WNPPC BANFF AB, FEB 17, 2017

# DEAP-3600PULSE FINDING AND PILE-UP IDENTIFICATION.

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# OVERVIEW

Light Generation and Detection

↓

Raw Signal Extraction (Pulse Finding)

↓

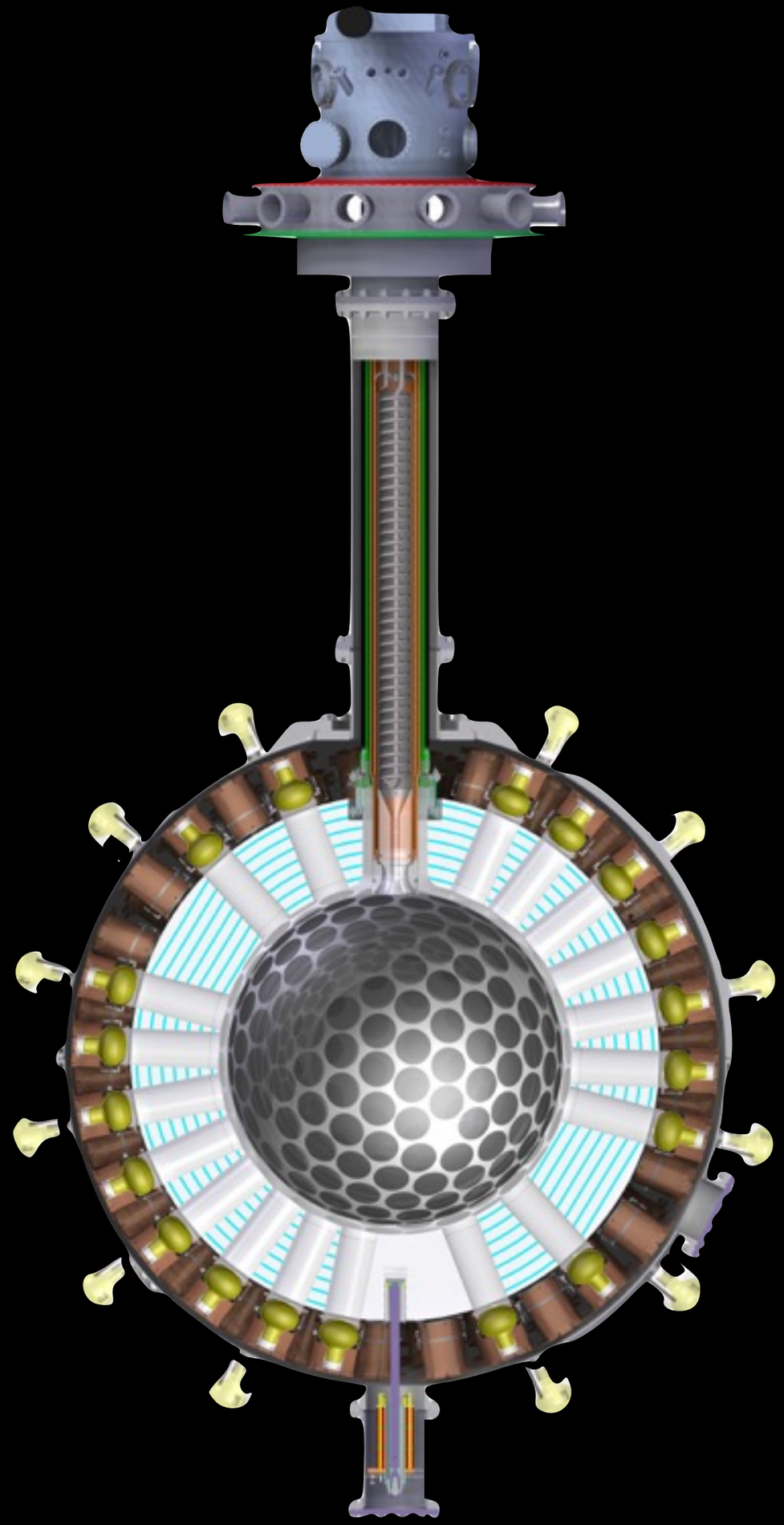
Basic Event Analysis (PSD)

↓

Identifying Event Pile-up

# Dark Matter Experiment Using Liquid Argon and Pulse Shape Discrimination

- **3600 kg of LAr (1000 kg fiducial).**
- **255 PMTs giving ~70% cathode coverage.**
- **Located 2 km (6000 mwe) underground in SNOLAB, Sudbury ON.**



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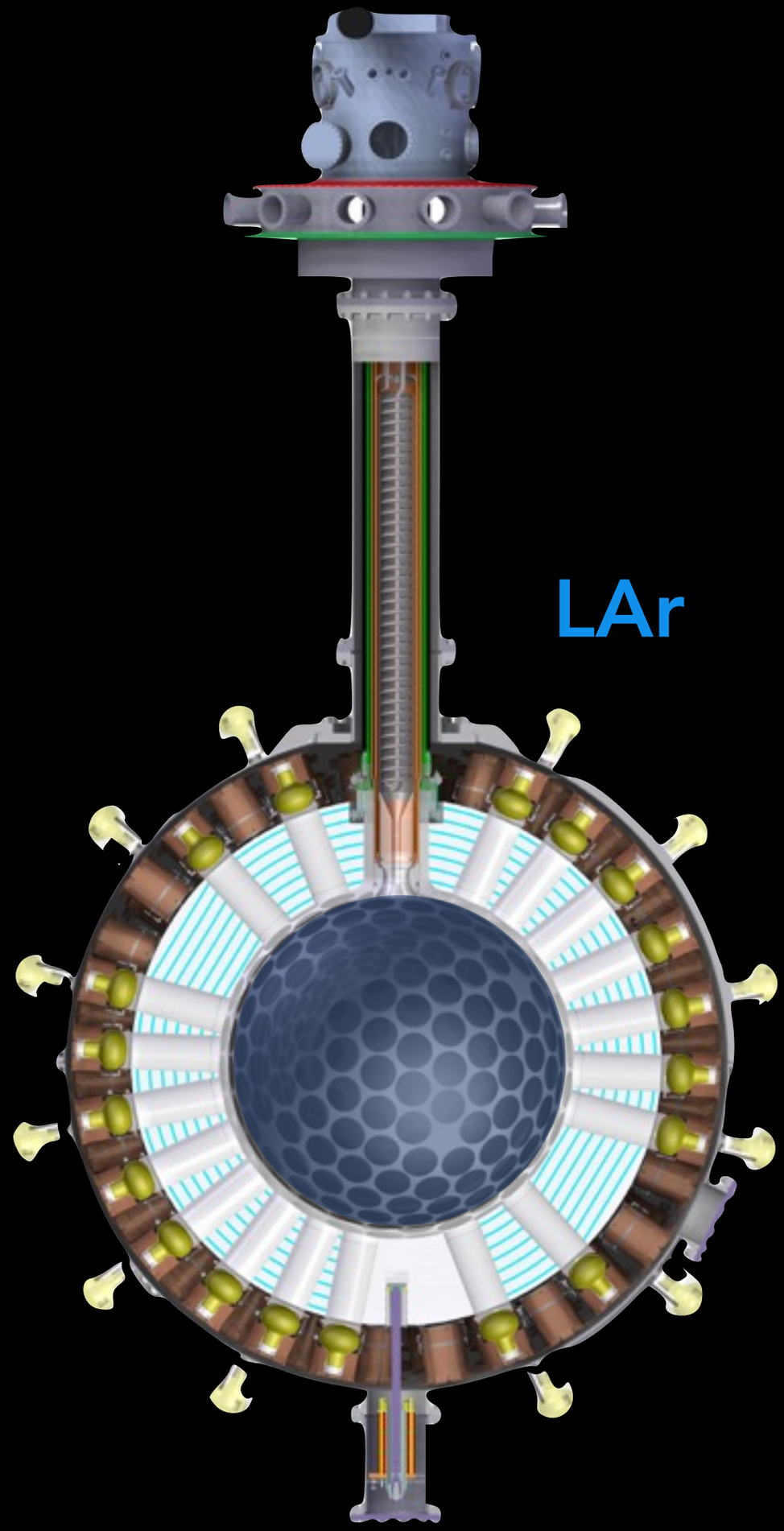

# Dark Matter Experiment Using Liquid Argon and Pulse Shape Discrimination

Ar Dimer States:
Singlet $\tau$ = ~6 ns Wavelength = 128 nm
Triplet $\tau$ = ~1500 ns

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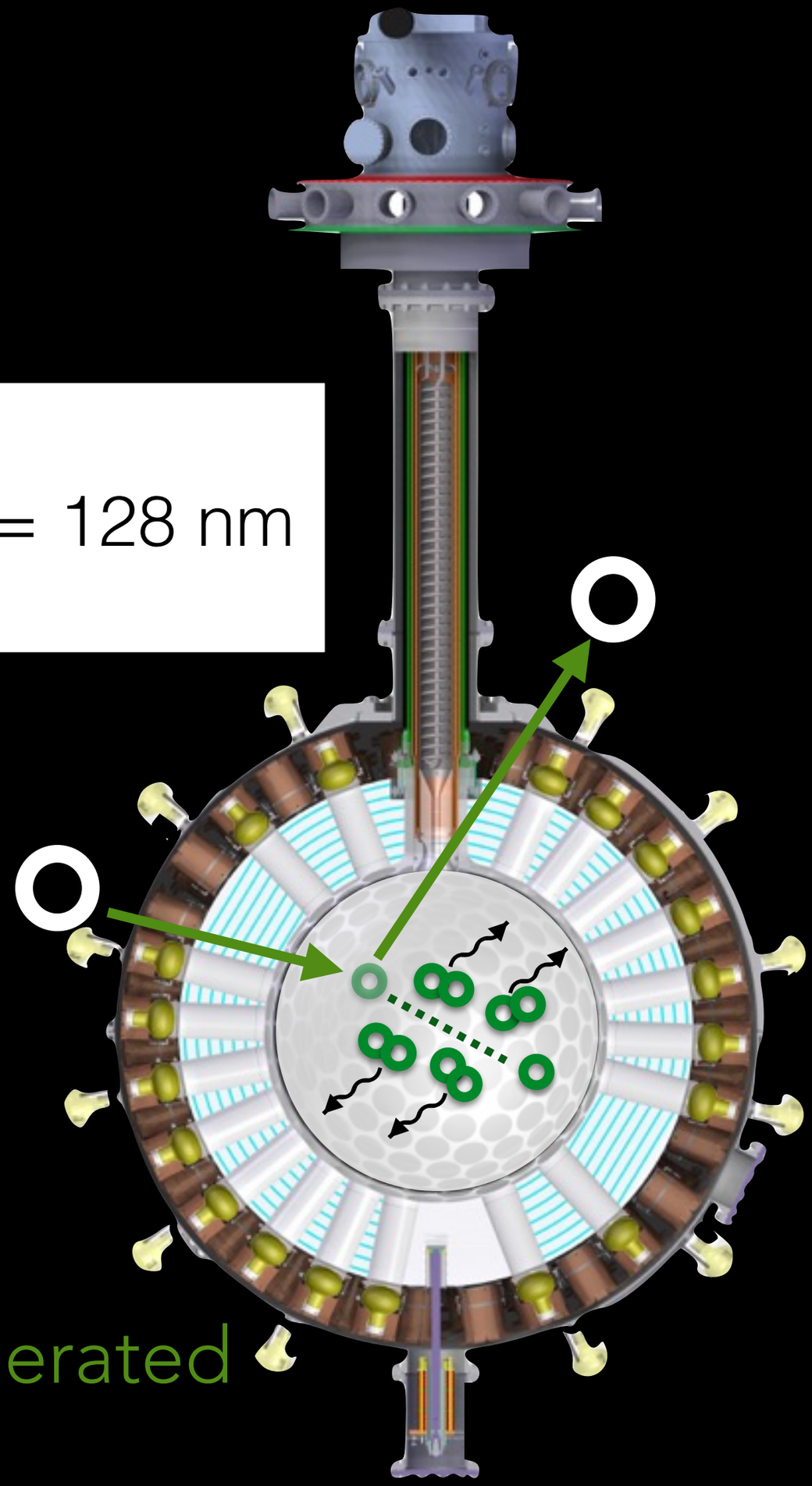

*track length exaggerated

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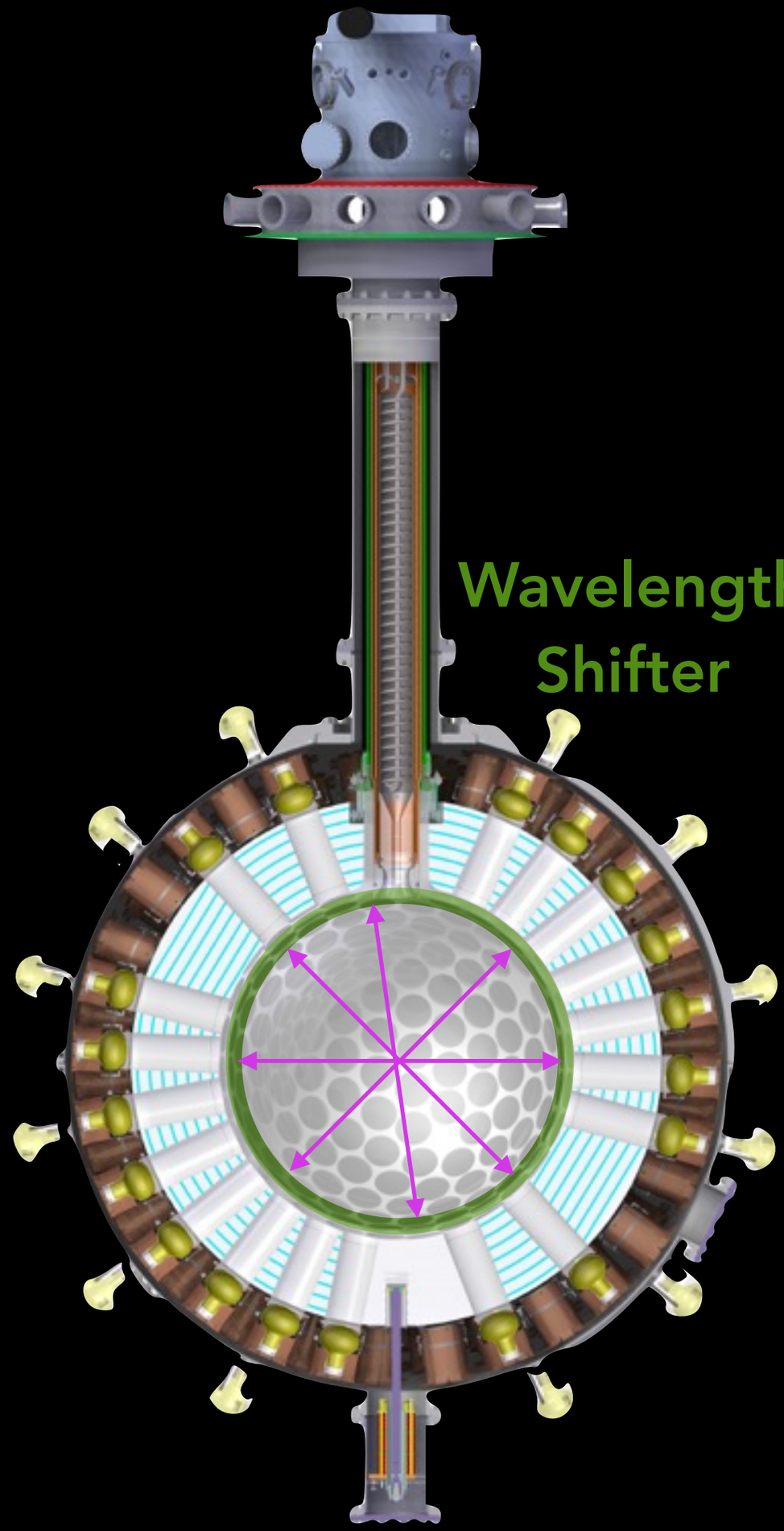

