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MONOLITH - Picosecond Time Stamping Capabilities In Fully Monolithic Highly Granular Silicon Pixel Detectors

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European Research Council
Established by the European Commission

ATTRACT

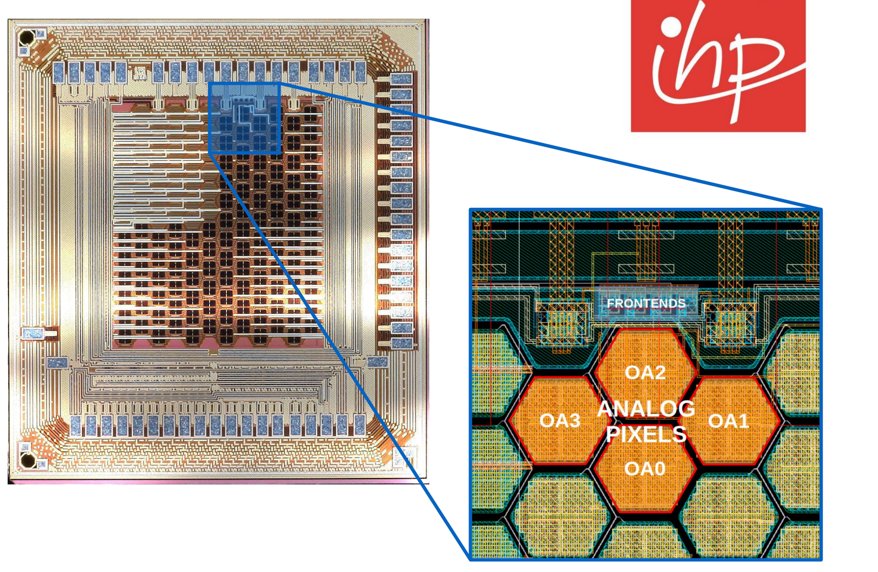
The MONOLITH H2020 ERC Advanced Project

- Aim at producing a monolithic silicon pixel ASIC with **picosecond-level time stamping**[1]:
  - fast and low-noise SiGe BiCMOS electronics
  - novel sensor concept, the **Picosecond Avalanche Detector**[2] (PicoAD)
- Ultra-fast current signal with low intrinsic jitter in a full-fill-factor highly-granular monolithic detector

MONOLITH

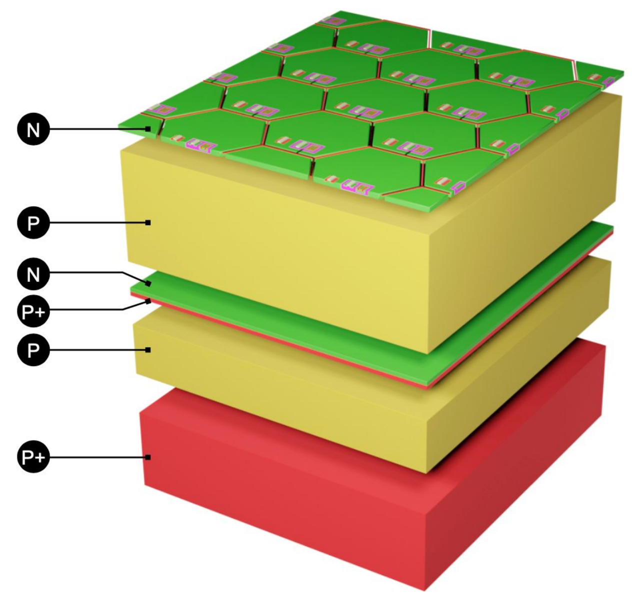
Monolithic Silicon Sensor in SiGe BiCMOS Technology

- Monolithic ASIC in **130nm SiGe BiCMOS** by IHP
- Proof-of-Concept prototype with hexagonal pixels of 65 μm side
- Two versions:
  - 24 μm depletion depth without gain layer[3]
  - 15 μm depletion depth with gain layer
- We characterized **four analog channels** (in orange in figure):
  - HBT preamplifier + two HBT emitter followers to 500 Ω resistance on pad



