LGADs for Astroparticle Physics Experiments in Space

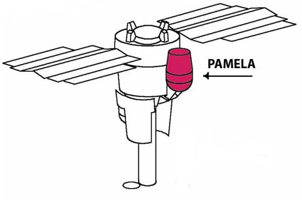
A. Bisht, G. Borghi, M. Boscardin, L. Cavazzini, M. Centis Vignali, F. Ficorella, O. Hammad Ali, G. Paternoster

18th Trento Workshop on Advanced Silicon Radiation Detectors

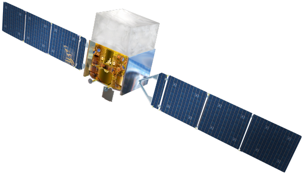
Current and future Cosmic Rays Space experiments

AMS

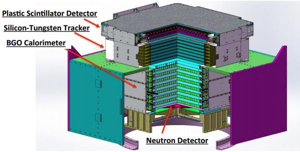
PAMELA



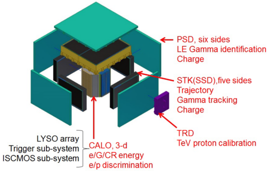
FERMI-LAT



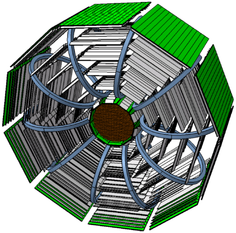
DAMPE



HERD



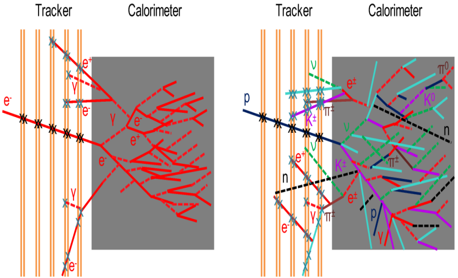
ALADINO



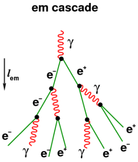
Objective: Higher energies and improved sensitivities

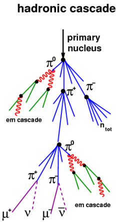
Time resolving tracking in space experiments

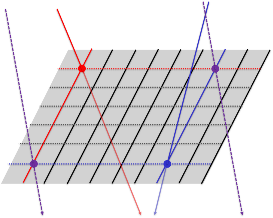
- Identification of back-scattered hits from calorimeters
- Ghost hits in "Si-MicroStrip" detectors
- Time-of-flight (ToF) measurement
- Improved e/p identification



$$\frac{\delta M}{M} = \frac{\delta p}{p} \bigoplus \gamma^2 \left(\frac{\delta \beta}{\beta} \right)$$



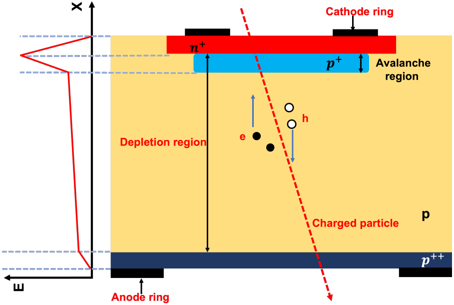




- d and anti-d
- $^3He/^4He$

[Matteo Duranti et al. Instruments 5.2 (2021)]

Low Gain Avalanche Diodes (LGAD)

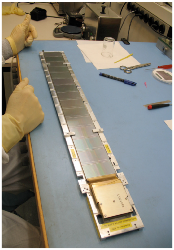


- Silicon detectors with charge multiplication
- Gain layer provides high-field region
- Radiation hard (10^{15} neq/cm^2)
- Low Noise (low shot noise)

- Improved SNR: 5-10 times better than current detectors
- Good timing resolution O(10 ps)

Space experiment requirements

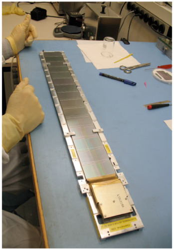
- Large area to cover → $O(m^2)$
- Low Earth Orbit Experiments
  →*Radiation is not an issue*
- Rate is not as high as in HEP
- Power constraint
  → *Reduce the number of channels*
- **Timing (∼ 50-100 ps) is desired**



- "Typical" Silicon sensor
  → Strips (100 μm pitch)
  → 60-100 cm long
  → ∼ 1 cm^2

