Timing resolution on an irradiated 3D silicon pixel detector

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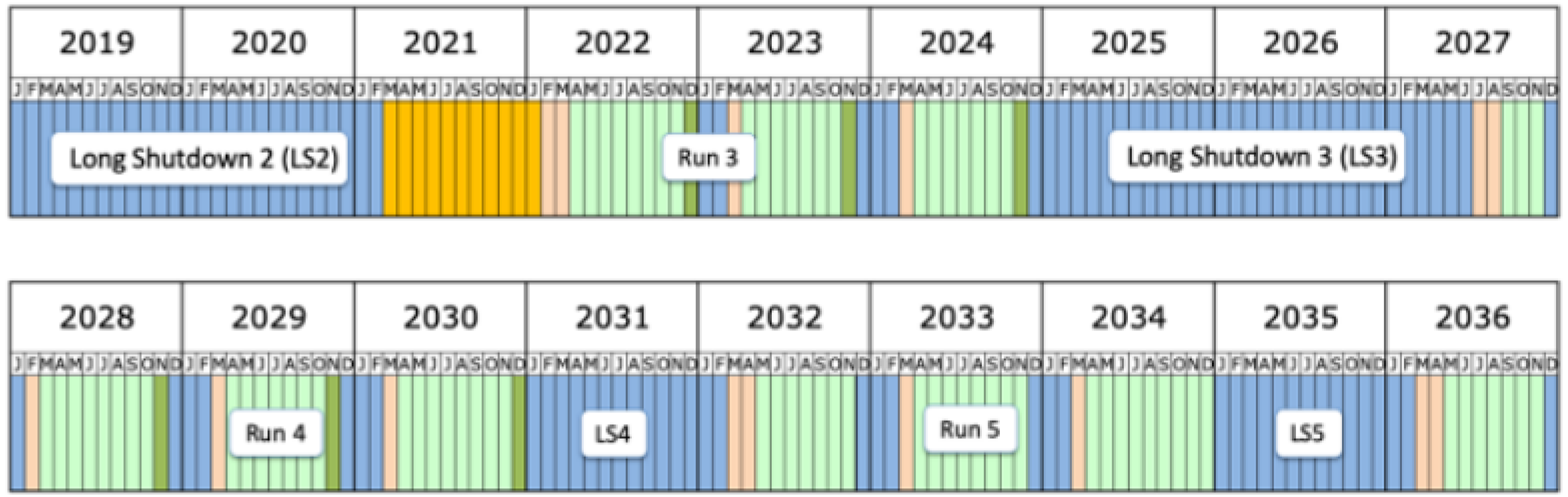
9-11 September 2021 - Workshop on pico-second timing detector for physics

Outline

- Needs timescale 10 y
- 3D Pixel Sensor CNM Production
- Experimental Setup
- 3D Time resolution before and after irradiation for 285μm thick sensor at −20°C

Needs on timescale 10y



Fixed targets

- NA61 Shine (beam monitor – measurement of each beam particle; p to Pb) (40 ps, 250 μm position resolution)

Rare decays

- NA62 (high intensity Kaon program at SPS)
  - GigaTracker upgrade (20-40 ps, ~few 100x100 μm2), $2\cdot10^{13}$ p on target/3s spill, extremely good efficiency required

Linear e-e machines

- Tracking: ~5 ns timing, but extremely low mass and position resolution (few μm)
- Forward Calorimetry: optional/beyond baseline (required GaAs/Si) to reduce the timing <1ns

Post LS3 LHC ($\Phi_{eq}>10^{16}$ cm^{-2})

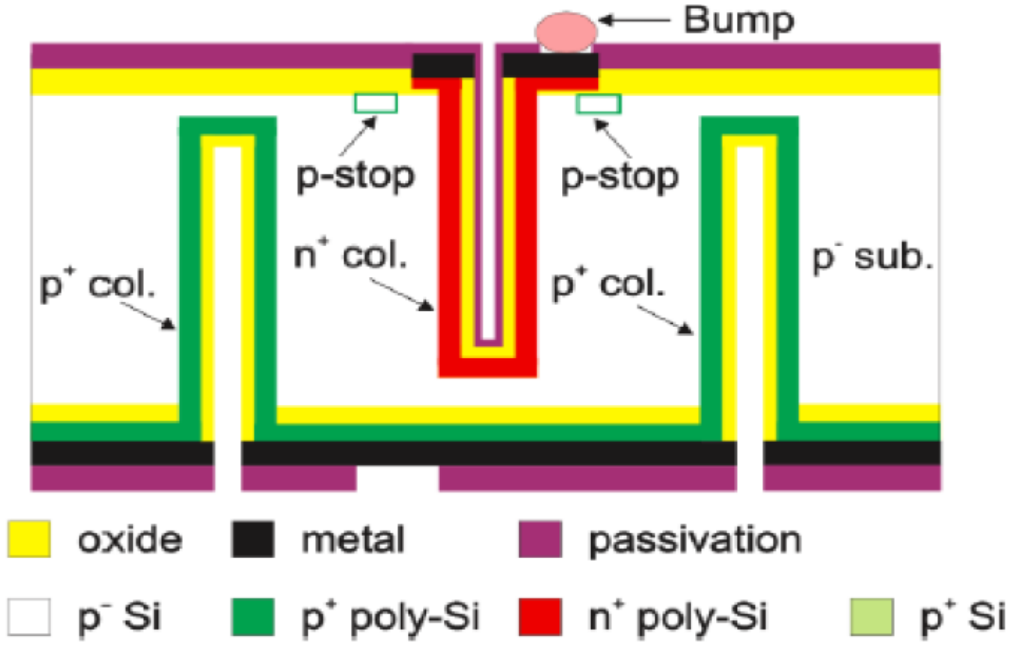
- LHC-B Velo II upgrade (>LS4)
  - L=$1.5\cdot10^{34}$ cm^{-2}s^{-1} (7.5x occ.) , max fluence $5\cdot10^{16}$ cm^{-2} with huge fluence spread over the sensor -> desired full 4D tracking
  - ~55 μm pitch, <50 ps/hit resolution (ongoing optimization)
- CMS (LS >4,5)
  - possible addition of pixel disks with high precision timing in the forward region (~100x100 μm^2, ~30 ps)
- ATLAS (LS >4,5)
  - replacement of LGADs in the inner rings of HGTD
  - replacement of the inner-most pixel layers with possible timing information <50ps

3D Pixel Sensor – CNM production

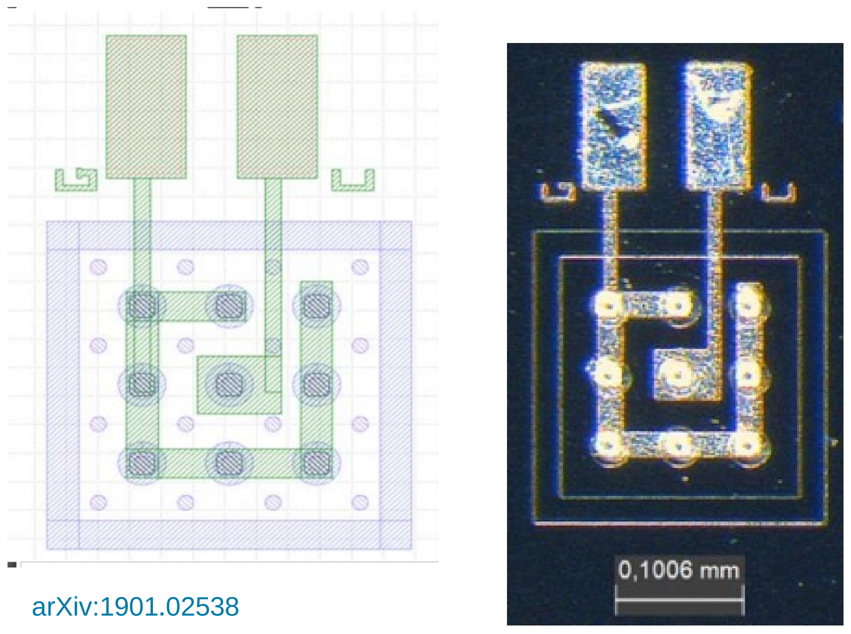
Features:

- thickness: 285µm
- cell size: 50x50 µm^2
- p-type bulk resistivity: ~5kΩcm
- diameter holes: 8-10 µm

