Design and production of timing optimised 3D silicon sensors for future LHC experiments and beyond

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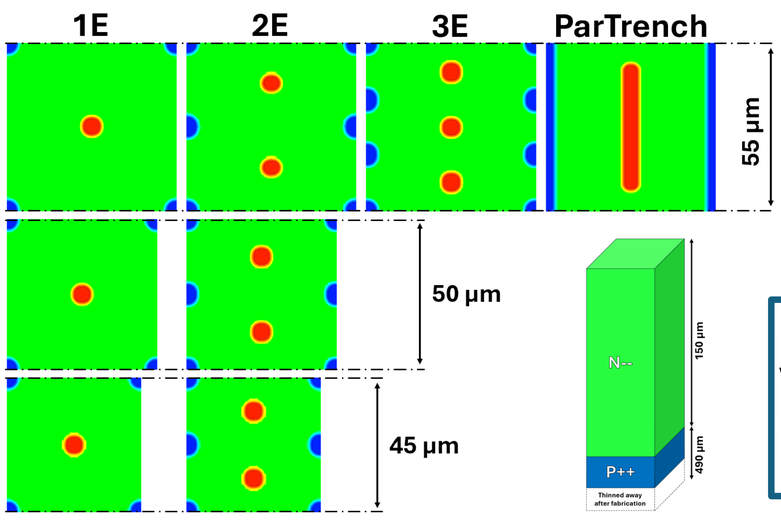
OVERVIEW: This study presents the design process conducted to develop a new, timing-optimized **3D silicon sensor** with **columnar electrodes**, which will be manufactured by **FBK**. This project builds upon prior R&D initiatives, such as **TimeSPOT** and **AIDAInnova**, in which high timing performance was achieved using trench electrodes. The current design study is also preparatory for upcoming beam test campaigns, which will feature timing-optimized **3D-trench** sensors from the AIDAinnova project, as well as a new batch of sensors, set for production in the first quarter of 2025. These sensors will use columnar electrodes with a smaller pitch and pixel matrices, along with a refined production process for improved hybridization yield. They will be compatible with future readout chips from the INFN **IGNITE-1** [1] and INFN IGNITE-X projects, respectively.

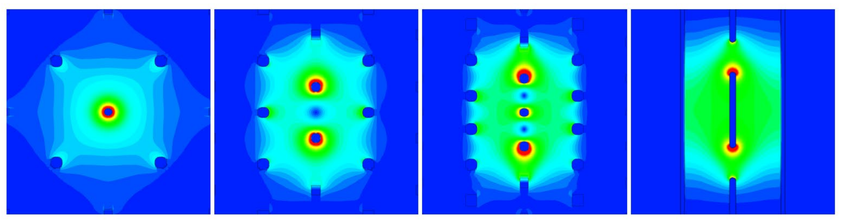
Design :

We are considering at starting point a parallel configuration of columns to approximate the TimeSPOT 3D-trench sensor [2].



↑ Section of the studied geometries

Devices were simulated based on their properties such as weighting field, bulk capacitance and intrinsic current induction (Ramo Map)



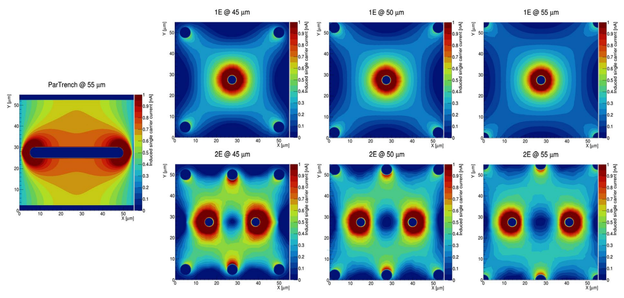
↑ Weighting field maps

Weighting field simulation shows reduced charge sharing for parallel column and 3D-trench geometries

Geometries selected with 1E, 2E and 3E configuration with 150 µm thick active bulk.