PicoAD Sensor Concept

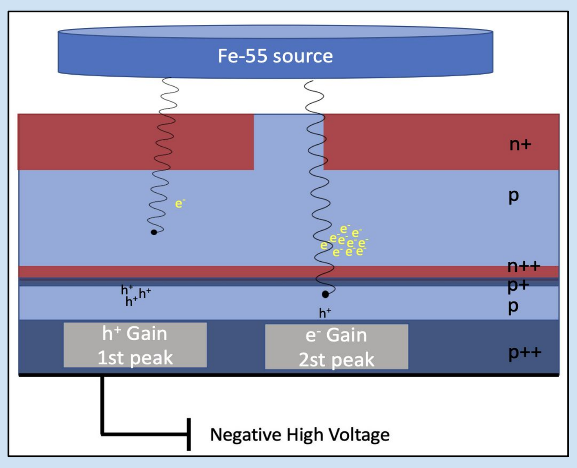
- The PicoAD uses a **multi-PN junction** to engineer the electric field and produce a **continuous gain layer** deep in the sensor volume

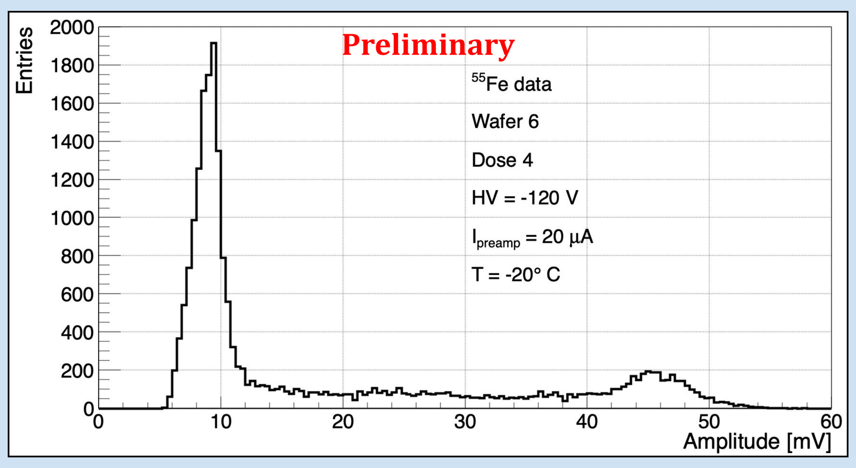


Gain Measurements

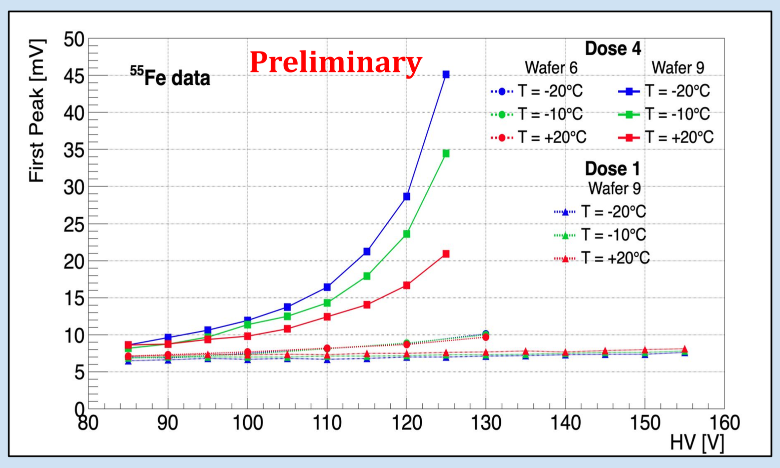
- Gain has been measured with a ^{55}Fe radioactive source:
  - mainly ~ 5.9 keV photons
  - point-like charge deposition

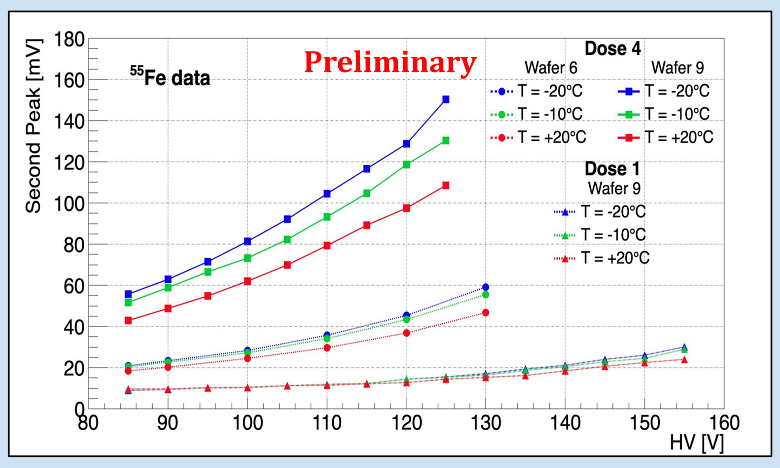
- **Two peaks** visible in the amplitude distribution that allow the study of both hole and electron gain at the same time