Schematic Cross Section

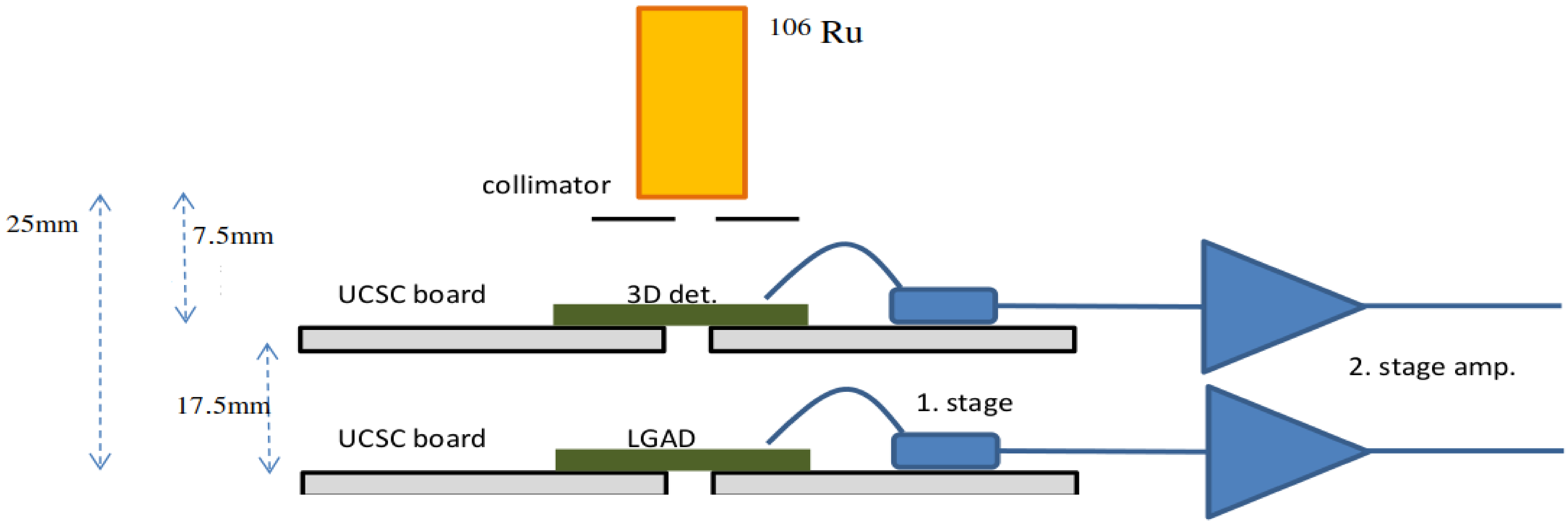


Design of a single cell structure



arXiv:1901.02538

Experimental Setup

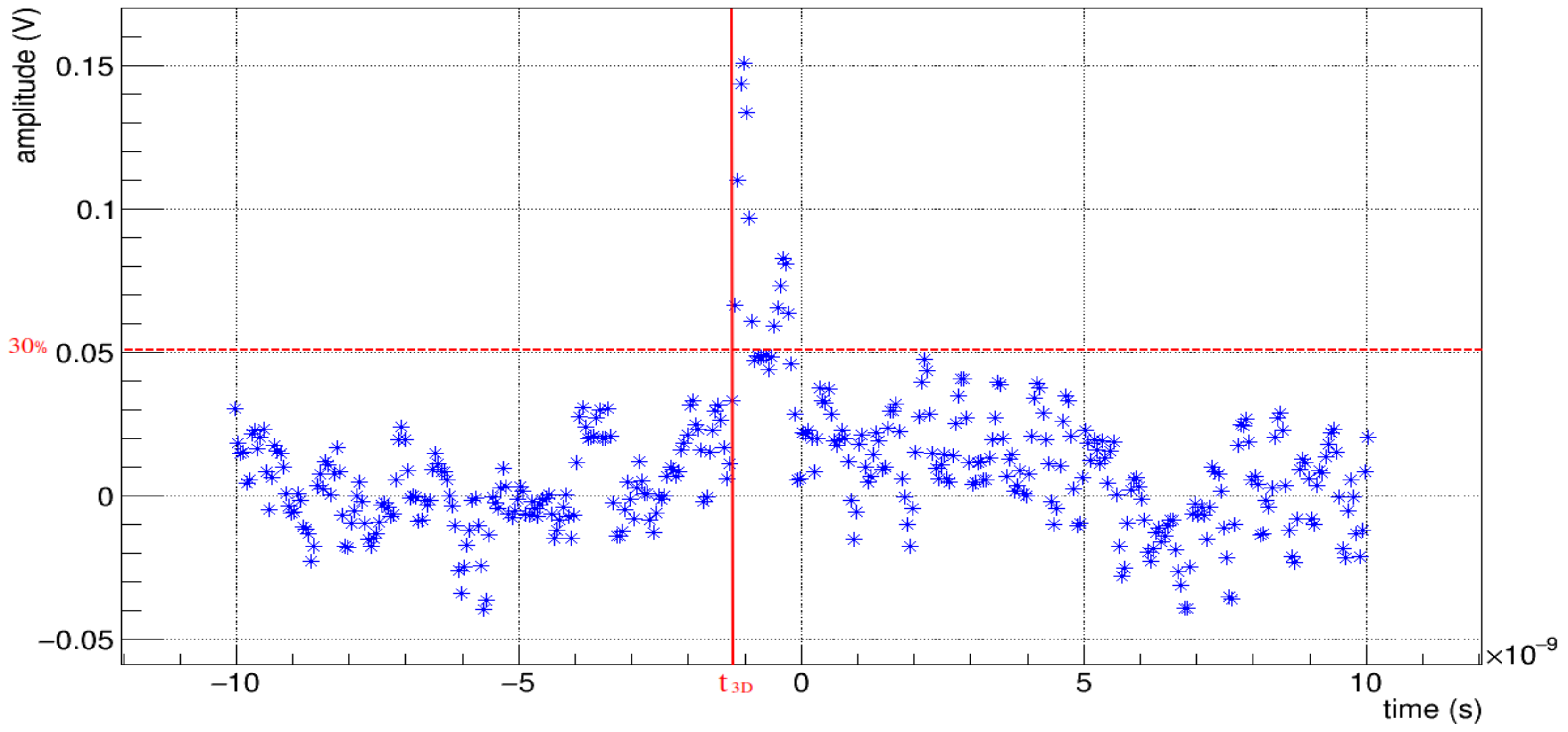


Signals in coincidence are analyzed

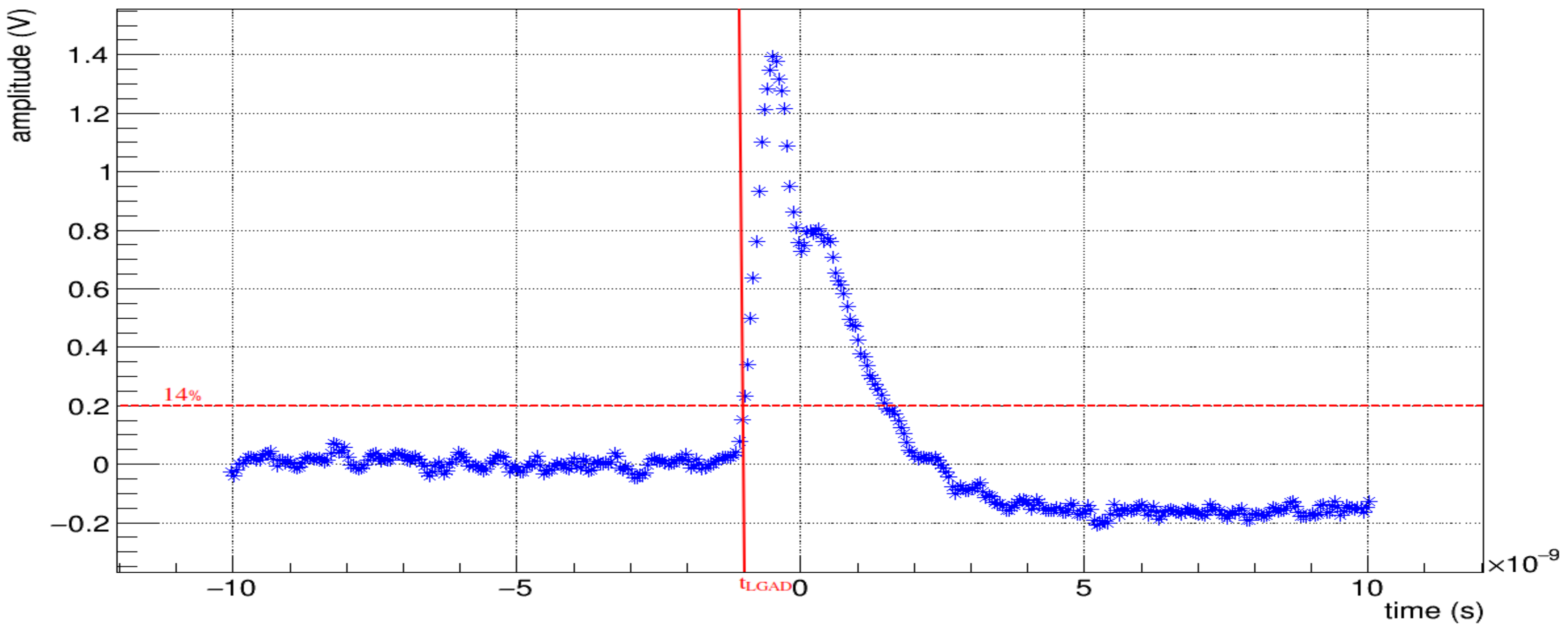
Source: ^{106}Ru
Board: Preamplified UCSC
LGAD: HPK50C – high gain 50 um thick (1 mm diameter)
Time resolution 39 ps (20°C) and 36 ps (-20°C)
2.stage amp: 4GHz
Readout: Waverunner 8404M oscilloscope 4GHz