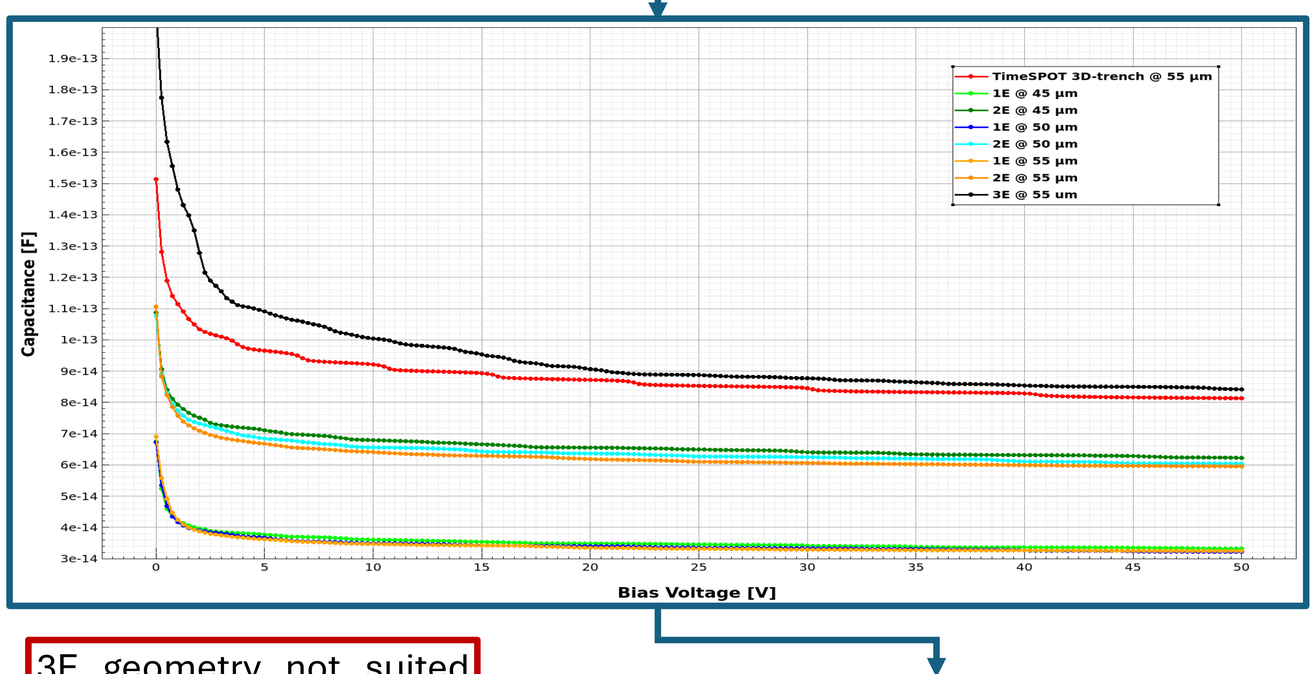
3D-trench is the reference device, due to its already demonstrated performance of time resolution below 20 ps, even after being irradiated above 10^{16} 1 MeV neq /cm^2 [3][4].

Single channel capacitance simulated and compared



↑ Ramo maps

Current induction on the readout electrode on different pixel sizes has been simulated, using Ramo Map approach, showing 2E @ 45 µm has second most intense induction after 3D-trench.



Simulation tools used:

Particle-matter interaction with Geant4

Design, quasi-stationary simulation and capacitance simulated with TCAD (SYNOPSYS TCAD)

Charge drift, diffusion and signal generation with TCoDe. (TCoDE TimeSPOT Code for Detector simulation)

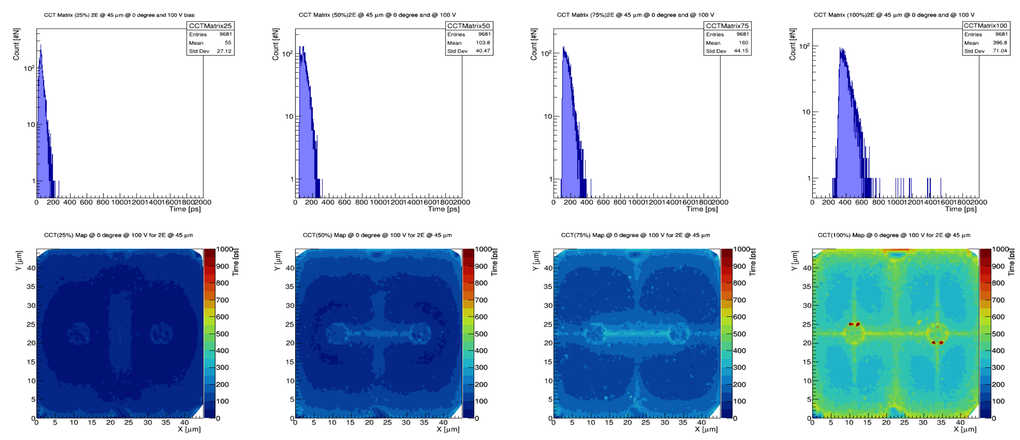
3E geometry not suited due to large intrinsic capacitance.

