LGAD Sensors for Space Applications

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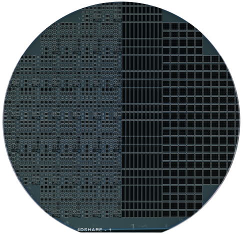
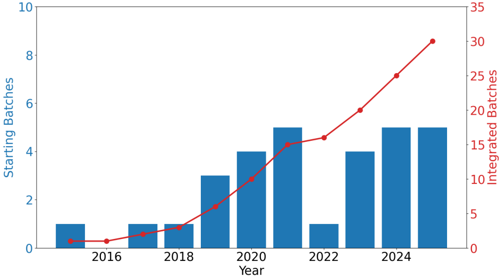
Fondazione Bruno Kessler

6 inch (150 mm)
Custom CMOS-like process

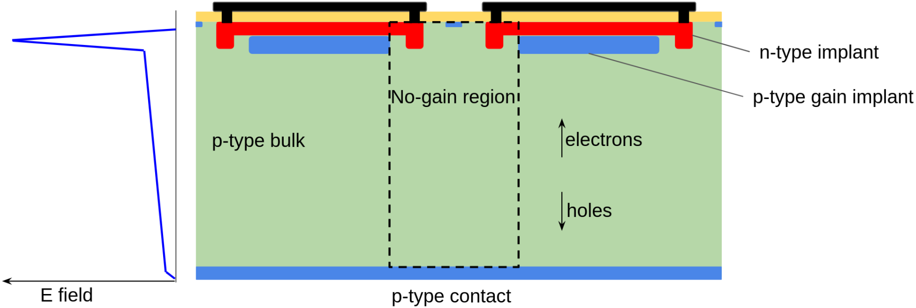
LGAD technologies:

- Standard
- Double sided (inverted)
- Trench isolated
- AC coupled (RSD)
- DC-RSD
- n-type





(Standard) Low Gain Avalanche Diodes



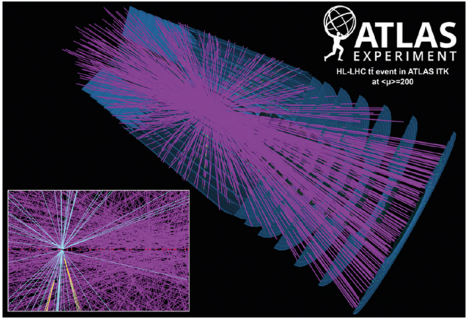
- Silicon detectors with charge multiplication
- Gain ≈ 10
- Gain layer provides high-field region
- No-gain region $\sim 30 - 80\ \mu$m
- Time resolution ~ 30 ps $\leftrightarrow$ thin $\sim 50\ \mu$m sensor
  ~ 1 mm^2 channel

- **Improve SNR of the system**
  (When the sensor shot noise is not dominating)
- Noise and power consumption
  $\Rightarrow$ low gain

High Luminosity LHC

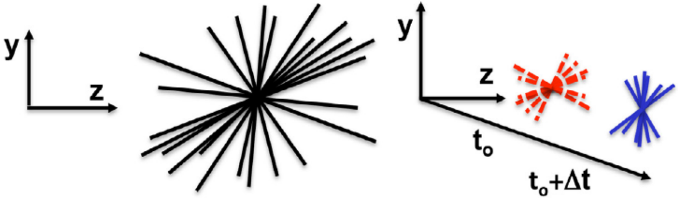
4D-tracking → simultaneous measurement of space and time of hits or tracks

[ATLAS simulation]



Use time coordinate to mitigate pile-up

[H. Sadrozinski et al. Rept. Prog. Phys. 81 (2018) 026101]

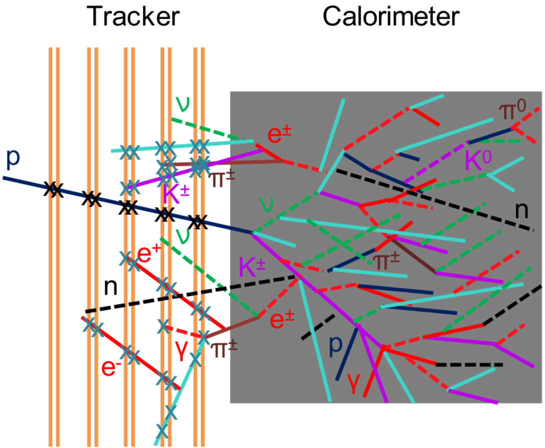


- Track time resolution ≈ 30 ps
- Radiation resistance to few 10^{15} n_{eq}/cm^2
- Hit time resolution at end of life ≈ 50 ps

