Timing Measurements and Popcorn Noise in Low Gain Avalanche Detectors

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Content

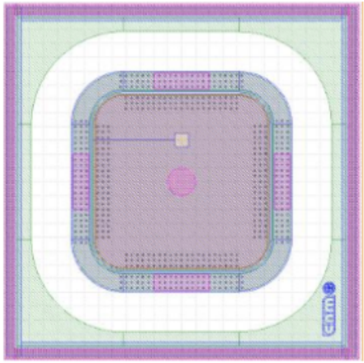
1) Overview: Studied Samples
2) CERN-SSD beta setup for timing
3) Popcorn noise in thin LGADs

Samples

LGADs produced by CNM run 11748 (AIDA 2020)

Two wafers with different active thickness:

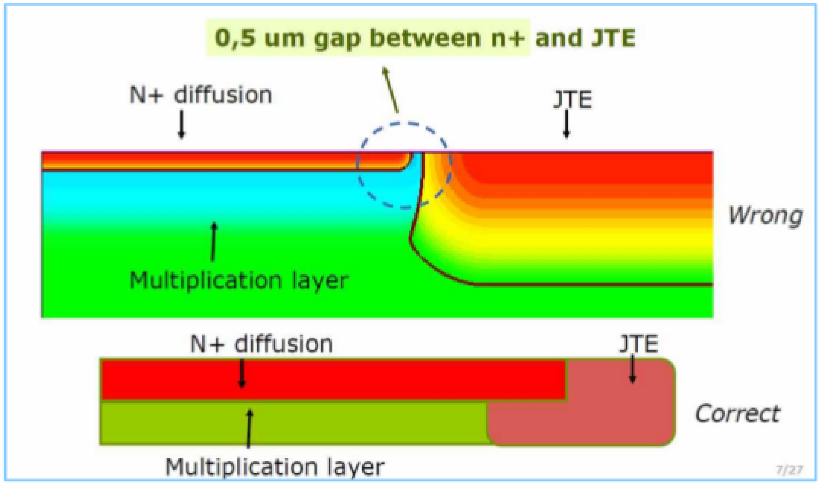
d = 50 µm and **d = 35 µm**



Total area: 2.6 x 2.6 mm^2

Active area: 1.3 x 1.3 mm^2

Intermediate Gain (1.8E13)

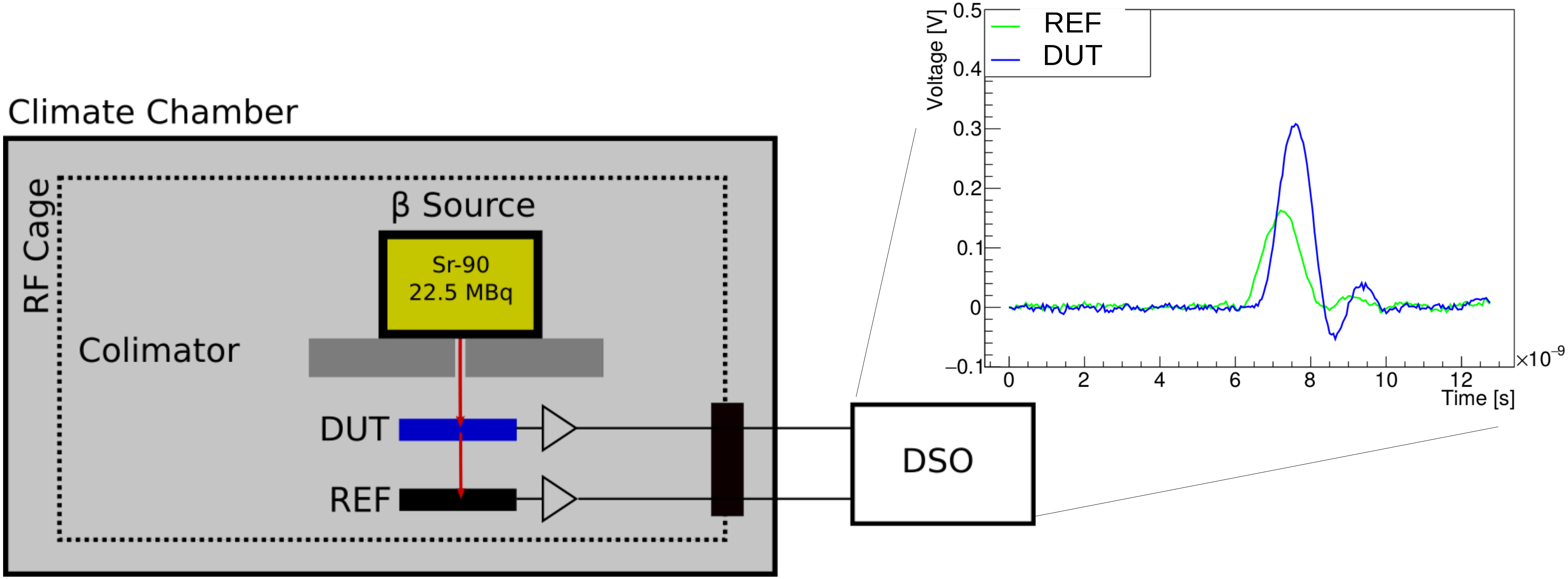


High leakage currents due to gap between JTE and n+ top layer

Irradiation at CERN proton source with 24 GeV/c protons

TCT-timing measurements done by Esteban Curras

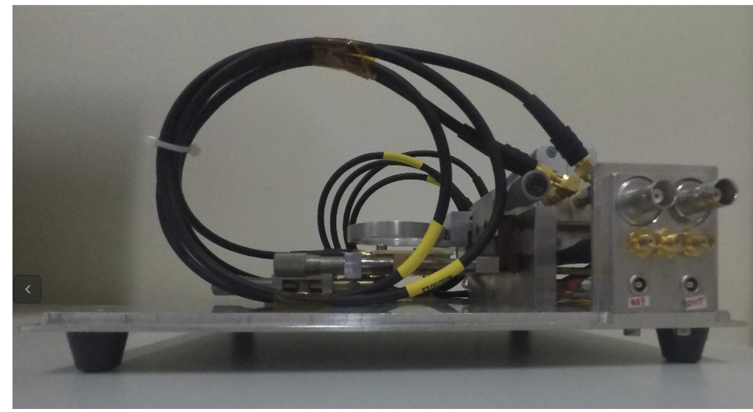
Beta Setup for Timing Measurements: Schematic



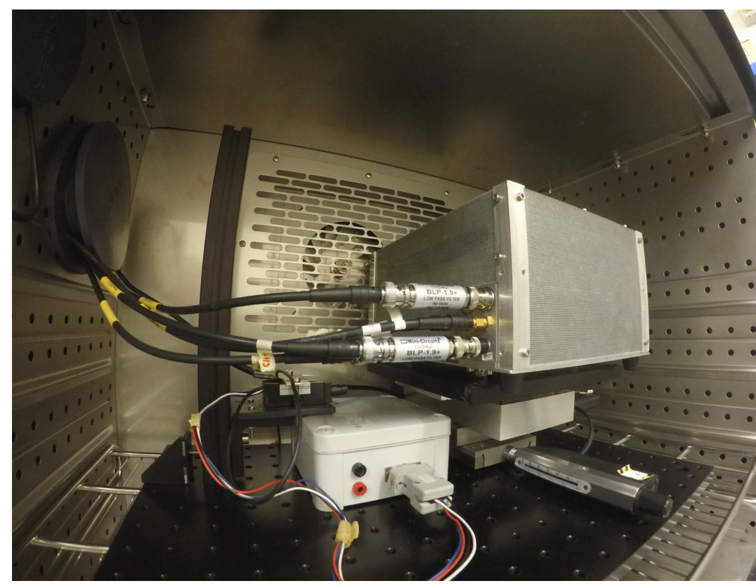
Scope: Agilent DSO 9254, 2.5 GHz, 20 GSa/s; operated at: 100 mV/div & 2 ns/div
Amplifier + Bias-T: Cividec C2-HV Broadband current amplifier (2 GHz; 40 dB)
Climate Chamber: Binder MKT115

Beta Setup for Timing Measurements: Setup Images

Top View



Side View



Setup in Climate Chamber

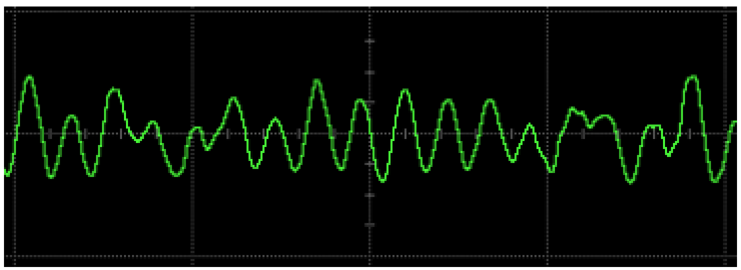
Setup and analysis code designed/written by **Matteo Centis Vignali** (while at CERN-SSD as fellow)