3D Waveform and analysis - σ_{3D}

3D Waveform

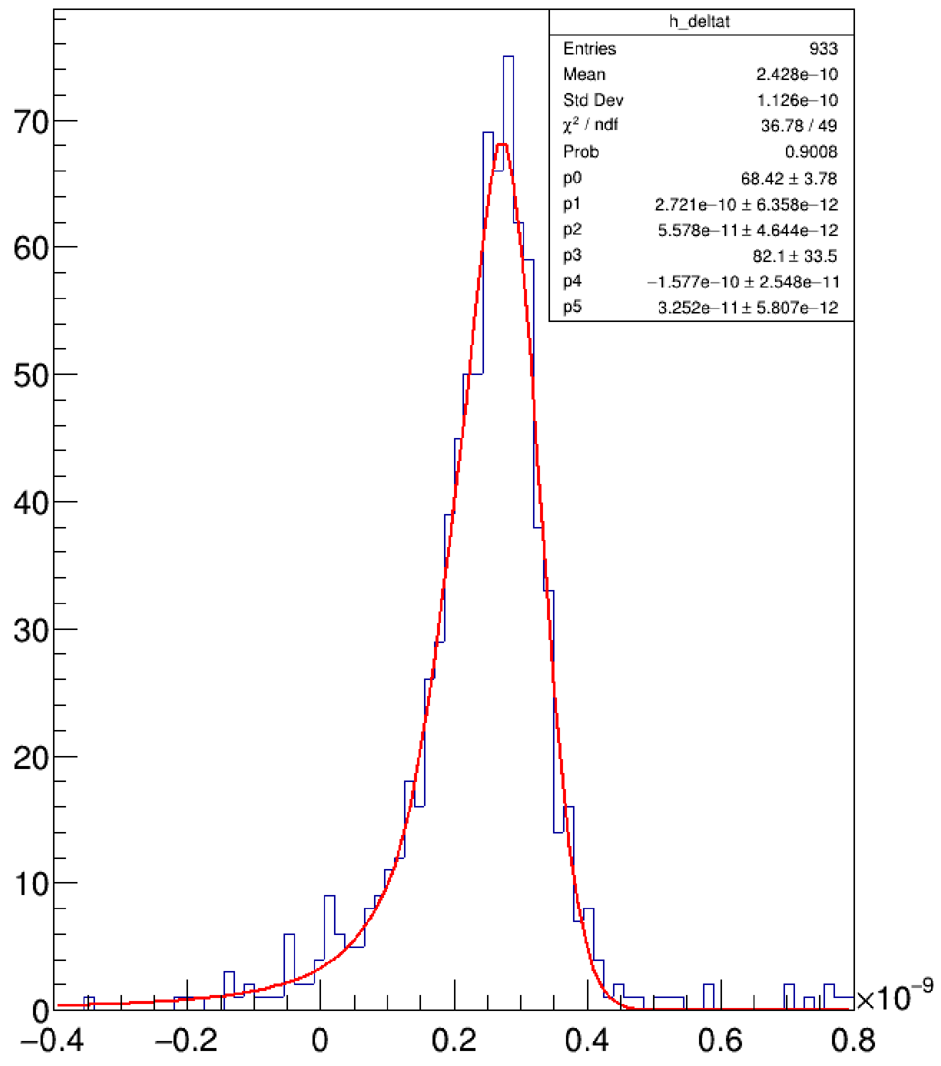


LGAD Waveform



CFD method

$\Delta t = t^*_{LGAD} - t^*_{3D}$

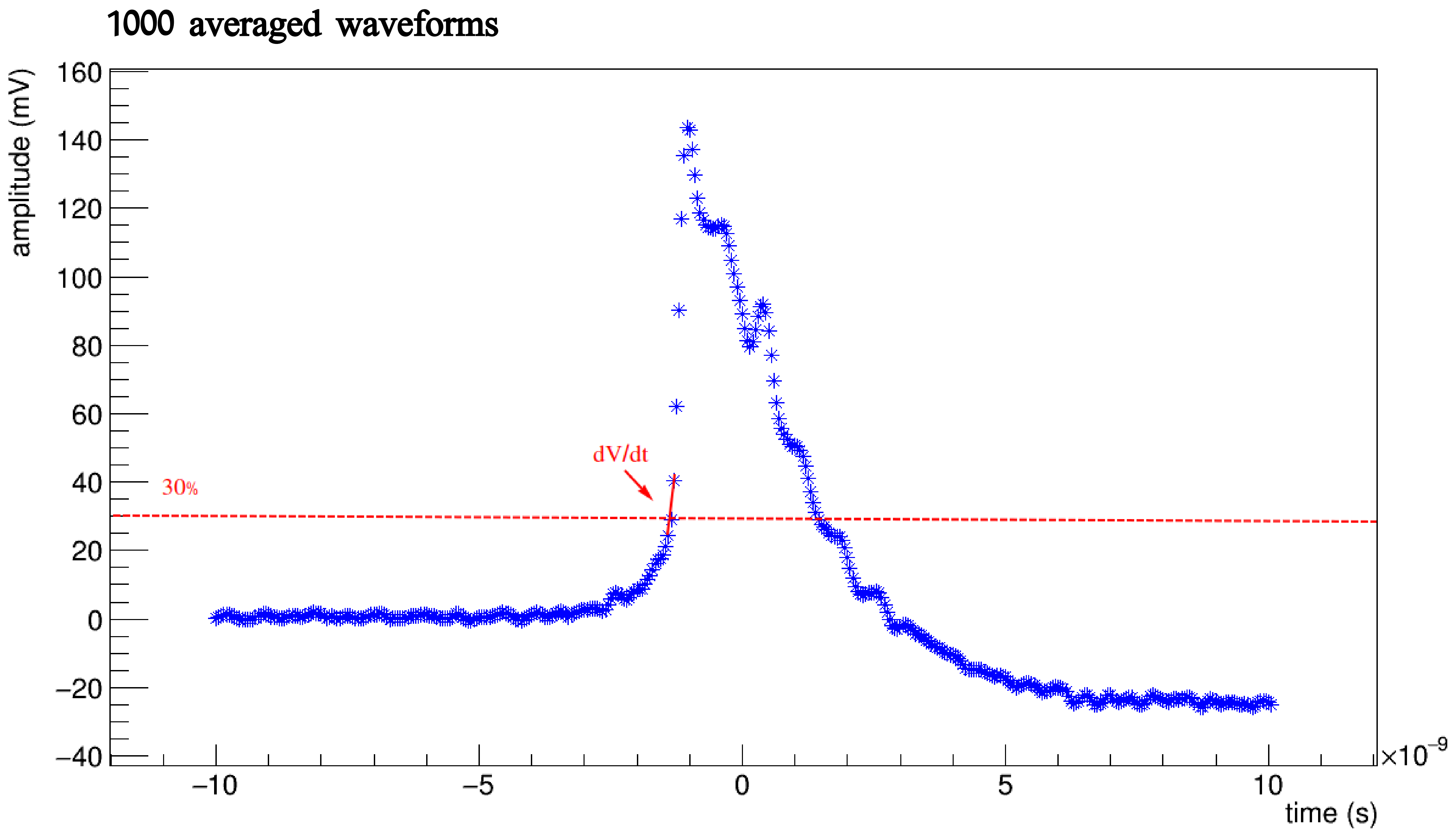


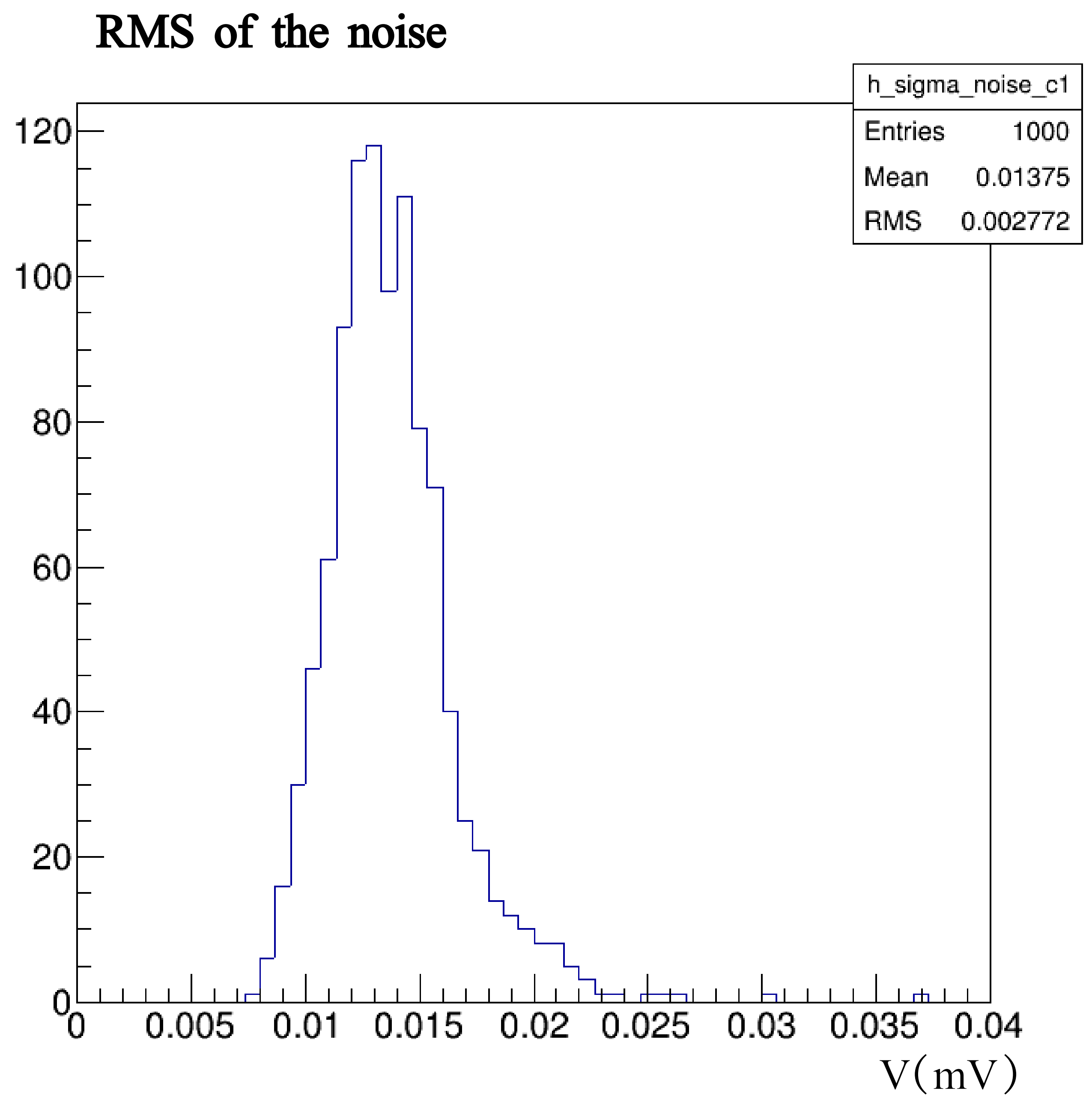
Fit on Δt to obtain: $\sigma_t = (\sigma^2_{LGAD} + \sigma^2_{3D})^{1/2}$

$\sigma^2_{wf} \approx \sigma^2_{3D} - \sigma^2_{j,3D}$