ATLAS and CMS are building their timing layers
FBK is producing sensors for CMS

4D-tracking in Space

[M. Duranti et al. Instruments 2021, 5, 20]



Timing in space experiments

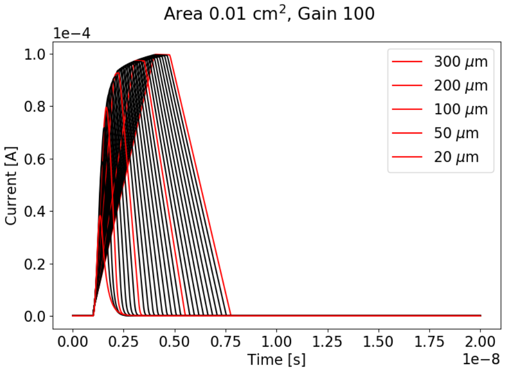
- Particle ID using TOF
- Identification of incoming or outgoing particles
- Identification of calorimetric showers and backsplash
- $\sigma_t \sim 100$ ps
- Particle rate + limited power
  $\Rightarrow$ channel size $\sim$ 1 cm^2
  $\rightarrow$ sensor capacitance

LGADs from HEP:

- Time resolution
- Radiation hardness
- Channel size

Also missing: low-power electronics

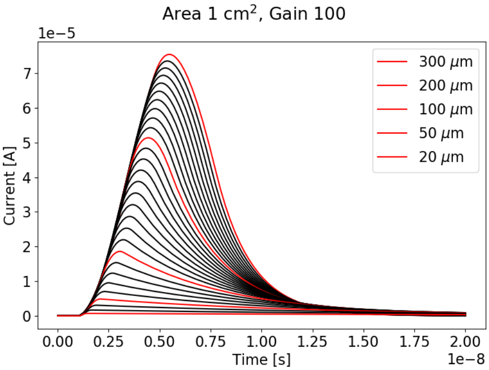
Thickness and Gain Optimization, Jitter Simulation



- LTspice simulation
- Sensor capacitance
- Uniform charge deposition (no Landau noise)
- Simplified gain layer model
- Assumed saturated velocities
- Noise from amplifier and sensor

Simple model favors thickness > 100 μm and gain > 100

Thickness and Gain Optimization, Jitter Simulation



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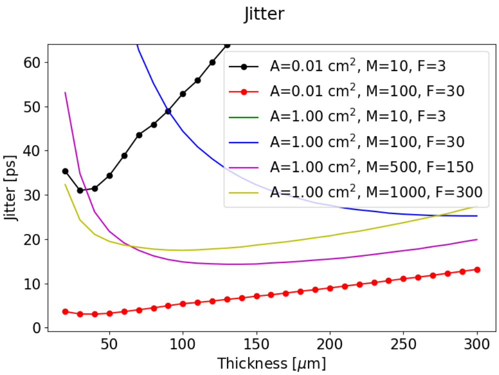

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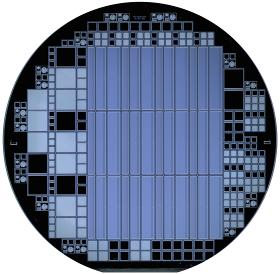
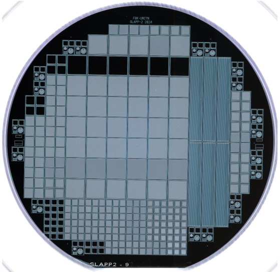
Space LGADs for AstroParticle Physics - SLAPP

Development in collaboration with INFN PG, TO



Goals:

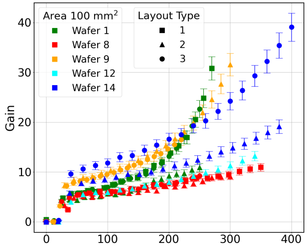
- Optimize gain (a lot of TCAD simulations, not shown here)
- Measure time resolution of 1 cm^2 sensors
- Measure time resolution of “long” strips (for LGAD standards)
- Study signal properties and propagation
  ...at c, 1 cm is $\sim$ 30 ps...

