Timing Characterization of LGADs for Space Based Applications

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FONDAZIONE BRUNO KESSLER

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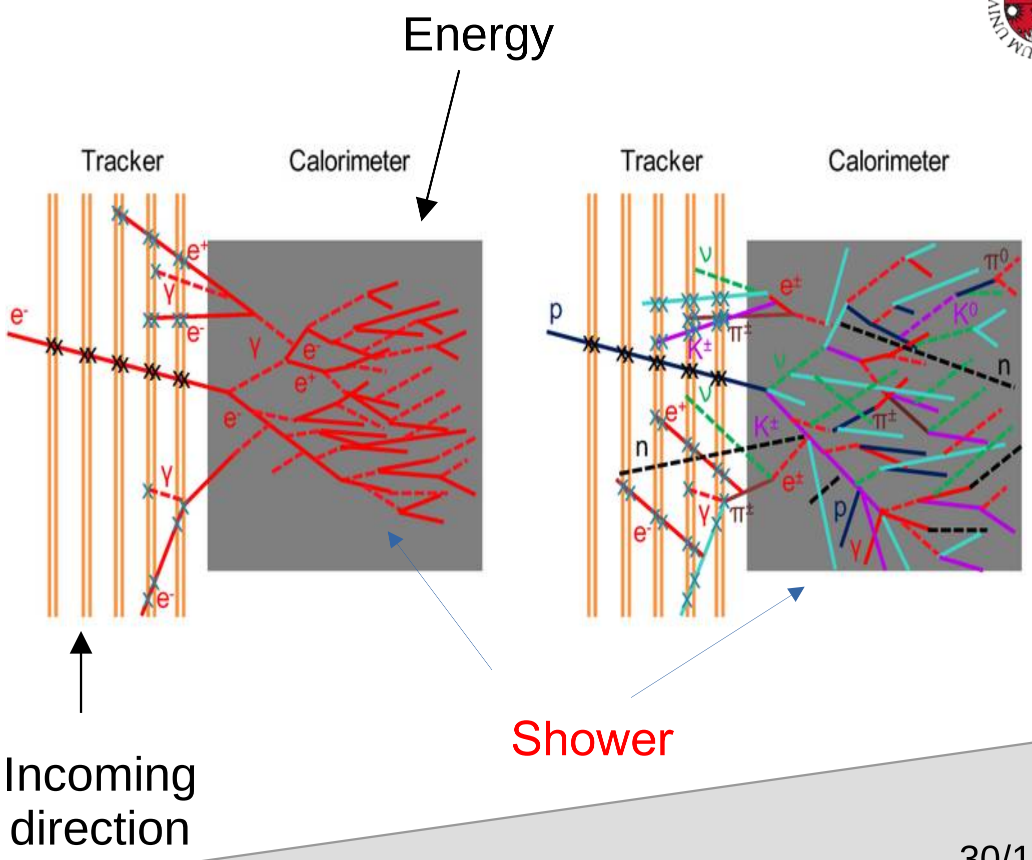
The Scientific Reason

Advantages of Timing

- Identification of back-scattered hits from calorimeters
- Time of Flight (ToF) measurements
- Improved e/p

Requirements in Space

- Power consumption
- Timing O(100 ps)
- Large Channel size ← (Small Particle Flux)



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The Scientific Reason

Advantages of ...

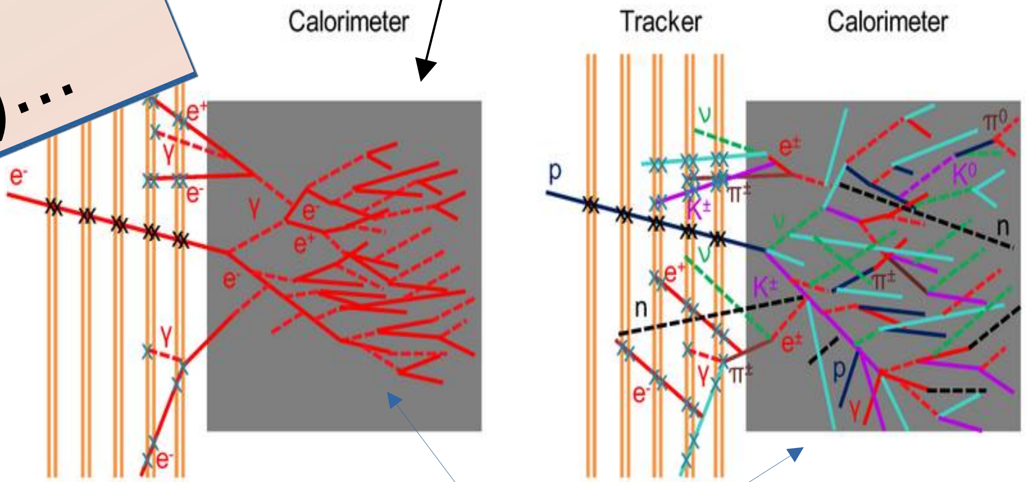
- Identification of h... calorimeter...
- T...
- In...

...s in Space

- Pow... ...umption
- Timing O(100 ps)
- Large Channel...

LGADs are good candidates: Time resolution O(10 ps)...

Energy



But are produced with channels of few mm^2

Space LGAD production

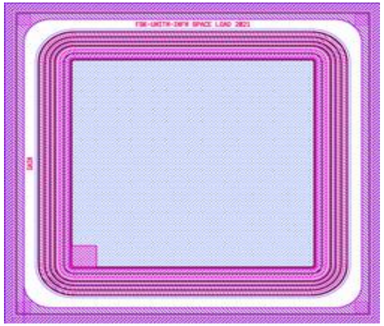
Active Thickness
- 50 um
- 100 um
- 150 um

Active Area
- 6.25 mm^2
- 25 mm^2
- 100 mm^2

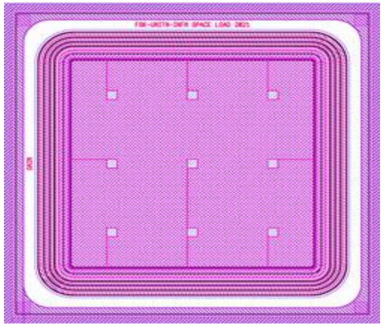
Layout Types

- **Type 1**: Open Frame
- **Type 2**: Fully Metallized, Contacts at the edge of the active area
- **Type 3**: Fully Metallized, Contact points spread in the active area

