Advances in the TCAD modelling of non-irradiated and irradiated Low-Gain Avalanche Diode sensors

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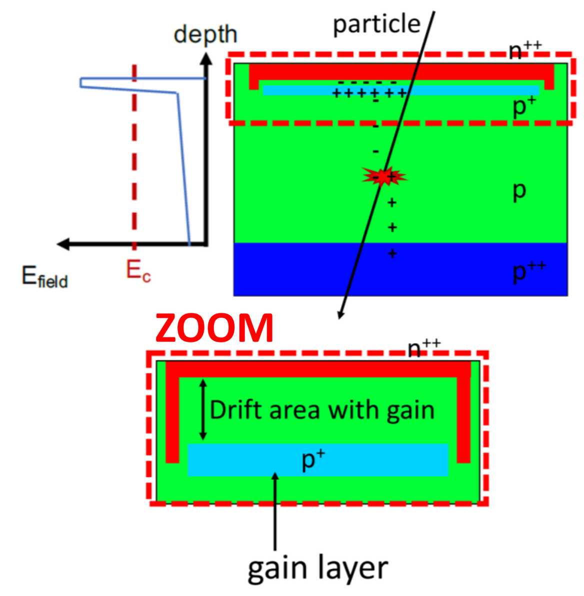
Motivations

- ✓ Developing radiation-resistant silicon detectors for particle tracking in the next generation of high-energy physics experiments (e.g., HL-LHC or FCC) able to efficiently operate in extreme radiation environments, $\Phi \sim 1\times10^{17}$ n_{eq}/cm^2 [1].
- ✓ The Low-Gain Avalanche Diode (LGAD) technology (see figure on the right) helps to mitigate the radiation damage effects by exploiting the controlled charge multiplication mechanism [2].
- ✓ To evaluate the impact of several design strategies and the radiation damage effects on the LGAD sensors electrical behavior:
  - o ad-hoc advanced Technology CAD (TCAD) modelling before and after irradiation;
  - o massive test campaign on specifically devised structures, both non-irradiated and irradiated ones.

  → **Validation** of the development framework (in this work, based on the **Hamamatsu technology** - **HPK**)

  → **Sensor design** and **optimization** before the large volume production.

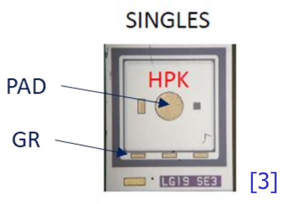


Measurements

DUT & Setup

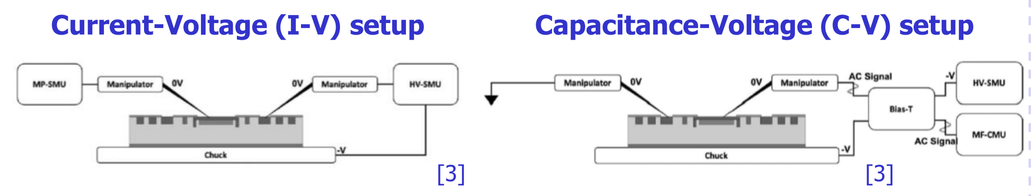
HPK2, Split1 (S1) & Split2 (S2)

