# Characterisation of EXFLU1 thin sensors with gain at high fluence

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## 1) EXFLU1 LGAD sensors

- Developing **radiation-resilient low-gain APDs** to operate in environments of up to $10^{17}$ $n_{eq}cm^{-2}$
- Planar p-type bulk of thickness 45, 30, 20, and 15 µm, with a 1 µm-thick p⁺ (B, Ga) **gain implant**
- Sensors to feature in the next generation of silicon detectors, e.g. **HL-LHC, FCC**

Simulation | Production | Testing | Irradiation

Perugia | FBK | Torino | JSI

**To characterise these LGAD sensors it is important to understand the gain removal mechanism and how it changes with radiation**

## 2) LGAD design and acceptor removal

Thin sensors measure location and time of a hit simultaneously and accurately

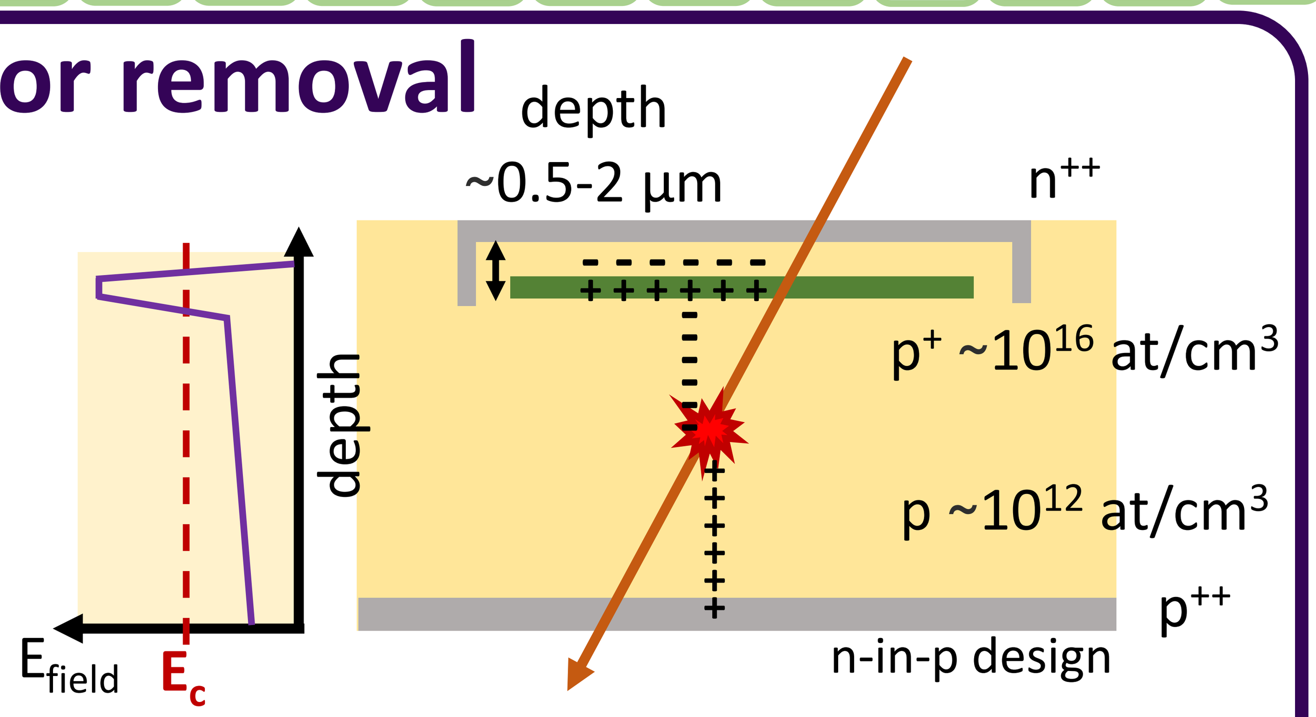
- Spatial and temporal resolution ~30 ps and ~10 µm
- Periphery structure tapers E field to mitigate breakdown

LGAD design can withstand ~300 kV/cm localised to the gain layer

- **Gain implant** depletes before bulk and avalanches
- Segmented low-noise, low-leakage **gain ~20-30**

