

OPTIMIZATION OF A 3D NEUTRON IMAGING SENSOR THROUGH COMBINED SIMULATION APPROACHES

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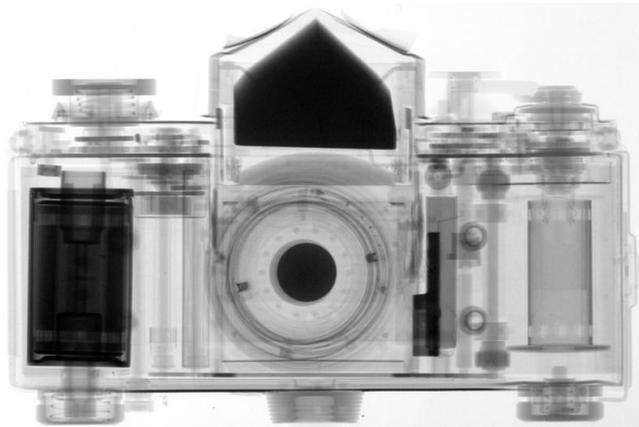


International Workshop
26th **iWoRiD**
on Radiation Imaging Detectors

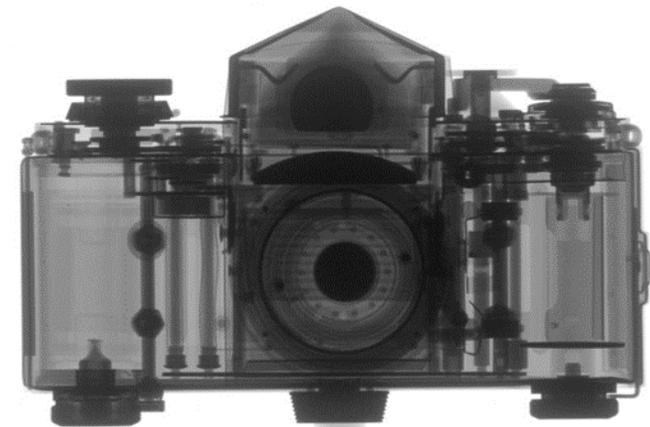
NEUTRON IMAGING

Neutron imaging provides additional information to X-ray imaging and can be used in many applications. In both techniques, image formation relies on the attenuation characteristics of the object under investigation. $\rightarrow I(x) = I_0 e^{-\mu x}$

Neutrons $\mu_n \propto \frac{1}{A}$



X-ray $\mu_x \propto Z$



NEUTRON SILICON DETECTOR



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The resulting efficiency for semiconductor planar detectors coated with ^{10}B or ^6Li is on the order of 3-4%

Coated 3D silicon detectors were first proposed as an alternative to planar silicon detectors in the late 80s, to increase the efficiency

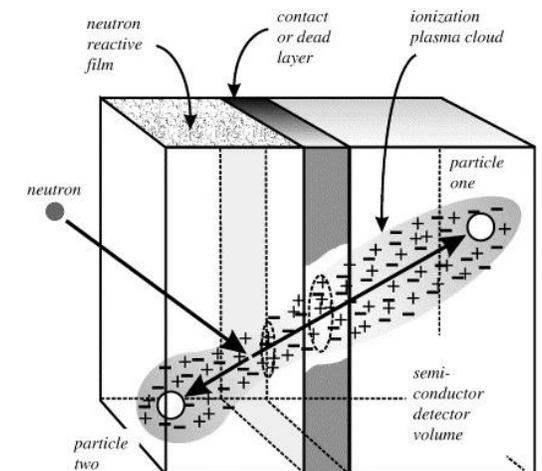
Kansas State University

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University of Trento & FBK & INFN

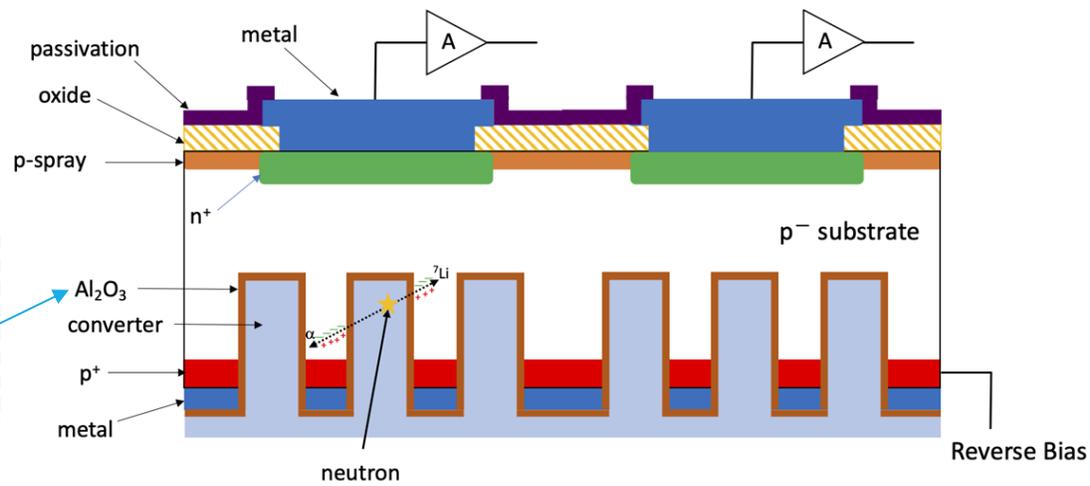
Groups engaged in the development of 3D sensors for neutrons



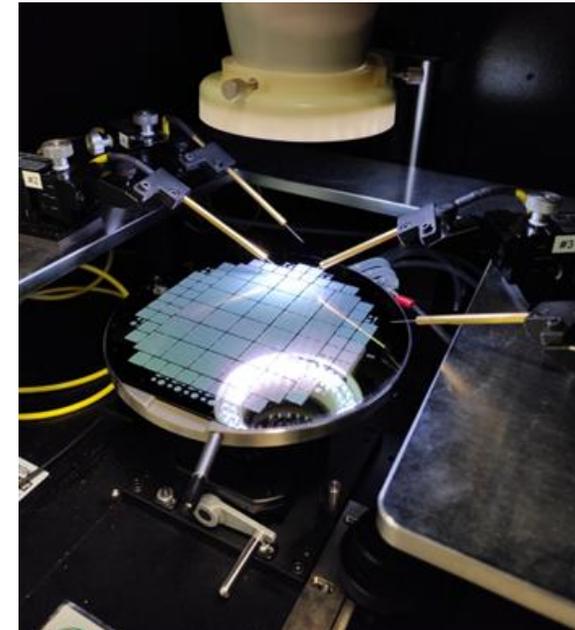
McGregor, Douglas S., et al. "Design considerations for thin film coated semiconductor thermal neutron detectors—I: basics regarding alpha particle emitting neutron reactive films." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 500.1-3 (2003): 272-308.

3D DETECTOR FOR NEUTRONS AT UNITN

The 3D detector consists of planar (thickness $275\ \mu\text{m}$) n-on-p pixels on the front side, whereas Deep Reactive Ion Etching (DRIE) is used only on the back side to etch deep ($\sim 25\ \mu\text{m}$) and narrow cavities to be filled by proper converting materials. The pixel pitch is $55 \times 55\ \mu\text{m}$ to ensure compatibility with Medipix electronics. This sensor derives from the Hyde2 project.