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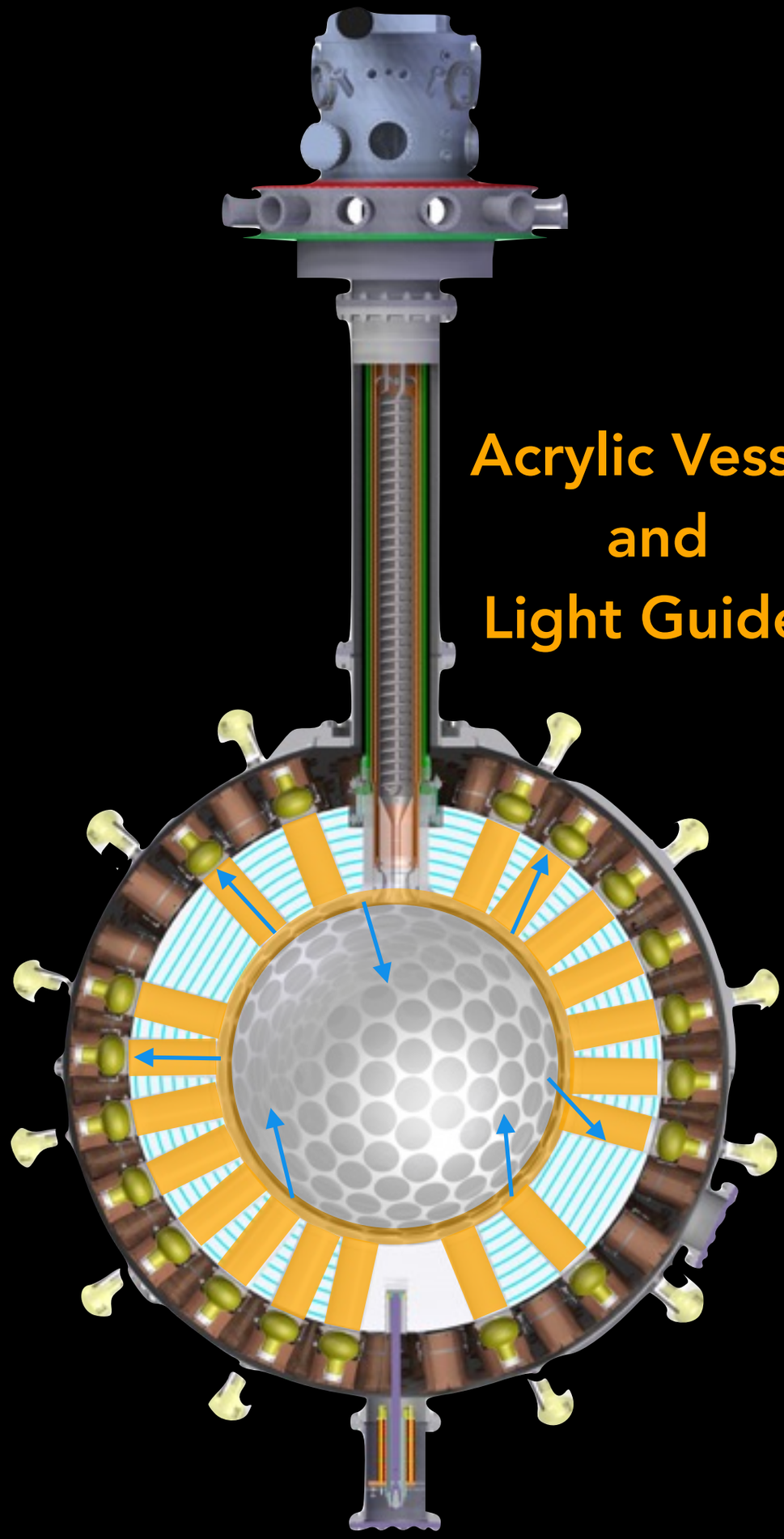

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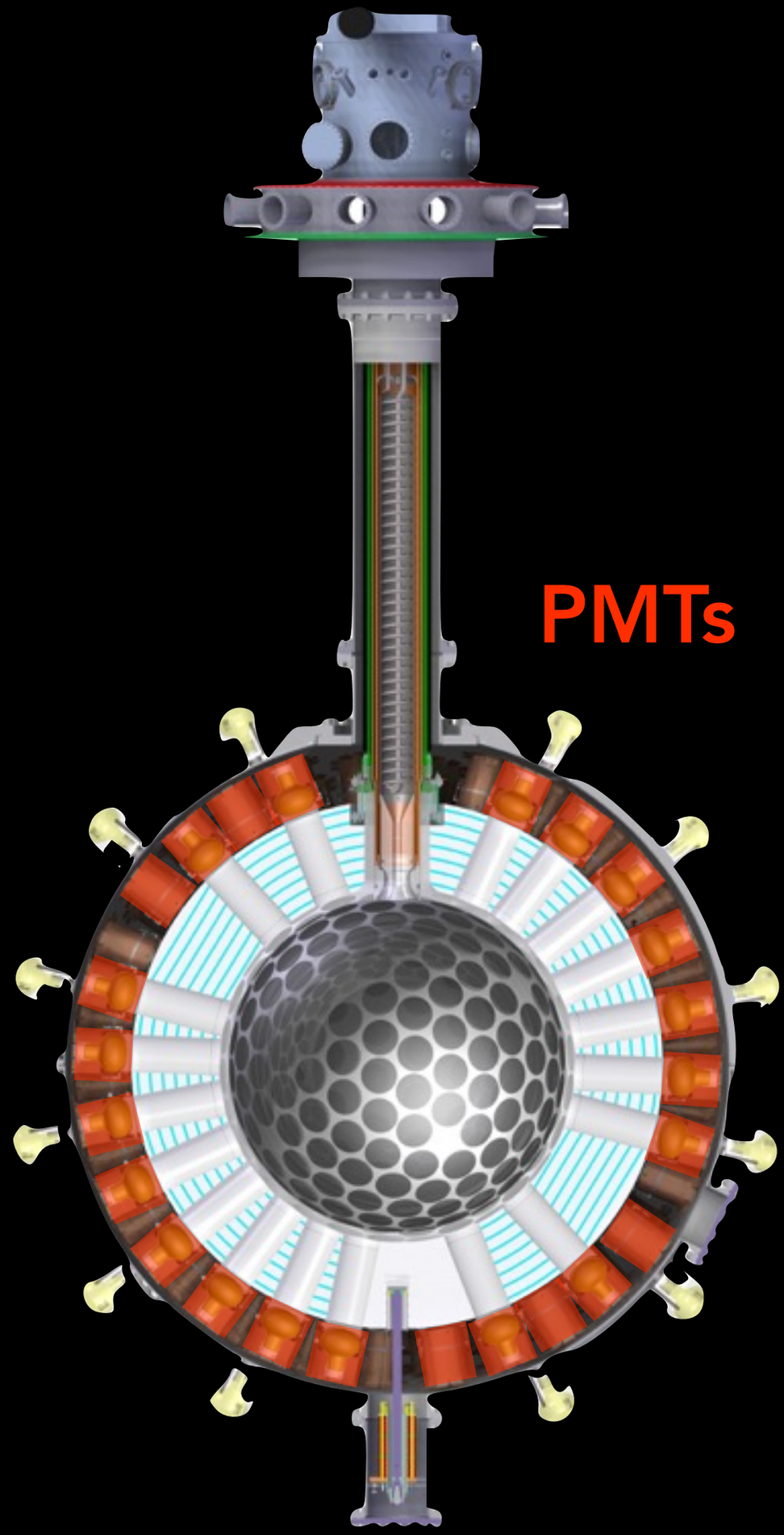
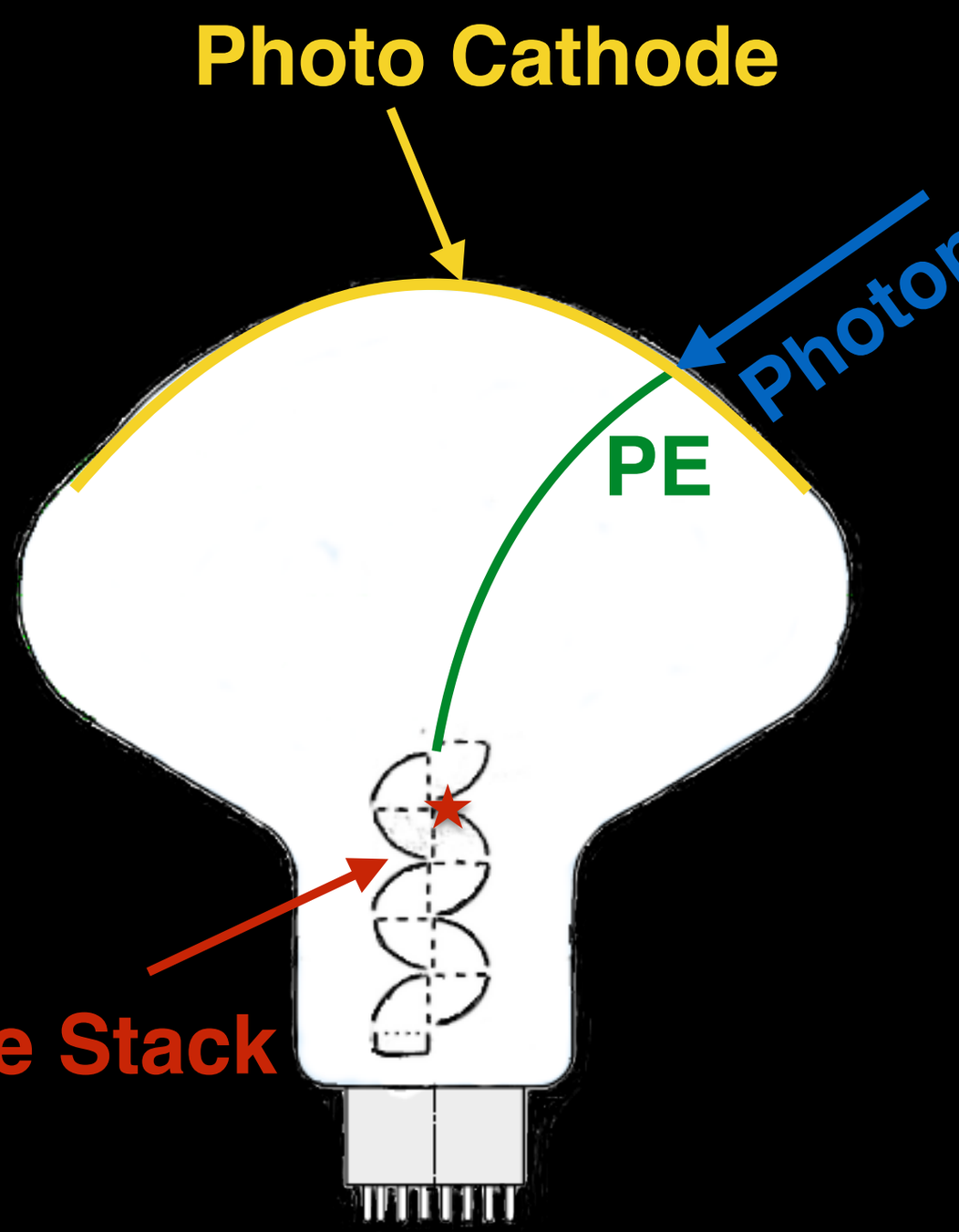


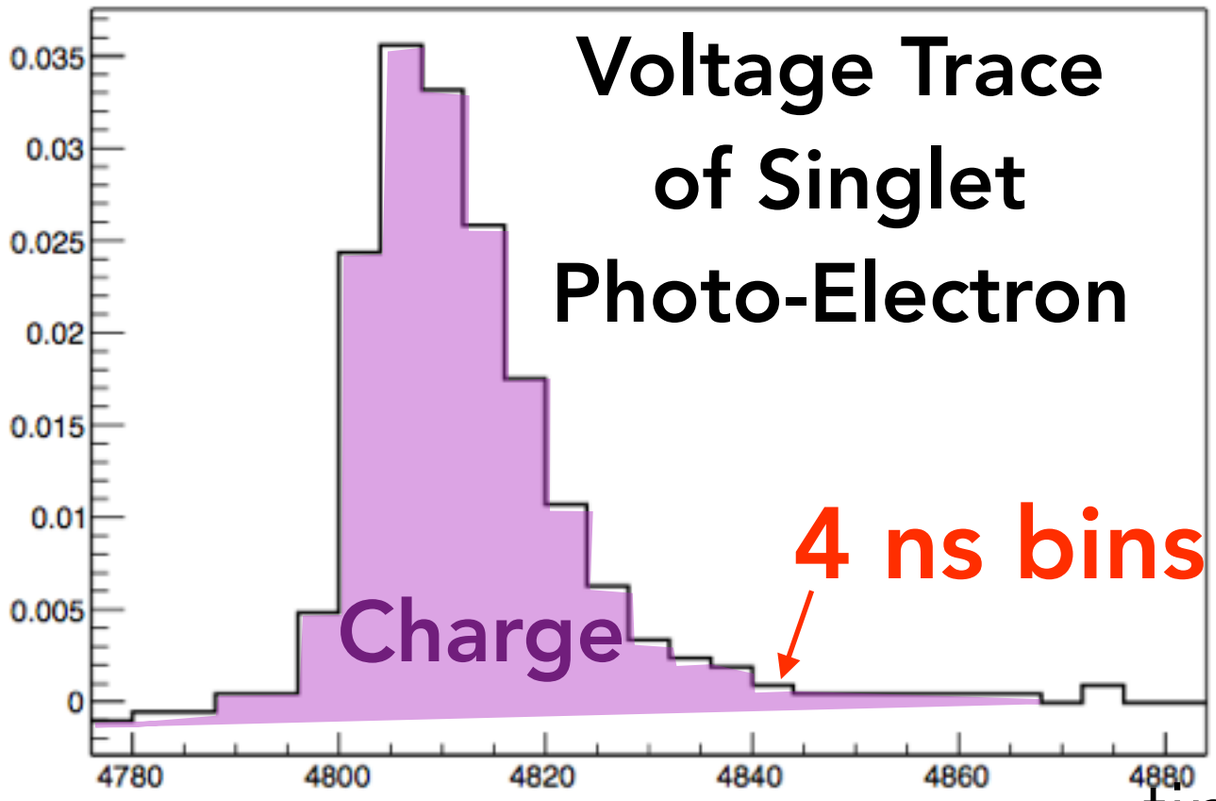
# Photo-Multiplier Tube

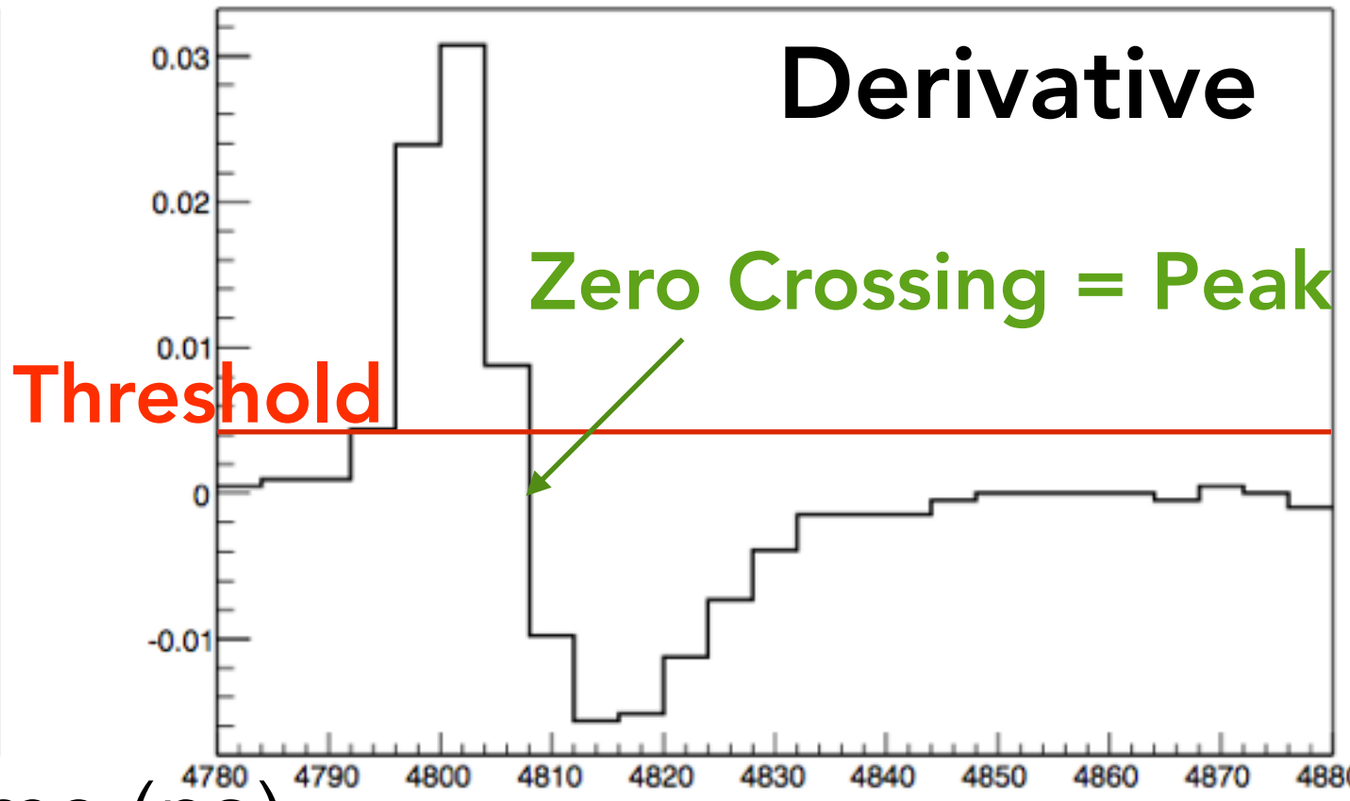
(A Brief Introduction)