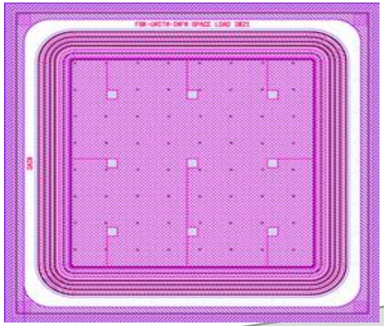
Type 1



Type 2



Type 3

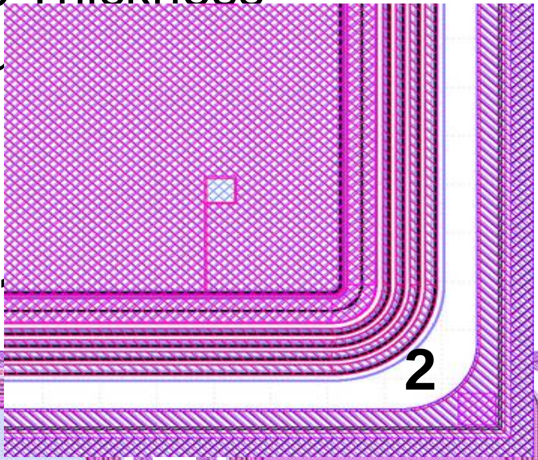


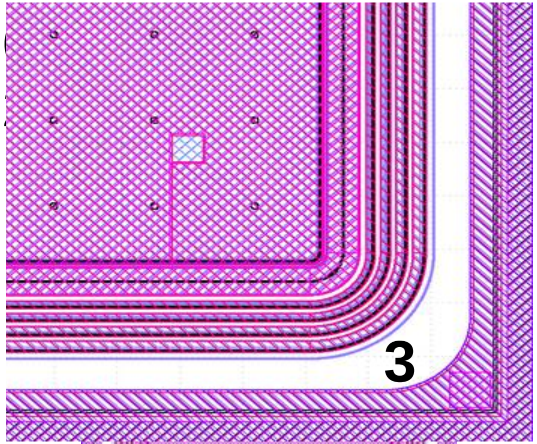
Space LGAD production

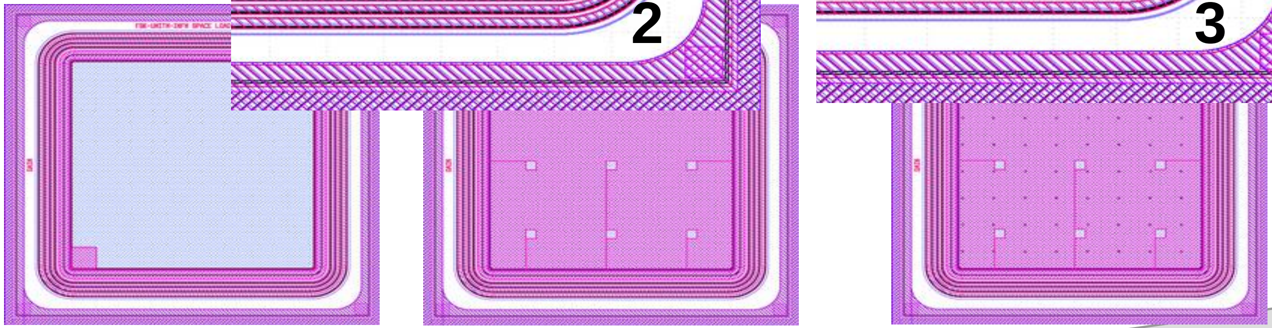
Active Thickness
- 50 u
- 100
- 150

Active Area
-
-
-

Type







Layout Types

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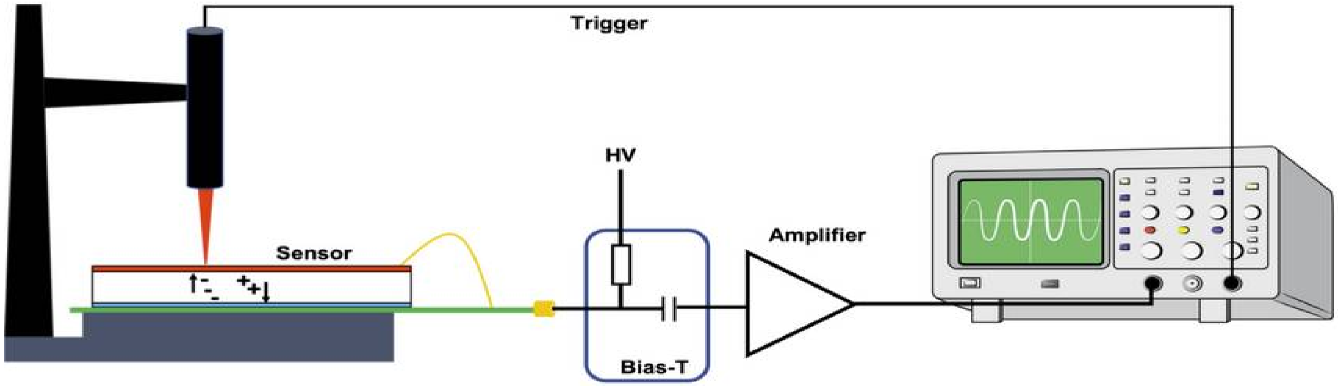
The Setup

Setup: Scanning TCT, Particulars



[A. Bisht, Development of Low Gain Avalanche Detectors for Astroparticle Physics Experiments in Space, Trento 2023]

PCB: FNAL
16 channels

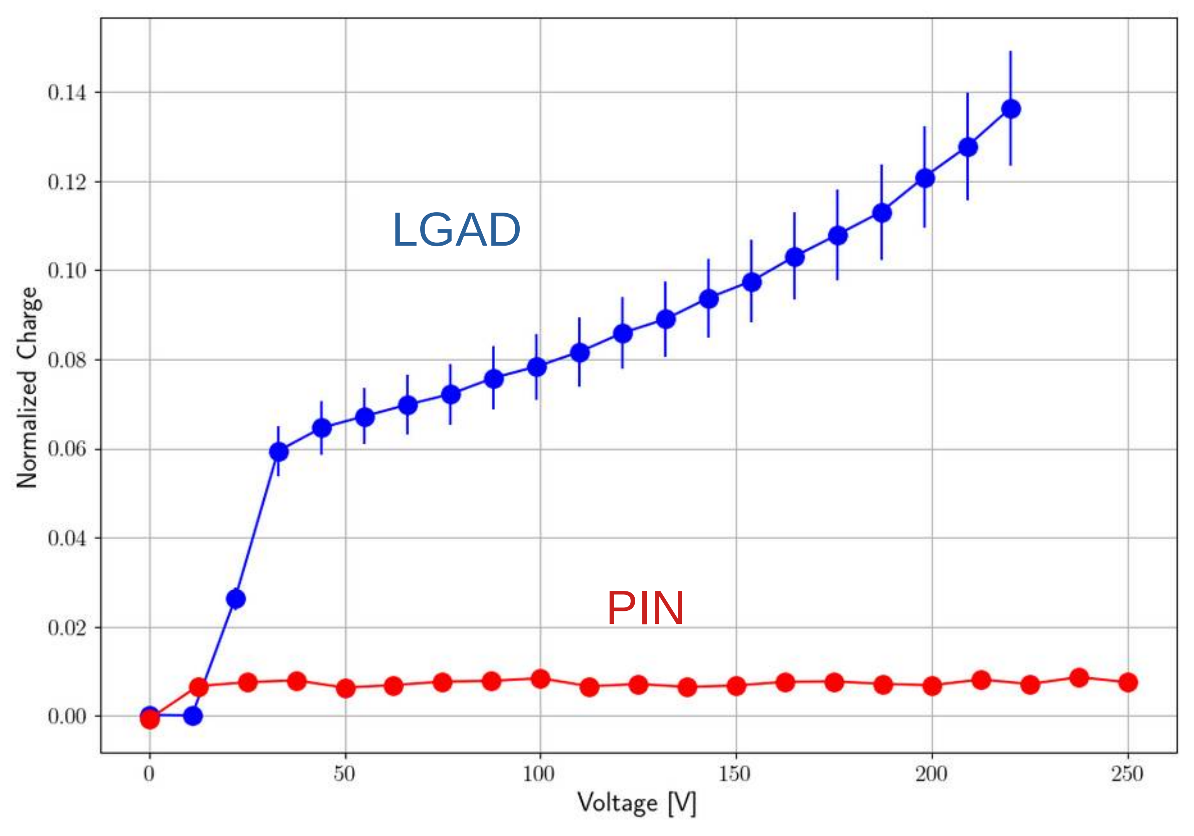
Infra-Red (1060 nm) and Red (600 nm) pulsed laser

X/Y translation stage (0.8 um precision)

Beam Monitor

1 MIP calibration with radioactive source

Gain



$$Gain = \frac{Ch_{LGAD}[fC]}{Ch_{PIN}[fC]}$$

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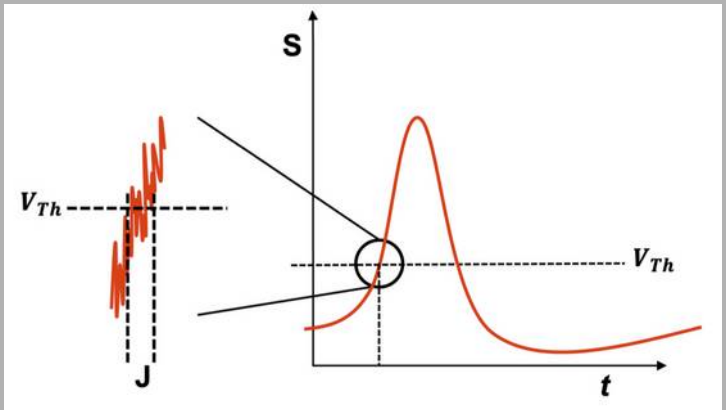
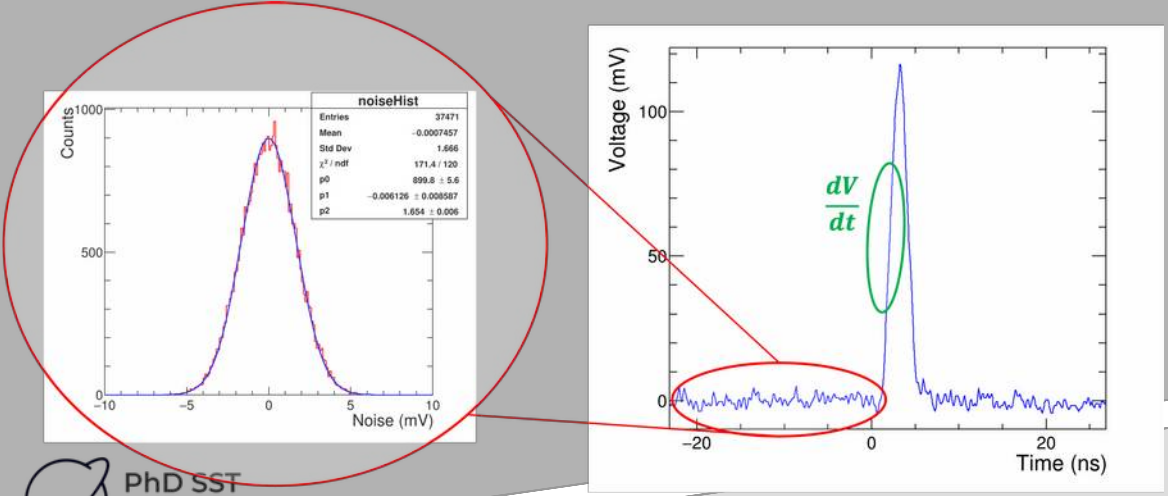
Jitter