3D Waveform and analysis - σ_j

$$\sigma^2_{wf} \approx \sigma^2_{3D} - \sigma^2_{j,3D}$$

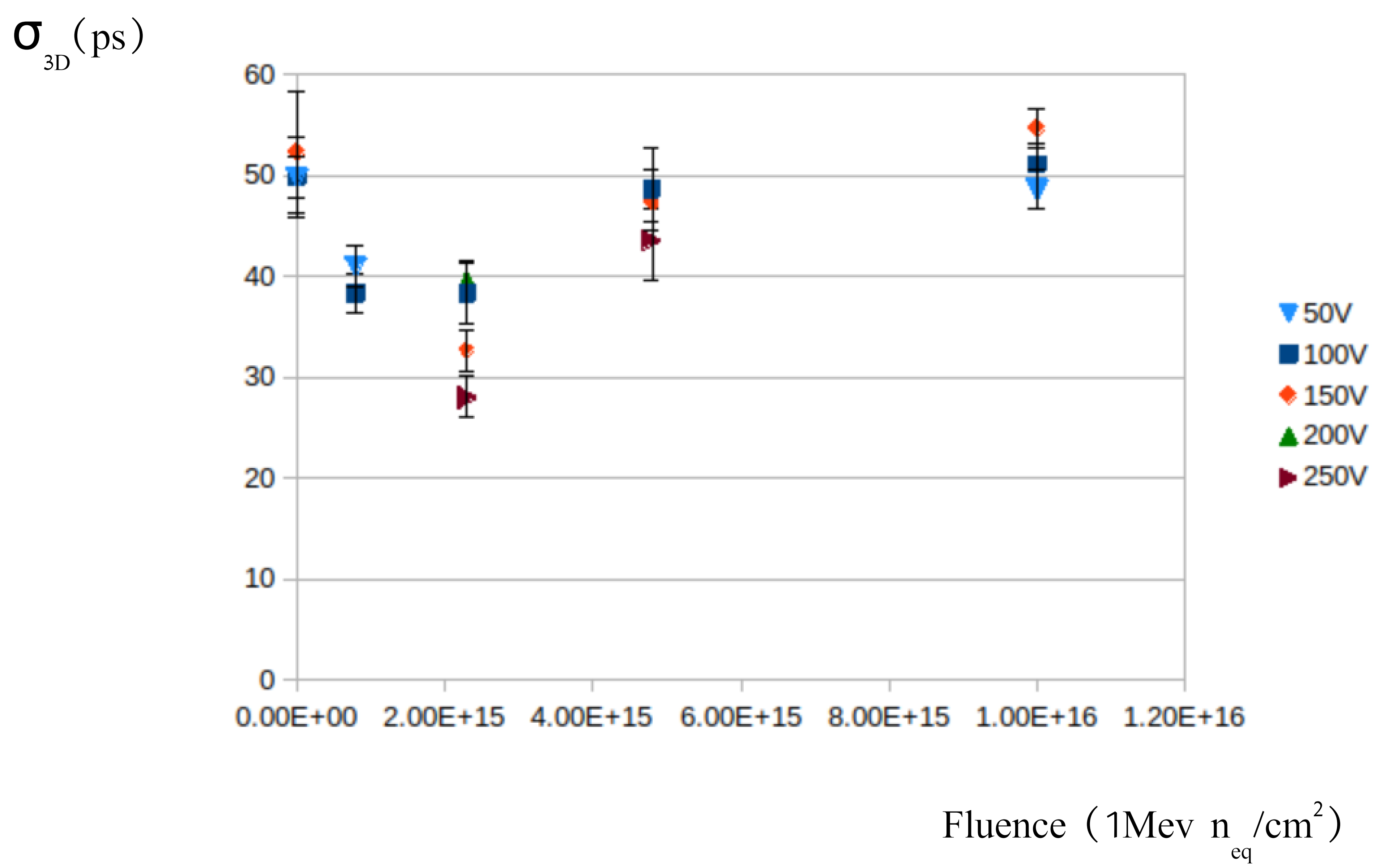




3D time resolution at -20°C VS Fluence

Annealed 60 min at 80°C

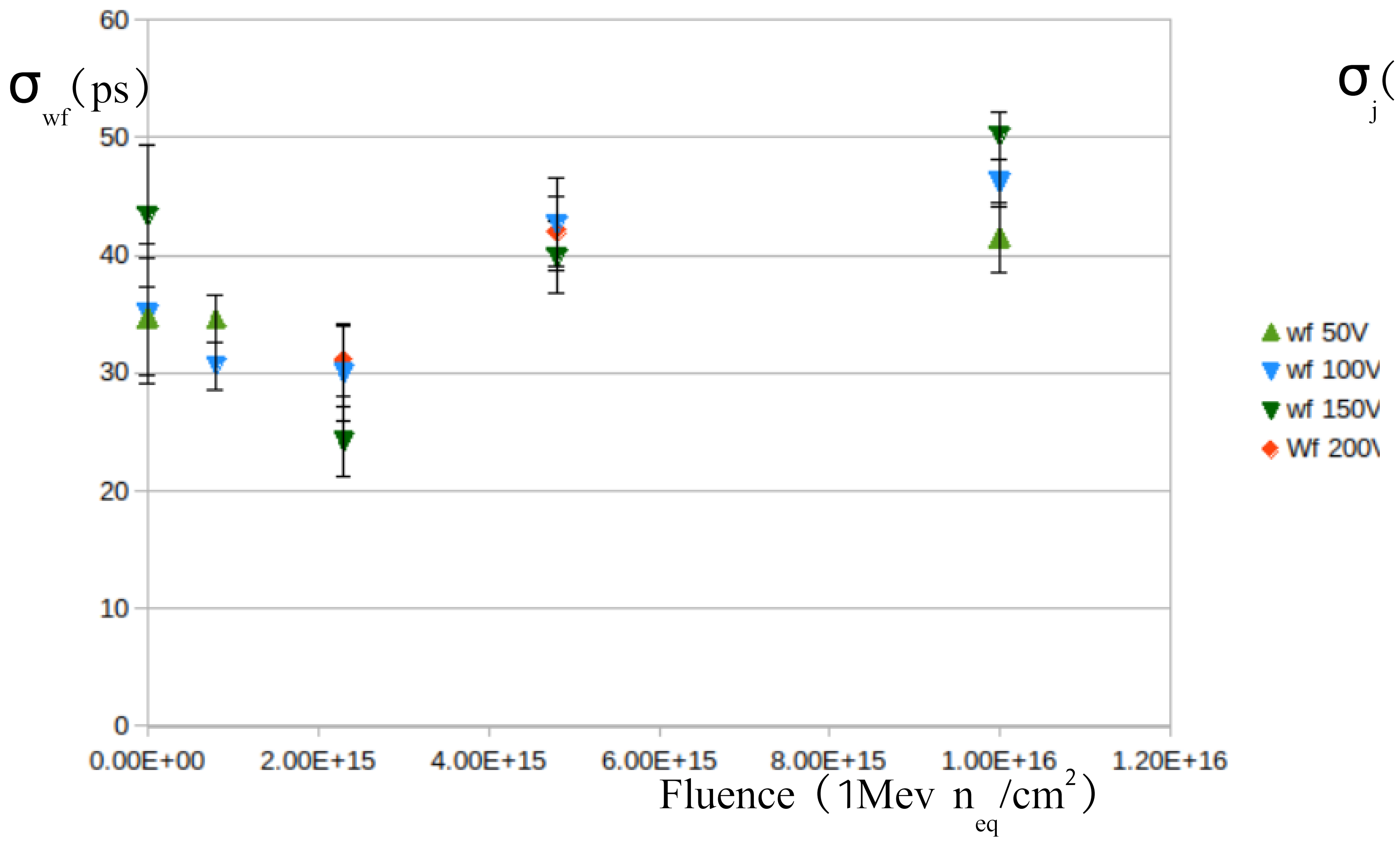
Irradiated at 8×10^{14} 1Mev n_{eq}/cm^2 - 2.3×10^{15} 1Mev n_{eq}/cm^2 – 4.8×10^{15} 1Mev n_{eq}/cm^2 – 1.0×10^{16} 1Mev n_{eq}/cm^2 at Ljubjiana