- **Photons release electrons (PE) from the photo cathode.**
- **Strong electric field accelerates the electron onto the dynode stack.**
- **At every dynode the number of electrons is multiplied until a measurable signal is created.**



# Pulse Finding

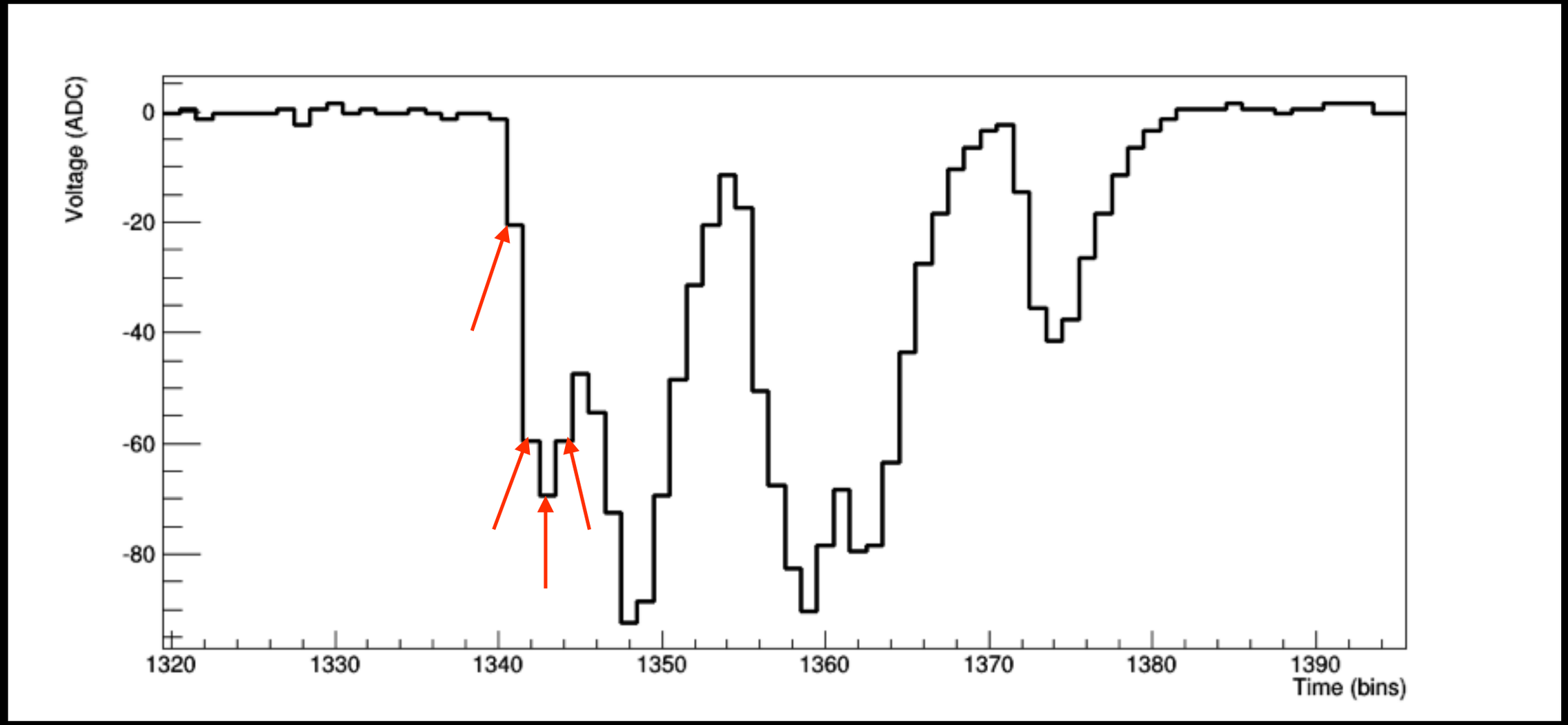



time (ns)

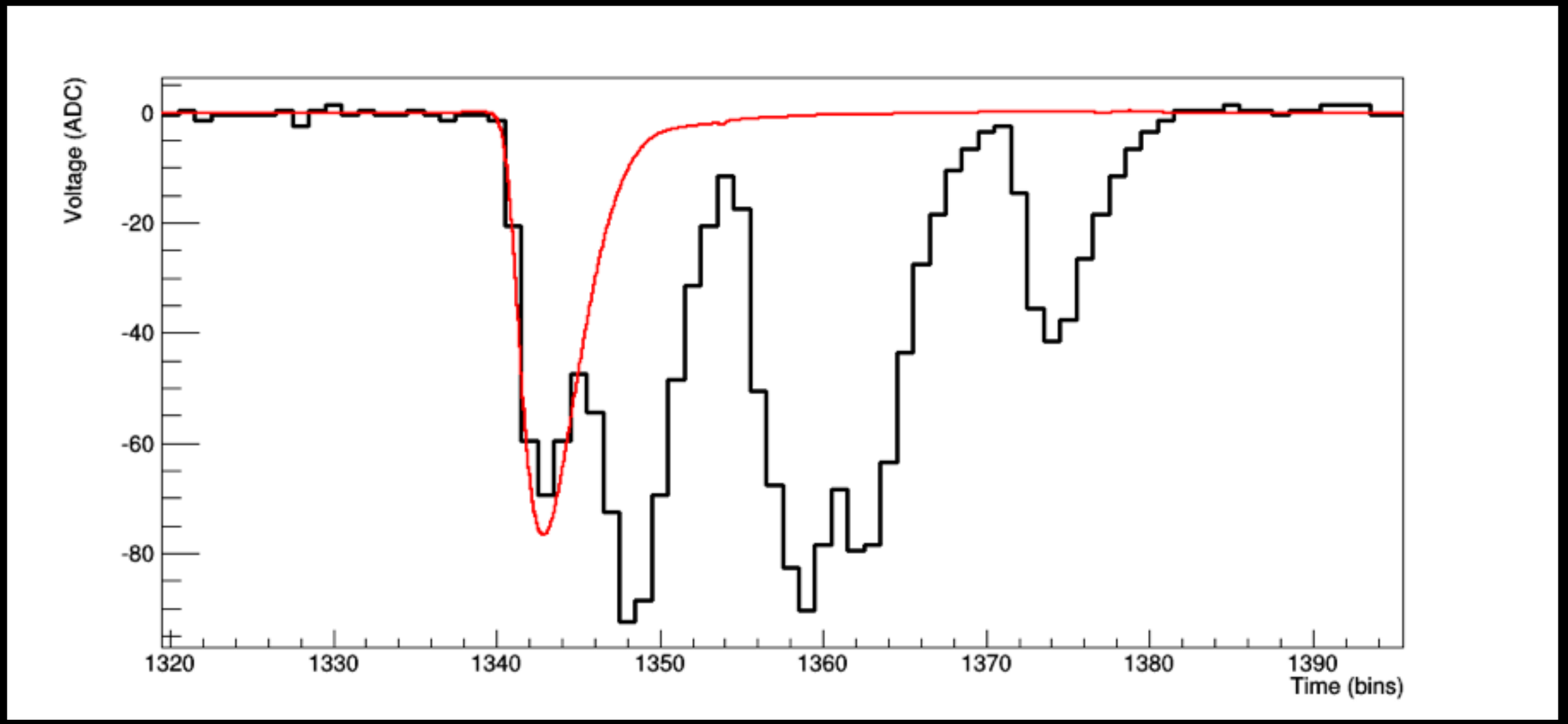
- **The Standard pulse finder for DEAP looks at pulses in derivative space and looks for a derivative threshold crossing.**
- **Pulse finding in derivative space reduces error due to baseline shifts.**