Two Acquisitions:

- ✓ Single Waveform → Noise Estimation
- ✓ Average Waveform → Slew Rate Estimation via Fitting the leading edge





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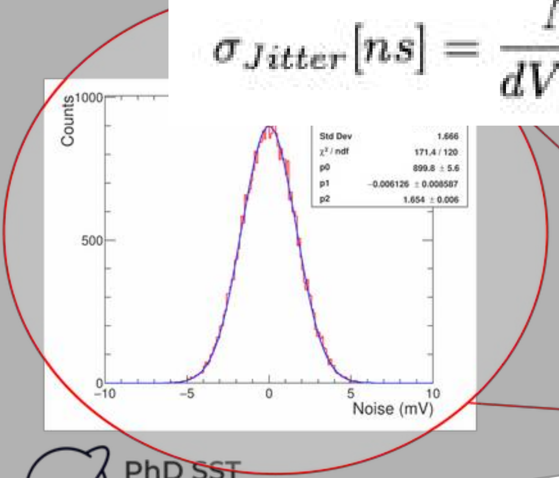
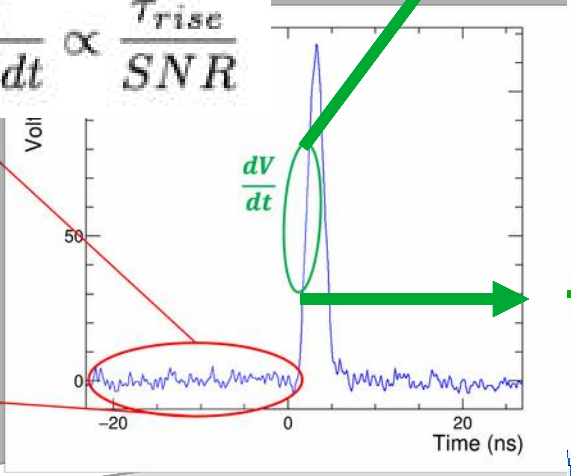
Jitter

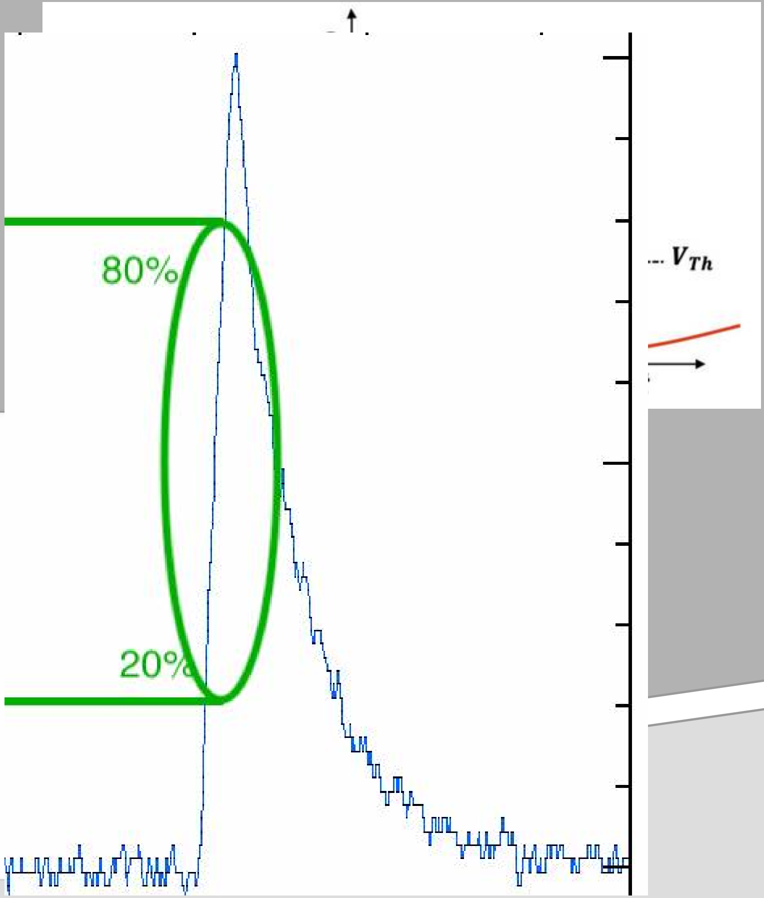
Two Acquisitions:

- ✓ Single Waveform → Noise Estimation
- ✓ Average Waveform → Slew Rate Estimation via Fitting the leading edge

$$\sigma_{Jitter}[ns] = \frac{N}{dV/dt} \propto \frac{\tau_{rise}}{SNR}$$







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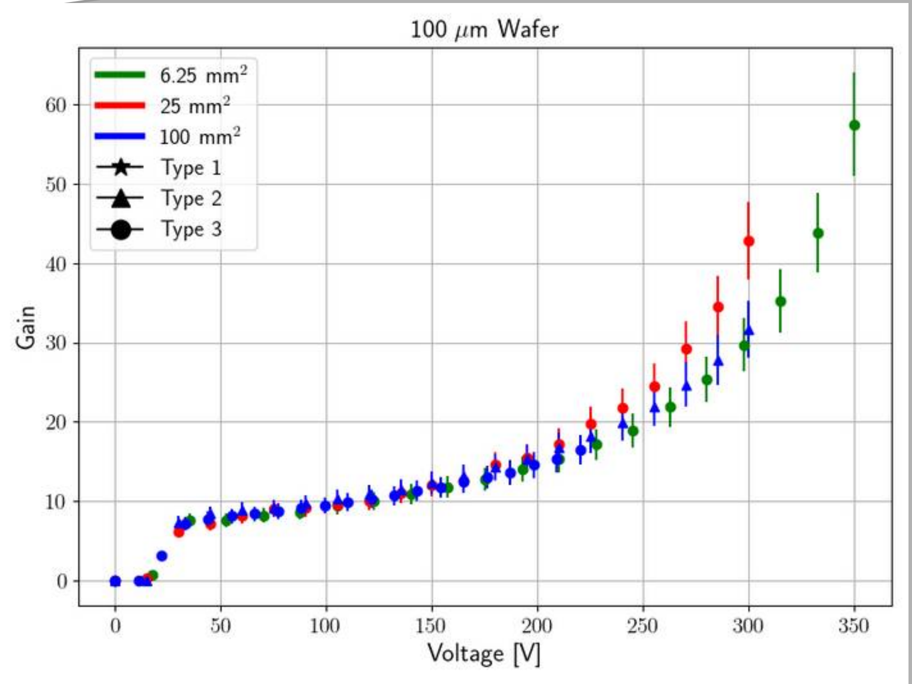
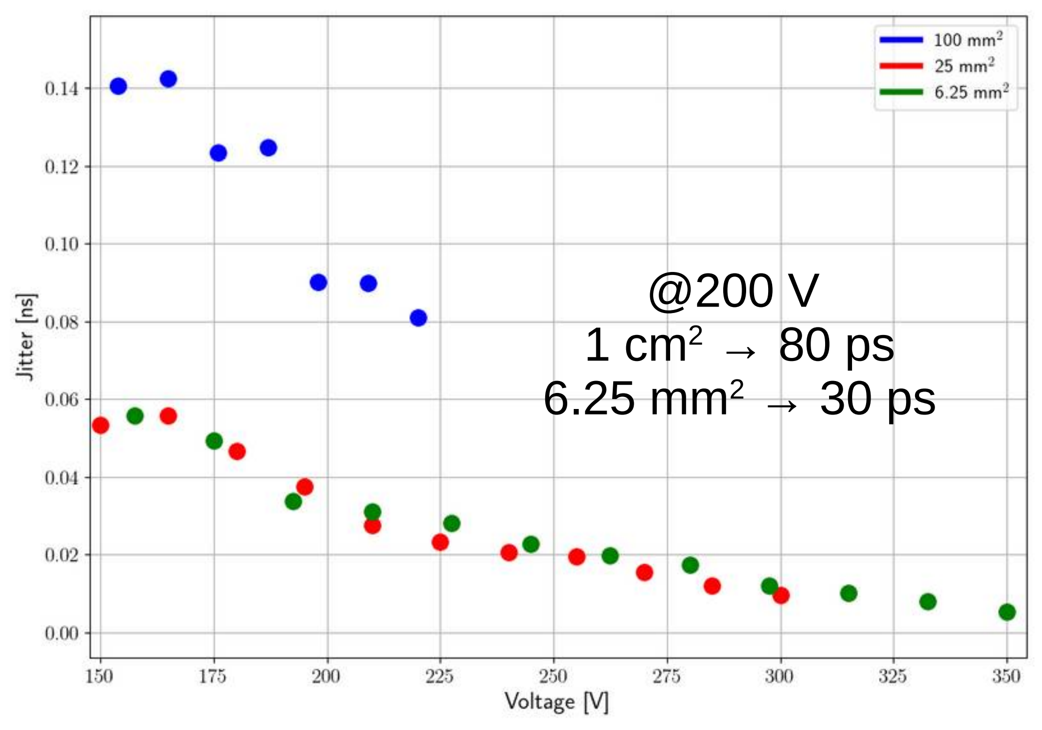
LGADs
Performance vs Area