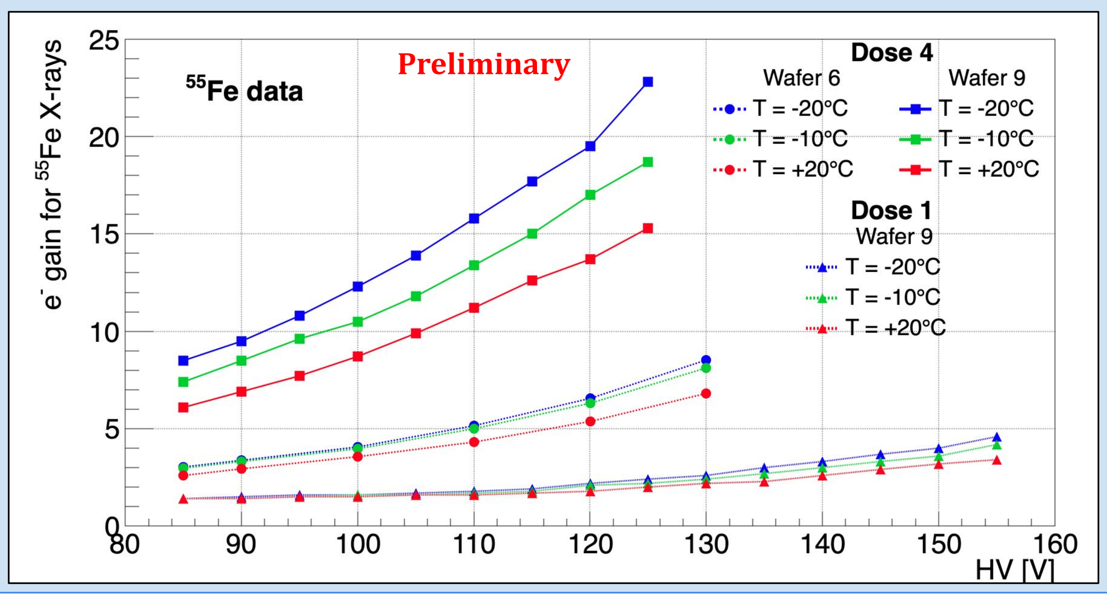


- **First peak** and **second peak** are extracted from the spectrum and used to calculate the gain for the ^{55}Fe X-rays



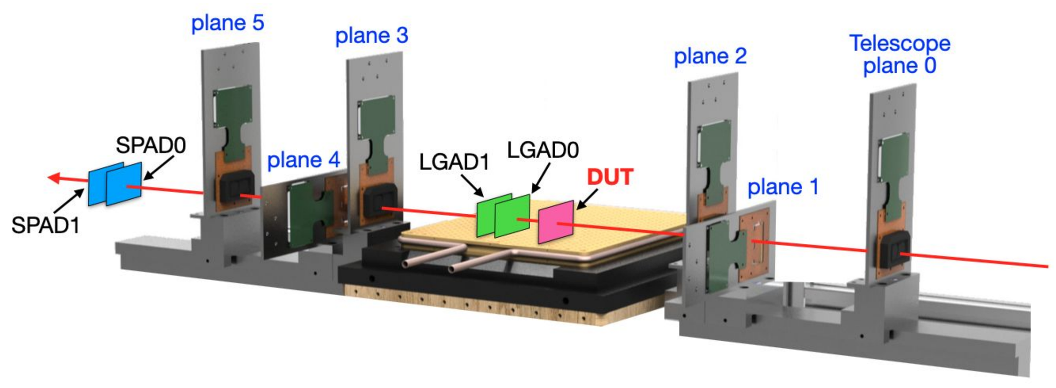


- Gain: ratio between second peak and first peak at lowest HV
- Different doses and wafers show different gain
- A **gain for ^{55}Fe X-rays of ~ 20** is reached at HV = 120 V and T = -20 ℃