REF Detectors calibrated by **Paul McKarris** (CERN Summer student 2019)

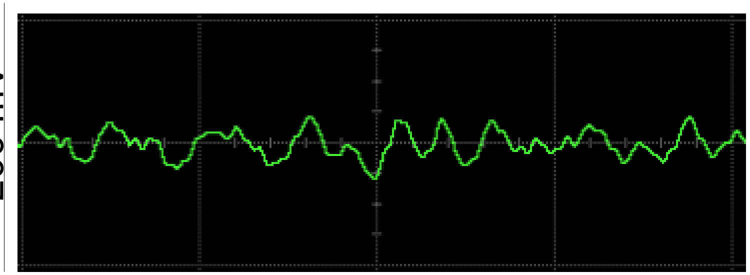
Detector [REF]
R9088_W9_LGA33
Vbias = 215 V

Beta Setup for Timing Measurements: Noise

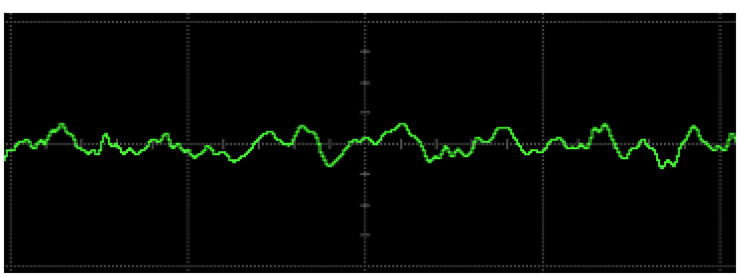
Climate Chamber open
No RF-Cage
→ **Bline RMS: 38 mV**



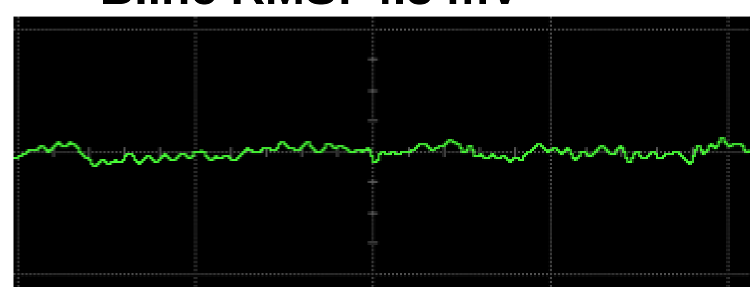
Climate Chamber closed
No RF-Cage
→ **Bline RMS: 11.5 mV**



Climate Chamber open
RF-Cage
→ **Bline RMS: 6.3 mV**

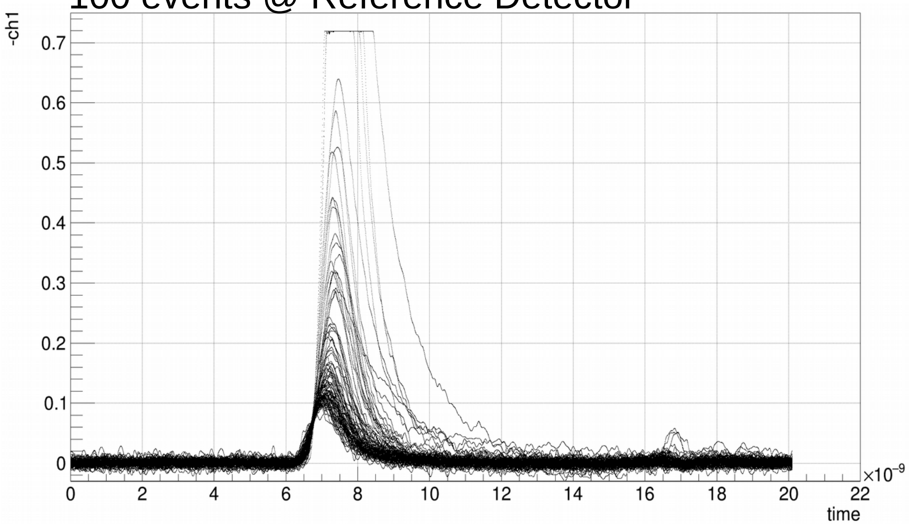


Climate Chamber closed
RF-Cage
→ **Bline RMS: 4.3 mV**



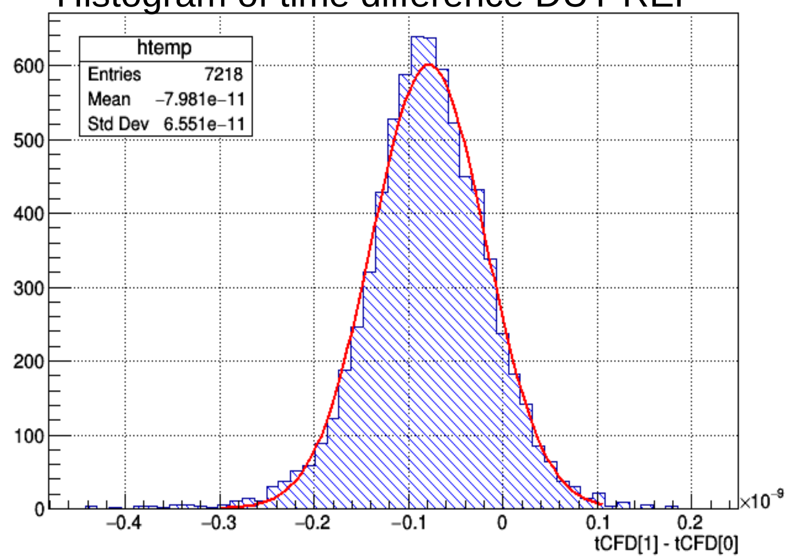
Beta Setup for Timing Measurements: Data Manipulation

100 events @ Reference Detector

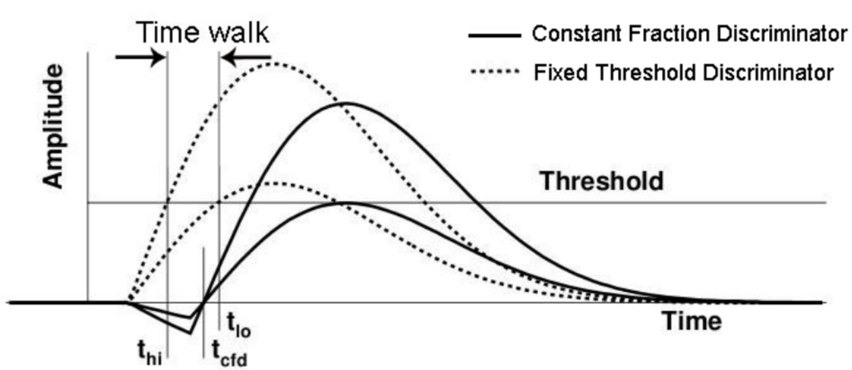


→ Need to eliminate time walk!

Histogram of time difference DUT-REF



Computed Constant Fraction Discrimination



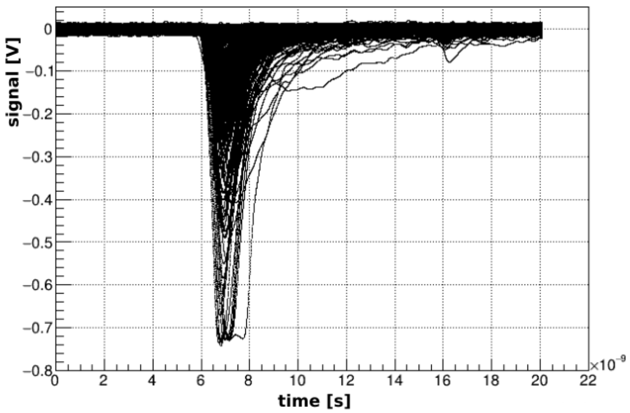
$$\sigma_{sys}^2 = \sigma_{dut}^2 + \sigma_{ref}^2$$

$$\sigma_{dut} = \sqrt{\sigma_{sys}^2 - \sigma_{ref}^2}$$

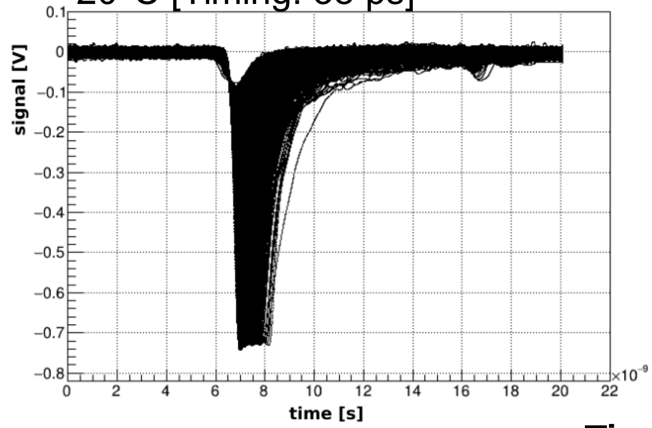
Beta Setup for Timing: Non-irradiated LGADs