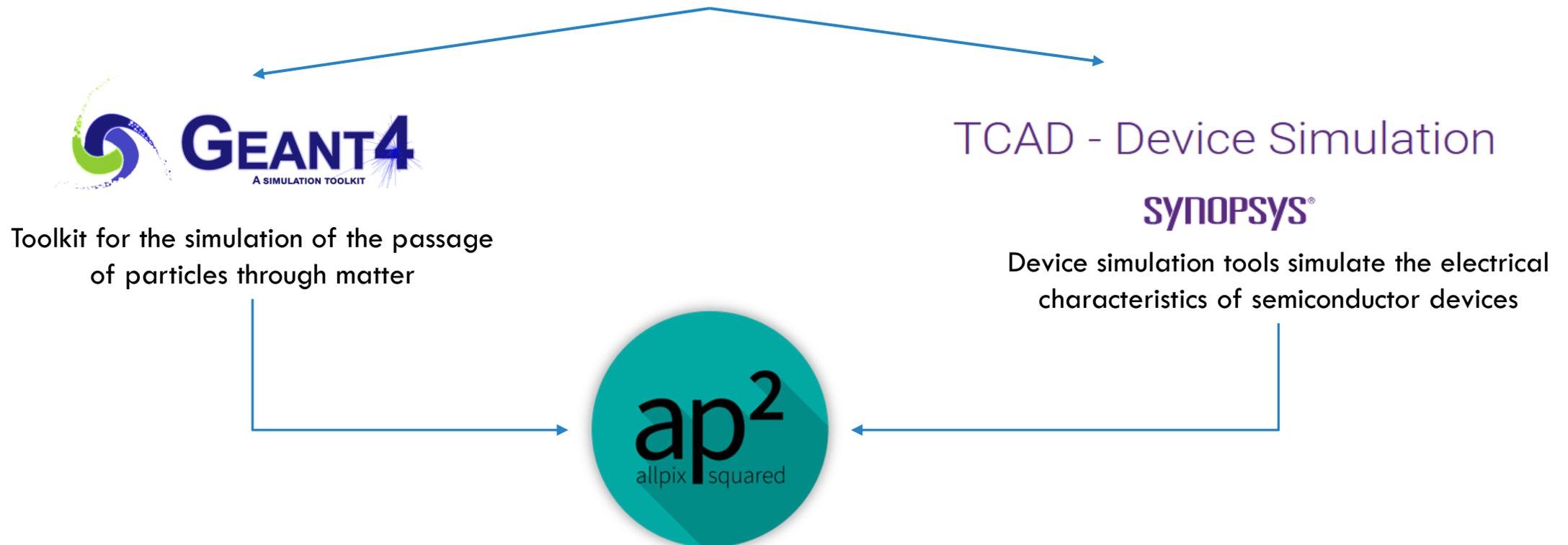
The passivation is necessary to reduce the effects caused by DRIE, as the creation of the p⁺ implant precedes the DRIE.

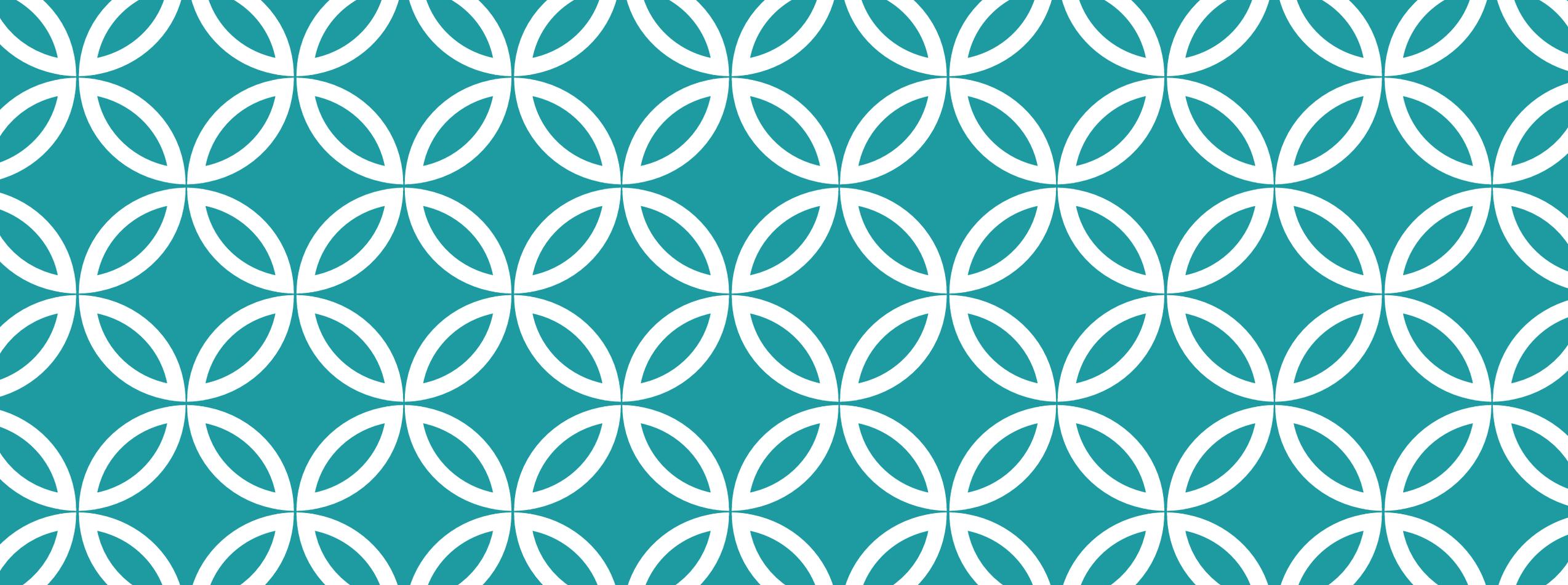




OPTIMAL GEOMETRY VIA SIMULATION

To simulate the proper functioning of the device, it was decided to separate the neutron capture part from the charge collection part. So two different software are used





GEANT4

Passage of particles through
matter

PLANAR DETECTOR



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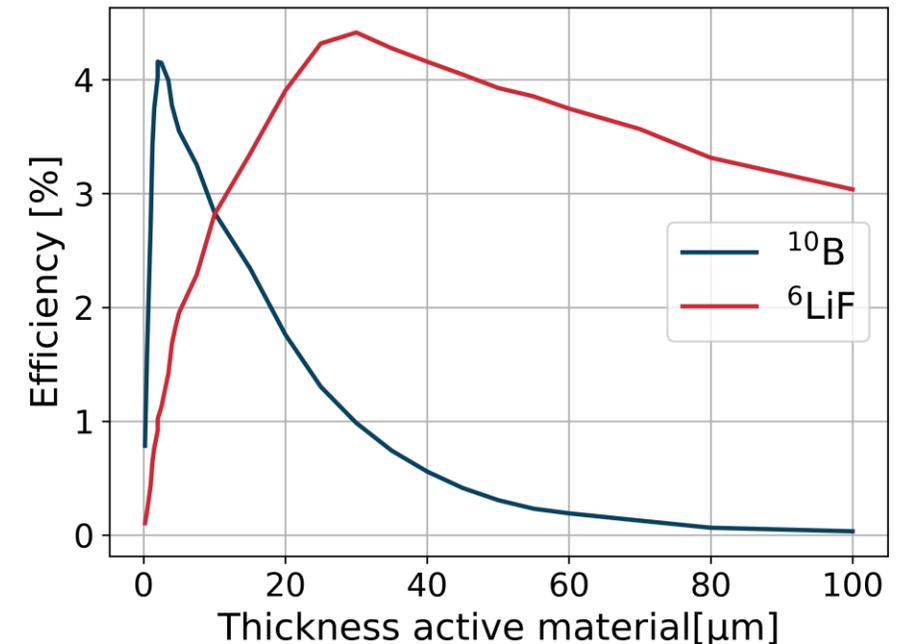


As reference the efficiency in the case of planar detector are simulated.

