TCAD & Monte Carlo simulations of 3D pixel sensors

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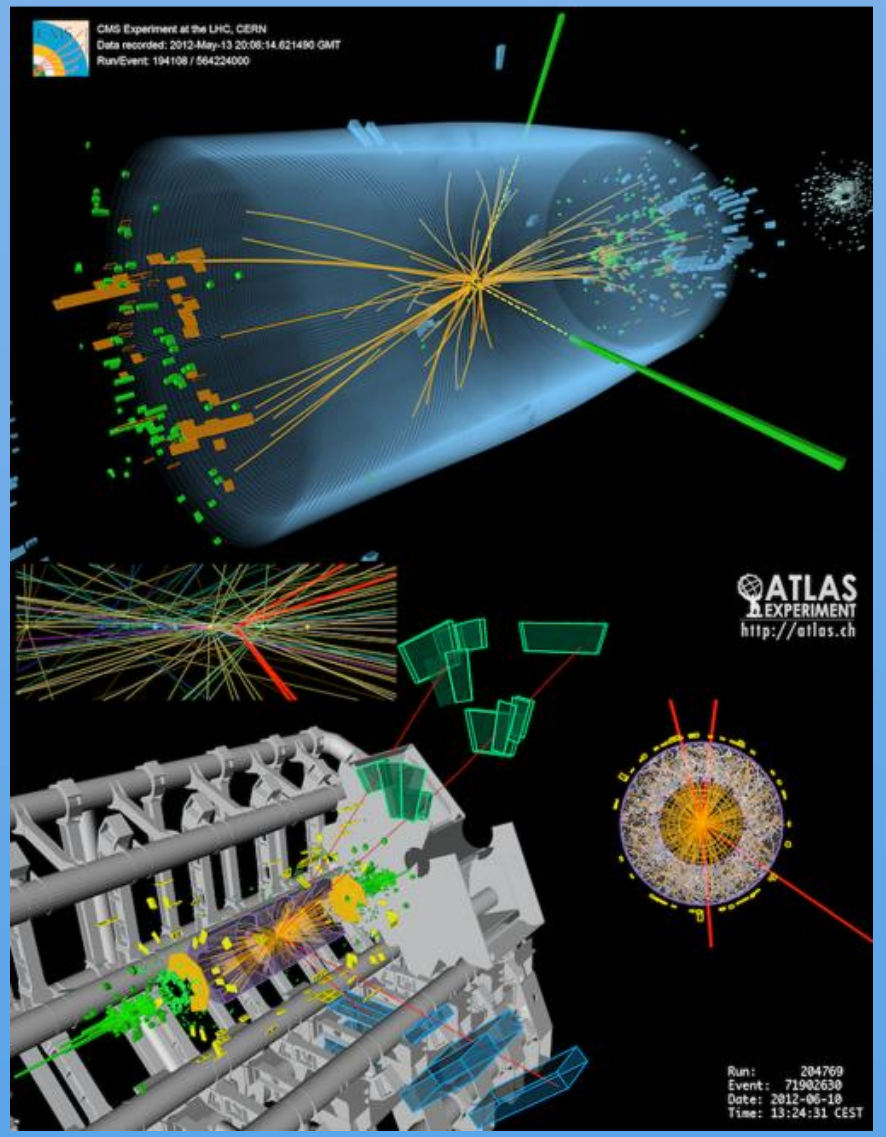
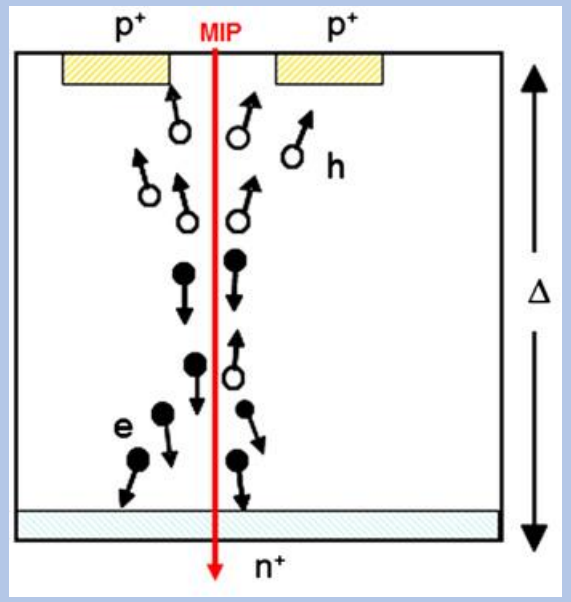


Introduction - From planar to 3D



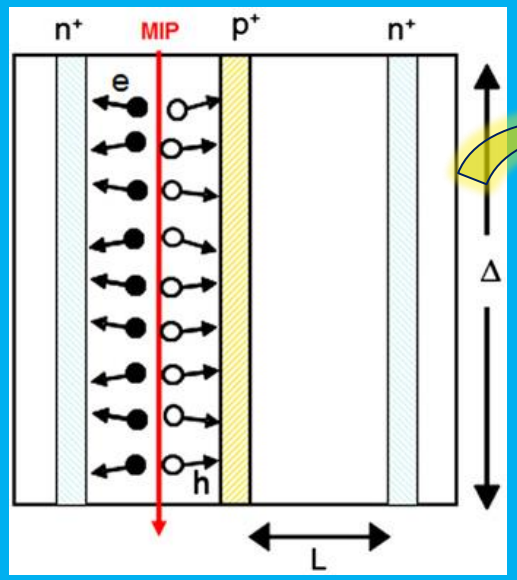
Schematic cross-sections planar sensors

ADVANTAGES:

- Relatively easy to fabricate;
- Low capacitance.

