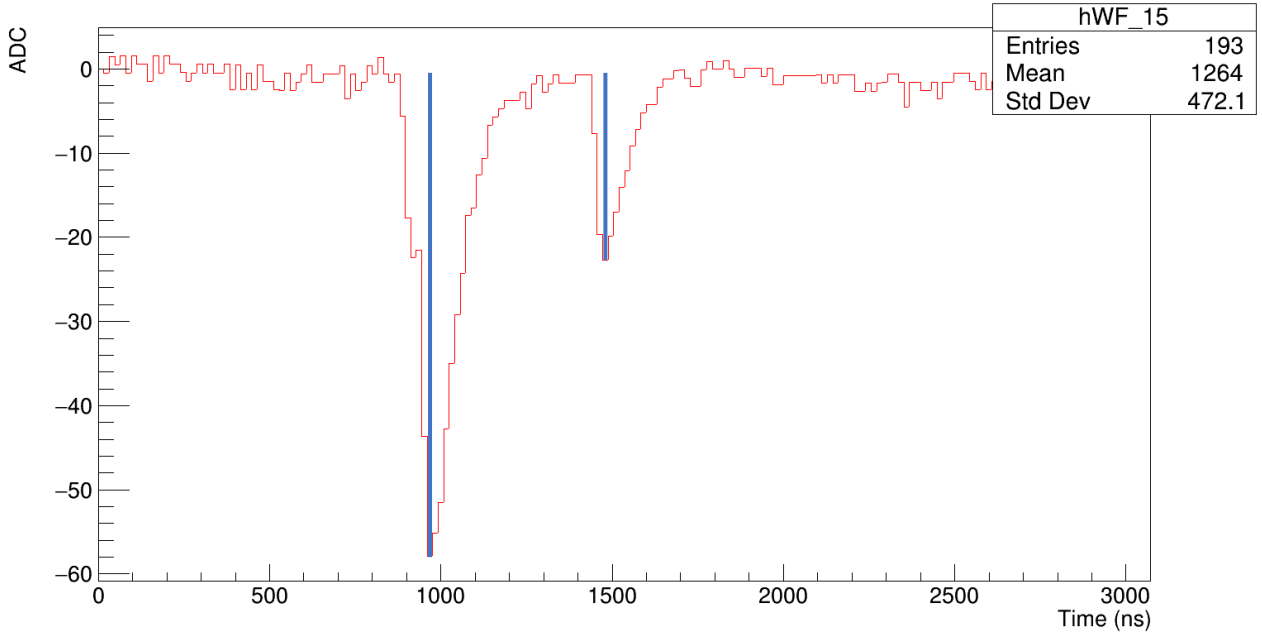

If one peak → single template fit

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