**Acceptor removal** deactivates p⁺ doping in gain layer

- Mechanism dependent on **initial acceptor density**, $p_0^+$, and **defect engineering** in the atomic lattice of the gain implant
- Extract fluence $\Phi = c_A^{-1}$ at which gain contribution is unity




$$p^+(\Phi) = p_0^+ \cdot e^{-c_A\Phi}$$

$c_A$ is the acceptor removal coefficient

## 3) Methodology

Measurements taken for four sensor thicknesses, before and after irradiation at fluences Φ = 1 x $10^{14}$ to 5 x $10^{15}$ $n_{eq}/cm^2$

| Thickness / µm | p⁺ dose | C dose | Diffusion | Bulk |
|---|---|---|---|---|
| 45 | 1.14 | 1.0 | CBL | n type* |
| 30 | 1.12 | 1.0 | CBL | high ρ |
| 20 | 0.96 | 1.0 | CBL | low ρ |
| 15 | 0.94 | 1.0 | CBL | low ρ |

*45 µm substrates are **type inverted**, where the bulk moves from p type to n type*

IV characteristics

- Perform **bias** scans up to depletion at 20, 0, and -20 °C

CV characteristics

- Determine the **depletion voltage** of the gain implant, $V_{gl}$
- Extract the **rate of degradation**, $c_A$, in $V_{gl}$ post-irradiation

Gain profile

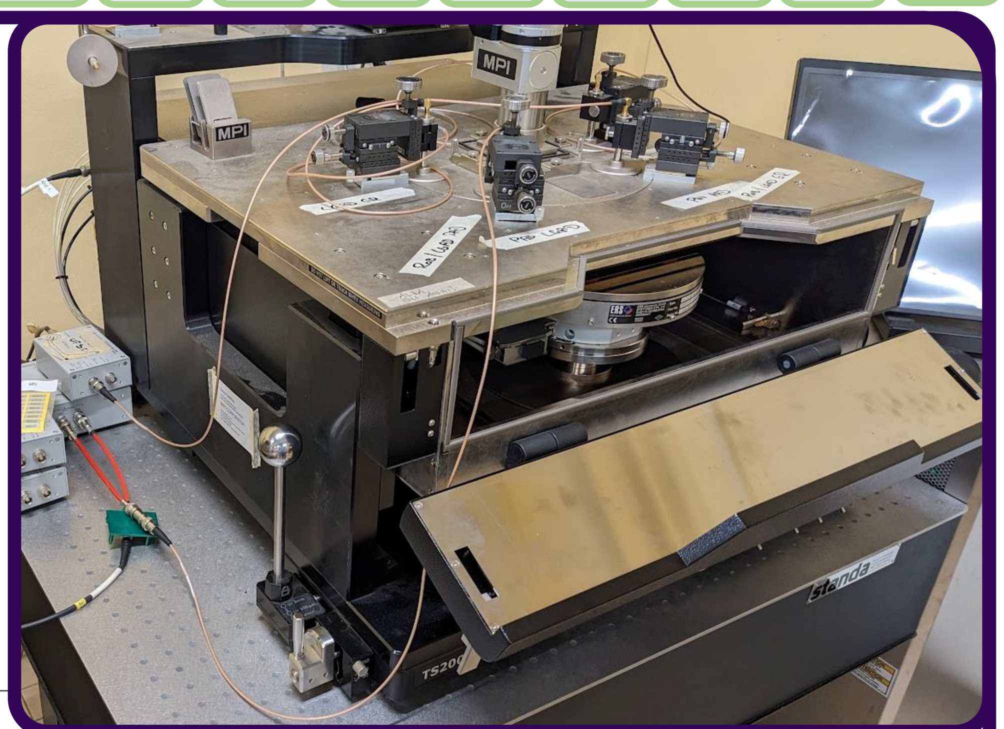
- Extract the contribution due to the gain implant
- Compare the **profiles** for different fluences

