Study of Afterpulsing of MPPC with Waveform Analysis

ICEPP, U Tokyo

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for Photon Sensor Group in KEK Detector Technology Project

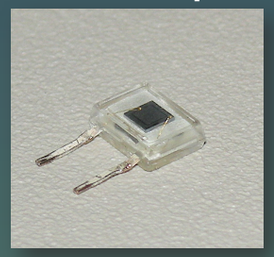
Introduction

1. Measurement of dark noises at 300 [K] temp.
2. Recording waveforms with digital oscilloscope and doing offline waveform analysis
3. Extraction of afterpulsing events

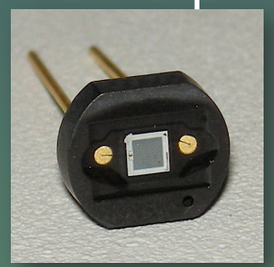
→The information about Recovery is obtained.

HPK MPPC

40x40 px



20x20 px



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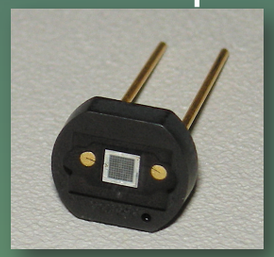
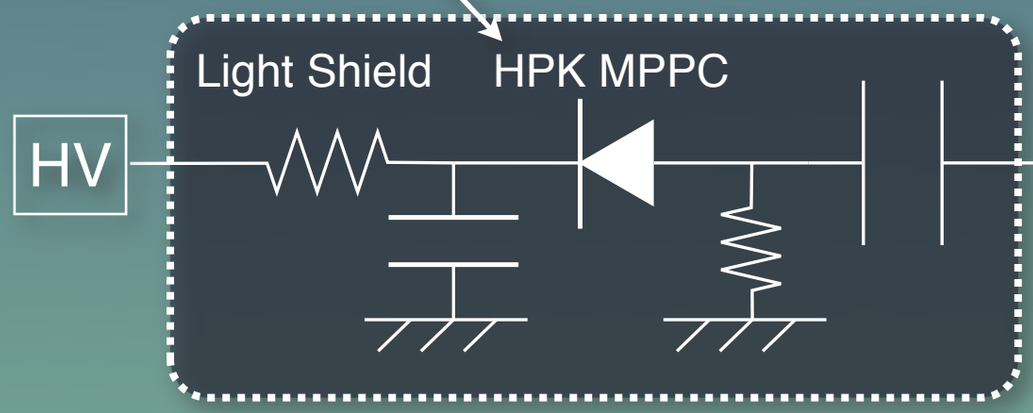




HPK Speed Amplifier
C5596 (x63)

Operation : +15V

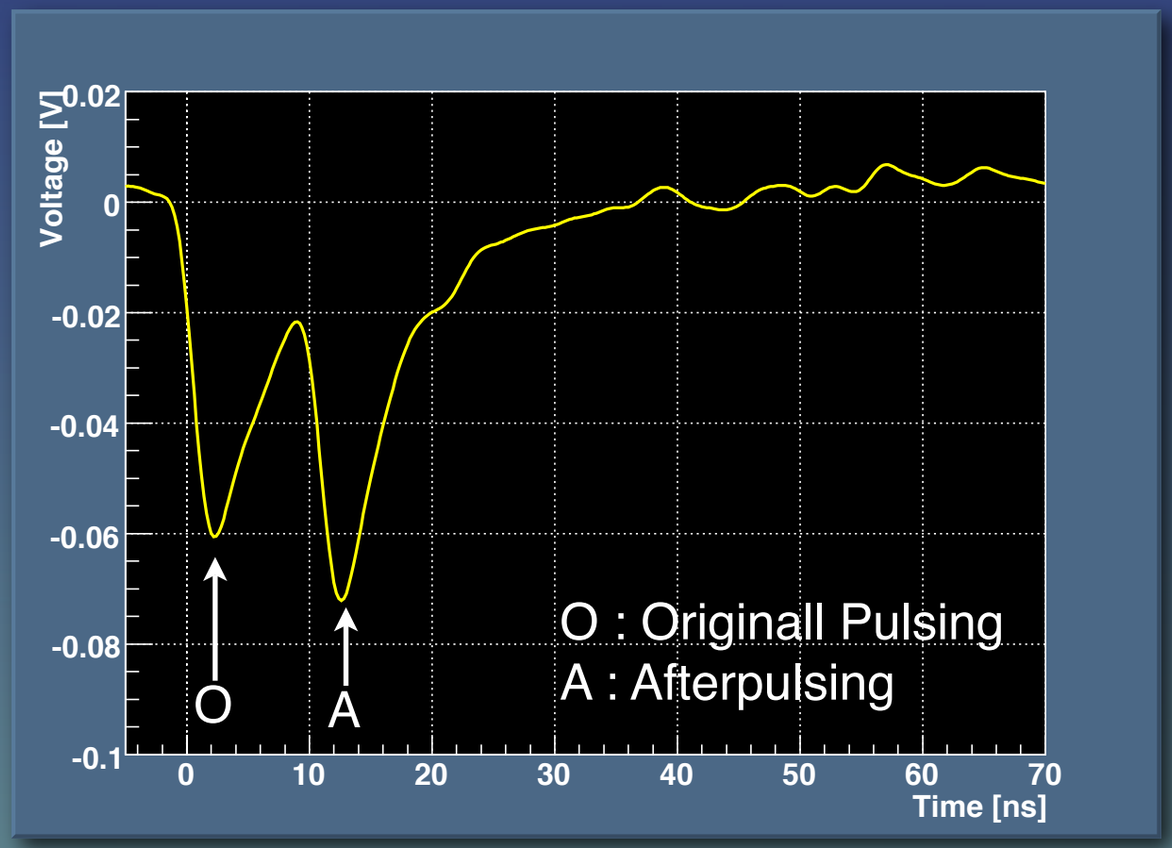
Digital Oscilloscope
LeCroy
WavePro 7300A

Bandwidth: 3 [GHz] @ 50 [Ω]
Maximum Sampling Rate: 20 [ps/div]

PC
Offline
Analysis

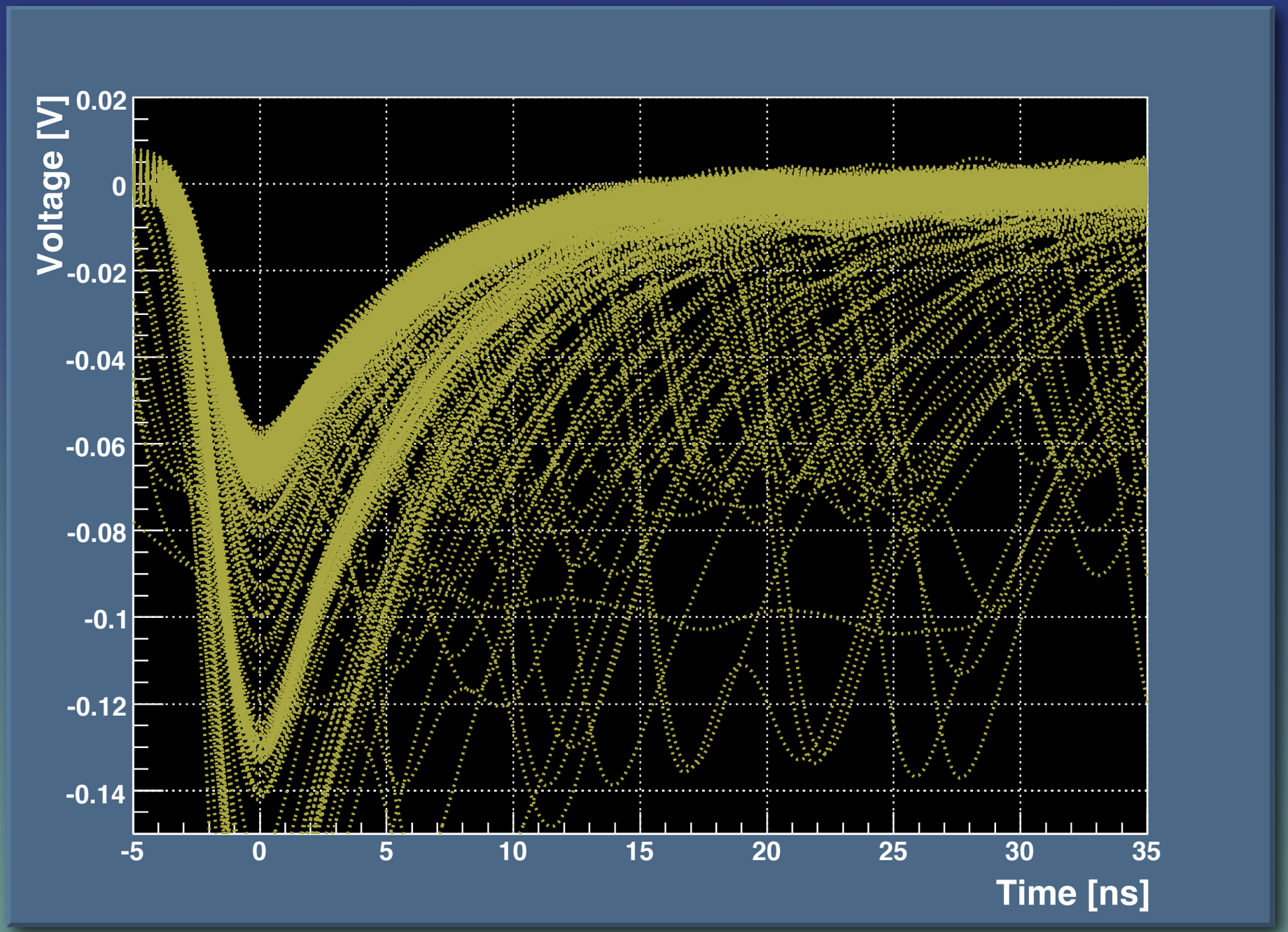
The Afterpulsing

- When original pulsing has occurred, some of the avalanching electrons are trapped at lattice defects in the crystal of the pixel.
- They are re-emitted in several time, and cause succeeding pulses.
- This phenomenon is known as “Afterpulsing”, and is distinguished from ordinary thermal pulsing.
- Afterpulsings occur in the same pixel that the original pulsing occurred just before.



- Because recovery process and afterpulsing are unrelated to each other, afterpulsings can occur during recovering.
- We can probe recovery process by measuring afterpulsing.

Extraction of Afterpulsing Events



Various Signals
O
O+N
O+A
O+(AC)
O+A+A
C
C+A
C+(AC)
C+A+A
etc...

O : original pulsing **C** : crosstalk(s) **N** : accidental noise

A : afterpulsing **(AC)** : afterpulse caused crosstalk(s)

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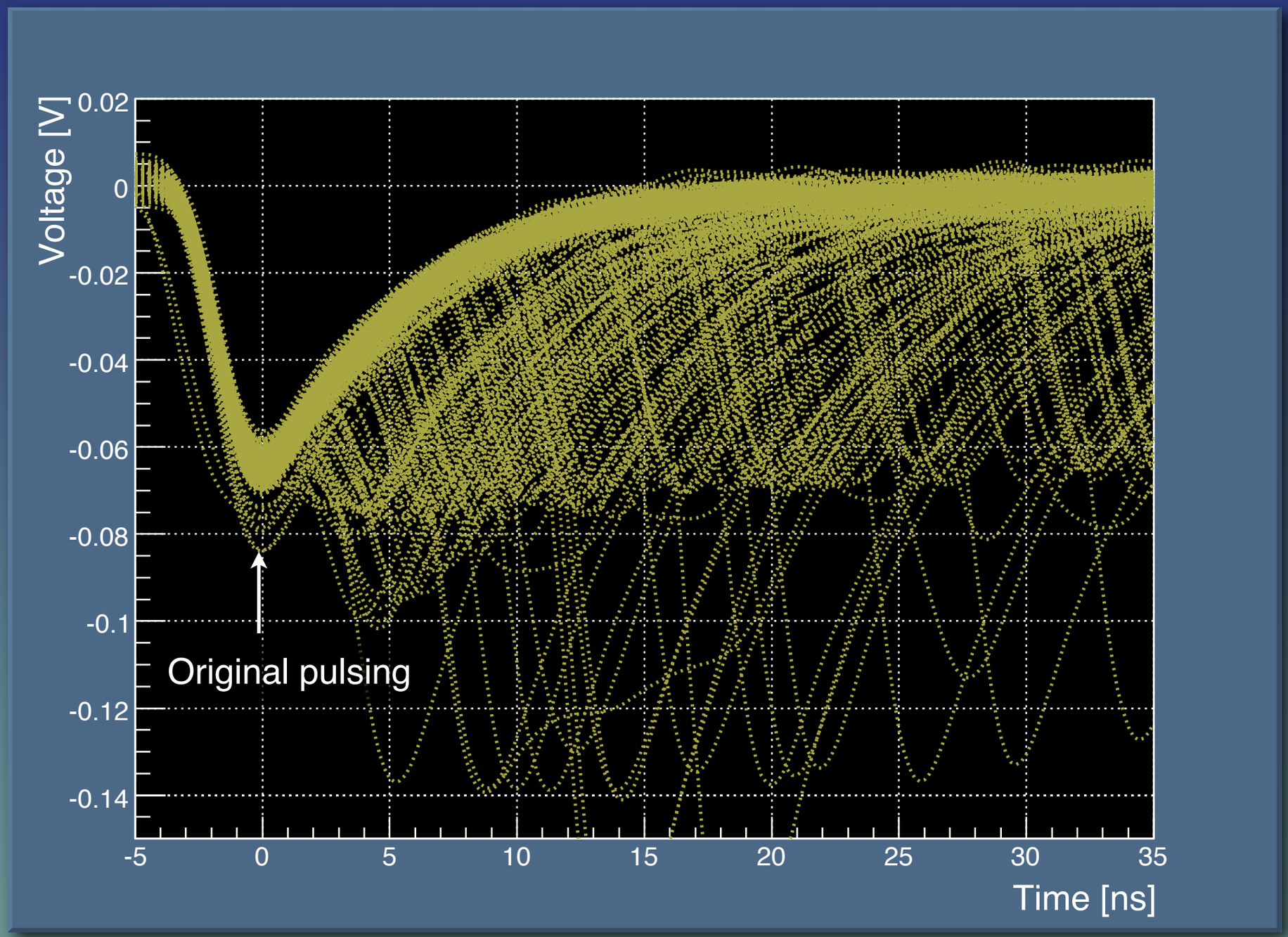

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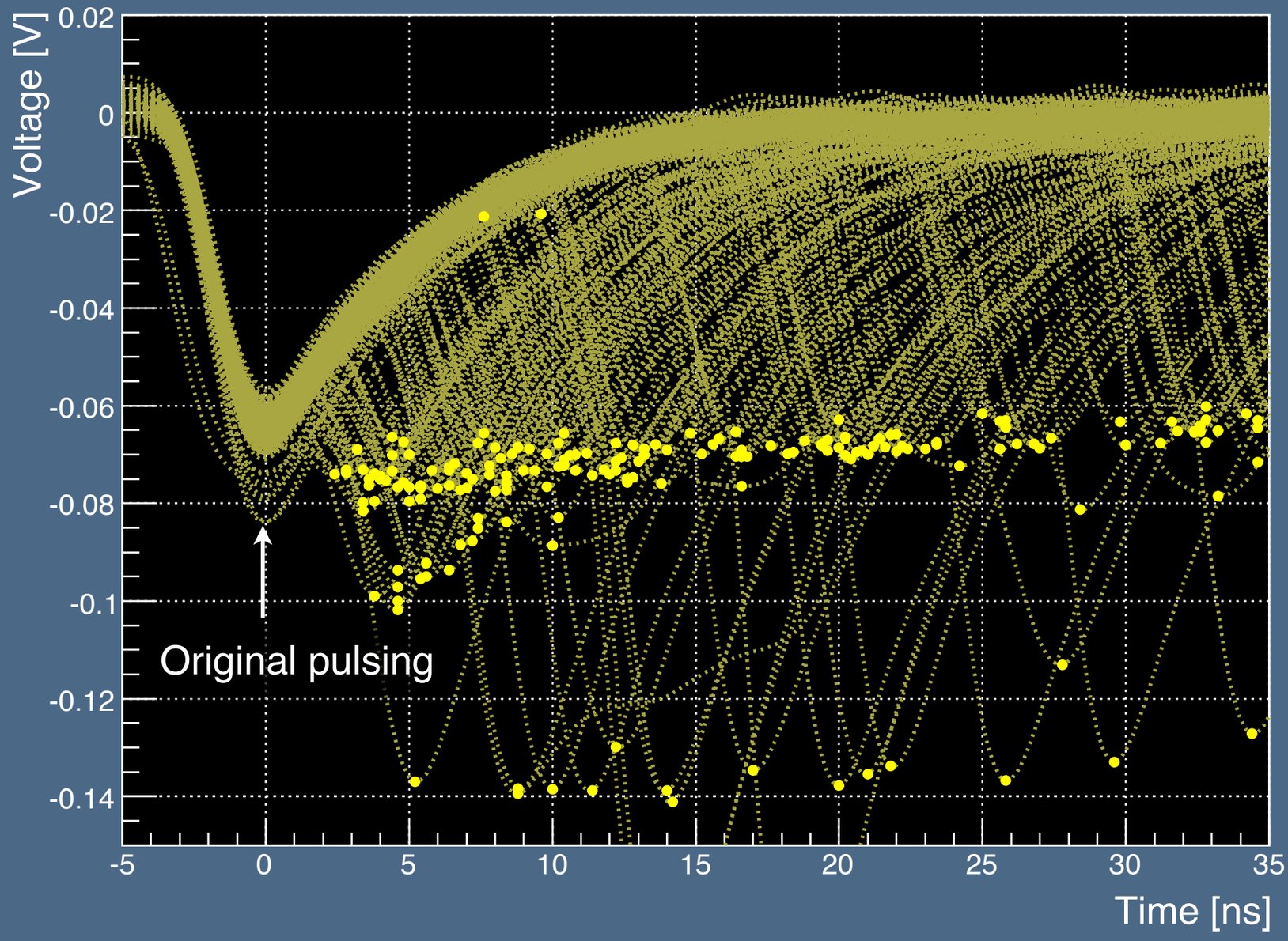