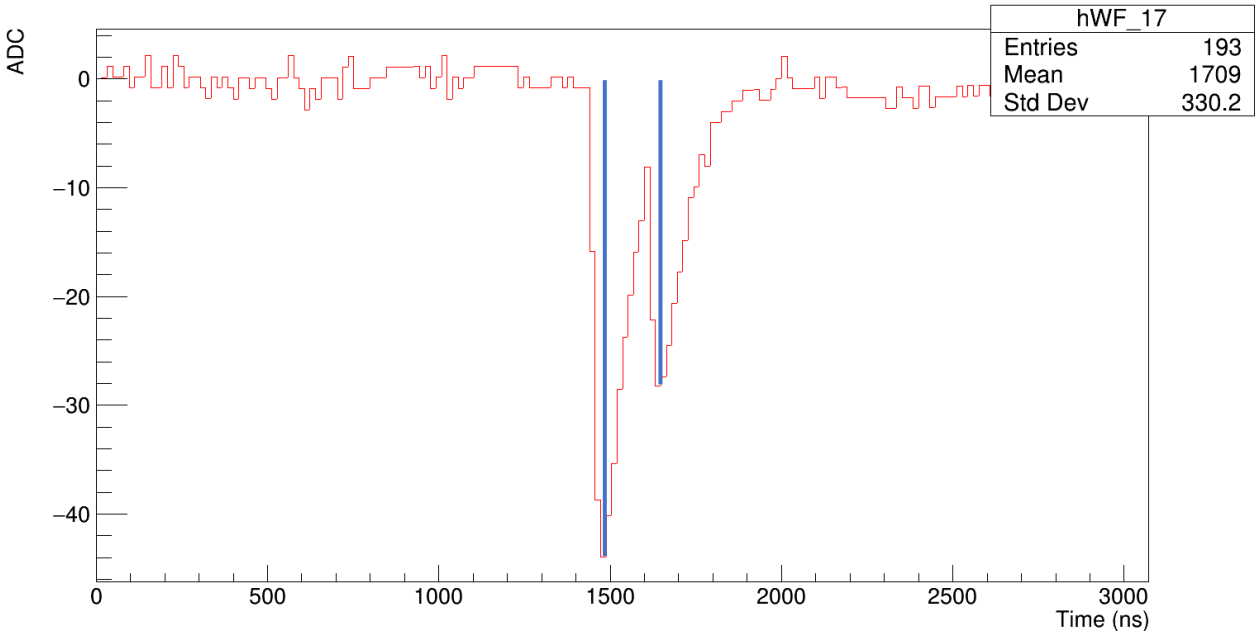
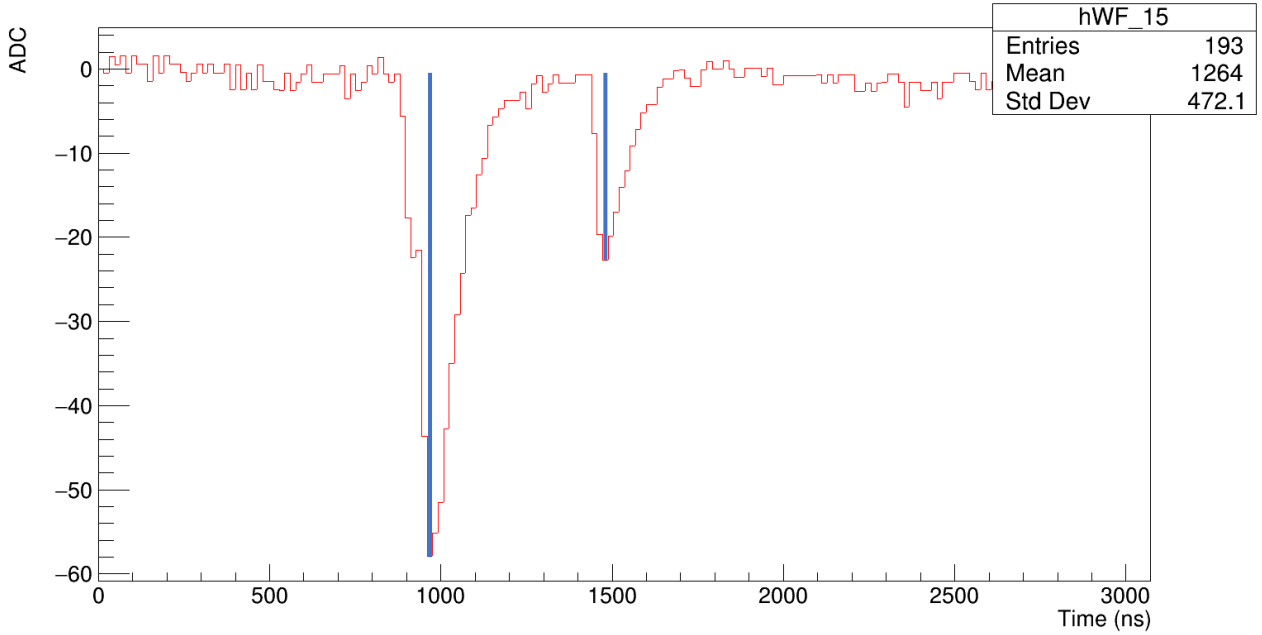
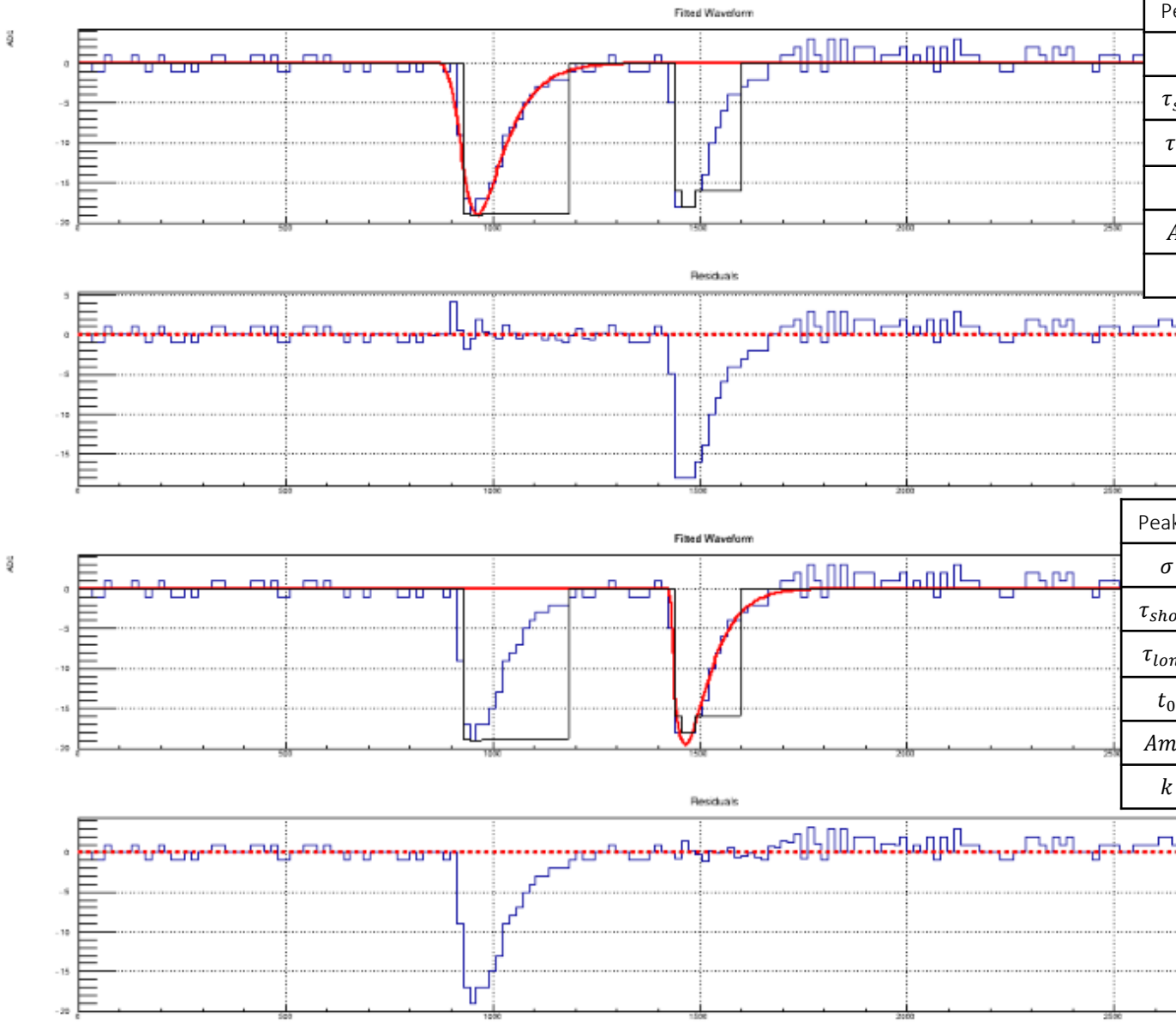




