Timing Characterization of 1 cm^2 LGAD pads for Space Experiments

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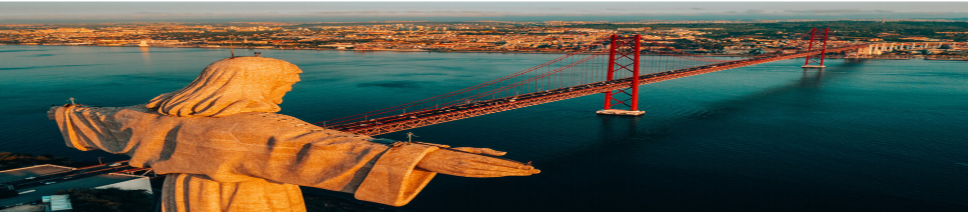
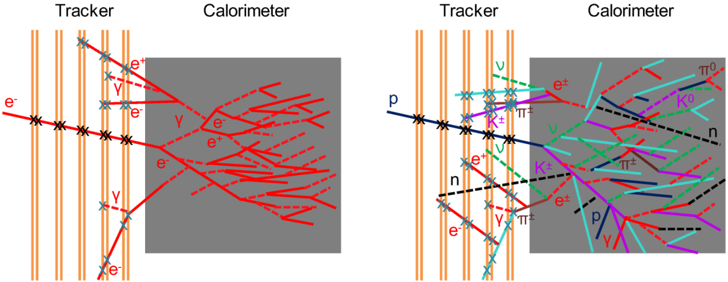


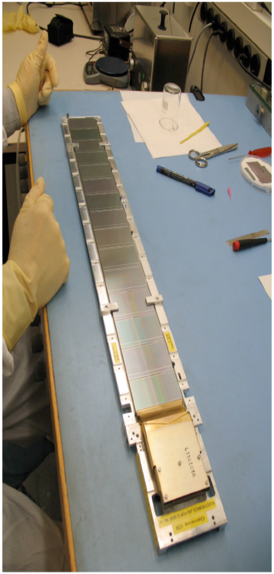
Time resolving tracking in space experiments



- **Timing $\sim$ 50-100 ps**
- Identification of back-scattered hits from calorimeters
- Time-of-flight (ToF) measurement
  $\rightarrow$ typically done using scintillators
- Improved e/p identification

Matteo Duranti et al. Instruments 5.2 (2021)

Space experiment requirements



- Large area to cover → $\mathcal{O}(m^2)$
- Power constraint
  → Reduce $N_{channels}$
- Small particle flux → Large channel size
- "Typical" Silicon sensor for space
  → Strips (100 µm pitch)
  → 60-100 cm long
  → $\sim$ 1 cm^2
- LGAD: suitable for timing
- LGAD channel size for HEP $\sim$ 1-2 mm^2
  → $\sigma_t \approx$ 30 ps for Min. Ioniz. Particle (MIP)

Scaling LGAD channel size to 1 cm^2

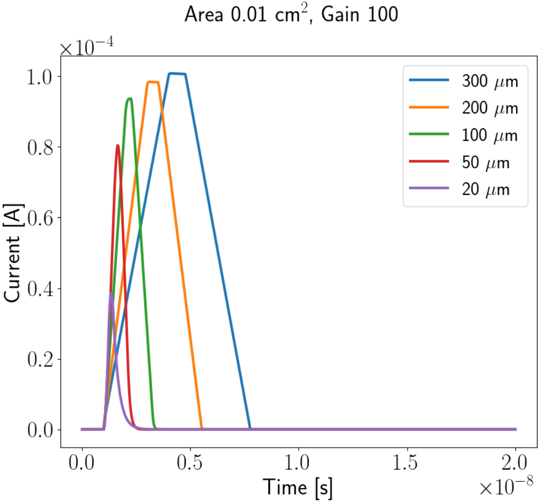
Capacitance?

Time resolution?