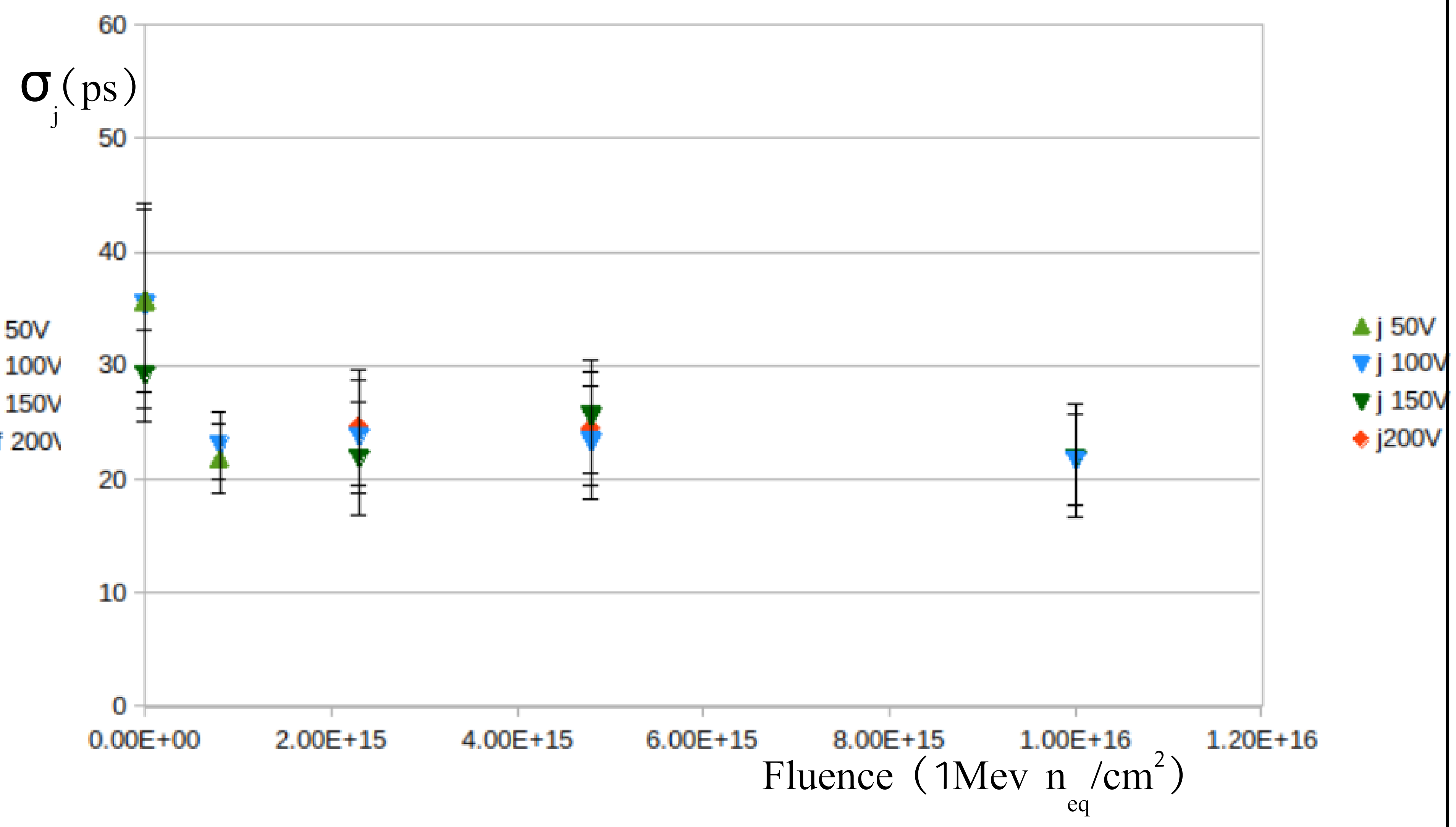


Weighting field and jitter at -20°C VS fluence

Annealed 60 min at 80°C

Irradiated at $8x10^{14}$ 1Mev n_{eq}/cm^2 - $2.3x10^{15}$ 1Mev n_{eq}/cm^2 – $4.8x10^{15}$ 1Mev n_{eq}/cm^{2} - $1.0x10^{16}$ 1Mev n_{eq}/cm^2 at Ljubjiana

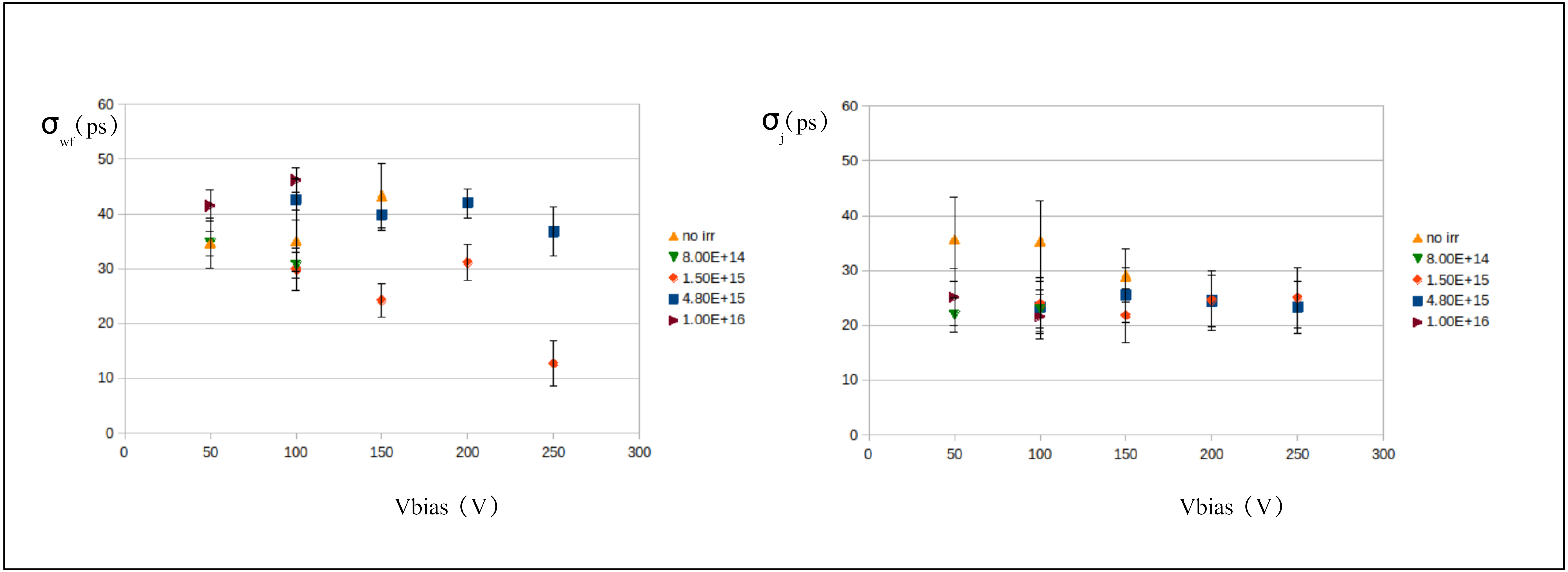




Weighting field and jitter contribution at -20°C VS Bias voltage

Annealed 60 min at 80°C

Irradiated at $8x10^{14}$ 1Mev n_{eq}/cm^2 - $2.3x10^{15}$ 1Mev n_{eq}/cm^2 – $4.8x10^{15}$ 1Mev n_{eq}/cm^2 - $1.0x10^{16}$ 1Mev n_{eq}/cm^2 at Ljubjiana

