Status of 3D pixel simulations

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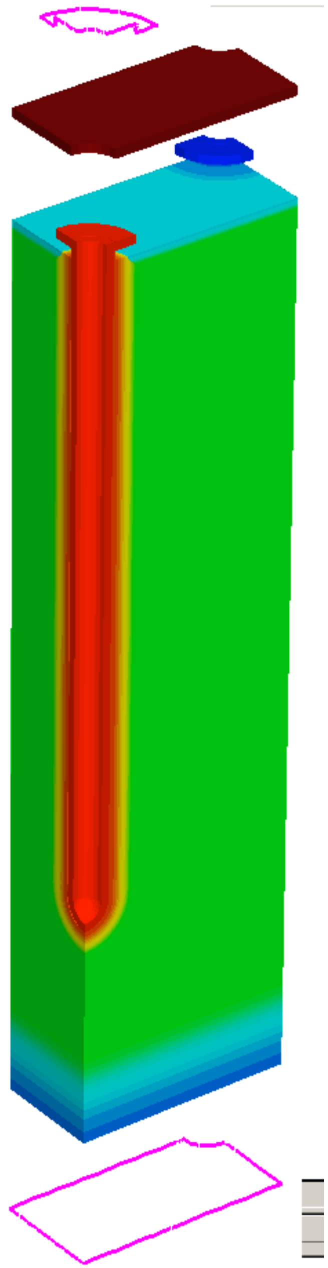
UNIVERSITA' DEGLI STUDI DI TRENTO

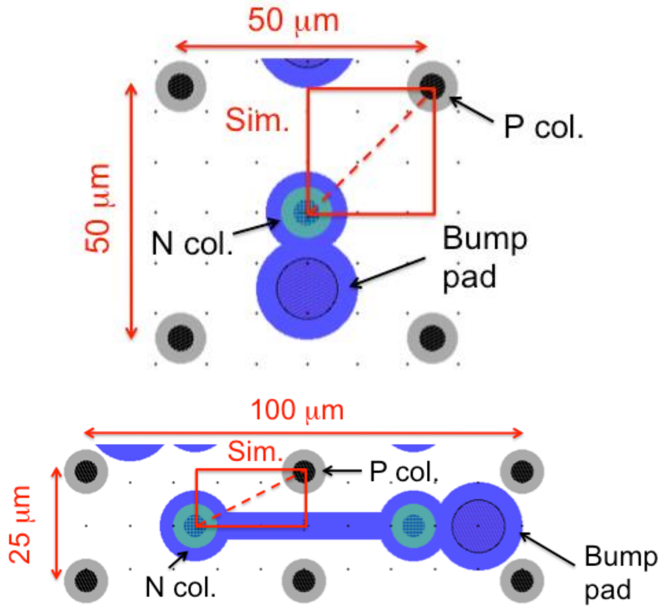
Outline

- Numerical Simulation in Trento
  - Electrical behaviors
  - Charge collection simulations
- Extraction of electrical quantity
- Ramo theorem code
- Conclusions