The QGSP_BIC_HP list is used.

Two different converter material are tested:

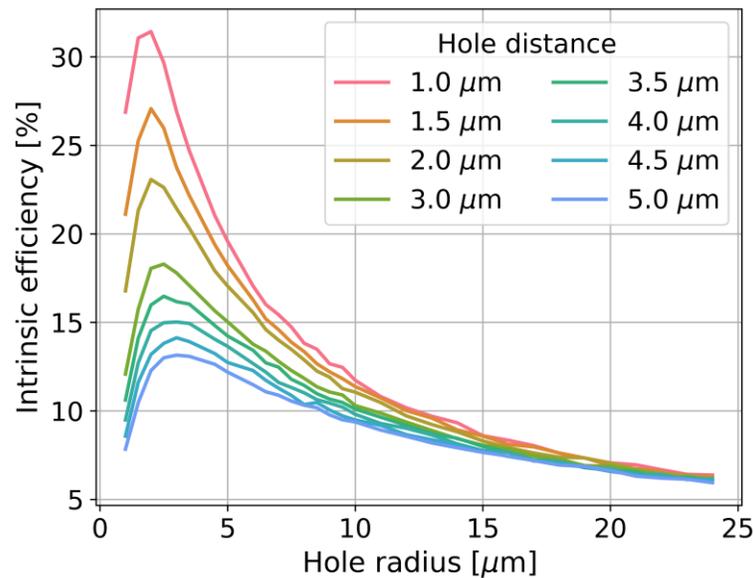
- ❖ ${}^6\text{Li}(n,\alpha){}^3\text{H}$
 - $Q=4.8\text{MeV}$ and $\sigma=8.7\cdot 10^2\text{ b}$
- ❖ ${}^{10}\text{B}(n,\alpha){}^7\text{Li}$
 - $Q=2.8\text{MeV}$ and $\sigma=3.6\cdot 10^3\text{ b}$



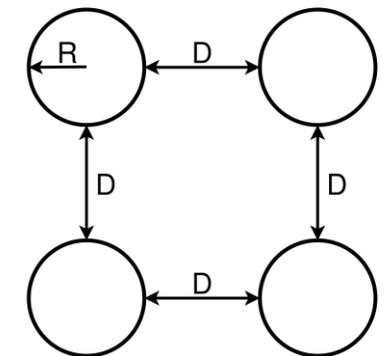
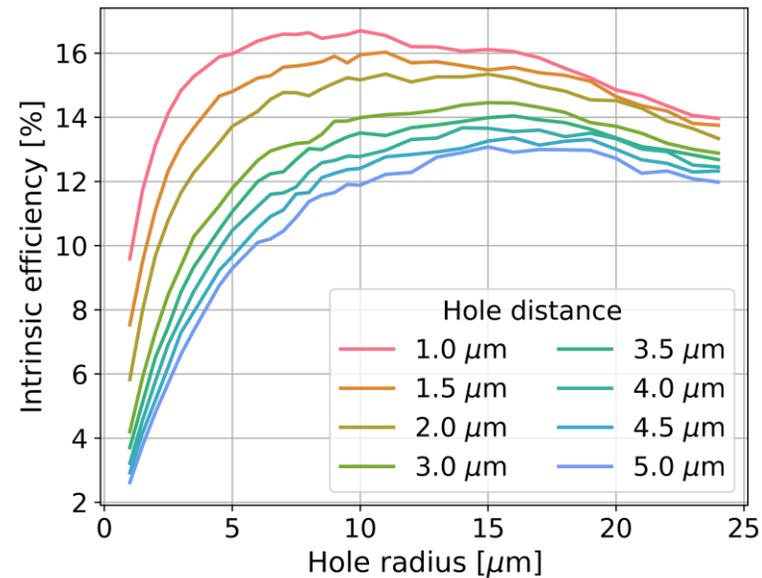
EFFICIENCY OF 3D SENSOR

The optimal radius (R) and distance (D) are determined to achieve the highest efficiency performance in the proposed device

Boron-10



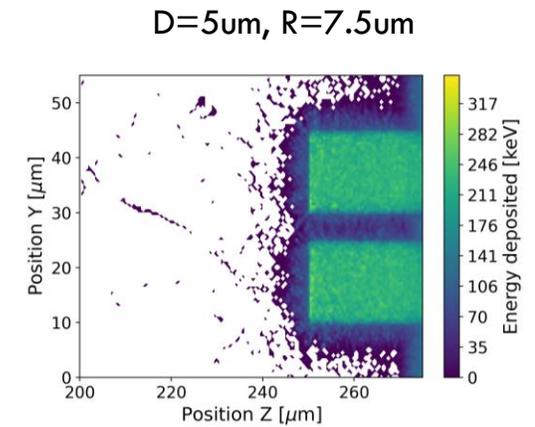
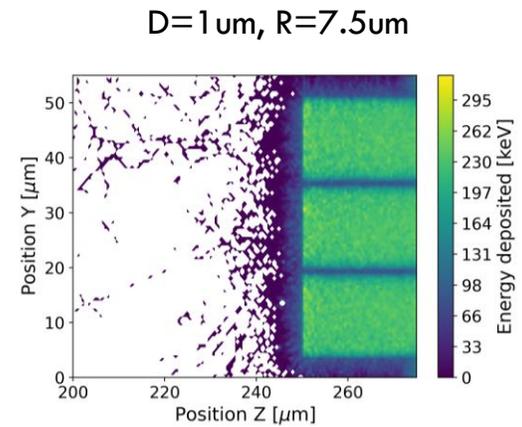
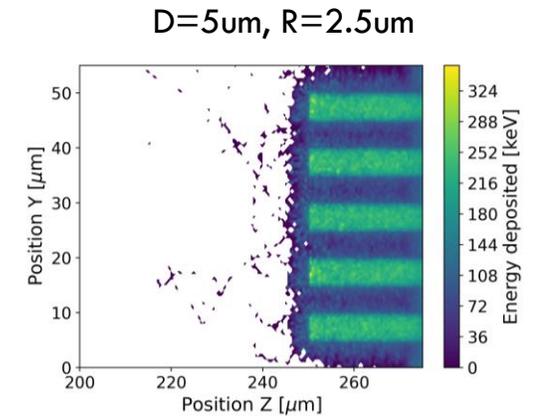
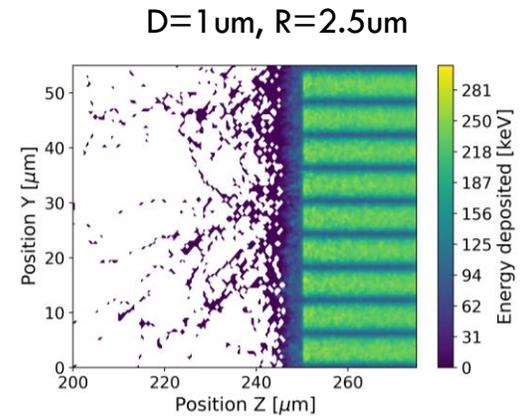
Lithium-6 Fluoride



ENERGY DEPOSITION MAPS -- ^{10}B

From GEANT4, the maps of the deposited energy were determined. A mesh with cubes of 500 nm side length was used.