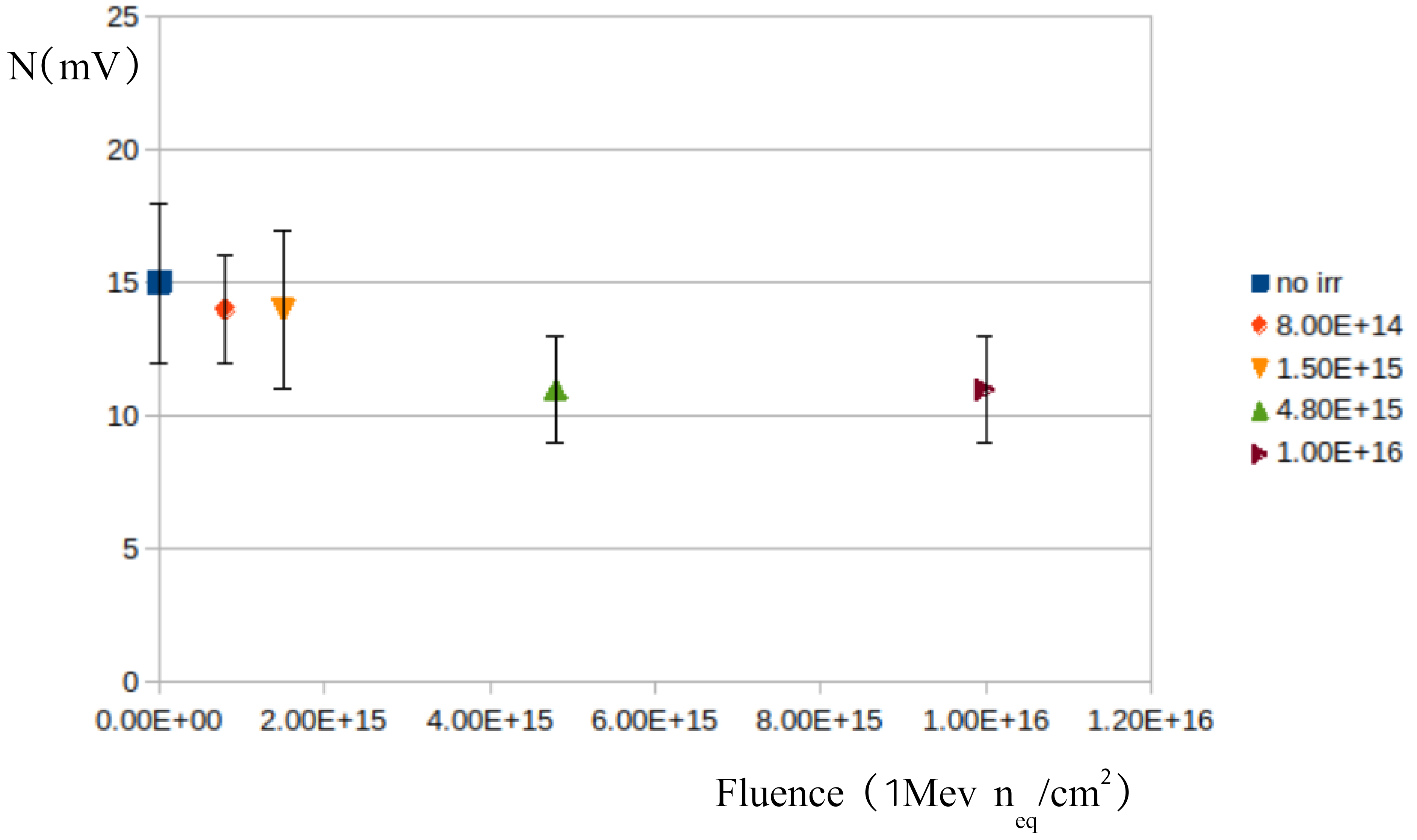


Conclusions

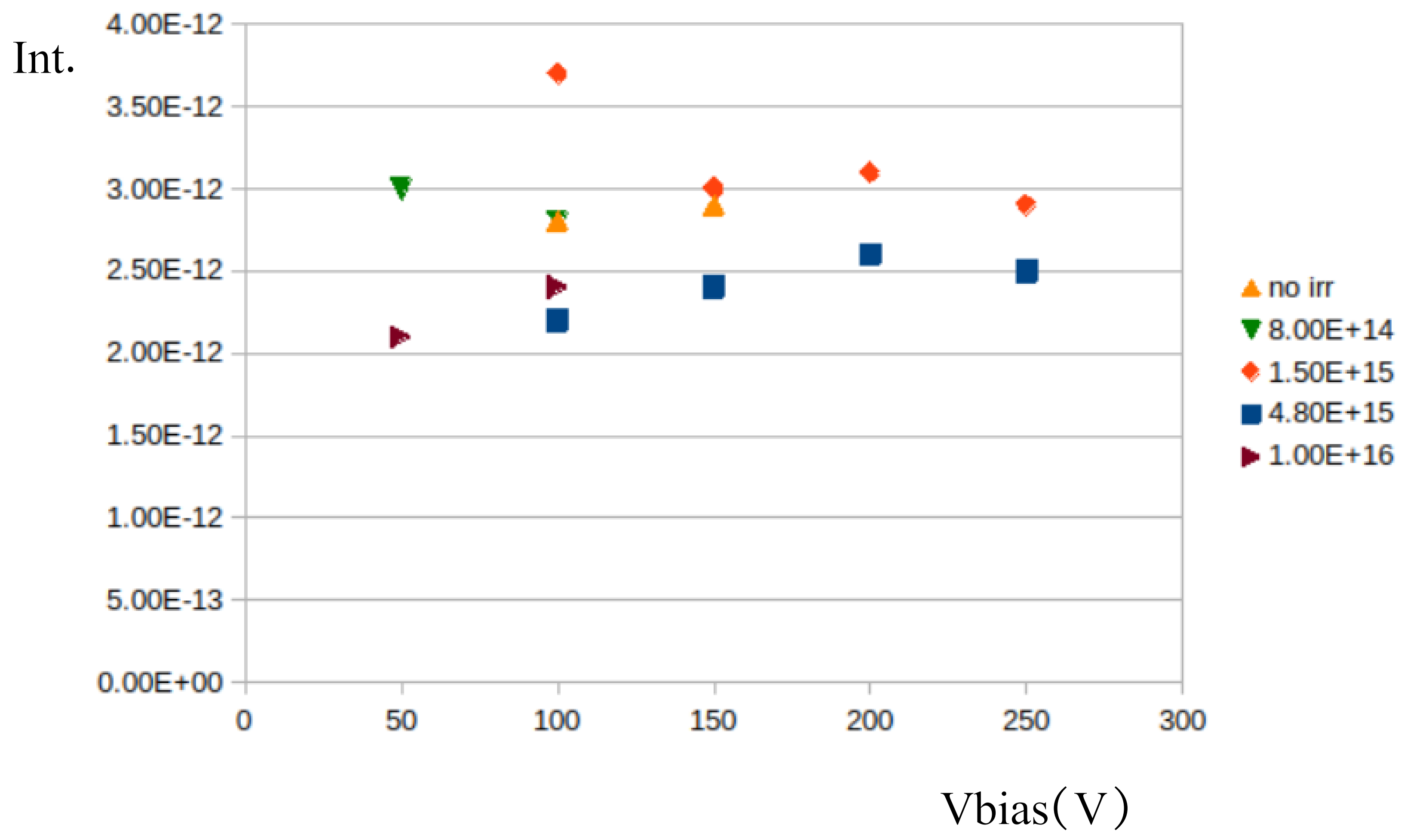
- We have reported data for 3D detector with thickness of 285 μm at 50,100,150,200,250 V_B at −20°C before and after n irradiation of $8x10^{14}$ 1MeV n_{eq}/cm^2 −$2.3x10^{15}$ 1Mev n_{eq}/cm^2 – $4.8x10^{15}$ 1Mev n_{eq}/cm^2 – $1.0x10^{16}$ 1Mev n_{eq}/cm^2
- Total time resolution of 50 ps, better resolution for intermediate fluences $8x10^{14}$ 1MeV n_{eq}/cm^2 −$2.3x10^{15}$ 1Mev n_{eq}/cm^2
- Behaviour of temporal resolution as a function of fluence attributable to weighting field contribute
- No remarkable difference for Vbias, for the last radiation dose it looks a bit better for 50V than for 100V