Pad size: 1.25 x 1.25 mm²
Edge distance: 300 µm

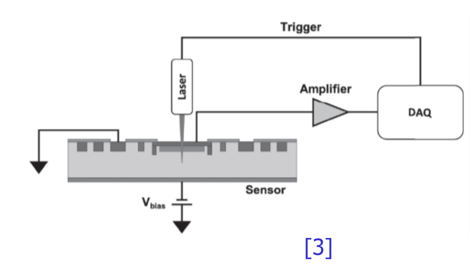


Sample	V_{GL} (V)	V_{BD} (V) @ 20 °C	C_{FD} (pF)
S1	54.5	145	3.6
S2	53.5	168	3.6

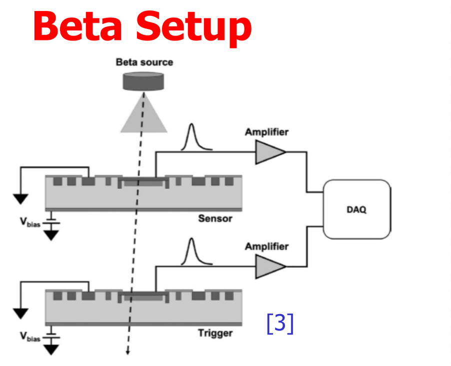
Probe Station



TCT Setup

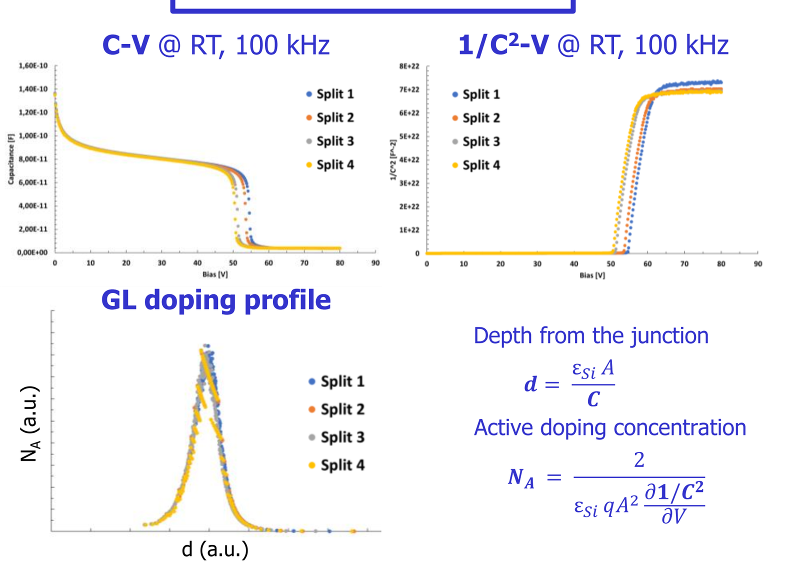


Beta Setup



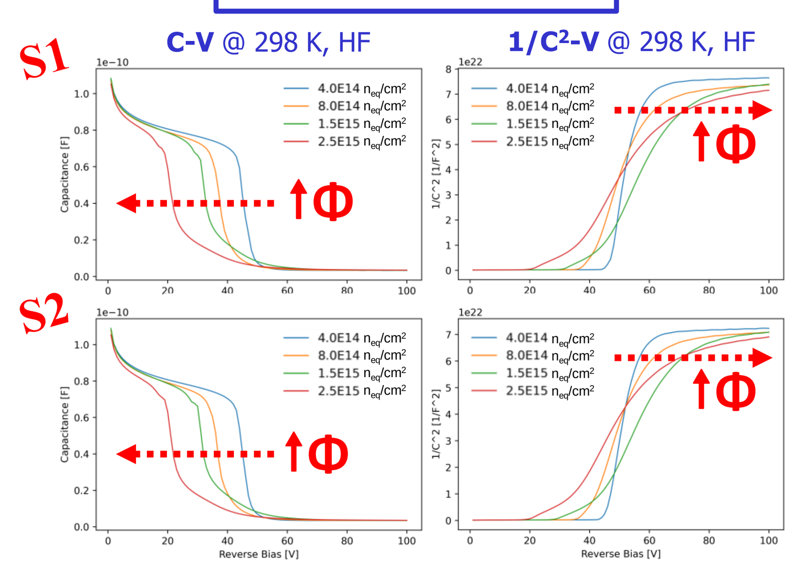
C-V & 1/C²-V

Pre-irradiation



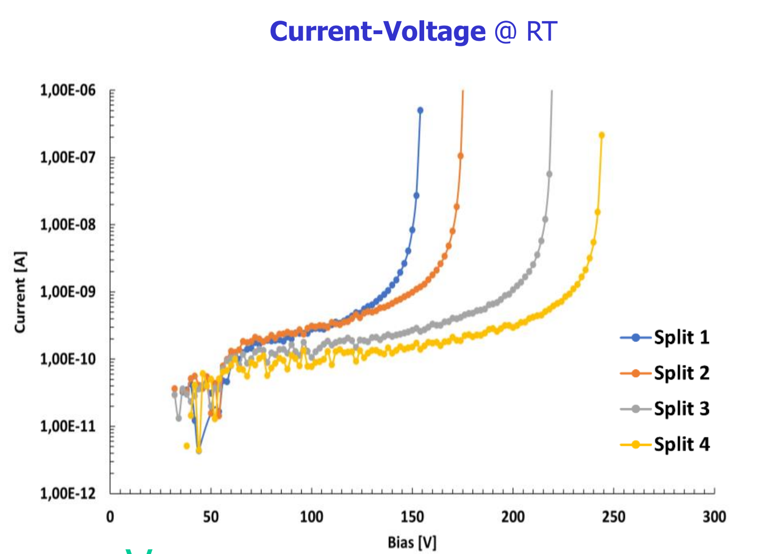
Extraction of the Gain Layer doping profile