^{10}B		D[um]	
		1	5
R[um]	2.5	32%	13%
	7.5	15%	10%



ENERGY DEPOSITION MAPS -- ${}^6\text{LiF}$



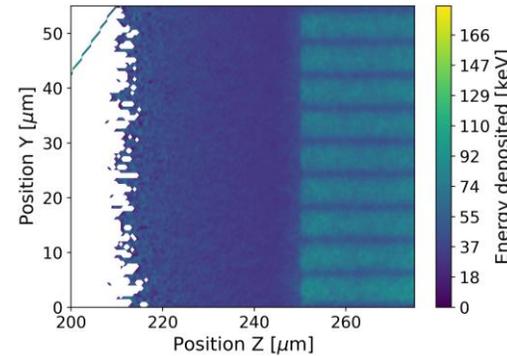
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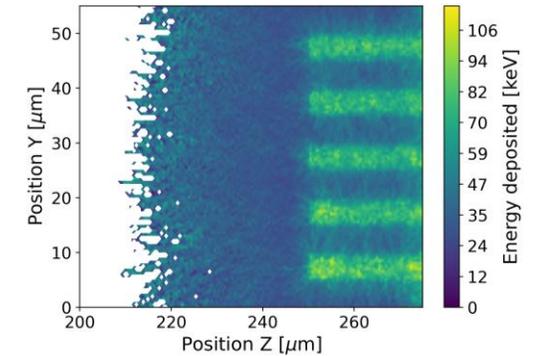
From GEANT4, the maps of the deposited energy were determined. A mesh with cubes of 500 nm side length was used.