Space experiment requirements

- Large area to cover → O(m^2)
- Low Earth Orbit Experiments
  →*Radiation is not an issue*
- Rate is not as high as in HEP
- Power constraint
  → *Reduce the number of channels*
- **Timing (∼ 50-100 ps) is desired**



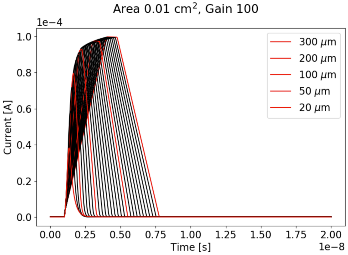
- "Typical" Silicon sensor
  → Strips (100 μm pitch)
  → 60-100 cm long
  → ∼ 1 cm^2

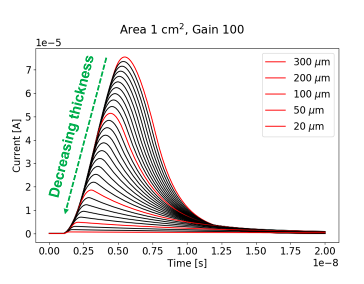
Scaling LGAD channel size to 1 cm^2

Capacitance?
Time resolution?

Thickness and Gain Optimization

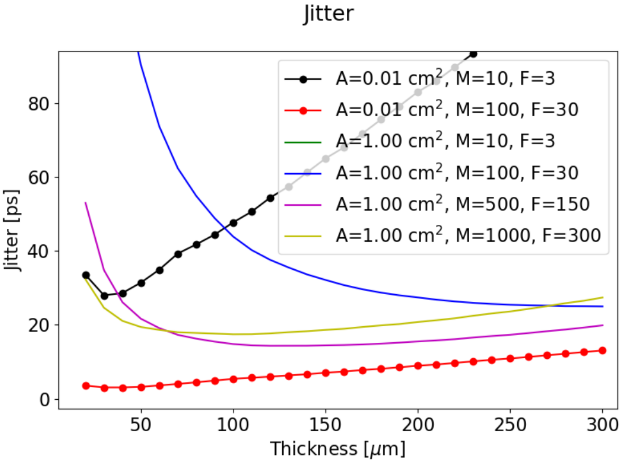
- LTspice simulation
- Sensor capacitance
- No Landau fluctuations (uniform charge deposition)
- Saturated velocities
- Total Noise = Amplifier $\oplus$ Sensor





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

Thickness and Gain Optimization



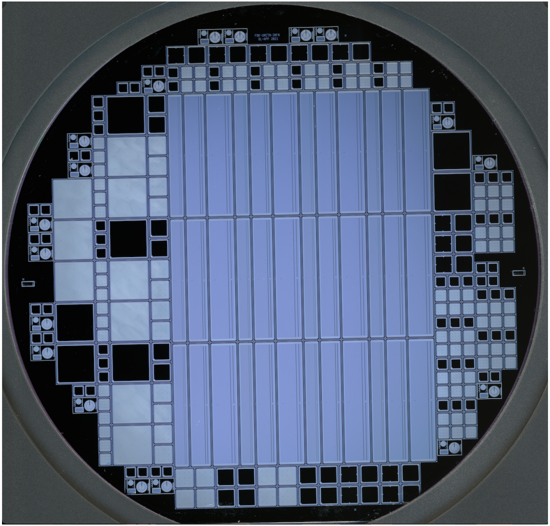
[M. Centis Vignali et al. VCI (2022)]

LGAD thickness $> 100\ \mu m$ and gain ≈ 100

Space LGADs

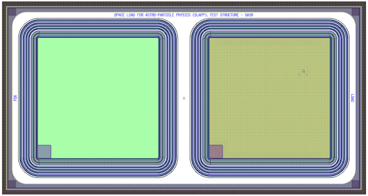
Production of new LGAD sensors under INFN project

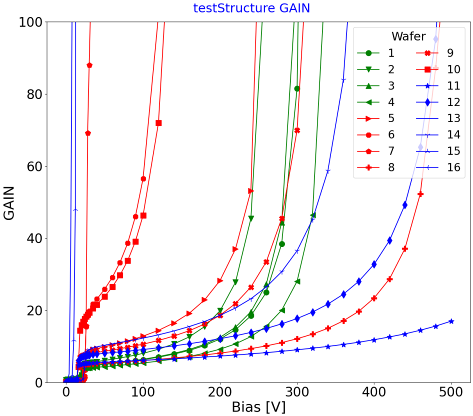
- Optimized for large areas
- Pad and strip sensors
- Strips: 100 μm, 150 μm, 200 μm pitch
- Active thickness: 50 μm, 100 μm, 150 μm thick
- Gain implant dose and energy optimized for high gain using TCAD
- Signal propagation