@200 V
1 cm^2 → 80 ps
6.25 mm^2 → 30 ps

Sensitive area plays a major role in the jitter

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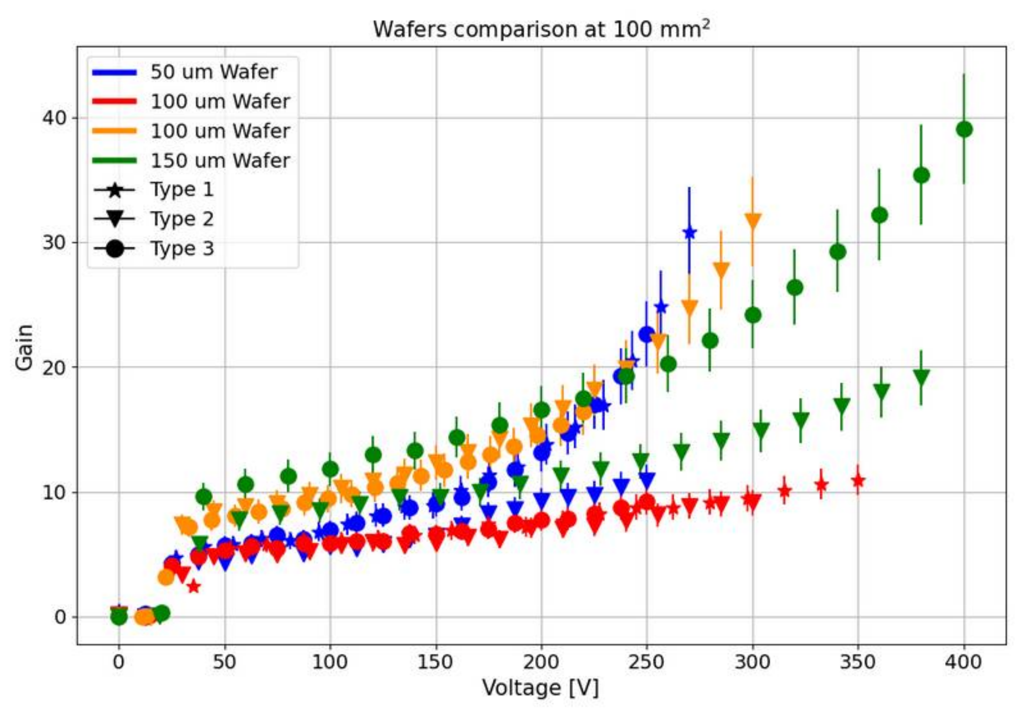
1 cm^2 LGADs Performance



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Gain smaller than expected (100)

1 cm^2 LGADs
Performance

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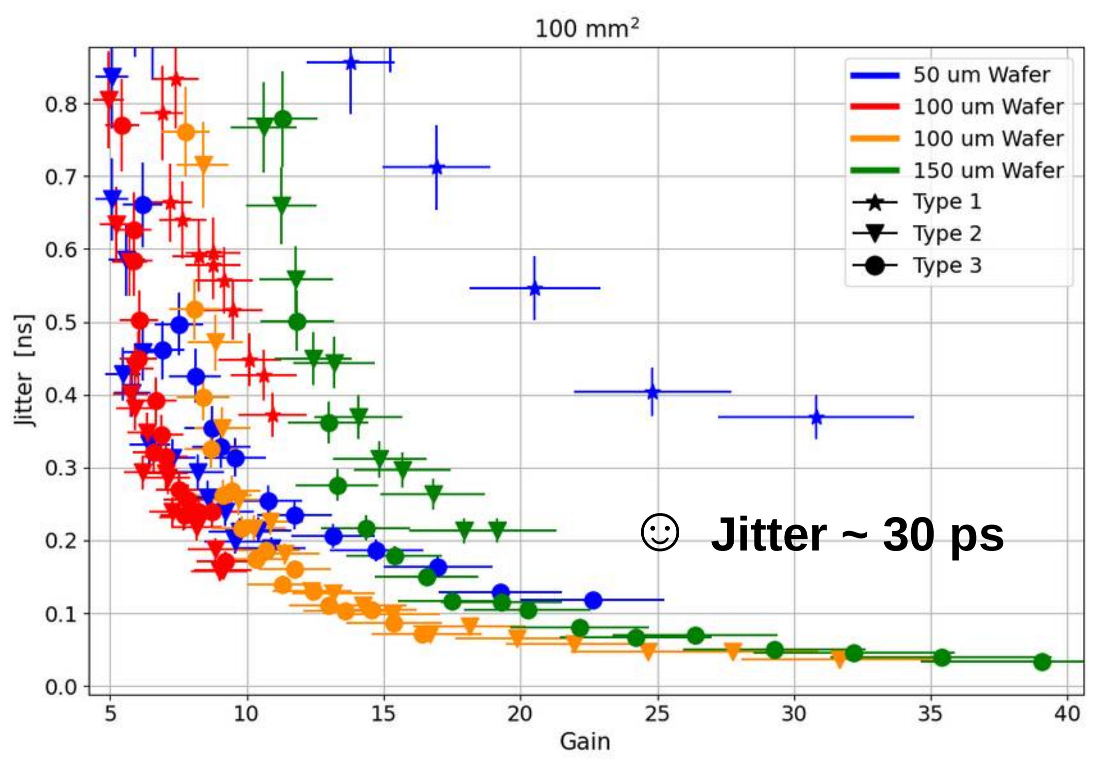