Post-irradiation

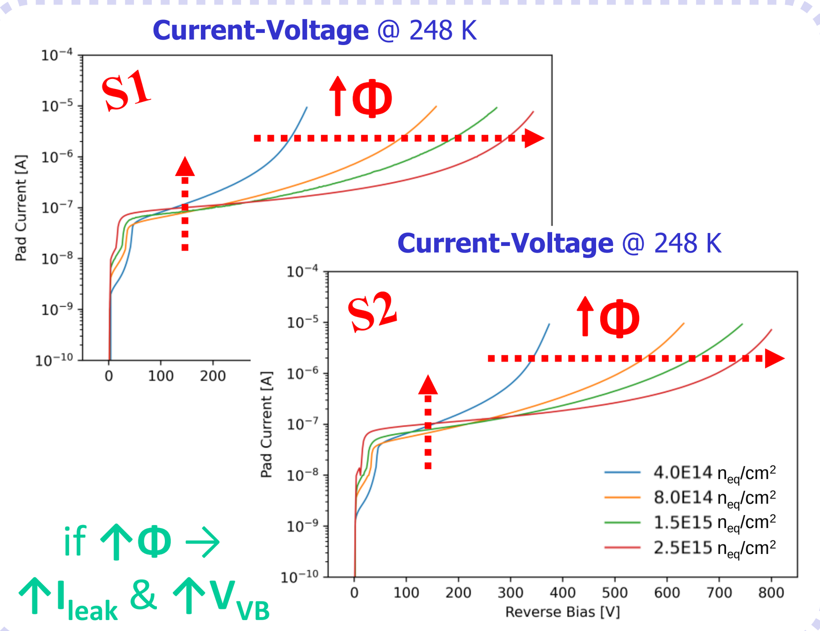


if ↑Φ → ↓V_{GL} & ↑V_{FD}

I-V

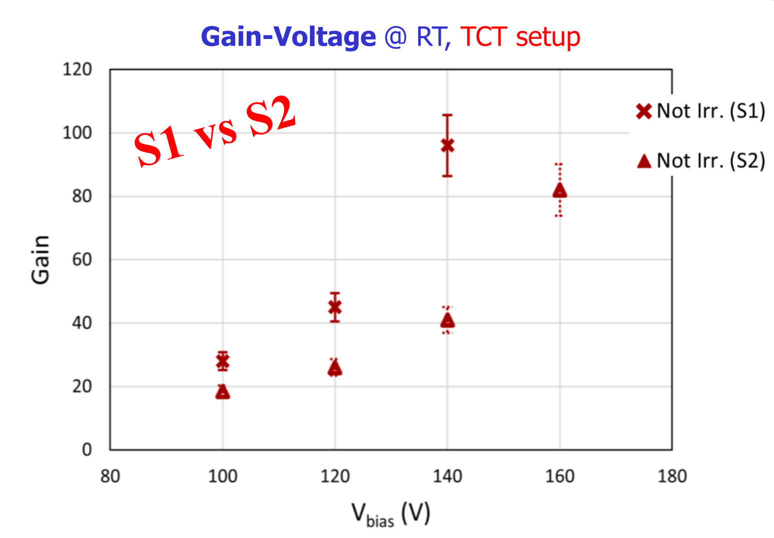


$V_{BD,S1} < V_{BD,S2}$