DISADVANTAGES:

- High full depletion voltage;
- Low temporal resolution.



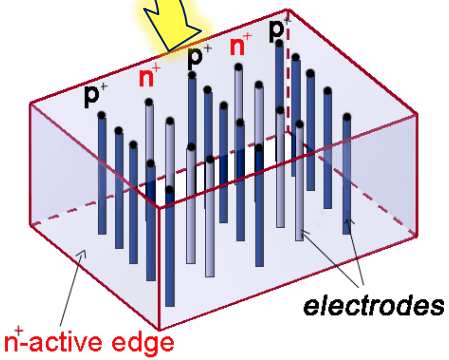
Schematic cross-sections 3D sensors

ADVANTAGES:

- Low depletion voltage;
- High Radiation tolerance.

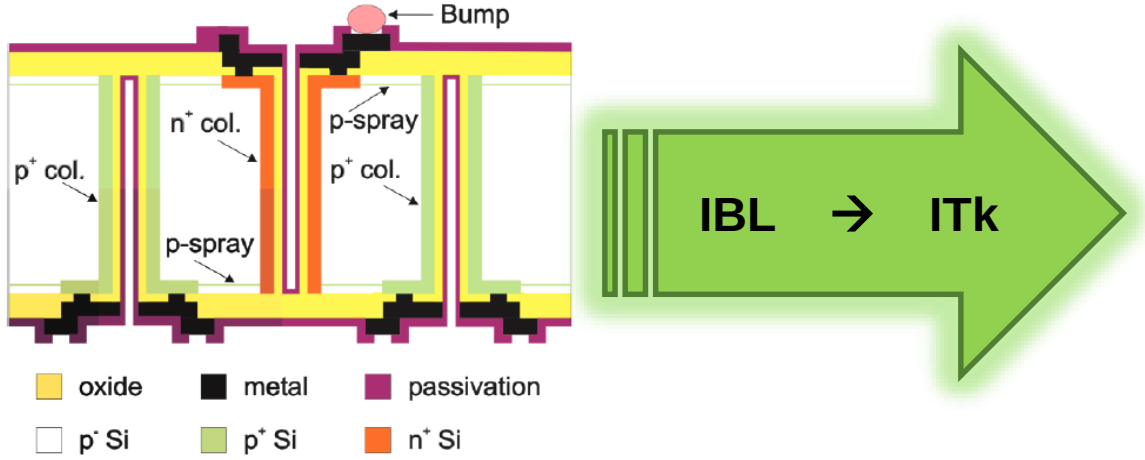
DISADVANTAGES:

- High capacitance;
- Complicated fabrication technology.



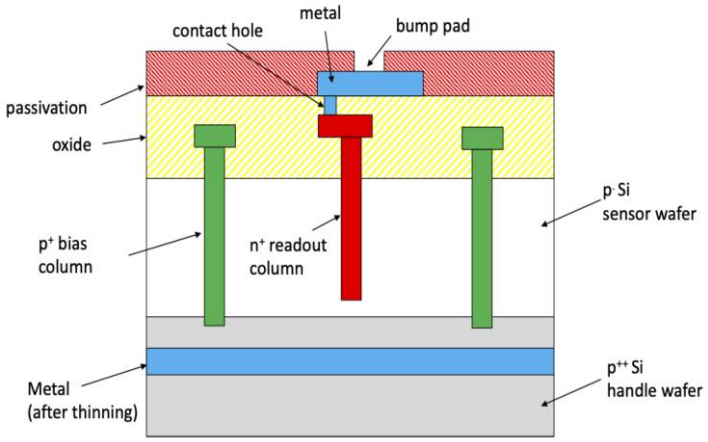
First generation design

Introduction – 3D Detectors for HL-LHC



IBL → ITk

Schematic of 3D-DDTC for LHC



Schematic of small-pitch 3D pixels for HL-LHC

ITk requirements:

- Ionizing/NIEL dose tolerant up to 250 Mrad, $2x10^{16}$ n_{eq} cm^{-2}
- Hit efficiency in active region after full dose > 97%

HL-LHC: High Luminosity LHC
LS: Long Shutdown
TeV: Tera electron Volt

Timeline of the ATLAS experiment

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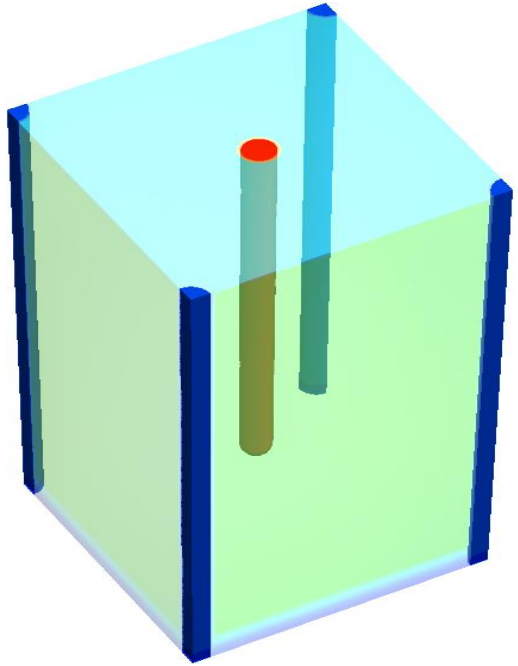
Introduction – small pitch 3D pixel sensors

Features:

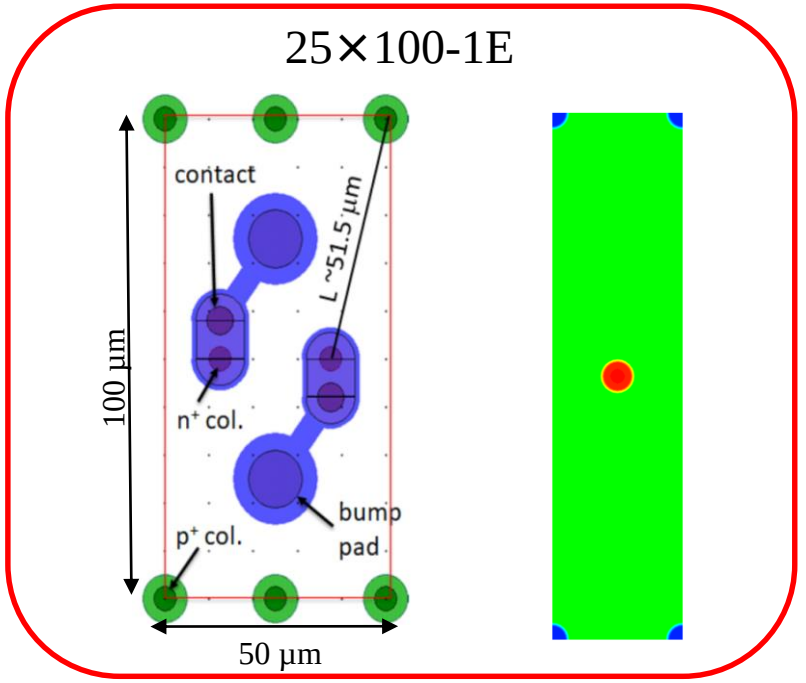
1). High radiation tolerance (~ 10^{16} n_{eq}/cm^2);

2). Low power dissipation;

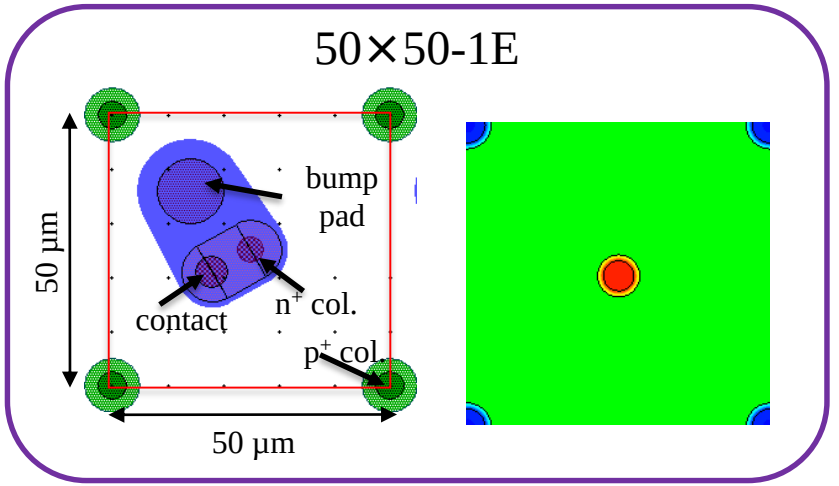
3). High fabrication yield.



3D rendering of small-pitch 3D pixel sensors



Central barrel of the L0 of ITk



Lateral rings of the L0 of ITk

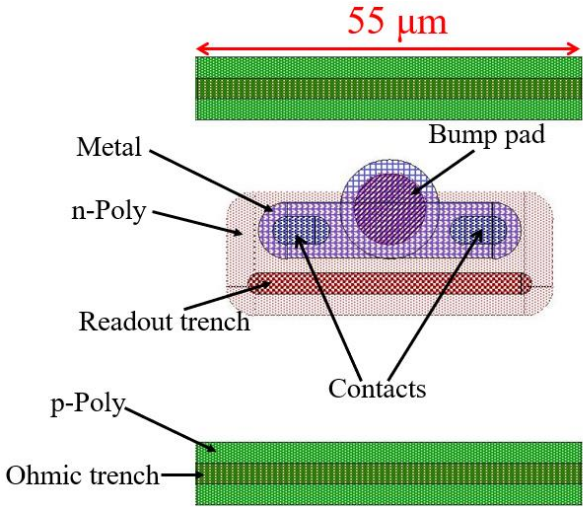
Introduction – 3D trench-electrode pixel sensors

Features:

1). Ultra high radiation tolerance (> $2*10^{16}$ n_{eq}/cm^2);

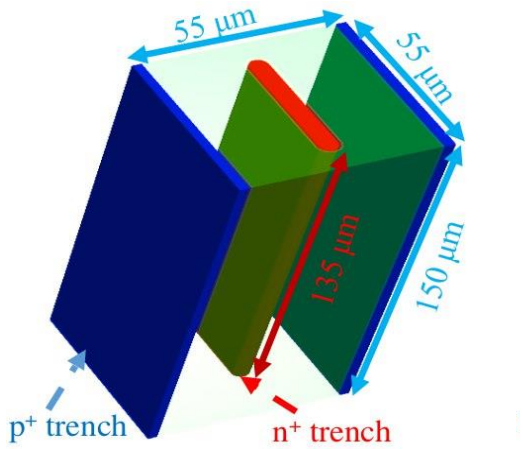
2). High temporal resolution (~10 ps);

3). Low power dissipation.