Multiple peaks→ multi-template fit

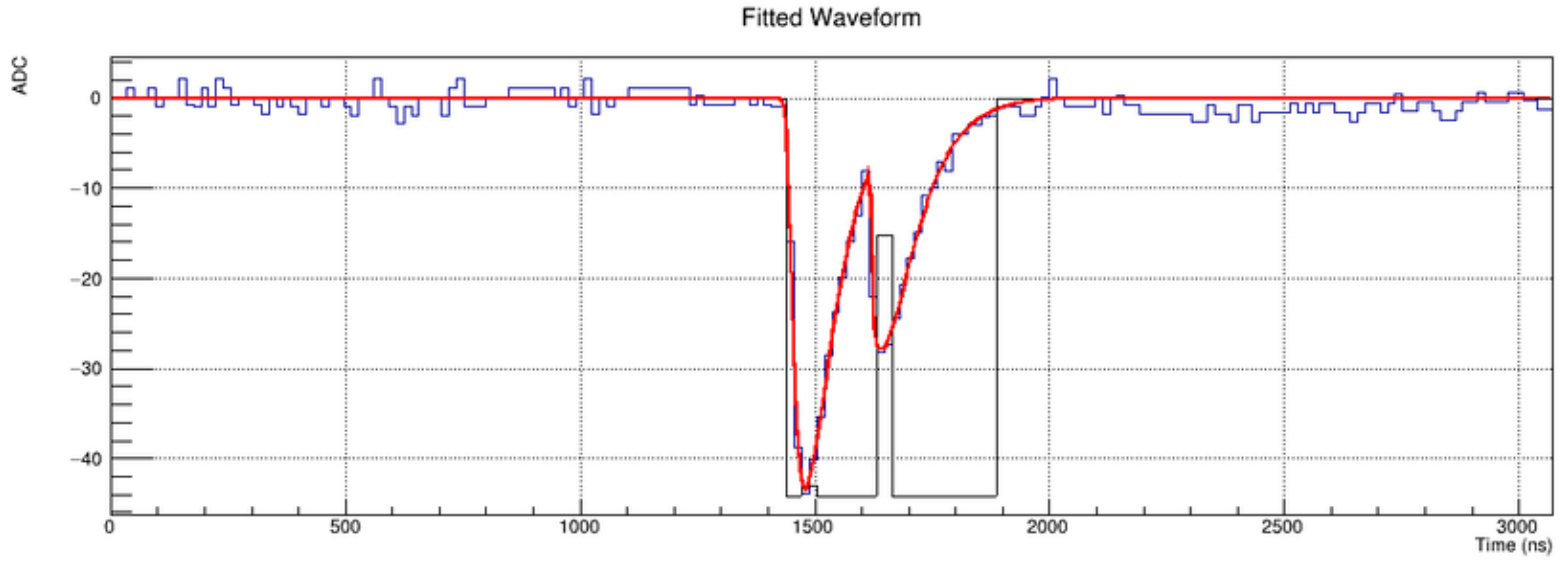
Results from fitter: single pulse(s)

