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Characterization and Simulation of Radiation Effects on Active Edges n-on-p Planar Pixel Sensors

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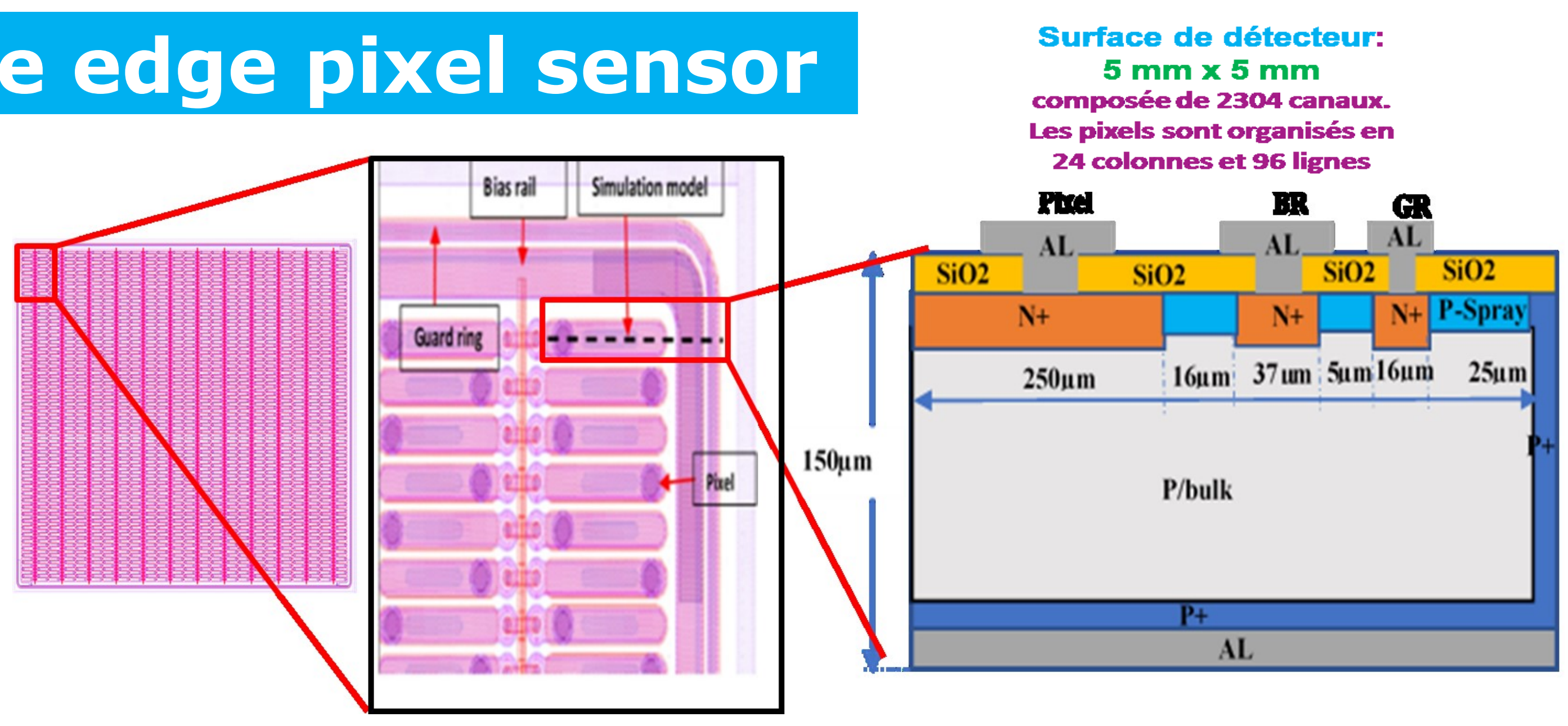
I/ Aim of the work

Future high-energy physics (HEP) experiments require highly segmented silicon sensors of increased geometrical efficiency with the ability to withstand extremely high radiation damage. The main objective of this work is to evaluate by simulation the performance of planar n-on-p sensors with active edges simulated at high radiation fluences up to 1×10^{16} n_{eq}/cm^2, using a three-level trap model for p-type silicon material. Taking advantage of the SIMS technique, an accurate representation of the structure was obtained in terms of doping profile. The breakdown voltage, leakage current, hole density and electric field distributions, and charge collection efficiency (CCE) are studied as a function of radiation fluence. Simulation is conducted using a Silvaco^{TM} TCAD software.