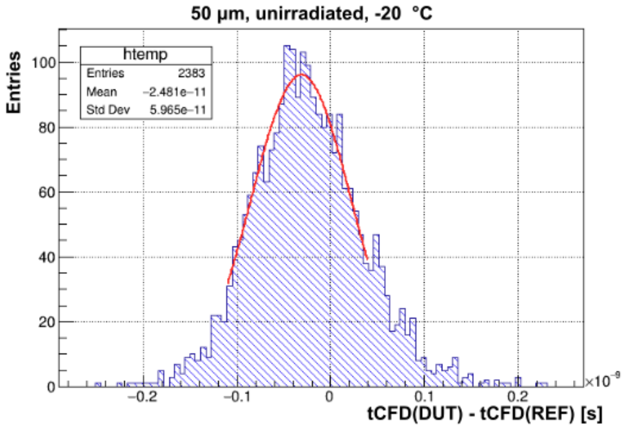
50 µm unirradiated

DUT: 11478_W11_DB_09
175 V -20°C

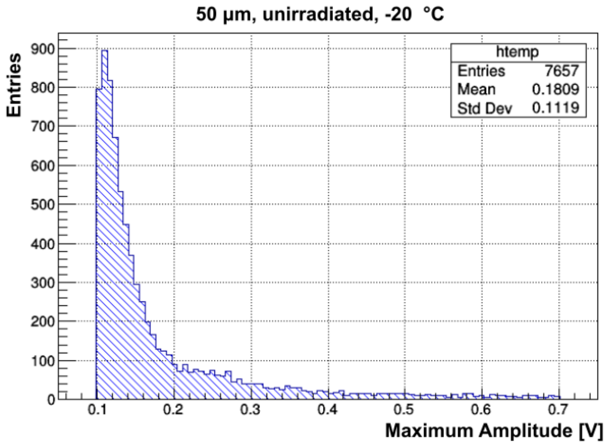


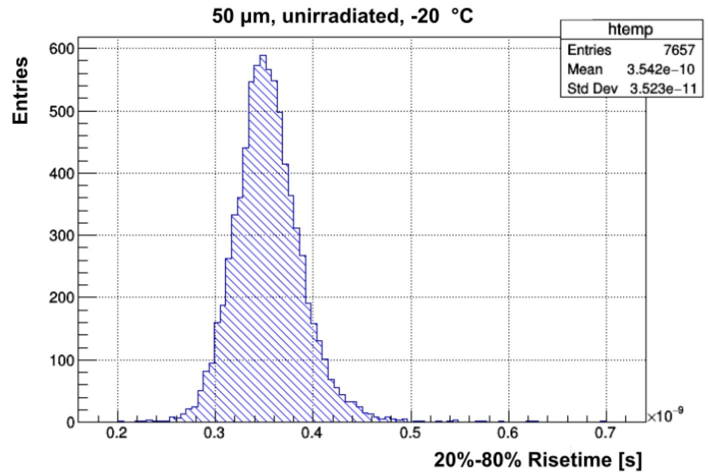
REF: R9088_W9_LGA33 175 V, -20°C [Timing: 38 ps]

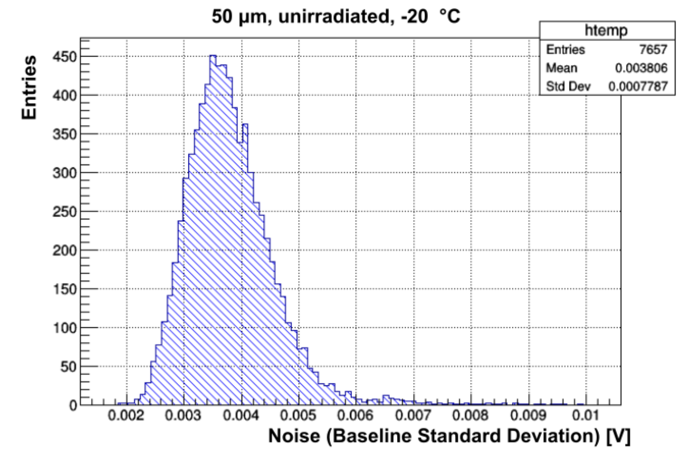




Timing: $\sigma_{Ref+DUT}$ = 53.7 s → σ_{DUT} = 37.9 ± 1 ps

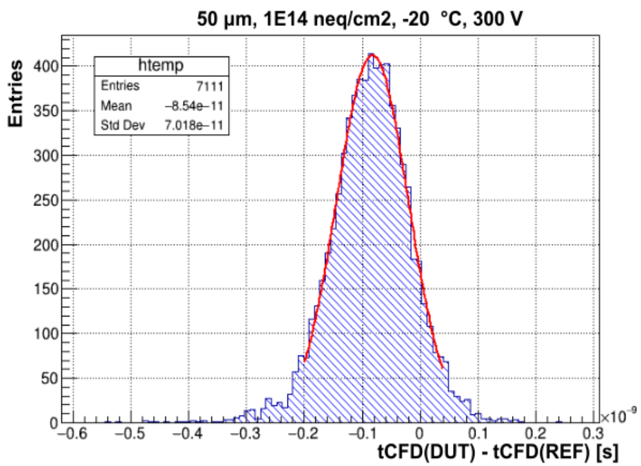


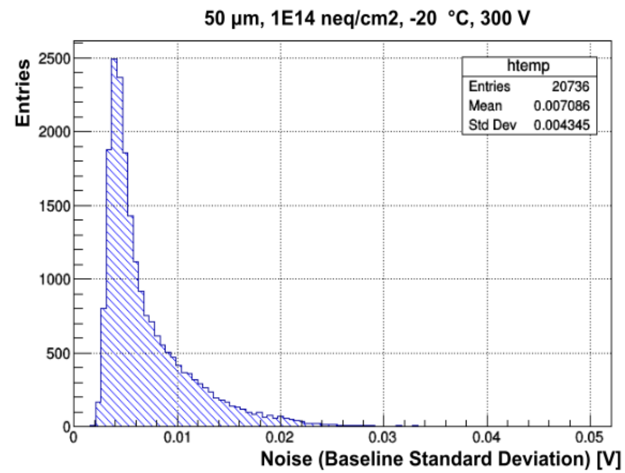




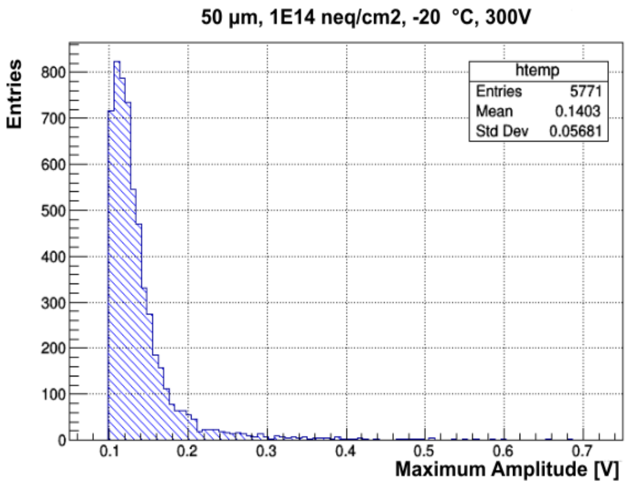
Beta Setup for Timing: irradiated LGADs

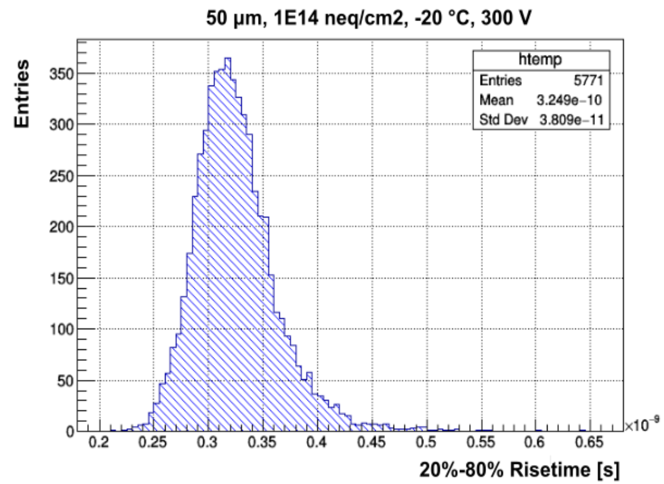
50 µm
1E14 neq/cm2





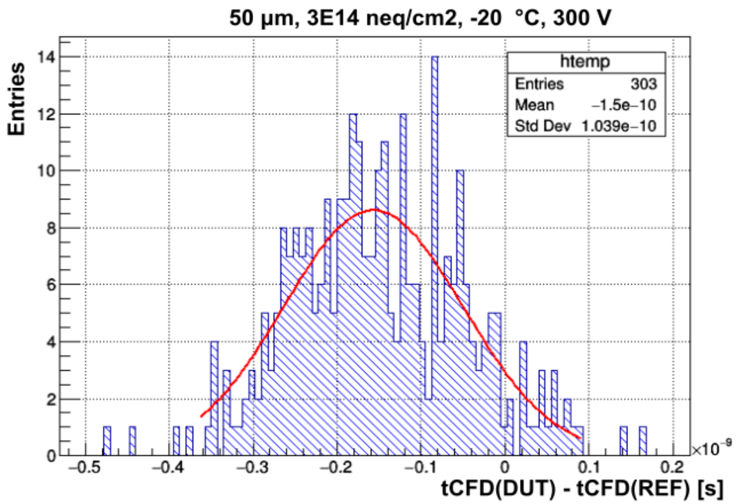
Timing: $\sigma_{Ref+DUT}$ = 62.7 ps → σ_{DUT} = 49.9 ps