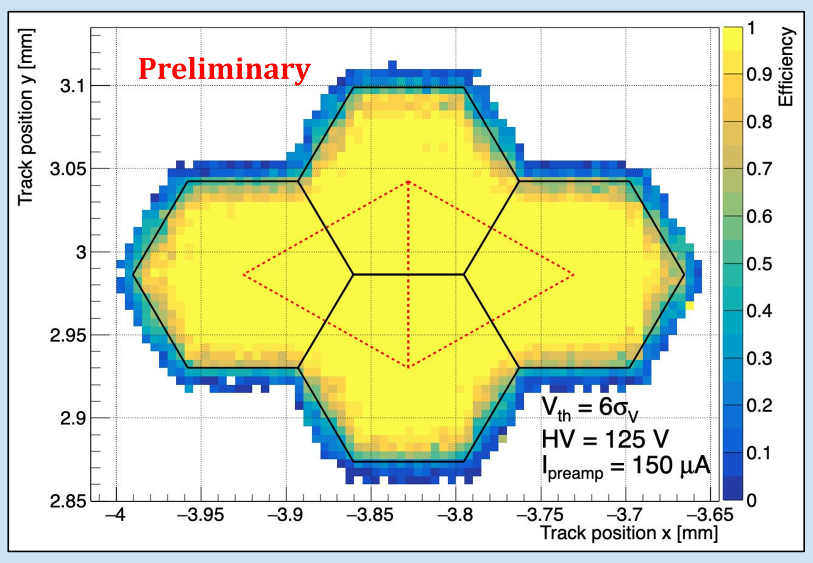


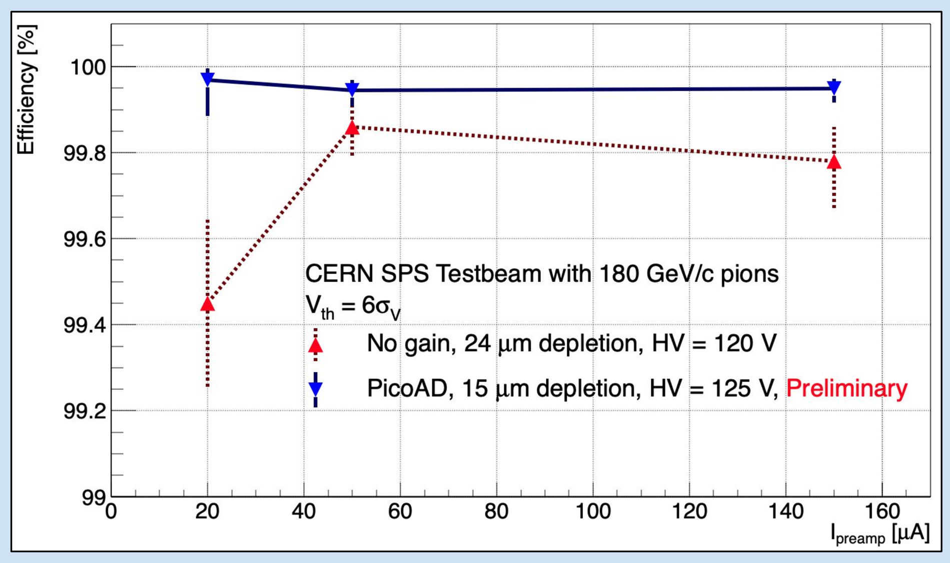
Efficiency and Time Resolution Measurements

- CERN SPS Testbeam with 180 GeV/c pions
- **UNIGE FE-I4** telescope[4] to provide the spatial information
- **Two LGADs** (σ_t ~ 40 ps) to provide the timing reference
- **Efficiency** and **timing resolution** have been measured as a function of:
  - High Voltage
  - Preamplifier current (related to power consumption)