# MULTI-PEAK PULSE



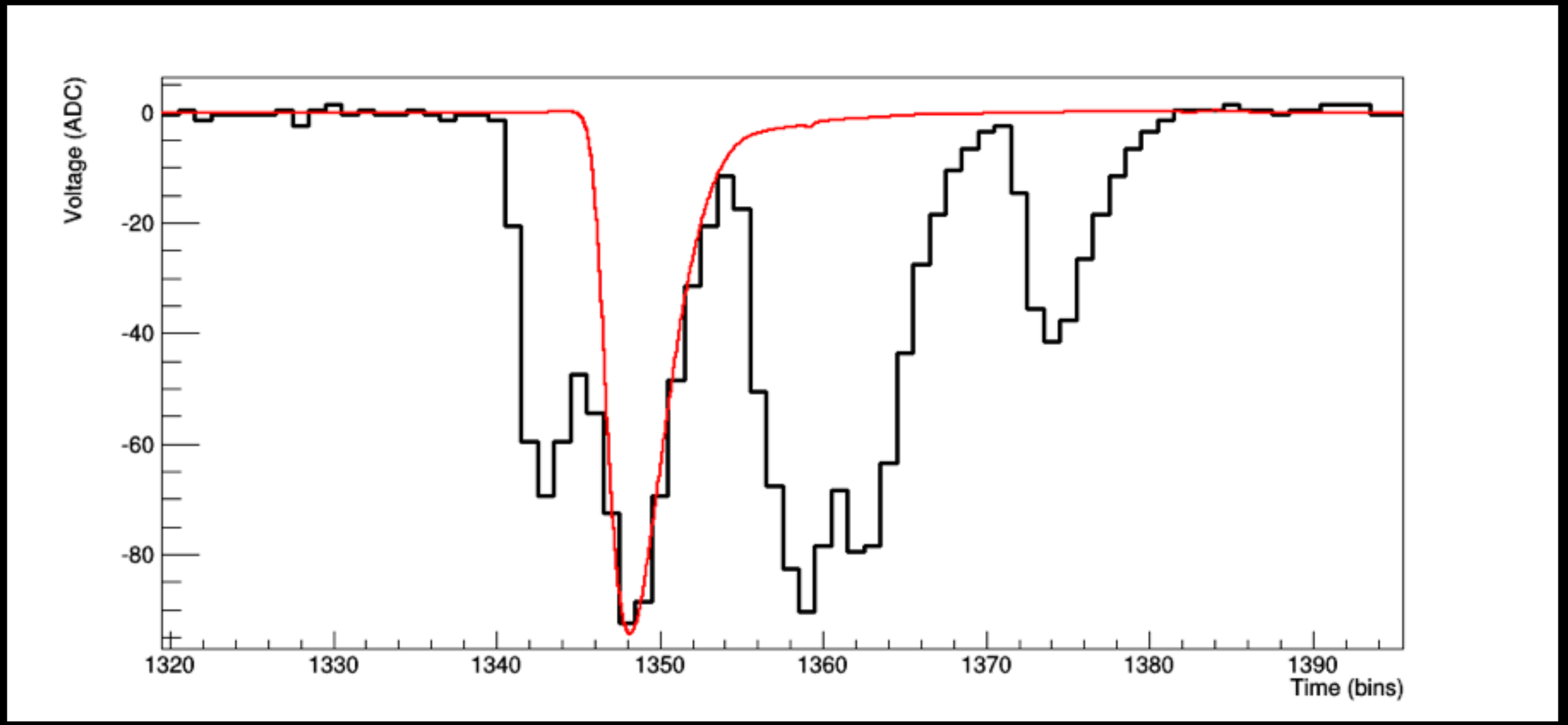

**4 samples around the rising edge are saved and used to fit out the peak time and charge.**

# MULTI-PEAK PULSE



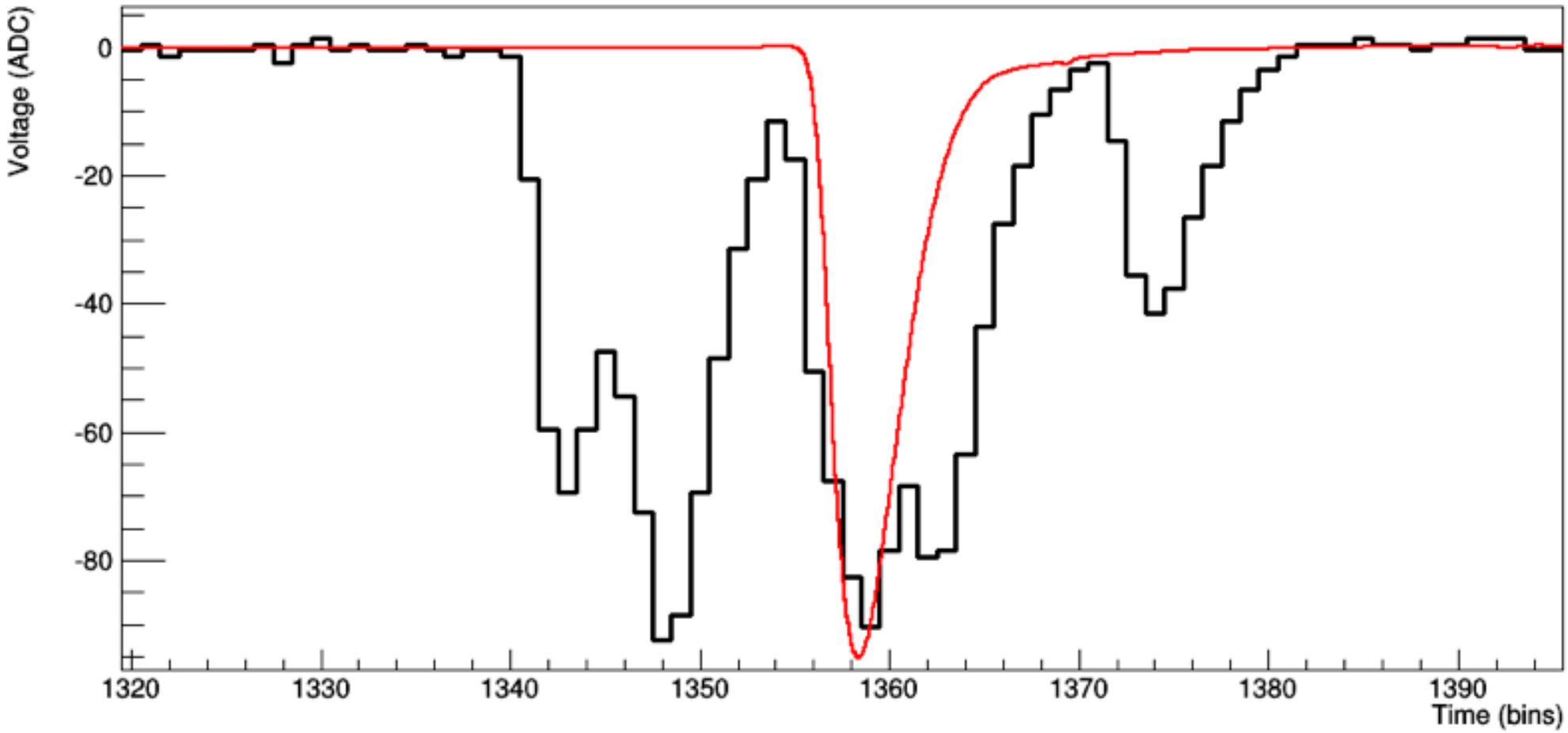

SubPeak at bin 1342.85 with Charge 14.18 pC

# MULTI-PEAK PULSE



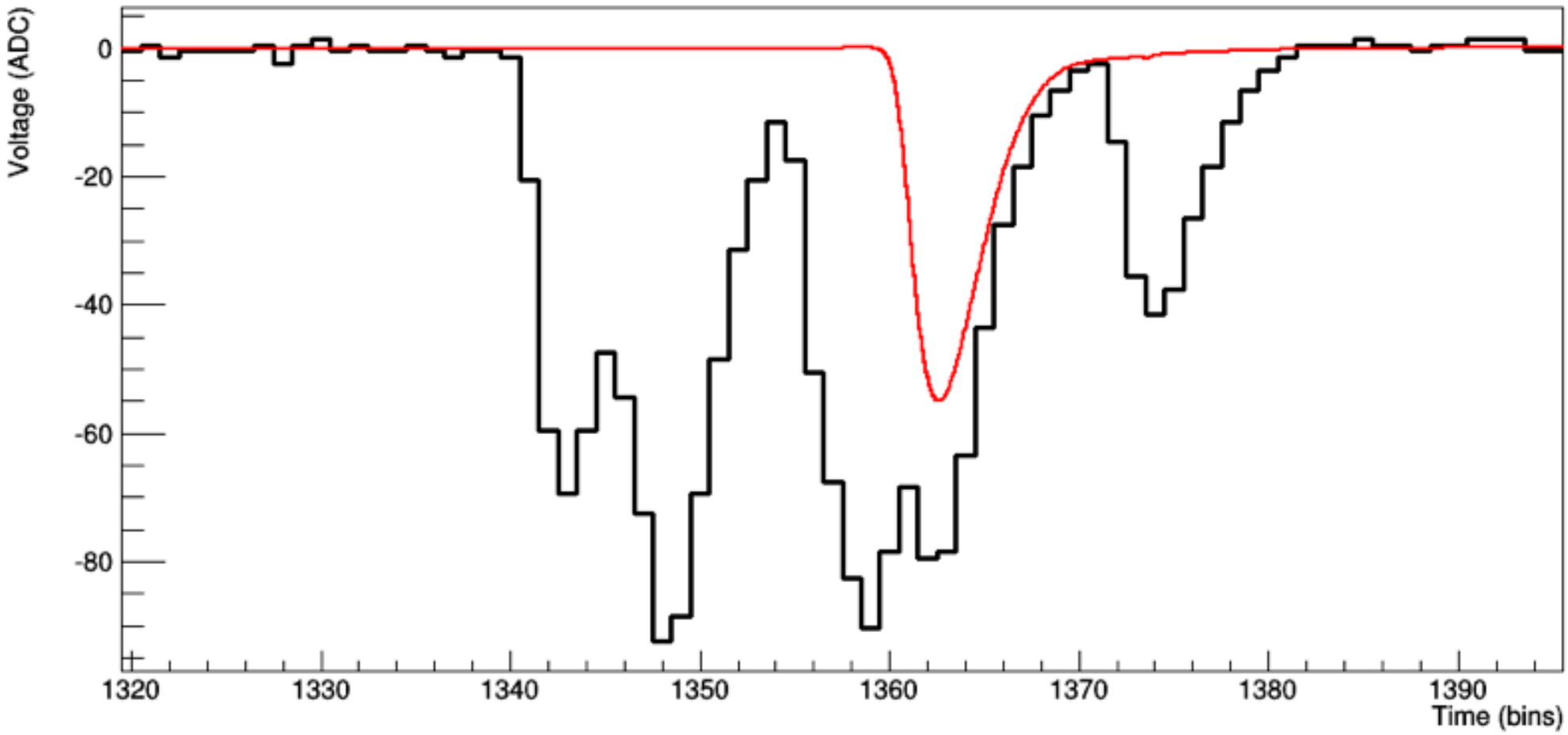

SubPeak at bin 1348.15 with Charge 17.44 pC

# MULTI-PEAK PULSE



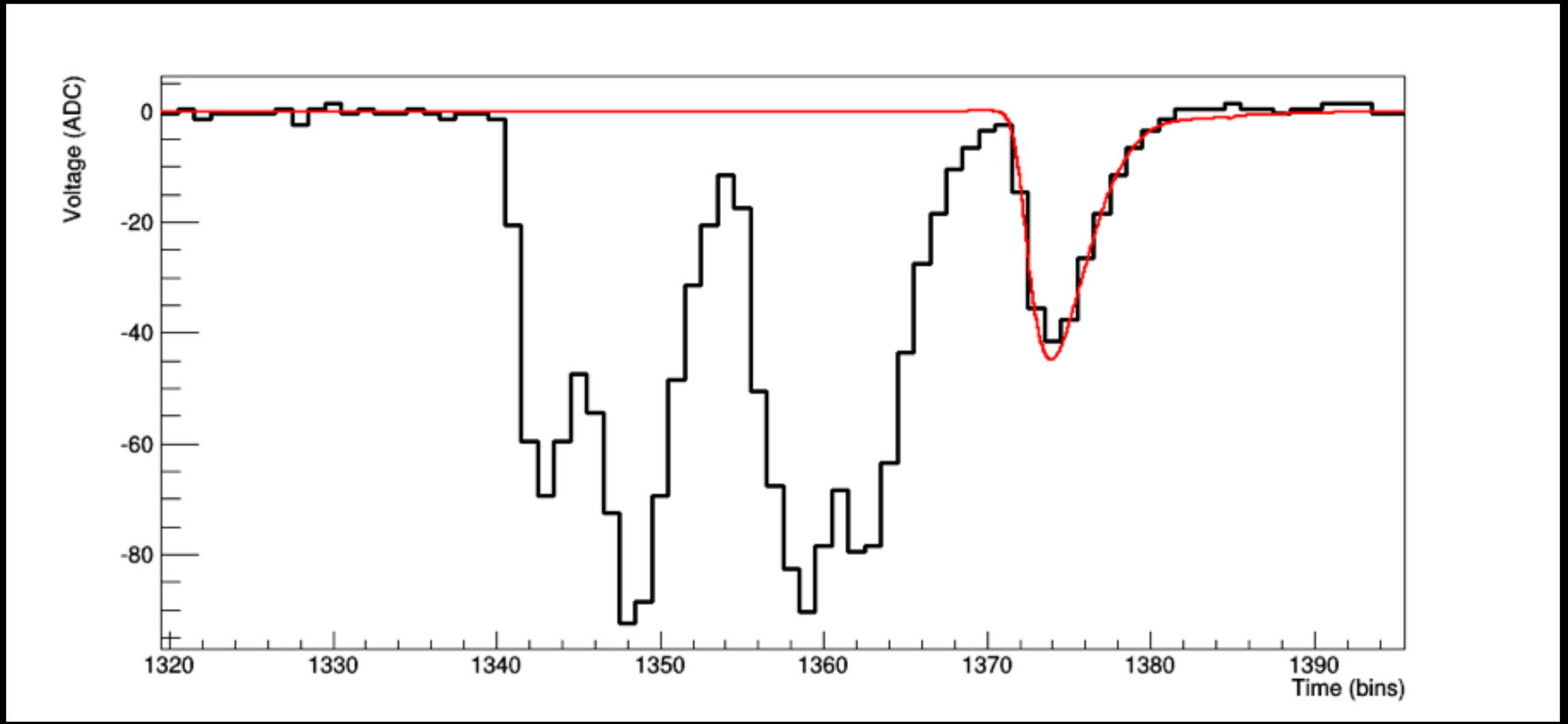

SubPeak at bin 1358.35 with Charge 17.58 pC

# MULTI-PEAK PULSE



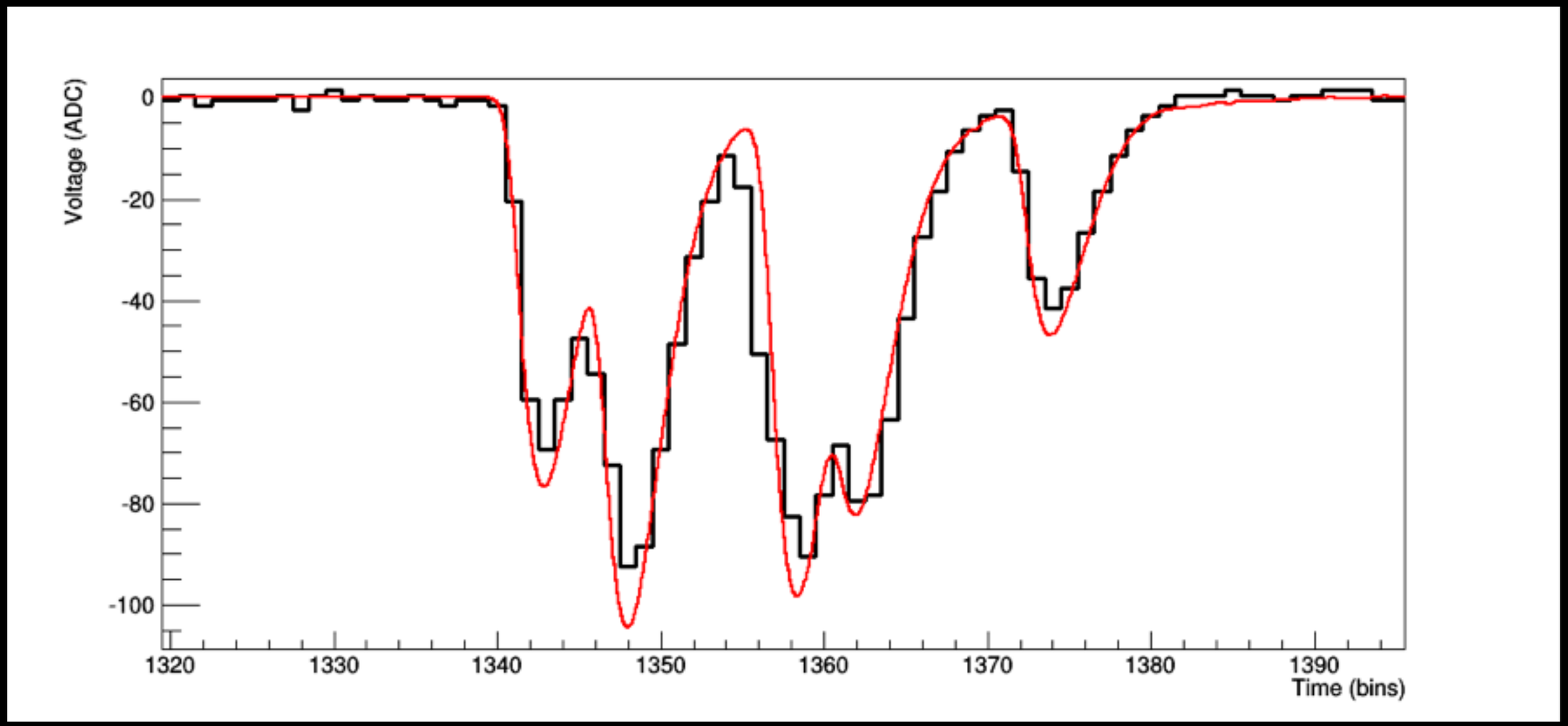

SubPeak at bin 1362.60 with Charge 10.17 pC

# MULTI-PEAK PULSE




SubPeak at bin 1373.90 with Charge 8.28 pC

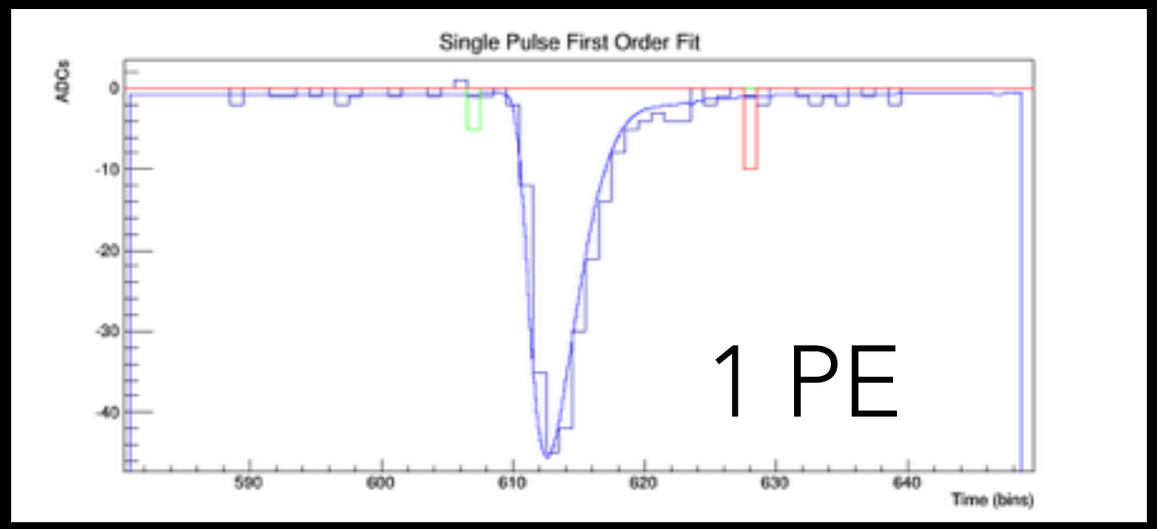
# MULTI-PEAK PULSE

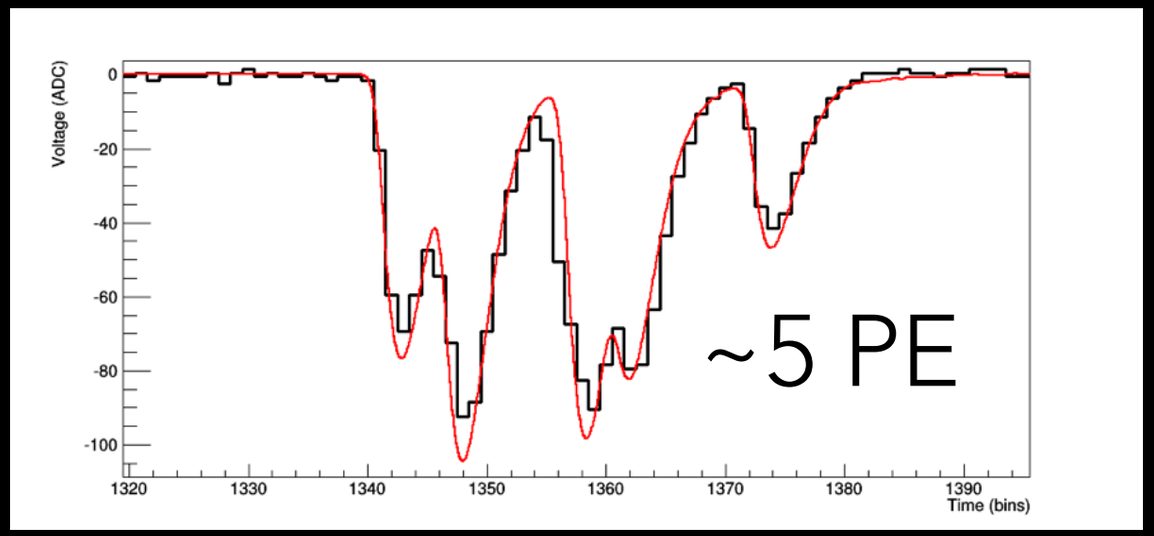



Summed Fit

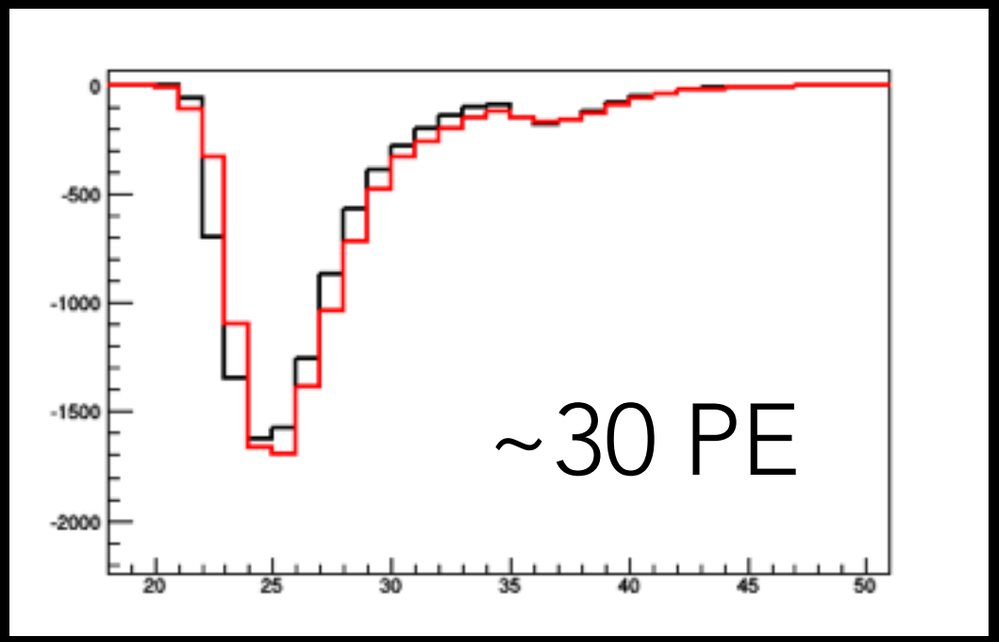
Total fit charge is renormalized to total integrated charge.