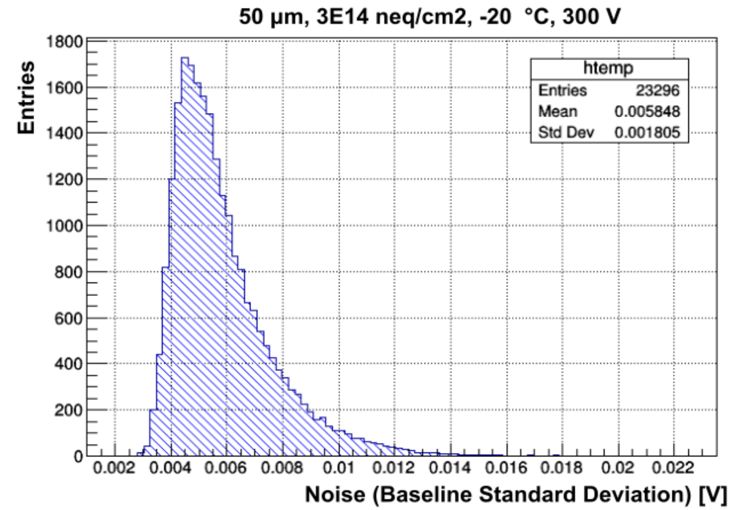




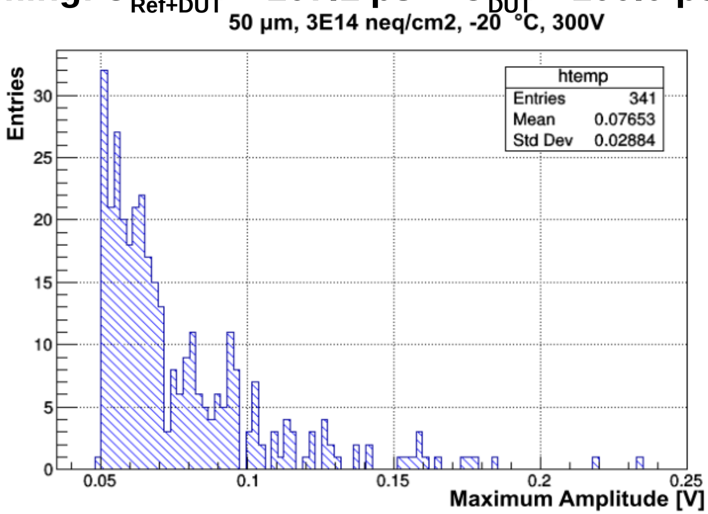
Beta Setup for Timing: irradiated LGADs

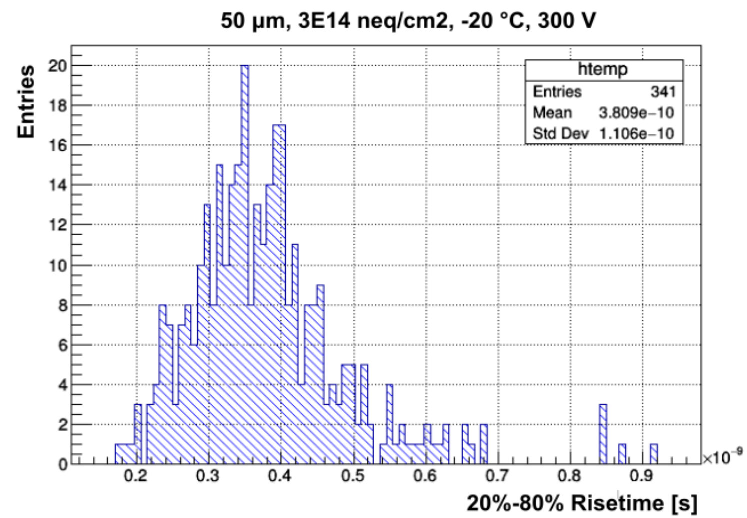
50 µm
3E14 neq/cm2





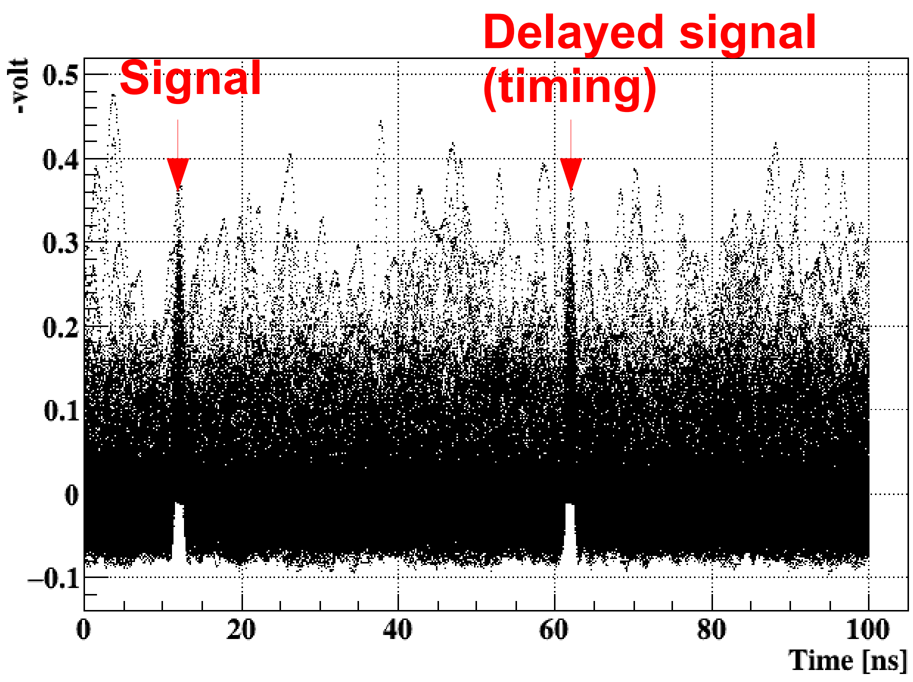
Timing: $\sigma_{Ref+DUT}$ = 107.1 ps → σ_{DUT} = 100.0 ps



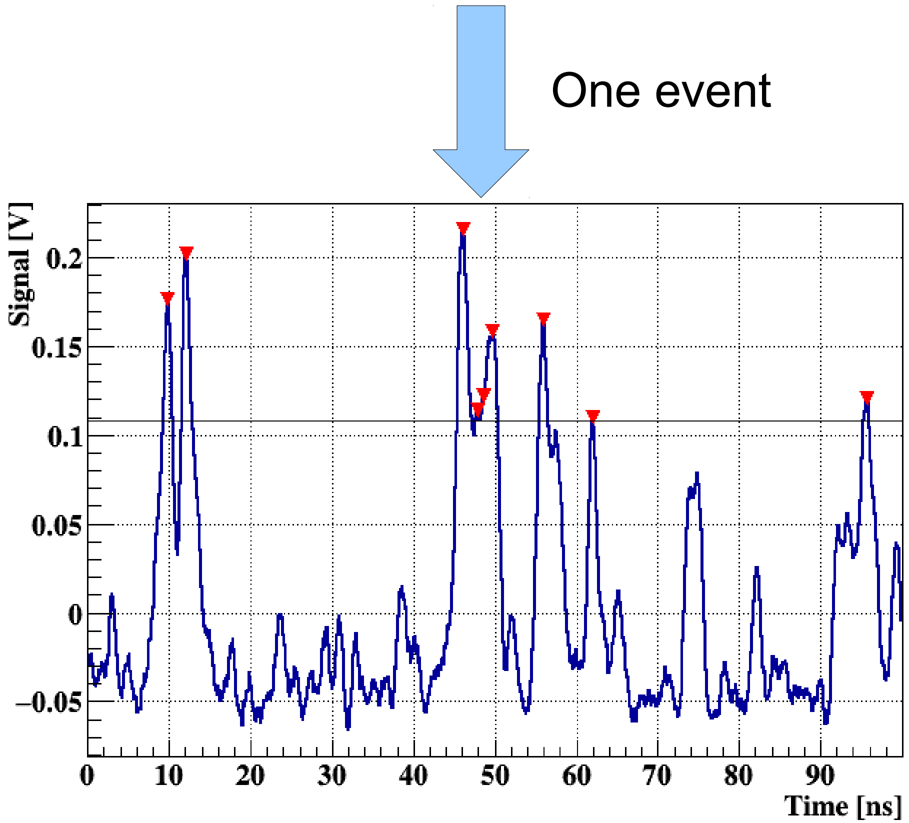


Conclusion Beta Setup

- CERN-SSD Beta Setup built by Matteo Centis
- Now Setup (and myself) being commissioned
  My contribution: reduced noise figure and improved measurement repeatability
- Reference detectors calibrated during summer 2019
- First measurements of AIDA2020 LGADs. Time resolutions vary from 39 ps (unirradiated) to 100 ps (3E14)