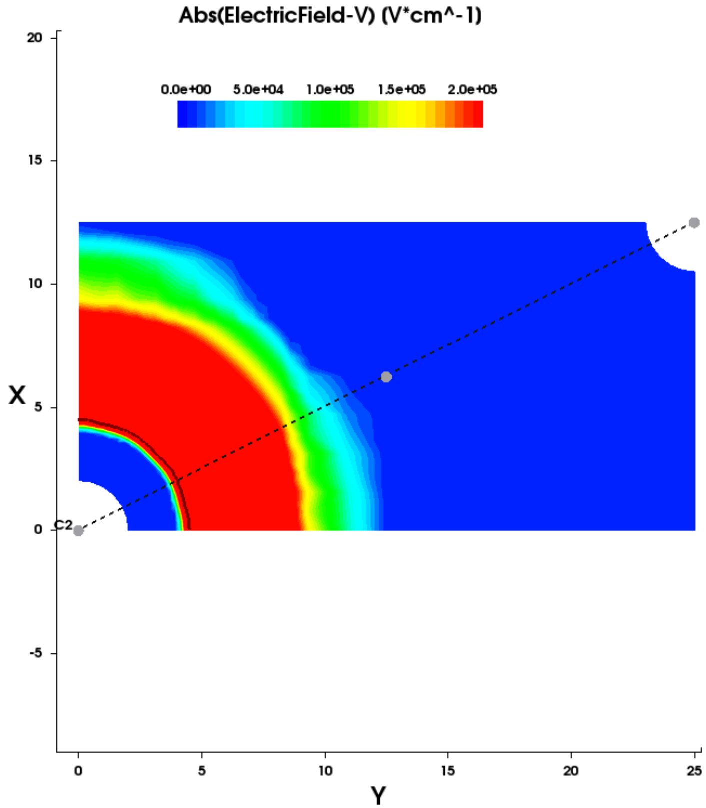
Numerical TCAD Simulation

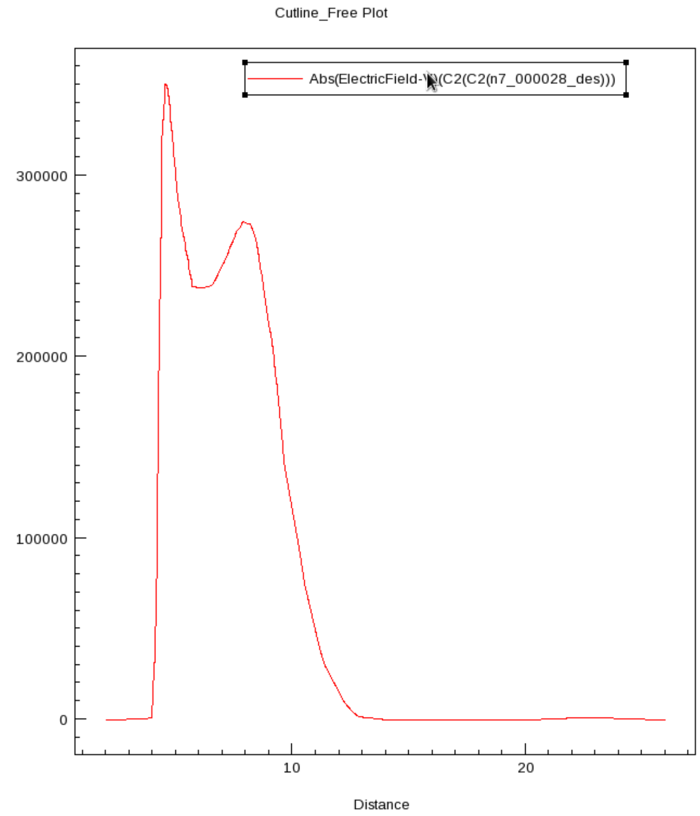
A 3D pixel





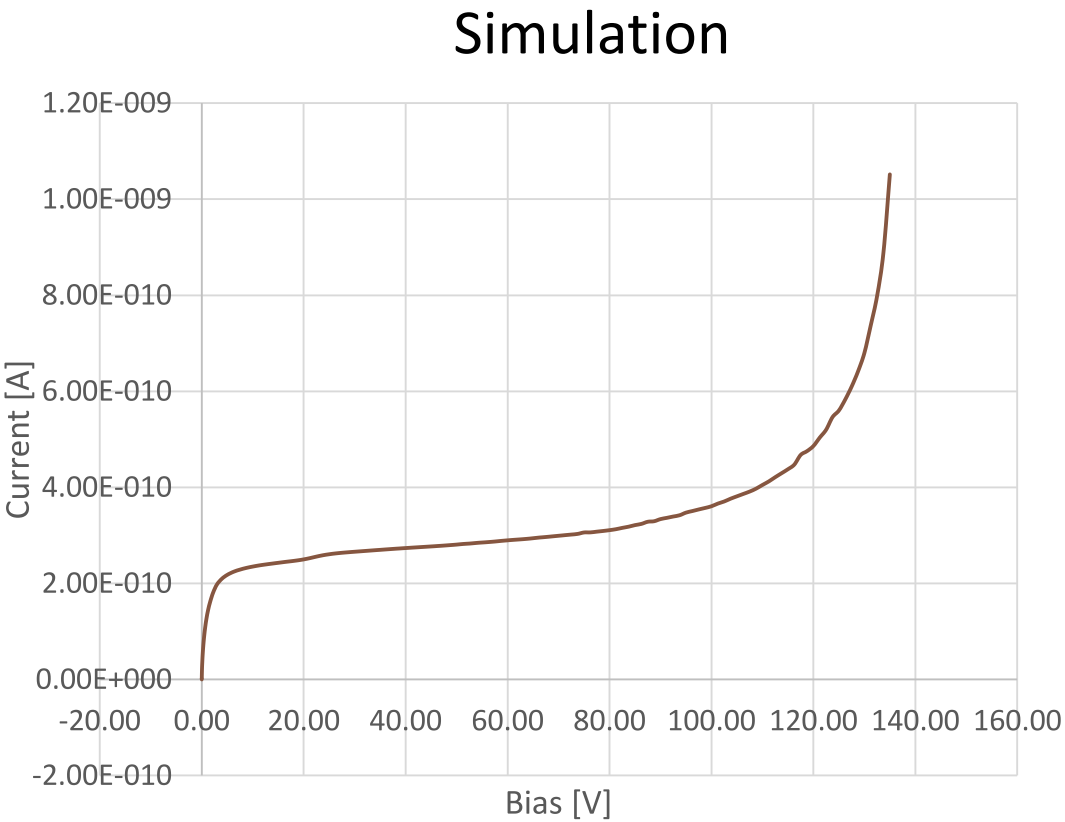
- Domain: 1/8 of pixel
- Geometry: 25x100
- Height: 100um
- Column length 75um
- No oxide charge

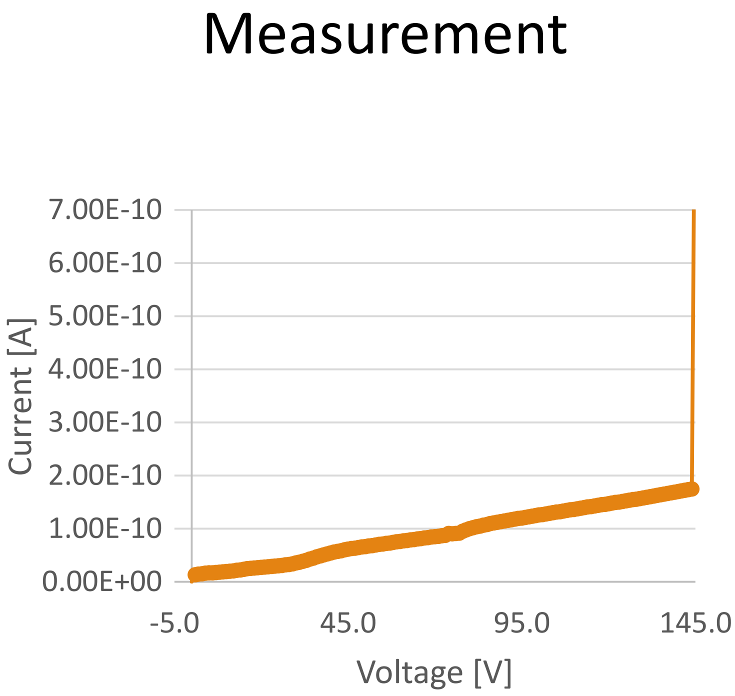




- ✓ Typical applications:
  - ✓ Breakdown analysis
  - ✓ Electrical field and potential profiles for different cross sections