${}^6\text{LiF}$		D[um]	
		1	5
R[um]	2.5	13%	6%
	7.5	16%	11%

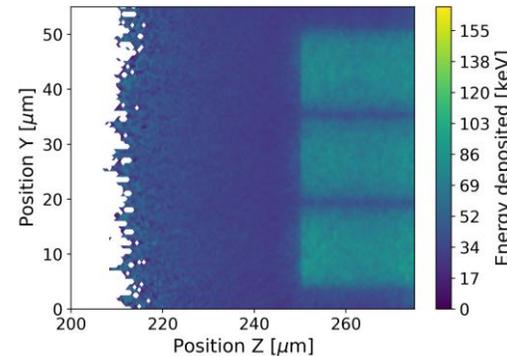
D=1 um, R=2.5um



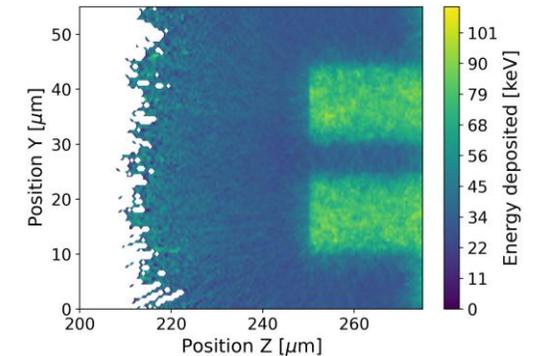
D=5um, R=2.5um

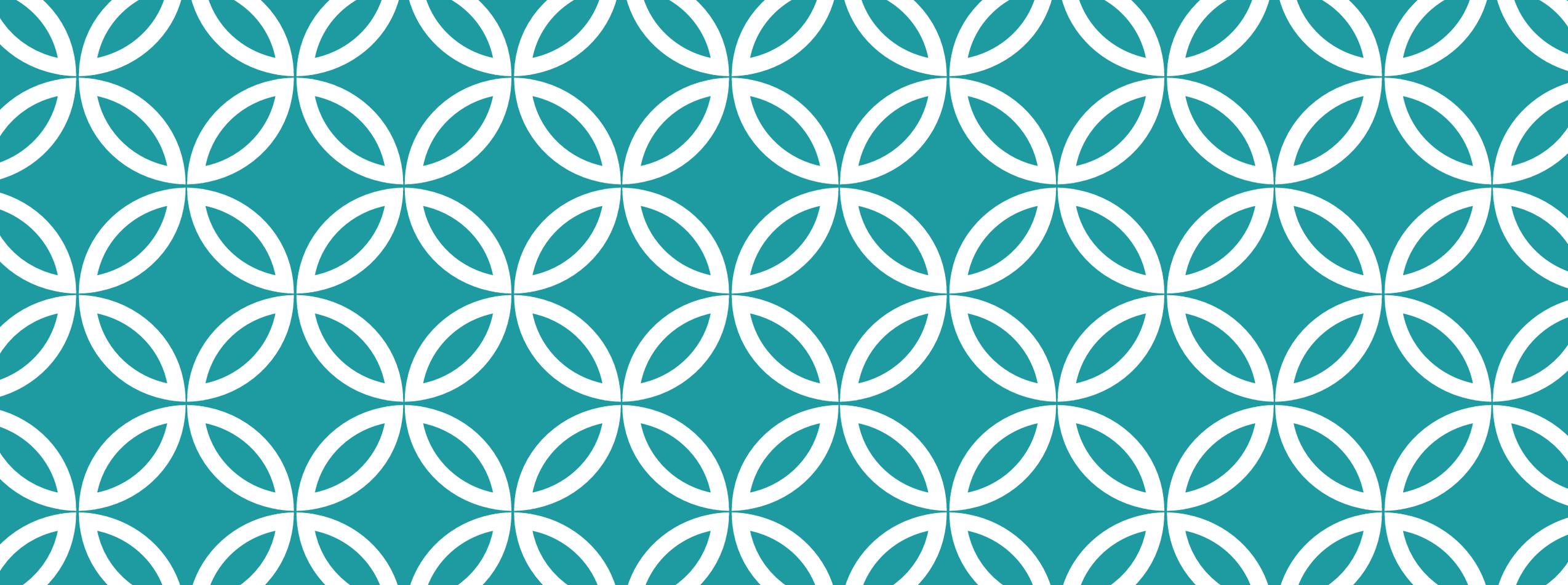


D=1 um, R=7.5um



D=5um, R=7.5um



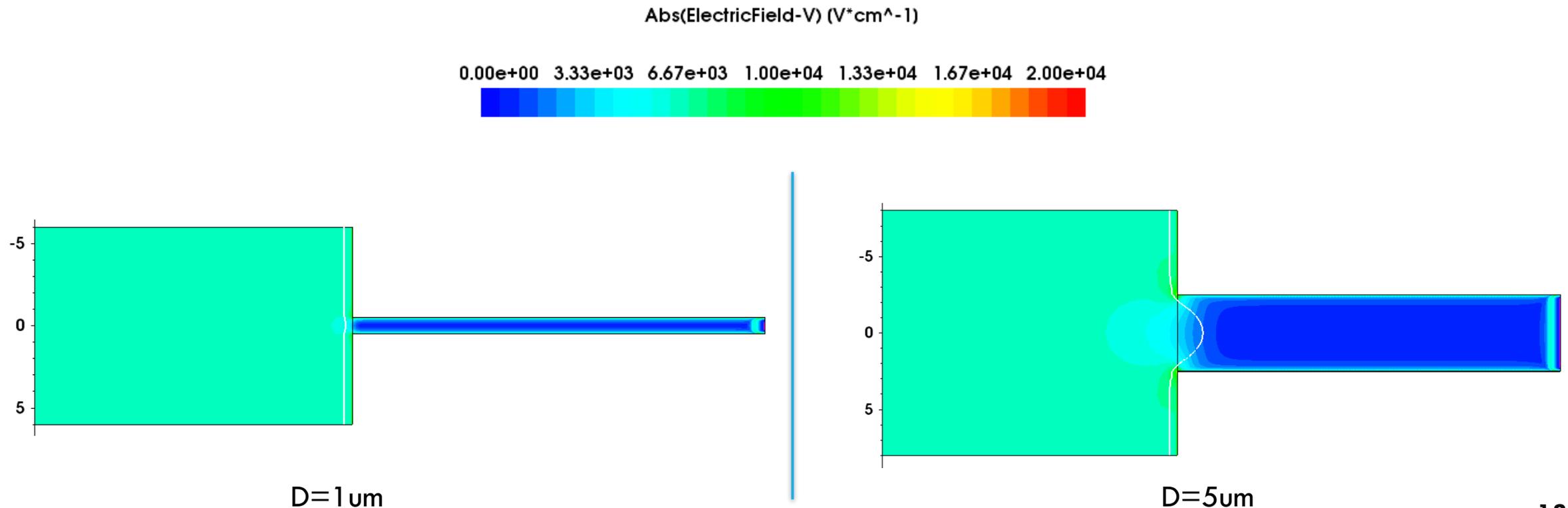


TCAD — DEVICE SIMULATION

Electrical characteristics of
semiconductor devices

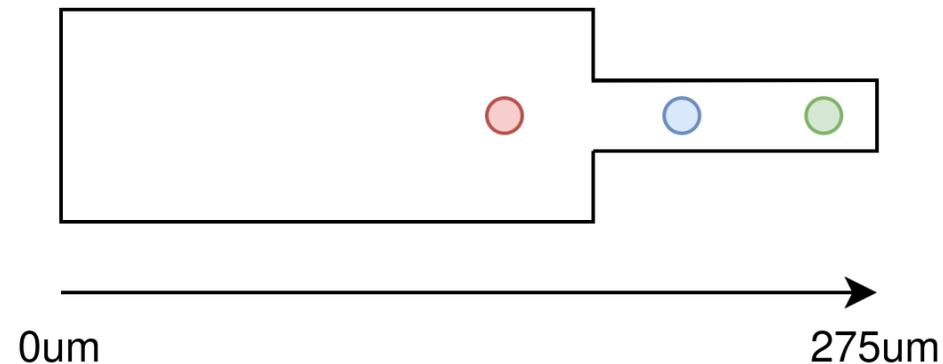
ELECTRIC FIELD MAPS

The simulation allows the extraction of the electric field map, which makes it possible to estimate and map the depletion region, necessary for the correct functioning of the sensor. The Q_{ox} (passivation layer) is set to $-1 \cdot 10^{11} \text{ cm}^{-2}$



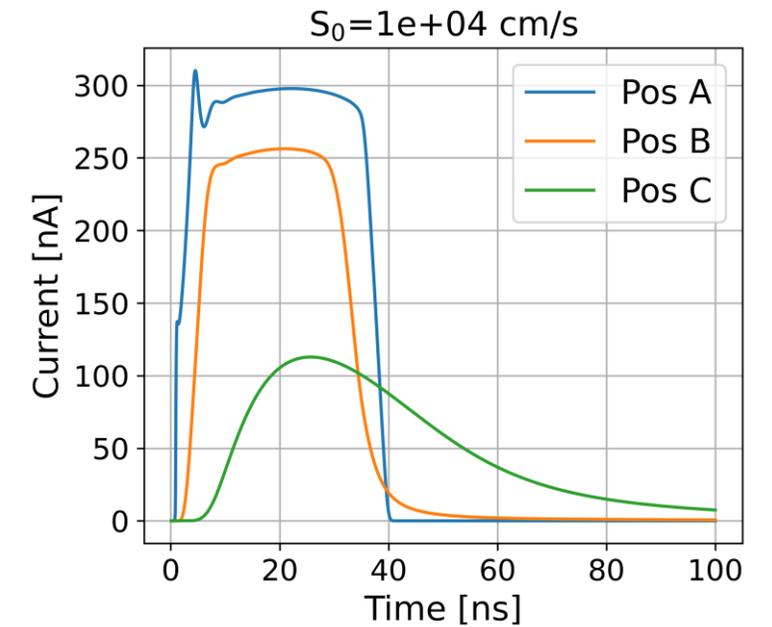
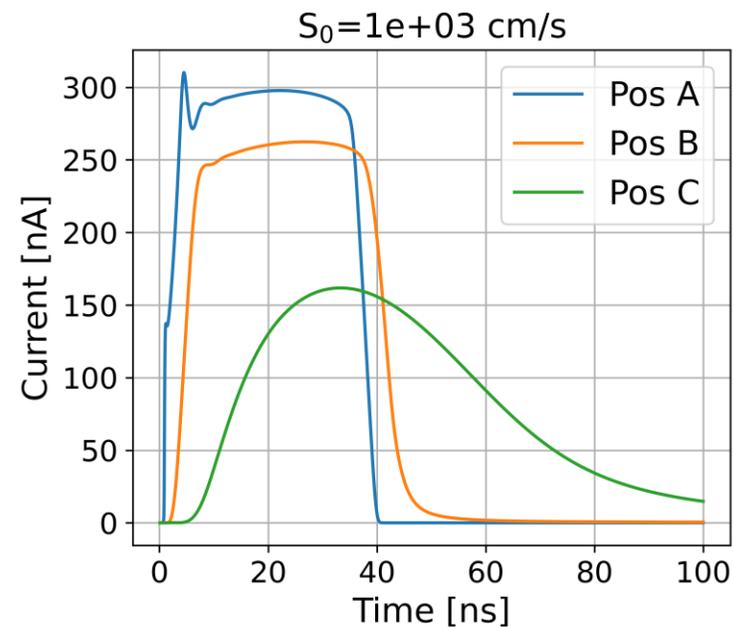
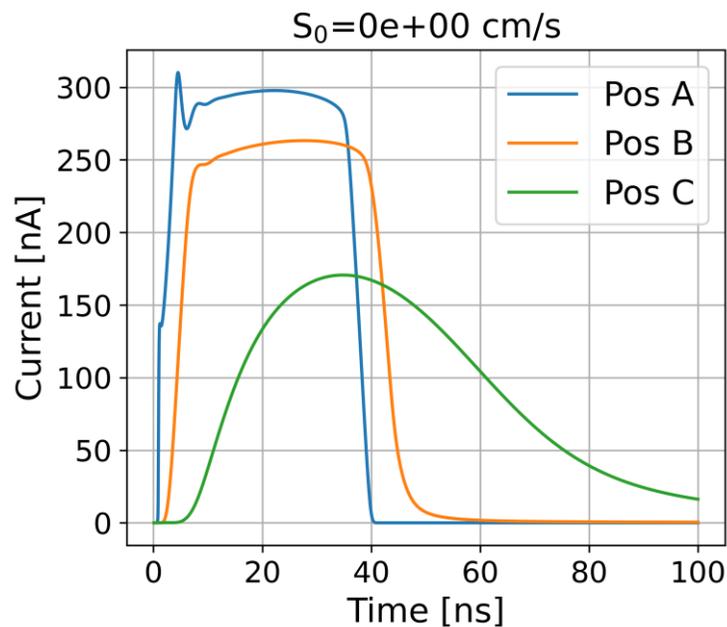
TRANSIENT SIMULATION

- ❖ **Simulation setup:** OpticalGeneration command used
- ❖ **Charge deposition:** Fixed number of charges deposited
- ❖ **Deposition positions:** Three distinct spatial locations:
 - ❖ **Red (A):** 245um
 - ❖ **Blue (B):** 258um
 - ❖ **Green (C):** 268um