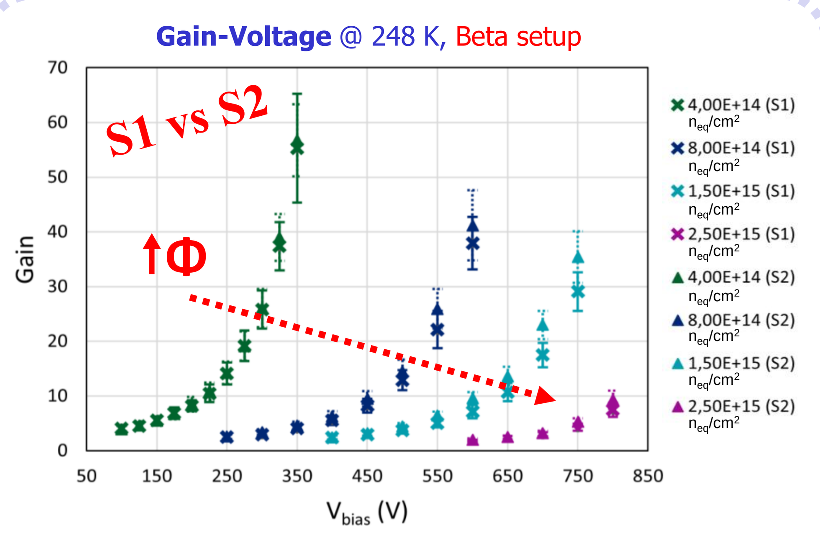


if ↑Φ → ↑I_{leak} & ↑V_{VB}

G-V



$Gain_{S1} > Gain_{S2}$

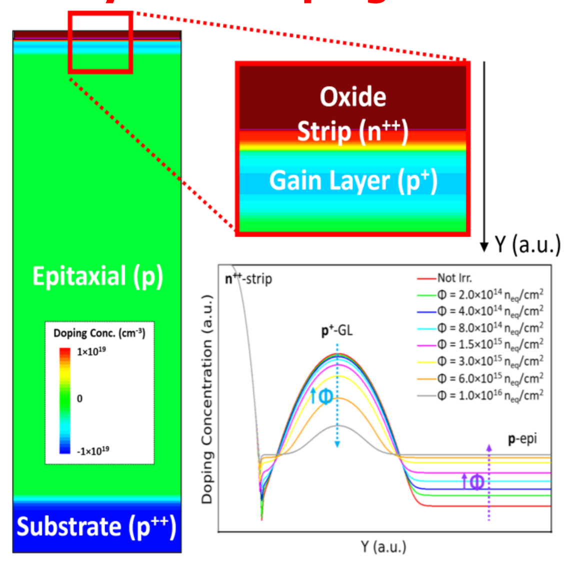


if ↑Φ → ↓**Gain** ($Gain_{S1} \approx Gain_{S2}$)