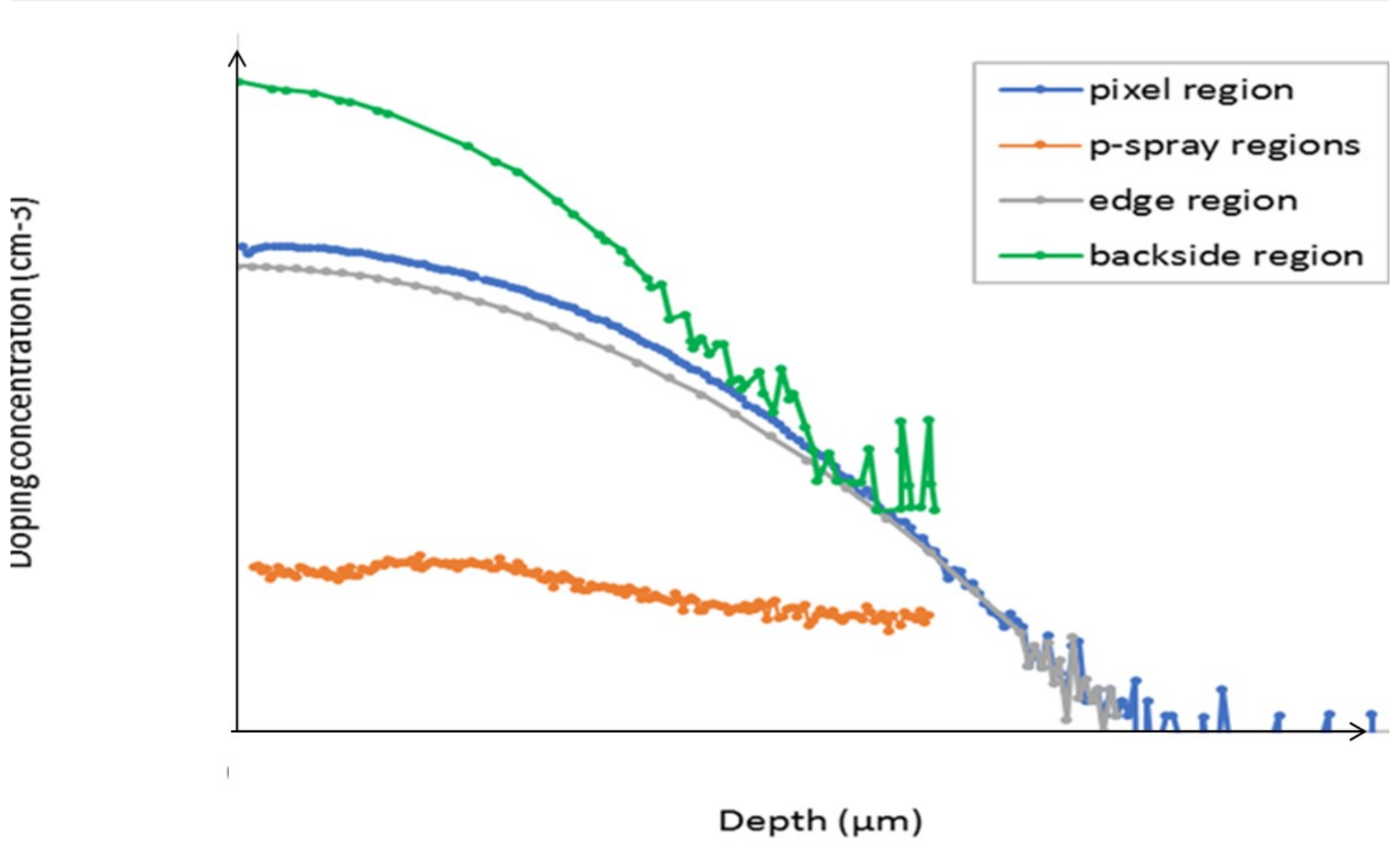
II/ Active edge pixel sensor

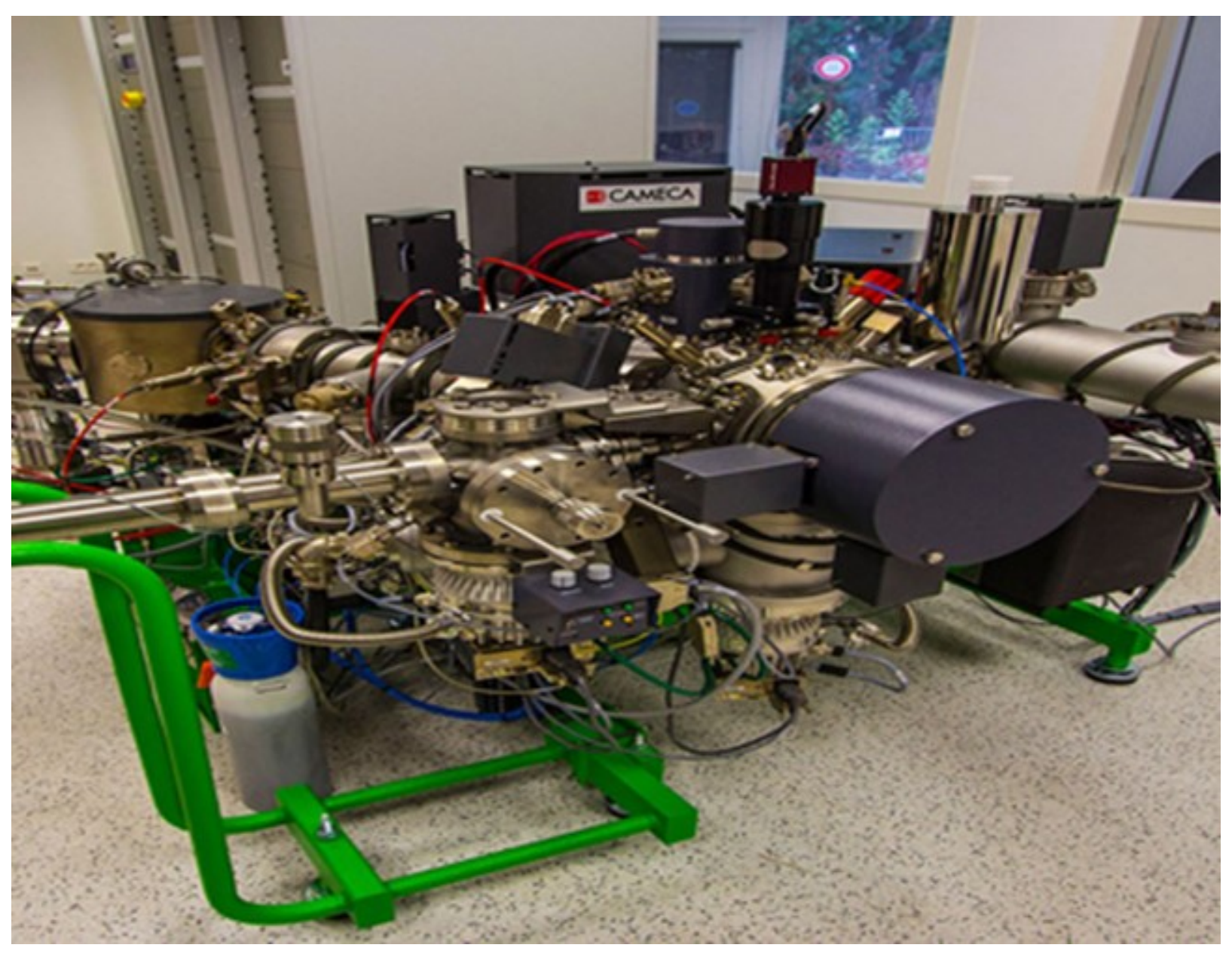
Active area:
- 5mmx5mm
- 2304 chnnels
- 24 col. and 96 row.
- This specific geometry was produced by Advacam Ltd



III/ Doping estimation through SIMS