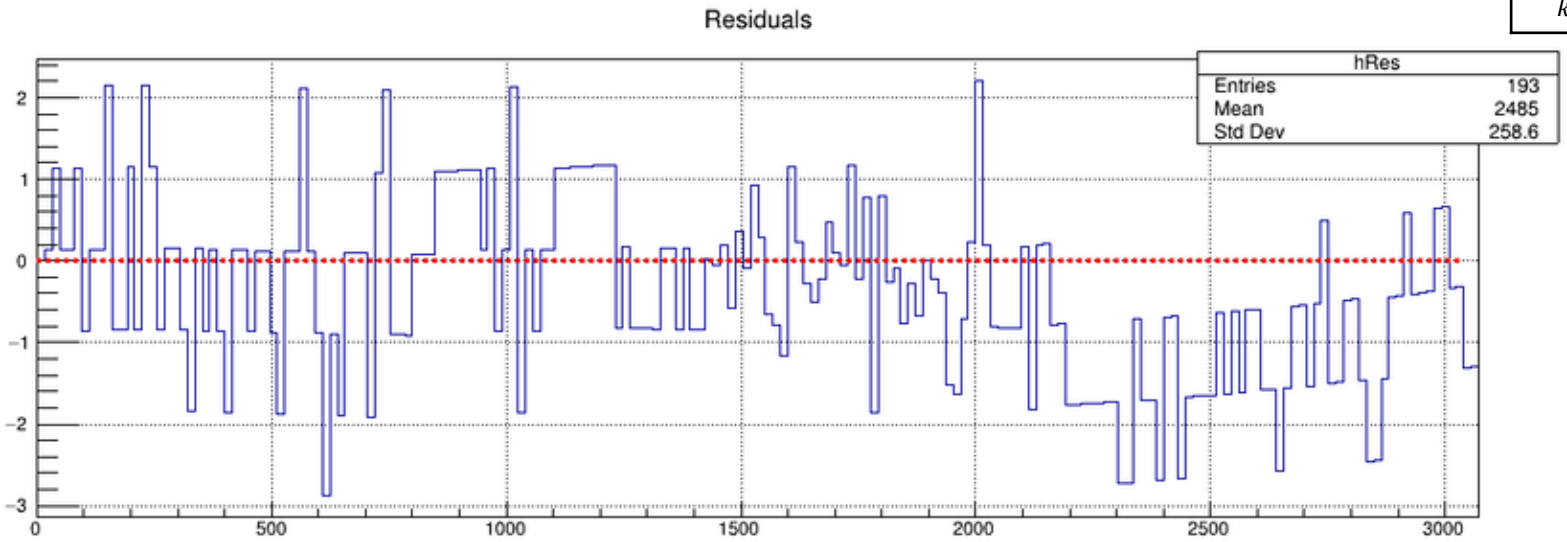


Peak 1	
σ	8.974 ± 3.621
τ_{short}	30 ± 7.5
τ_{long}	59.11 ± 5.31
t_0	1449 ± 7.7
Amp	-5031 ± 351.5
k	1.668 ± 0.719

Peak 2	
σ	2.775 ± 5.99
τ_{short}	47.226 ± 5.627
τ_{long}	52.526 ± 5.783
t_0	1621 ± 4.879
Amp	-2861 ± 317
k	6.967 ± 8.79

Results from fitter: compound pulse





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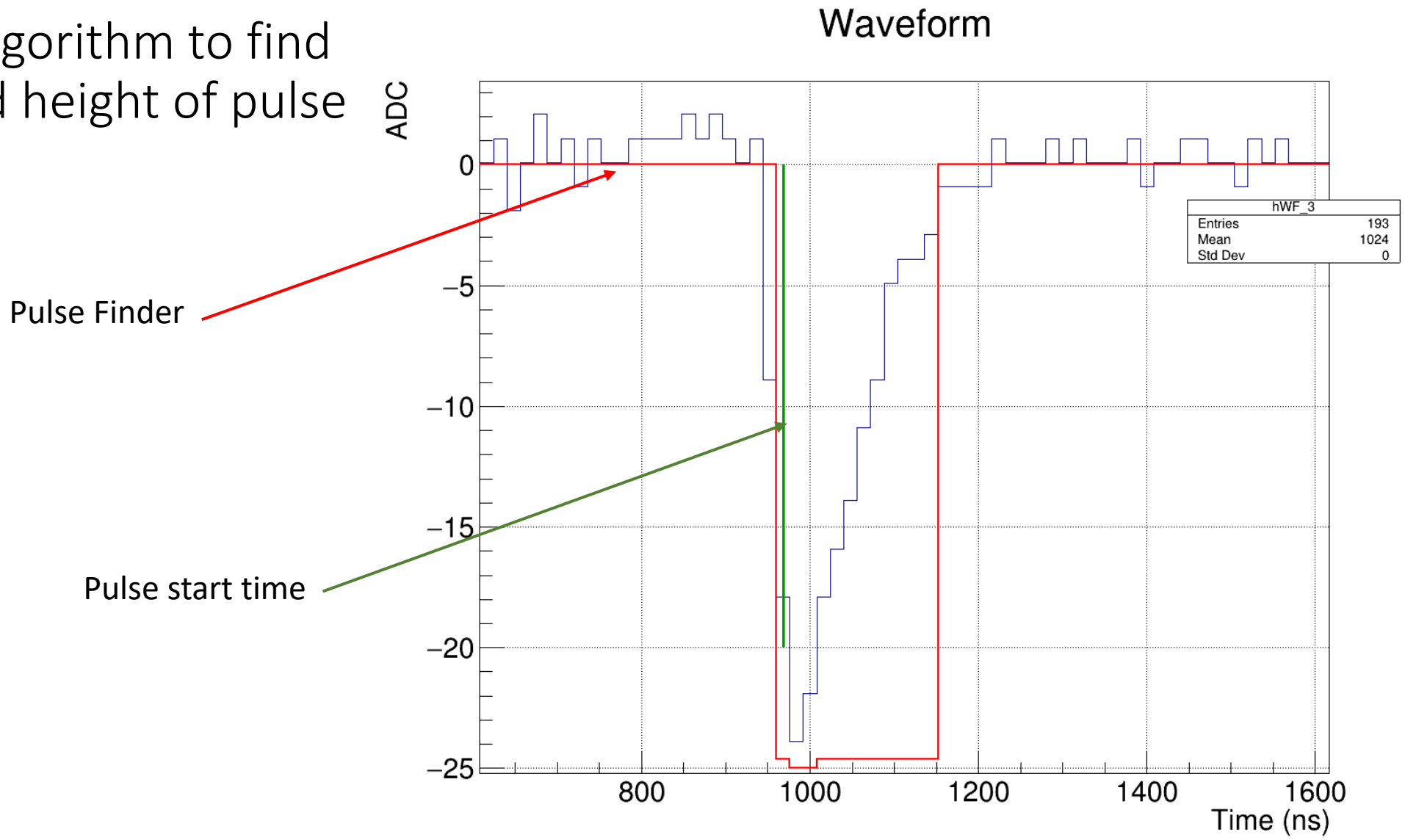
Pulse finder vs. pulse fitter