Matteo Duranti et al. Instruments 5.2 (2021)

Thickness and Gain Optimization

- LTspice simulation
- Sensor capacitance
- Uniform charge deposition (No Landau fluctuations)
- Saturated velocities
- Noise = Amplifier $\oplus$ Sensor



[M. Centis Vignali et al. VCI (2022)]

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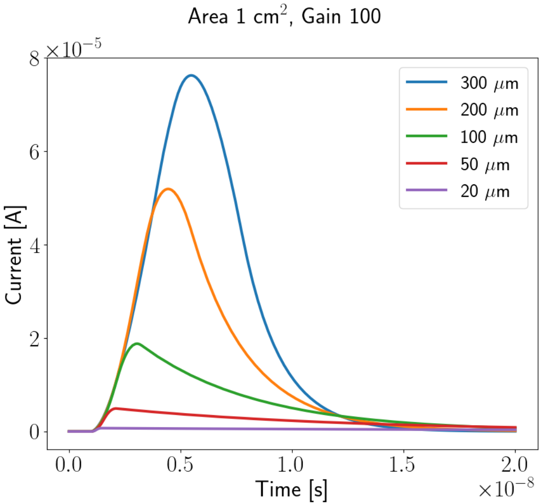

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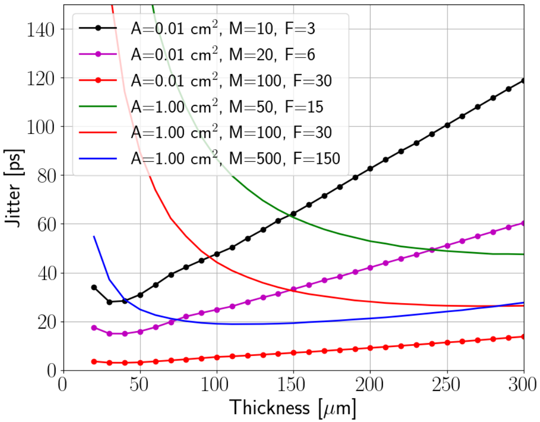

LGAD thickness > 100 μm, gain ≈ 100

[M. Centis Vignali et al. VCI (2022)]

Space LGADs

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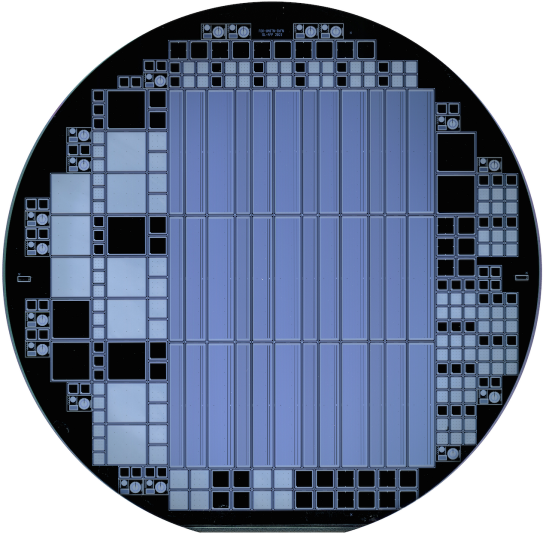
Production of large LGAD sensors under the INFN project

- A total of 16 wafers
- Pad and strip sensors
- Strips: 100 µm, 150 µm, 200 µm pitch
- Active thickness: → 50, 100, and 150 µm
- Gain implant dose and energy optimized for high gain using TCAD
- Optimized for large areas
- Signal propagation

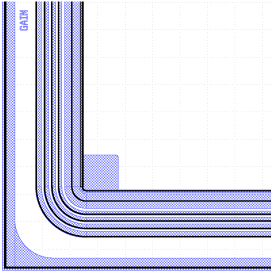


Samples investigated

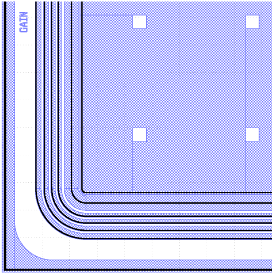
- Pad active area:
  - A (6.25 mm^2)
  - B (25 mm^2)
  - C (100 mm^2)

- Pad types:
  - **Type-1**: Metal frame
  - **Type-2**: Fully Metallized, Contacts at the edge of the active area
  - **Type-3**: Fully Metallized, Contacts covers all active area