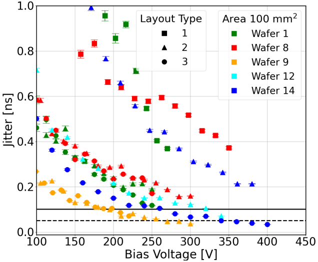


- Two batches (one “in convenzione” one on FBK effort)
- Pad and strip sensors
- Variations:
  - Thickness: 50, 100, 150 μm
  - Gain layer design
  - Coupling between Si and metallization

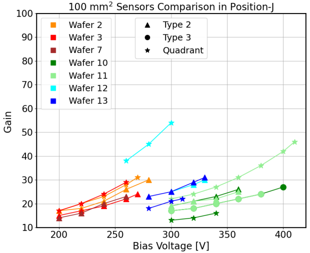
SLAPP Gain and Jitter

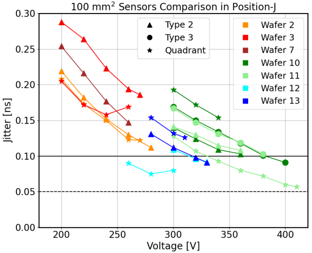
SLAPP 1





SLAPP 2





[A. Bisht et al. Instruments 2024, 8(2), 27]

[L. Cavazzini PhD thesis 2026]

- 1 cm^2 sensors
- Pulsed IR laser
- 1 MIP equivalent charge
- Max gain $\sim$ 50
- Jitter below 50 ps

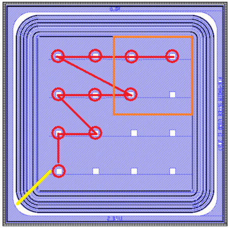
Promising results

Uniformity of Response and Signal Propagation

FONDAZIONE BRUNO KESSLER

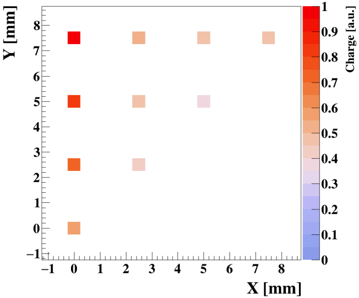
[L. Cavazzini PhD thesis 2026]

Wire bonding placement



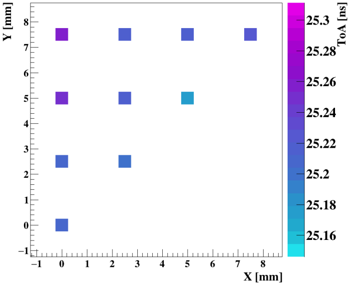
Charge

3_A_02_01, 270 V



Time of Arrival

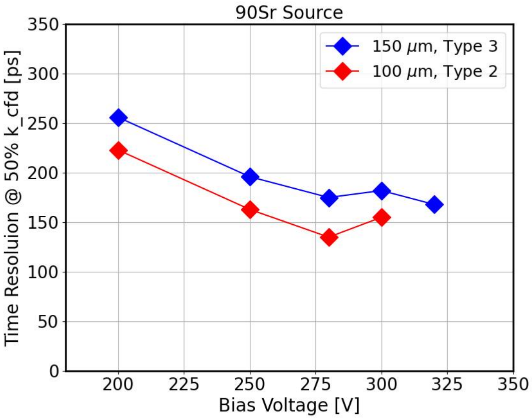
3_A_02_01, 270 V



- 1 cm^2 100 μm thick sensor
- Gain variation over area from bulk doping
- ToA variation $\sim$ 100 ps with non-trivial signal propagation
- Signal propagation contributes $\sim$ 30 ps to the time resolution