## 4) IV characteristics

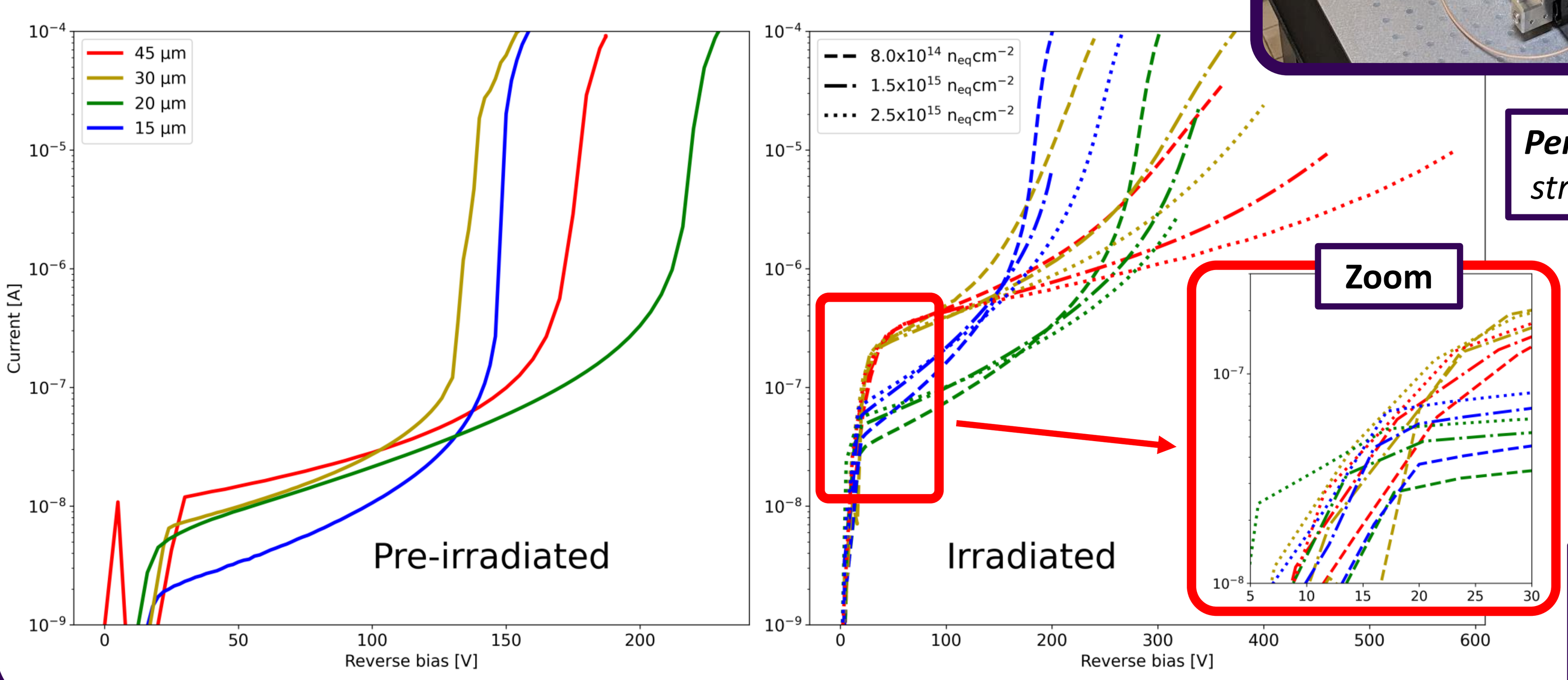
Comparison of temperature and irradiation on IV trends

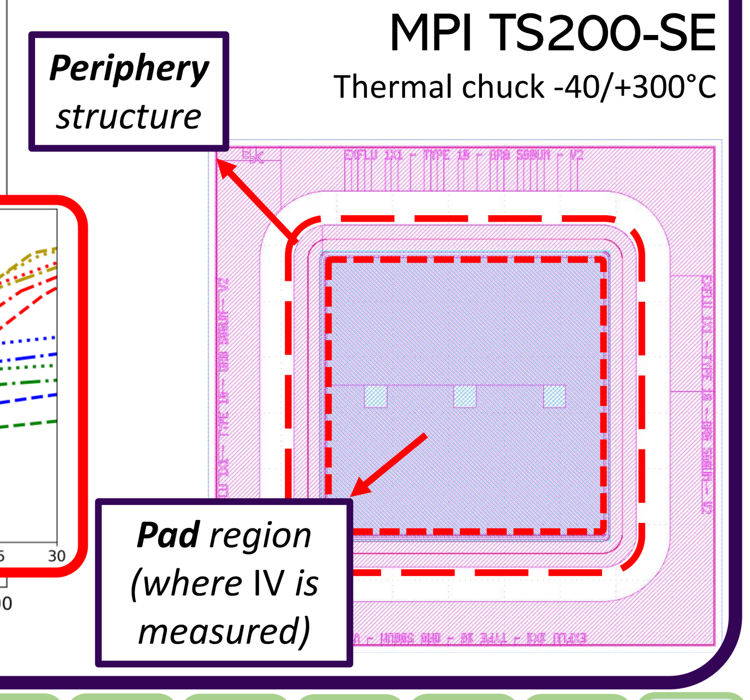
- **Gain layer breakdown** visible at low biases **~30 V**
- **Irradiation** degrades this gain layer breakdown "bump"
- $V_{gl}$ **decreases** as fluence increases (conversely to the bulk)
- **Bulk breakdown** trend identical to PIN sensors (not shown)