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1 cm^2 LGADs
Uniformity

1 cm = 30 ps
@ light speed

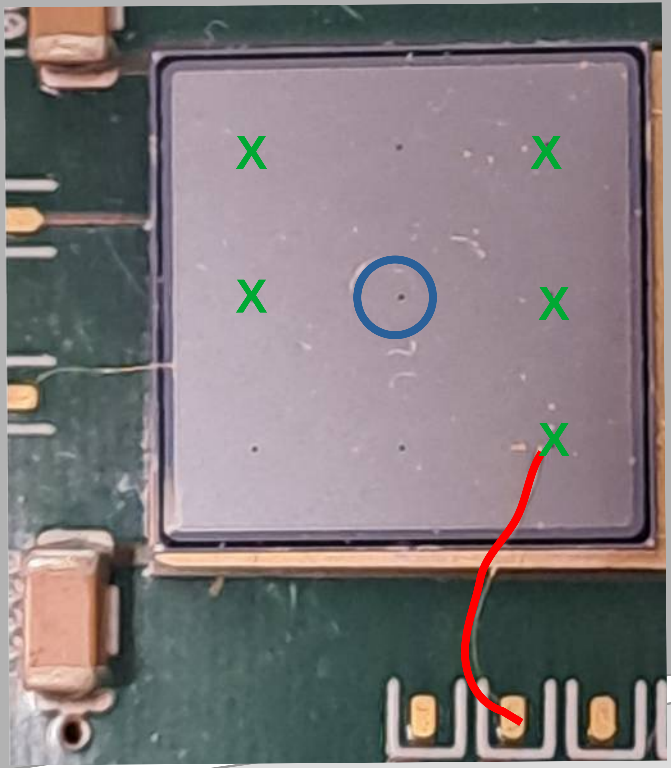
↓

Signal formation and
transmission variability

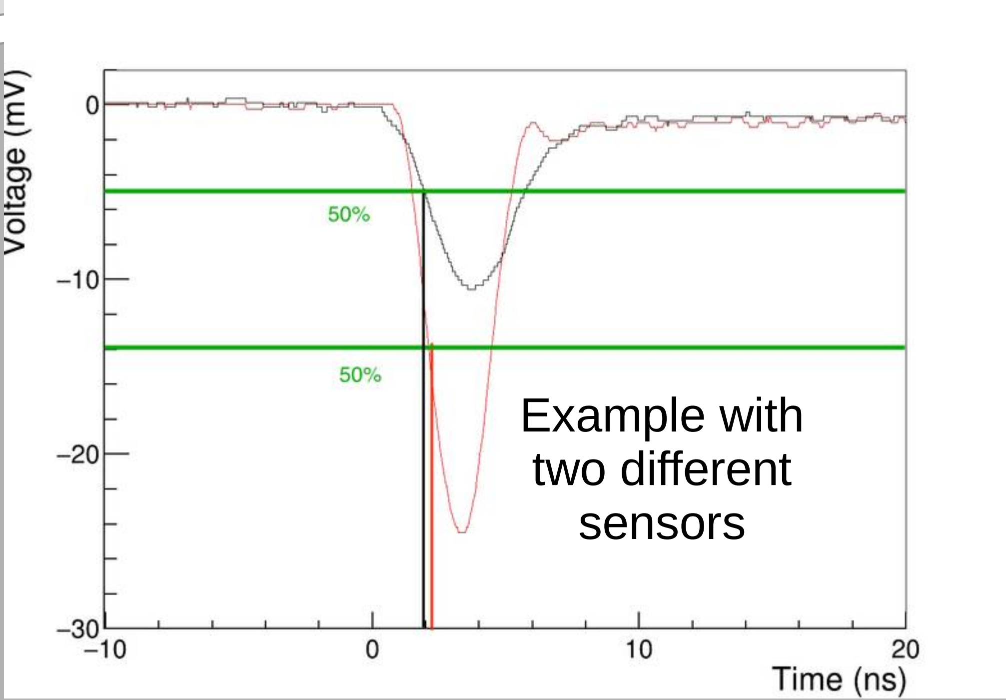
Reference point
is the signal bond

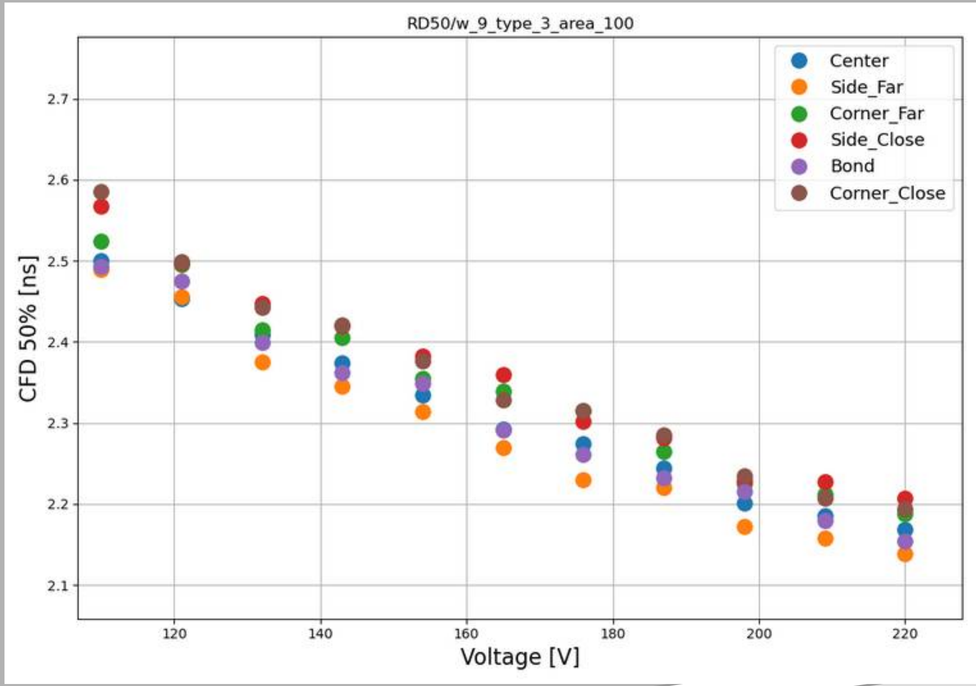
"Standard" Hit
position

X = Uniformity
Check points

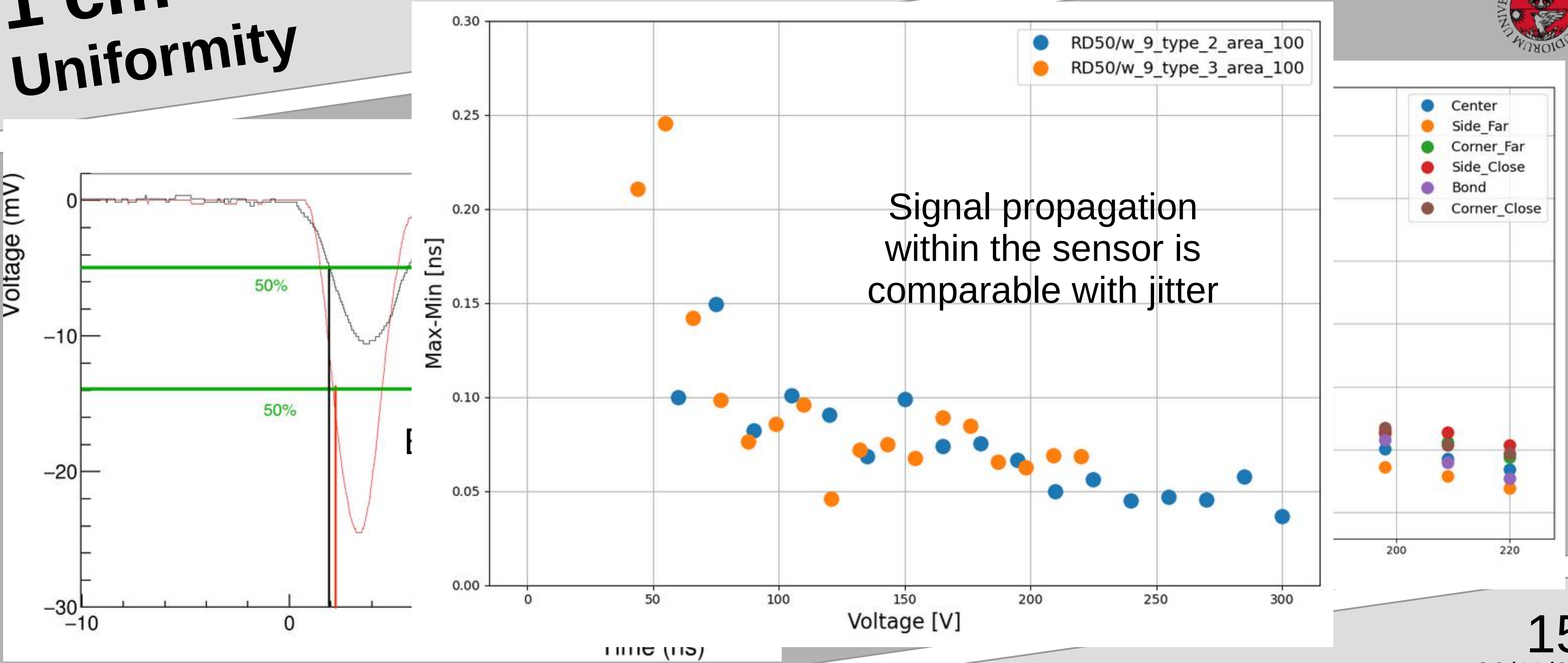


1 cm^2 LGADs
Uniformity





1 cm^2 LGADs
Uniformity



Conclusions

With the current technology, LGADs have time resolution capabilities O(10 ps), in case of a mm^2 device.