Backup - Analysis

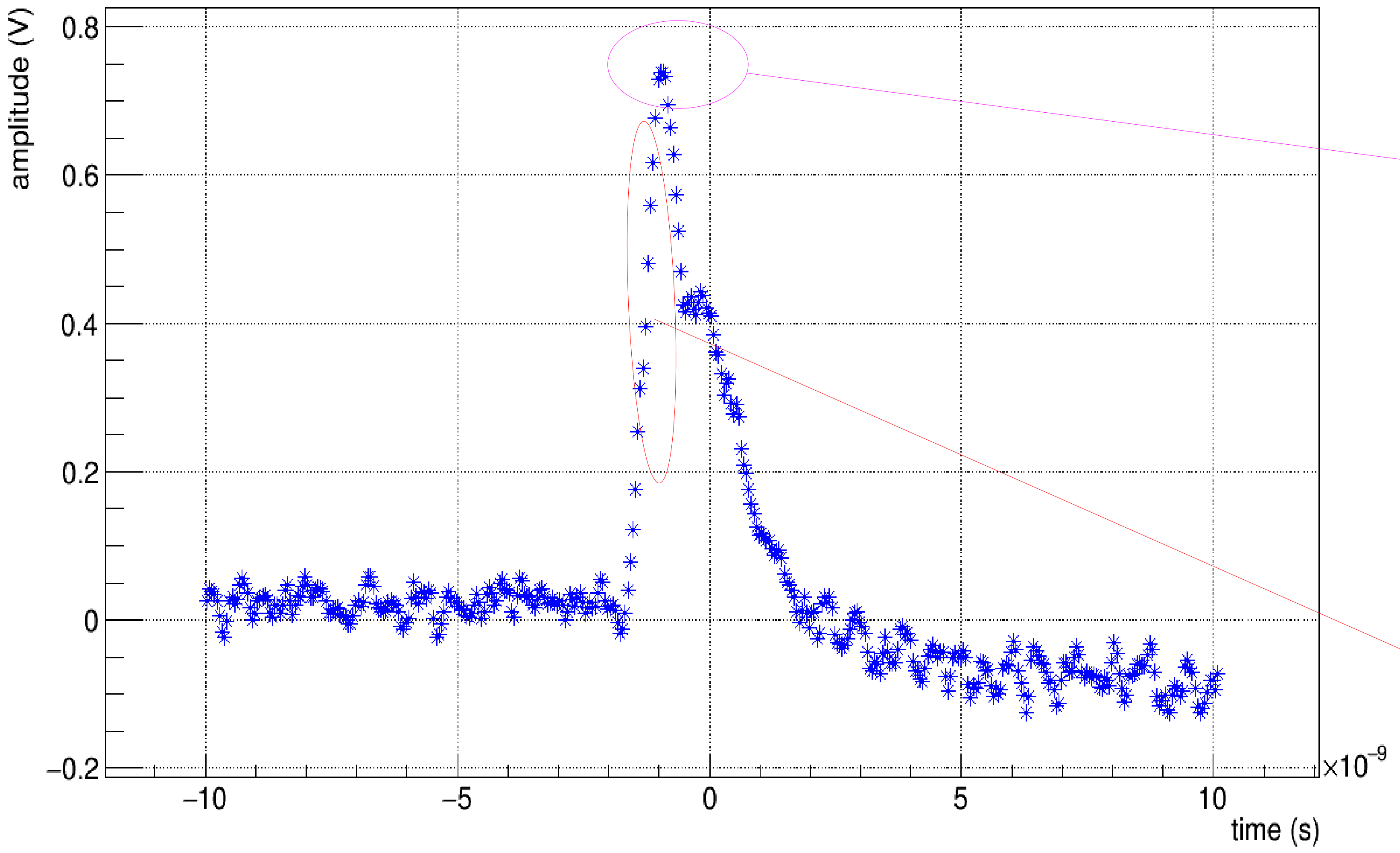
Noise



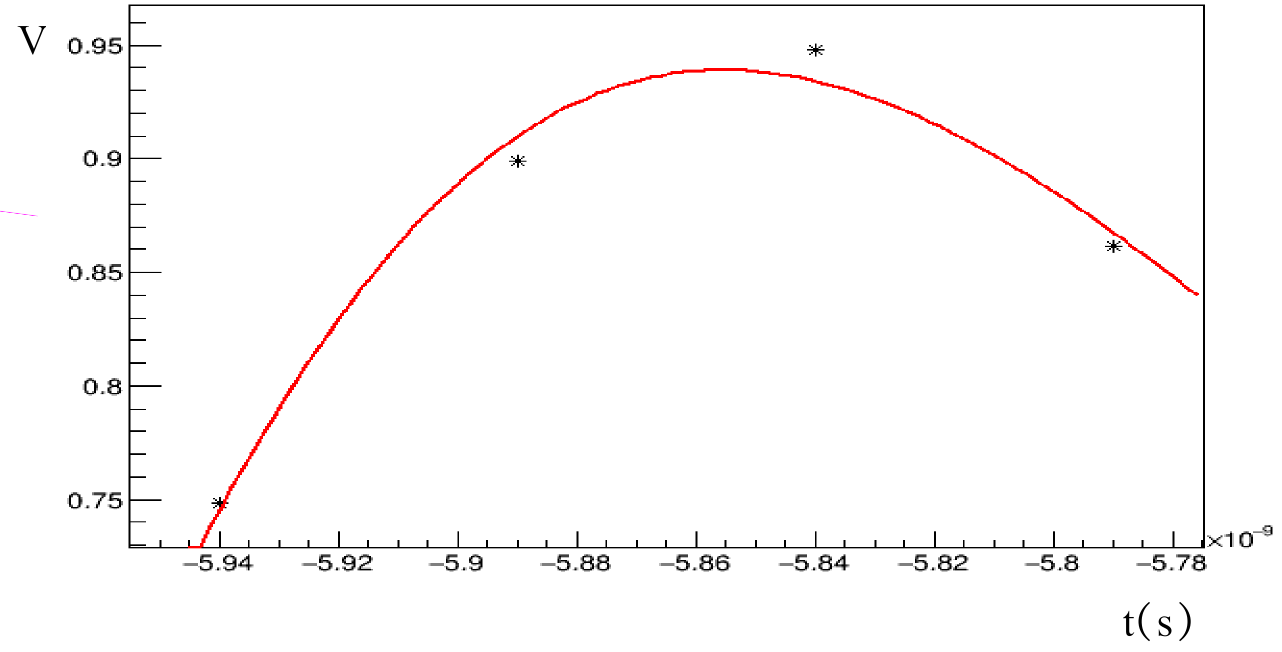
Charge Collection -20



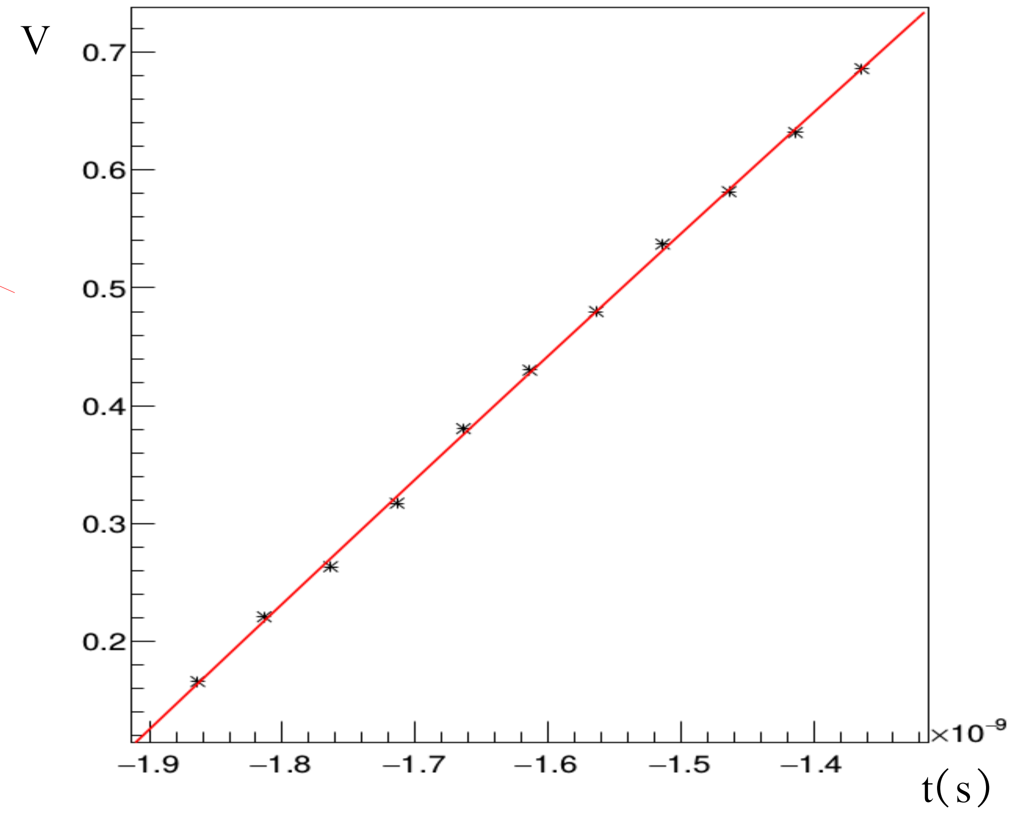
LGAD Waveform Analysis



3)



4)



1) Noise estimation: gaus fit on the first 100 pt. (5 ns)