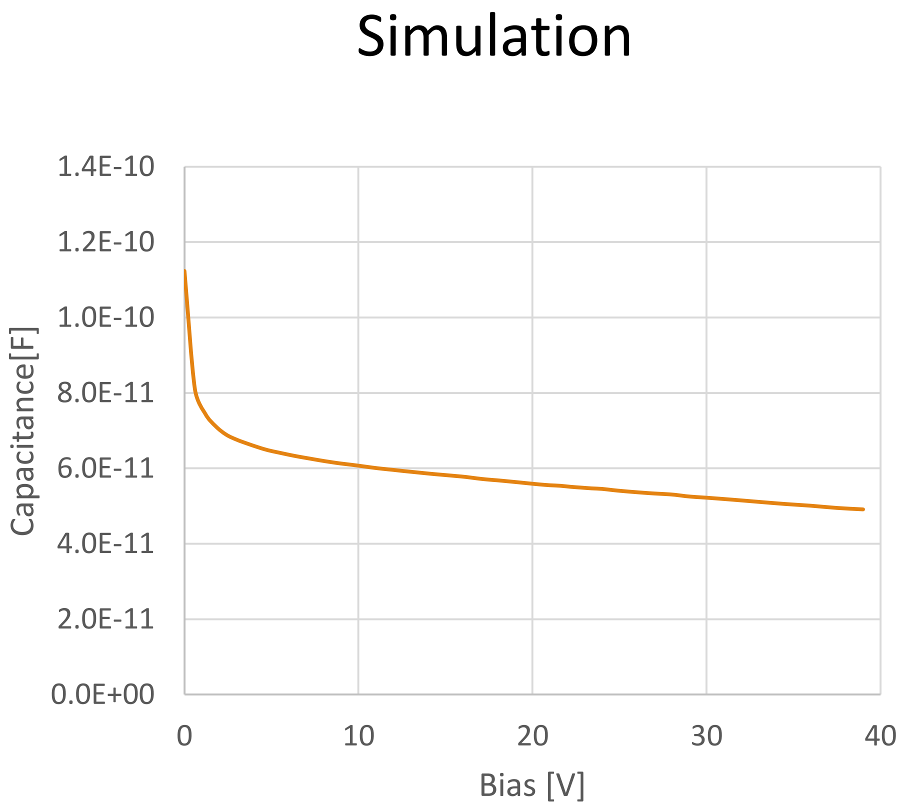
TCAD Simulations: IV

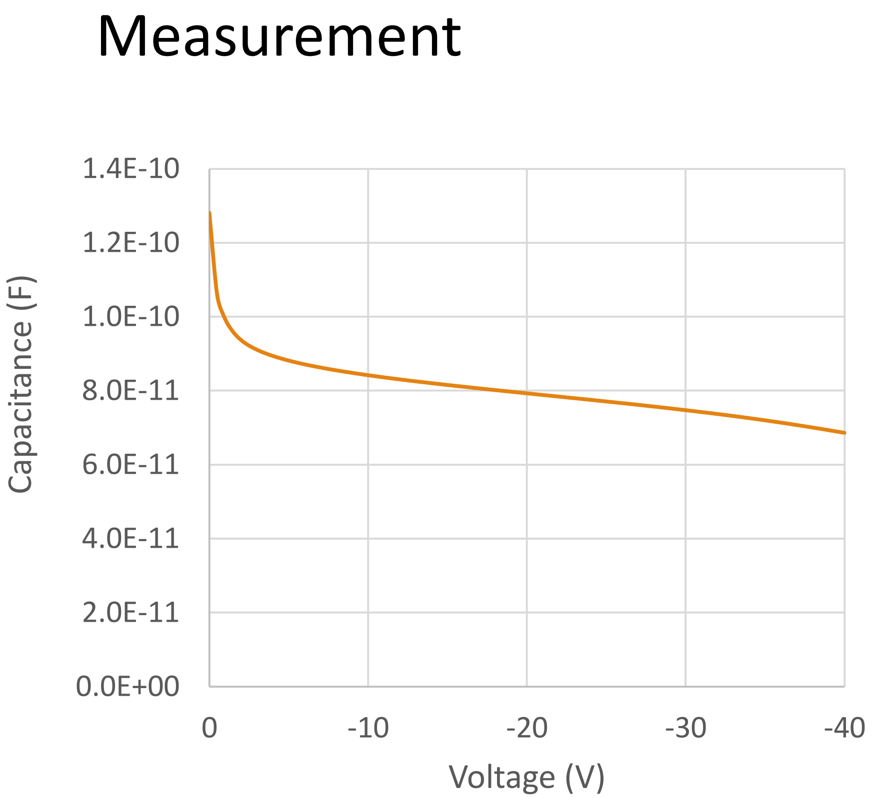




Good agreement for the breakdown Voltage

TCAD Simulations: CV





Additional models

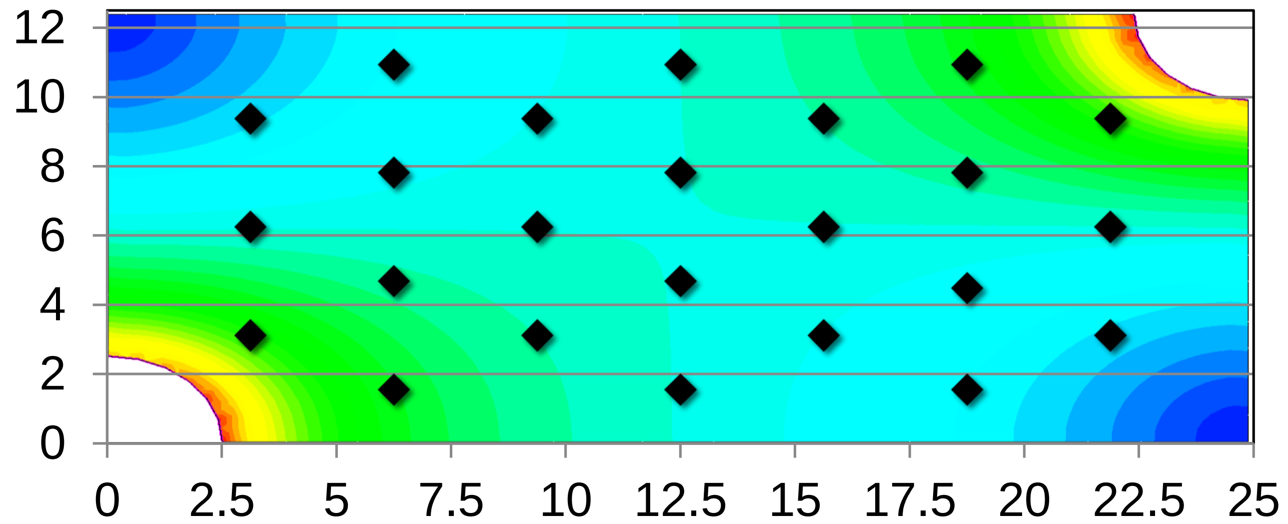
- Bulk damage models:
  - Different models for different irradiation levels
  - Three level traps model
- Simplified simulation domain (~2d): (1/4 or 1/8 of pixel)
- MIP (heavy ion model): vertical hits at several different positions representing different electric field values and repeat at different bias voltage
- Average charge over all hit positions (@20 ns)
- Normalization to injected charge
- Impact ionization model not (yet) active

"NEW": parameters as in D. Passeri et al., PM 2015 (doi:10.1016/j.nima.2015.08.039)

Simulation points for “25x100” geometry

Pos	X	Y
1	6.25	1.5625
2	18.75	1.5625
3	3.125	3.125
4	9.375	3.125
5	15.625	3.125
6	21.875	3.125
7	6.25	4.6875
8	18.75	4.4875
9	6.25	7.8125
10	18.75	7.8125
11	3.125	9.375
12	9.375	9.375
13	15.625	9.375
14	21.875	9.375
15	6.25	10.9375
16	18.75	10.9375
17	3.125	6.25
18	12.5	1.5625
19	12.5	4.6875
20	12.5	7.8125
21	12.5	10.9375
22	21.875	6.25
23	9.375	6.25
24	15.625	6.25