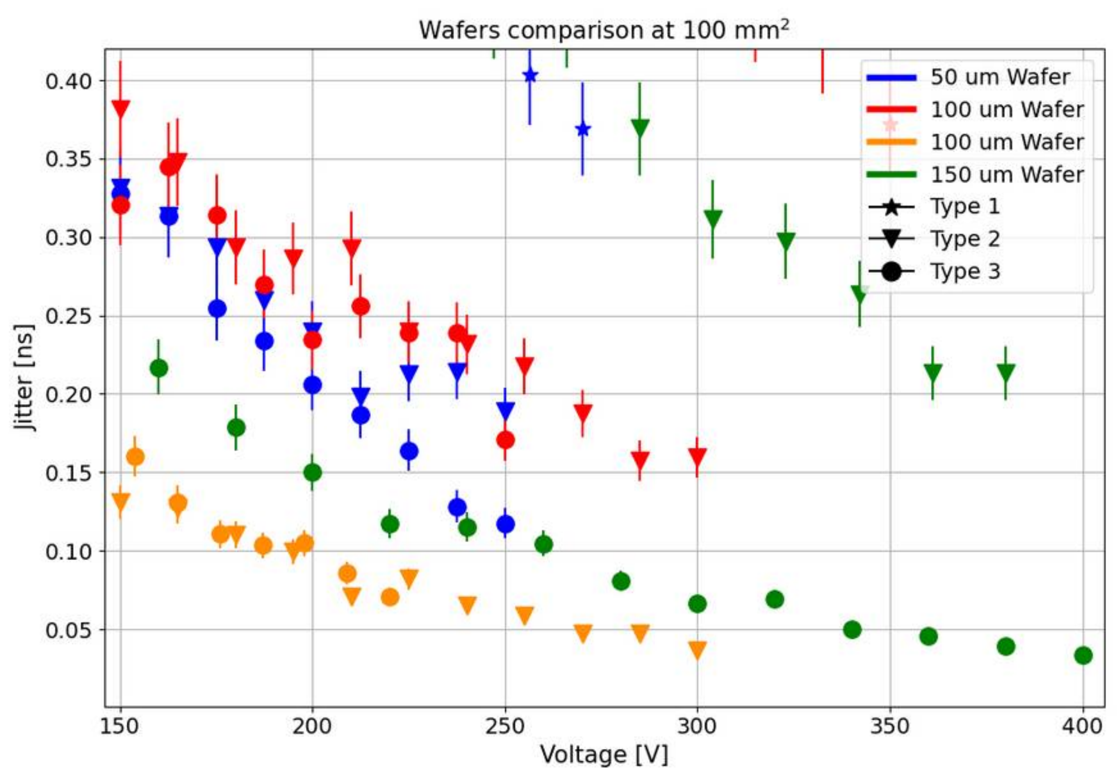
We produced 1 cm^2 devices which achieve:

“

100 um @ 300 V→35 ps
150 um @ 400 V→30 ps

Must be considered the Time of Arrival (< 50 ps) of the signal for the Resolution, **for every layout**

”



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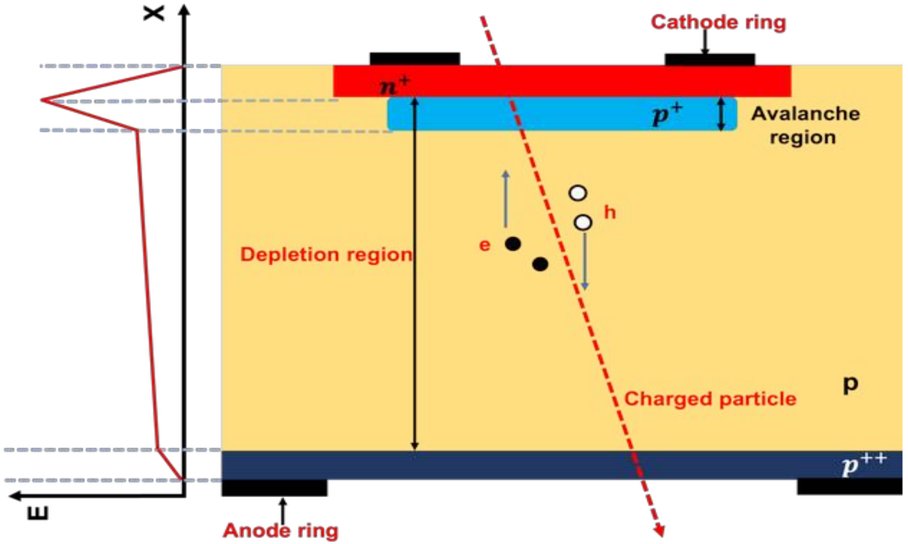
LGADs in Brief



[G. Kramberger et al. NIMA 2018,
DOI: https://doi.org/ 10.1016/j.nima.2018.02.018]

- Silicon detector with charge multiplication
- Gain layer provides high-field region
- Improved SNR: 5-10 times better than current PIN detectors
- Excellent radiation hardness > 10^{15} neq/cm^2
- **Time resolution O(10 ps)**
- **Typical channel area 1-2 mm^2**

$$i_S = -\frac{dQ}{dt} = q\,\vec{E}_w\,\vec{v}$$

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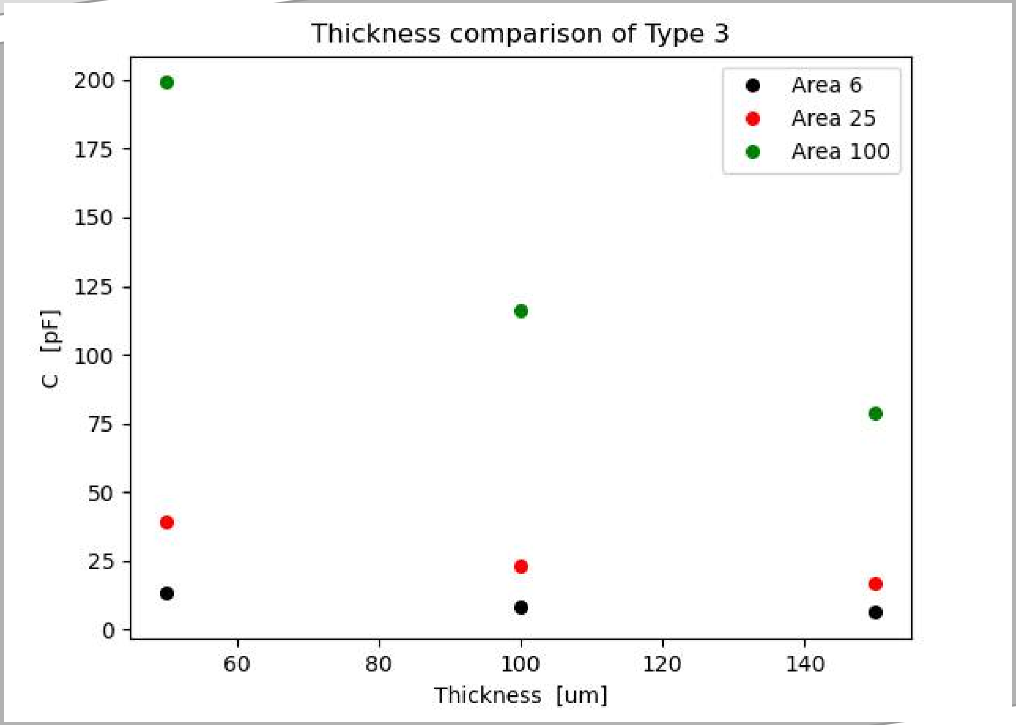
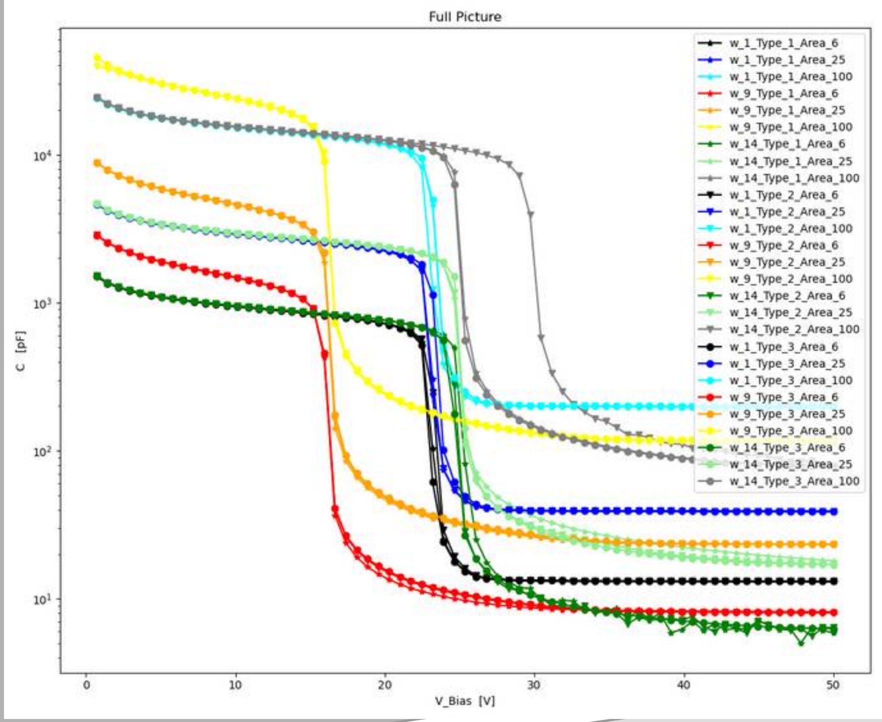
Preliminary: Capacitance