Gain: using IR LED

- T $= 24^\circ$ with illumination.
- 50 μm
- 100 μm
- 150 μm

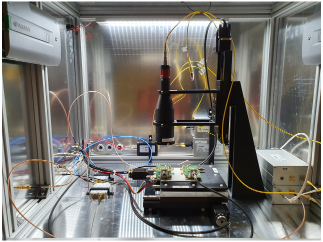




- value of gain highly depends on the dose and energy of the implant
- less steep curves for better operating voltage

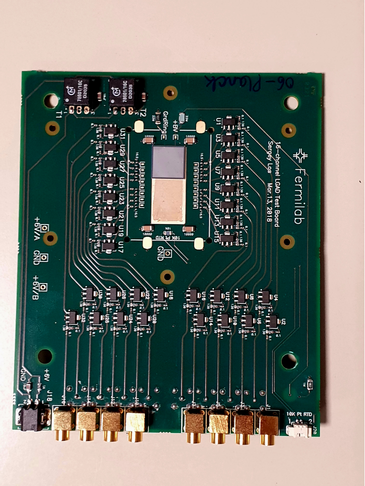
Experimental setup: Transient Current Technique (TCT)

- Infra-Red (1060 nm) and Red (600 nm) pulsed Laser
  $\rightarrow$ 10-15 μm spot
- X/Y translation stage (0.8 μm precision)
  $\rightarrow$ precise inter-pixel scan and DUT maps
- Beam monitor



16-channel Fermi Board

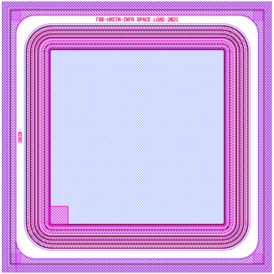
(2 stage Amplification)



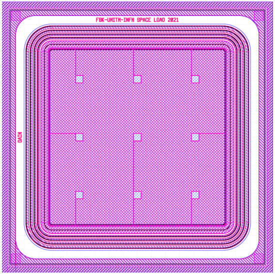
Samples investigated

- Pad active area:
  - A (6.25 mm^2)
  - B (25 mm^2)
  - C (100 mm^2)
- Pad types:
  - **Type-0**: Metal frame
  - **Type-1**: Fully Metallized, Contacts at the edge of the active area
  - **Type-2**: Fully Metallized, Contacts covers all active area

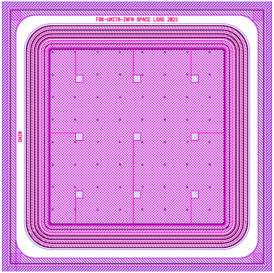
Type-0



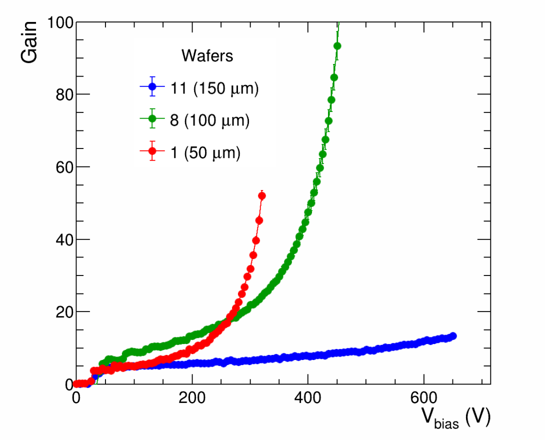
Type-1



Type-2



Gain: using TCT setup

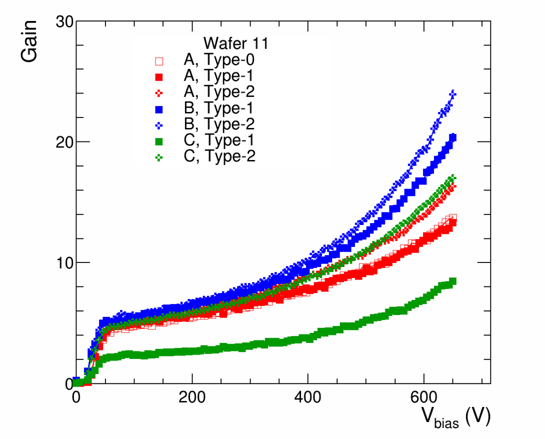


$$Gain = \frac{Charge_{LGAD}}{Charge_{PIN}}$$

- Laser Intensity: 1 MIP
- substrate active thickness:
  - 50 μm
  - 100 μm
  - 150 μm