Can study the gain degradation in CV measurements



MPI TS200-SE
Thermal chuck -40/+300°C

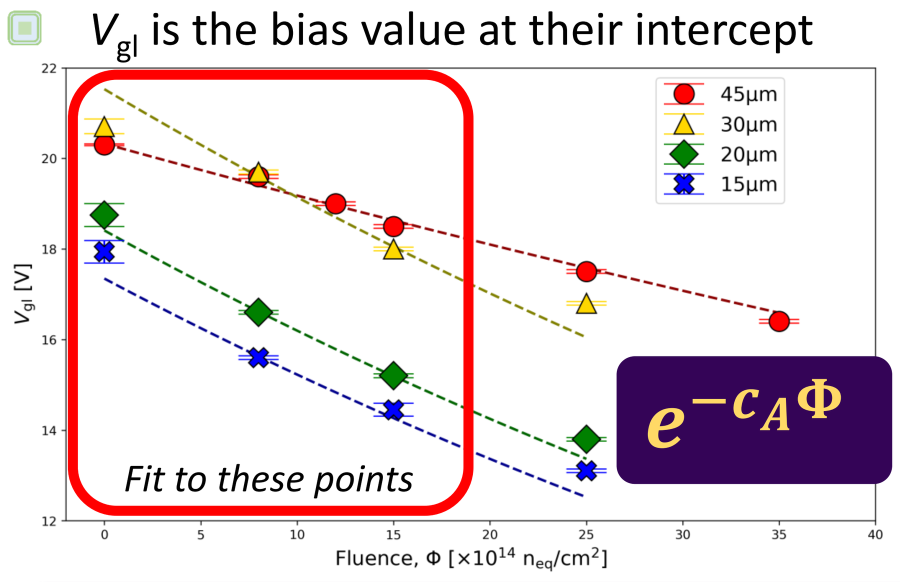


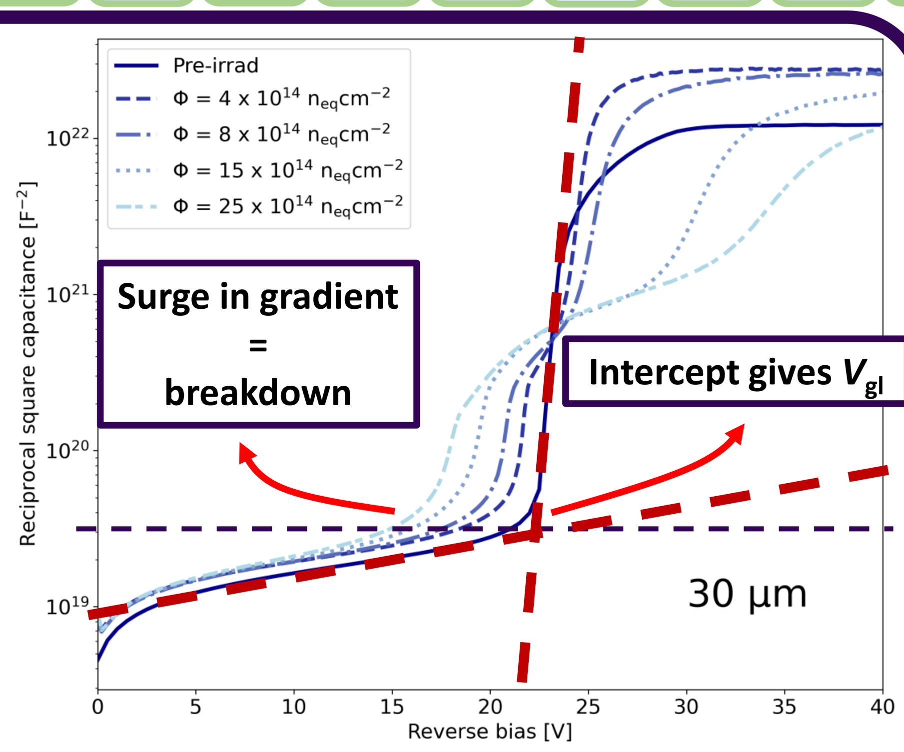




## 5) CV characteristics

Extract $V_{gl}$ from the $C^{-2}V$ curve

- Two linear fits about the breakdown
- $V_{gl}$ is the bias value at their intercept