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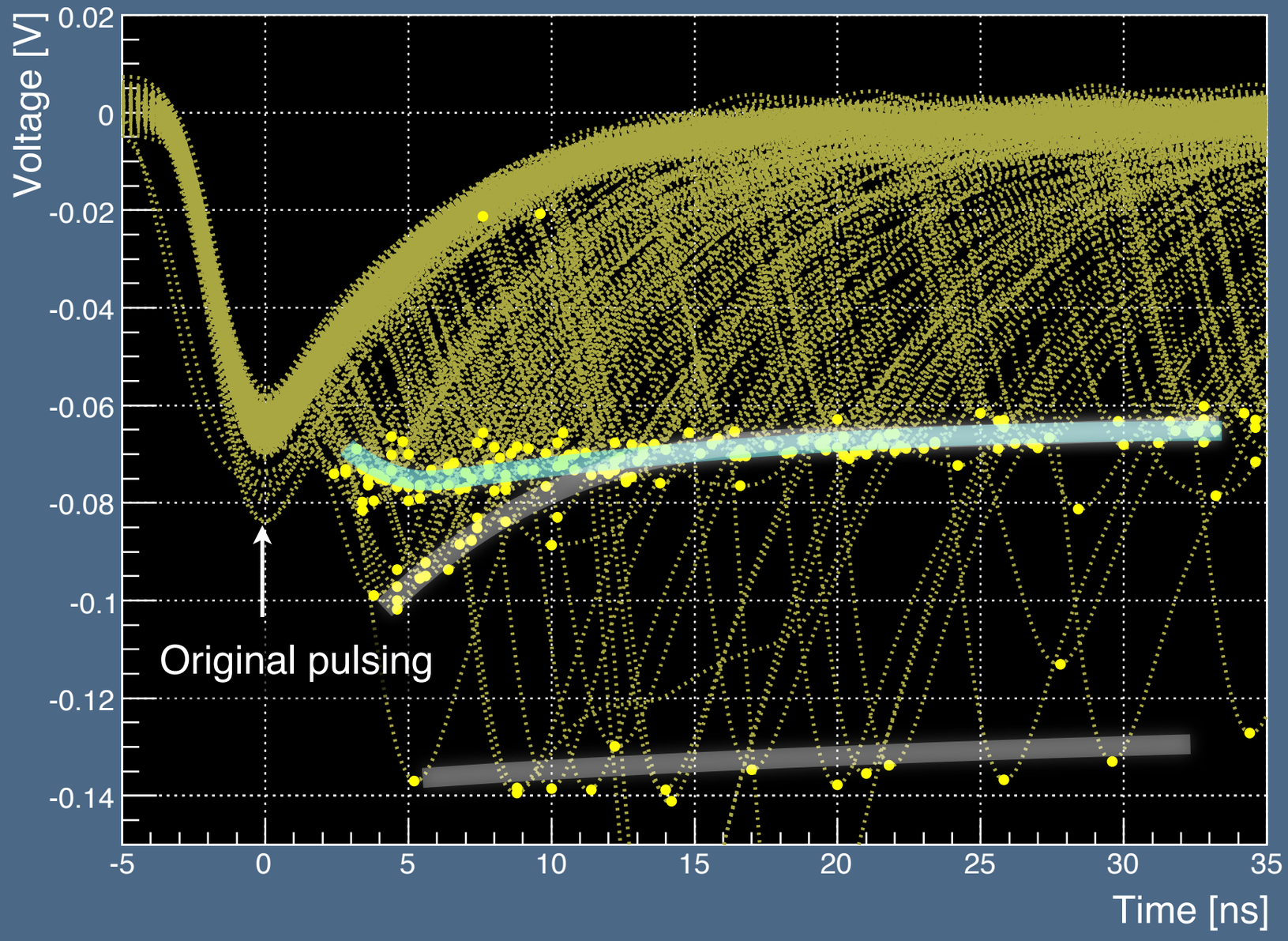

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O+A+A C C+A
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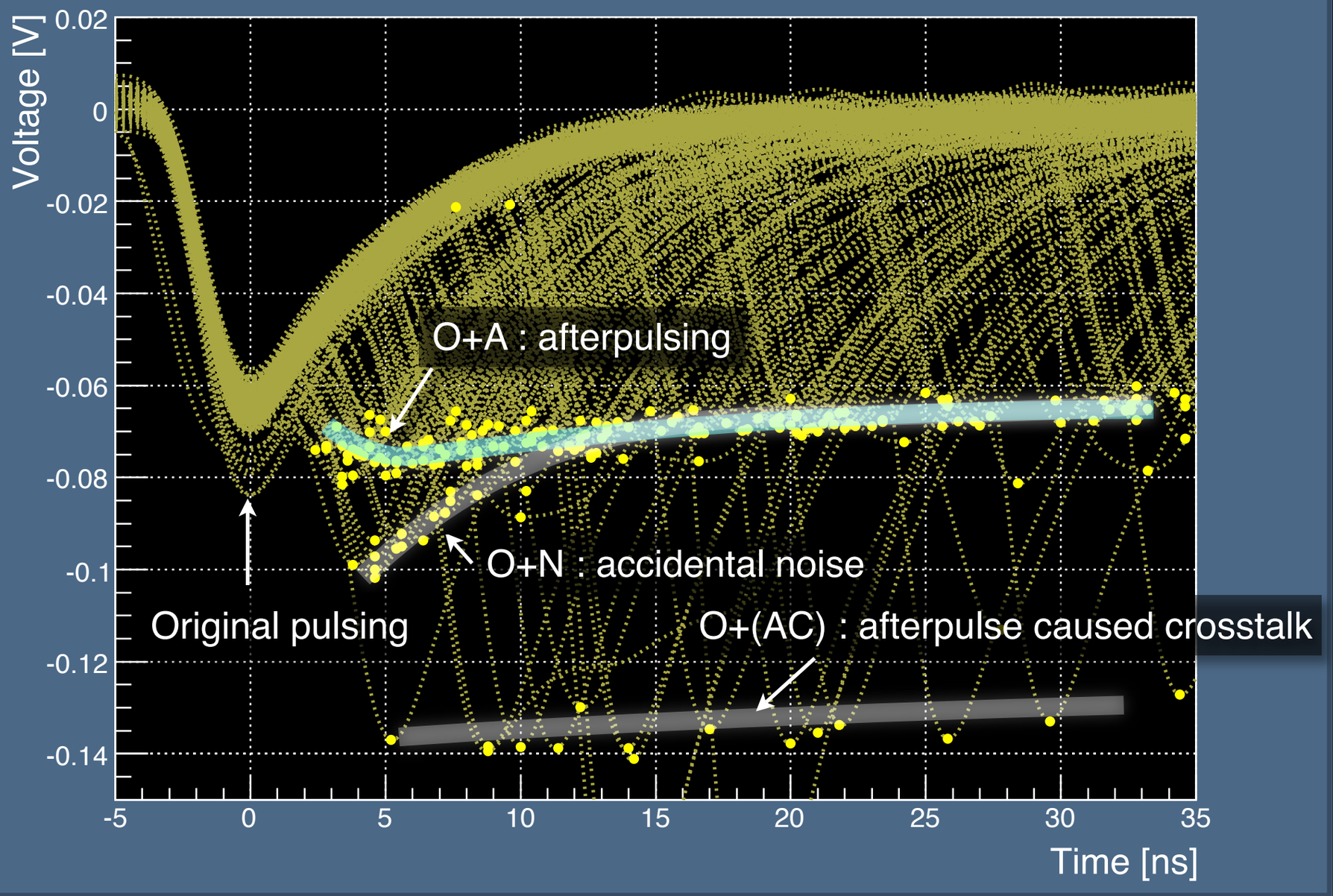

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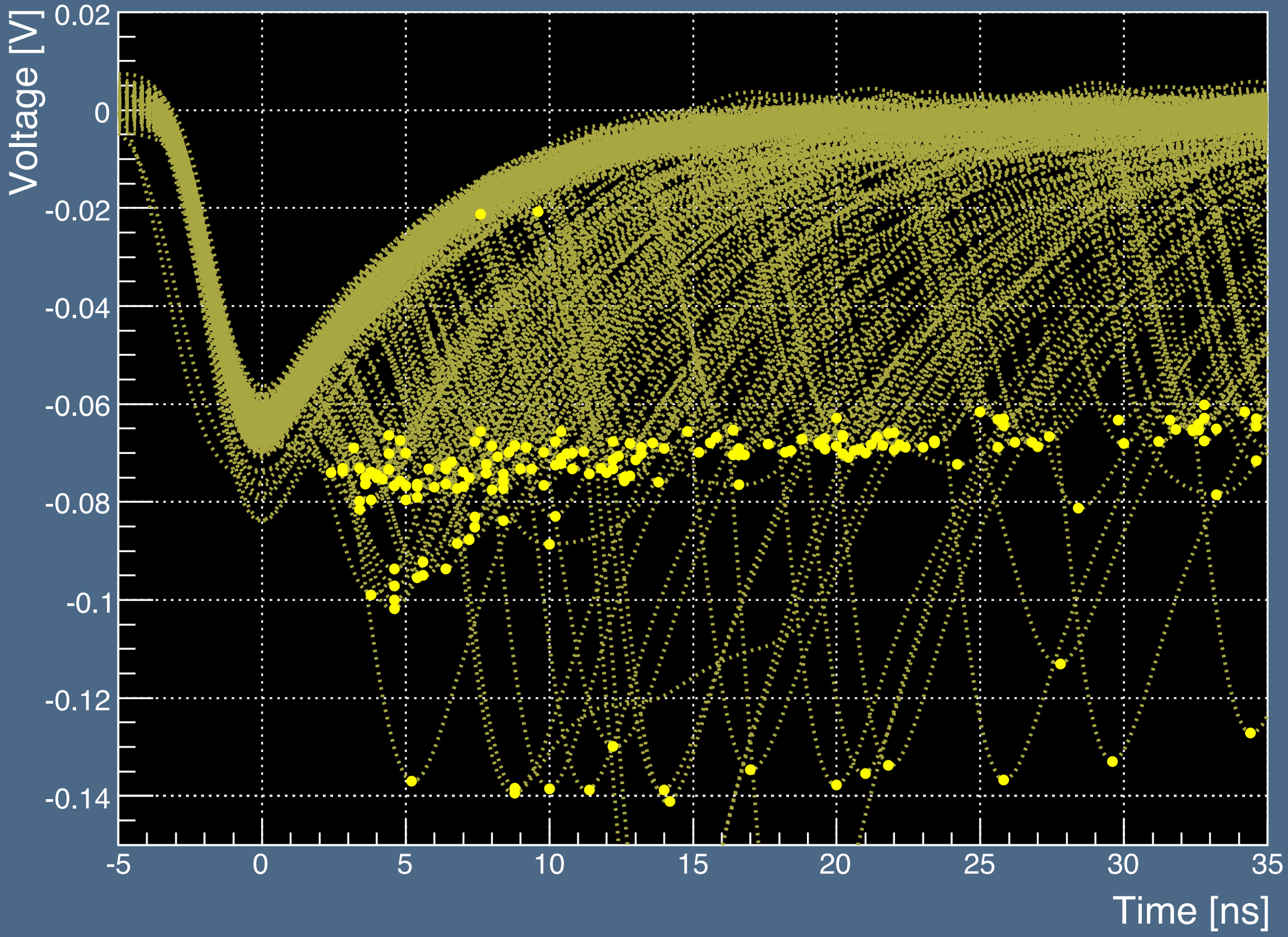
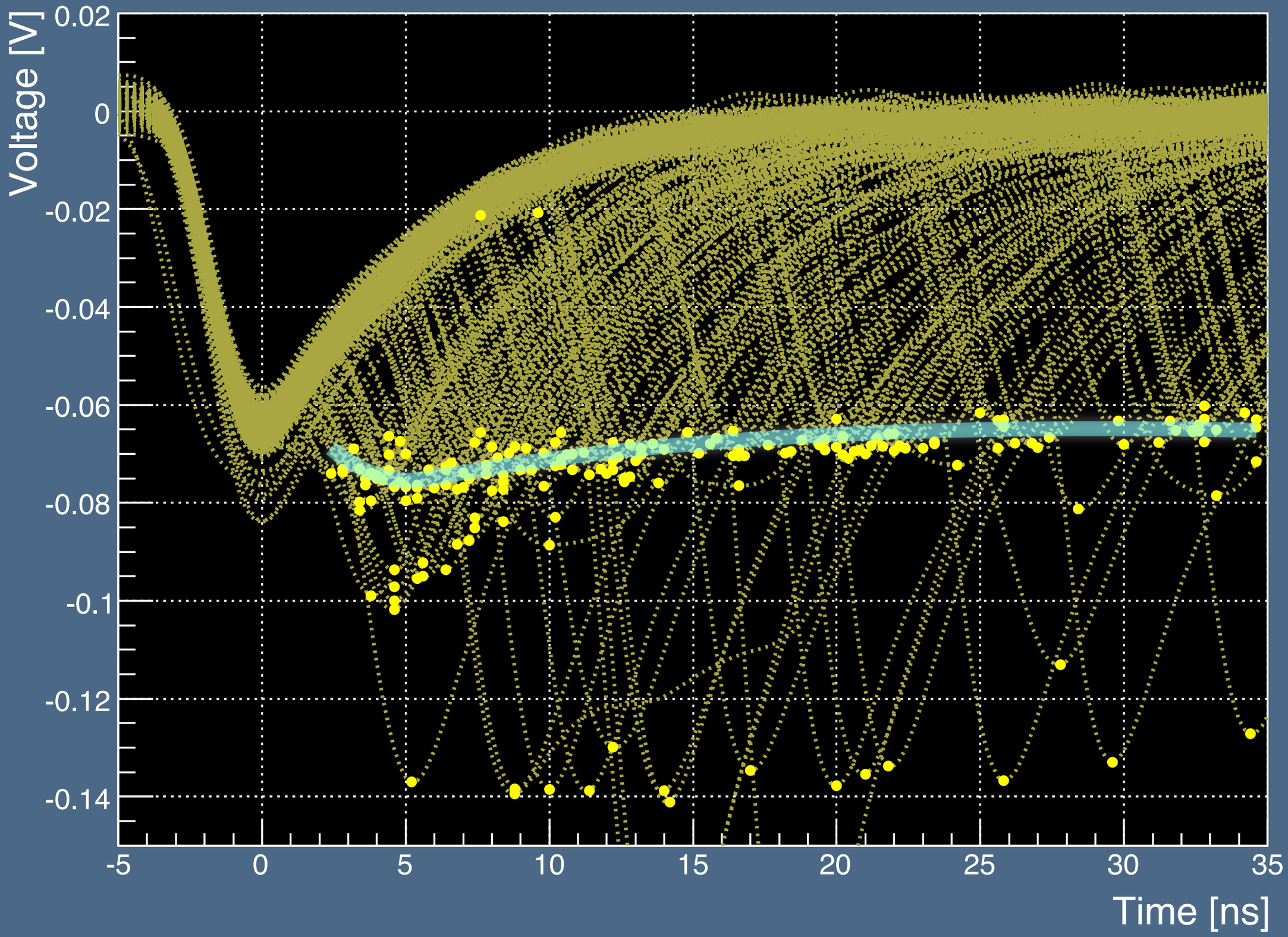