Gain curves follow similar trend as measured with the IR LED

Gain: using TCT setup



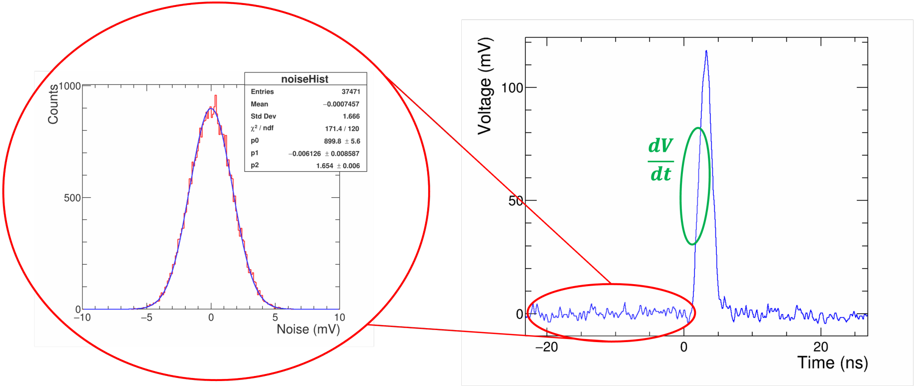
$$Gain = \frac{Charge_{LGAD}}{Charge_{PIN}}$$

- Laser Intensity: 1 MIP
- Low bias voltage: gain value is similar
- High bias voltage: gain value has a spread of about 20%
- One device show low gain values compared to others

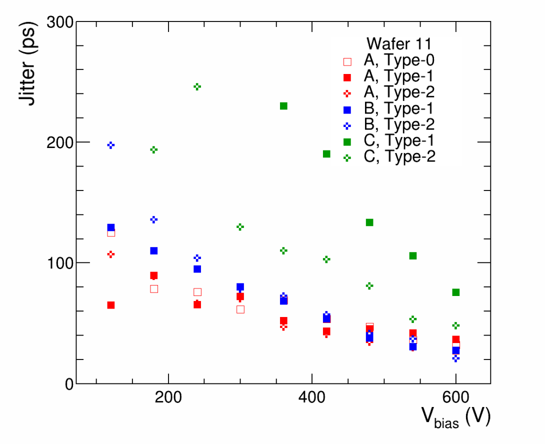
Jitter Measurements

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

- Measurement (no averaging in Oscilloscope) → Noise estimation
- Measurement (256 averages in Oscilloscope) → Slew rate estimation



First Jitter measurements of 1 cm^2 LGADs



- Laser intensity: 1 MIP
- substrate thickness: 150 μm
- pad sizes:
  - A (6.25 mm^2)
  - B (25 mm^2)
  - C (100 mm^2)
- Metallization:
  - □ metal frame
  - ■ fully metallized
  - ✚ fully metallized + contact openings

σ_{Jitter} $\sim$ **44 ps for an LGAD 1 cm^2**

Summary

- Standard LGADs batch dedicated to the space experiments.
- Increase active thickness to reduce the capacitance
- Increase the gain to about 100 for reduced Jitter values
- $\sigma_{Jitter} \sim 44$ ps $\rightarrow$ 100 mm^2 active area
- $\sigma_{Jitter} \sim 20$ ps $\rightarrow$ 6 mm^2 active area.

Current Status and Outlook

- Timing measurements with beta source
- Possible beam test

Summary

- Standard LGADs batch dedicated to the space experiments.
- Increase active thickness to reduce the capacitance
- Increase the gain to about 100 for reduced Jitter values
- $\sigma_{Jitter} \sim 44$ ps $\rightarrow$ 100 mm^2 active area
- $\sigma_{Jitter} \sim 20$ ps $\rightarrow$ 6 mm^2 active area.

Current Status and Outlook

- Timing measurements with beta source
- Possible beam test

Thank you for your attention