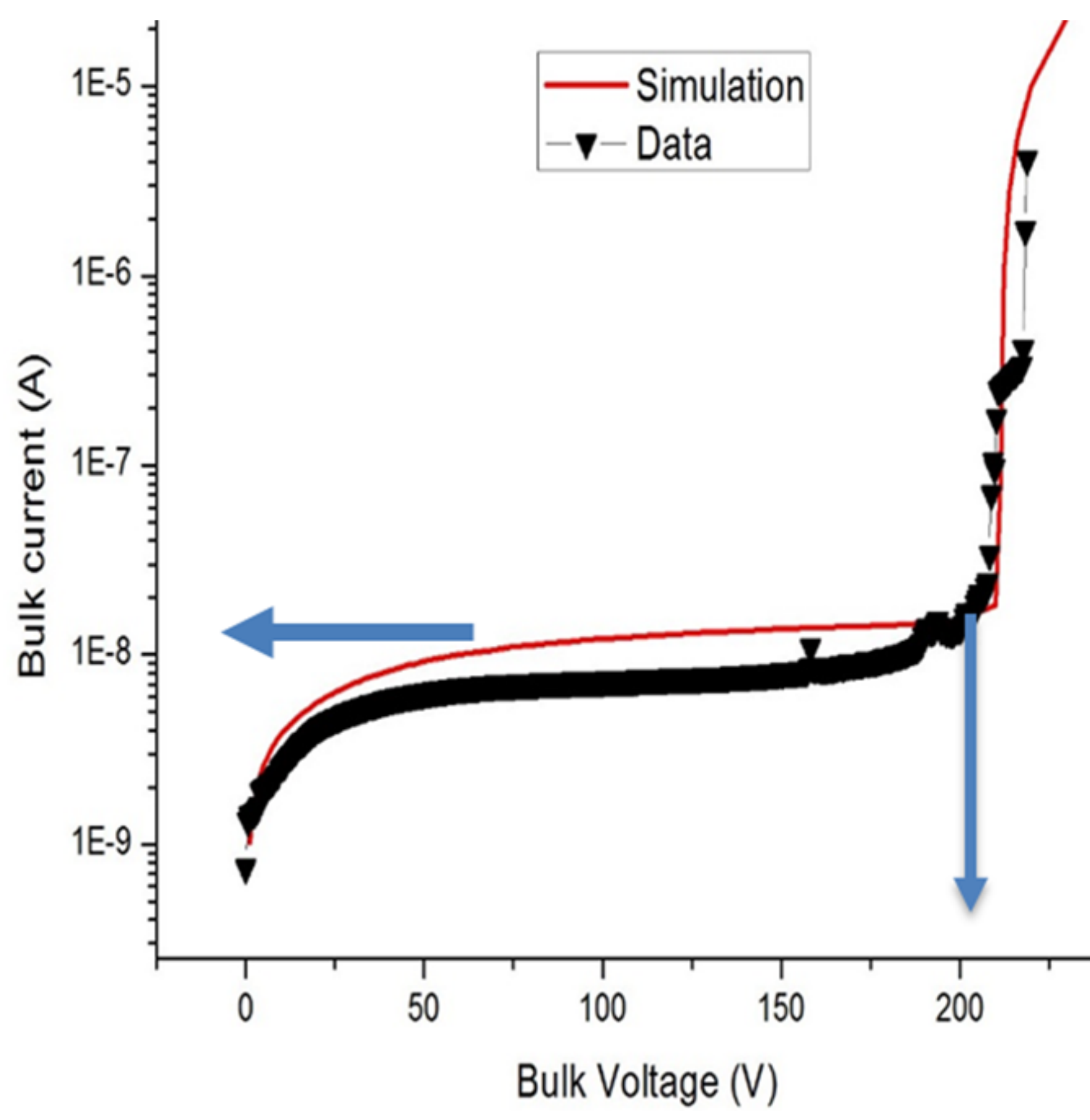
Secondary ion mass spectroscopy (SIMS) is a powerful tool allowing for a detailed characterization of the implanted doping profile. Measurements presented in this study were conducted at the **GEMAC CNRS laboratory** using the Cameca IMS-7F system.