Voltage [V]
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-5
0
5
10
15
20
25
30
35
Time [ns]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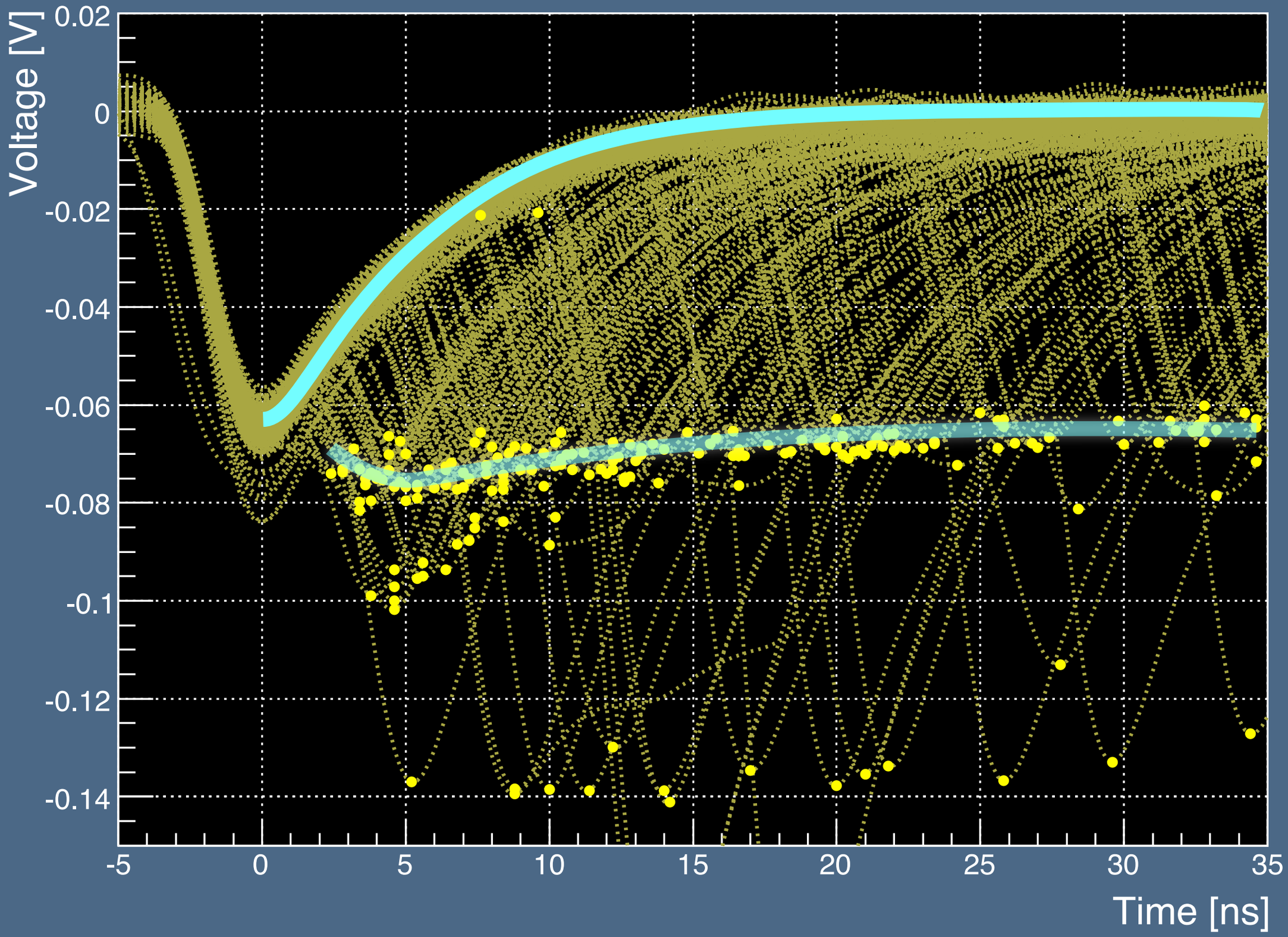
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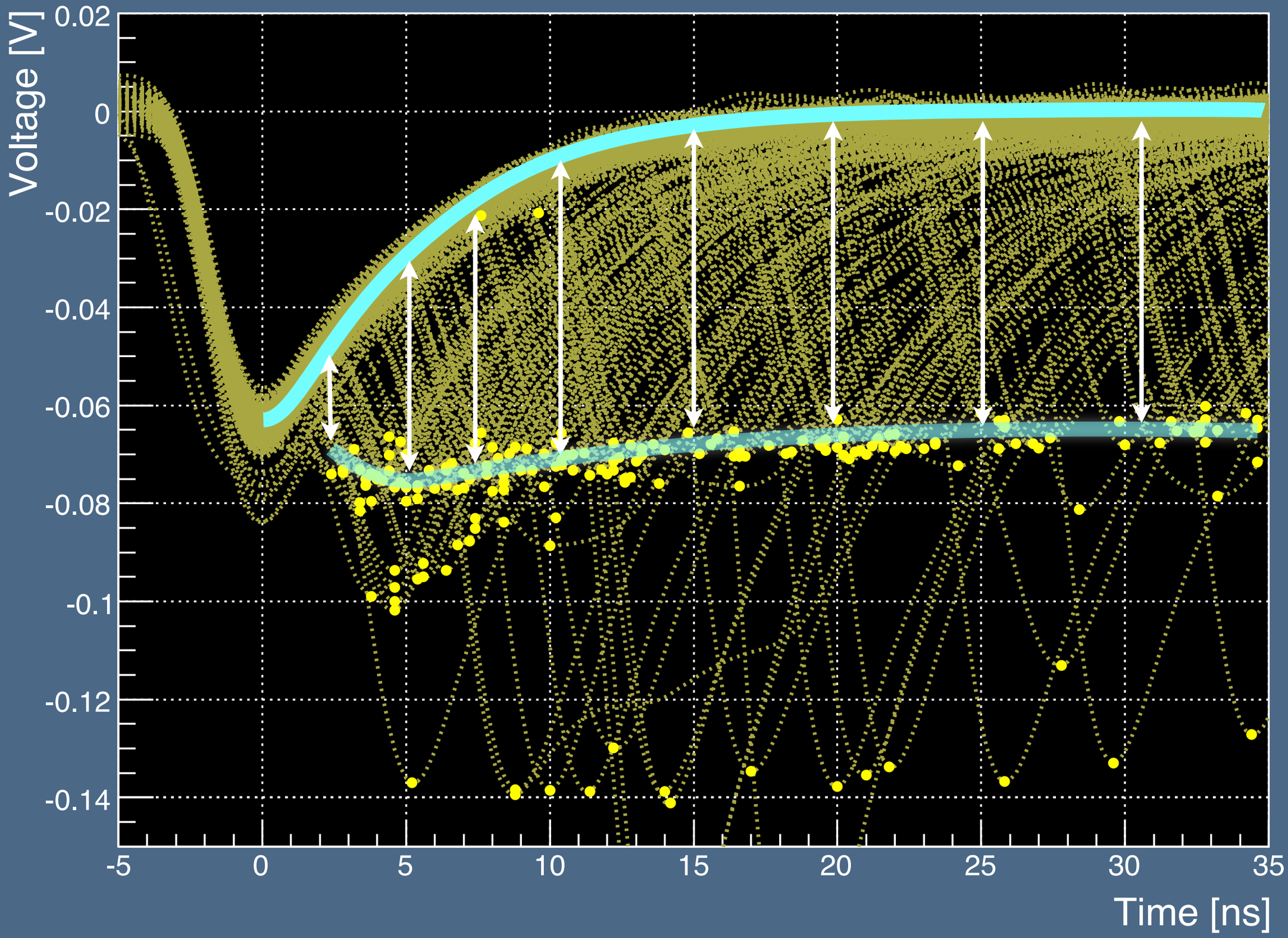
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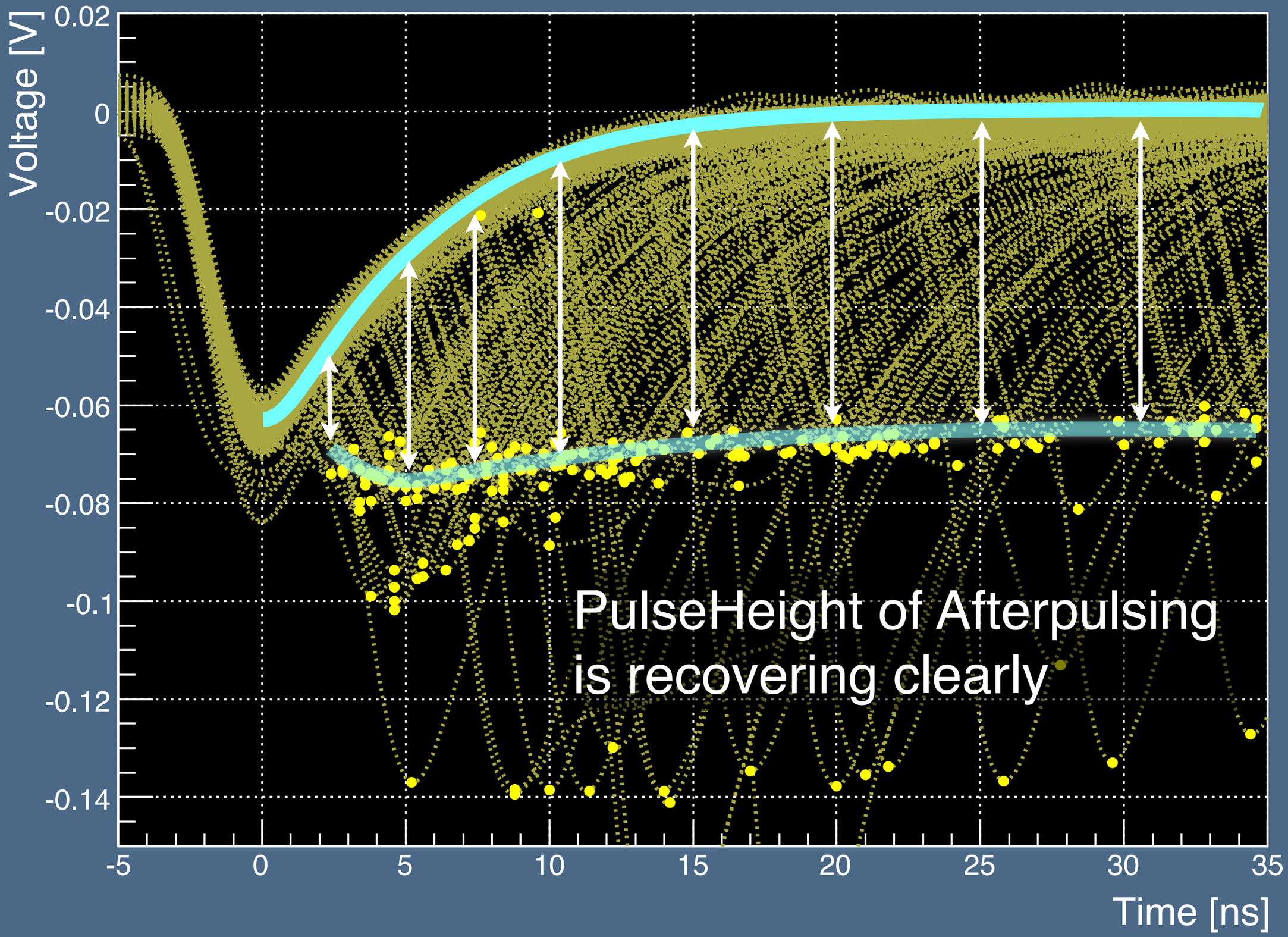
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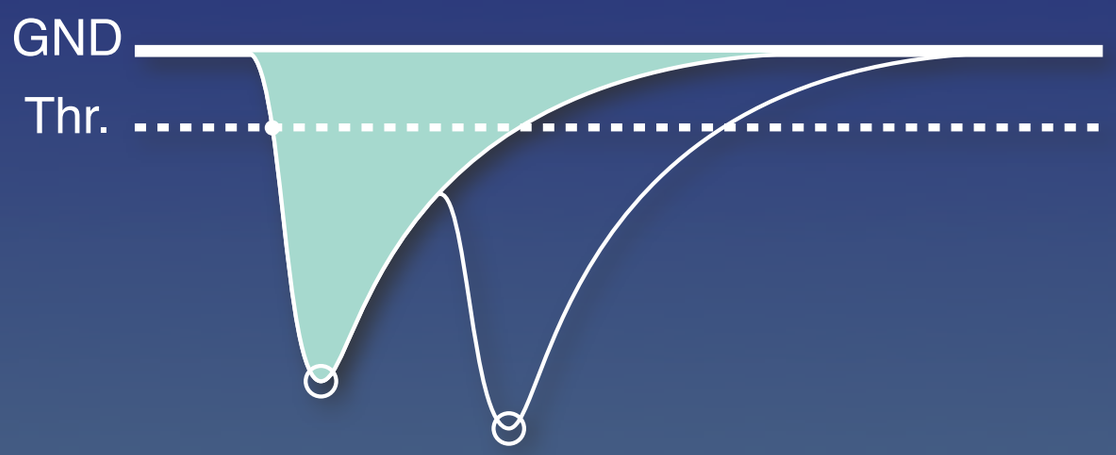
-0.12
-0.14
-5
0
5
10
15
20
25
30
35
Time [ns]
PulseHeight of Afterpulsing
is recovering clearly

The Afterfraction



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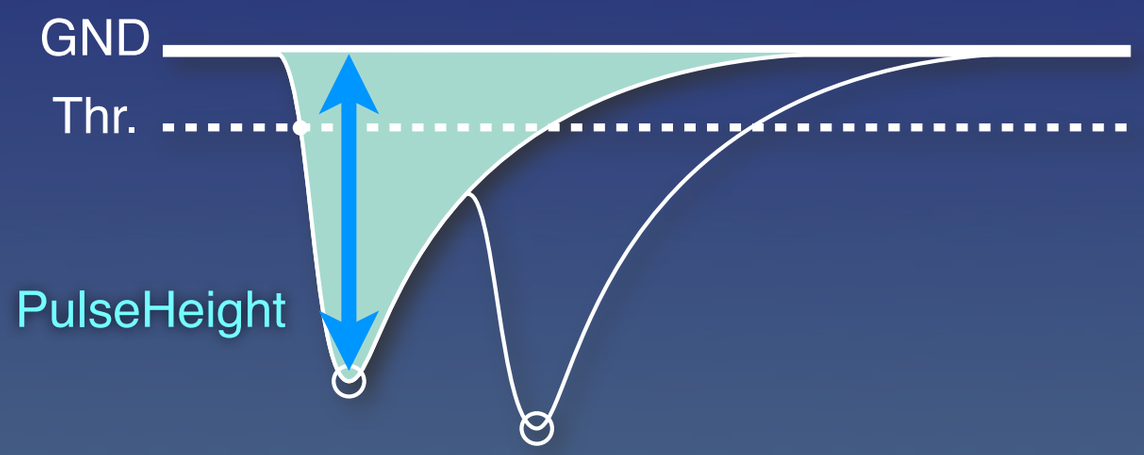

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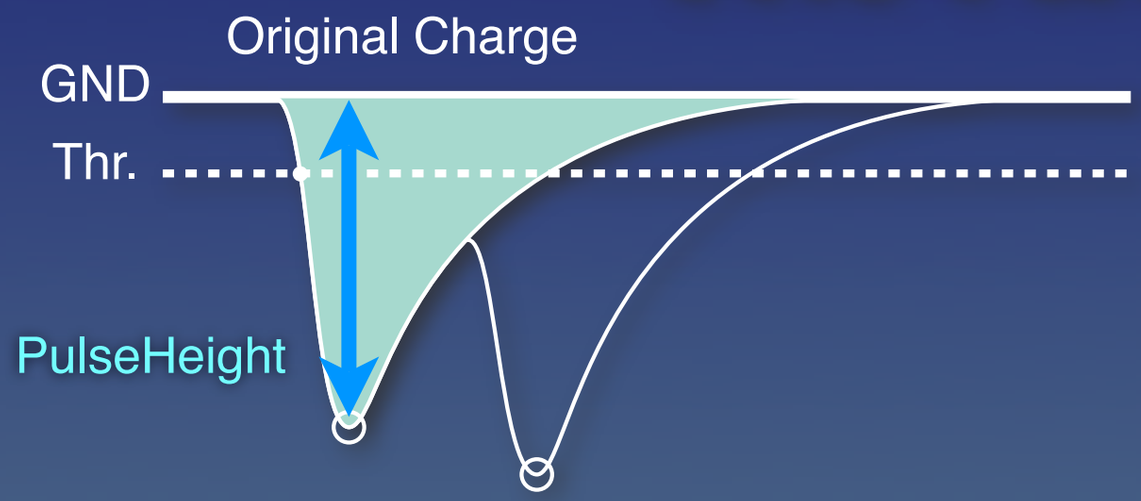

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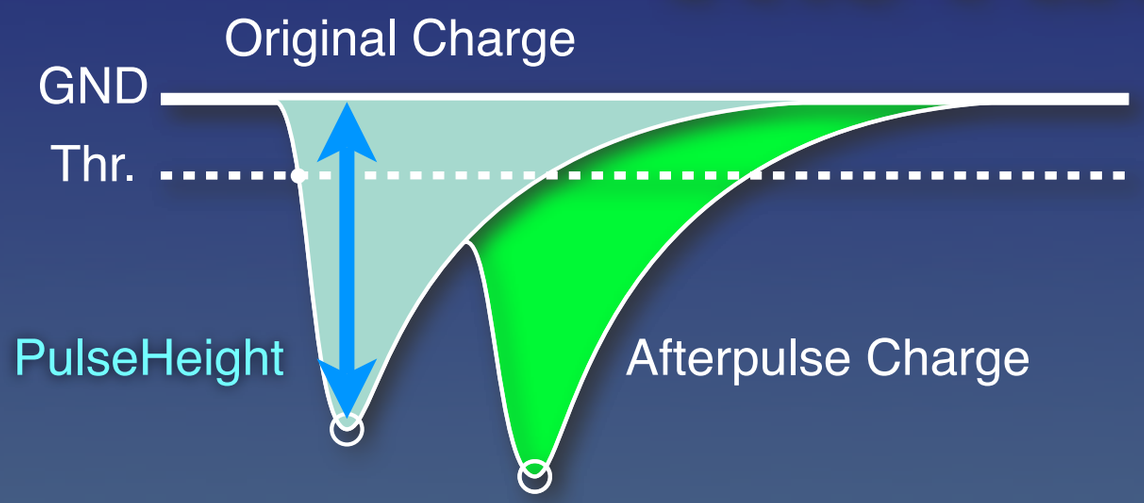

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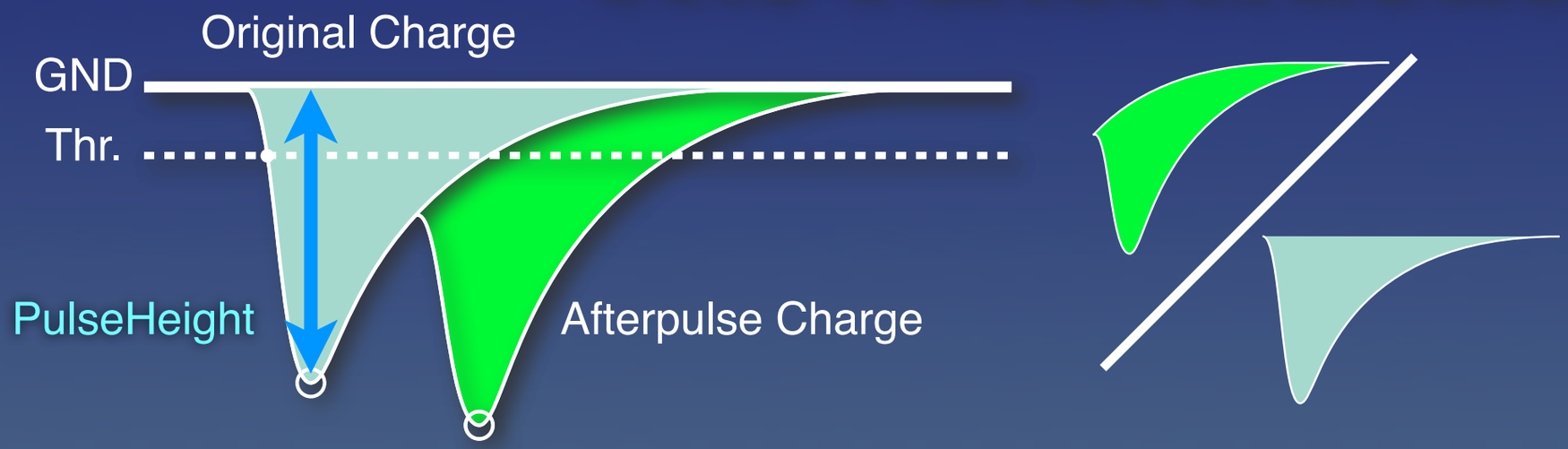

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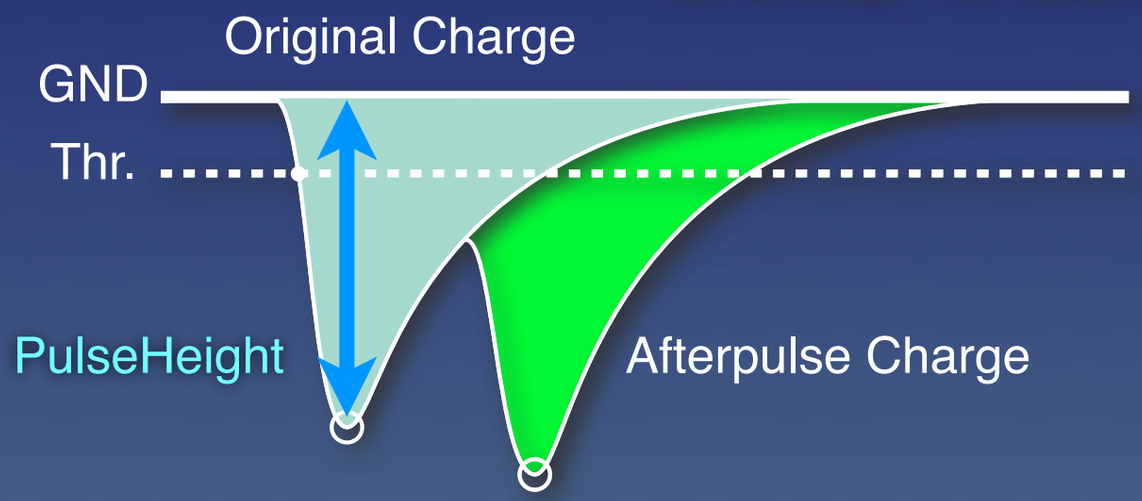

= Afterfraction

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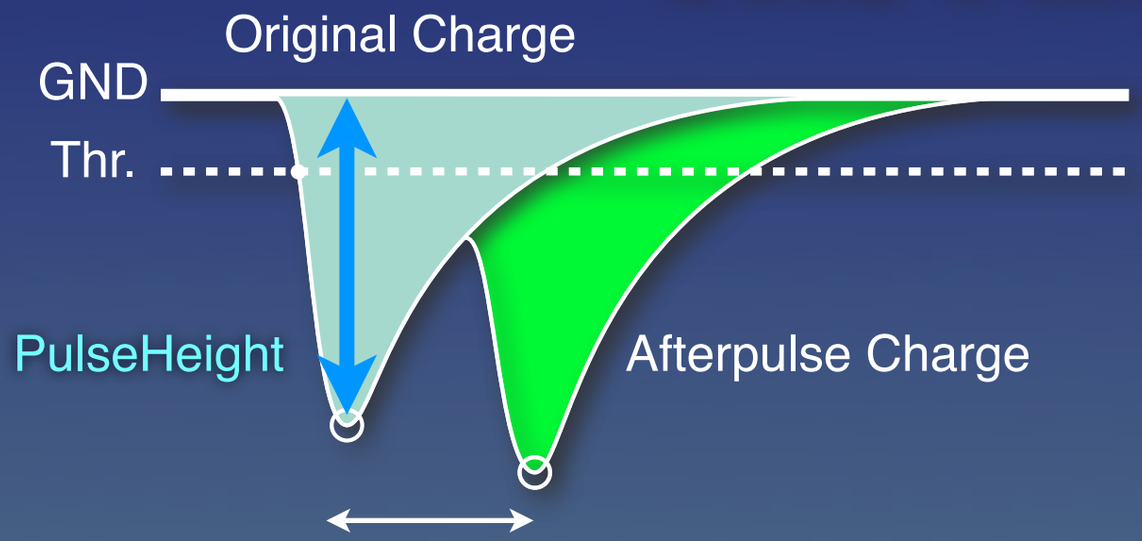