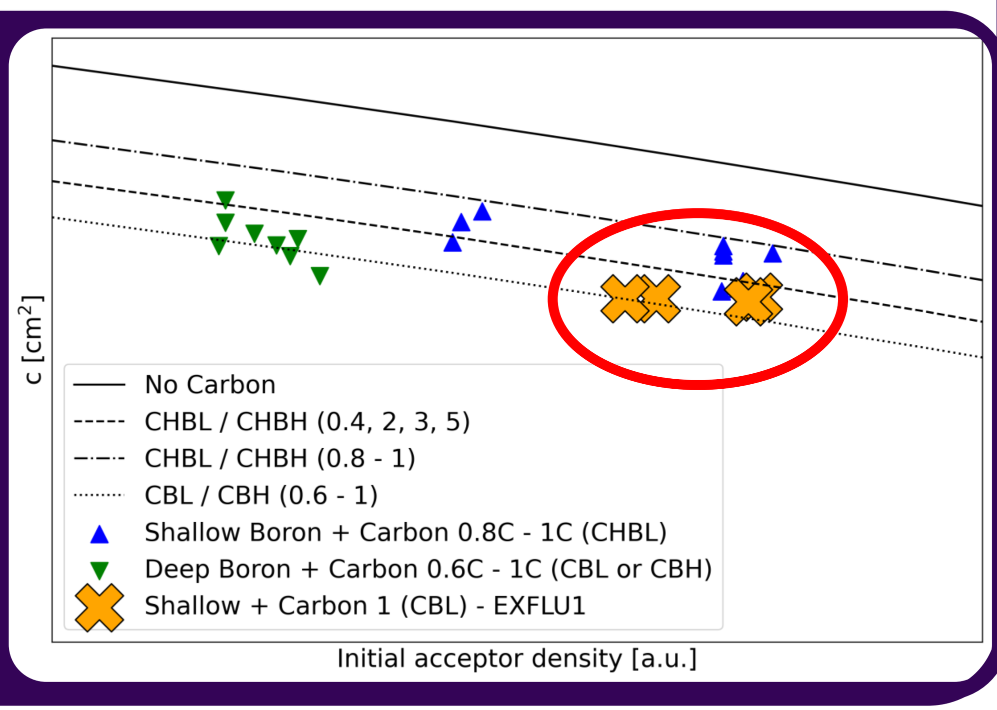



- Compare $c_A$ against initial acceptor density

**Best acceptor removal measurements to date!**

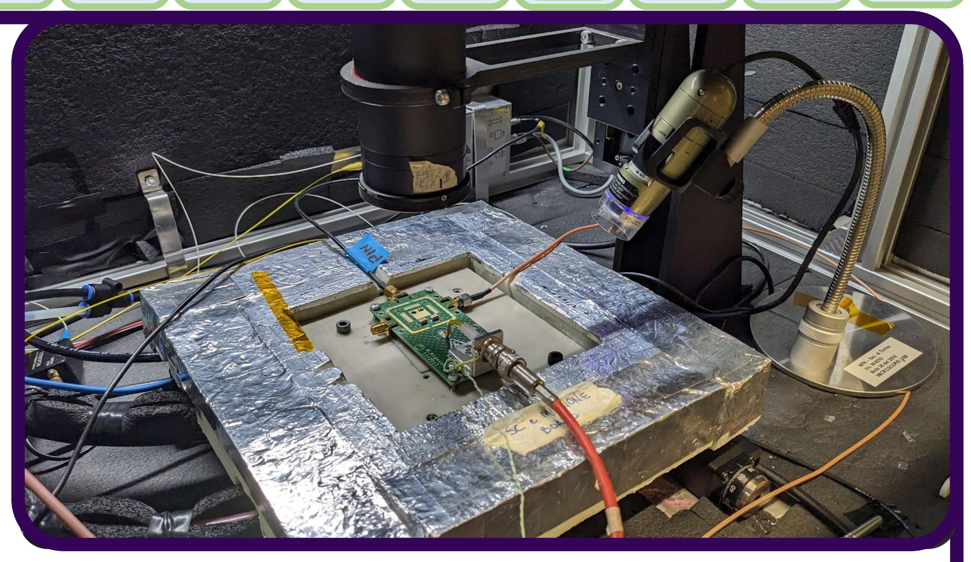
| $c_A$ [x $10^{-16}$ $cm^2 n_{eq}^{-1}$] | Thickness | $c_A$ |
|---|---|---|
| | 45 | 1.39 |
| | 30 | 1.34 |
| | 20 | 1.37 |
| | 15 | 1.37 |