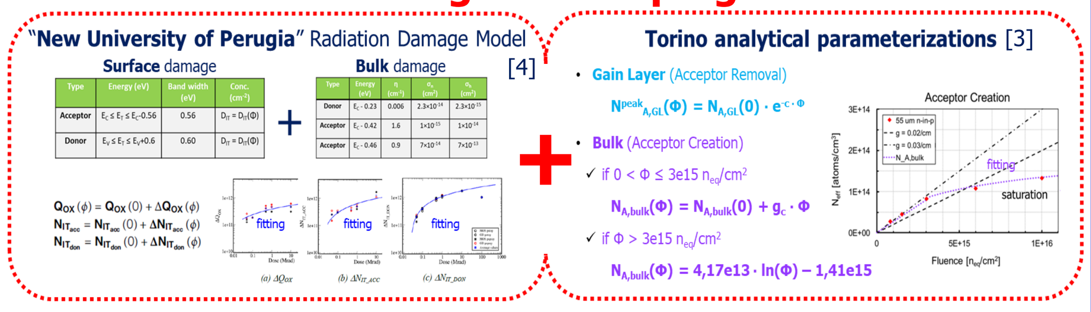
Simulations

TCAD model

Layout & Doping Profile



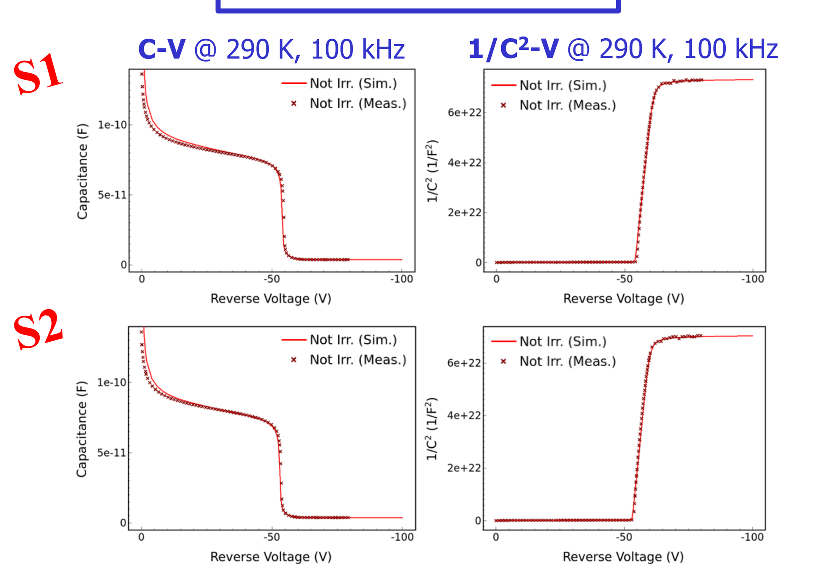
"PerugiaModDoping"



The "Perugia Modified Doping" (PerugiaModDoping) numerical radiation damage model has been already validated by comparing the results of TCAD simulations with experimental data carried out from the measurements of sensors coming from the UFSD2 and UFSD3.2 FBK productions, before and after irradiation [5].