TRANSIENT SIMULATION $D=1\mu\text{M}$

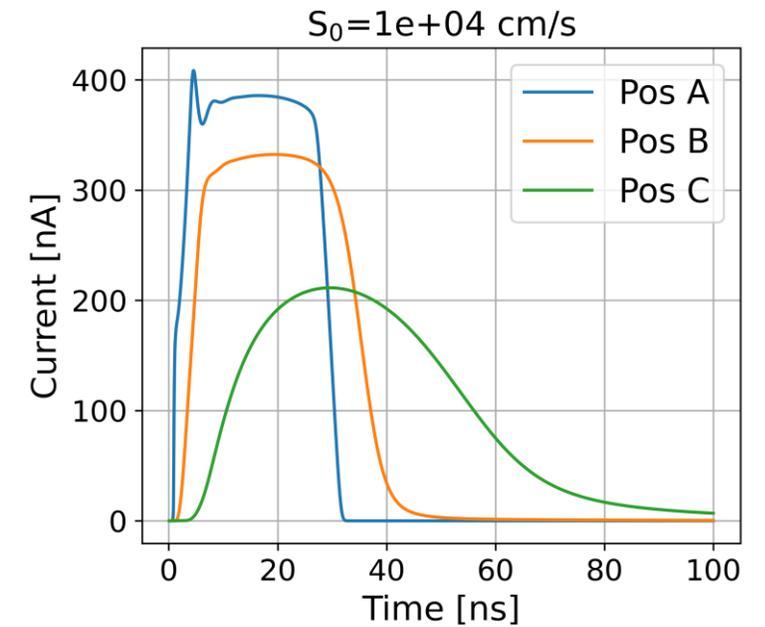
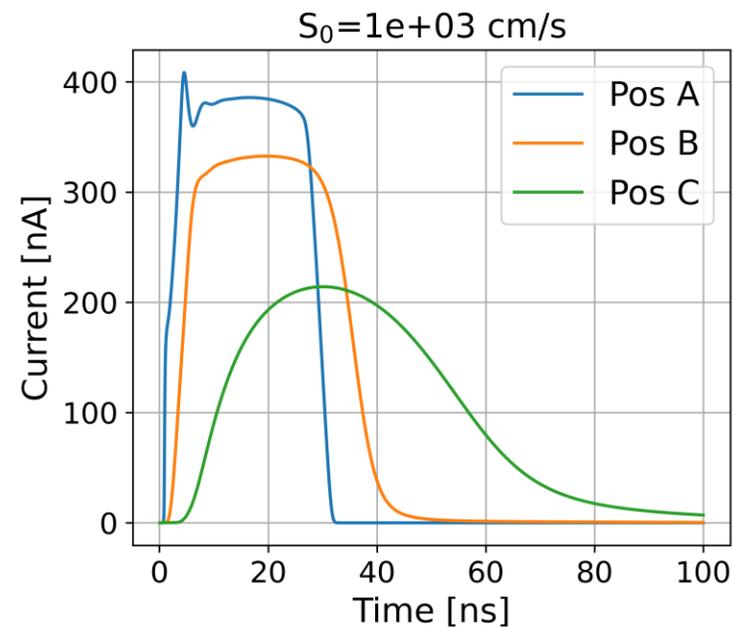
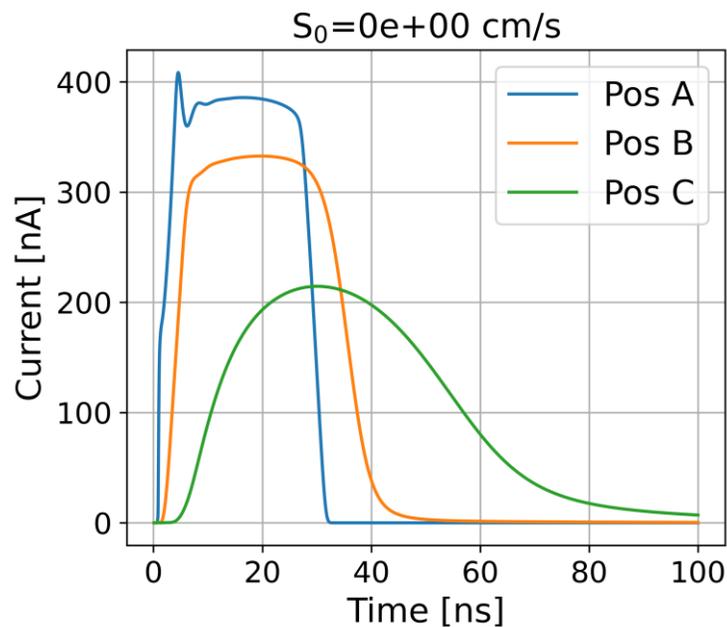
Different value of Surface recombination velocity (S_0) are simulated



TRANSIENT SIMULATION $D=5\mu\text{M}$

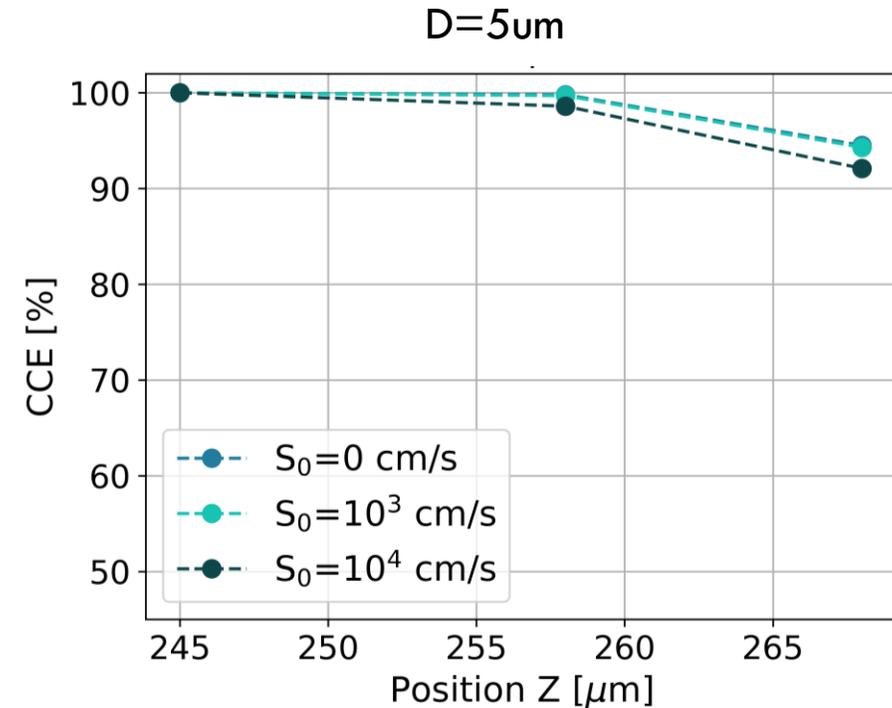
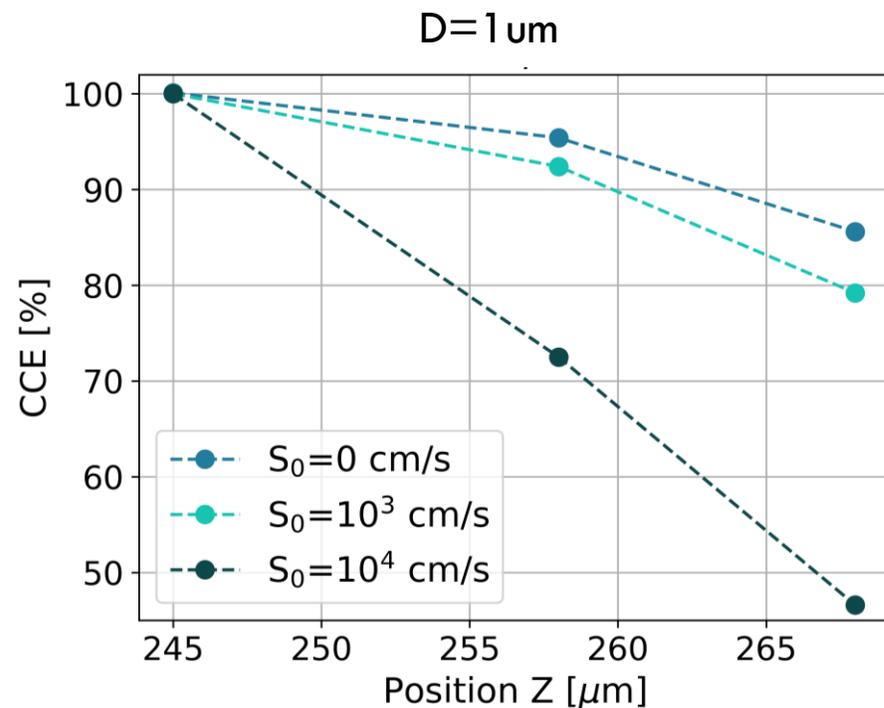