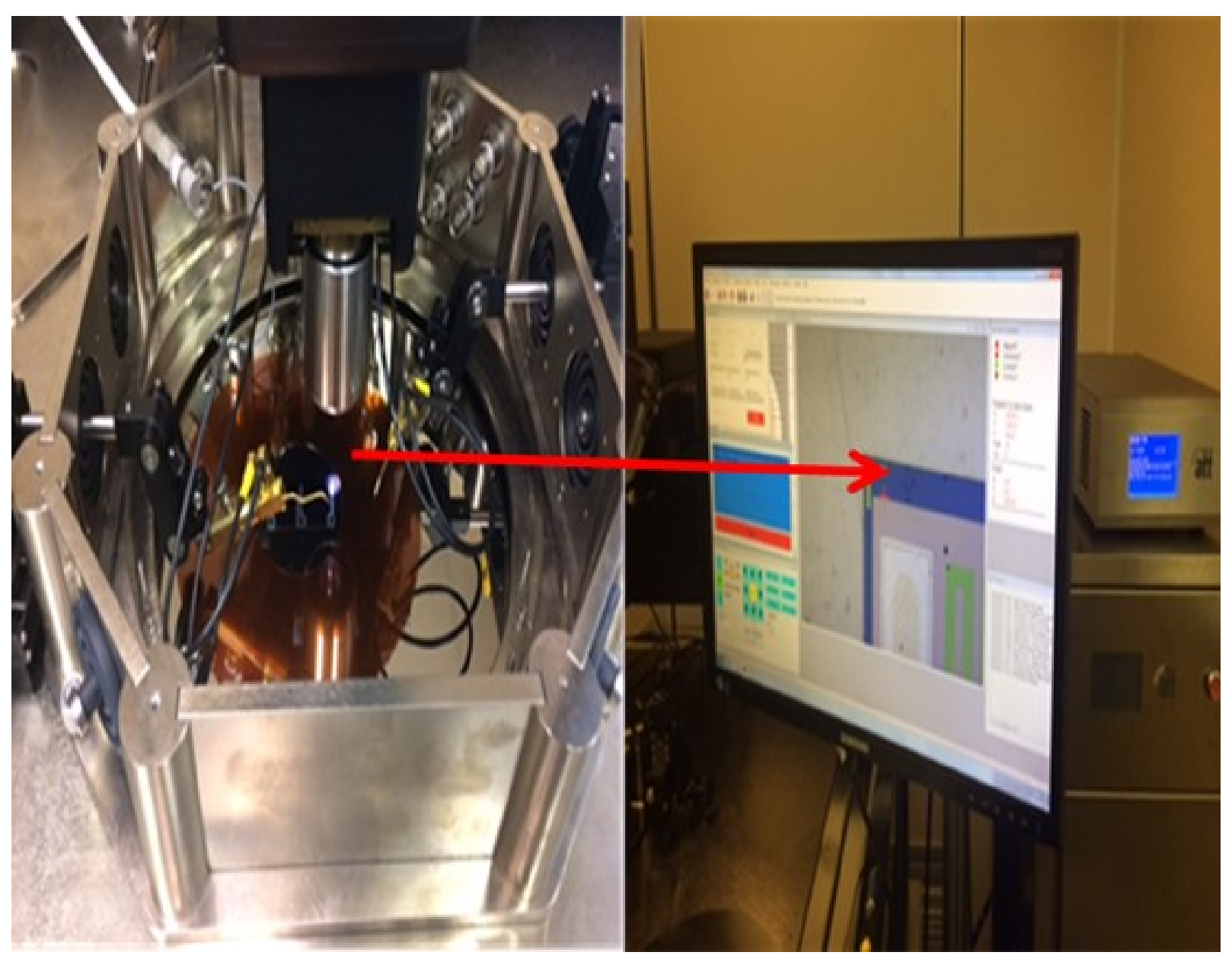




IV/ Device performance before irradiation

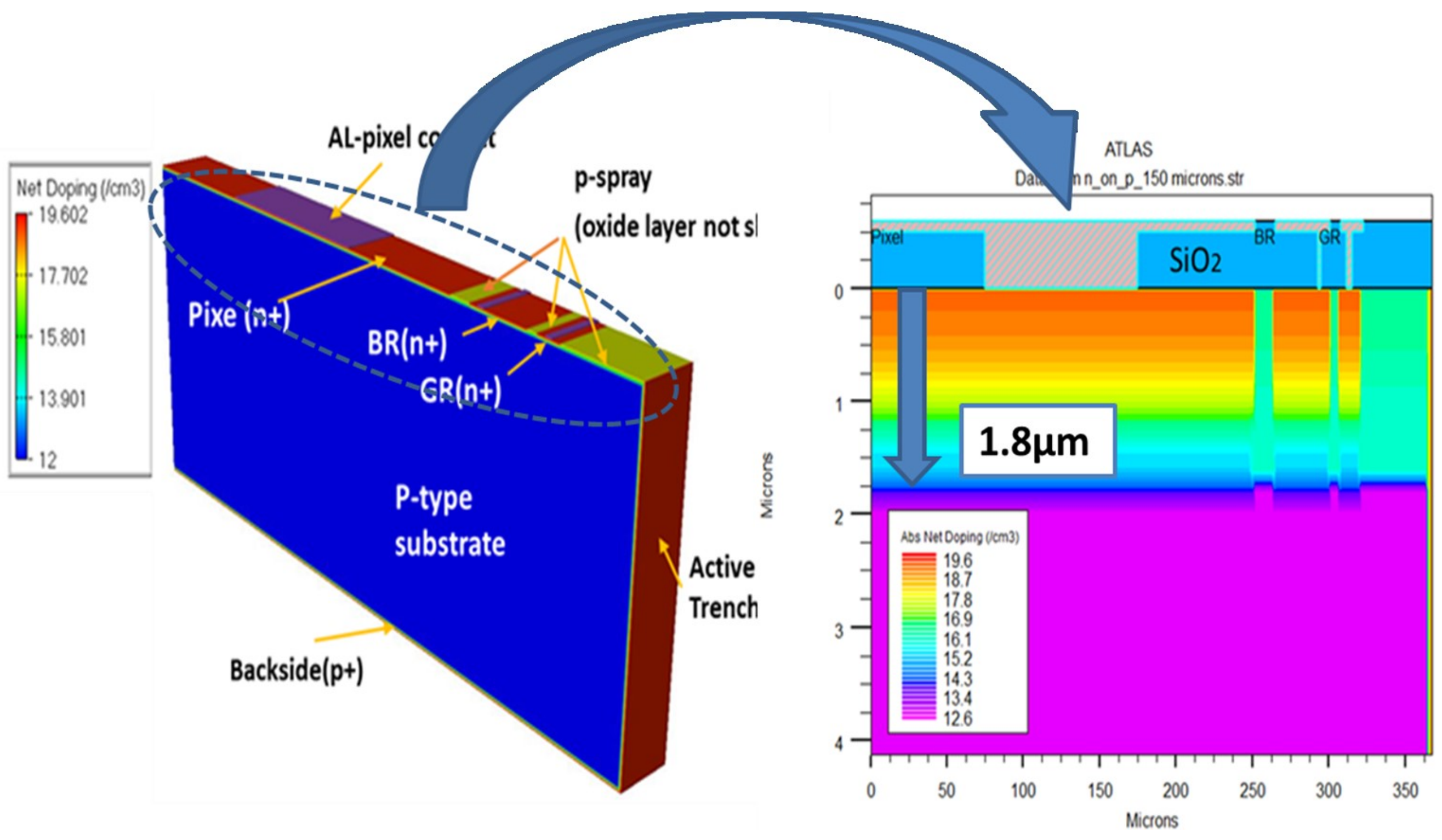
Simulations for **leakage current** are performed using the same parameterized values as above and by adjusting the **minority carrier lifetime to 2.5 x10^{-5} s** in order to match the simulation with measurements . It can be seen from the following Figure that the simulated leakage current matche well with measurements **(~ 10 nA).**





- The **breakdown voltage** is about **-200V** at room temperature.
- Measurements were conducted at the IJCLab CNRS laboratory using the Probe Station Signatone WL350.