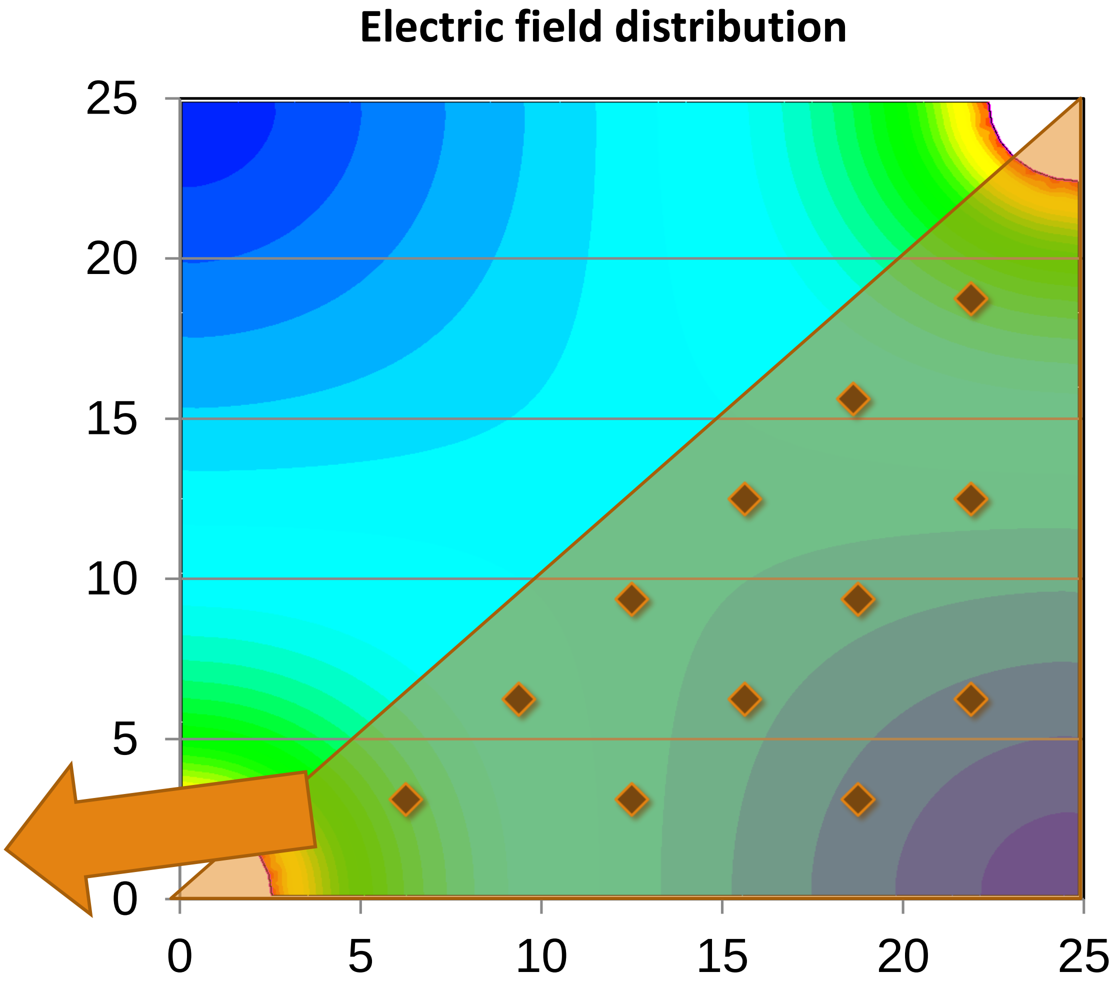
Electric field distribution



In this case it is not possible to use the symmetry principle. The domain is 1/8 of pixel

Simulation points for "50x50" geometry

Pos	x	y
1	6.25	3.125
2	18.75	3.125
3	9.375	6.25
4	15.625	6.25
5	21.875	6.25
6	18.75	9.375
7	18.625	15.625
8	21.875	18.75
9	12.5	3.125
10	12.5	9.375
11	15.625	12.5
12	21.875	12.5



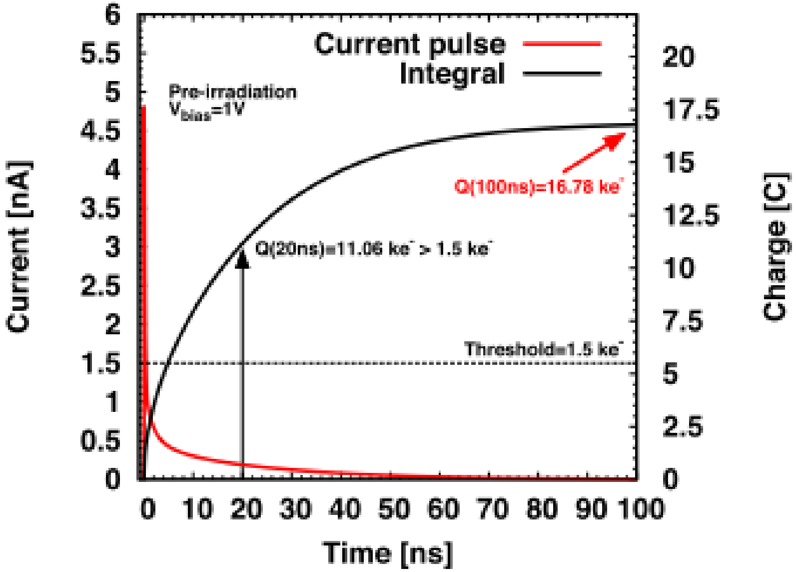
Due to the symmetry it is possible to use half the simulation domain

Data post-processing

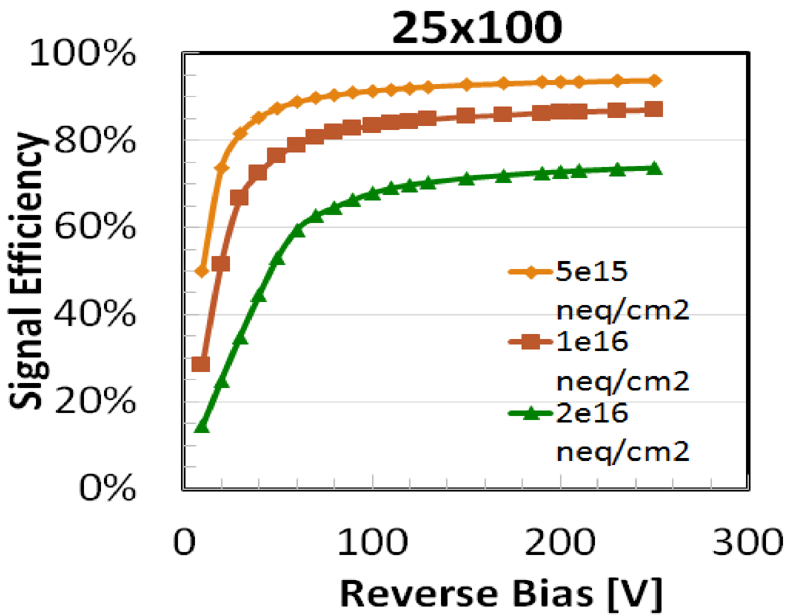
The simulator only returns a current pulse as function of time.
Post-processing is required.