Continuous trench
(Gap = 0)

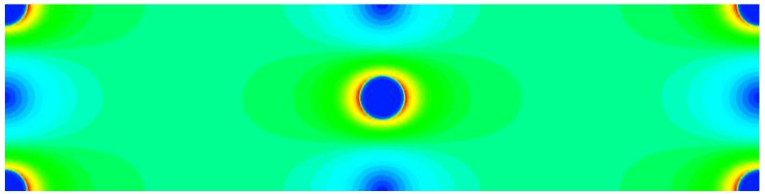
Potential application:
4D tracking for post-LHC



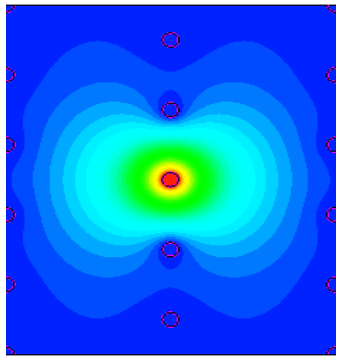
3D rendering of the
continuous trench design

TCAD Simulations – small pitch 3D pixel sensors

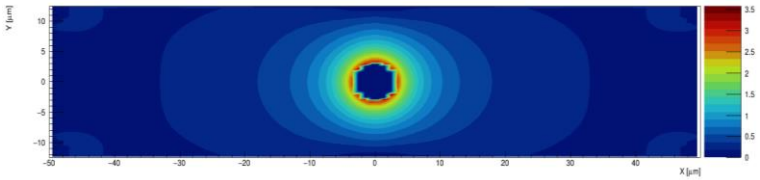
25×100-1E



Electric Field, V_b=100V

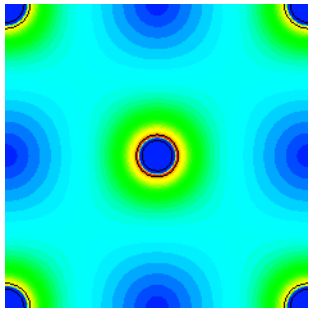


Weighting Potential
(1×5 array)

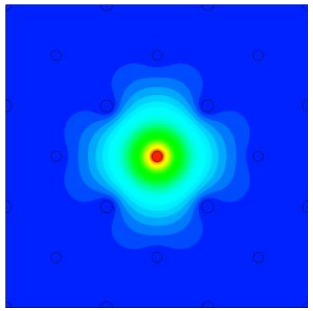


Total Induced Current, V_b=100V

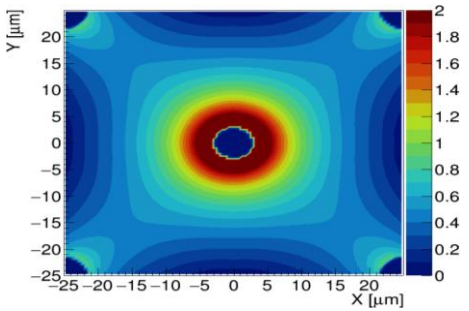
50×50-1E



Electric Field, V_b=100V



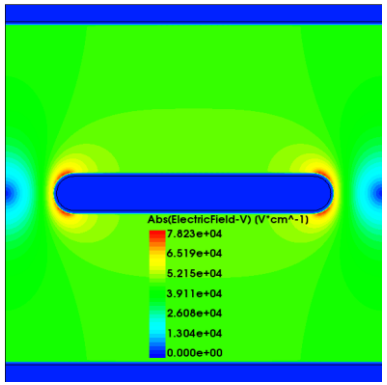
Weighting Potential
(3×3 array)



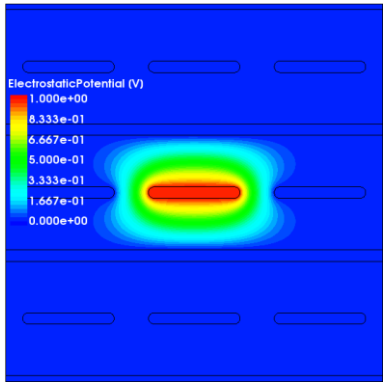
Total Induced Current, V_b=100V

TCAD Simulations –3D trench-electrode pixel sensors

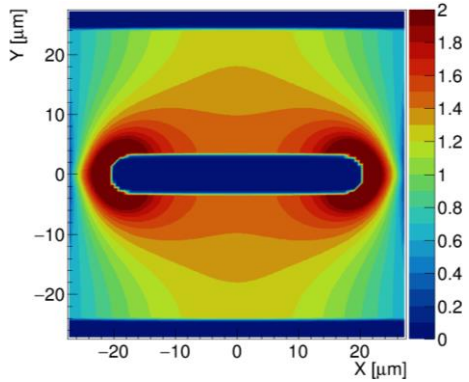
Continuous trench (Gap = 0)



Electric Field, V_b=100V

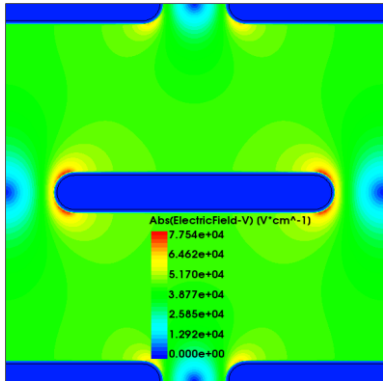


Weighting Potential
(3×3 array)