SLAPP Time Resolution with Particles

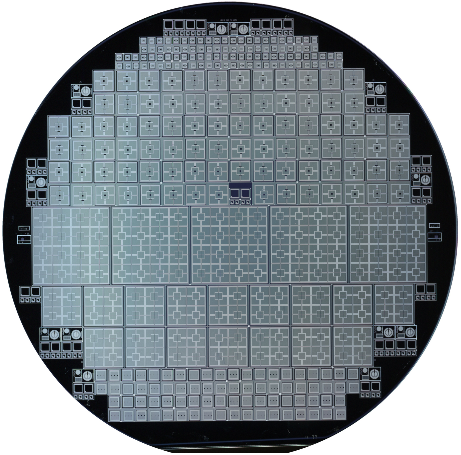
[L. Cavazzini TREDI2025]



- **Time resolution of 135 ps on 1 cm^2, 100 μm thick sensor**
- Expected improvement with different electronics

ADA-5D

CSNV project with PD, PI, PV, SI, TIFPA. PI Paolo Brogi



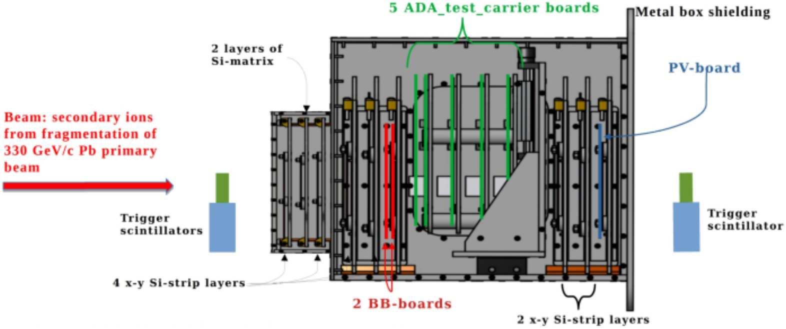
Goals:

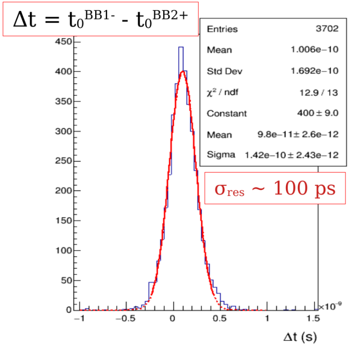
- **5D-tracking:** space, time, charge
- Use dE/dx for nuclei identification
  $\Rightarrow$ thicker sensors are favored
- Provide time information
- Develop low-power readout electronics
- Develop a detector system

- One LGAD batch done, one starting
- Thickness: 150, 275 μm
- 3×3 mm^2 channels
- Different gain layer designs

ADA-5D Time Resolution

[P. Brogi TREDI2025]

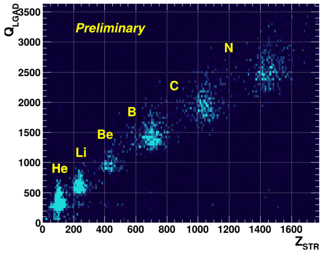


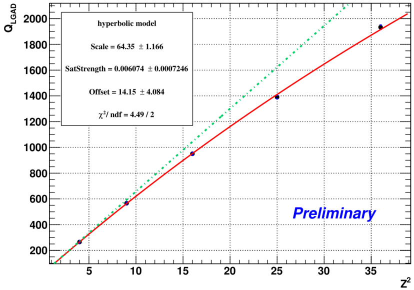


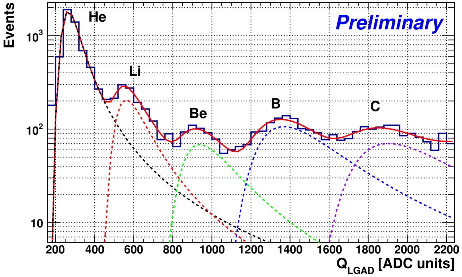
- Mixed ions beam
- **Time res. 100 ps on 3×3 mm^2 channel, 150 μm thick sensor**

ADA-5D Nuclei ID

[M. Mattiazzi et al. 2026 JINST 21 C04055]