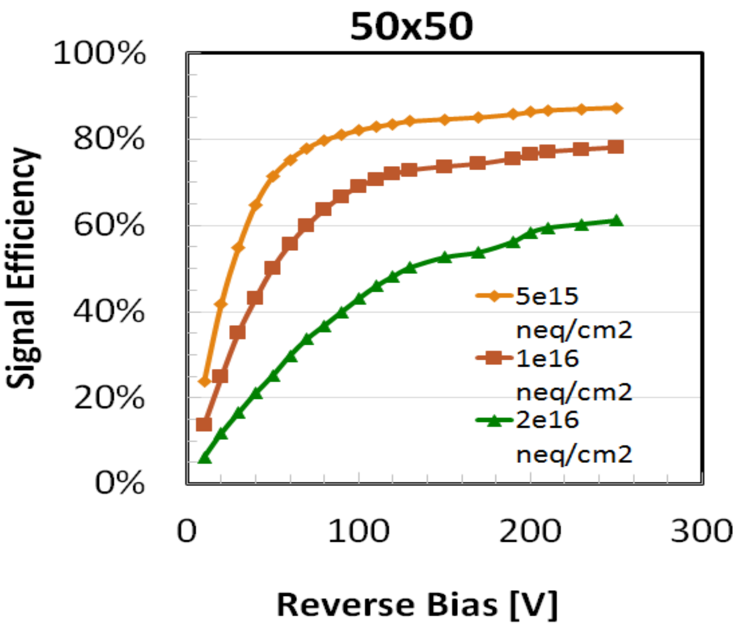
Emulate readout operation:

1. Subtract the leakage current from the current pulse
2. Perform a numerical integration in the time domain
3. Average over all the hit position for a constant bias voltage

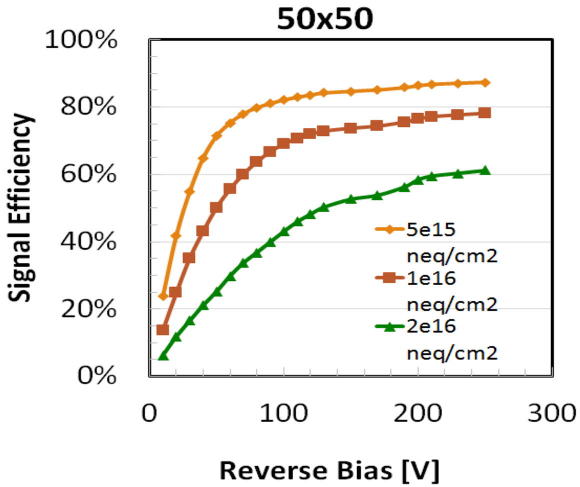


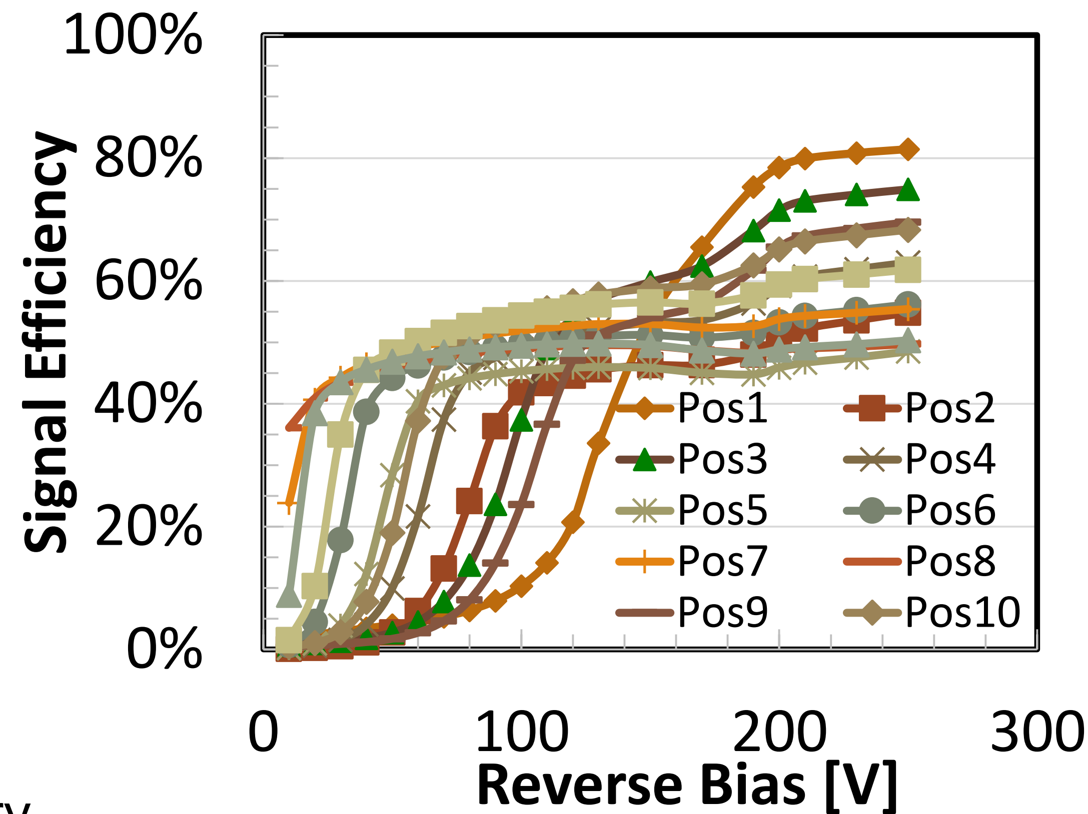
Average Signal Efficiency





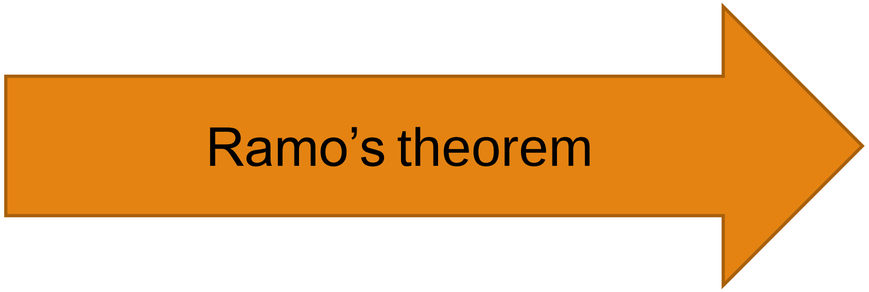
Signal Efficiency





Many points have a particular behavior:

- At low voltage the CCE is very low
- At High voltage they become the points with the highest CCE



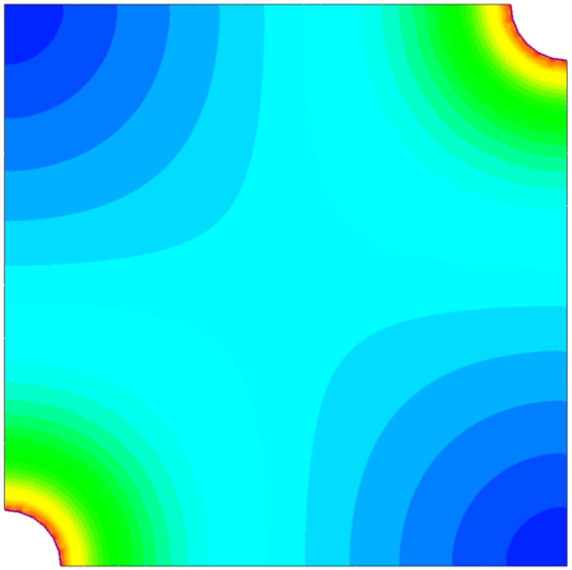
Preliminary results of Ramo's Theorem

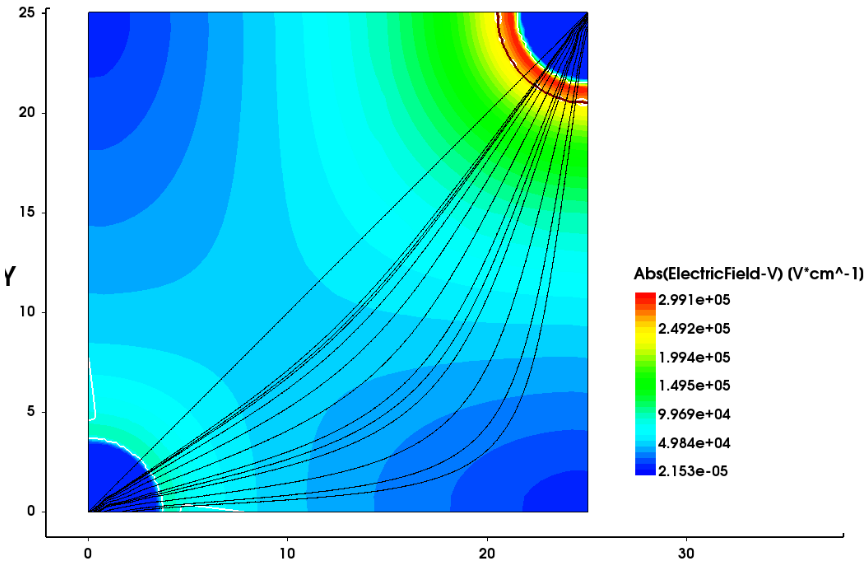
$$i_k = q\vec{v} \cdot \overrightarrow{E_Q}$$

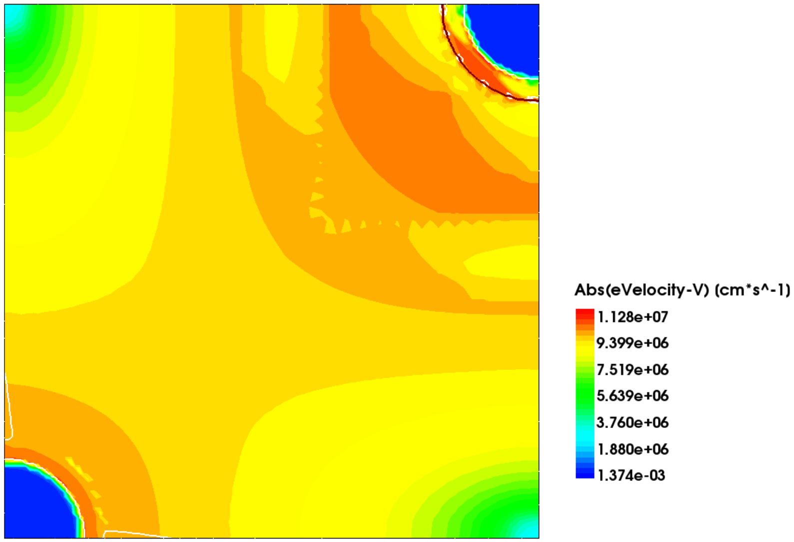
- ✓ $\overrightarrow{E_Q}$ is the "weighting Field"
- ✓ The weighting field depends only on geometry and determines how charge motion couples to a specific electrode
- ✓ $\vec{v}$ is the velocity of charge in the silicon for a given Electric field
- ✓ The electric field determines the charge trajectory and velocity.

The data analysis program included in the Synopsys suite can return text files containing the coordinates inside the structure and the related electrical quantities desired.