## 6) Gain Profile

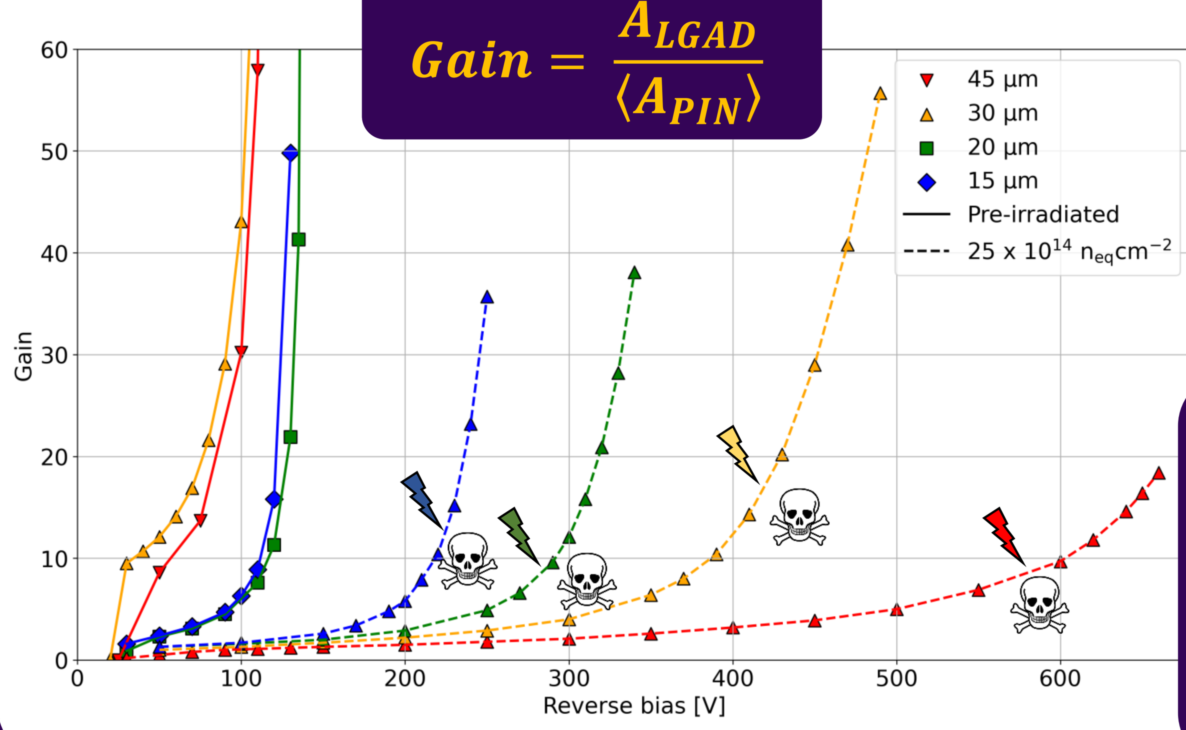
Gain profile obtained using TCT

- Transient current technique performed inside a black box at -10°C
- NIR laser at 4 MIPs incident on LGAD-PIN
- Measure signal for increasing bias



TCT Setup from Particulars
Pico-second IR laser at 1064 nm
Laser spot diameter 10 µm
Cividec broadband amplifier (40dB)
Oscilloscope LeCroy 640Zi

$$Gain = \frac{A_{LGAD}}{\langle A_{PIN} \rangle}$$




Gain profiles at pre-irradiation and Φ = 2.5 x $10^{15}$ $n_{eq}/cm^2$

☠ Single event breakdown limit shown for these results

SEE: 43rd RD50 talk on single event breakdown ref. Marco Ferrero

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