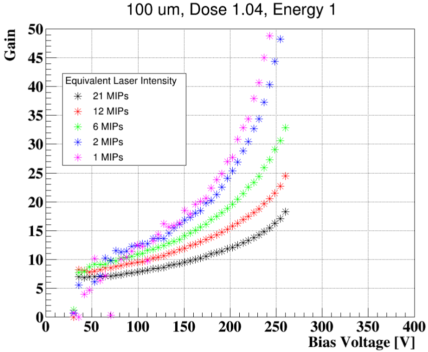


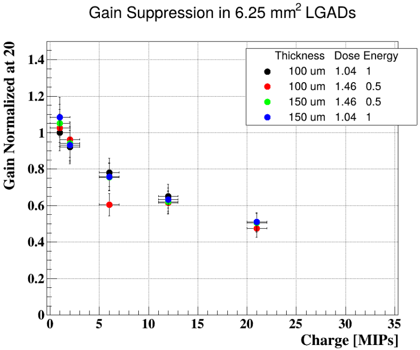


- **Good separation power for light elements, 275 μm thick sensor**
- LGAD charge correlates with strip sensor charge
- LGAD response is not linear with Z^2
  $\rightarrow$ saturation effects

Gain Suppression in SLAPP

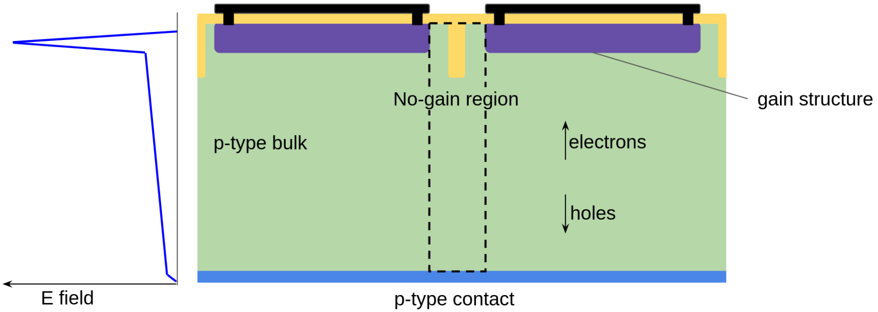
[L. Cavazzini PhD thesis 2026]





- IR laser with different intensities
- Fix bias to obtain a given gain at 1 MIP intensity
- Increase laser intensity
- The studied gain layer designs and thicknesses have the same behavior

Trench Isolated LGADs



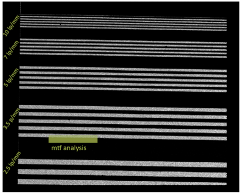
- Trenches substitute the isolation structures
- Trench width about 1 μm $\Rightarrow$ fill factor close to 100%
- No-gain region: $\sim$ 2-3 μm for 50 μm sensors, $\sim$ 5 μm for 275 μm sensors

[G. Paternoster et al. IEEE EDL Vol 41 Issue 6 (2020) 884-887]

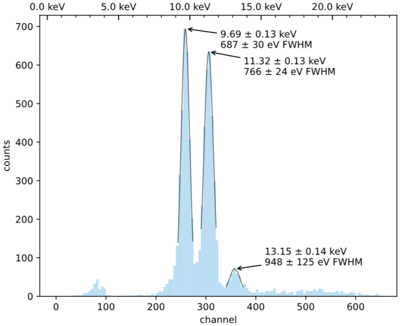
X-ray Measurements with XPOL

[M. Minuti et al. Frontiers in Sensors Volume 6 - 2025]

Huttner test



Au Fluorescence



XPOL-III ASIC

- 304 x 352 pixels
- 50 μm hexagonal pitch
- Self triggering
- X-ray detection with analog readout
- With 300 μm silicon sensor:
  - 7 μm spatial resolution
  - 620 $\pm$ 30 eV energy resolution

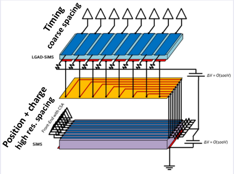
Within the Space It Up project:

- Collaboration with INFN PI Massimo Minuti
- Backside illuminated TI-LGADs
- Use gain to boost x-ray signal
- Extend low energy measurements to $\sim$ 1 keV

Near Term Activities

PTSD Sensors

- Combine LGAD and strip sensors to improve total capacitance
- Enable large area LGAD strip sensors
- More details: [M. Duranti TREDI2026]