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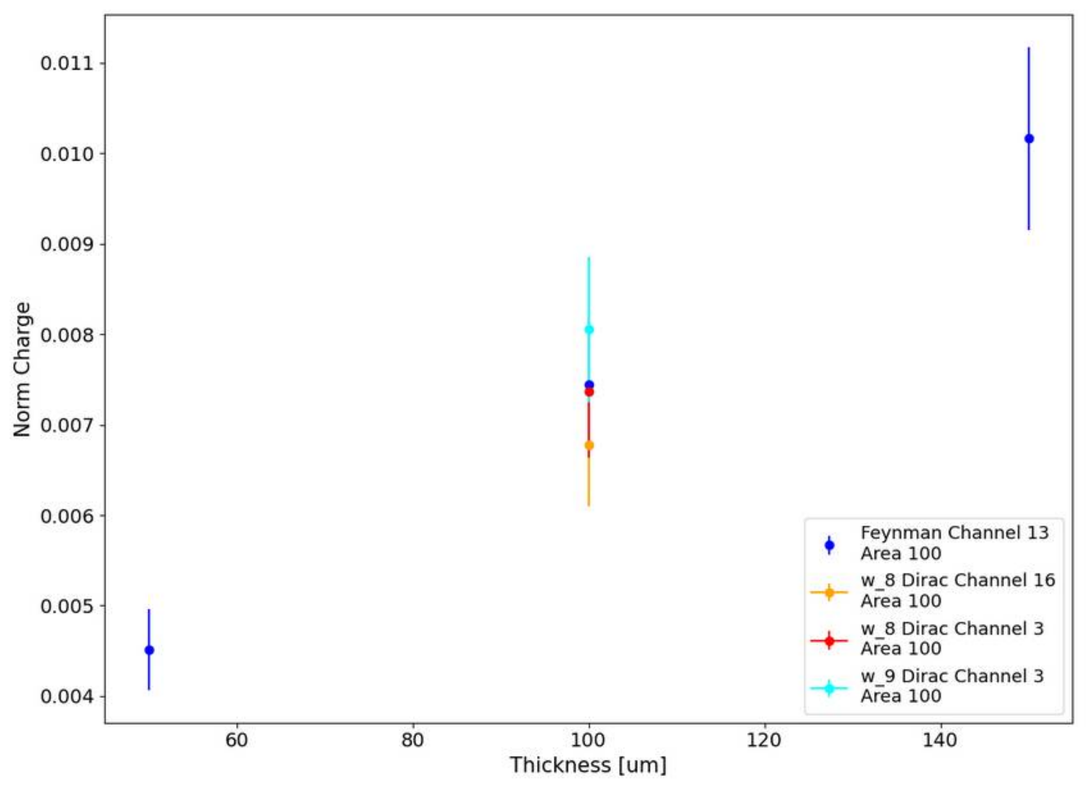
Preliminary: Charge vs Thickness

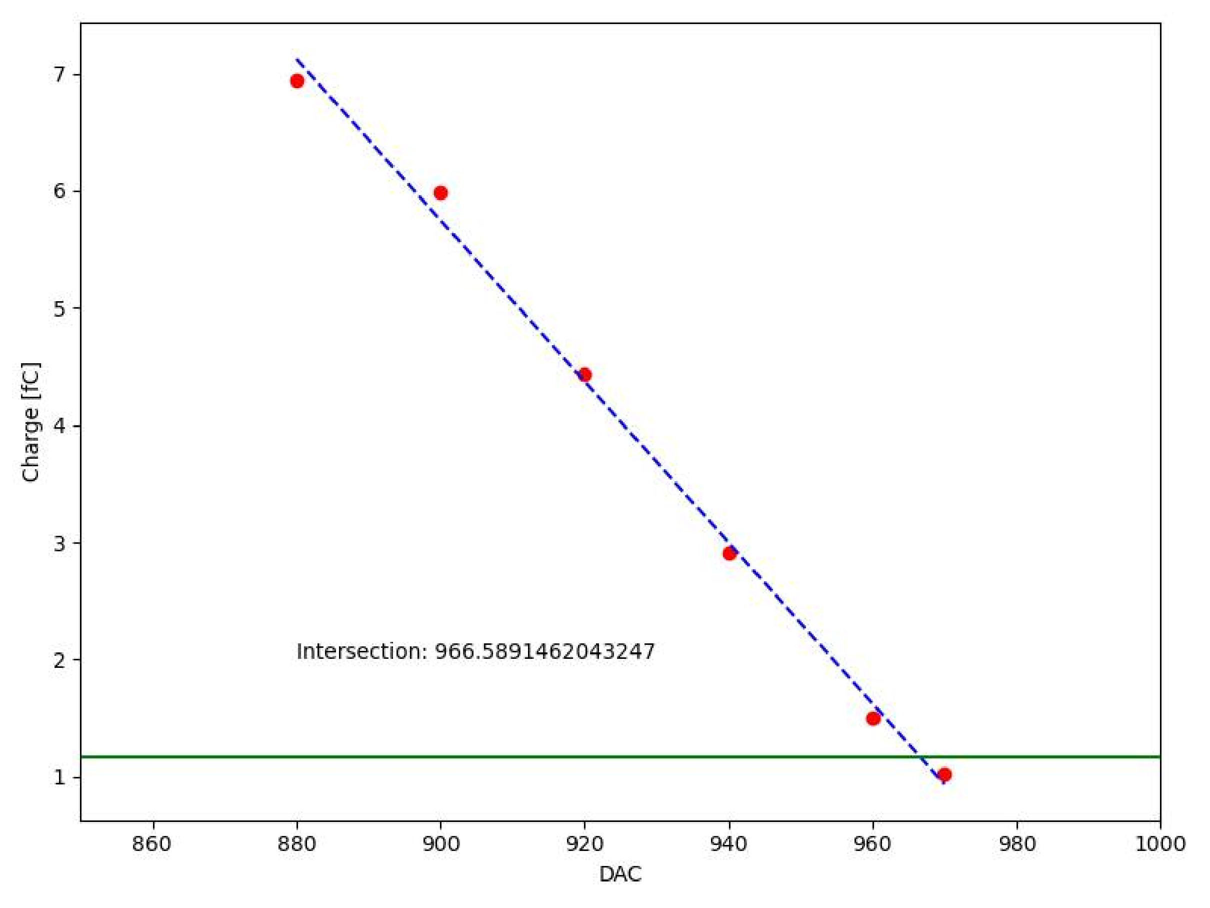
PCB channel Internal gain:

Beam Monitor Fluctuation
→ Normalized Charge

Charge Sistematic Error ~ 8%



Calibration



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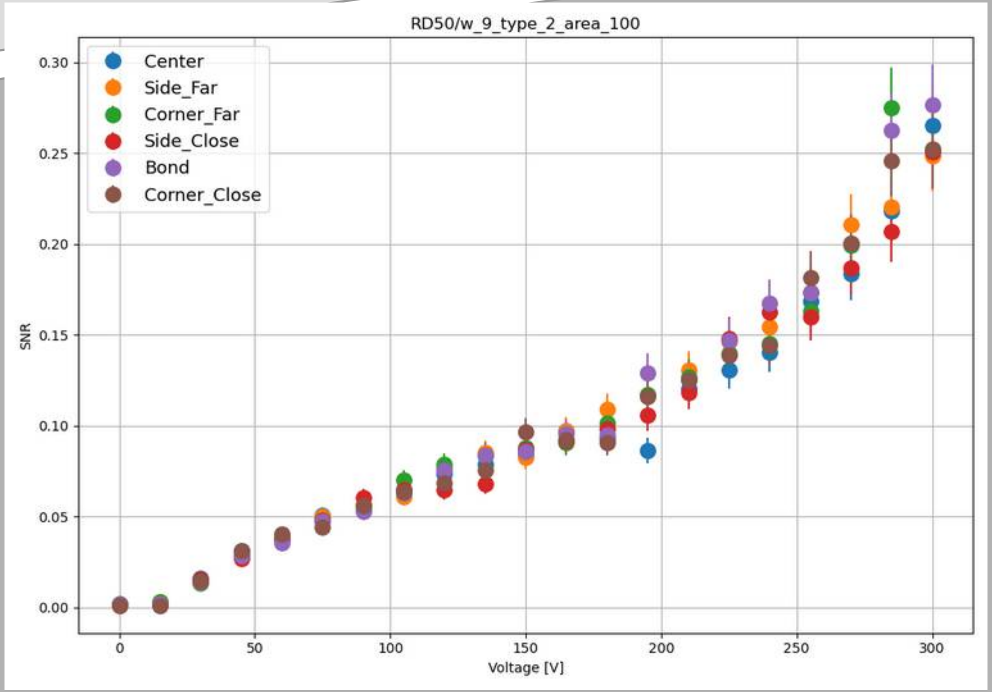
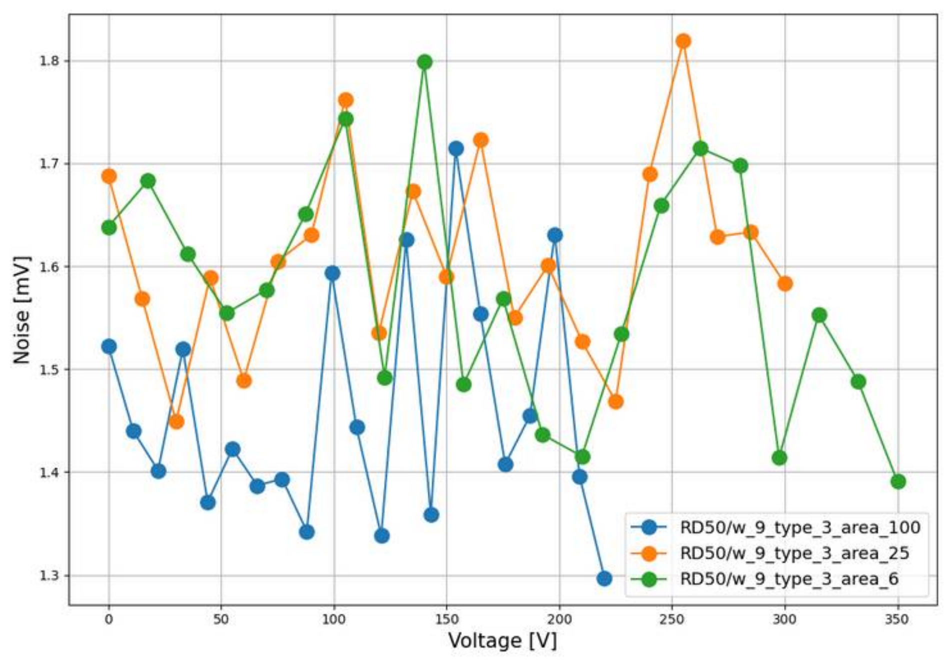
Noise



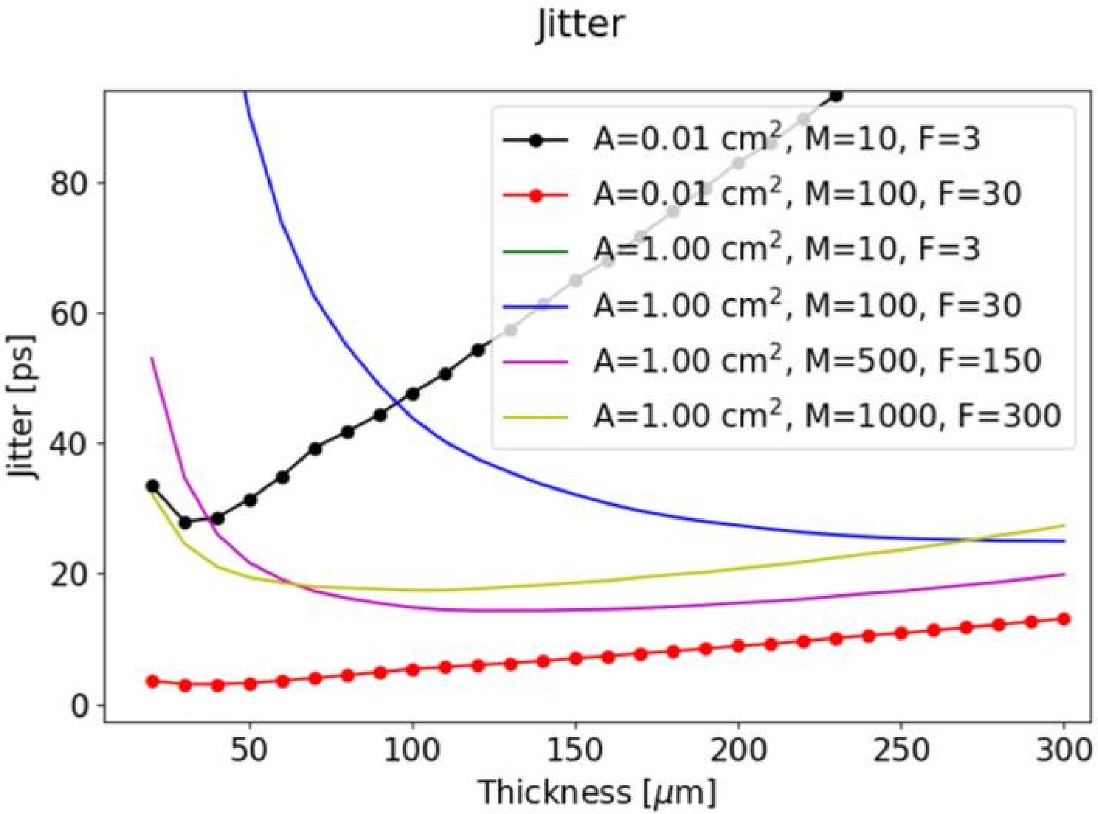
RD50/w_9_type_2_area_100
Center
Side_Far
Corner_Far
Side_Close
Bond
Corner_Close
SNR
Voltage [V]



Noise [mV]
Voltage [V]
RD50/w_9_type_3_area_100
RD50/w_9_type_3_area_25
RD50/w_9_type_3_area_6

Jitter vs Thickness Simulations

LT-Spice Simulation
M = Gain
F = Excess Noise Factor



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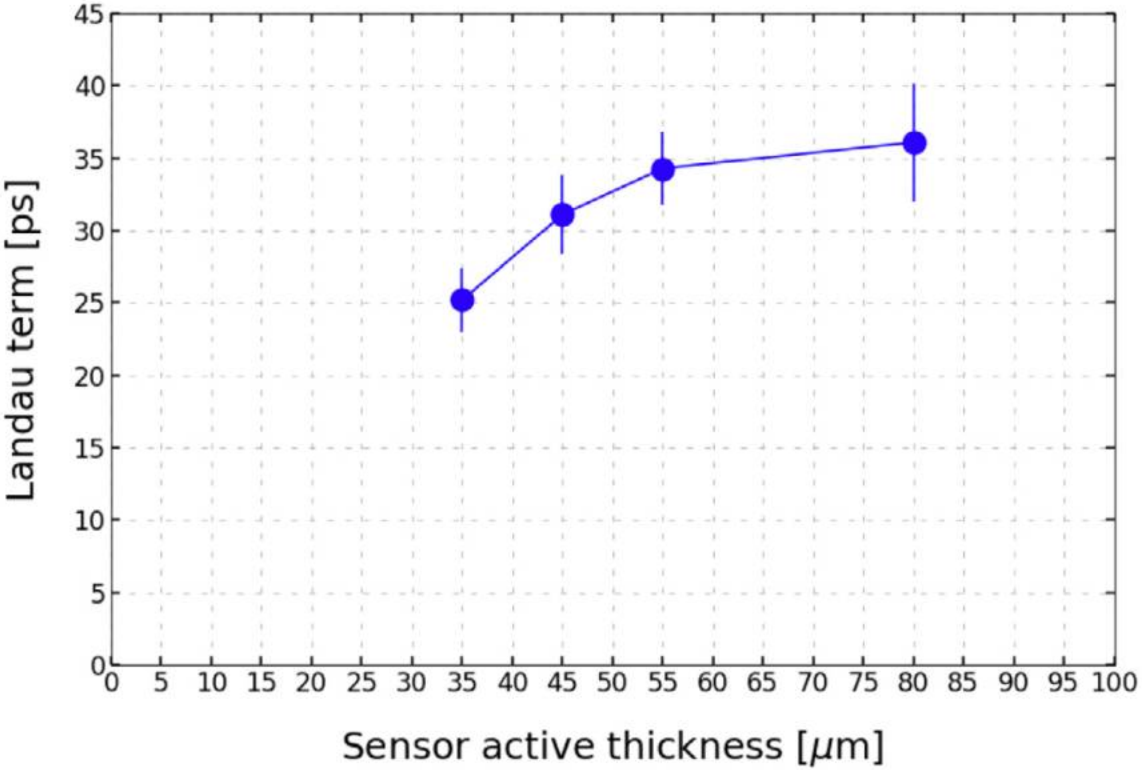
Landau Noise

The non-uniform energy deposition generated by an impinging MIP, amplified by the gain, creates variations of the signal shape on an event-to-event basis



https://doi.org/10.1016/j.nima.2022.166739

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SLAPP Production