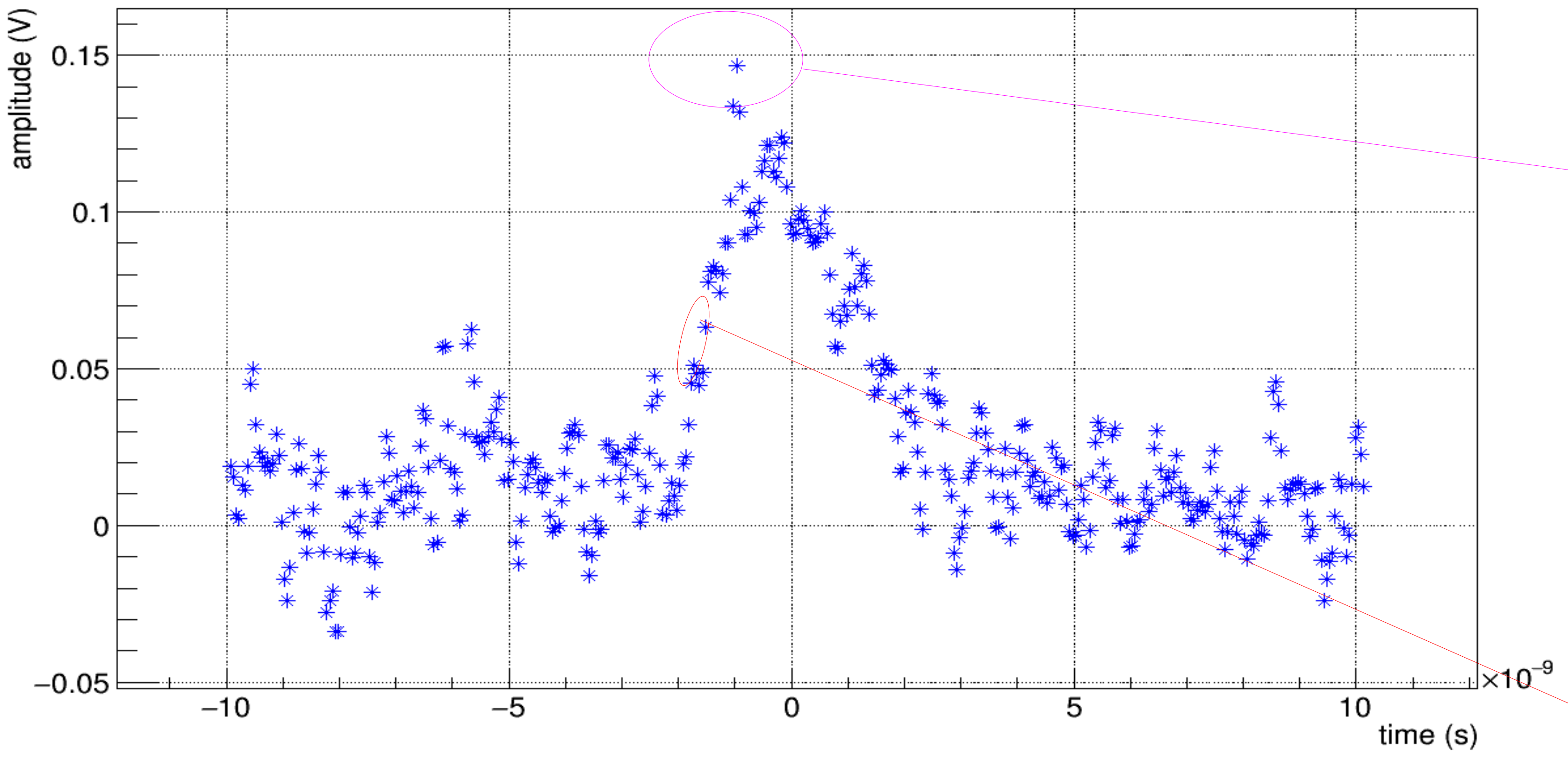
2) Offset correction

3) Landau fit around the maximum value in amplitude (4 pt.) and extrapolation of t_{MAX}

4) Landau fit (11 pt.) on the waveform rising

5) Extrapolation of t^{*}_{LGAD}

3D Waveform analysis



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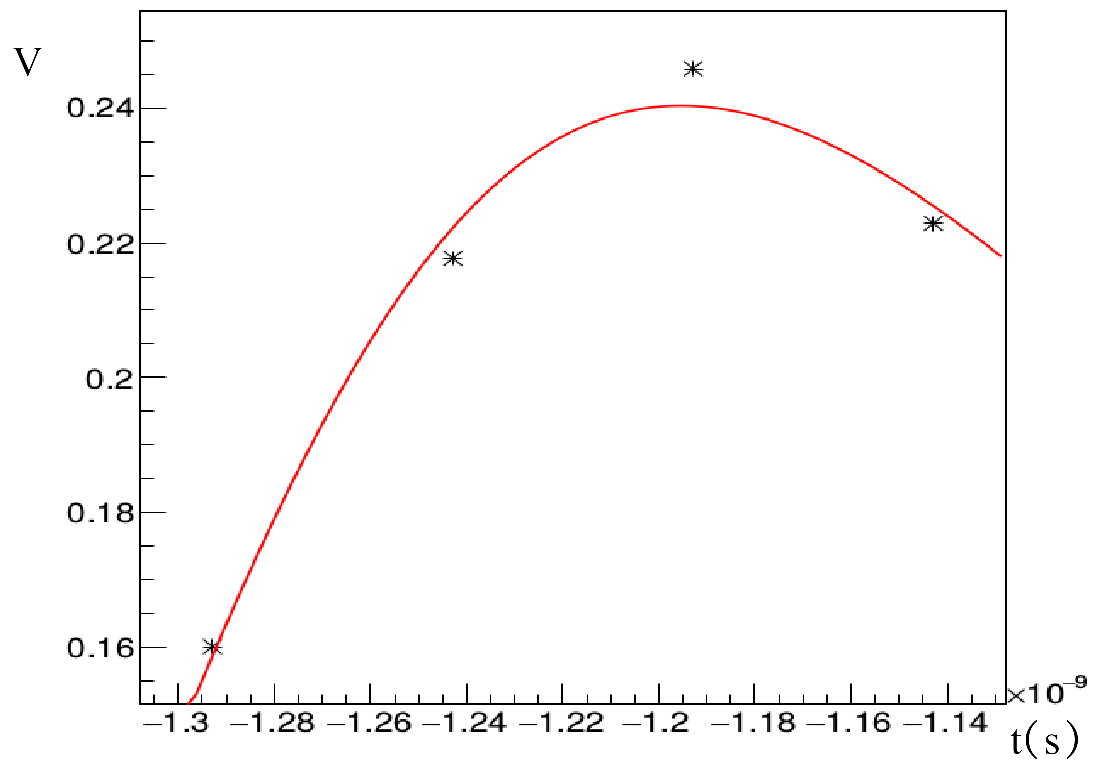

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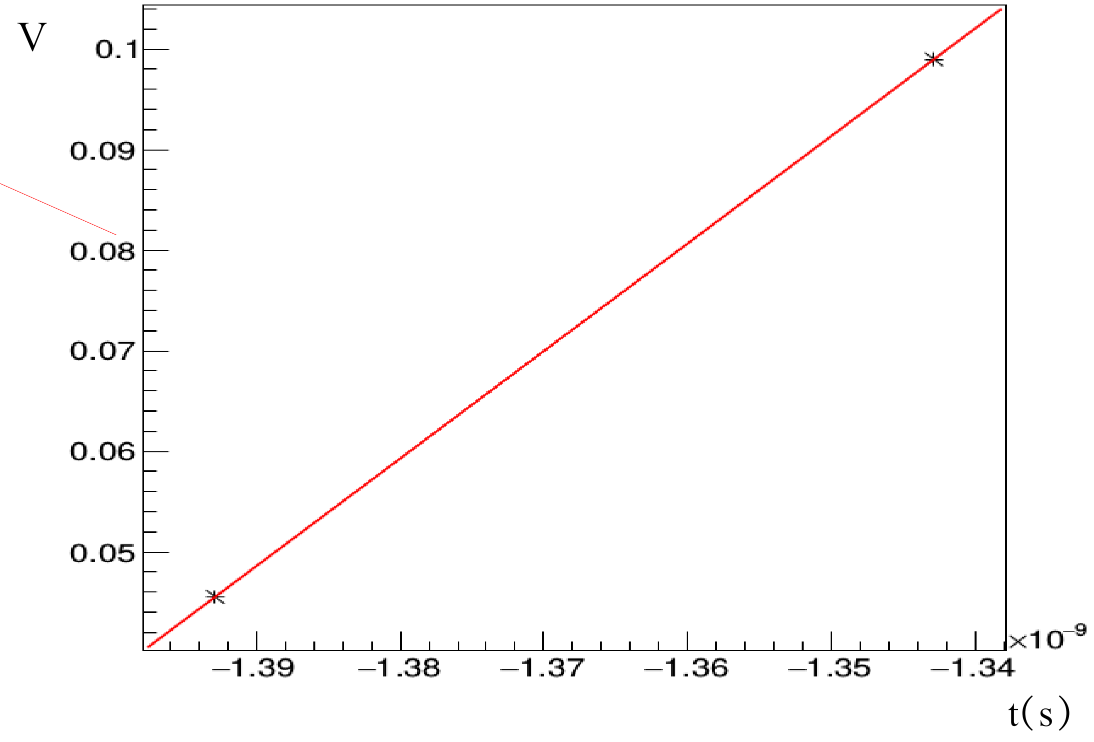

1) Noise estimation: gaus fit on the first 100 pt. (5 ns)

2) Offset correction

3) Landau fit around the maximum value in amplitude (4 pt.)
and extrapolation of t_{MAX}

4) Linear fit (2 pt.) with the first point which crosses the threshold and the previous one

5) Extrapolation of t^*_{3D}