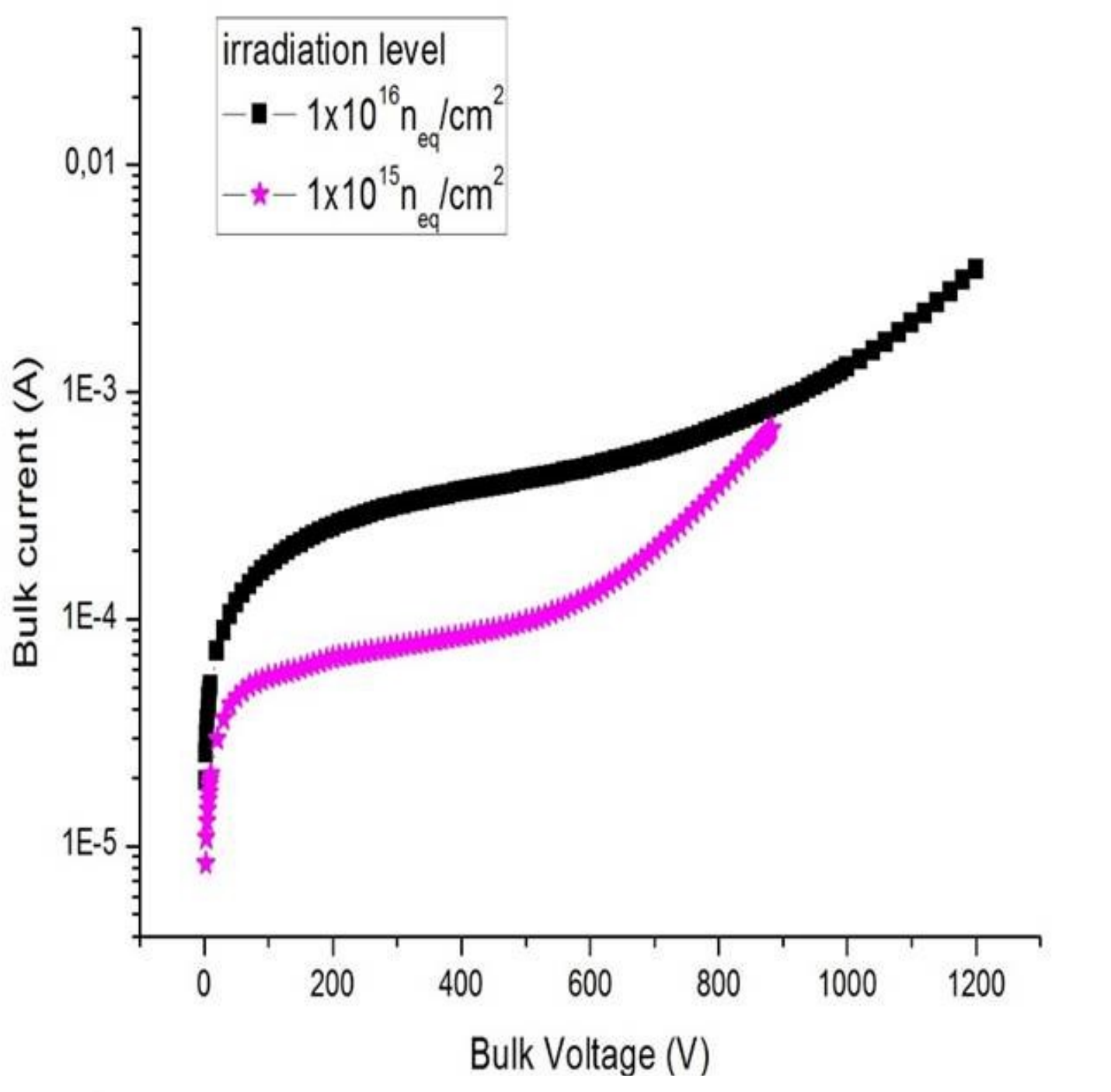
V/ Device performance after irradiation



- 3D representation (left) and zoomed 2D cross section (right) of the net doping concentration in the n-on-p planar active edge pixel sensor as a function of the depth for the border region. Oxide layers are not demonstrated in 3D representation. Scale in log (Atoms/cm3)
- For this work, ahigh-resistivity Float Zone <100> p-type silicon substrate is used in an n-in-p configuration, with a total thickness of 150 µm. The n+ and p-spray regions are defined using doping profiles obtained by SIMS measurements.
- The radiation damage model used in this analysis is based on the so-called Perugia three-level trap model, Combined bulk and surface radiation damage effects at very high Fluences in Silicon.