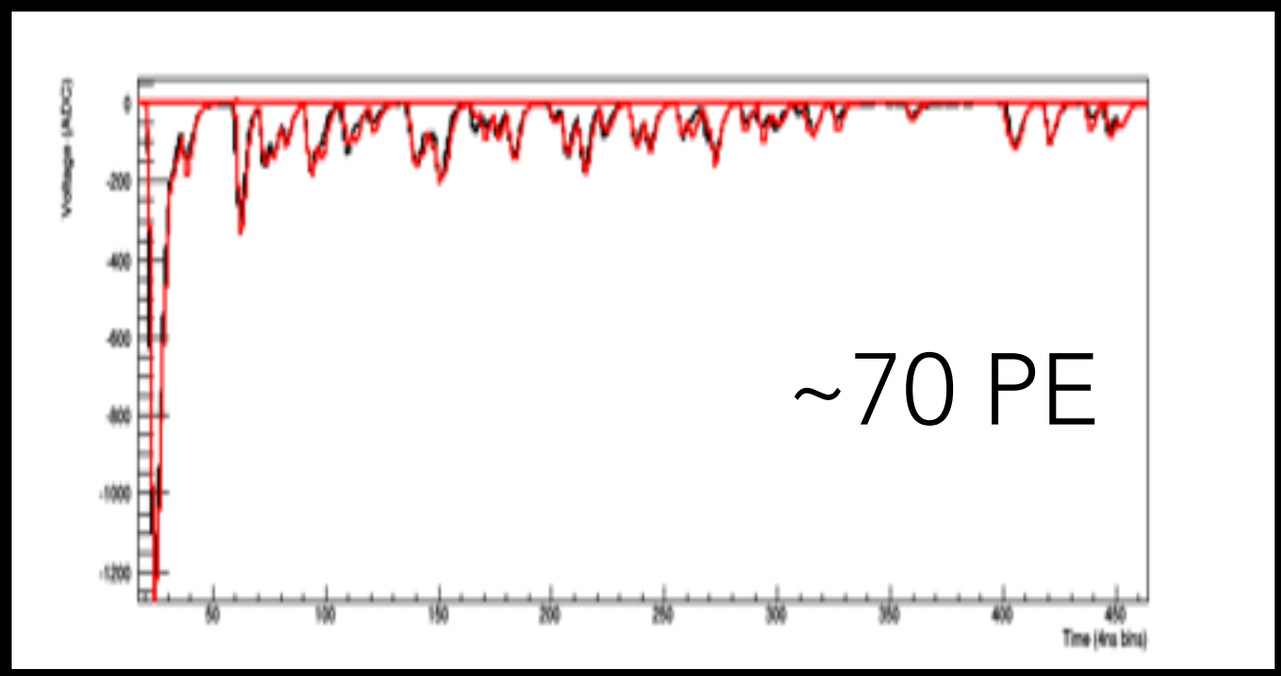
# Pulse Finding




## Pulse finding can handle single to many 10's of PE



# Preliminary Timing Resolution

## From MC Pulse Simulation:

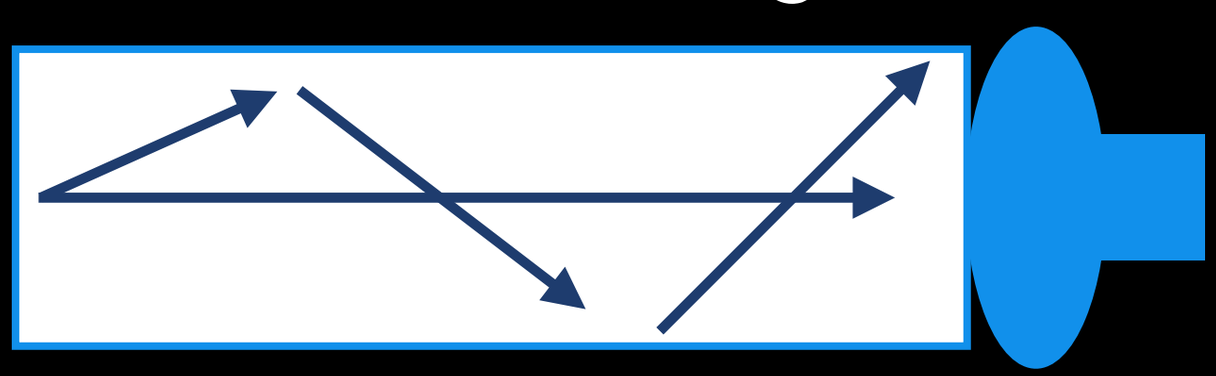
**Peak Finding: $\sigma$ ~0.2 ns**

Improvement from just using peak time (~4 ns).

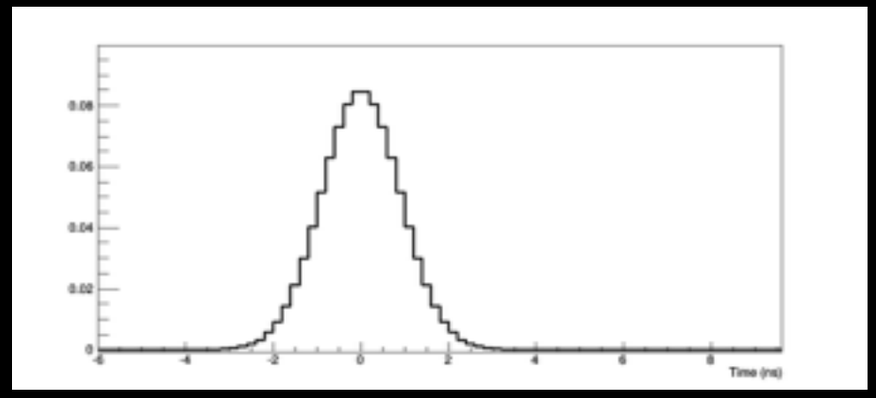
## From Spherical Laser Source (Laserball):

LG Scattering

PMT Time Response



+

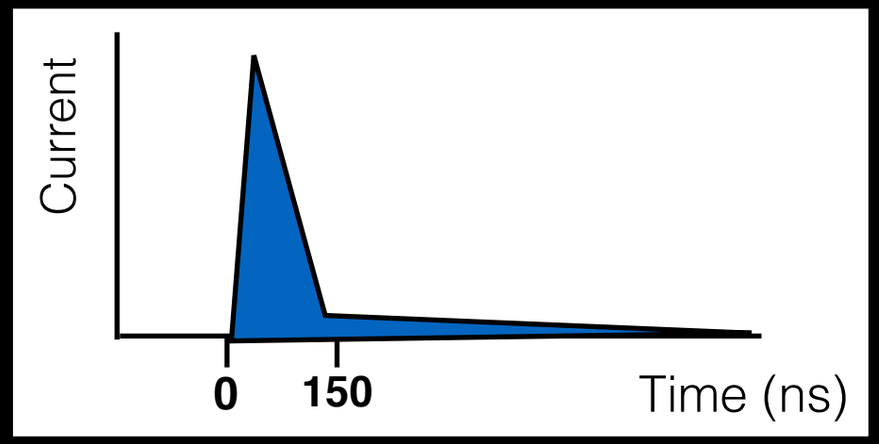



Overall photon time resolution $\sigma$ ~ 1.4 ns

**Peak finding no longer dominates time resolution!**

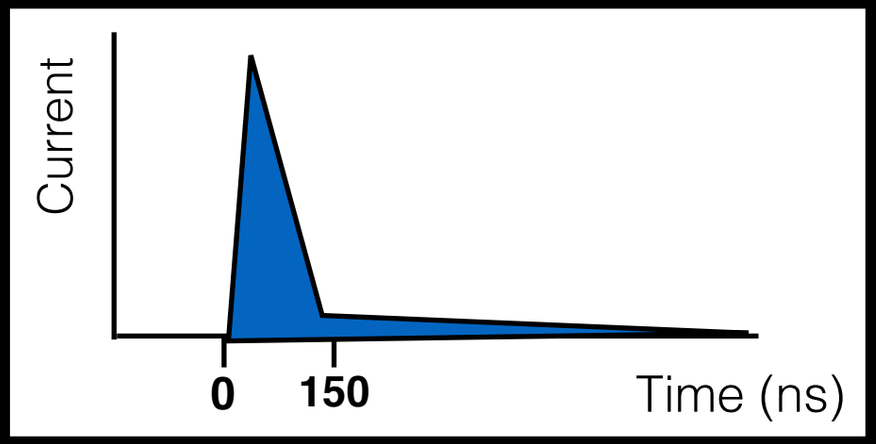
# PULSE SHAPE DISCRIMINATION

*This pulse refers to collection of all pulses in waveform.