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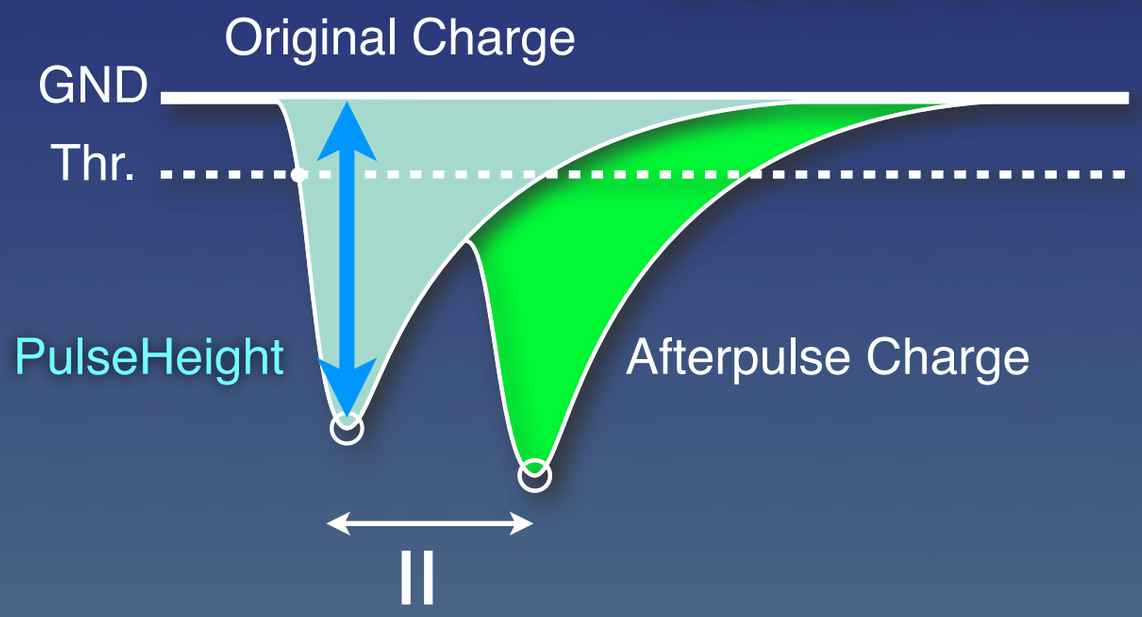

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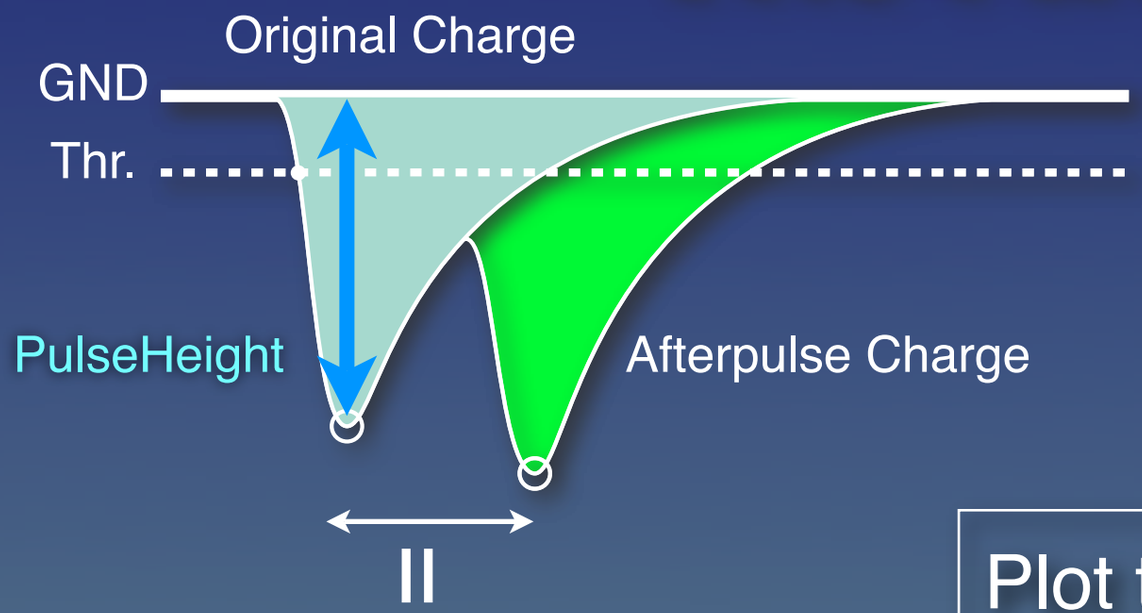

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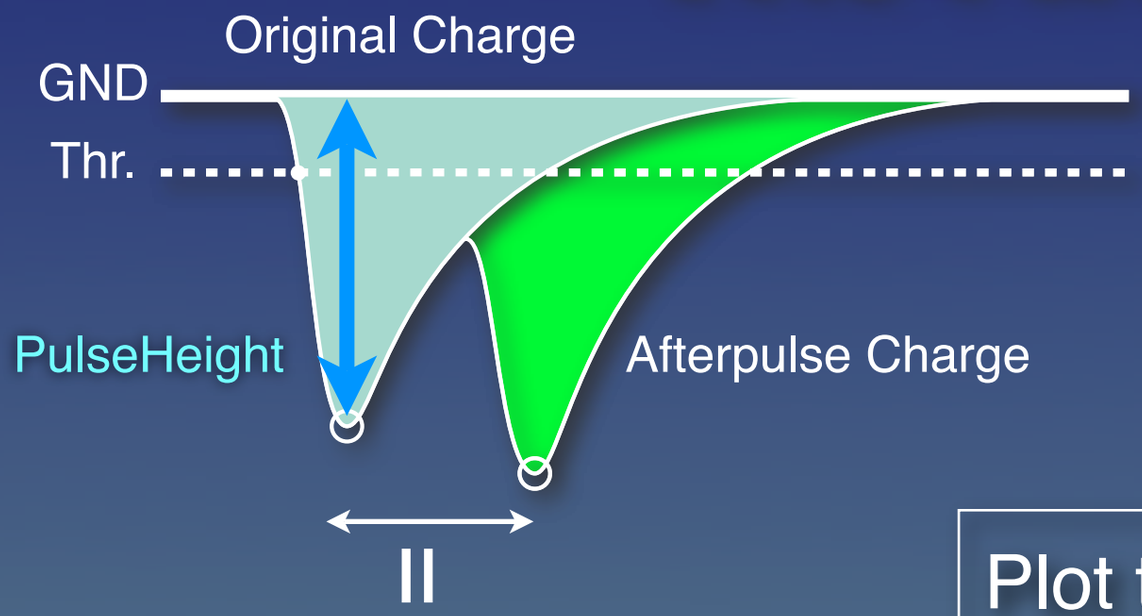
II

Interval Time

Plot the interval time vs. afterfraction for each event

The Afterfraction



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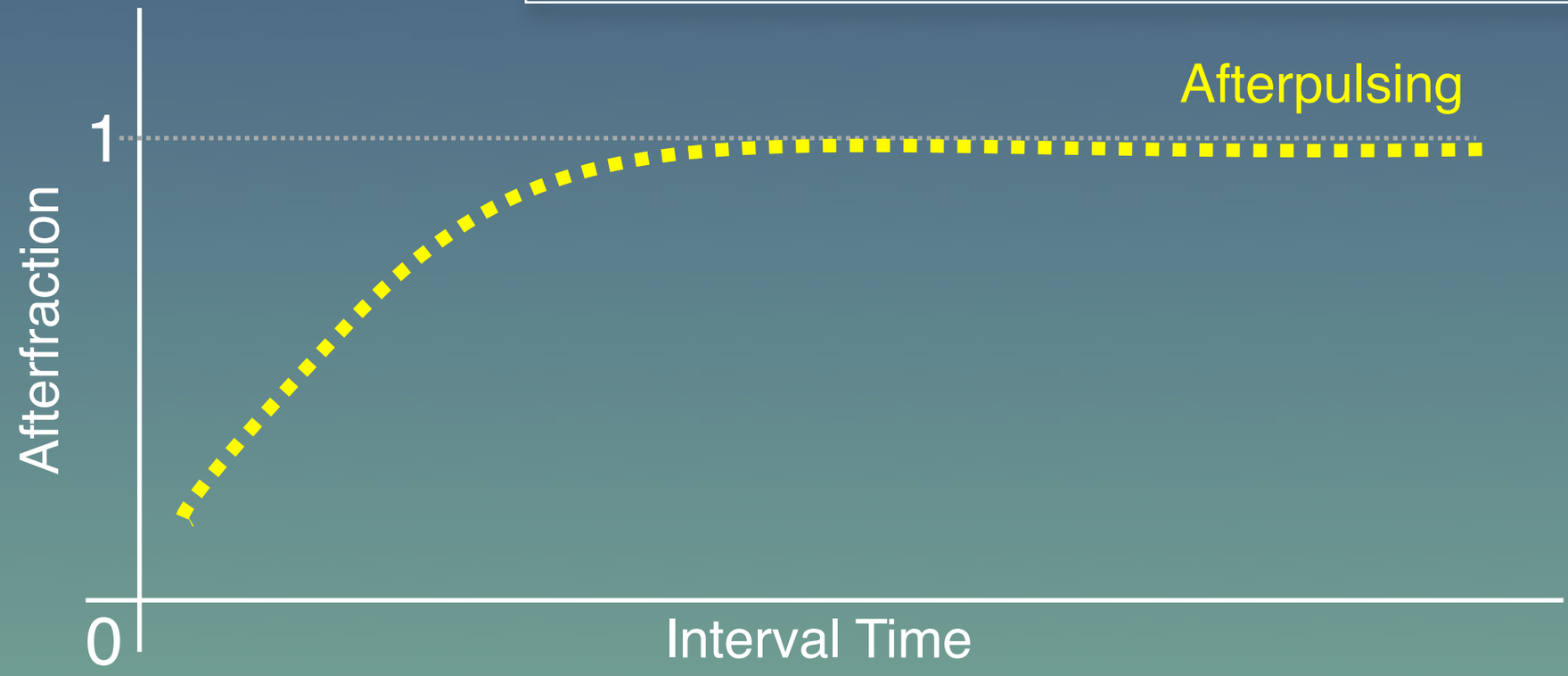

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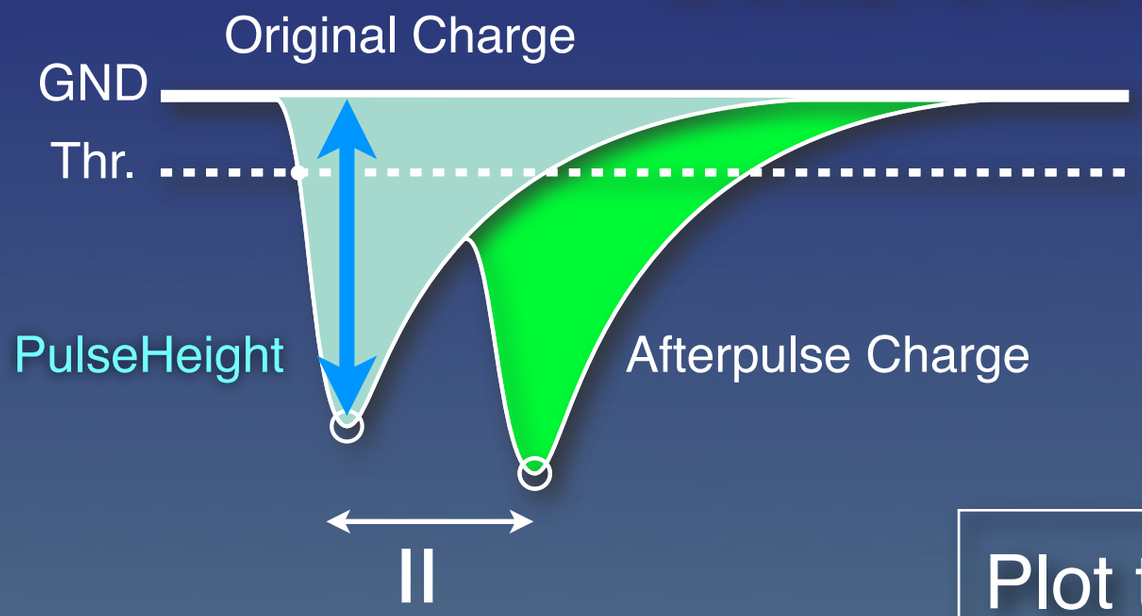

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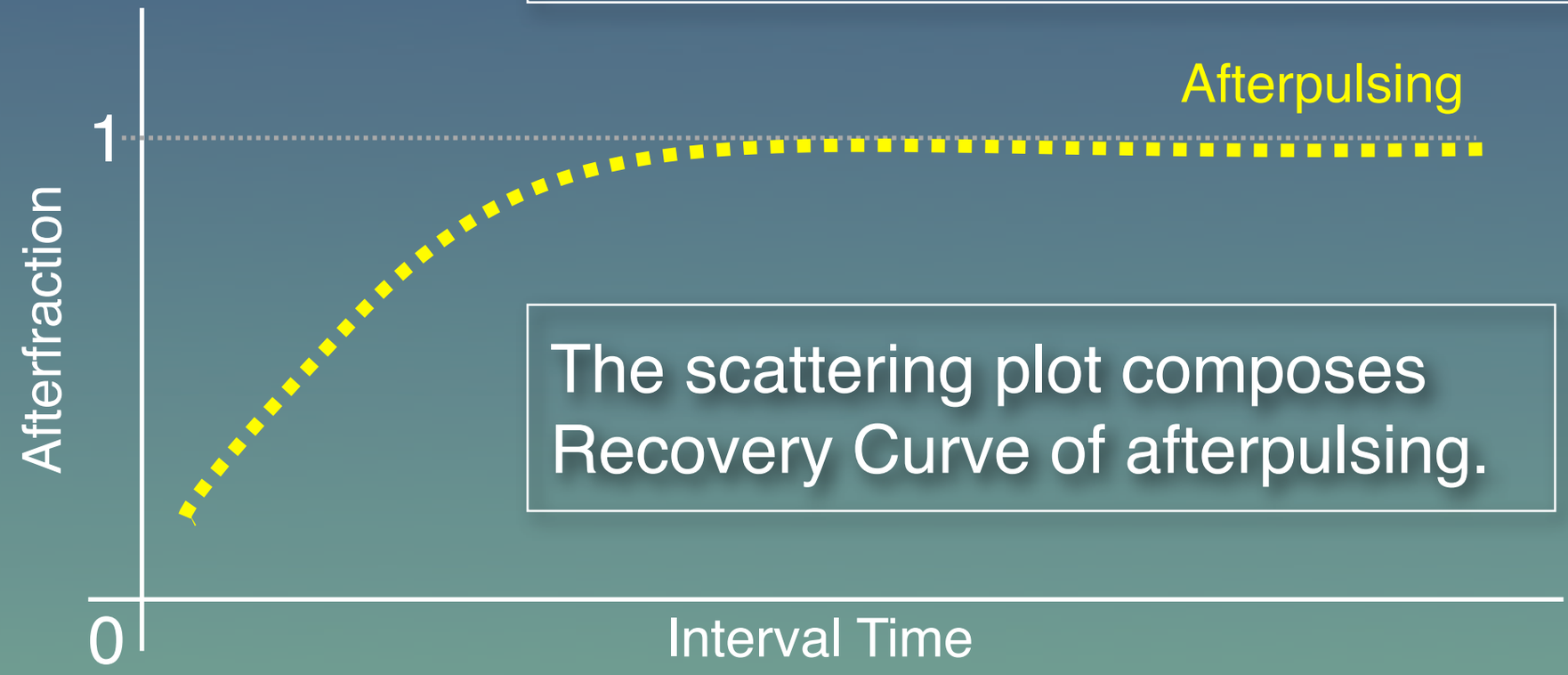

The scattering plot composes Recovery Curve of afterpulsing.

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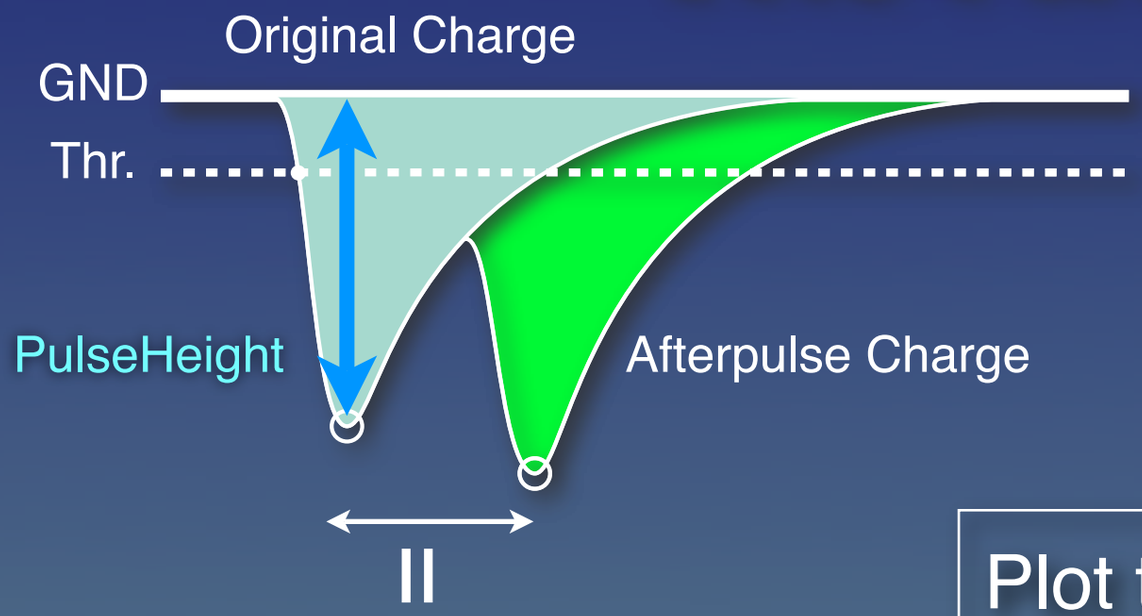

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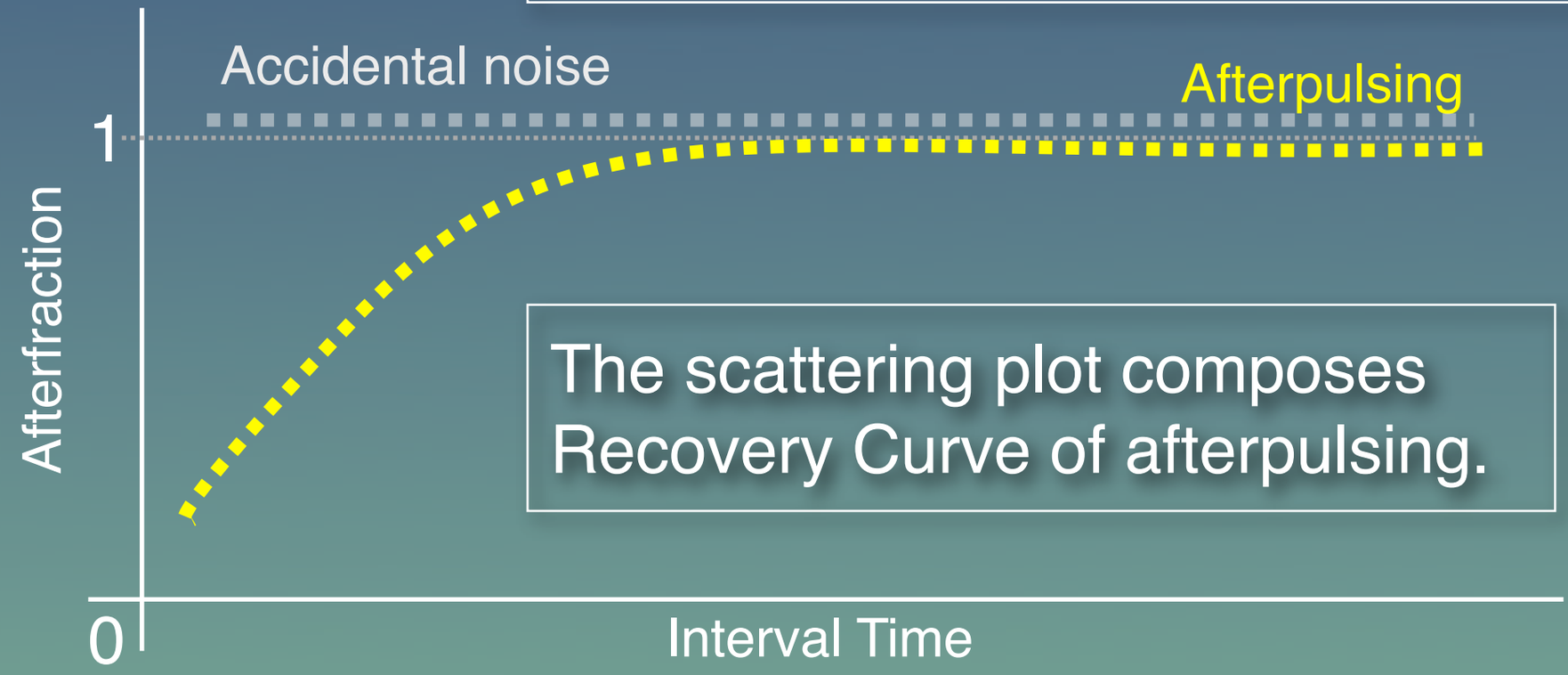