- ✓ Electrostatic potential ⇒ scalar quantity
- ✓ Electric field ⇒ vector with 3 components (E_x , E_y , E_z)
- ✓ Velocity ⇒ vector with 3 components (V_x , V_y , V_z)







Traps effect in Ramo's theorem

$$Q(t) = Q_0 e^{-t/\tau}$$

An important parameter is the Trapping time τ

$$\frac{1}{\tau_{\mathrm{eff}_{\mathrm{e,h}}}} = \sum_t N_\mathrm{t}(1 - P_\mathrm{t}^{\mathrm{e,h}})\sigma_{\mathrm{t}_{\mathrm{e,h}}} v_{\mathrm{th}_{\mathrm{e,h}}}$$

G. Kramberger et al. / Nuclear Instruments and Methods in Physics Research A 476 (2002) 645–651

$$\frac{1}{\tau_{\mathrm{eff}_{e,h}}} = \sum_t N_t(1 - P_t^{e,h})\sigma_{t_{e,h}} v_{th_{e,h}}$$

Traps
Cross section

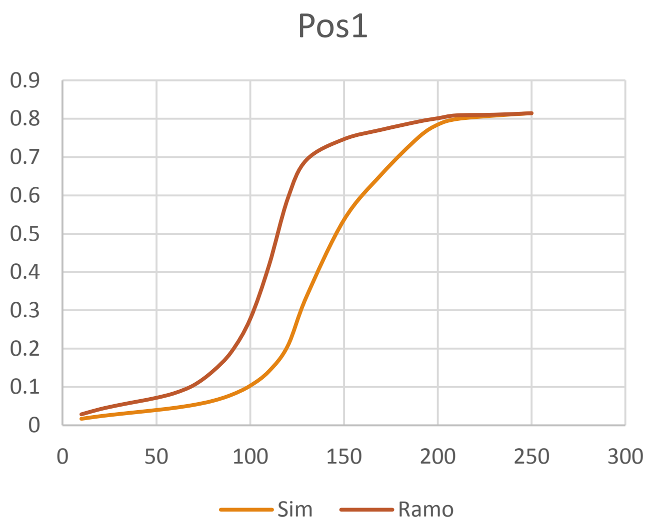
Defect concentration

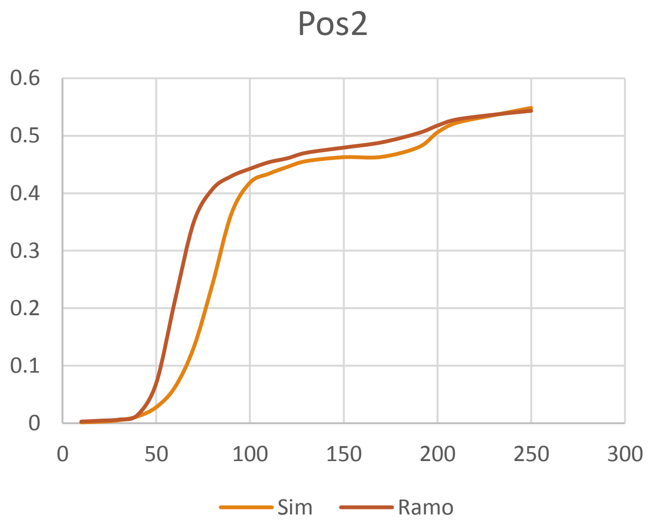
Occupation
Probability

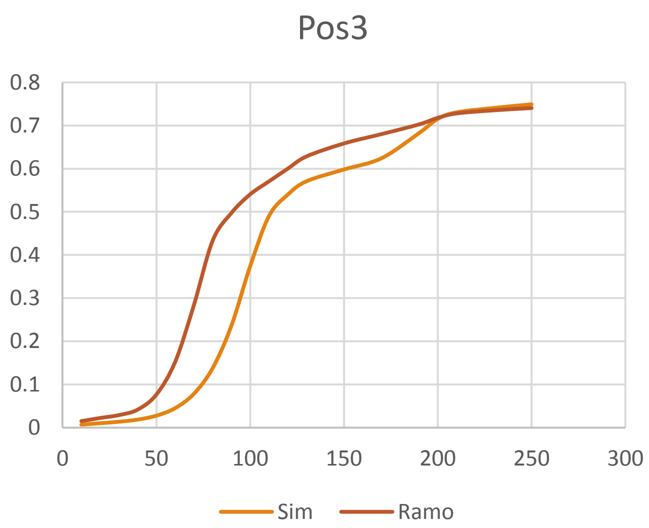
Thermal velocity
(Green 1990)

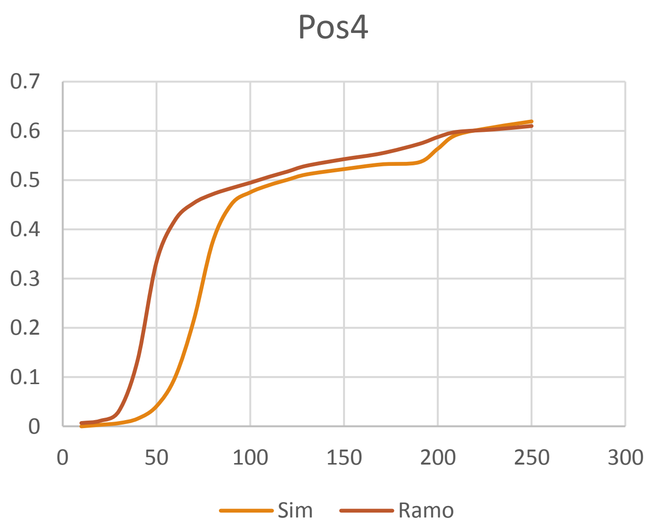
τ_e	9.03E-10 s
τ_h	1.10E-10 s

Simulation comparison Signal Efficiency (1)