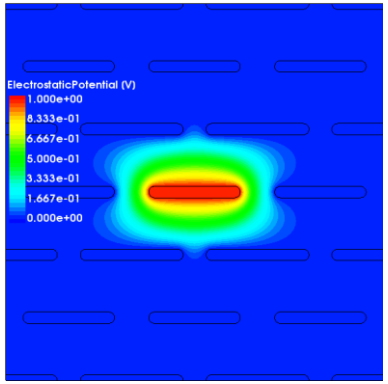


Total Induced Current, V_b=100V

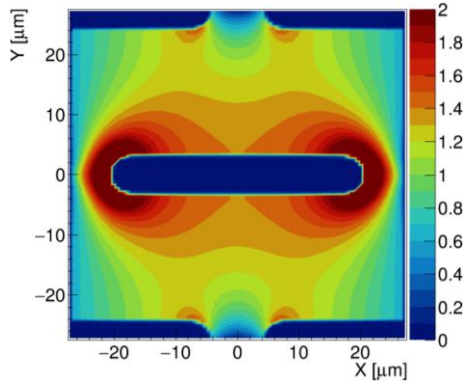
Dashed trench (Gap = 10)



Electric Field, V_b=100V



Weighting Potential
(3×3 array)



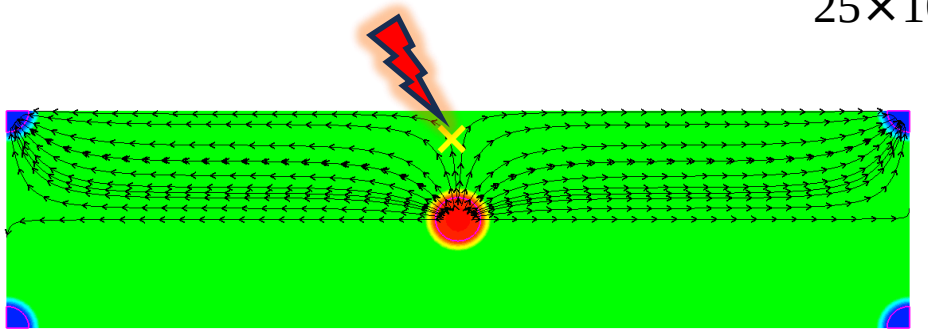
Total Induced Current, V_b=100V

Monte Carlo Simulations – small-pitch 3D pixel sensors

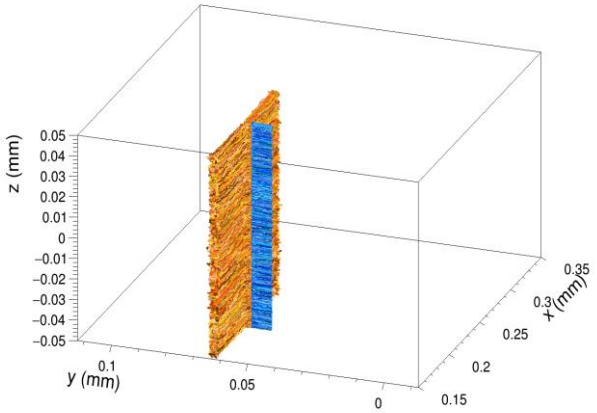
model = "fixed"

MIP direction = 0 0 1

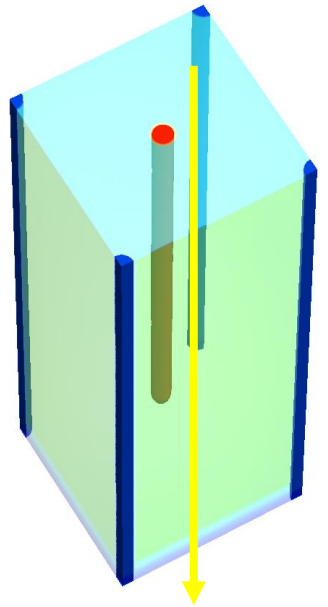
25×100-1E



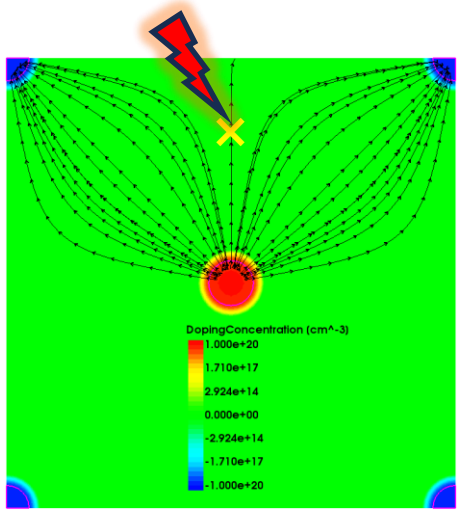
Impinging MIP perpendicular to the surface



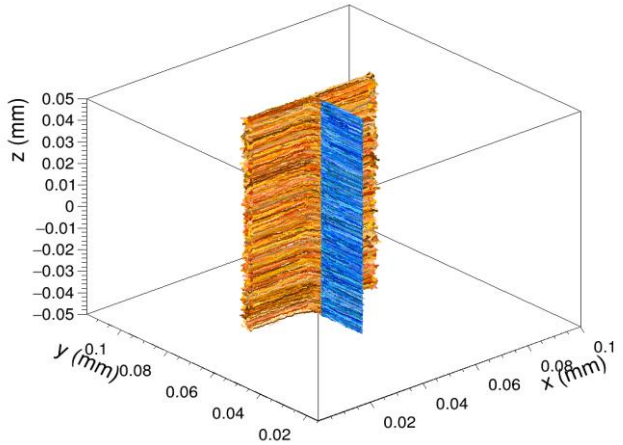
Line graph of the propagated charges



50×50-1E



Impinging MIP perpendicular to the surface



Line graph of the propagated charges

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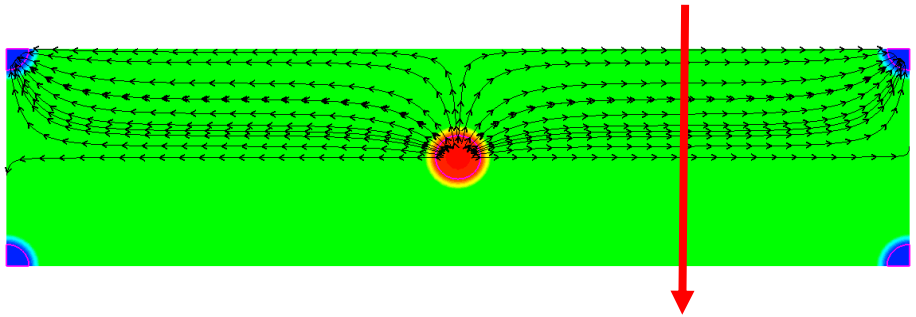
Monte Carlo Simulations – small-pitch 3D pixel sensors