One event



Popcorn noise in thin LGADs: intro

- Run 11748 thin (35 and 50 μm) LGADs studied with IR top illumination at CERN-SSD TCT+

35 μm: 1 non-irrad, 4@1e14, ----- ,1@1e15 neq/cm^2
50 μm: 1 non-irrad, 1@1e14, 2@5e14,1@1e15 neq/cm^2

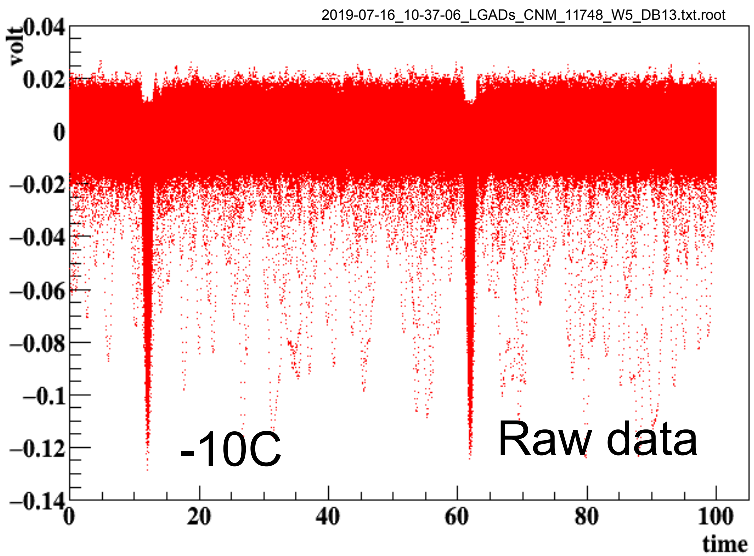
- Devices measured in timing configuration (direct injection followed by pulse copy after 50 ns)
- Popcorn noise (sudden increase of baseline activity) observed.
- We calculated popcorn dependency on:
  - Voltage
  - Temperature
  - Fluence
  - Thickness
- Popcorn noise estimated counting number of peaks (in 100 ns long measurement) above a threshold.

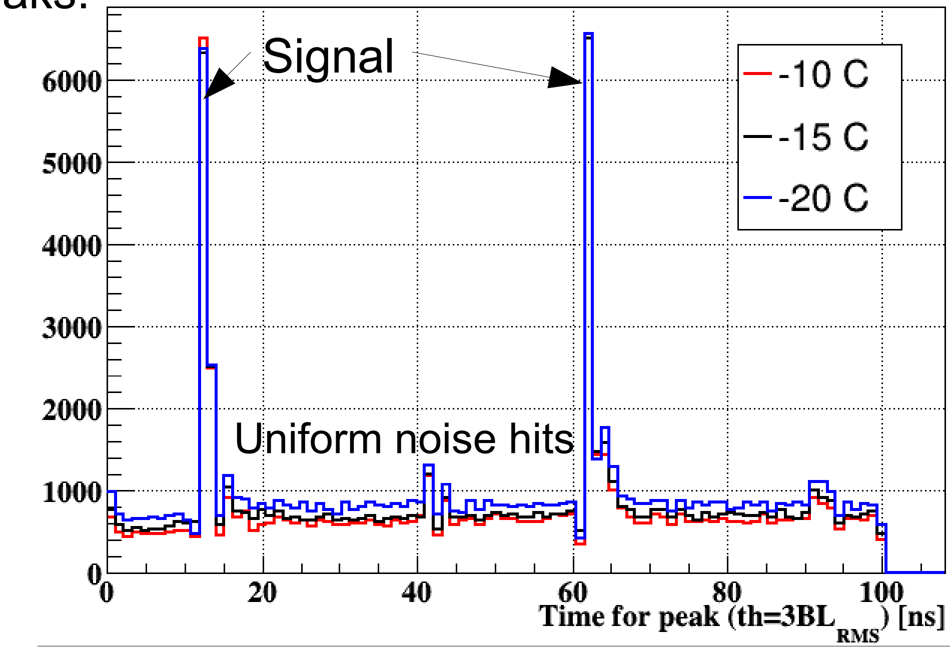
The threshold is referred to the baseline amplitude (in RMS) of events without popcorn noise

Analysis records: time of each peak, amplitude, number of noise peaks, varying threshold, bias, temperature...

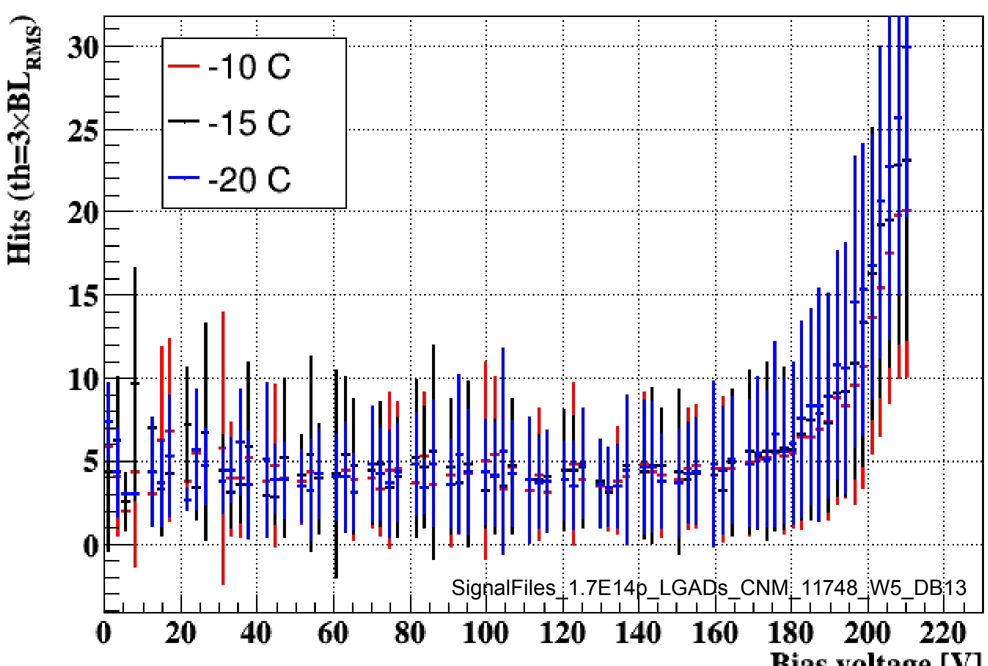
W5_DB13 (35 μm) 1.7E14p

- Algorithm detects both signal peaks and noise peaks:

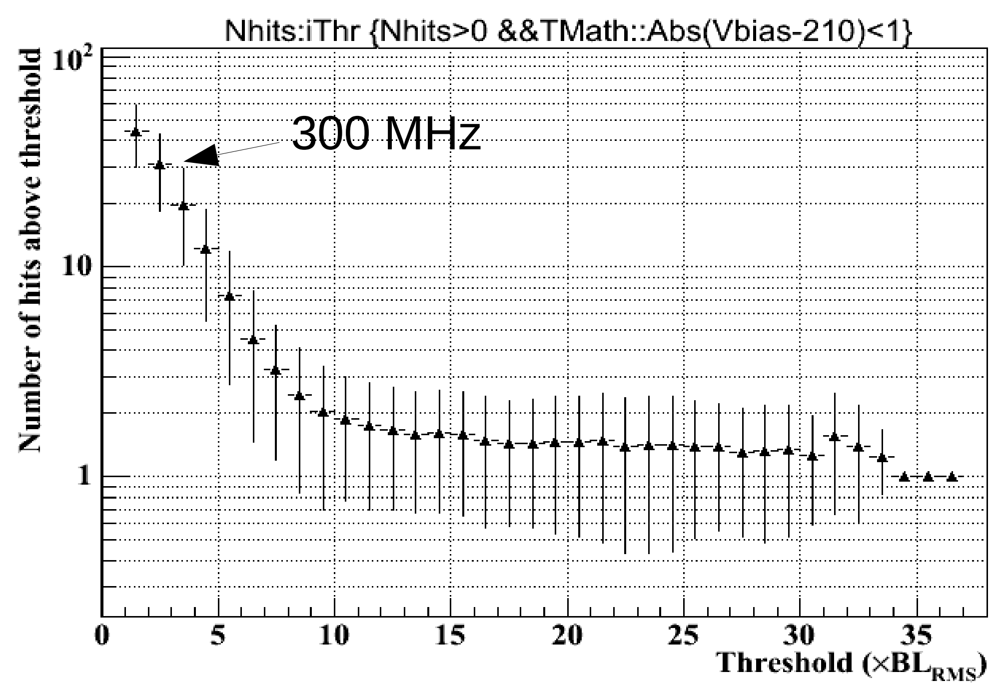




- Number of hits versus bias (fixed threshold)