Study of Fundamental Sensor properties

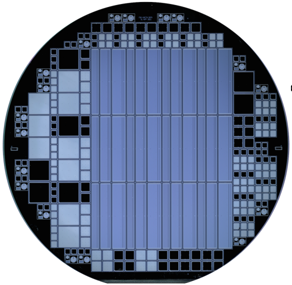
- 1 PhD student (on LGAD and SDDs): signal modeling, strip measurements
- 1 PhD position starting this year on LGADs for x-ray detection in space

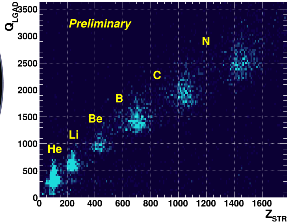
Proposal for INFN Call

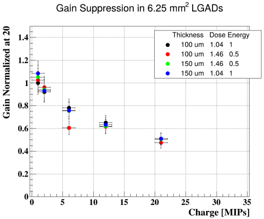
- 5D-tracking: LGAD sensors + Low power electronics
- Goal: make a system to be tested on a nanosatellite

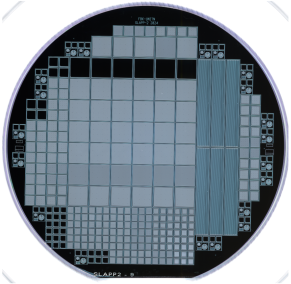
Summary

- 3 completed LGAD batches dedicated to space applications
- 3 further sensors batches foreseen (ADA-5D, Space It Up, PTSD)
- Study of fundamental sensor properties and design
- Fabrication of sensors for projects









Appendix: The LGAD Zoo

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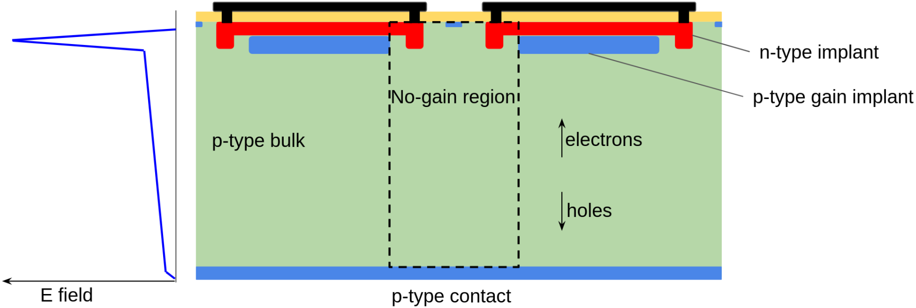

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  ~ 1 mm^2 channel

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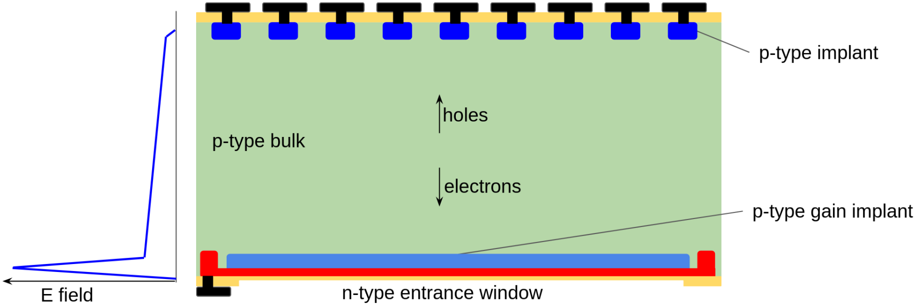
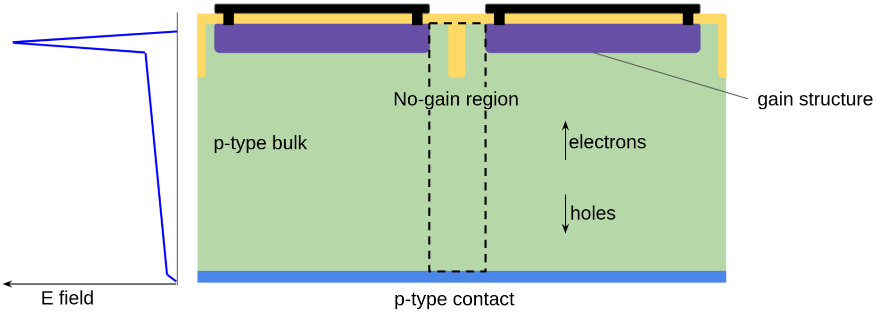
Double Sided (Inverted) LGADs