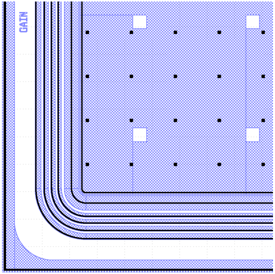
Type-1



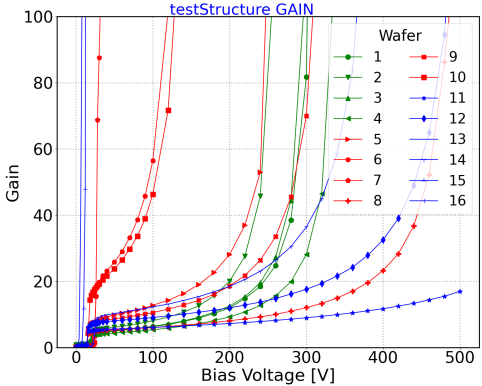
Type-2



Type-3



Gain: using IR LED

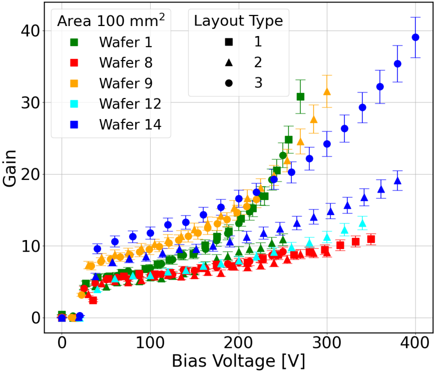


- Operating temperature $= 24°$ with illumination.

$$Gain|_{LED} = \frac{(I_{light} - I_{dark})|_{LGAD}}{(I_{light} - I_{dark})|_{PIN}}$$

- value of gain highly depends on the dose and energy of the implant
- Early breakdown:
  100 µm → 6, 7, 10
  150 µm → 13, 15, 16
- 50 µm: gain of $\mathcal{O}(10)$, $200 \leq V_{bd} \leq 300$
- 100 µm wafer 8, 9
- 150 µm wafer 11, 12, and 14

Gain: using TCT



- Laser intensity: 1 MIP

$$Gain = \frac{Q_{LGAD}}{Q_{PIN}}$$

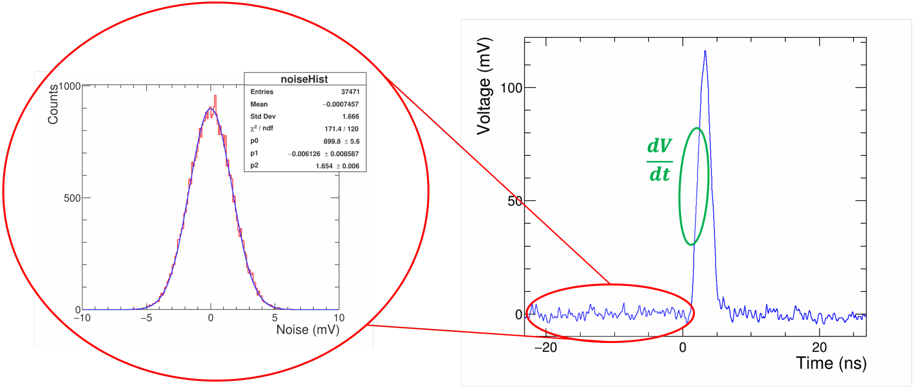
- The gain trend is consistent with the gain measured from the test structures using LED.
- The impact ionization model used for this work tend to overestimate the gain.

- Errors account for uncertainties due to amplifier response evaluated through repeated measurements
- The non-uniformity of gain among the devices from same wafer is due to the non-uniformity in the implant dose of the gain layer.

Jitter Measurements

$$\sigma_{jitter} = \frac{\sigma_{Noise}}{Slew\ Rate\ (dV/dt)}$$

- Measurement (no averaging in Oscilloscope) → Noise estimation
- Measurement (256 averages in Oscilloscope) → Slew rate estimation
- Slew-Rate: slope of the line that best fits the leading edge between 20% and 80% of signal amplitude



Jitter Measurements

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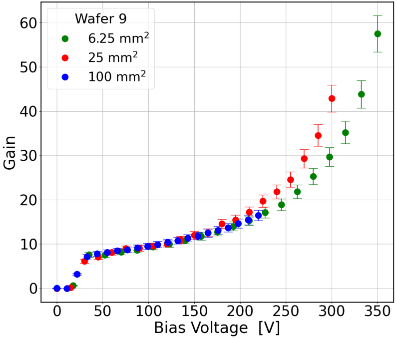
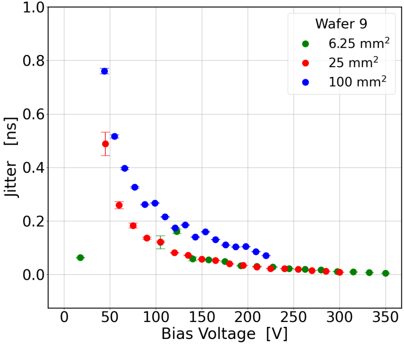
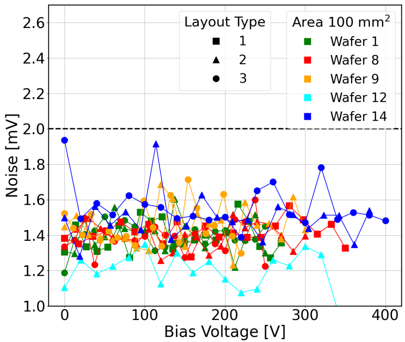
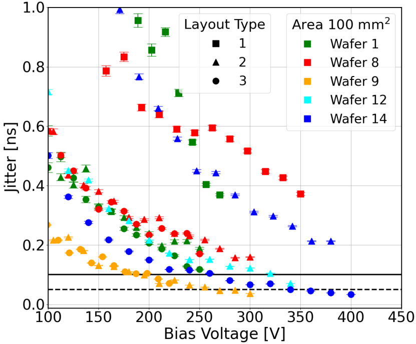