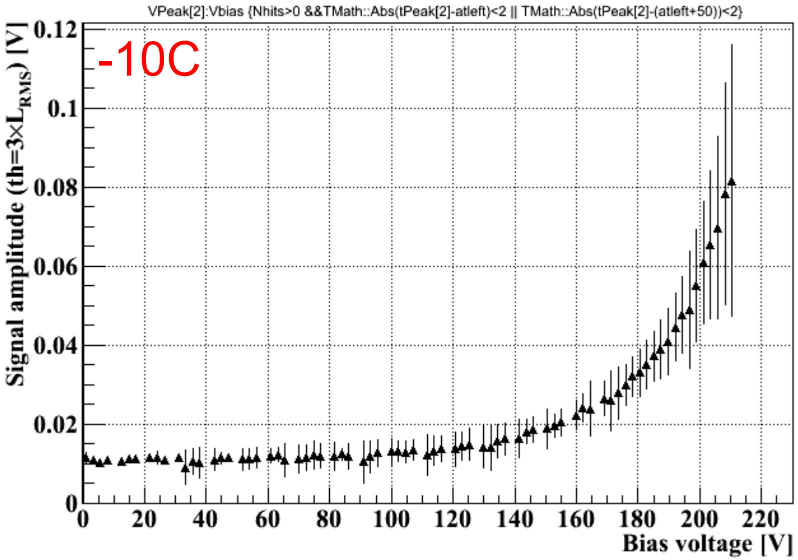


- Number of hits versus threshold (fixed bias)

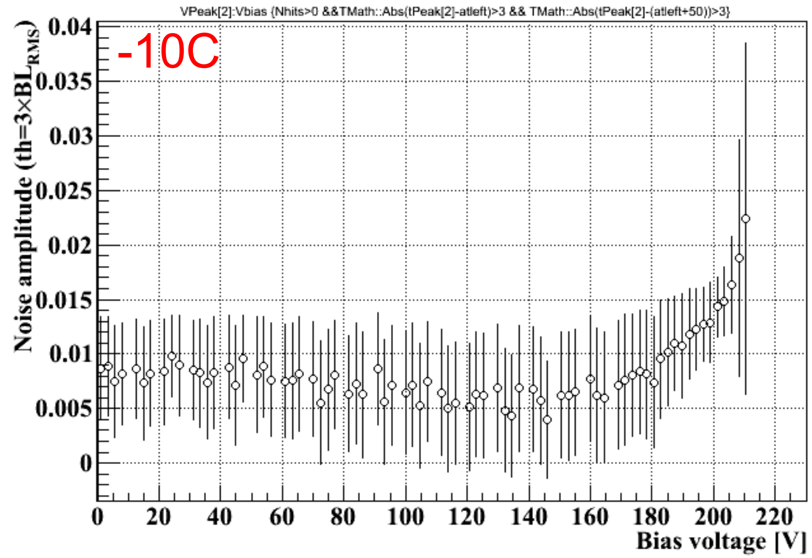


W5_DB13 (35 µm) 1.7E14p

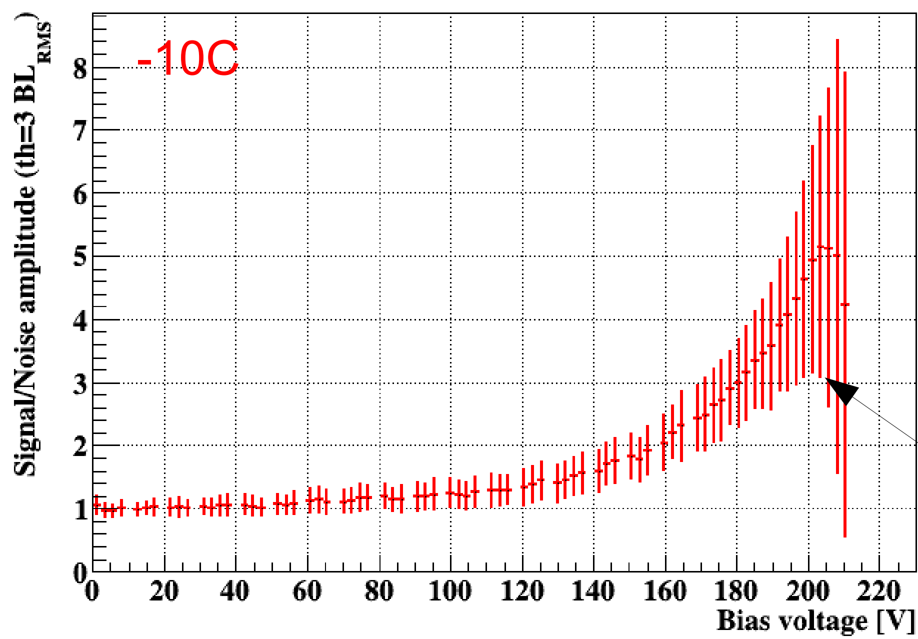
Signal amplitude vs bias



Noise amplitude vs bias



Signal amplitude over noise amplitude vs bias



Turnover point taken as criteria for maximum operation voltage!

SignalFiles_1.7E14p_LGADs_CNM_11748_W5_DB13.files

Popcorn and temperature

W5_DB13 (35 μm) 1.7E14p

Measured same detector at -10 C, -15 C and -20C

Calculated ratio of Signal over Noise amplitudes versus bias voltage, for a fixed threshold.

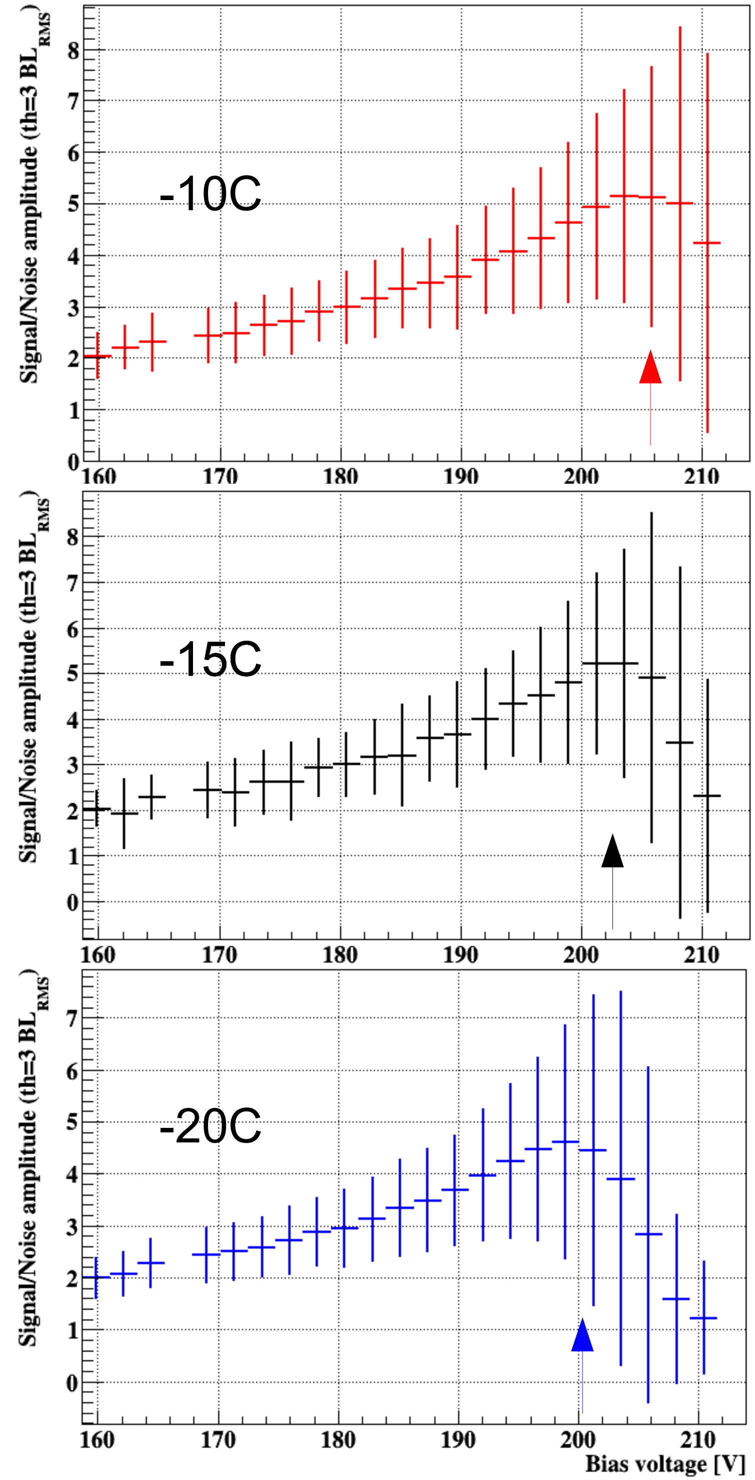
Goal is to define maximum operational voltage