- Continuous gain area in the active region ⇒ 100% fill factor
- Double sided process → active thickness is the wafer thickness ⇒ not optimal for timing
- Readout side is ohmic
- Readout side separated from LGAD side ⇒ no restrictions on channel dimensions

[G.F. Dalla Betta et al. NIM A 796 (2015) 154]

Trench Isolated LGADs



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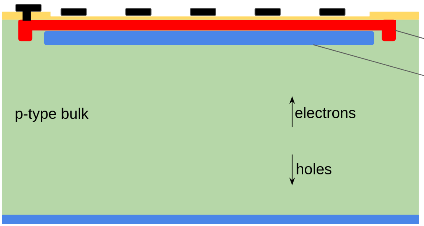
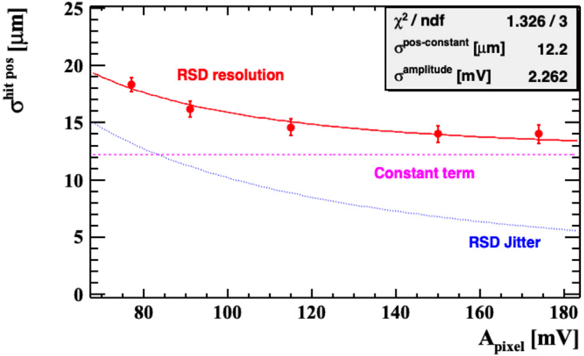
[G. Paternoster et al. IEEE EDL Vol 41 Issue 6 (2020) 884-887]

AC-LGADs (Resistive Silicon Detectors)



[L. Menzio et al. NIMA 1065 (2024) 169526]

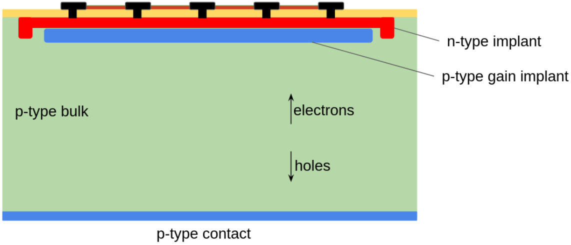


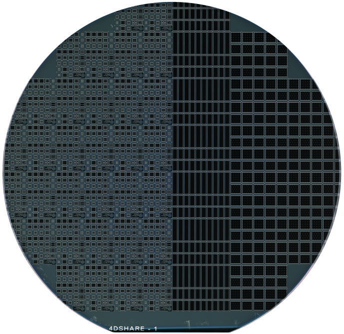
- Continuous gain layer
- Time resolution
- Resistive charge division
  ⇒ Larger channel pitch for same resolution
- Bipolar signal with recharge tail
- Biasing only at sensor edge
- Poor signal confinement

∼15 μm resolution with 450 μm readout pitch
∼50 ps time resolution

Resolution about 3-4% of readout pitch

DC Resistive Silicon Detectors





- Continuous gain layer
- Time resolution
- Resistive charge division
  $\Rightarrow$ Larger channel pitch for same resolution
- ~~Bipolar signal with recharge tail~~
- ~~Biasing only at sensor edge~~
- ~~Poor signal confinement~~

Variations of:

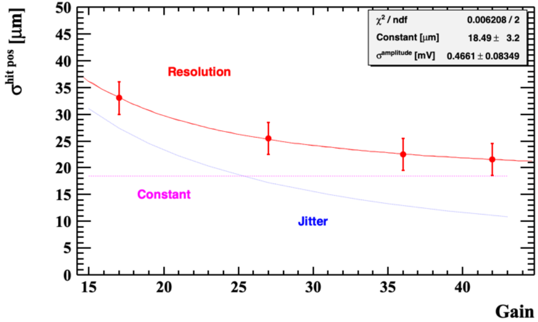
- Resistivity
- Contact fabrication
- Geometry: pixels, strips, square, triangular