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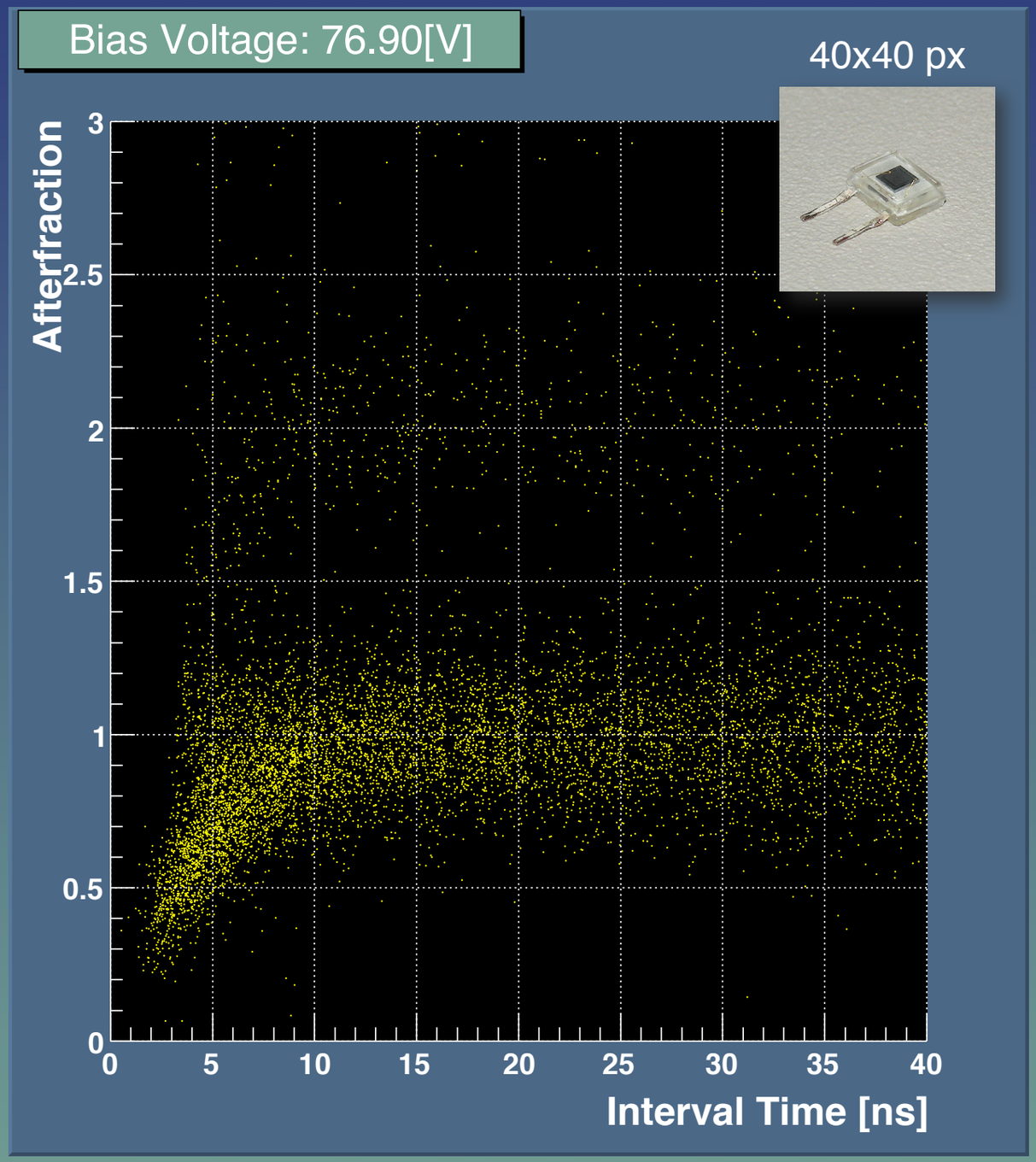
40x40 Pixels MPPC Recovery Curve



Measurement

- 50% recovery : ~ 3 [ns]
- 90% recovery : ~ 9 [ns]

Fitting

- 63% (=1-1/e) : ~ 4 [ns]
  (Fitted to $1 - \exp[-t/\tau]$)

Measurement Conditions
- Bias Voltage : 76.9 = V_0 + 3.3 [V]
- Temperature : ~ 300 [K]
- Sampling Rate : 200 [ps/Sample]
- Noise Reduction : ERES*, bit=2.0
- Charge Estimation Gate : -5 ~ 60 [ns]

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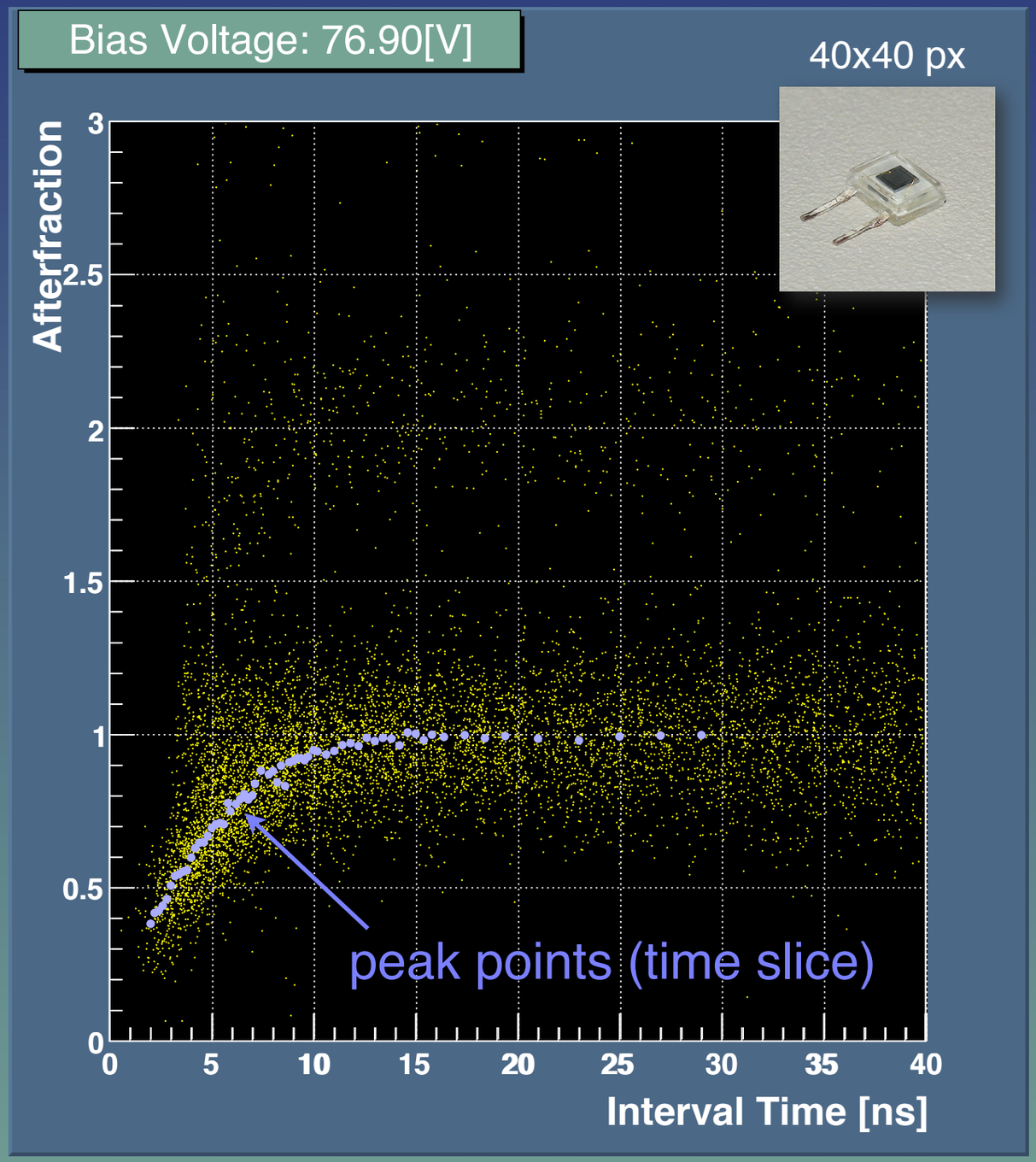

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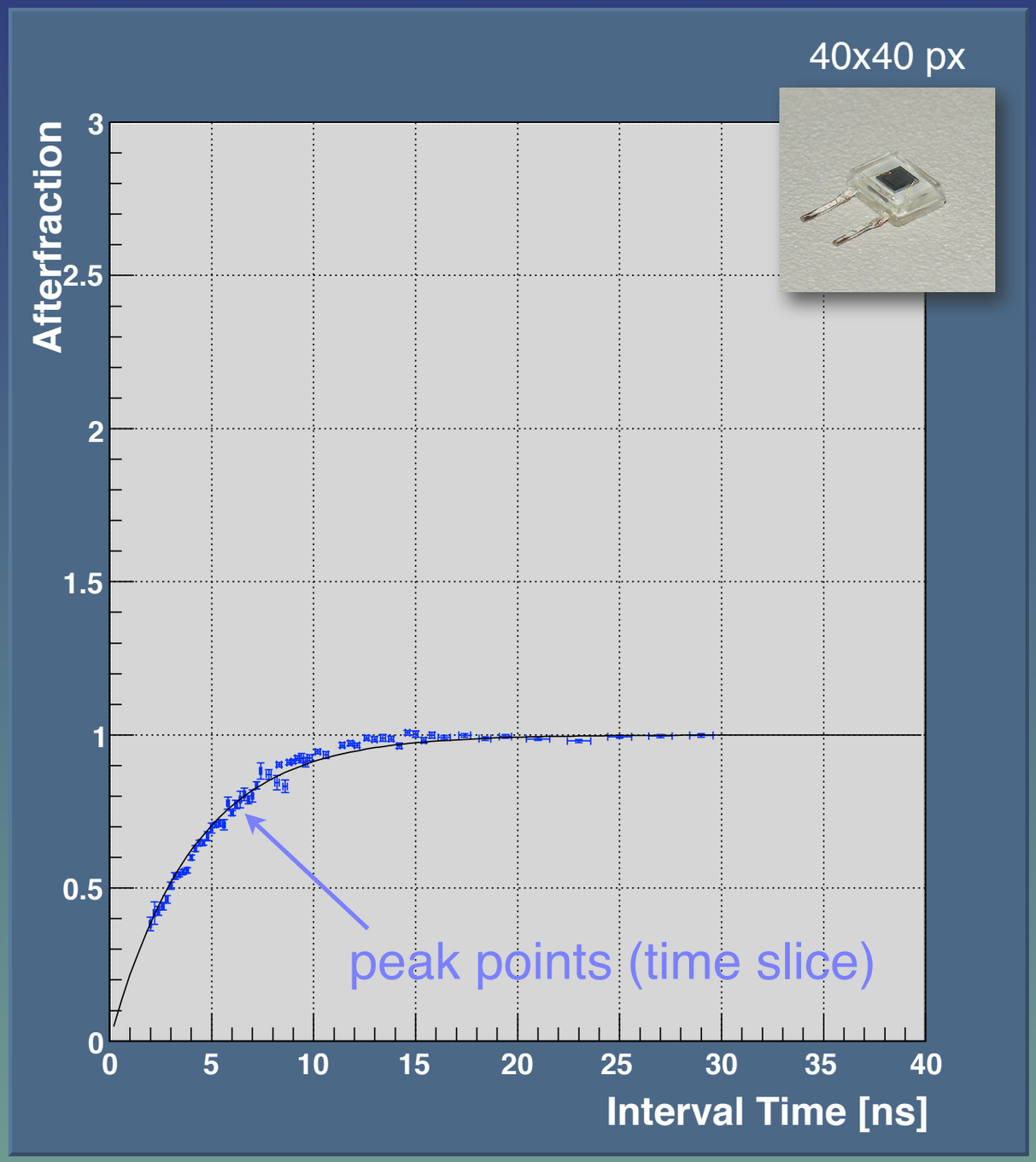

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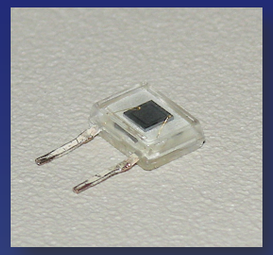
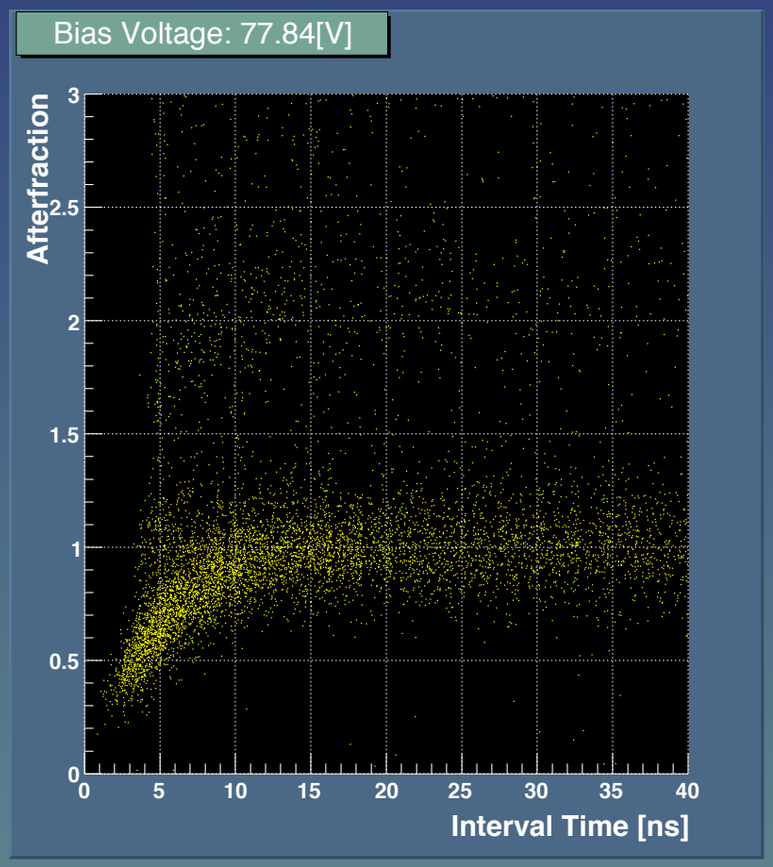


Bias Voltage Variation

V_0 + 4.2 [V]



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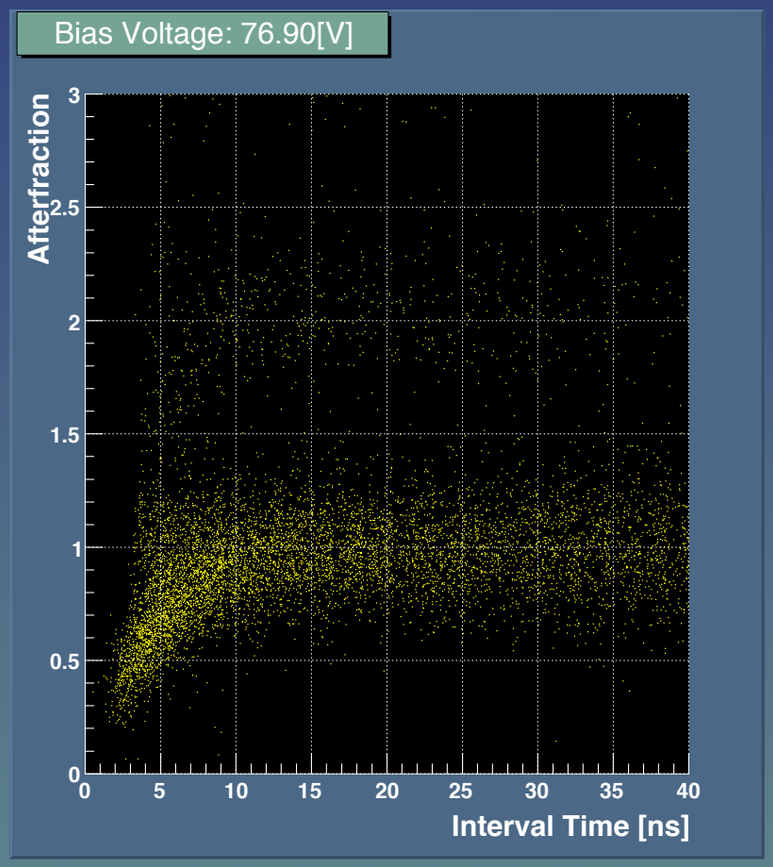
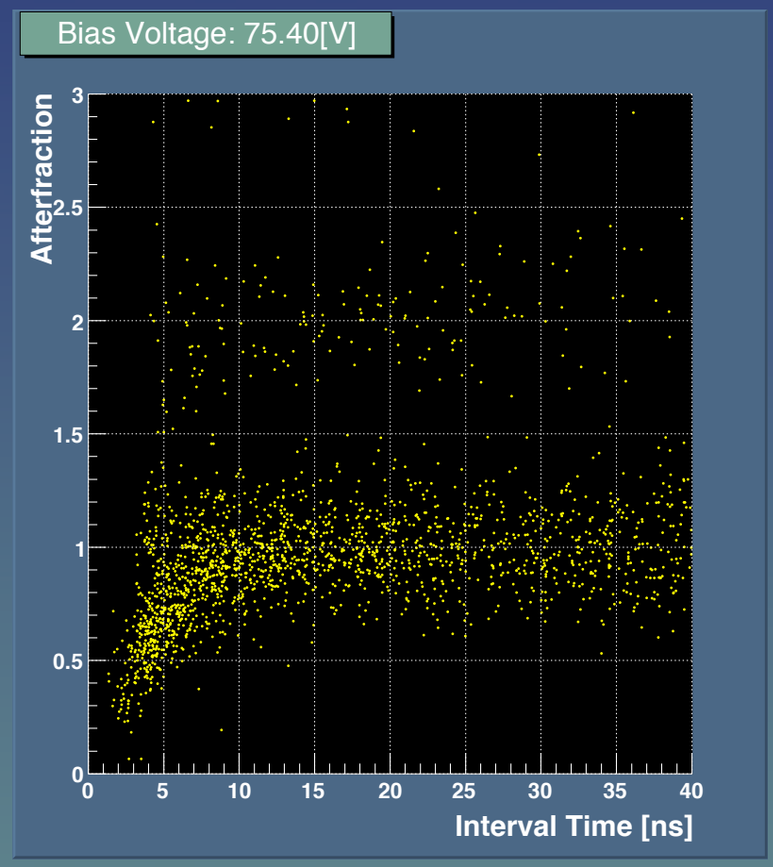