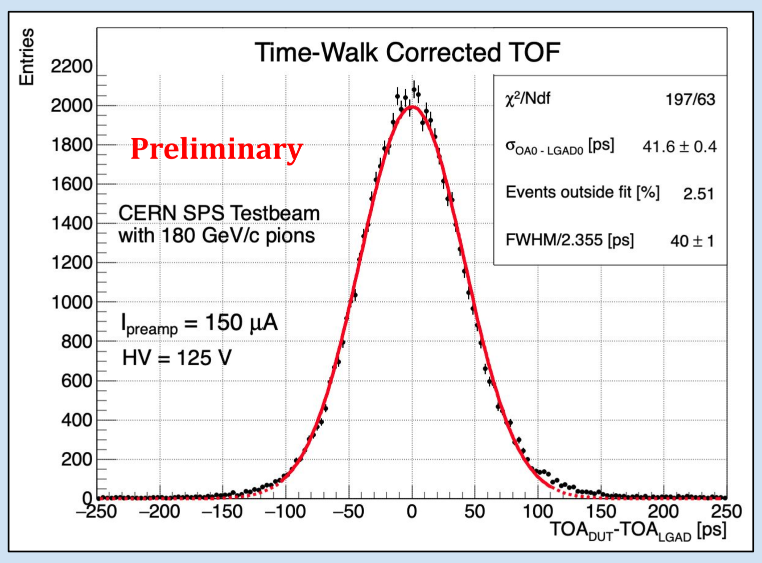


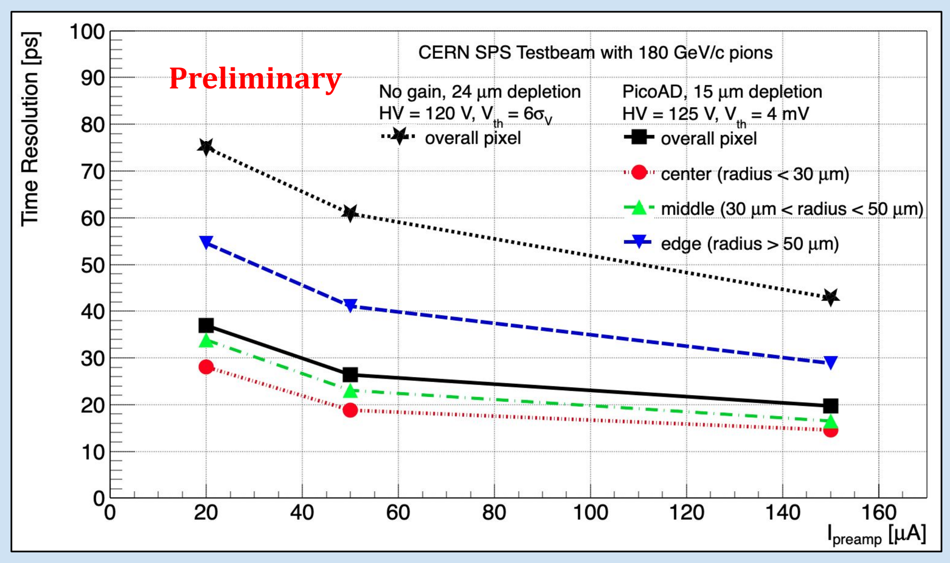
- The four analog pixels have efficiency **> 99.5 %** for all the working conditions





- **Gaussian Time-Of-Flight distributions**
- The overall timing resolution is σ_t **= (20.1±0.3) ps** for HV = 125 V and I_{preamp} = 150 μA
  - σ_t = (14.5±1.1) ps at the center of the pixel (radius < 30 μm)





- The **gain layer improves** the efficiency and the time resolution

Conclusions

- Proof-of-concept of PicoAD sensor (not yet optimized for timing) and HBT frontend:
  - **gain for ^{55}Fe X-rays of up to 23**
  - efficiency **> 99.5 %**
  - time resolution σ_t **= (20.1±0.3) ps**

Outlook

- Optimization for timing of the sensor design with TCAD
- Smaller pixels pitch and thicker active layer to achieve ≲ 10 ps
- Development of picosecond TDC for fully monolithic chip

References

- [1]MONOLITH H2020 ERC Advanced Project Web Page - https://www.unige.ch/dpnc/en/groups/giuseppe-iacobucci/research/monolith-erc-advanced-project/
- [2]G. Iacobucci, L. Paolozzi and P. Valerio. Multi-junction pico-avalanche detector. *European Patent EP3654376A1, US Patent US2021280734A1*, Nov 2018
- [3]G. Iacobucci *et al.* Efficiency and time resolution of monolithic silicon pixel detectors in SiGe BiCMOS technology. *JINST*, 17 P02019, 2022
- [4]Benoit *et al.* The FE-I4 telescope for particle tracking in testbeam experiments. *JINST*, 11 P07003, jul 2016

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