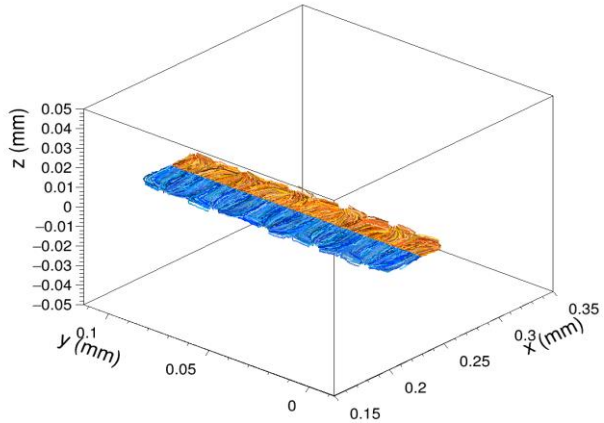
model = "fixed"

MIP direction = 0 1 0

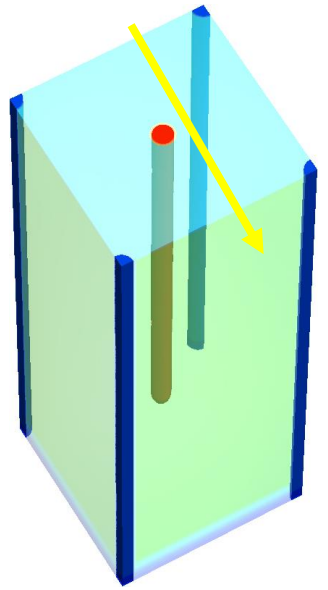
25×100-1E



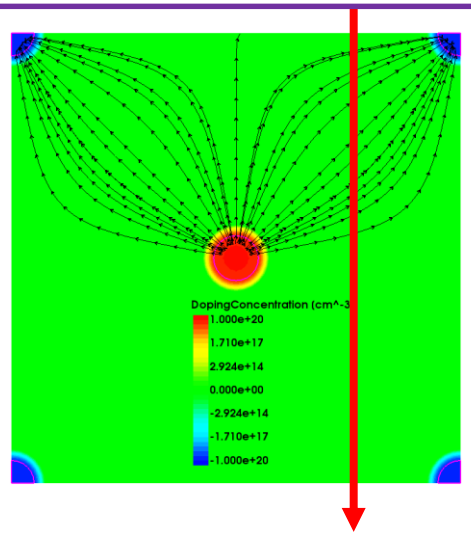
Impinging MIP perpendicular to the Y axis



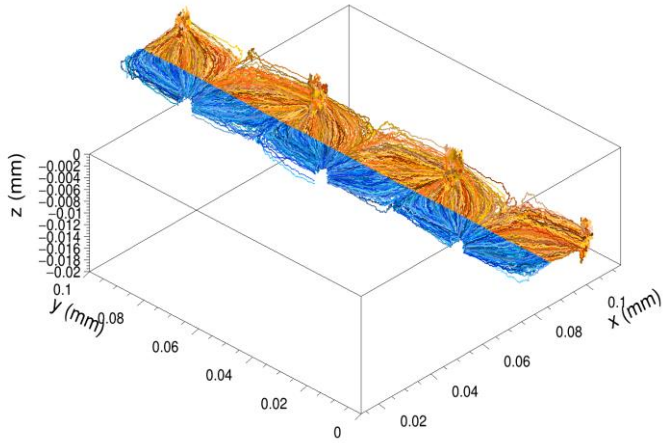
Line graph of the propagated charges



50×50-1E



Impinging MIP perpendicular to the Y axis



Line graph of the propagated charges

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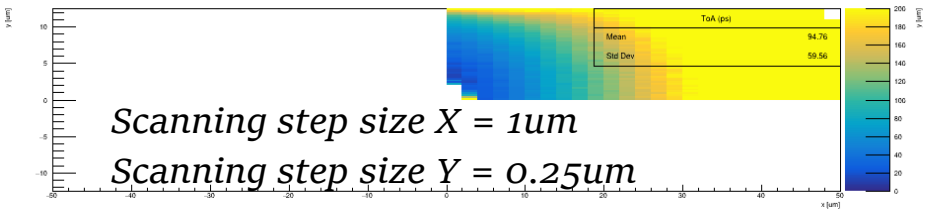
Monte Carlo Simulations – small-pitch 3D pixel sensors

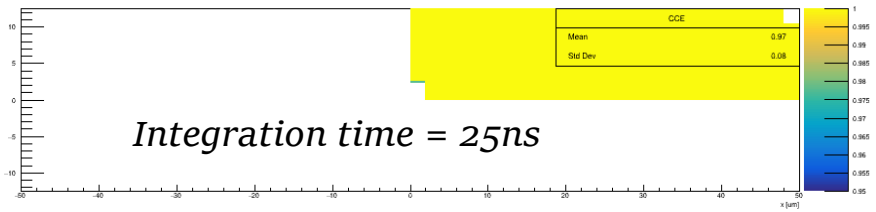
model = "scan"