V_0 + 2.8 [V]



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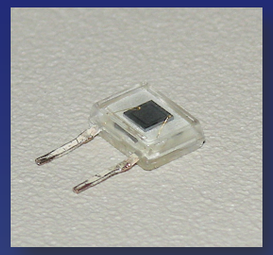

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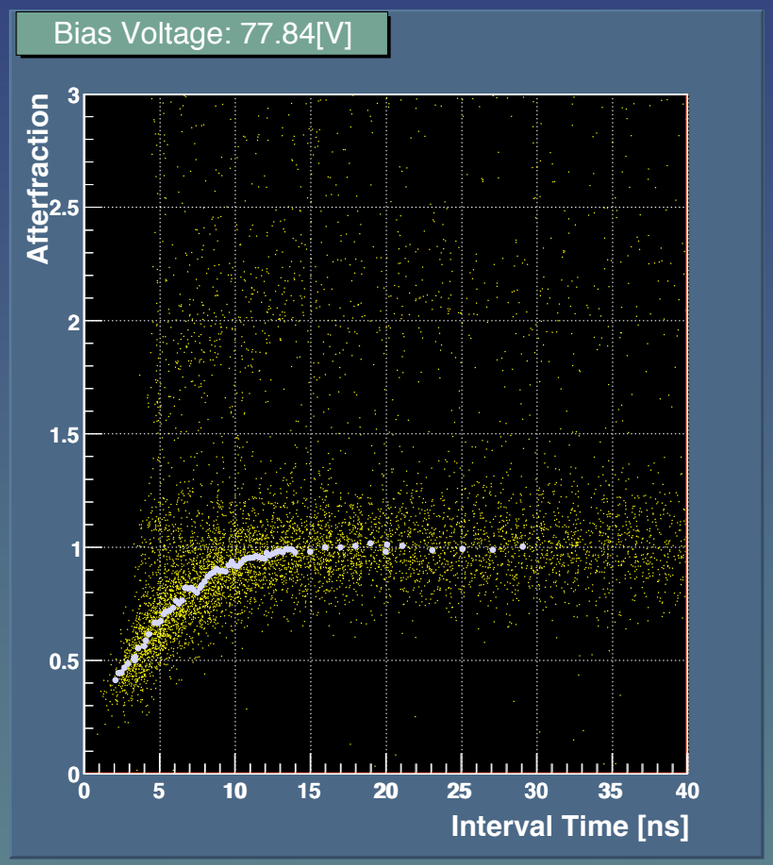

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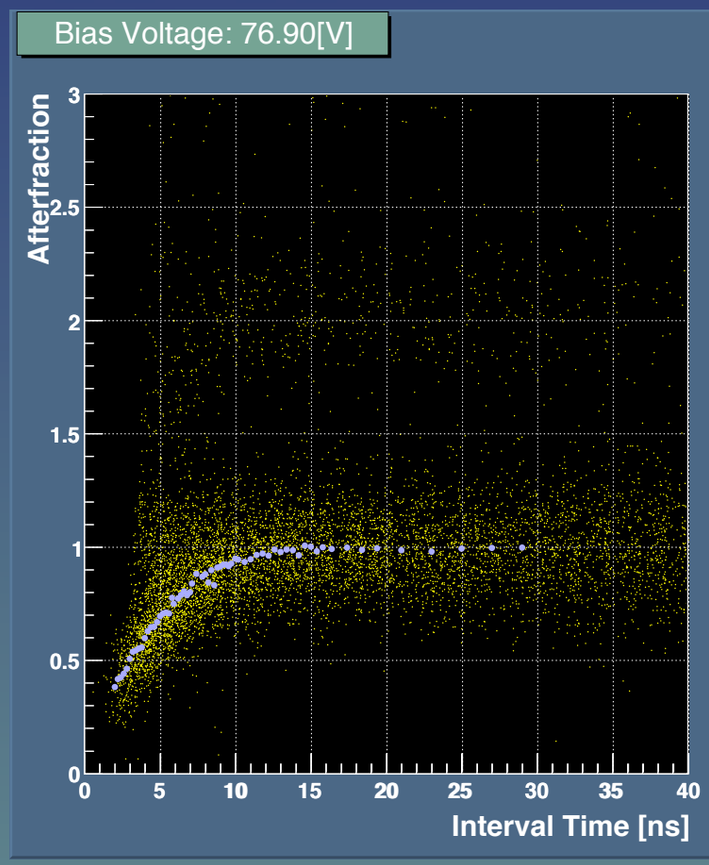

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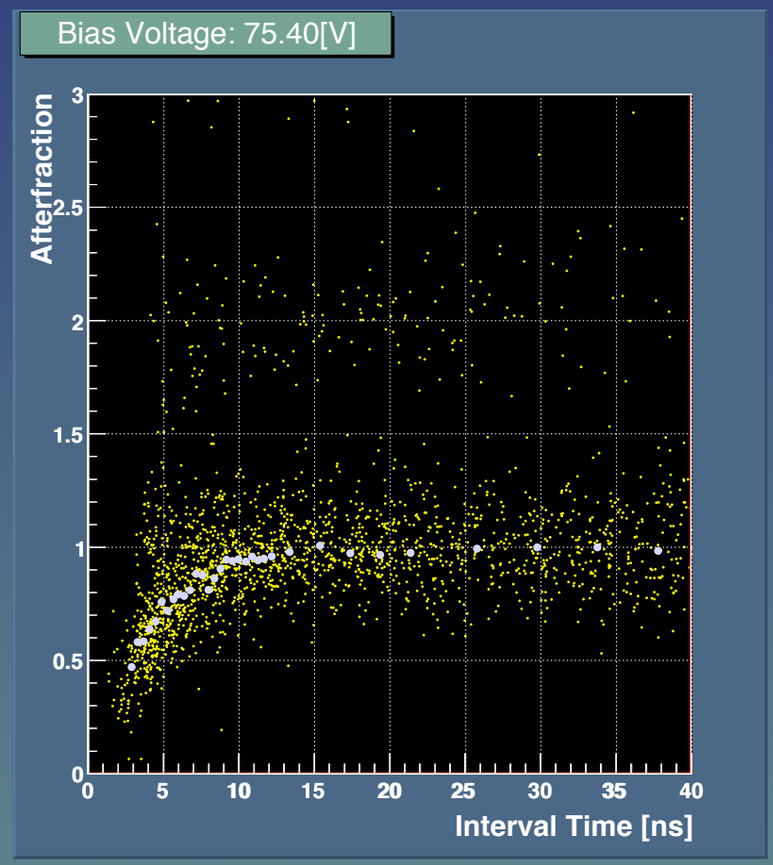

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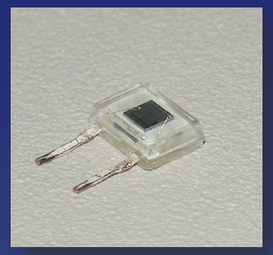

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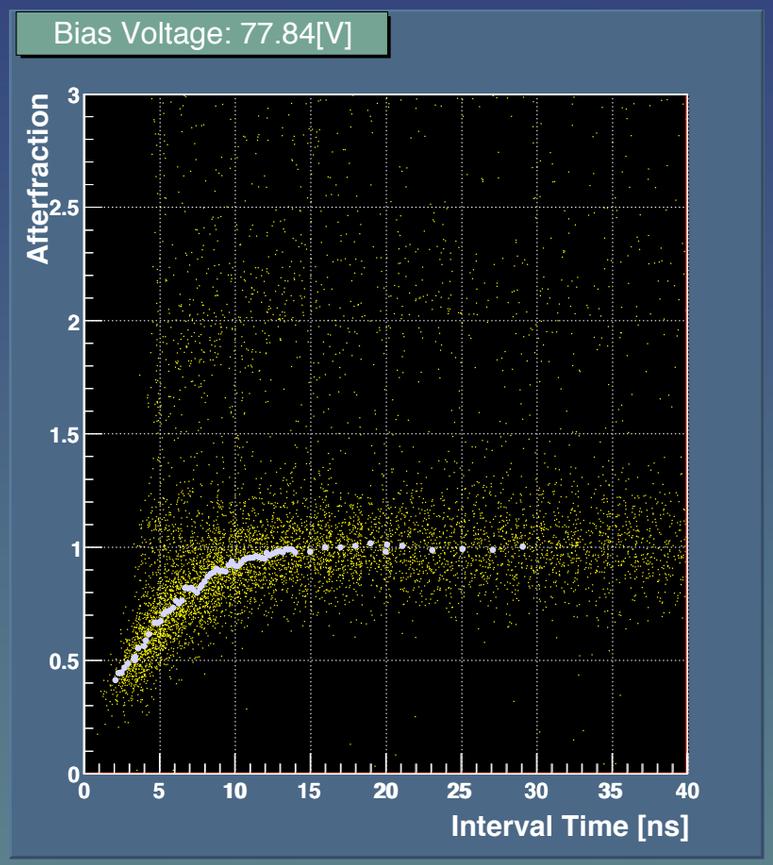

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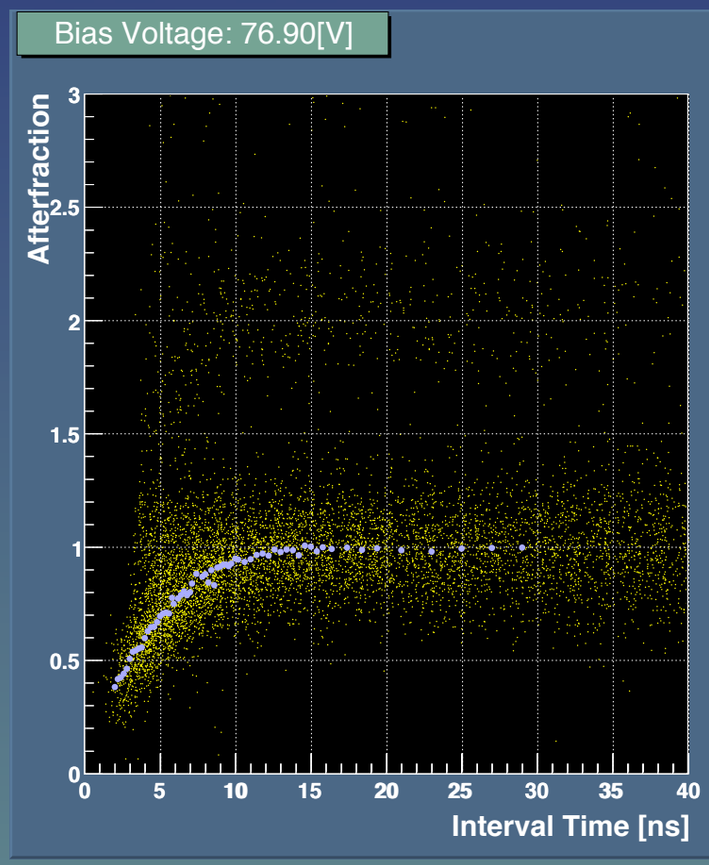

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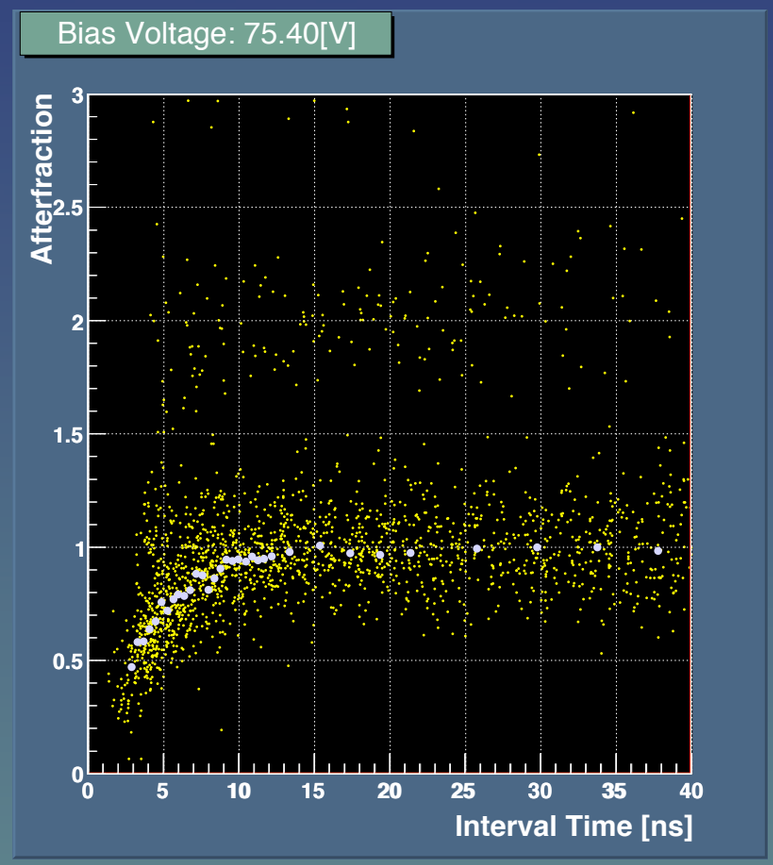
63% (=1-1/e) : ~ 4 [ns]

V_0 + 2.8 [V]

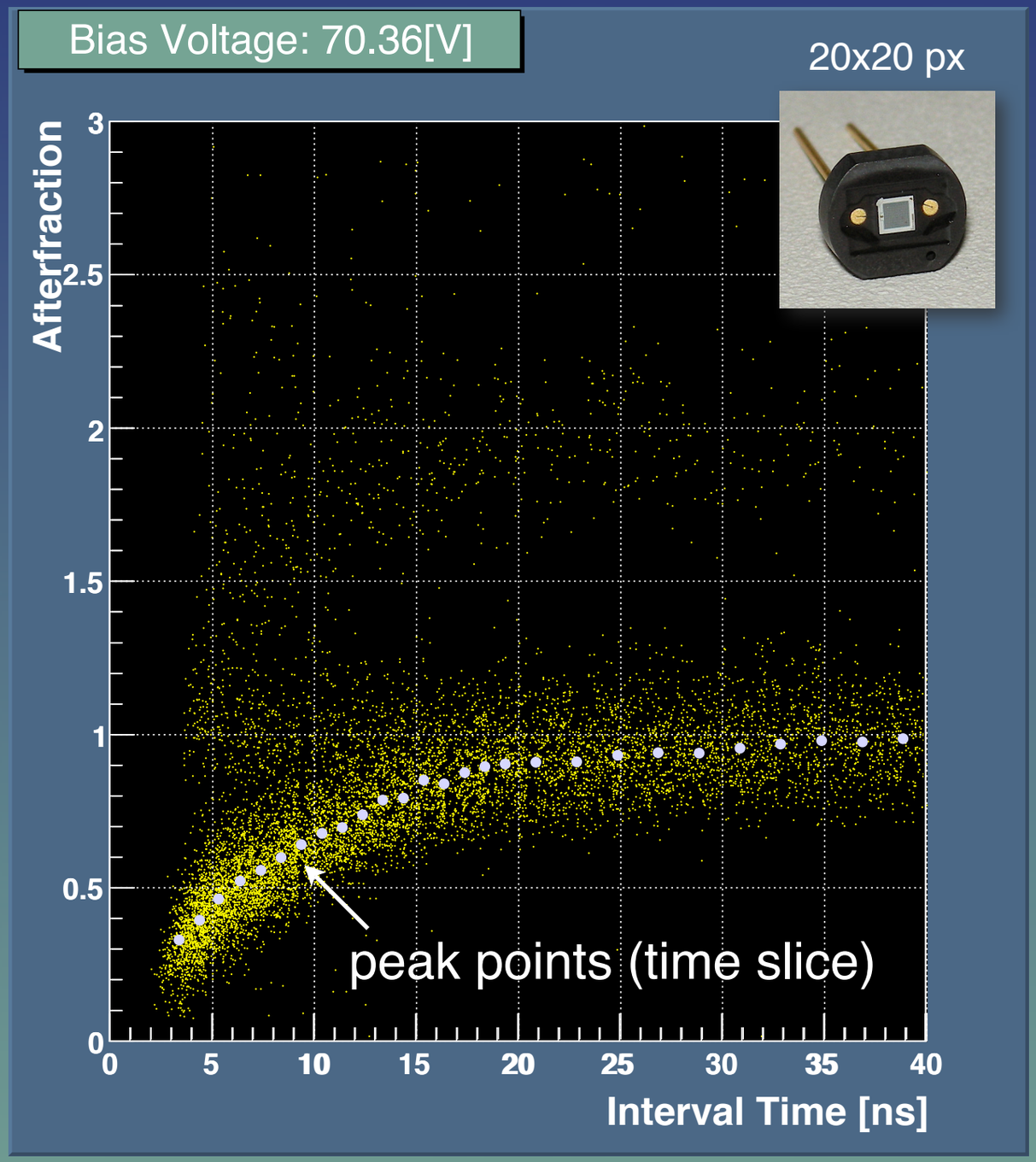


50% recovery : ~ 3 [ns]
90% recovery : ~ 9 [ns]

63% (=1-1/e) : ~ 4 [ns]

Recovery Curve does not vary significantly by bias voltage.