- Brute-force algorithm to find start time and height of pulse



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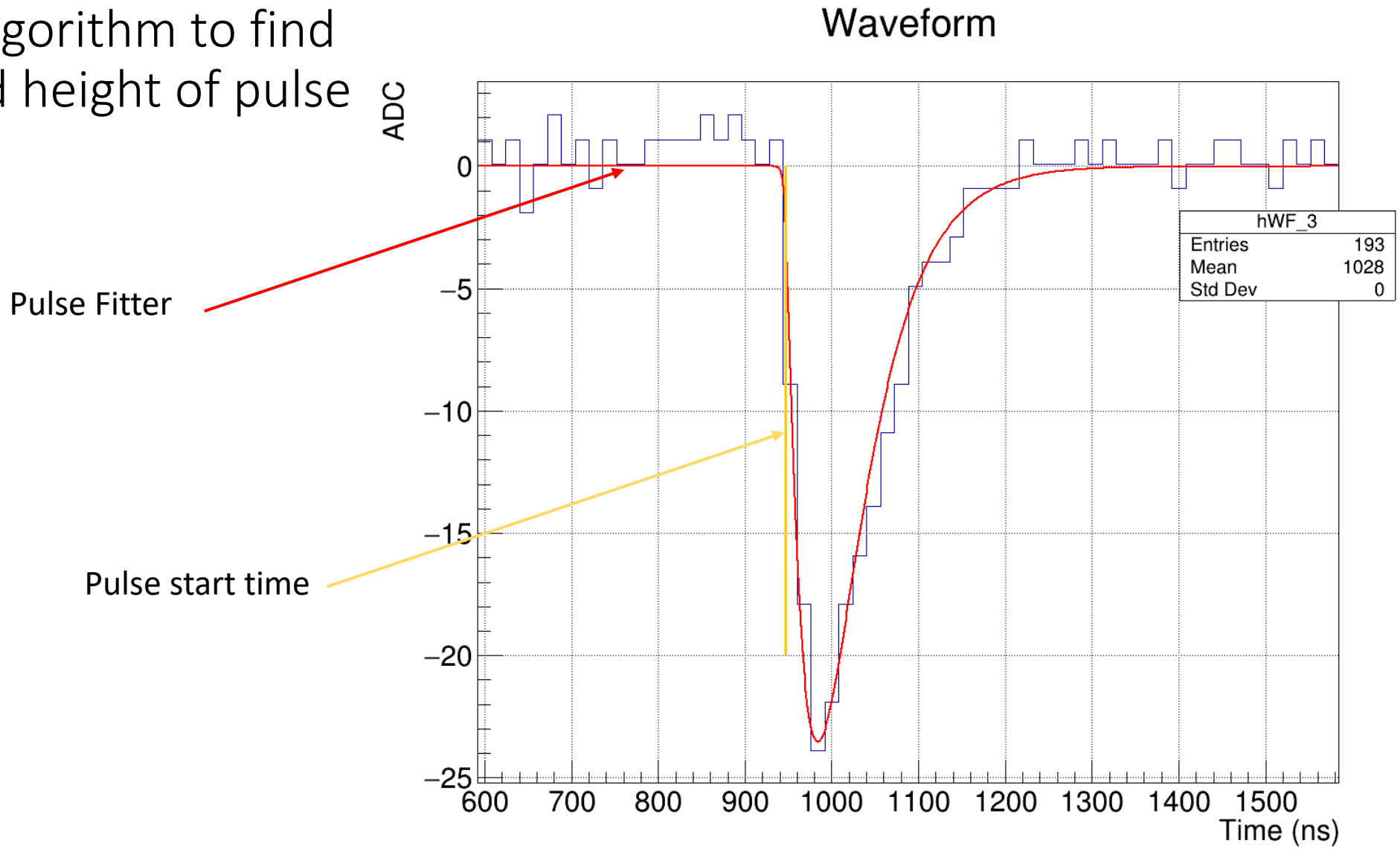
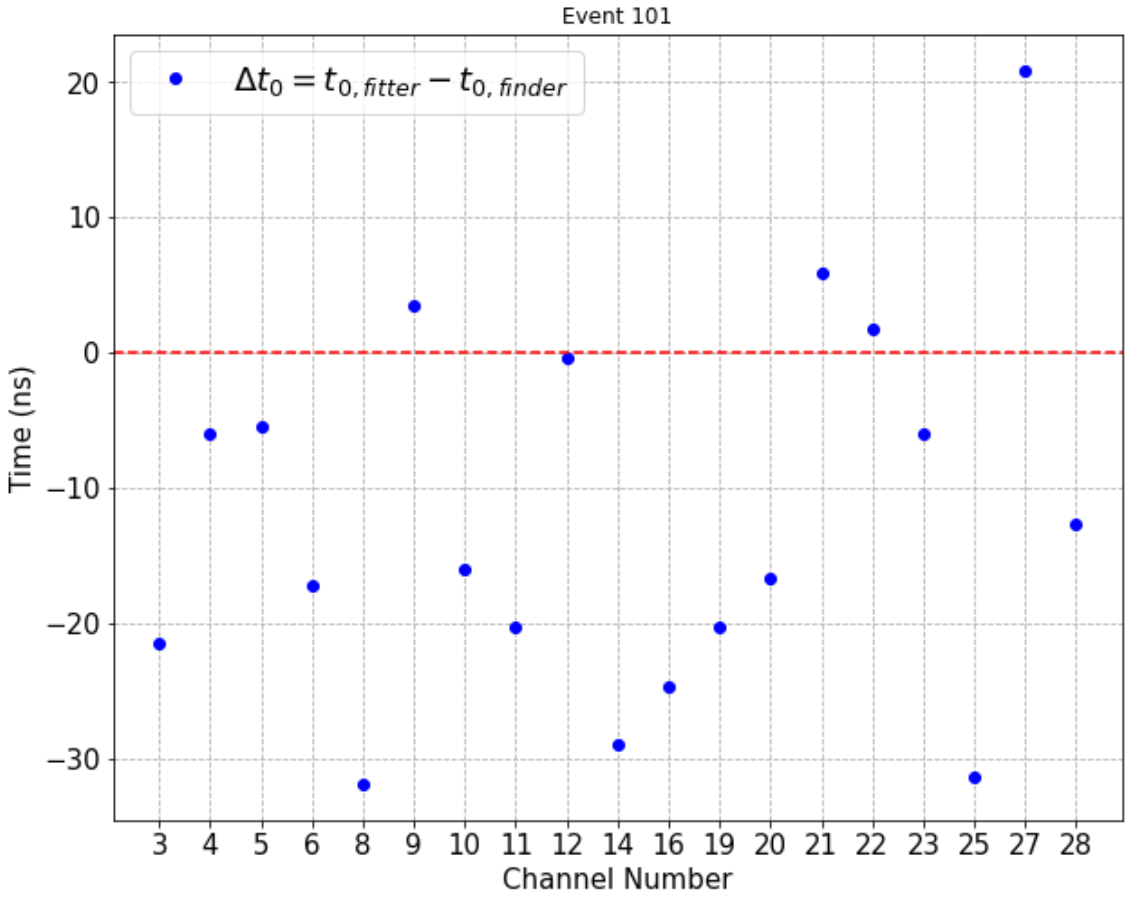
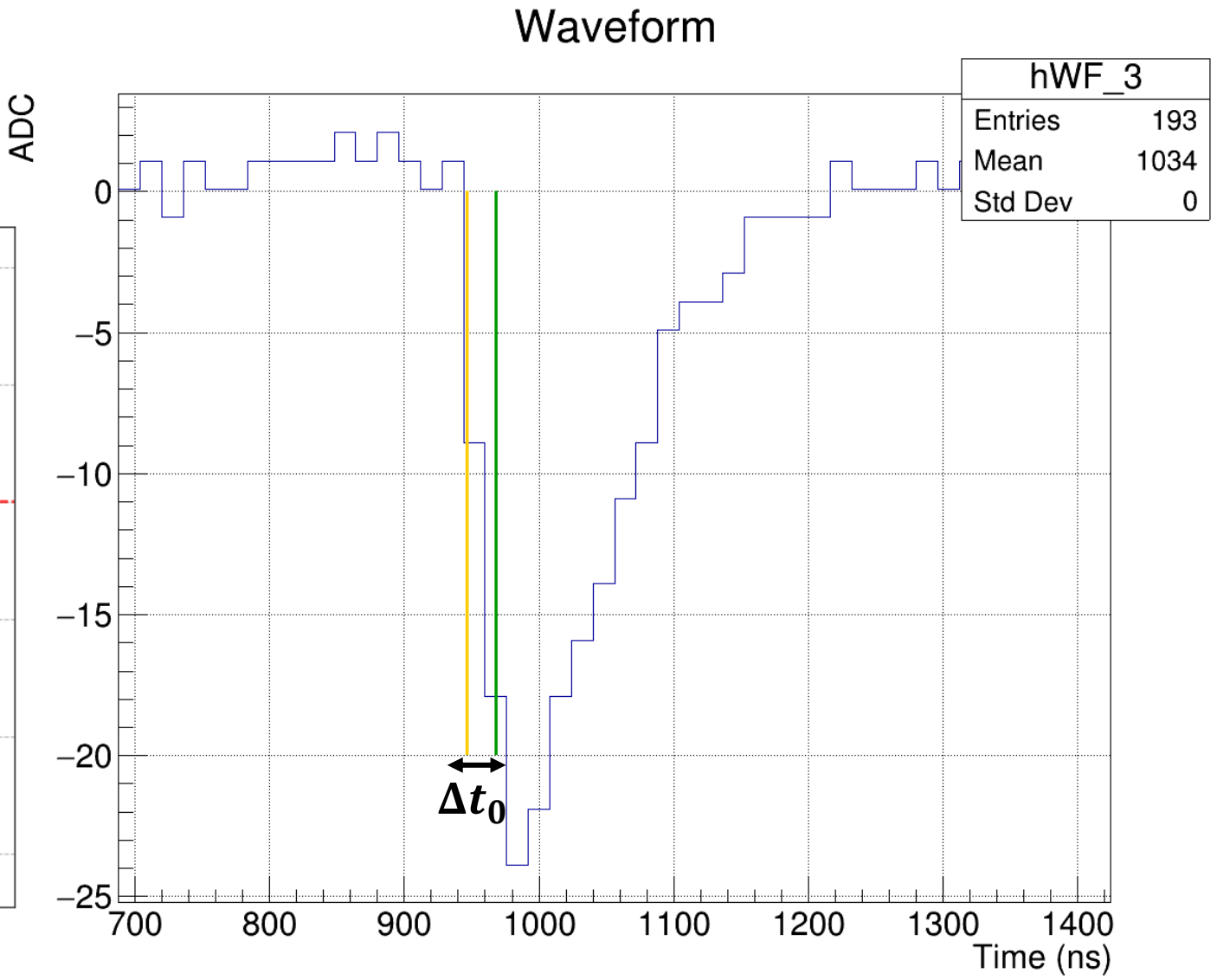