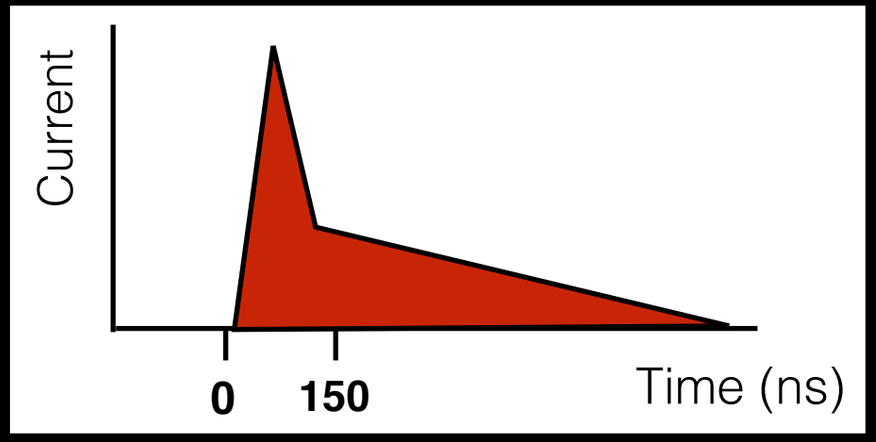



**Nuclear Event (WIMP/Neutron/Alpha)**

# PULSE SHAPE DISCRIMINATION

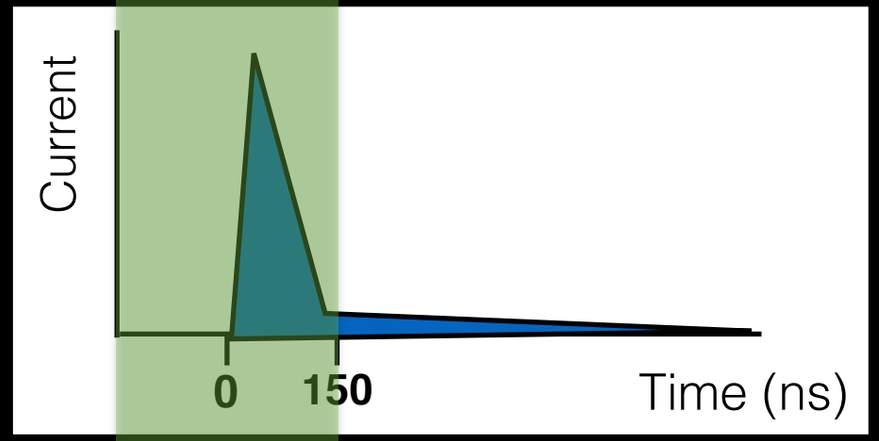


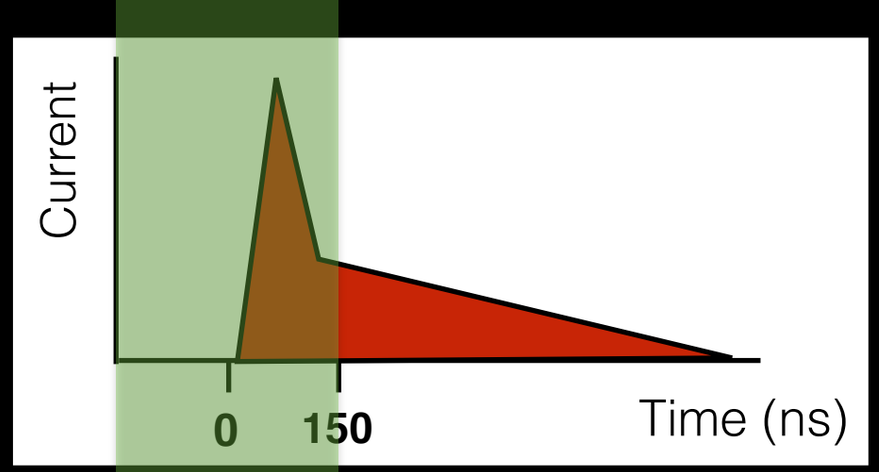

$$fPrompt = \frac{\text{prompt charge}}{\text{total charge}}$$




**Electromagnetic Event (Beta/Gamma)**

# PULSE SHAPE DISCRIMINATION



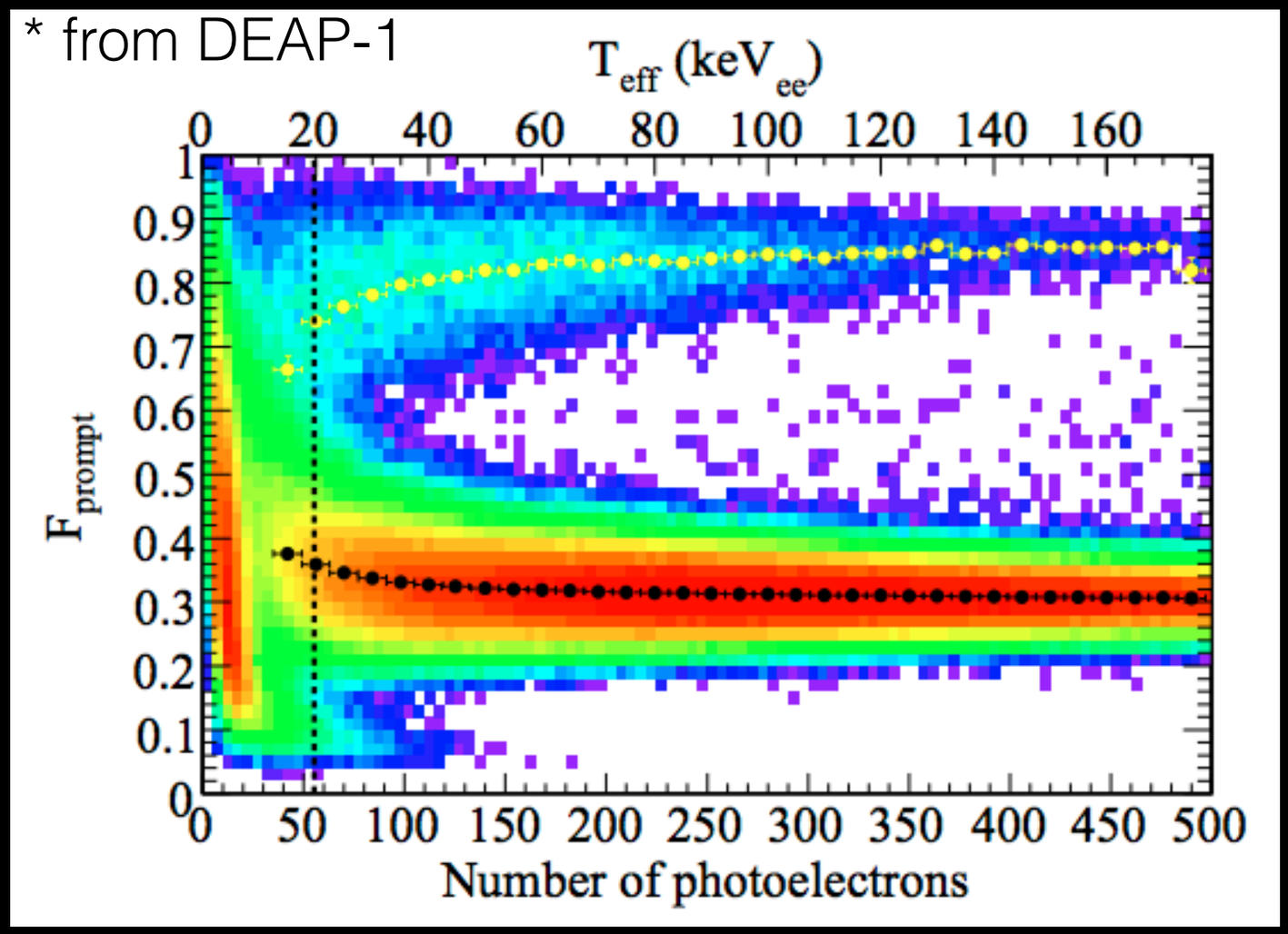



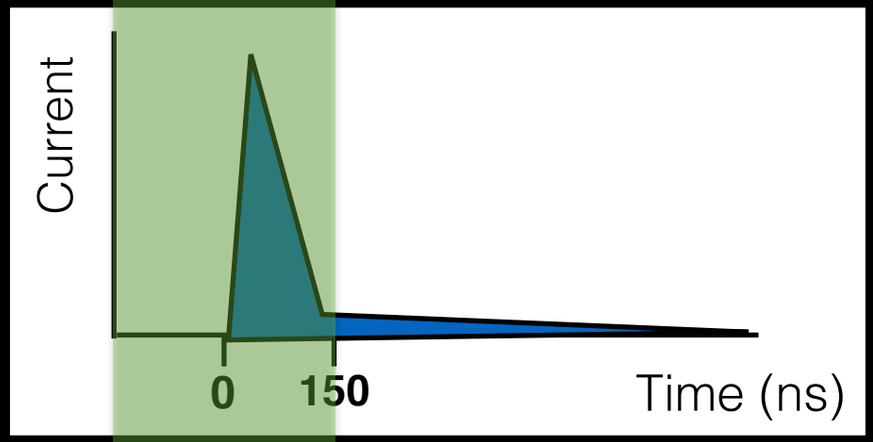

$$\text{fPrompt} = \frac{\text{prompt charge}}{\text{total charge}}$$

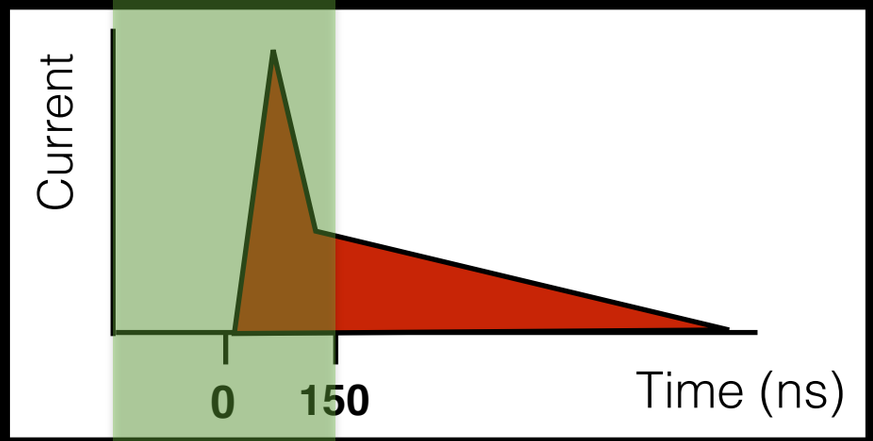
**Prompt**

# PULSE SHAPE DISCRIMINATION

* from DEAP-1



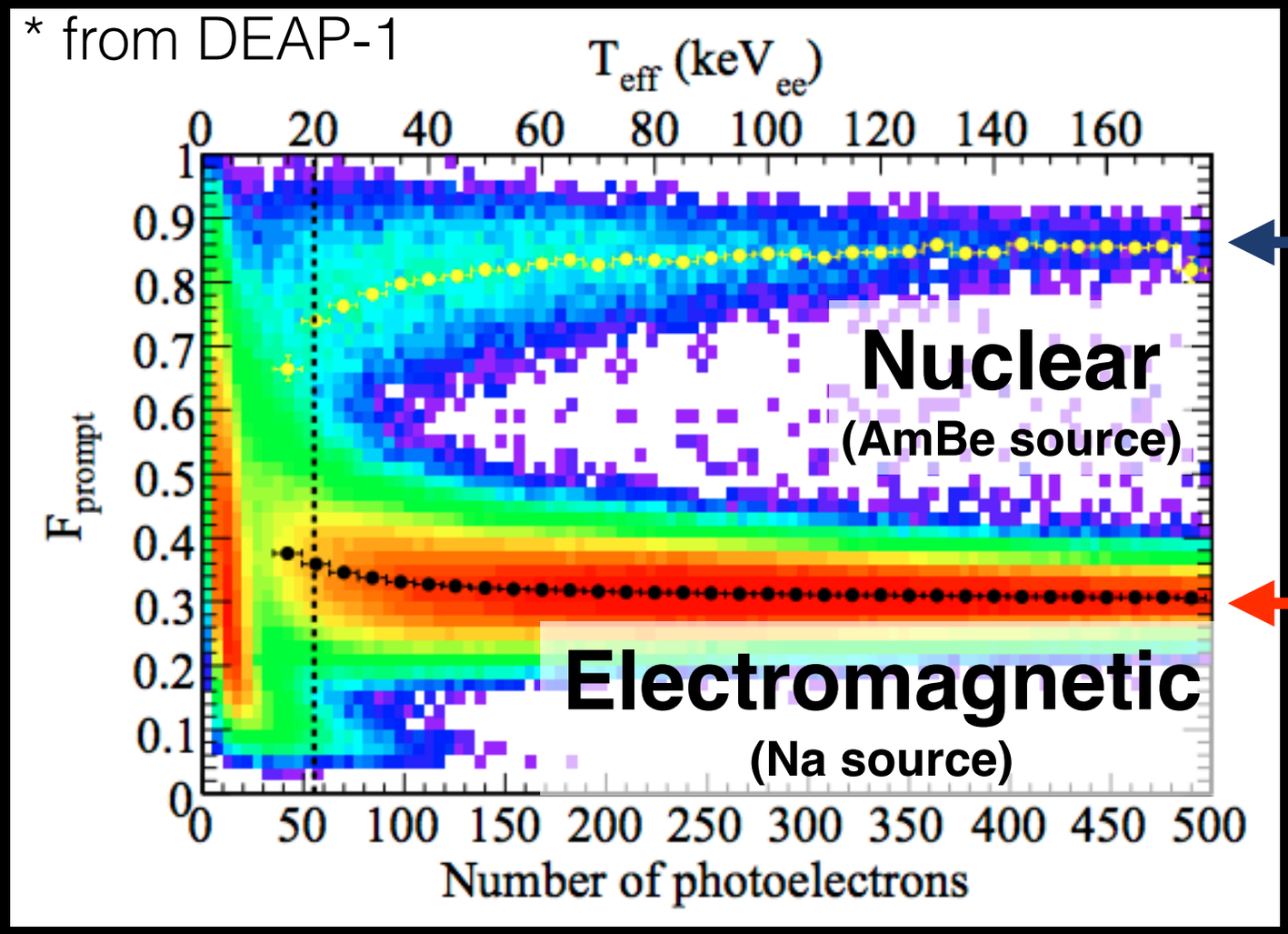

$$\text{fPrompt} = \frac{\text{prompt charge}}{\text{total charge}}$$

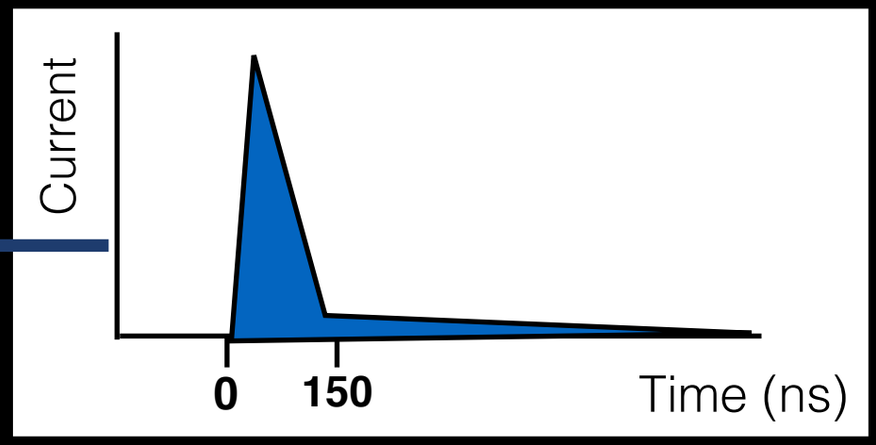
**Prompt**

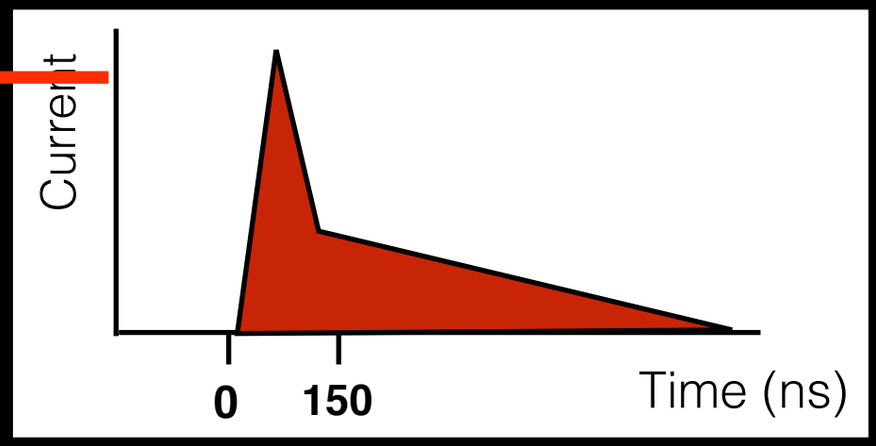
***Astroparticle Physics Volume 85, December 2016, Pages 1–23**

# PULSE SHAPE DISCRIMINATION

* from DEAP-1



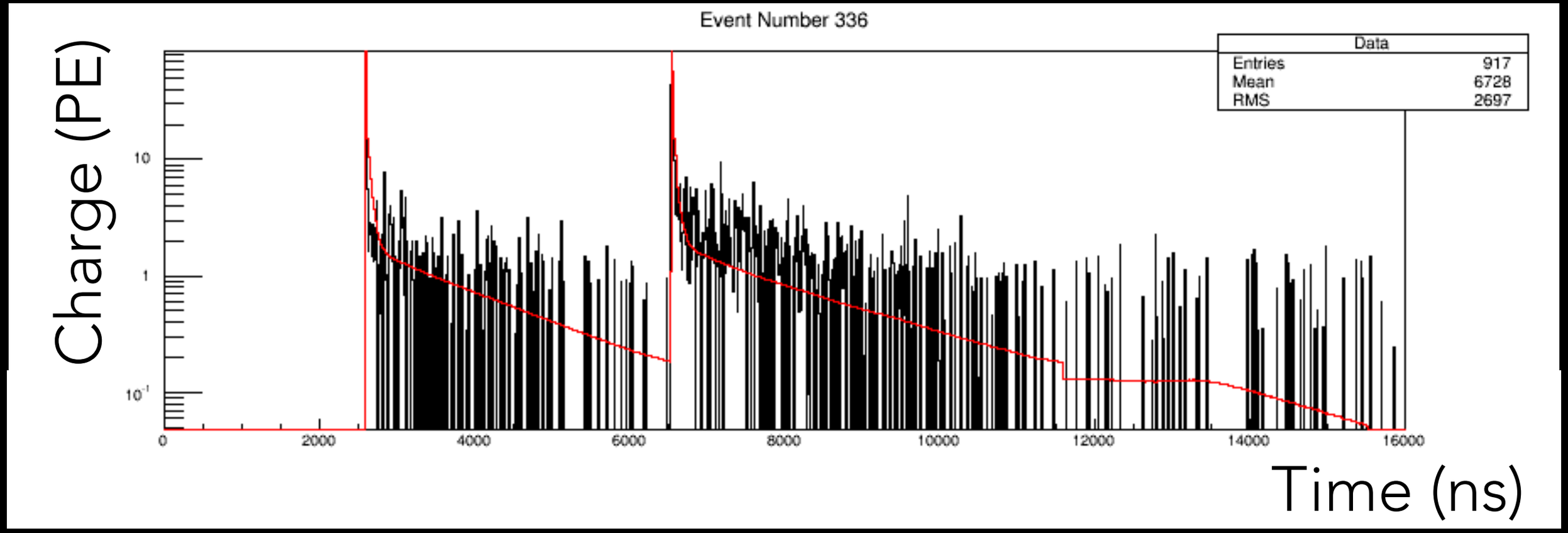




**$10^{10}$ electromagnetic background rejection above 20 keV$_{ee}$**

***Astroparticle Physics Volume 85, December 2016, Pages 1–23**

# PILE-UP

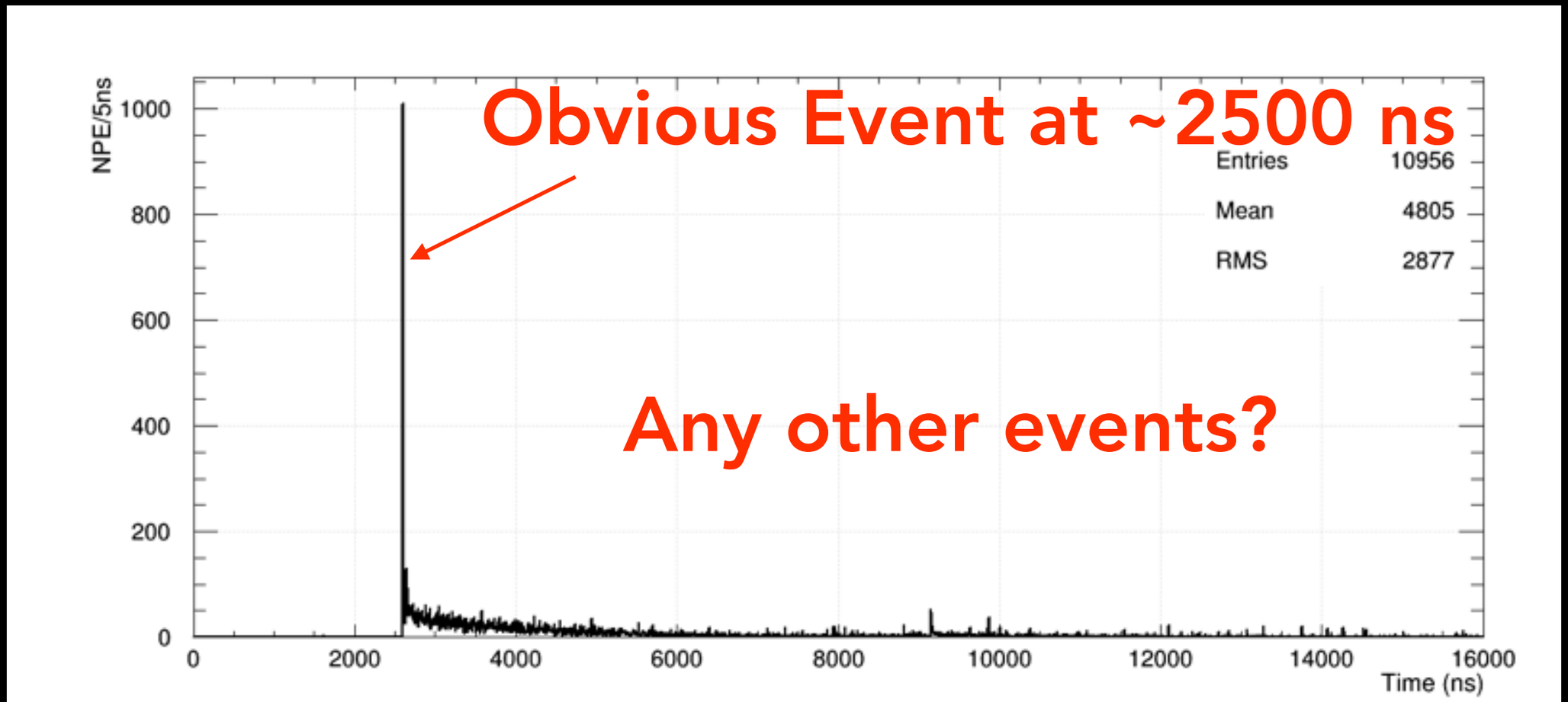
- PSD works good for single events; however, it needs some help when dealing with multiple overlapping events.
- The pile-up rate for Ar39 events is ~4% within the 16 us event window.