The capacitance increases proportional to the number of readout column used by a factor of 40 fF for every single column.

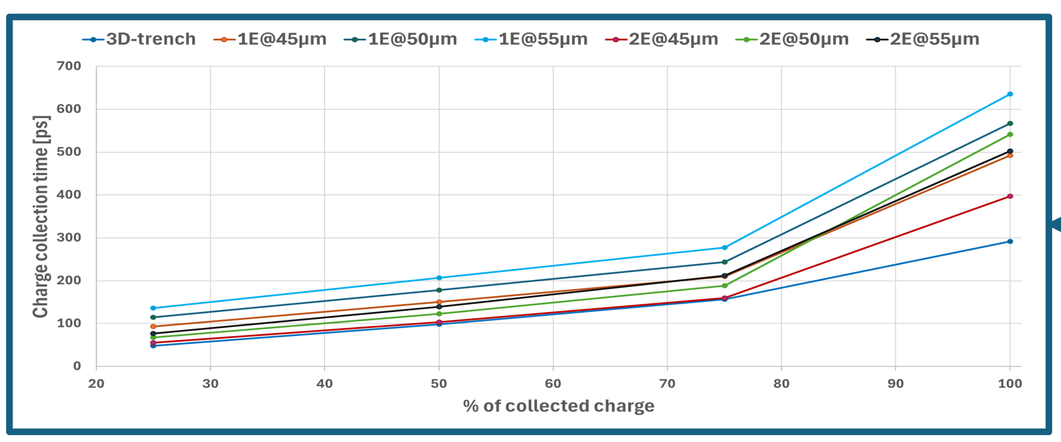
Transient simulation:

Sensor simulation involved the use of 15k events for each angle of crossing (0°, 10° and 20°).

Charge collection time has been measured and compared to the 3D-trench. 2E design has been considered closes in terms of charge collection time distribution to the 3D-trench and, therefore main candidate for implementation of the final layout.



↑ Charge collection time distribution and map for a 2E geometry @ 45 um pitch

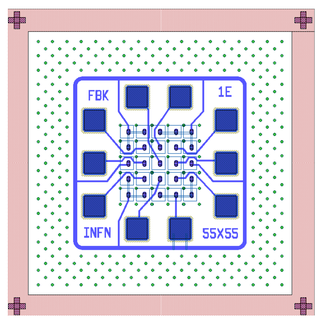


↑ Overall comparison of the average charge collection time distribution over all studied geometries

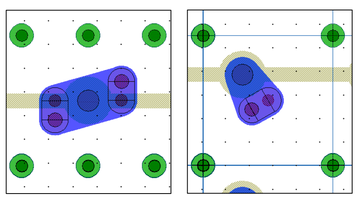
Layout:

Layout has been defined based on choices made after the design study and the development of the incoming IGNITE-1 ROC.

50 µm and 45 µm pitch matrices are included in the layout with sizes of 64x64 up to 256x256 pixel.



← 3x3 pixel structure for charge sharing studies



↑ layout for the 1E and 2E geometries.

Pixel geometries will include 1E and 2E readout electrodes to compare best tradeoff capacitance/charge collection time. Dedicated test structures will be included for dedicated studies such as charge sharing.

Upcoming activities

Sensor batch submission and production during first semester 2025.

Simulation of the 3x3 pixel structure will be performed by the end of 2024 and will be compared with future test beam data featuring the test structure included in the batch.

References

[1] Recent developments in the IGNITE project

[2] TimeSPOT 3D trench sensor

[3] TimeSPOT 3D trench sensor test-beam results

[4] results after irradiation