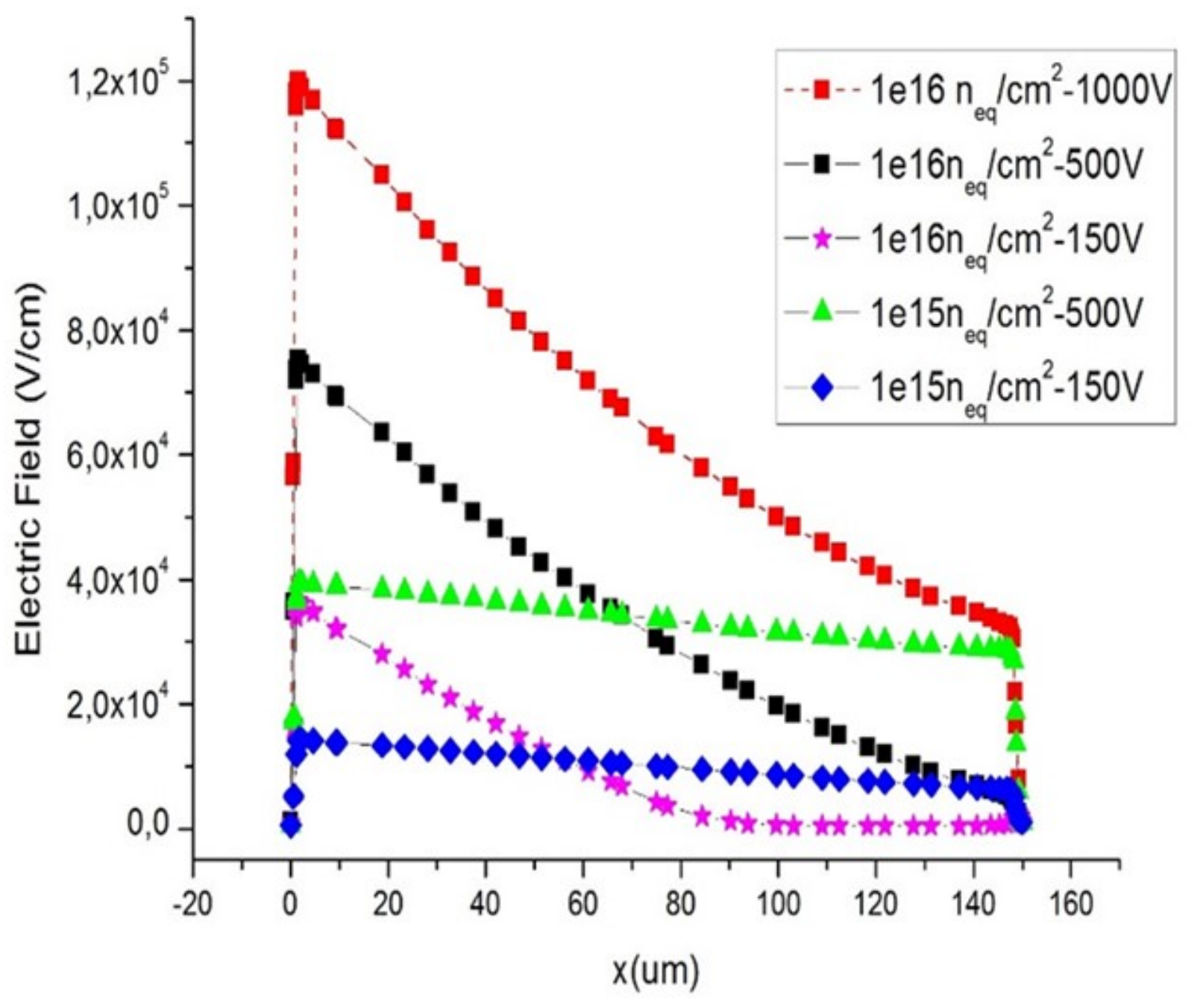
→ **Leakage current :**

The comparison of the simulated leakage current for different fluences is presented.
For comparison, a matrix exposed to a **fluence of 10^{15} n_{eq}/cm^2**. At this value, a breakdown voltage of **around −900V at 248K** is expected Increasing the **fluence to 10^{16} n_{eq}/cm^2** the breakdown value up **to ~ −1200V (black dots)** The simulated leakage current remains close to **~ 0.06mA for 10^{15}** n_{eq}/cm^2 at bias voltage of **~ −200V. ,** but this value increases slightly **to ~ 0.2mA for 10^{16} n_{eq}/cm^2** at same bias voltage.