Signal grows faster than noise until a turnover point where the ratio decreases (noise growth)

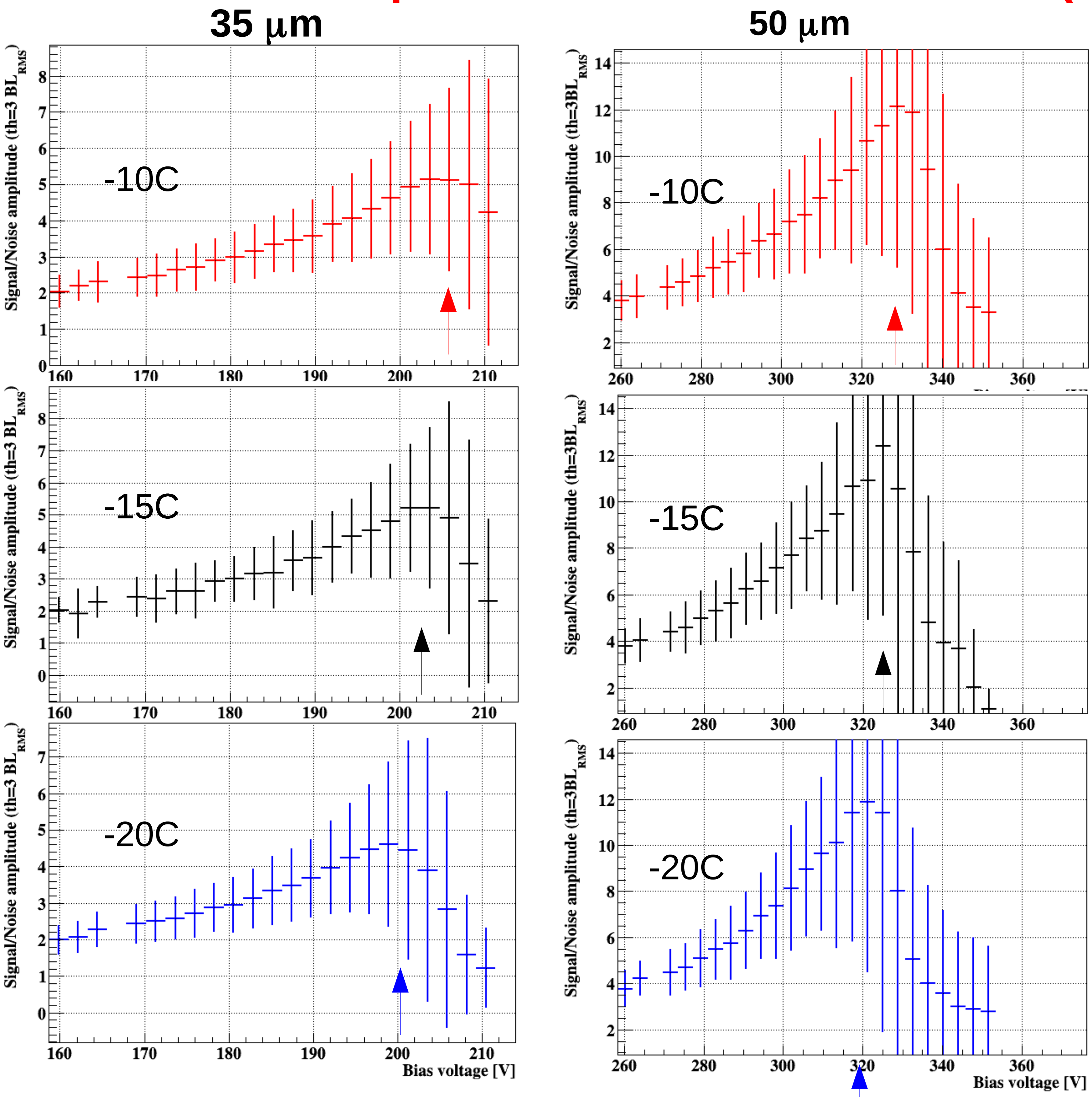
The turnover point slightly depends on T, but seems to be a second order effect

Maximum operational voltage:
1e14 neq/cm2 → (~200 V, 35 μm)

ZOOM



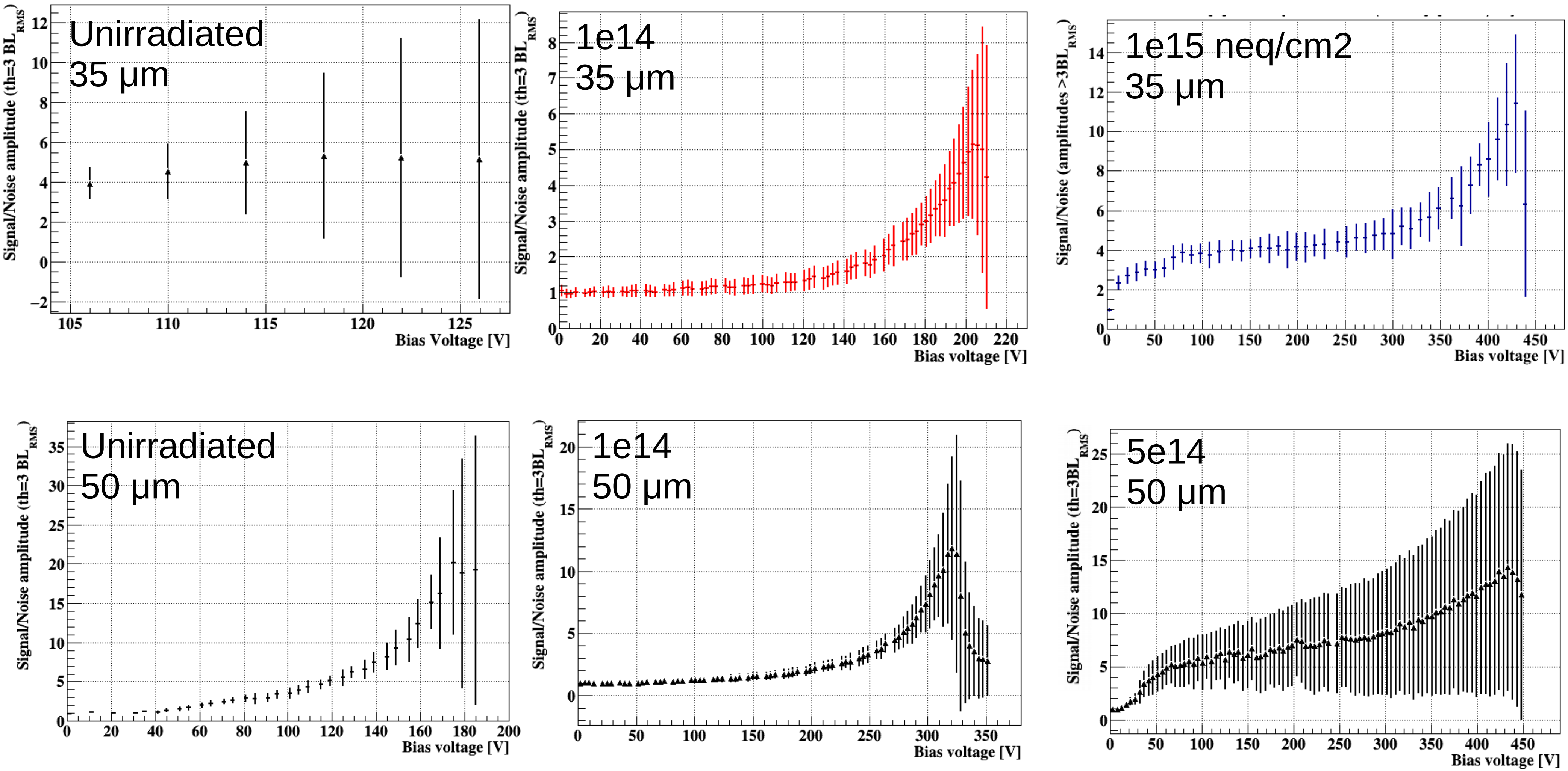
Popcorn and detector thickness (1e14 neq)



Thicker detectors withstand higher voltage!