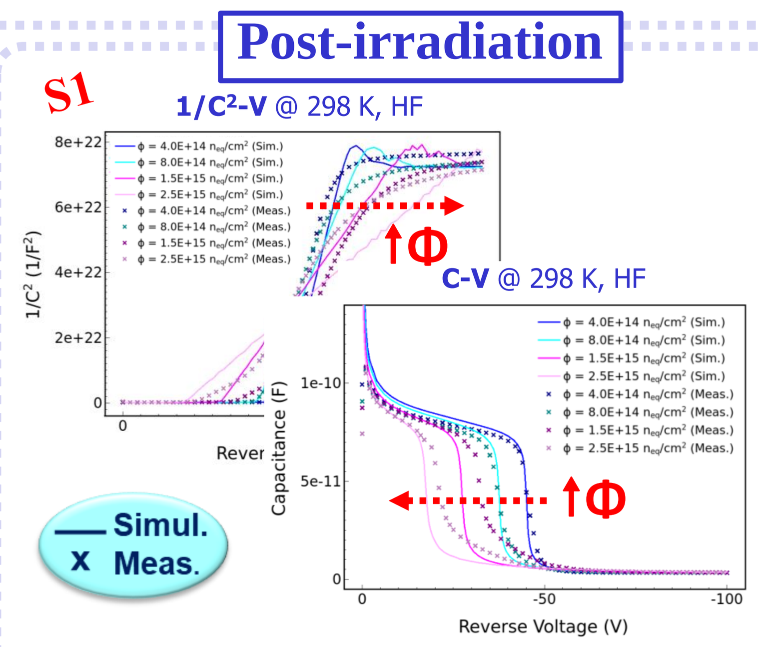
C-V & 1/C²-V

Pre-irradiation



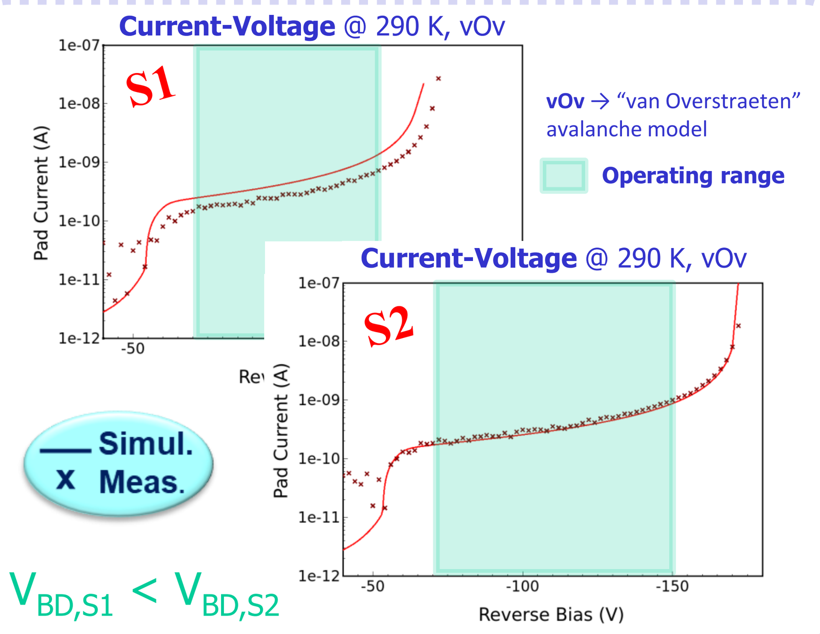
Tuning of the doping profile (C-V matching)