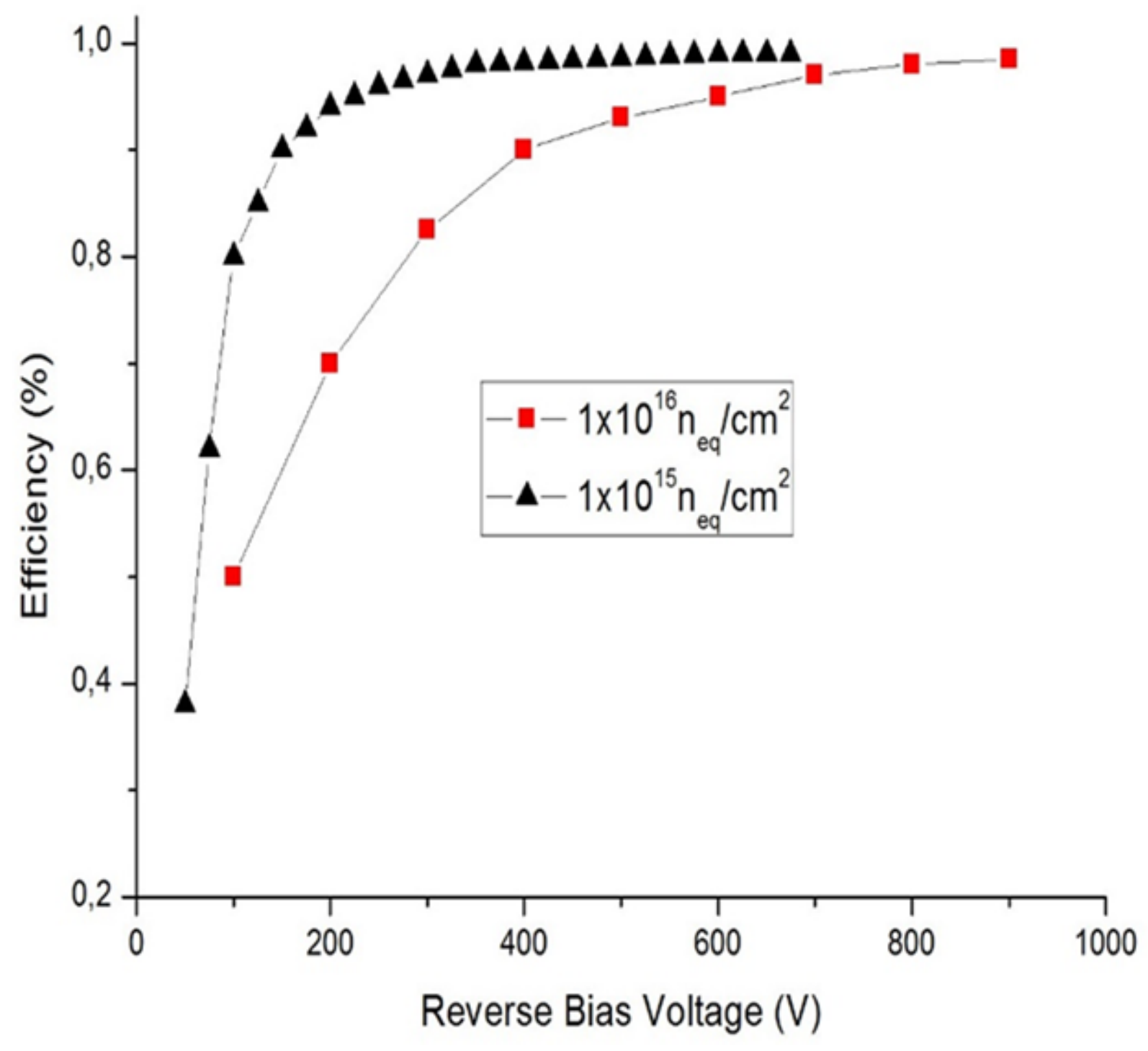
→ **Electric field distribution**

The appearance of the high electric field is shown in this Figure, where a simulation of the electric field at the center of the pixel (125µm) for a sensor reversely biased at different bias voltages is presented for the fluences **values of 10^{15} and 10^{16} n_{eq}/cm^2**. When the sensor is biased at **− 1000 V** and irradiated with fluences of up to **10^{16} n_{eq}/cm^2**, the corresponding value of the maximal electric field is estimated to **120kV/cm** that requires the introduction of the Selberherr's Impact Ionization Model phenomenon in the simulation.



→ **Charge collection efficiency (CCE)**

To study CCE after irradiation, the transient current was simulated for different reverse bias voltages. The detector is illuminated by a **1060nm wavelength laser light** with a rectangular **2ns** width signal. The pulse is sent perpendicular to the detector surface in **125µm** incidence point hitting the center of the pixel region. Optical source power was set to generate the same charge that would be released by a minimum ionizing particle (MIP) traversing **150µm** thick silicon. TCAD software computes the ionization charge generated by the laser pulse, mostly uniformly deposited in the bulk depth, and performs a transient simulation over **10 ns** time.



V/ Conclusion

In this work, TCAD simulation was used to study the effects of radiation damage in active edge sensors for future high-energy physics experiments.

- The simulations indicate an increase in the breakdown voltage after irradiation. The possible range of operation bias voltage for a pixel module with a 150µm thick sensor is 400–600V for 1×10^{15} n_{eq}/cm^2 and 600–800V for 1×10^{16} n_{eq}/cm^2.
- Results obtained with particle beams favor the active edge technology.
  - A module with a 150µm thick sensor reaches an efficiency of 98.2% at 1×10^{15} n_{eq}/cm^2 at a moderate bias voltage of −400V.
  - After an irradiation, up to 1×10^{16} n_{eq}/cm^2 is shown to achieve an efficiency of 98% as observed at bias voltage −800V.

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