Pulse finder vs. pulse fitter

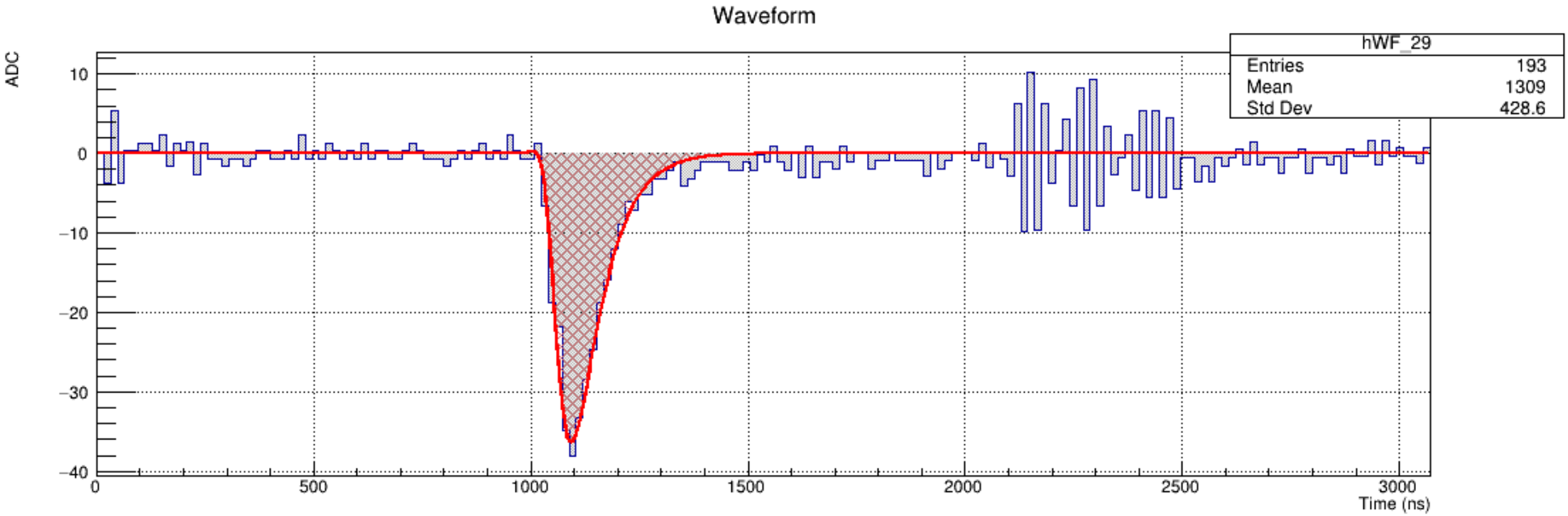
- Systematic overestimate of start time by pulse finder