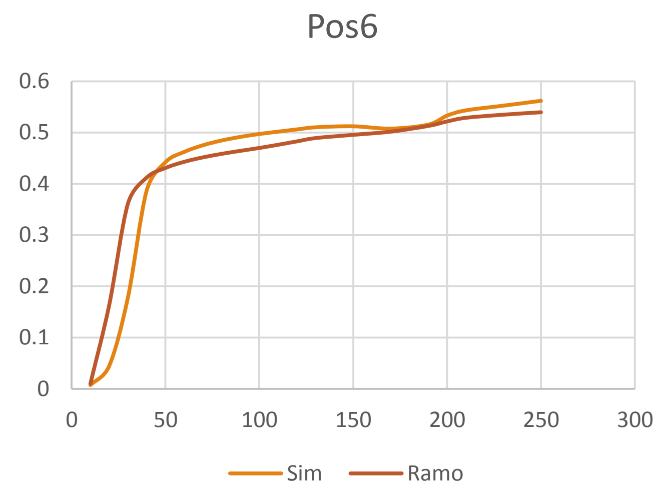


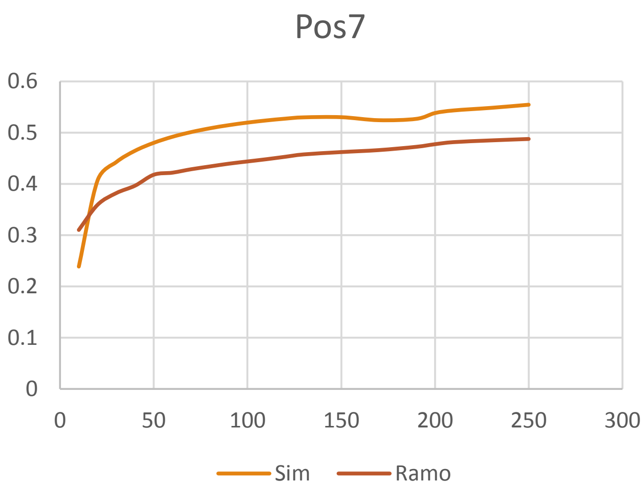


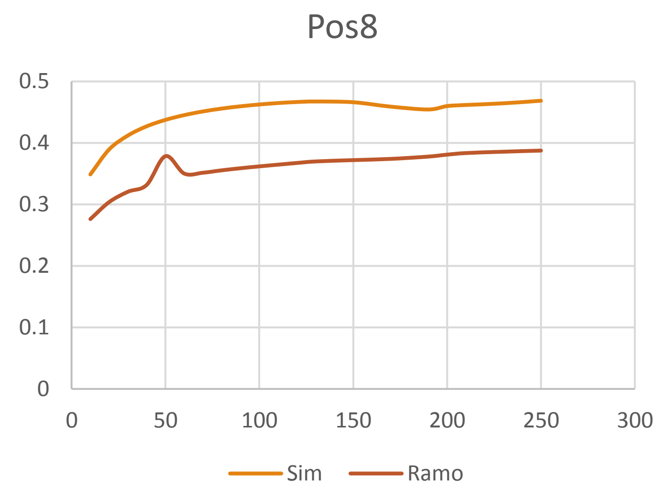




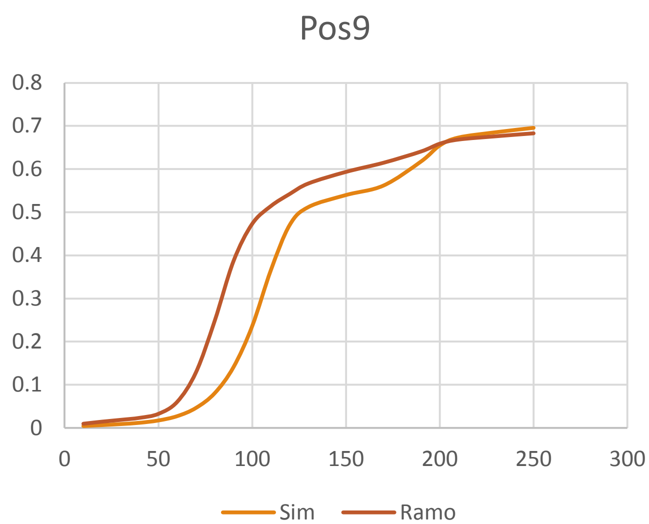
Simulation comparison Signal Efficiency (2)

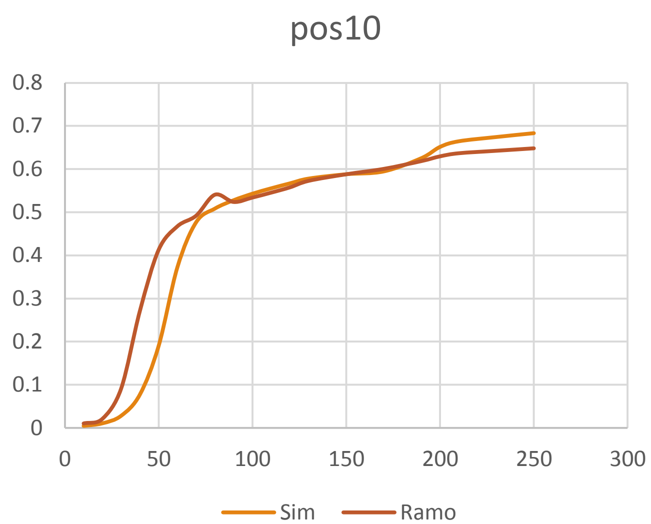


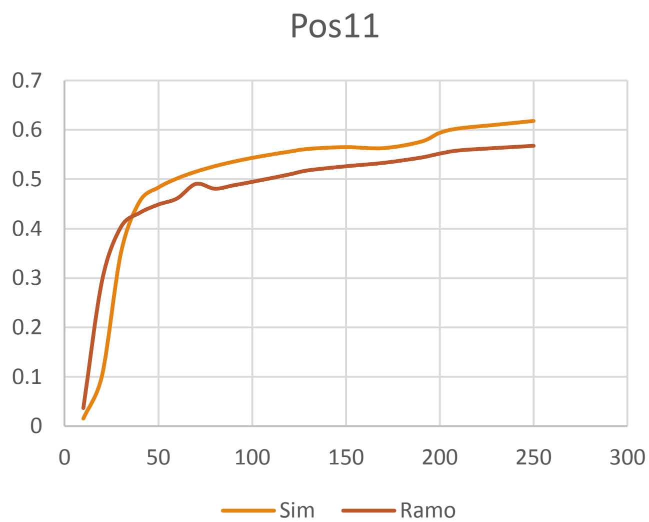


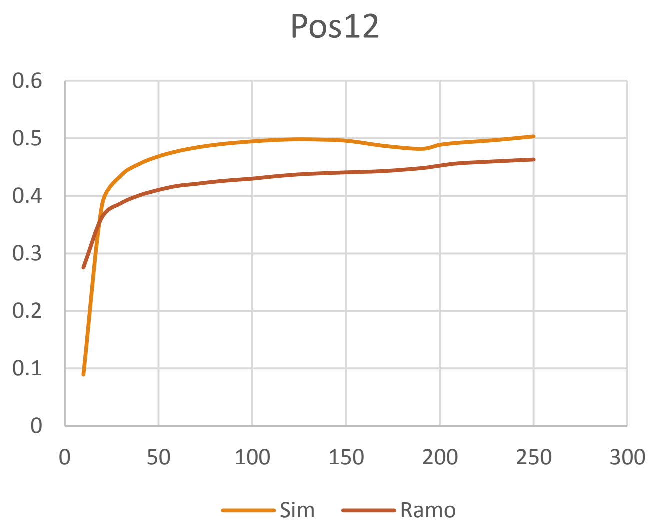


Simulation comparison Signal Efficiency (3)









Conclusion and future work

- The simulation of electrical quantities is producing good results in both PRE and POST irradiation conditions
- Simulations with new Perugia model yield better SE results, more compatible with expectations from existing data
- Ramo’s theorem gives good results
- At large voltage the electric field can be high: simulations can include impact ionization effects
- Montecarlo simulation can be implemented