- 100 µm thick sensors
- Smaller active areas result in a steeper leading edge with higher amplitude
- Collected charge is practically the same

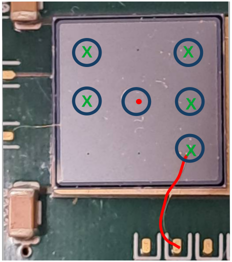
Jitter Measurements: 1 cm^2 sensors

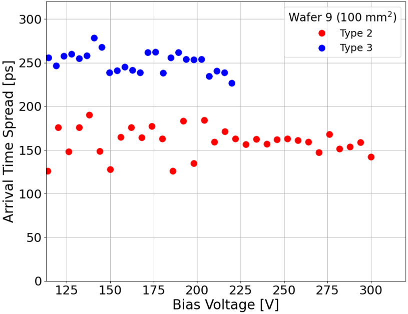




- The average noise remains below 2 mV
- Lack of trend → shot noise is not the dominant noise figure in the system
- $\sigma_{jitter} < 100$ ps : wafer 9, 12, and 14
- $\sigma_{jitter} < 50$ ps : 36 ps for wafer 9 (100 μm), and 34 ps for 14 (150 μm)

Uniformity





- Reference point is the signal near to the bond
- Hit position
- X = Check points for uniformity
- Contribution of the arrival time to the timing resolution is:

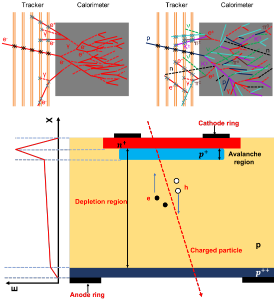
$$\sigma_{uni} = \frac{153}{\sqrt{12}}\ ps \approx 44\ ps$$

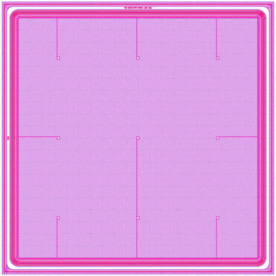
- Time resolution due to jitter and non-uniformity of the signal shape at 300 V is:

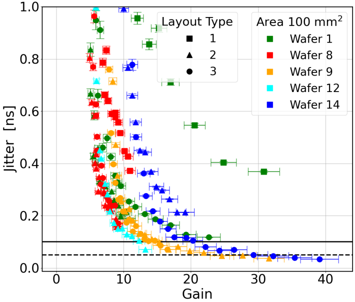
$$\sigma_t = \sigma_{Jitter} \oplus \sigma_{uni} \approx 60ps$$

Summary

- Include timing measurement for each hit/track in the silicon tracker
- LGADs $\rightarrow$ suitable candidate based on the timing performance for HEP experiments
- Increase the active area of the LGADs
  $\rightarrow$ Gain $\sim \mathcal{O}(100)$ and Thickness ($>$100 μm)
- Space LGADs production optimized to study large area LGADs
- Jitter under 40 ps for 1 cm^2 LGADs, and $\sigma_t \approx 60$ ps including non-unformity effects

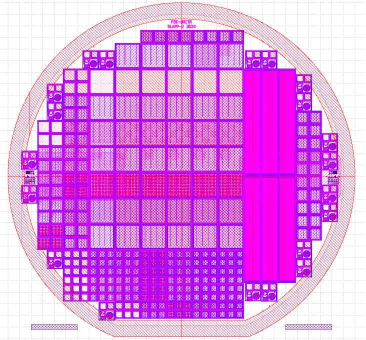






Future prospects

- New production batch to further study the timing resolution and effects of signal propagation
- Time resolution using particle source



THANK YOU FOR YOUR ATTENTION