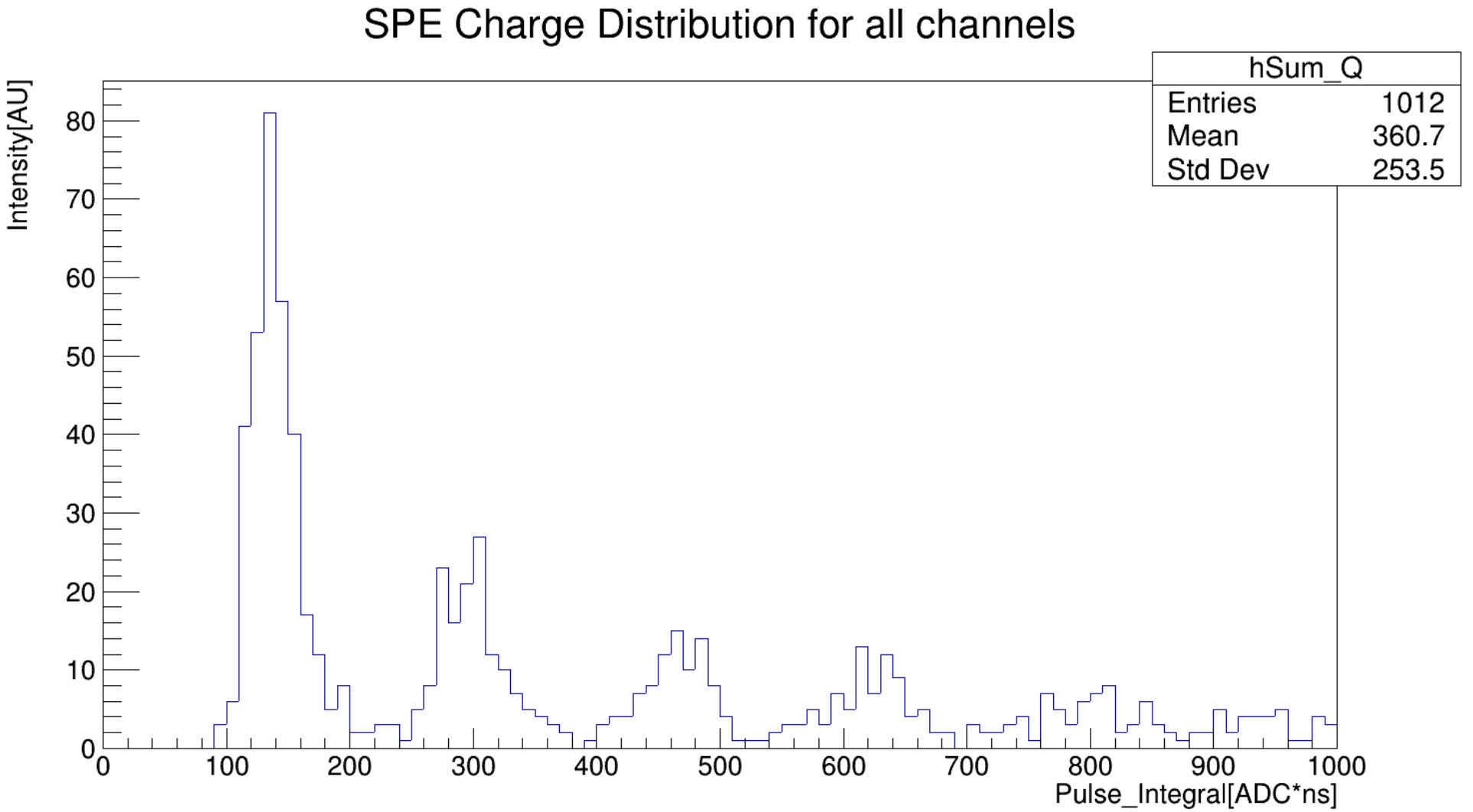


Energy resolution

- Area under curve
- Pulse finder disregards noise found in waveform



Next steps: Improve resolution



- Demonstrate better resolution with pulse fitter compared to pulse finder

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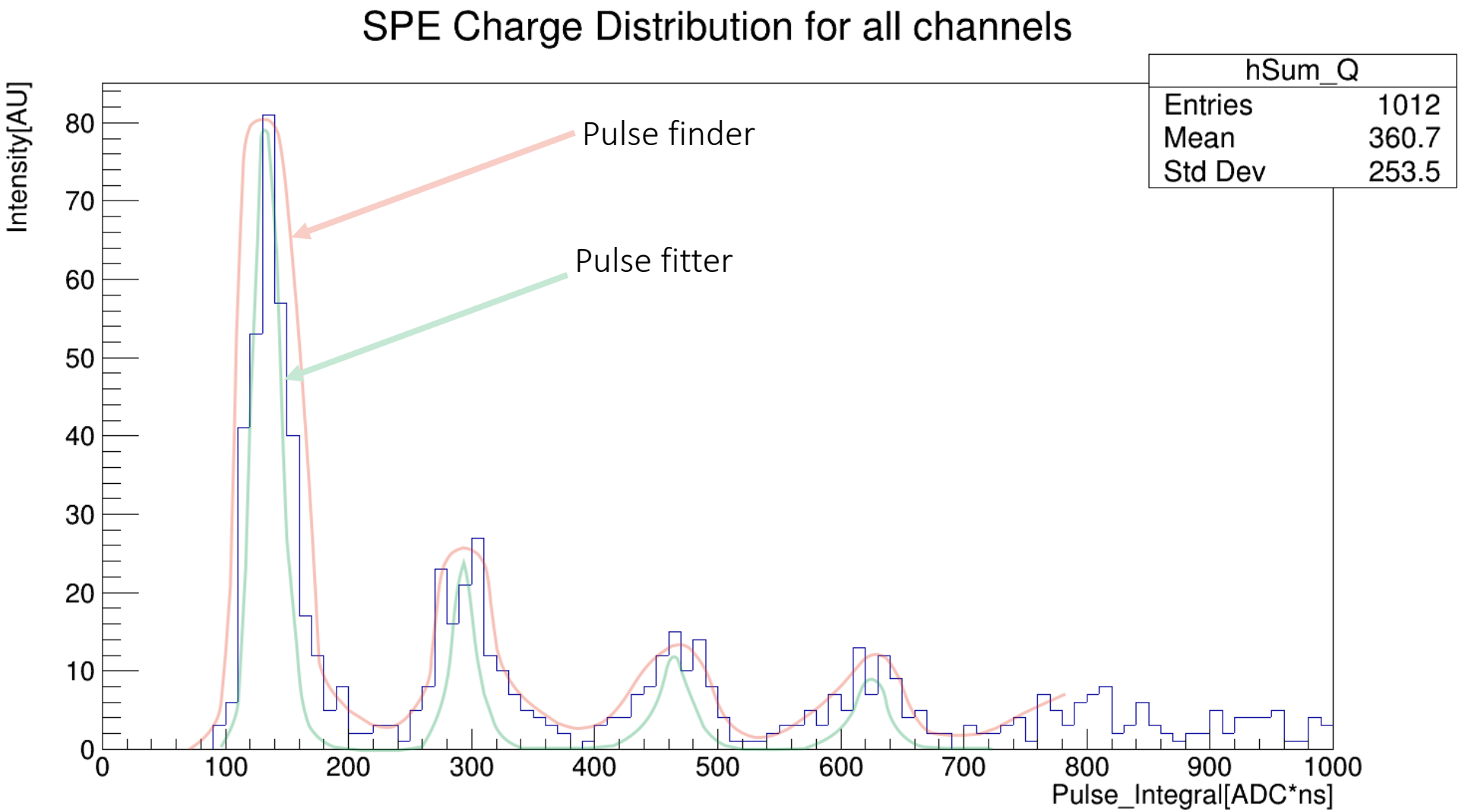

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Acknowledgements

Thank you for listening!

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BNL

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CRSNG

Conclusion

- SiPM technology is photodetector of choice
- After-pulsing affects LoLX data
- Pulse fitter is advantageous compared to pulse finder
- Pulse fitter for time and energy resolution