*rough fits to show locations of two events

# MULTI-EVENT FINDING

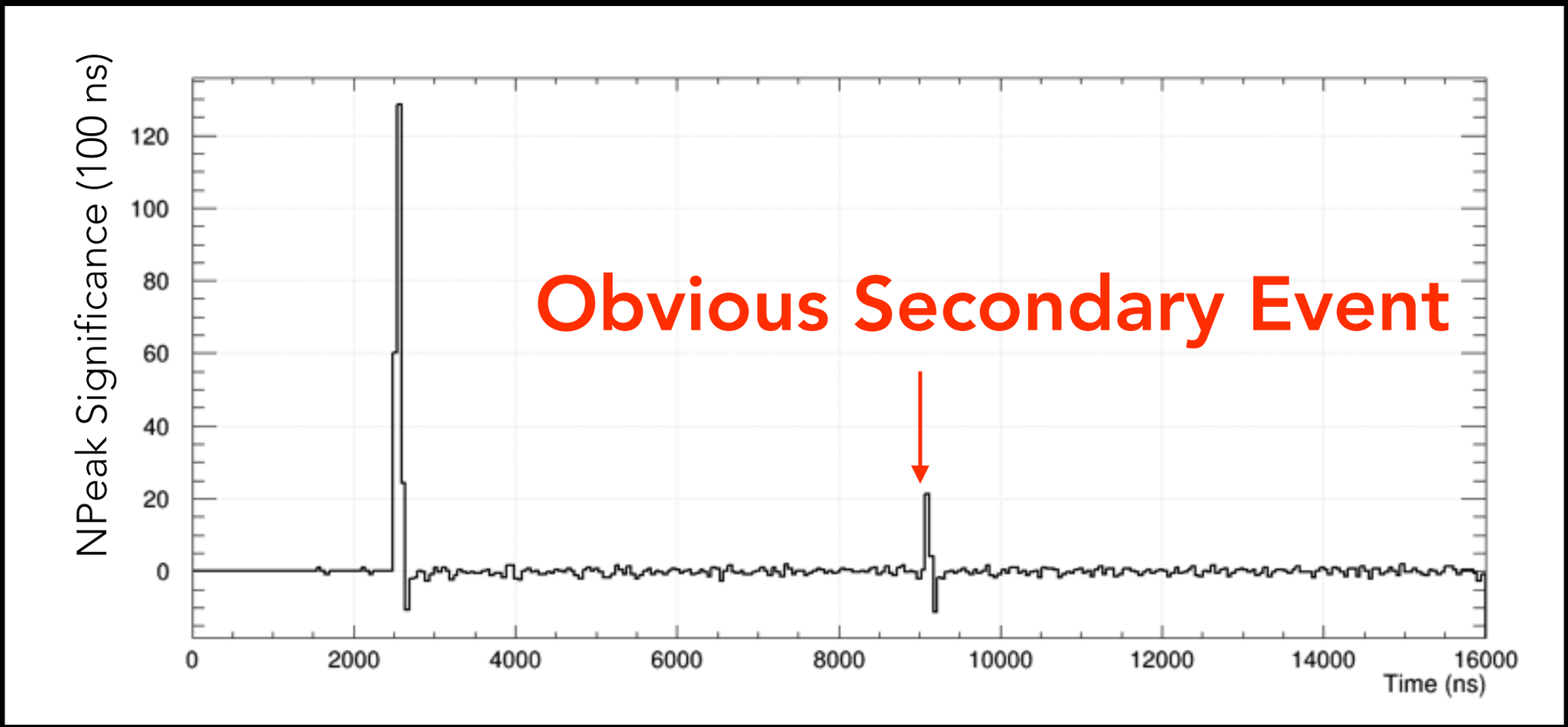
Sample Event
~20,000 Detected Photons



# MULTI-EVENT FINDING

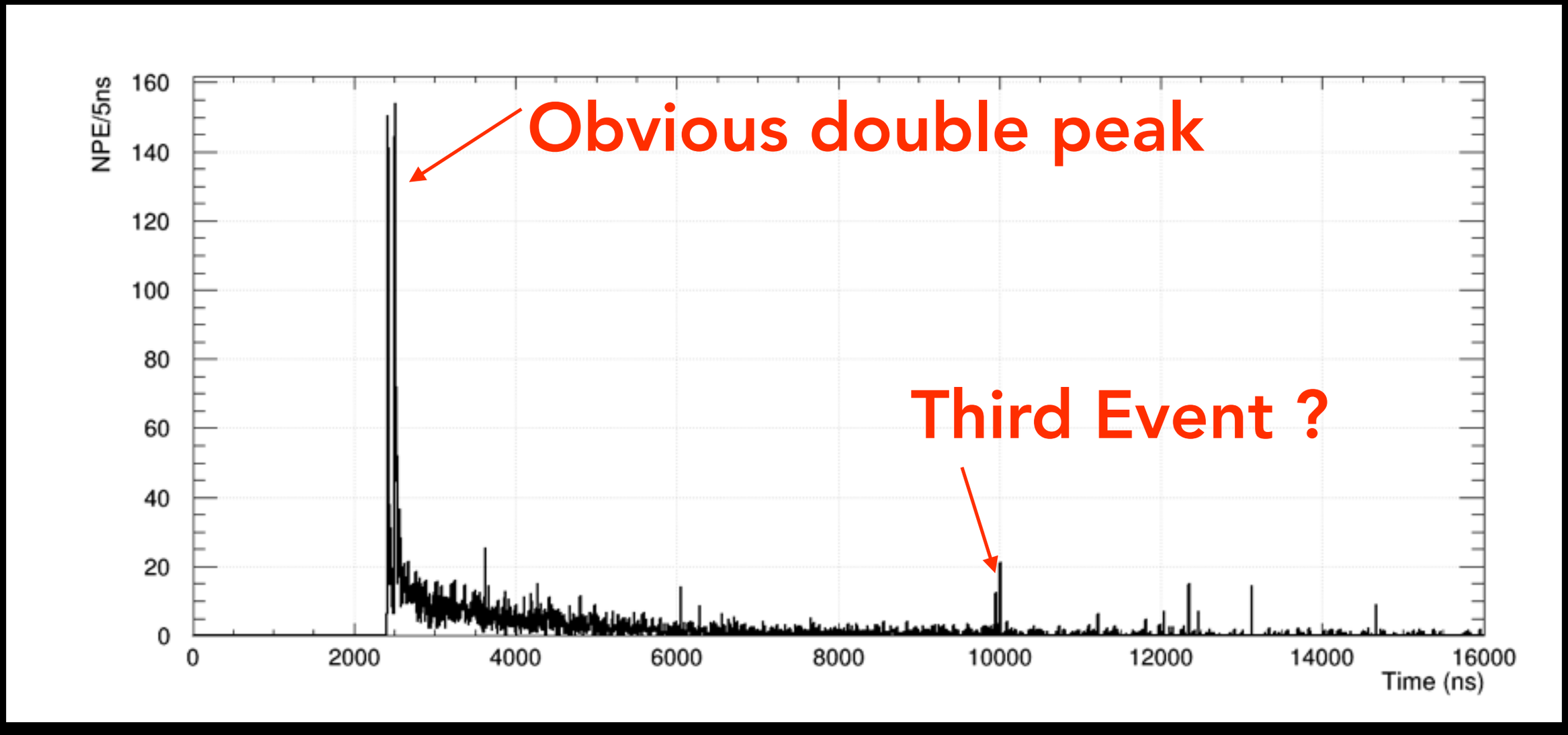
- Events are found by finding statistically significant increases in peak counts within the event window.

**First pass is performed with 100 ns binned data**



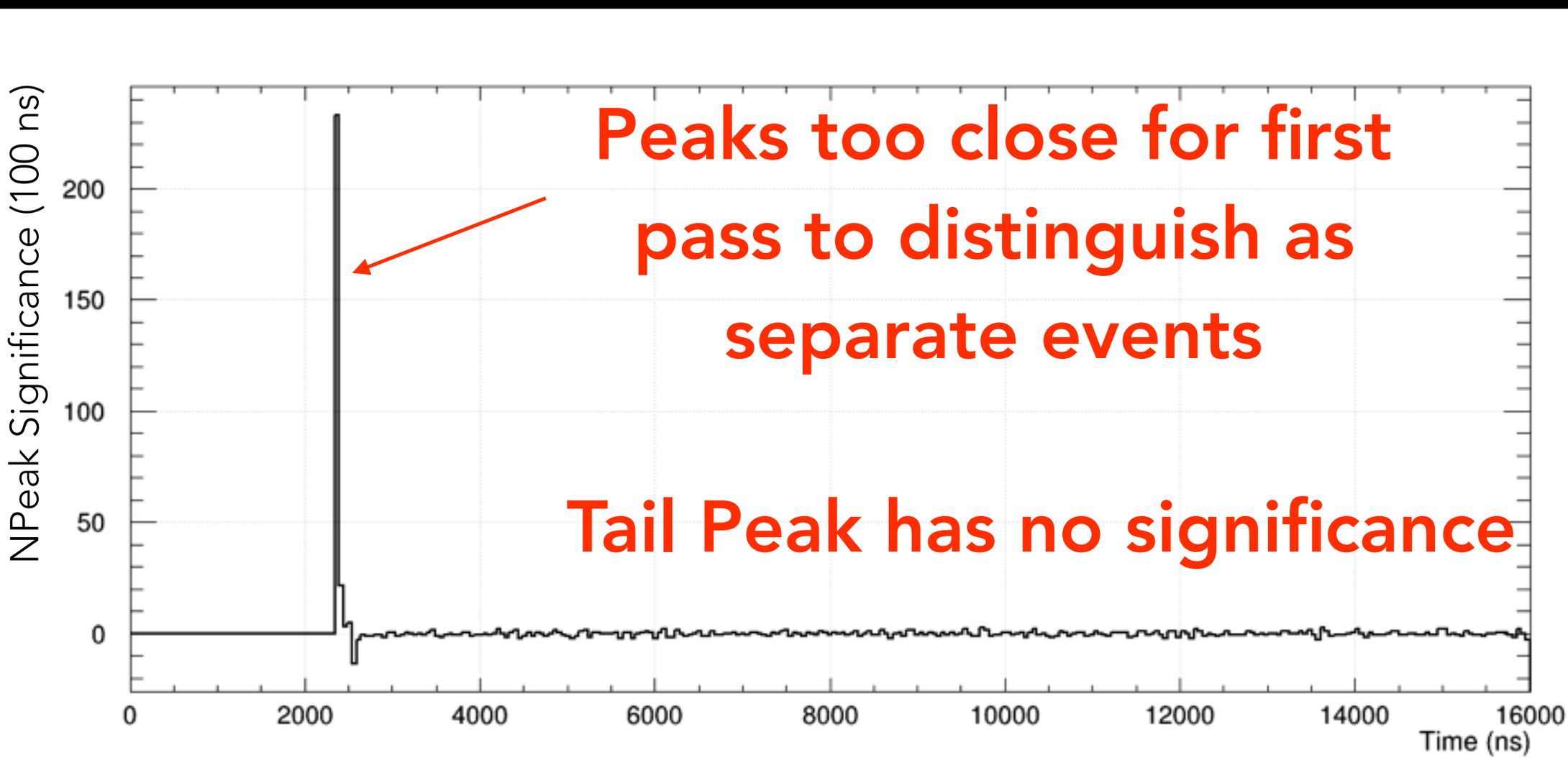
# MULTI-EVENT FINDING

Sample Event
~6000 Detected Photons



# MULTI-EVENT FINDING

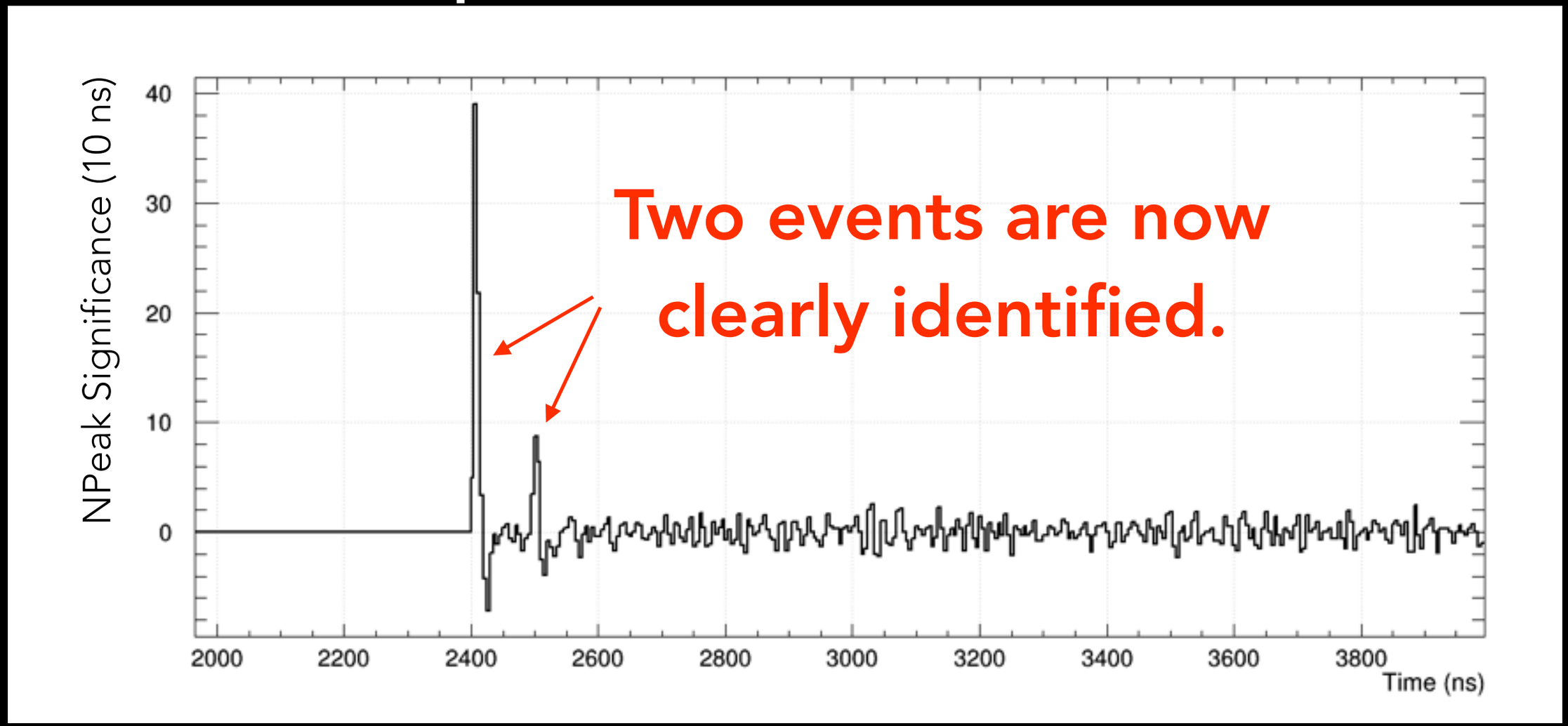
First pass:



# MULTI-EVENT FINDING

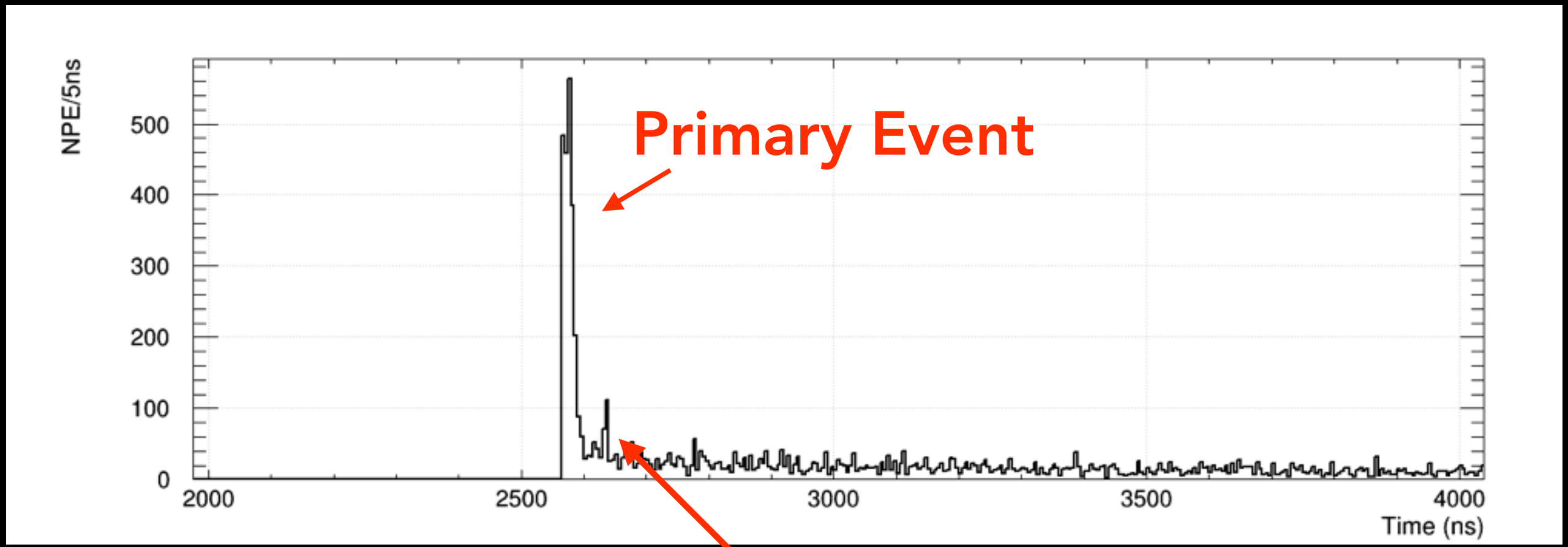
- First pass single events are put through second pass with finer precision focused around the single event.

**Second pass is performed with 10 ns binned data around +/- 500 ns of first pass event time.**



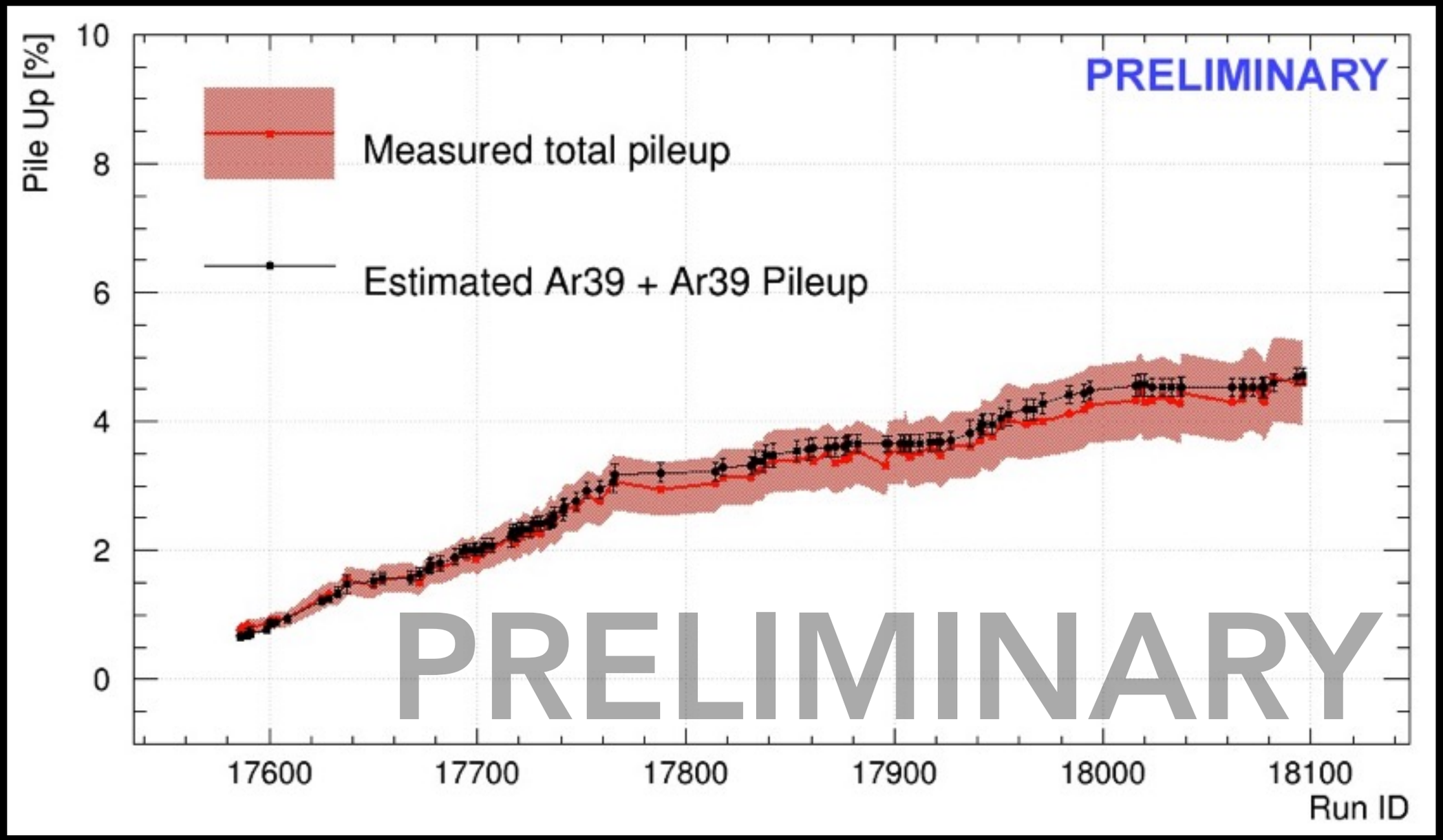
# MULTI-EVENT FINDING

- To catch very prompt events that only trigger a single PMT, pulses that have more than 50 PE of energy are added as events if they are well separated from prompt peaks.




Secondary event with few peaks but significant charge in single peak (beyond what naturally would occur from PE pile-up or from PMT effects).

# MULTI-EVENT FINDING




Measured rate of Pile-up is constant with expected rate based on LAr mass in detector.

# CURRENT STATUS

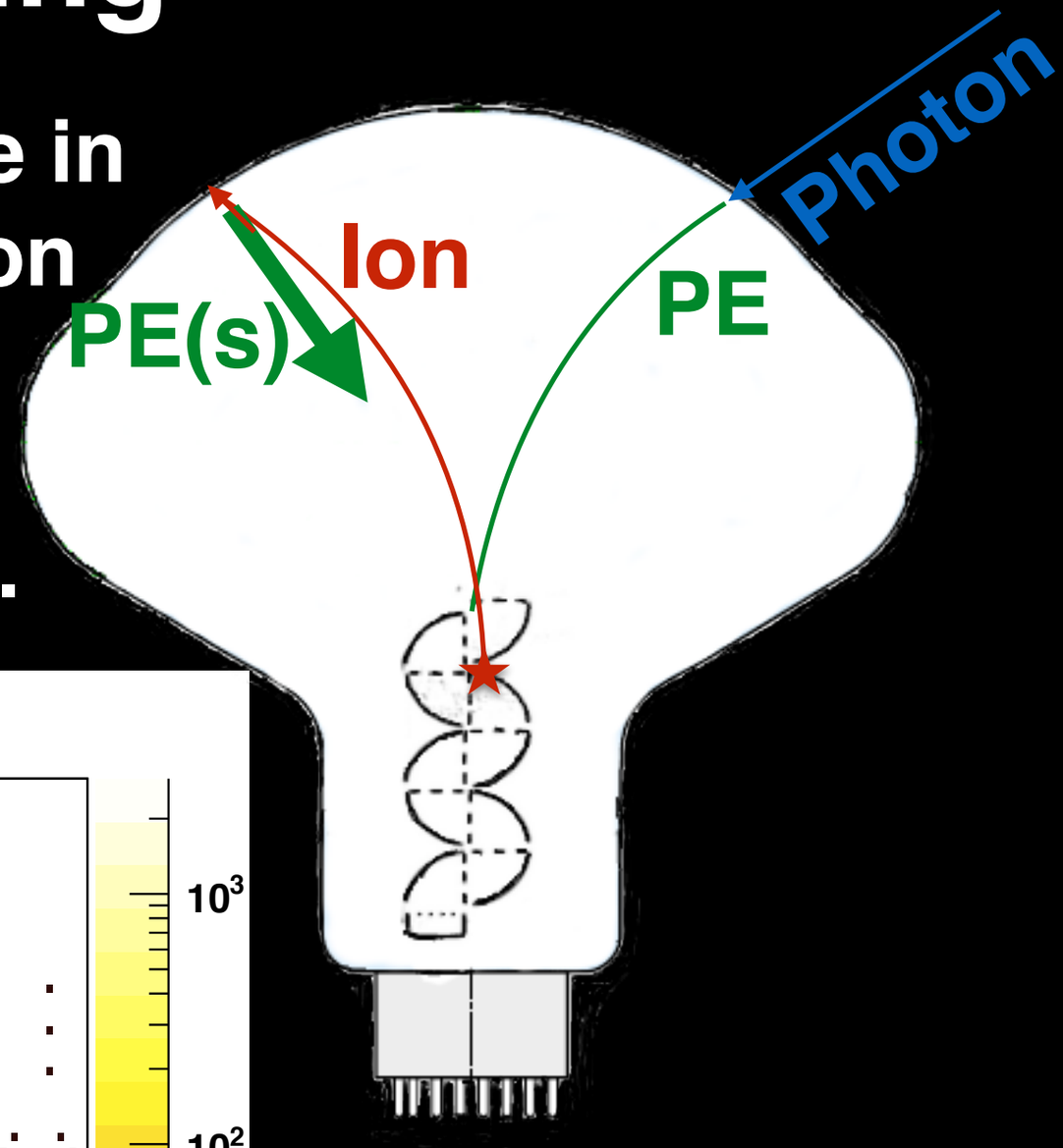
- DEAP-3600 is currently built and running with ~3260 kg of LAr.
- First data set  of LAr fill is being analyzed.
- Expect first physics result Spring/Summer 2017.

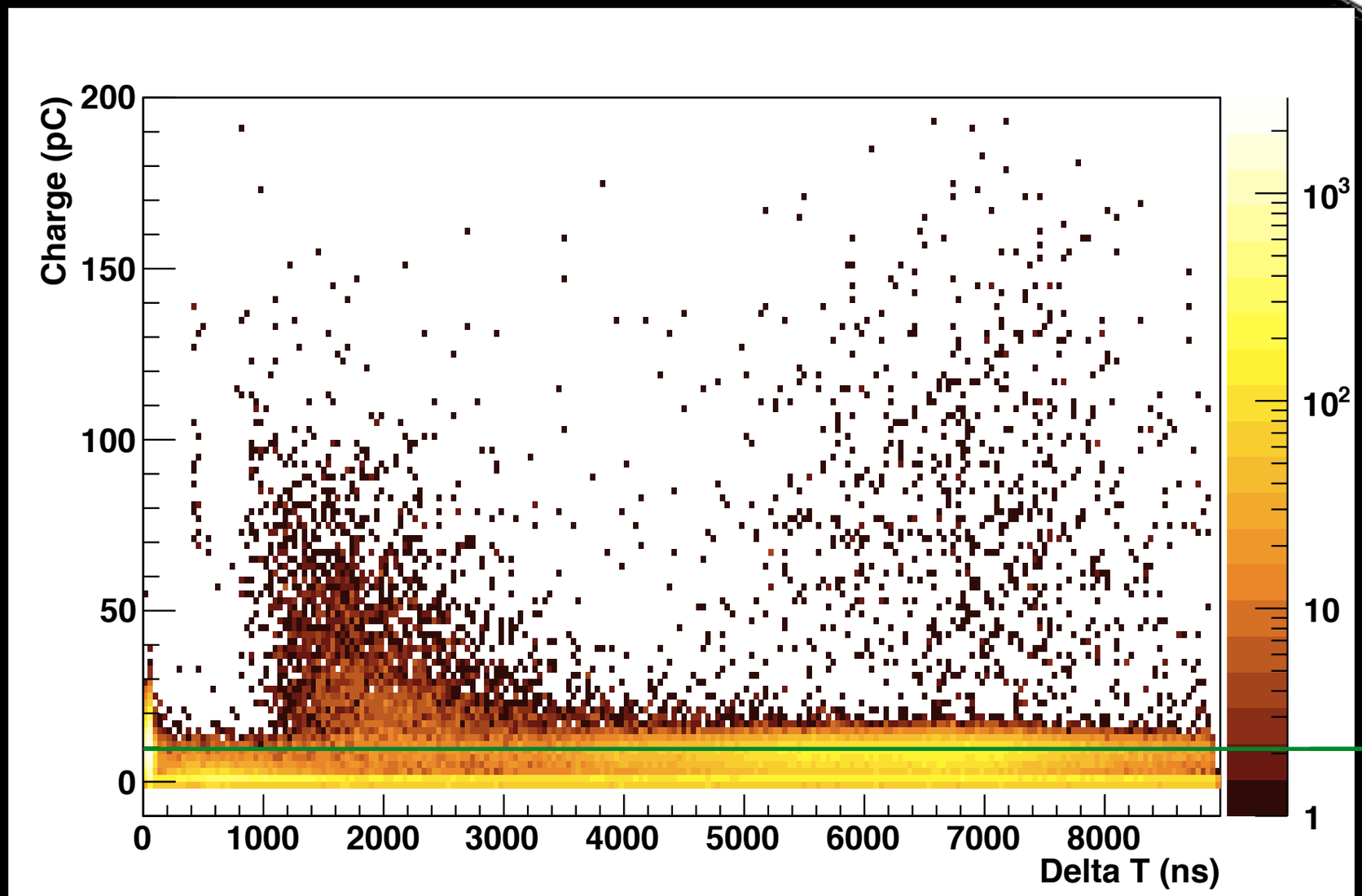
~60 collaborators in Canada, the UK, and Mexico

Visit us at www.deap3600.ca

# Afterpulsing

**Caused by ions created somewhere in the dynode-chain during the electron avalanche. Due to large mass, take significant time to hit cathode and can release multiple PE in collision.**




~1 SPE Charge

# NPeak Significance

$$\text{NPeaksig\_i} = \frac{\text{NPeak\_i - NPeak\_i-1}}{\text{SQRT(Average NPE)}}$$

NPeak_i = Number of Peaks in i'th time bin (100ns Course and 10 ns fine).

Average NPE = ave number of PE in last 500 ns(course), 50 (fine).

Think of this variable as the poisson significance of the increase in number of peaks.