MIP direction = 0 0 1

25×100-1E

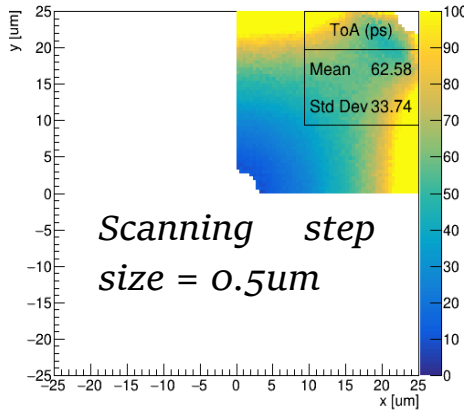


ToA map of the central pixel (a quarter)

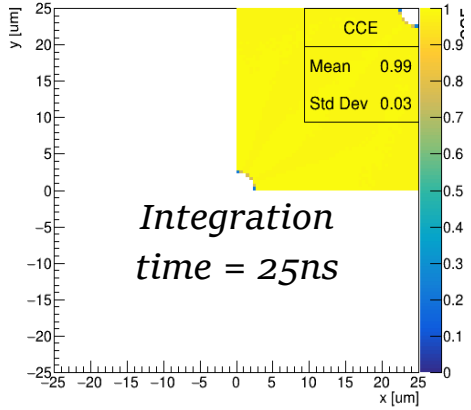


CCE map of the central pixel (a quarter)

50×50-1E



ToA map of the central pixel (a quarter)



CCE map of the central pixel (a quarter)

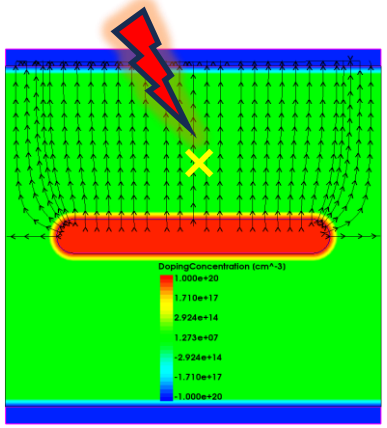
A quarter of the central pixel should be enough to evaluate the performance of the entire pixel due to symmetry.

Monte Carlo Simulations – 3D trench-electrode pixel sensors

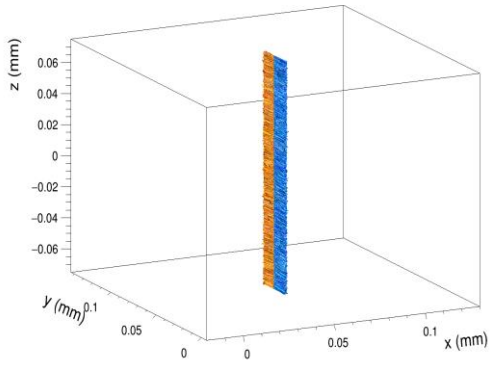
model = "fixed"

MIP direction = 0 0 1

Continuous trench (Gap = 0)



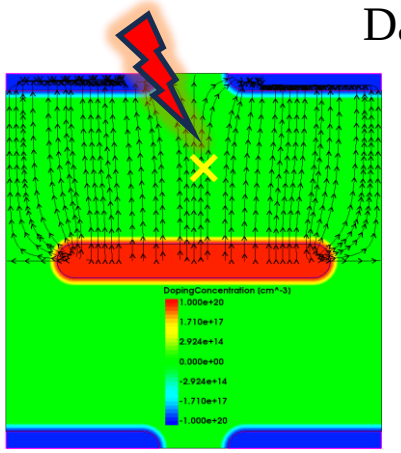
Impinging MIP perpendicular to the surface



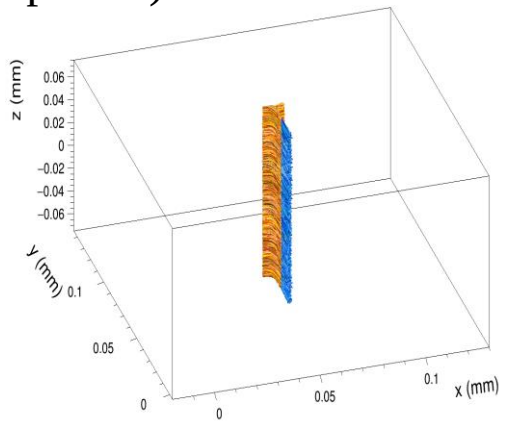
Line graph of the propagated charges

Charges are collected as indicated by the drift lines from TCAD simulations.

Dashed trench (Gap = 10)



Impinging MIP perpendicular to the surface



Line graph of the propagated charges

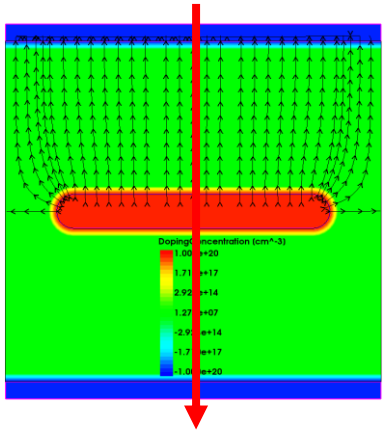
A clear hole drift path bending can be seen on the line graph.