20x20 Pixels MPPC Recovery Curve



Measurement

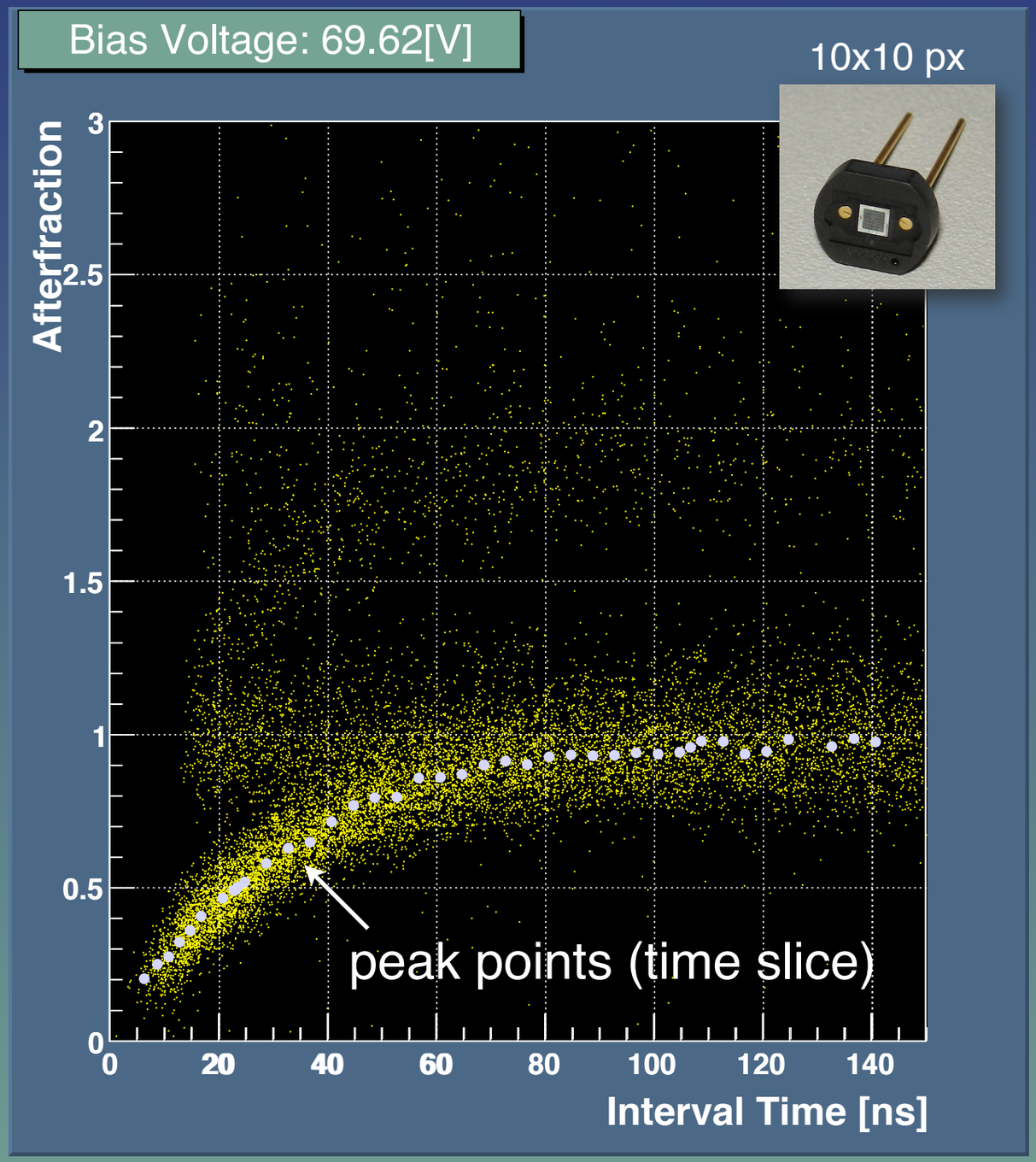
- 50% recovery : ~ 6 [ns]
- 90% recovery : ~ 19 [ns]

Fitting

- 63% (=1-1/e) : ~ 9 [ns]
  (Fitted to $1 - \exp[-t/\tau]$)

Measurement Conditions
- Bias Voltage : 70.36 = V_0 + 2.7 [V]
- Temperature : ~ 300 [K]
- Sampling Rate : 200 [ps/Sample]
- Noise Reduction : ERES*, bit=2.0
- Charge Estimation Gate : -5 ~ 60 [ns]

10x10 Pixels MPPC Recovery Curve



Measurement

- 50% recovery : ~ 24 [ns]
- 90% recovery : ~ 77 [ns]

Fitting

- 63% (=1-1/e) : ~ 33 [ns]
  (Fitted to $1 - \exp[-t/\tau]$)

Measurement Conditions
- Bias Voltage : 69.62= V_0 + 0.87 [V]
- Temperature : ~ 300 [K]
- Sampling Rate : 400 [ps/Sample]
- Noise Reduction : ERES*, bit=2.5
- Charge Estimation Gate : -15 ~ 150 [ns]

Relationship between Recovery and Time Const.

	40x40 px	20x20 px	10x10 px
Afterpulsing 1-1/e Recovery	~ 4 [ns]	~ 9 [ns]	~ 33 [ns]
Pulse Shape returning time (RC Time Const.)	~ 5 [ns]	~ 11 [ns]	~ 35 [ns]

Afterpulsing recovery time are consistent with pulse shape returning time.

Summary

- Dark noise @ 300 [K]
- Afterpulsing Extraction
- Offline Waveform analysis

➡ Recovery Curve is obtained.

Voltage Dependence

40x40 px	76.40 [V]	76.90 [V]	77.84 [V]
50%	3 [ns]	3 [ns]	3 [ns]
63% (1-1/e)	4 [ns]	4 [ns]	4 [ns]
90%	9 [ns]	9 [ns]	9 [ns]

- Recovery Curve does not change significantly by bias voltage.

MPPC Type Variation

	40x40 px 76.90 [V]	20x20 px 70.36 [V]	10x10 px 69.62 [V]
50%	3 [ns]	6 [ns]	24 [ns]
63% (1-1/e)	4 [ns]	9 [ns]	33 [ns]
90%	9 [ns]	19 [ns]	77 [ns]

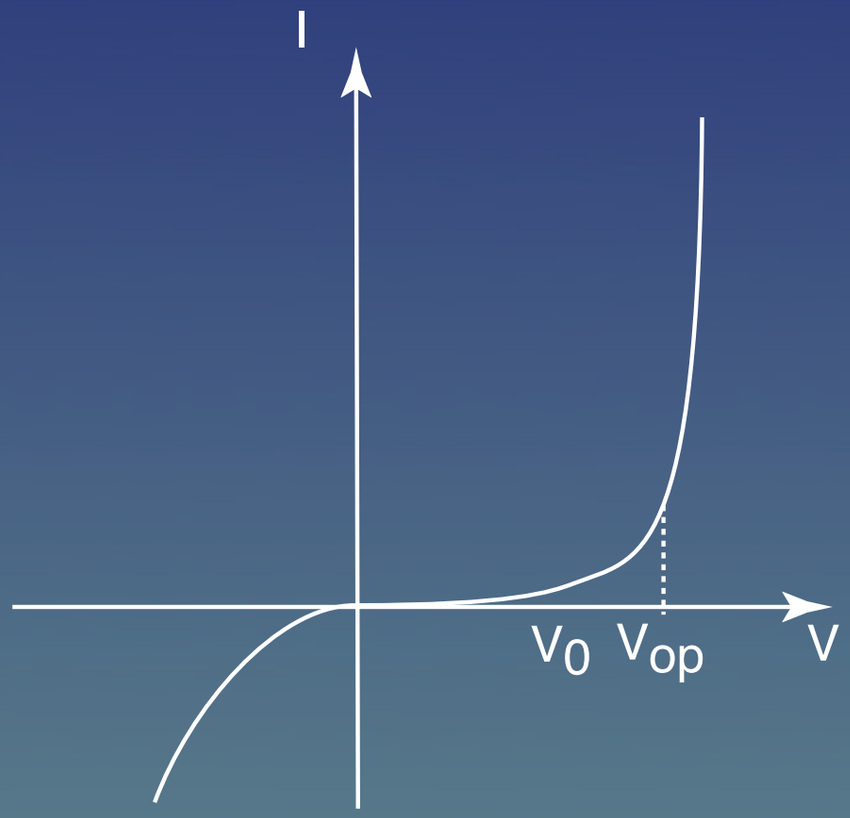
- Afterpulsing recovery time are consistent with pulse shape returning time.

Prospects

- More sharp and precise recovery curve will be obtained by improving waveform analysis method.
- We are now planning to study recovery using two laser pulses shooting the same pixel of MPPC in a row, with short-time interval down to 1 [ns] or shorter.

Backup

The Recovery



- MPPC is a PIN-junction semiconductor device, and is operated at Geiger-mode.
- After avalanche occurrence, bias voltage goes down to the Breakdown Voltage V_0 . There must be time for recovery to the Operating Voltage V_{op} .
- During recovering, bias voltage is less than V_{op}. The amplitude of pulses are smaller than that under V_{op}.

The Oscilloscope

- LeCroy WavePro 7300A
- Digital Oscilloscope
- OS: Windows XP
- Bandwidth: 3 [GHz] @ 50 [Ω]
- Maximum Sampling Rate: 20 [ps/Sample]
- Vertical Resolution : 8bit

©LeCroy

Noise Reduction

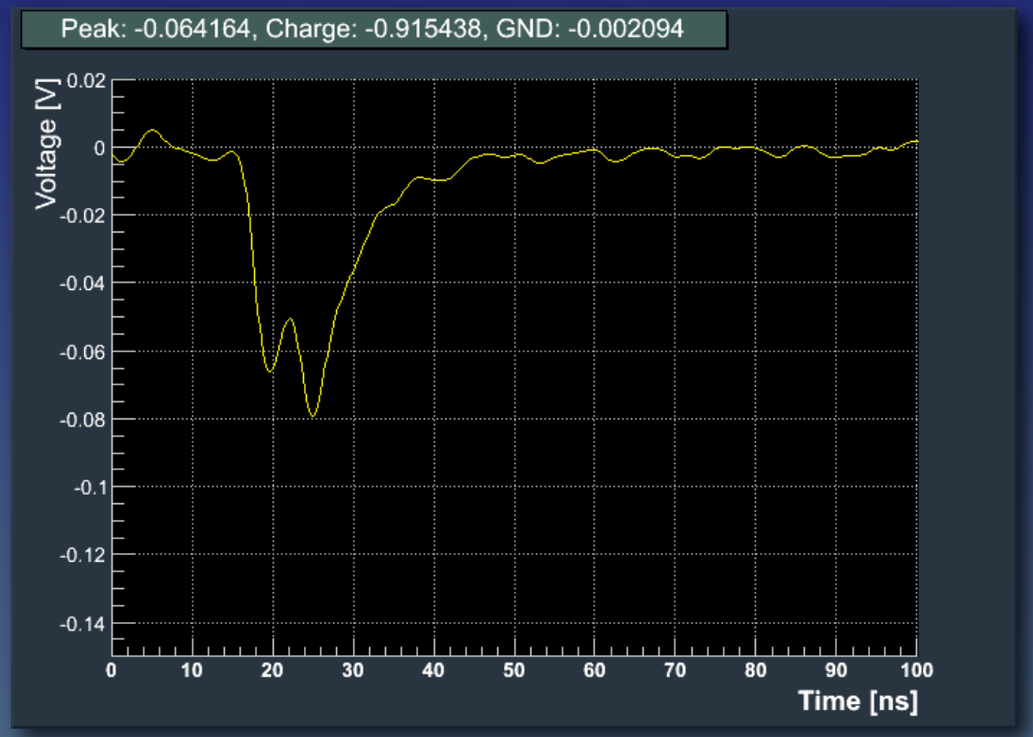
- We used LeCroy ERES (Enhanced RESolution) filtering.
- It is similar to smoothing with moving-average filter, but is more efficient concerning bandwidth and pass-band filtering.
- We used the mode 2.0.
- Sampling Rate: 200 [ps/Sample] for 200 [ns] (1k pts/file)

Resolution increased by	-3 [dB] Bandwidth (x Nyquist)	Filter Length (Samples)
0.5	0.5	2
1.0	0.241	5
1.5	0.121	10
2.0	0.058	24
2.5	0.029	51
3.0	0.016	117

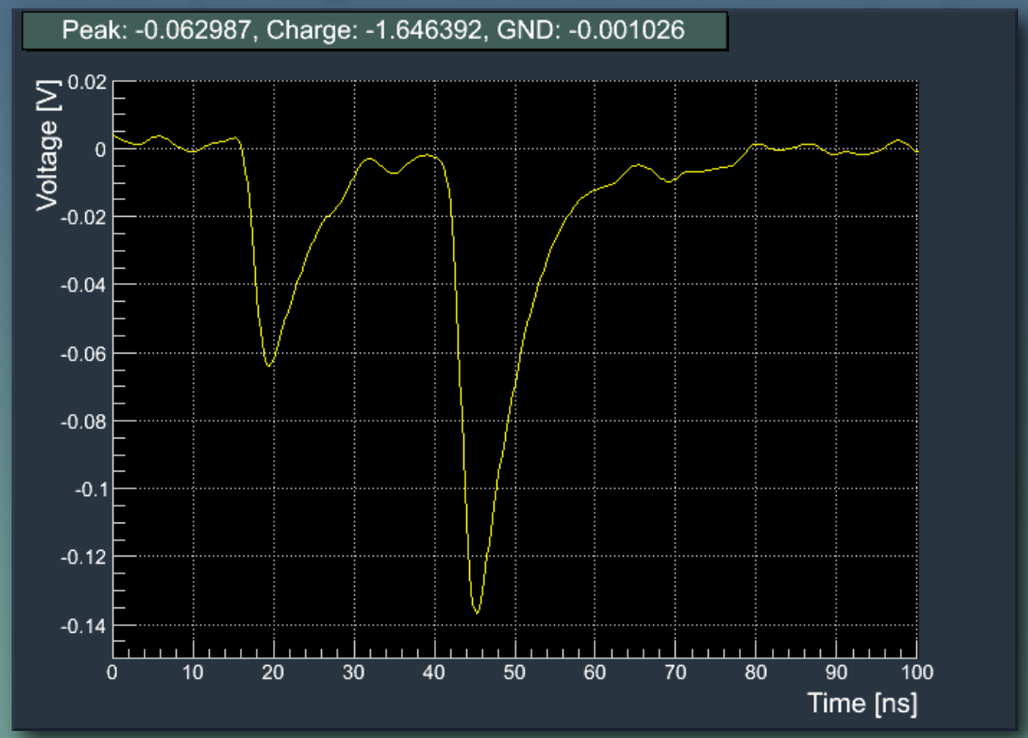
Noise Reduction

Waveform Example

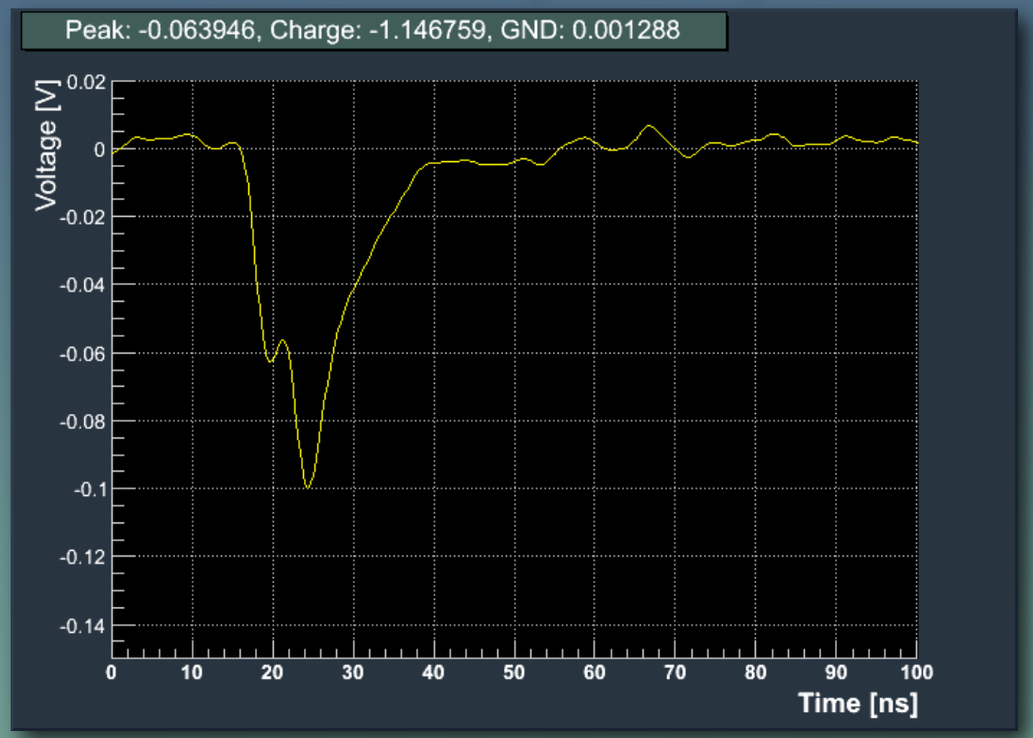
Afterpulsing : O+A



Afterpulsing caused Crosstalk : N+(AC)

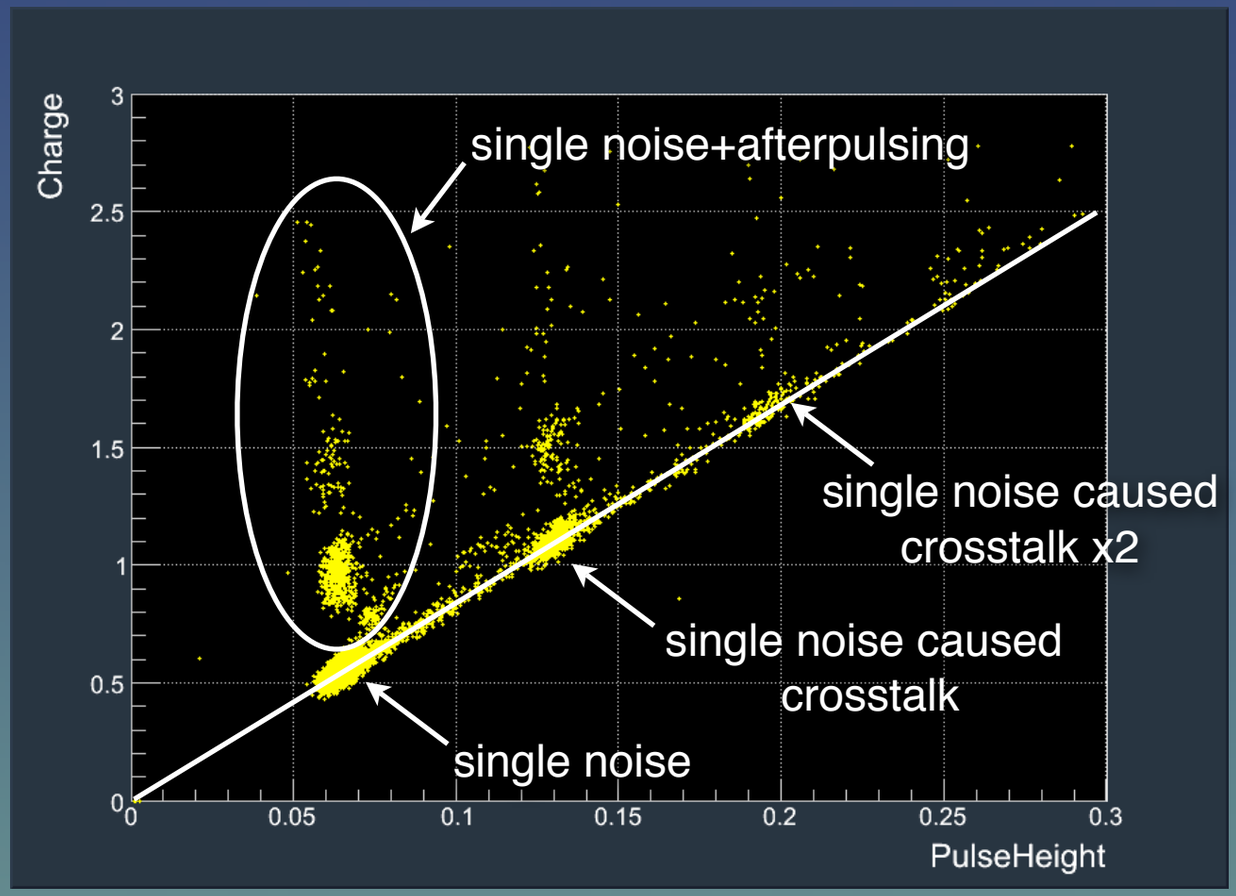


Accidental Noise (inference) : O+N



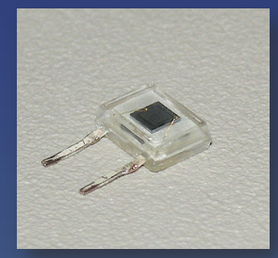
The Proportionality of Pulseheight and Charge