Trenches used for signal confinement

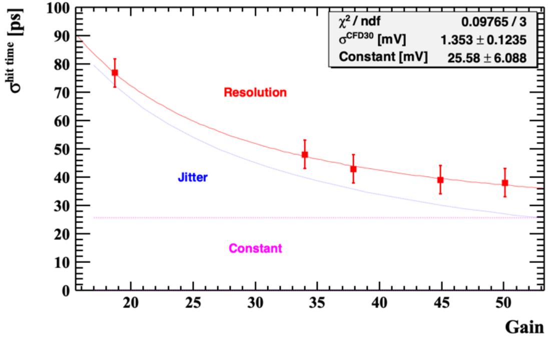
Resolution

[R. Arcidiacono VCI2025]

Space

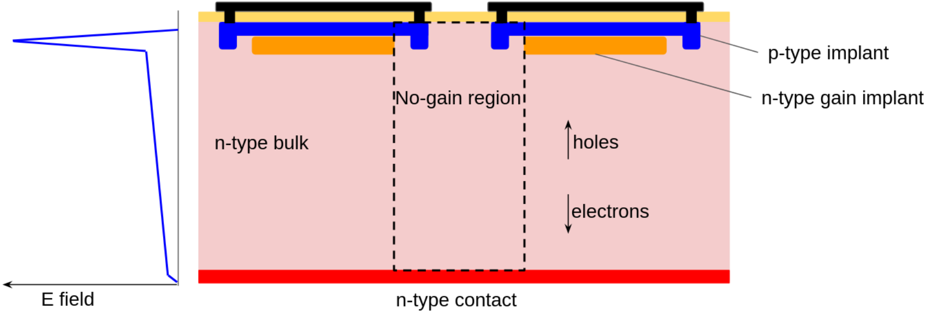


Time



- Square cells 500 μm side
- 20 μm spatial resolution
- 40 ps time resolution
- **Spatial resolution is $\sim$5% of pitch**
- **4D tracking**

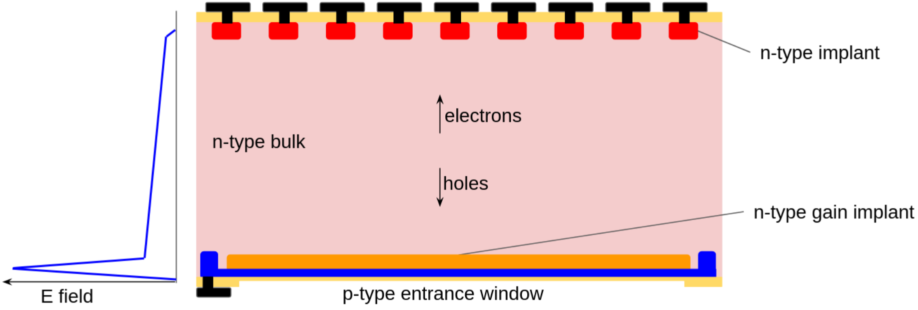
NLGAD



- Change polarity of all implants and bulk
- Study donor removal in the gain layer
- Holes gain for energy deposition in the bulk
- Electrons gain for superficial energy deposition

- Might be interesting for low energy x-rays:
  - Reduced shot noise due to lower gain for dark current
  - Improved gain for superficial interactions

NLGAD



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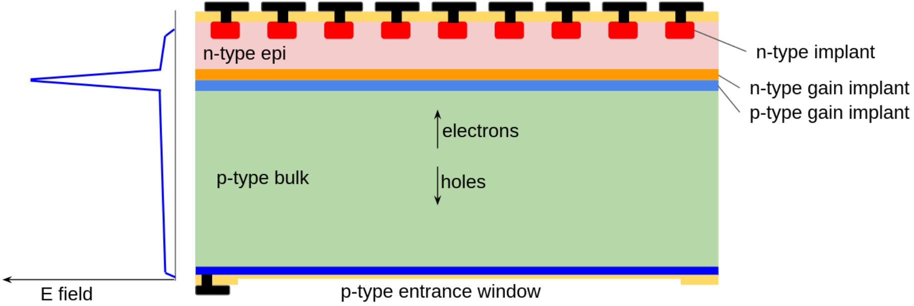
DJ-LGAD



n-type epi
n-type implant
n-type gain implant
p-type gain implant
electrons
p-type bulk
holes
E field
p-type entrance window