Monte Carlo Simulations – 3D trench-electrode pixel sensors

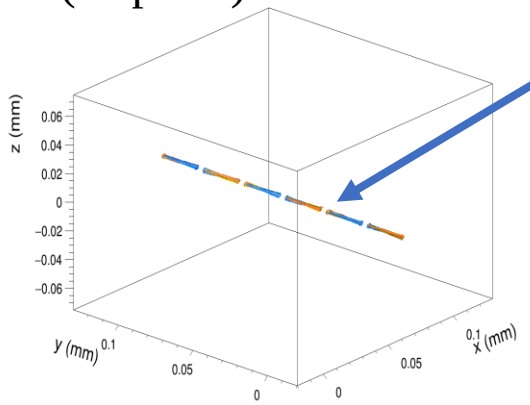
model = "fixed"

MIP direction = 0 1 0

Continuous trench (Gap = 0)



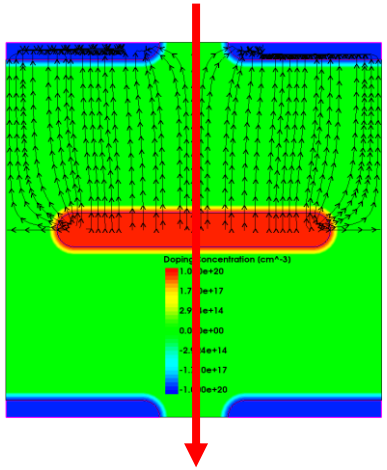
Impinging MIP perpendicular to the Y axis



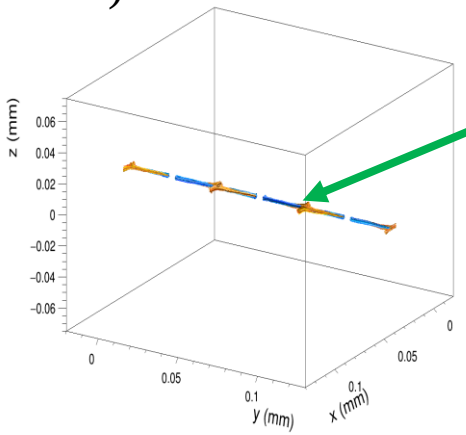
Line graph of the propagated charges

The gaps correspond to the electrodes (implants).

Dashed trench (Gap = 10)



Impinging MIP perpendicular to the surface



Line graph of the propagated charges

Hole drift path broadening due to the gap introduced.

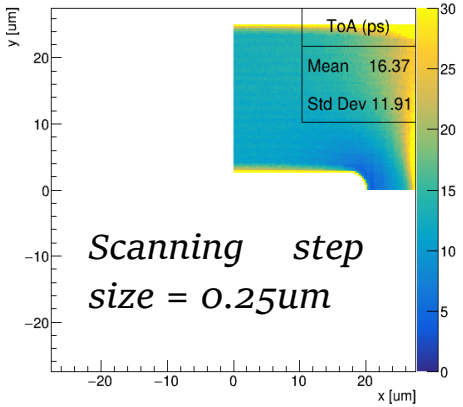
Monte Carlo Simulations – 3D trench-electrode pixel sensors

model = "scan"

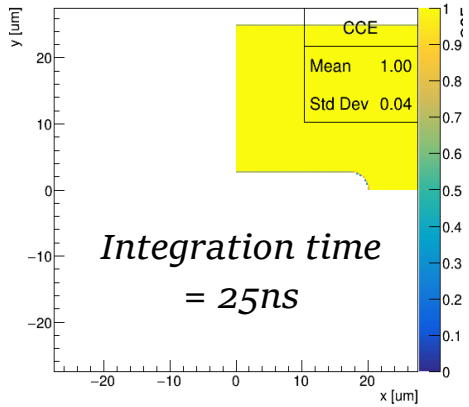
MIP direction = 0 0 1

The ToA is in good agreement with the measured value.

Continuous trench (Gap = 0)



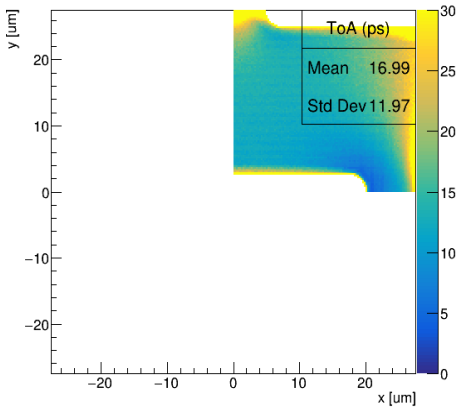
ToA map of the central pixel (a quarter)



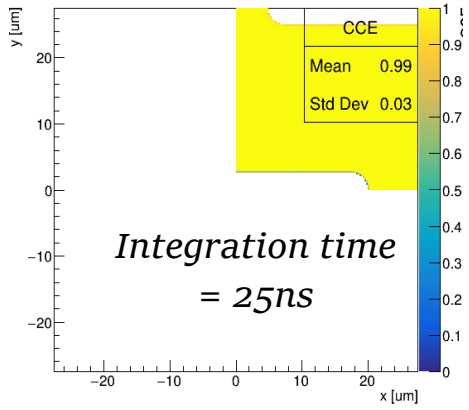
CCE map of the central pixel (a quarter)

No degrade in the ToA observed for the new structure!

Dashed trench (Gap = 10)



ToA map of the central pixel (a quarter)



CCE map of the central pixel (a quarter)

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Future work

Allpix^2 is a very powerful platform for full chain simulation in sensor R&D. Preliminary simulation results in good agreement with the experiments, proving the approach to be viable.

Future work will mainly focus on:

1). Evaluating the performance (of different 3D sensors) after bulk damage;

2). Simulation of new structures.

Thank you!