200 V (35 μm) vs 320 V (50 μm)

Popcorn and fluence



Maximum operation voltages (th=3BL_{RMS})

Non irradiated	35 μm,~100 V	Non irradiated	50 μm, ~170 V
1e14 neq/cm2	35 μm, ~200 V	1e14 neq/cm2	50 μm, ~320 V
1e15 neq/cm2	35 μm,~435 V	5e14 neq/cm2	50 μm, ~435 V

Popcorn noise in thin LGADs: Conclusion

- Popcorn noise observed in thin LGADs
- Hit counting algorithm helps to define voltage working range
- Criteria chosen turnover point of Signal/Noise amplitude vs voltage

Maximum operation voltages (th=3BL_{RMS})

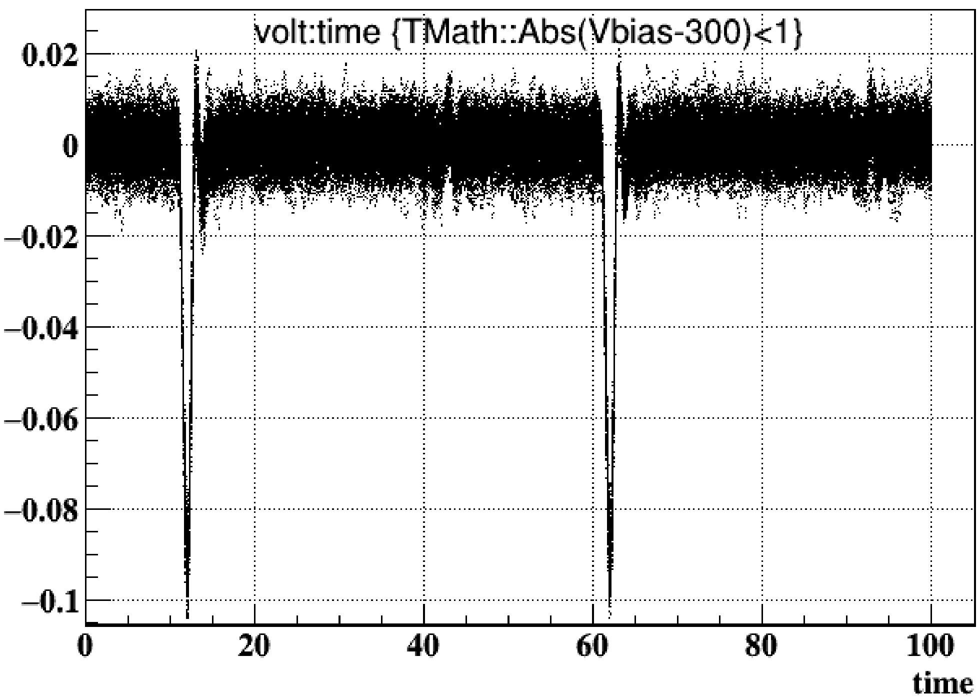
Non irradiated	35 μm,~100 V
1e14 neq/cm2	35 μm, ~200 V
1e15 neq/cm2	35 μm,~435 V
Non irradiated	50 μm,~170 V
1e14 neq/cm2	50 μm,~320 V
5e14 neq/cm2	50 μm, ~435 V

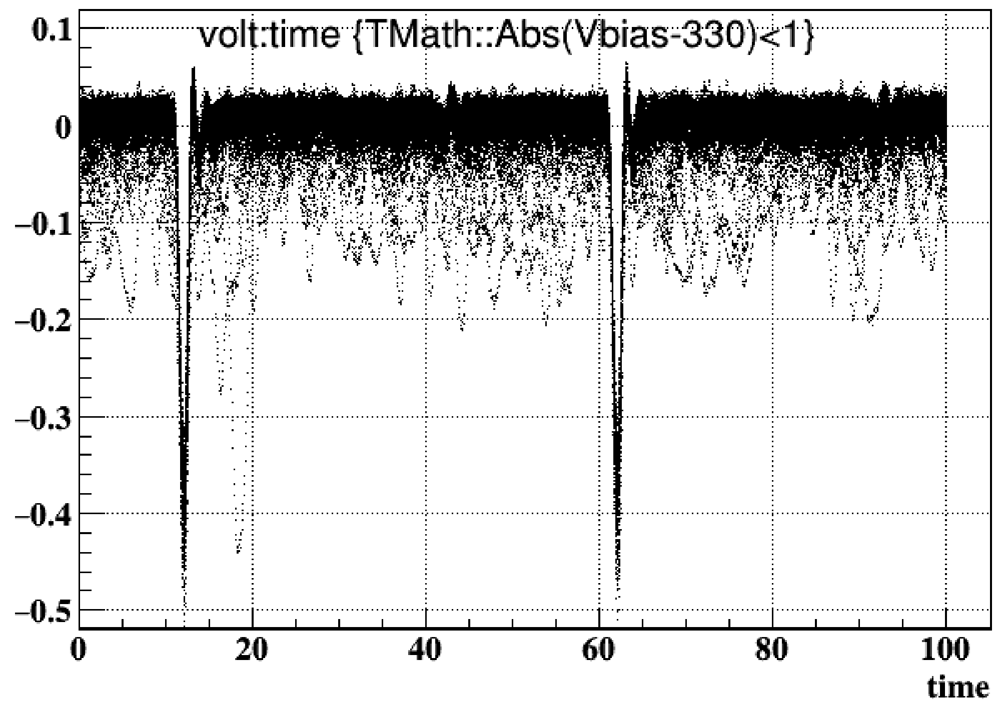
- Detector voltage stability against popcorn improves with :
  Thickness
  Fluence

Backup

1E14 neq/cm2 2019-07-15_20-15-50_LGADs_CNM_11748_W11_DB13.txt.root

Backup

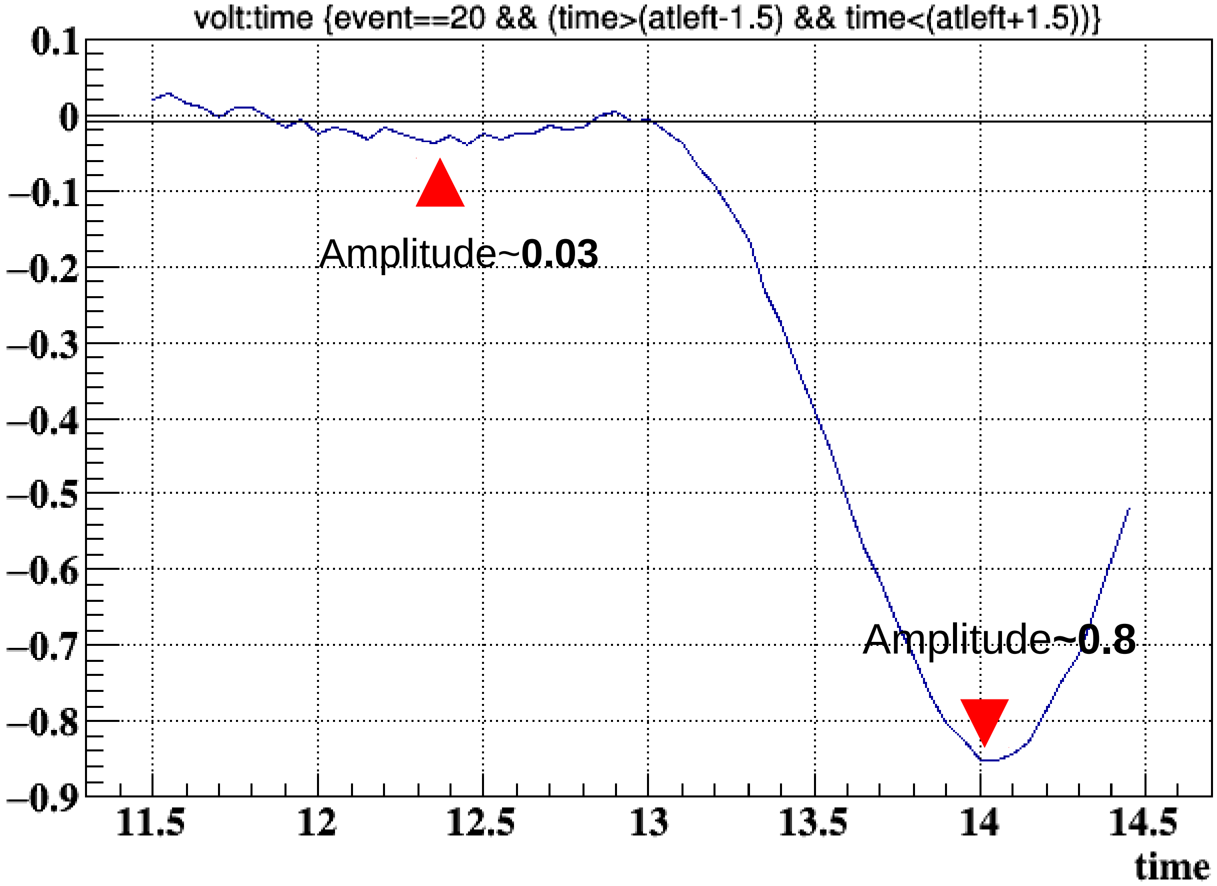




1E14 neq/cm2 2019-07-15_20-15-50_LGADs_CNM_11748_W11_DB13.txt.root

Why spread increases at high voltages?

At high voltages noise is bigger. Then more peaks cross the $3BL_{RMS}$ threshold, with very different amplitudes:



BL_{RMS}=0.0031408

$3BL_{RMS}$

Big spread of peaks crossing small threshold at high bias: 0.03 → 0.8