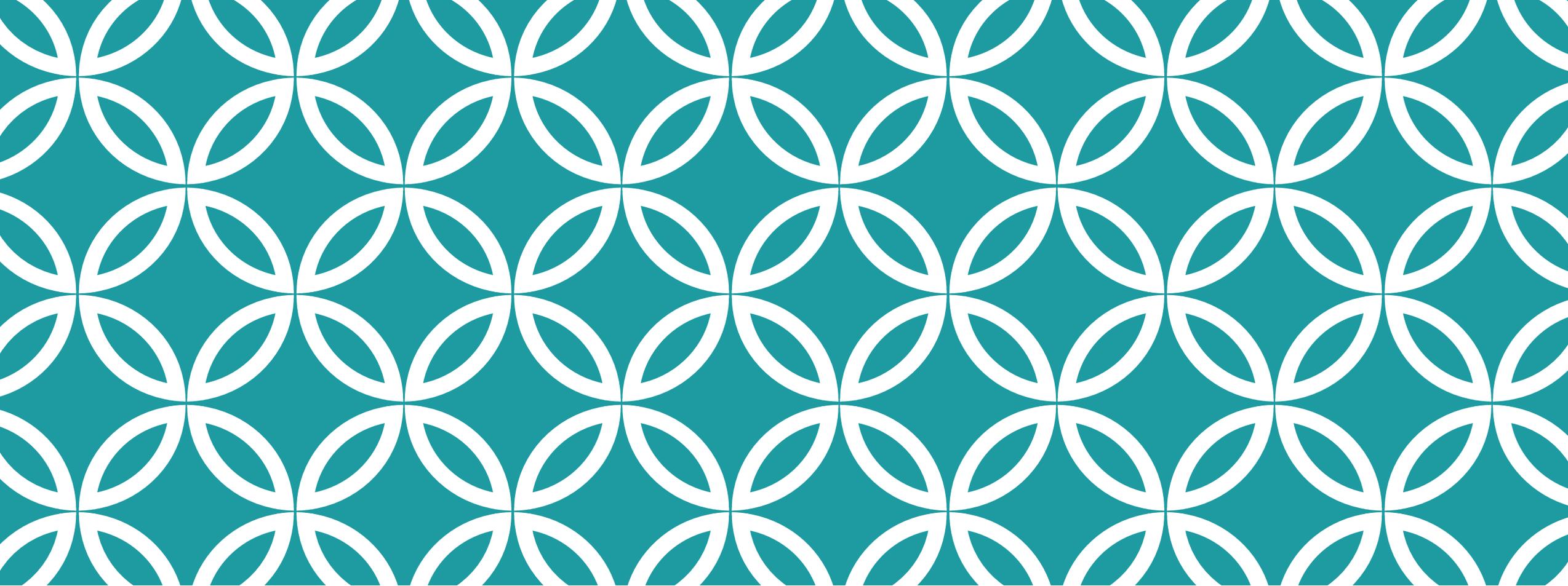
Different value of Surface recombination velocity (S_0) are simulated



TRANSIENT SIMULATION RESULTS

A maximum of three points per geometry is considered, due to the time required for each individual simulation.