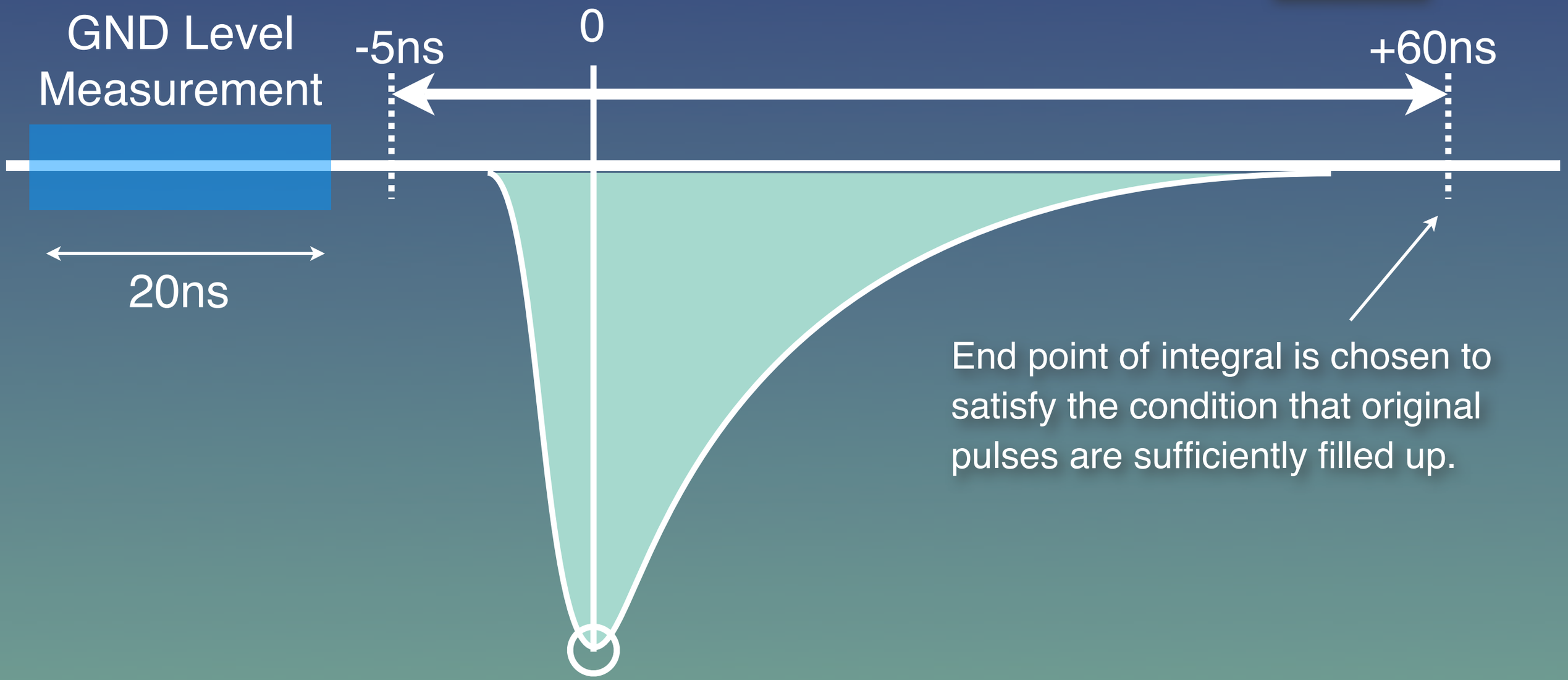
- We used the proportionality of pulseheight and charge for estimating the charge of Original pulsing.
- ERES mode filter distorts the waveform, but it does not change the integral of the pulse.
- We measured the relationship between the (filtered) pulseheight and the charge of Normal pulsing.



Original Charge Estimation

Example : 40x40 px MPPC

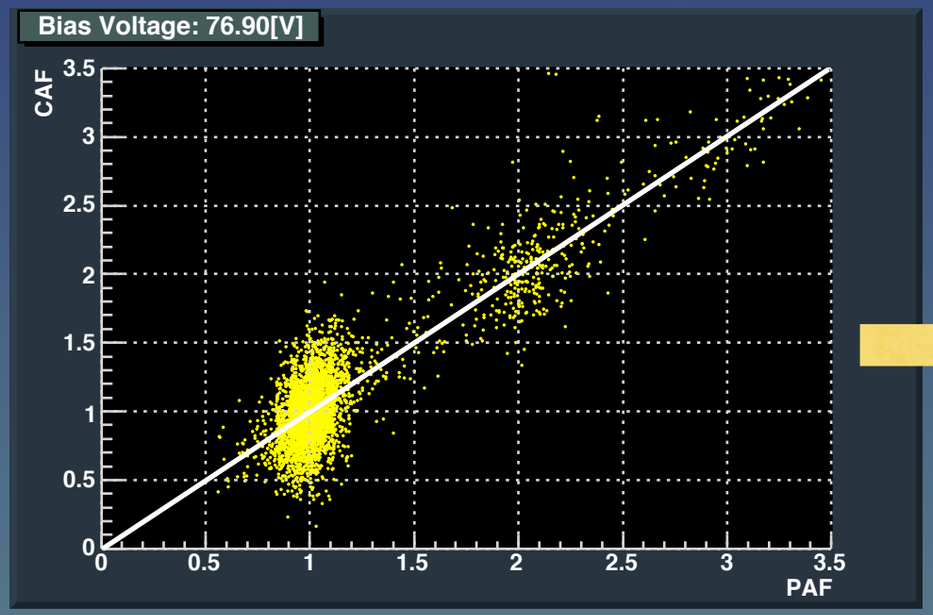


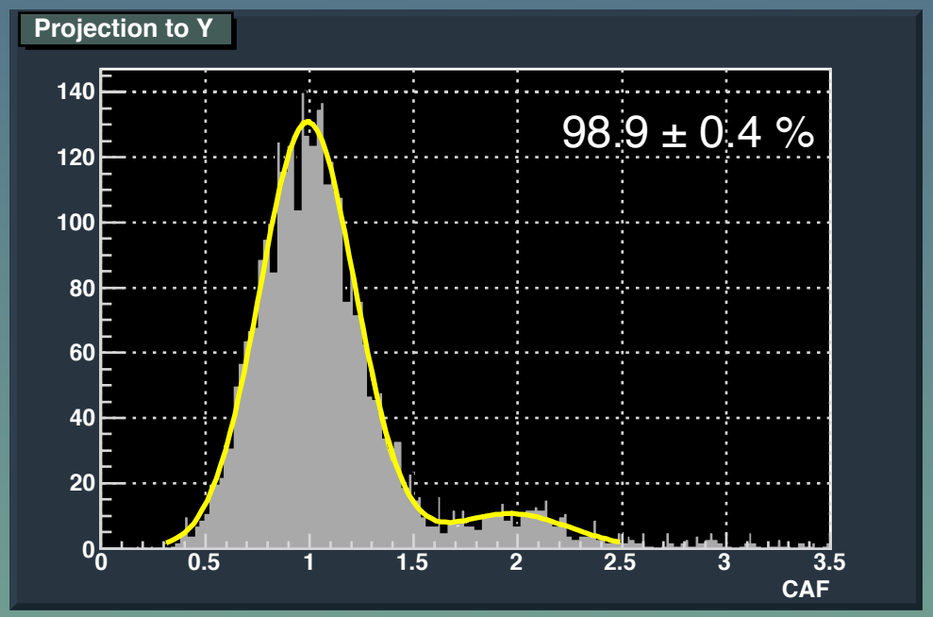


Charge Afterfraction vs. Pulseheight Afterfraction

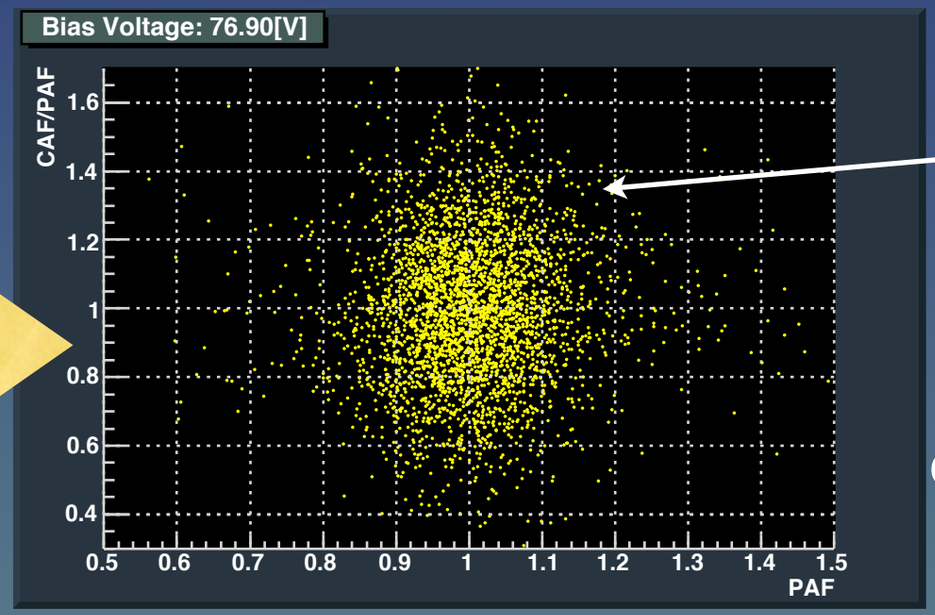
Events which afterpulsing occurred later than 70 [ns] of 40x40 px MPPC (recovered stage)

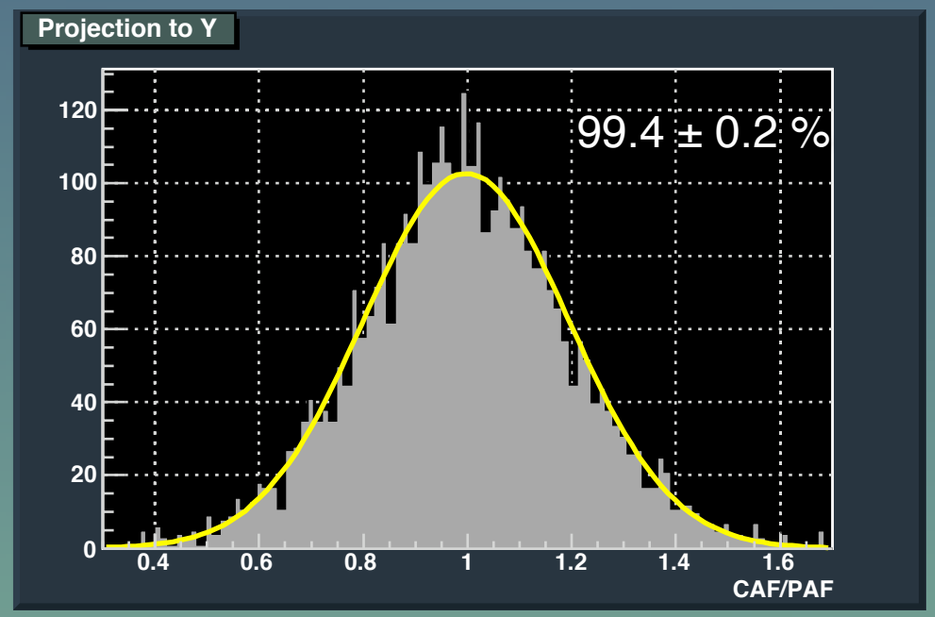
Pulse afterfraction (PAF) vs.
Charge afterfraction (CAF)





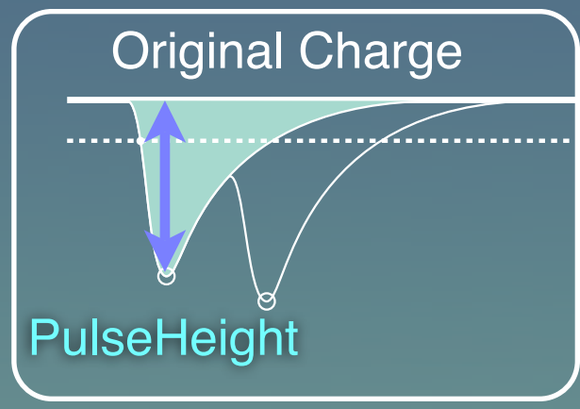
PAF vs. CAF/PAF



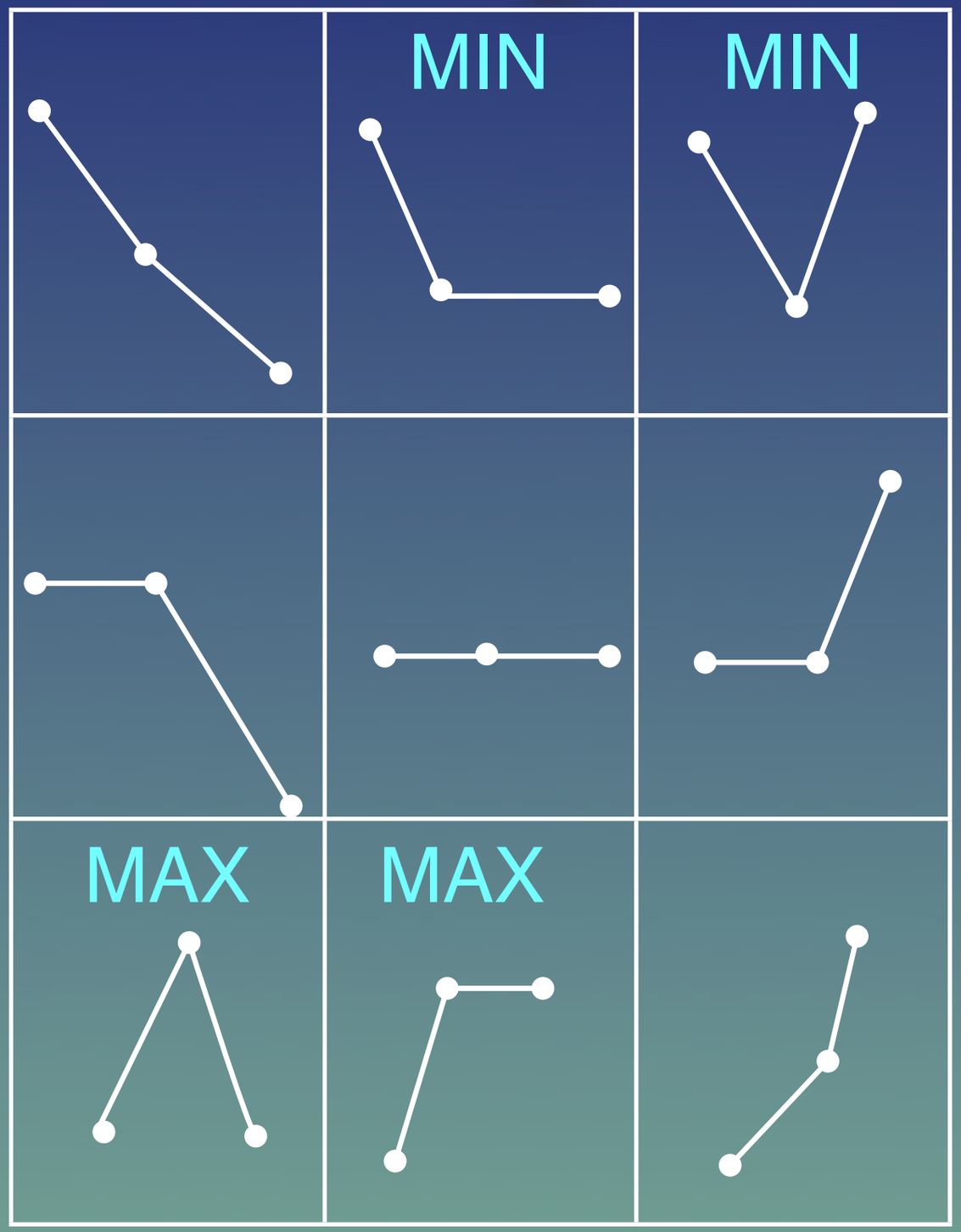


No Correlation

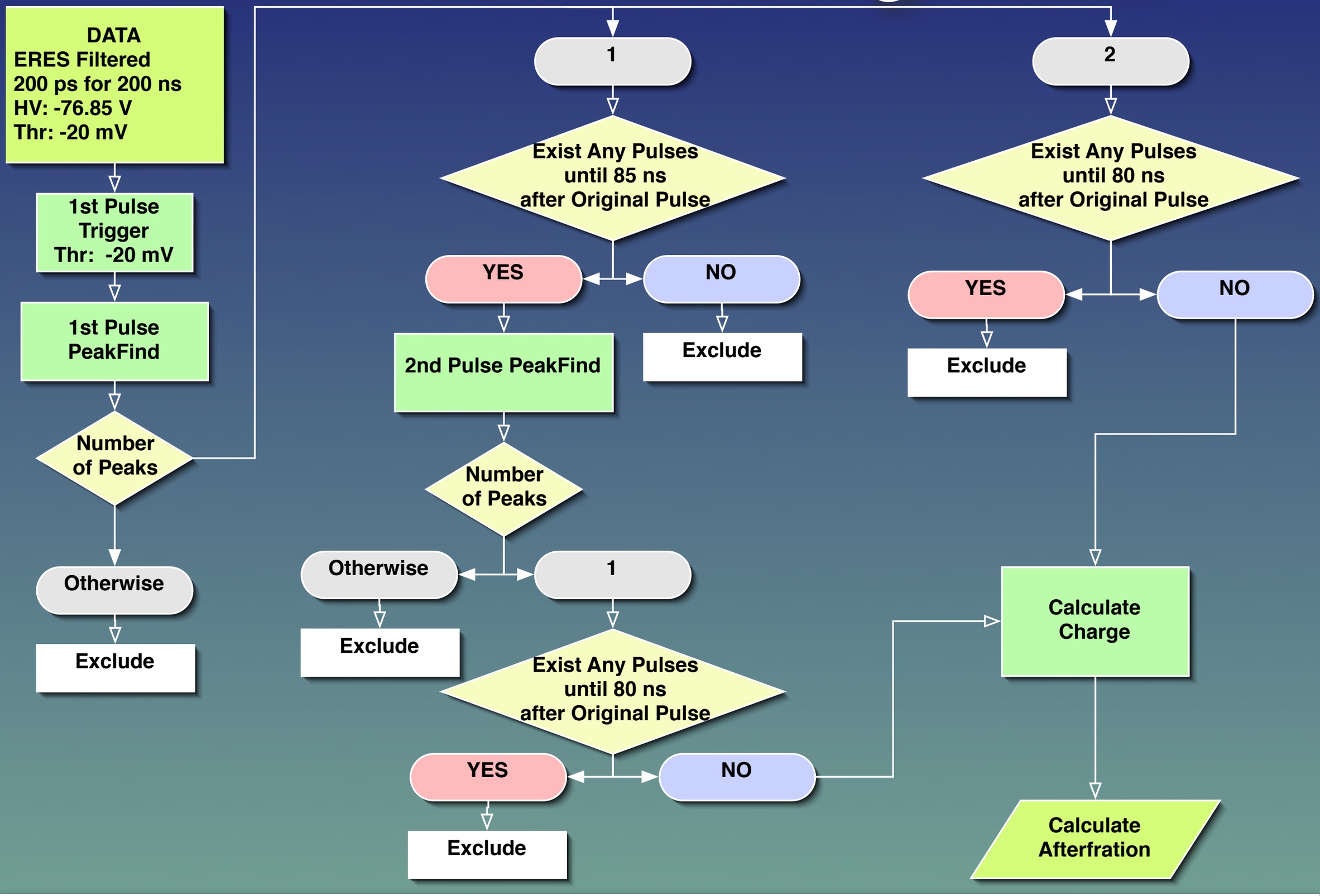
Original charge estimation is accurate.



Peak Finding Criterion



Events Extraction Algorithm



Recovery Fitting