Post-irradiation

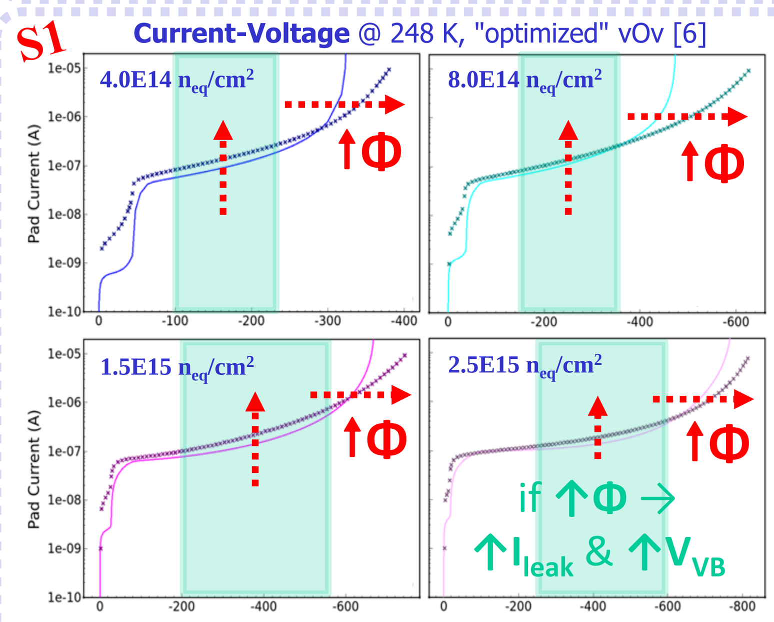


if ↑Φ → ↓V_{GL} & ↑V_{FD}

I-V

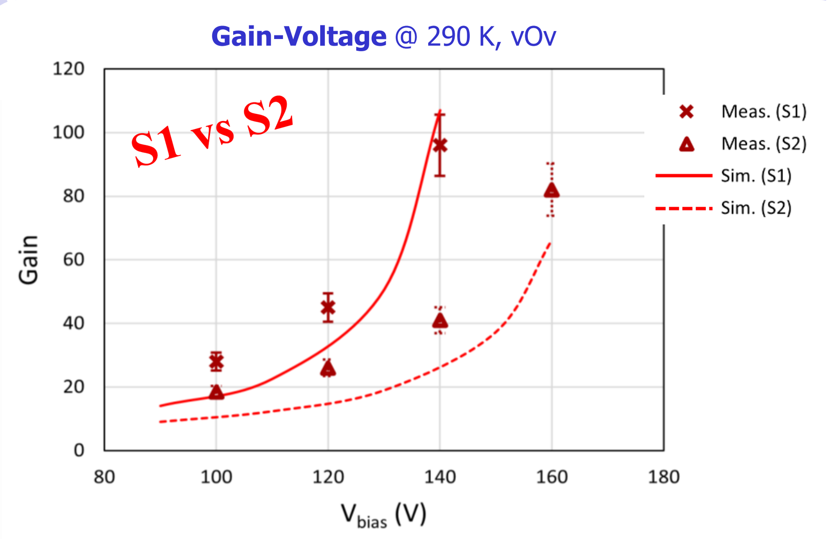


$V_{BD,S1} < V_{BD,S2}$

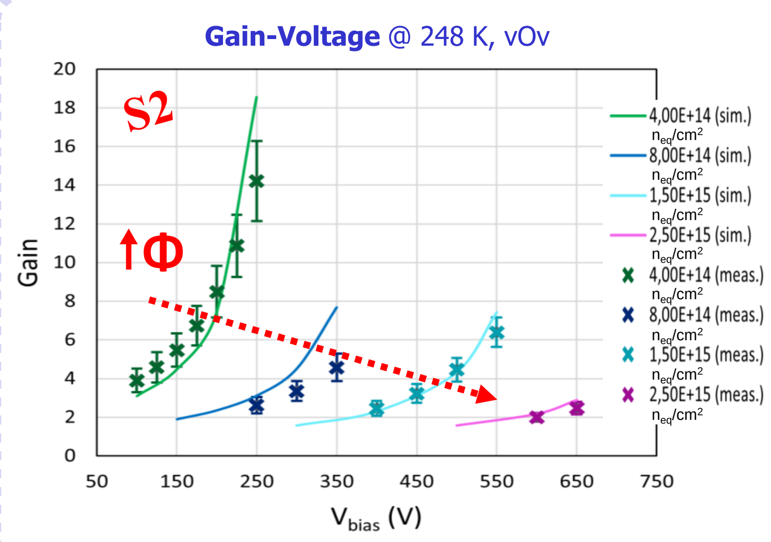


if ↑Φ → ↑I_{leak} & ↑V_{VB}

G-V



$Gain_{S1} > Gain_{S2}$



if ↑Φ → ↓**Gain** ($Gain_{S1} \approx Gain_{S2}$)

Outcome

- ✓ Validation of a TCAD model for the numerical simulation of LGAD sensors.
- ✓ "Perugia Modified Doping" radiation damage model → physics-based approach
  - o Traps parametrization ("New University of Perugia" modelling scheme)
  - o GL and bulk effective doping evolution with Φ ("Torino analytical parametrizations")
- ✓ Extensive test campaign on LGAD devices coming from the 2nd production of the Hamamatsu technology (HPK2), both non-irradiated and irradiated ones.
- ✓ The behaviour of the sensors in terms of I-V and C-V characteristics, as well as their response to different stimulus (laser and beta source) under different operating conditions (i.e., T, f and Φ) have been well reproduced in simulation.
- ✓ A good agreement has been already achieved with the UFSD2 and UFSD3.2 FBK sensor productions [5].

  → **General-purpose** and **high-predictive model** within the operating region of the sensor.

References

[1] V. Sola *et al.*, "Next-generation tracking system for future hadron colliders", Pos (Vertex2019) 034.

[2] G. Pellegrini *et al.*, "Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications", NIM, A 765 (2014) 12-16.

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