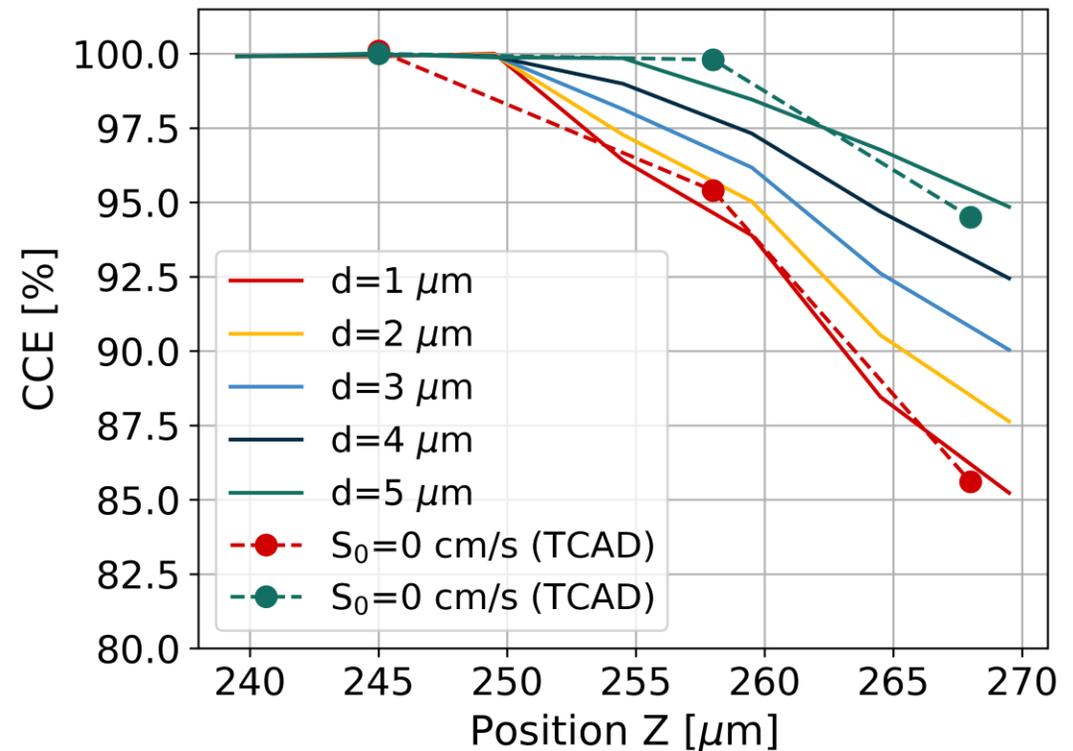


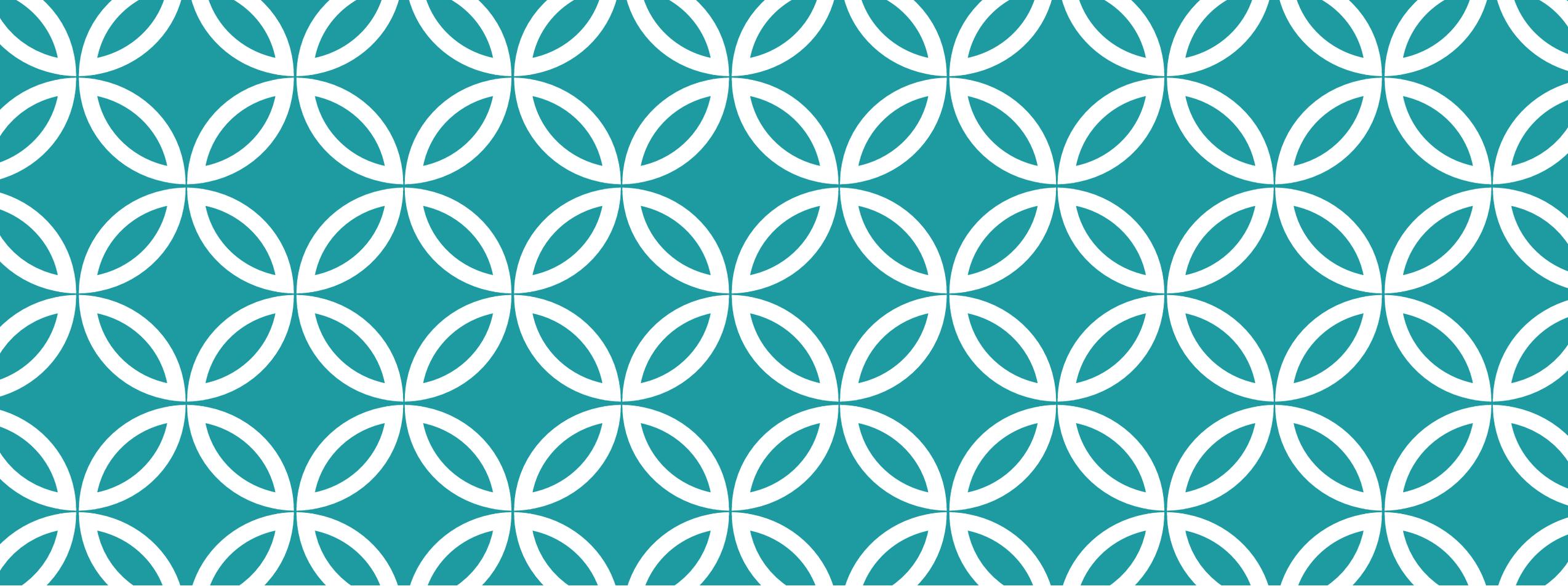
ALLPIX2 SIMULATIONS

Semiconductor Detector
Monte Carlo Simulation
Framework

CHARGE COLLECTION EFFICIENCY

- ❖ TCAD simulations used as reference
- ❖ The Allpix² code was modified because 3D detector geometries are not implemented.
- ❖ Computational time drastically reduced.





FINAL REMARKS



MAIN GOAL

Data from neutron capture and
charged particle interaction

Electric field and
weighting potential map



Find the most efficient
configuration

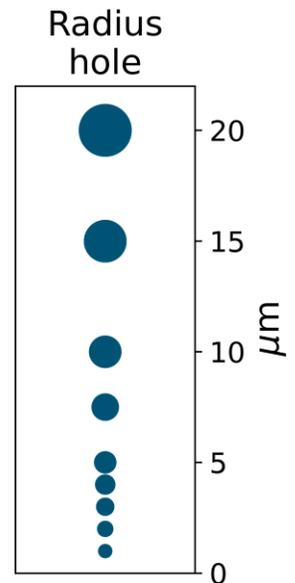
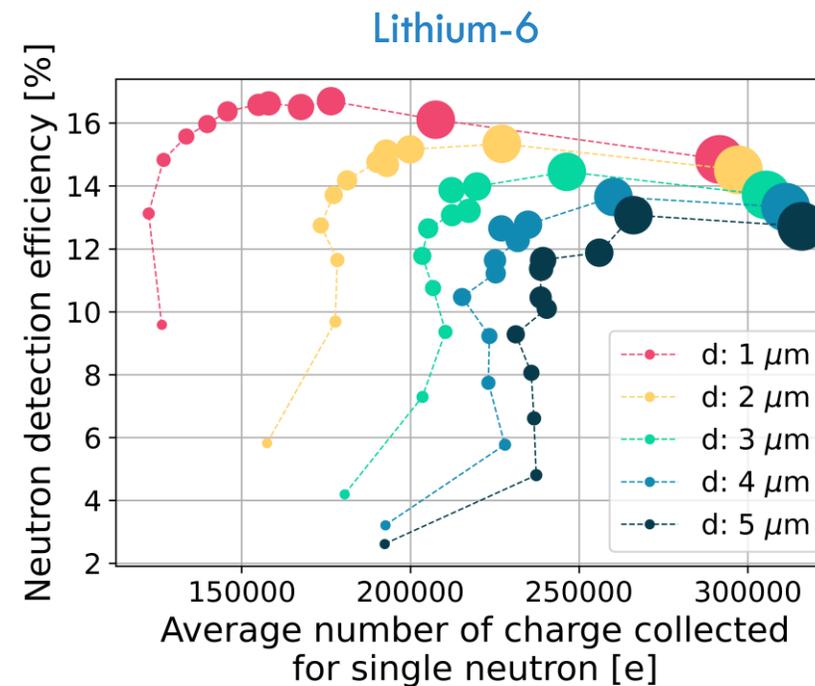
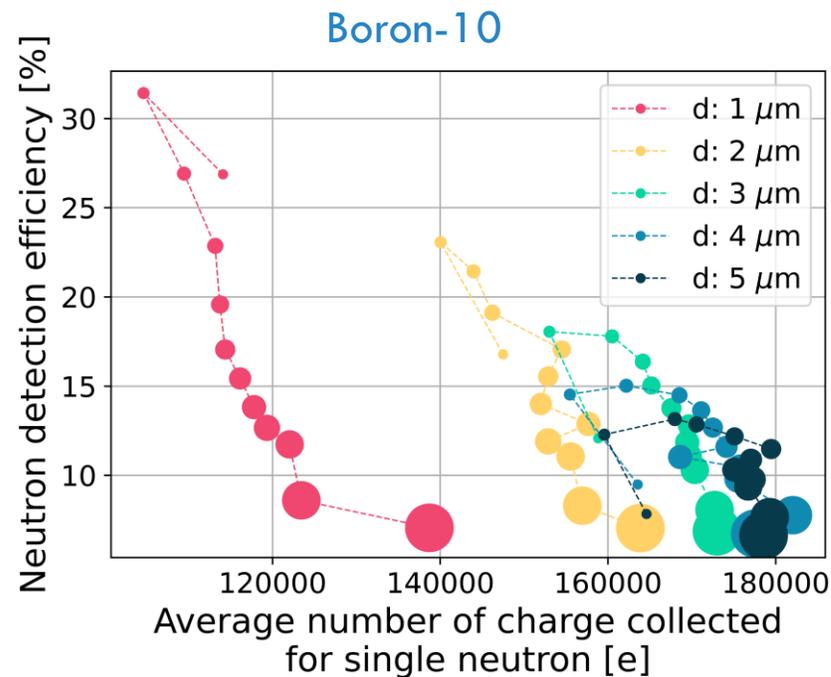
FINAL RESULTS



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By merging the results from Allpix² and Geant4, it is possible to identify the geometry that maximizes both intrinsic efficiency and the collected charge per single event



CONCLUSION



- ❖ According to GEANT4, the configuration with boron and small, closely spaced holes can result in an efficiency greater than 30%.
- ❖ TCAD data indicates that the most effective configuration involves large, widely spaced holes.
- ❖ Allpix² is now fully operational, and code modifications are being applied to enable data merging and identify the optimal sensor configuration.



The next step is to prototype sensors to validate whether these results can be achieved in practice.



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Thanks for
your attention



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Backup slides

ALLPIX2 CONFIGURATION

The used module:

- ❖ **DepositionPointCharge**
 - ❖ `source_type = "point"`
- ❖ **DopingProfileReader & ElectricFieldReader & WeightingPotentialReader**
- ❖ **TransientPropagation**
 - ❖ `mobility_model = "jacoboni"`
 - ❖ `surface_reflectivity = 1.0`