3D silicon sensors with columnar shaped electrode geometry for fast timing tracking detectors

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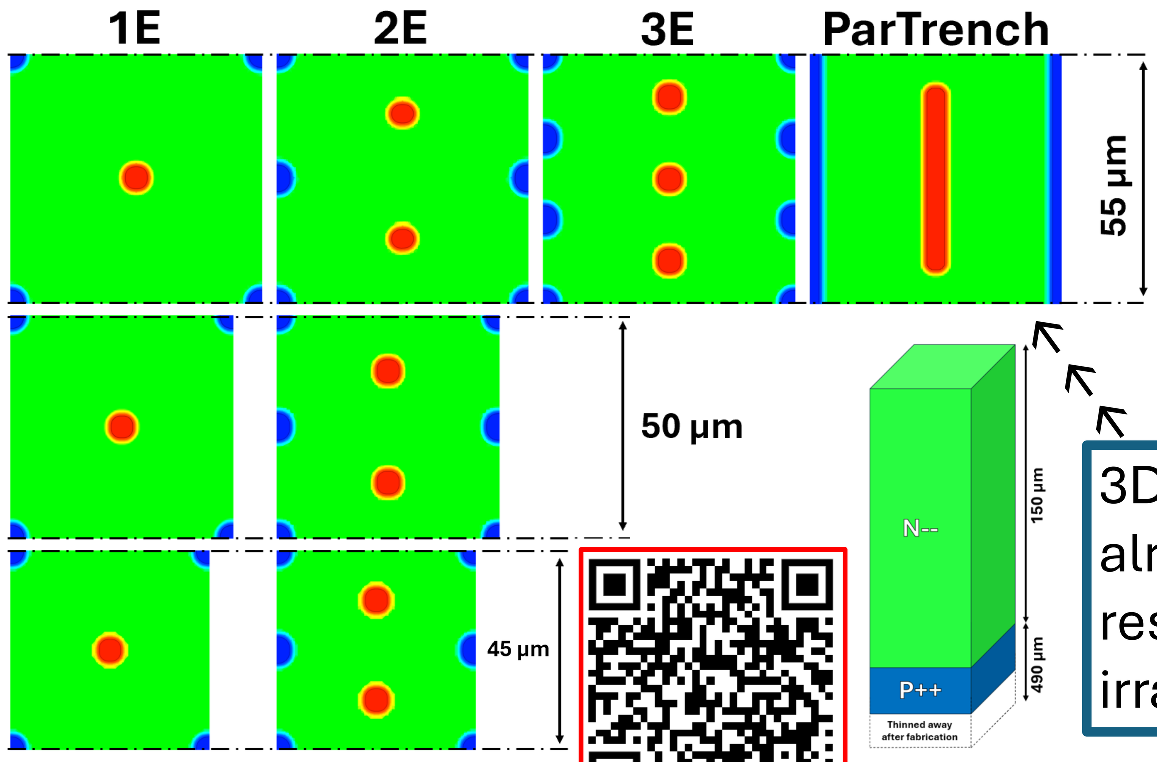
OVERVIEW: We present accurate and extensive studies on 3D-column silicon sensors, aimed at high-resolution space-time (4D) tracking for future collider experiments. Such studies are a follow-up of the TimeSPOT-project and AIDAInnova initiative, where we developed timing optimized 3D-trench silicon sensors [1], which have been proved to reach a time resolution around 10 ps rms up to extreme fluences (above 10^{17} new/cm2) [2] [3]. In this study, three configurations, 1E, 2E, and 3E, based on a parallel electrode configuration are designed, simulated, and compared with the established parallel trench geometry. Additionally, the impact of varying pitch sizes (45 µm, 50 µm, and 55 µm) on performance are investigated. 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, such as the IGNITE32/64 and INFN IgniteER, respectively [4].

Sensor design :

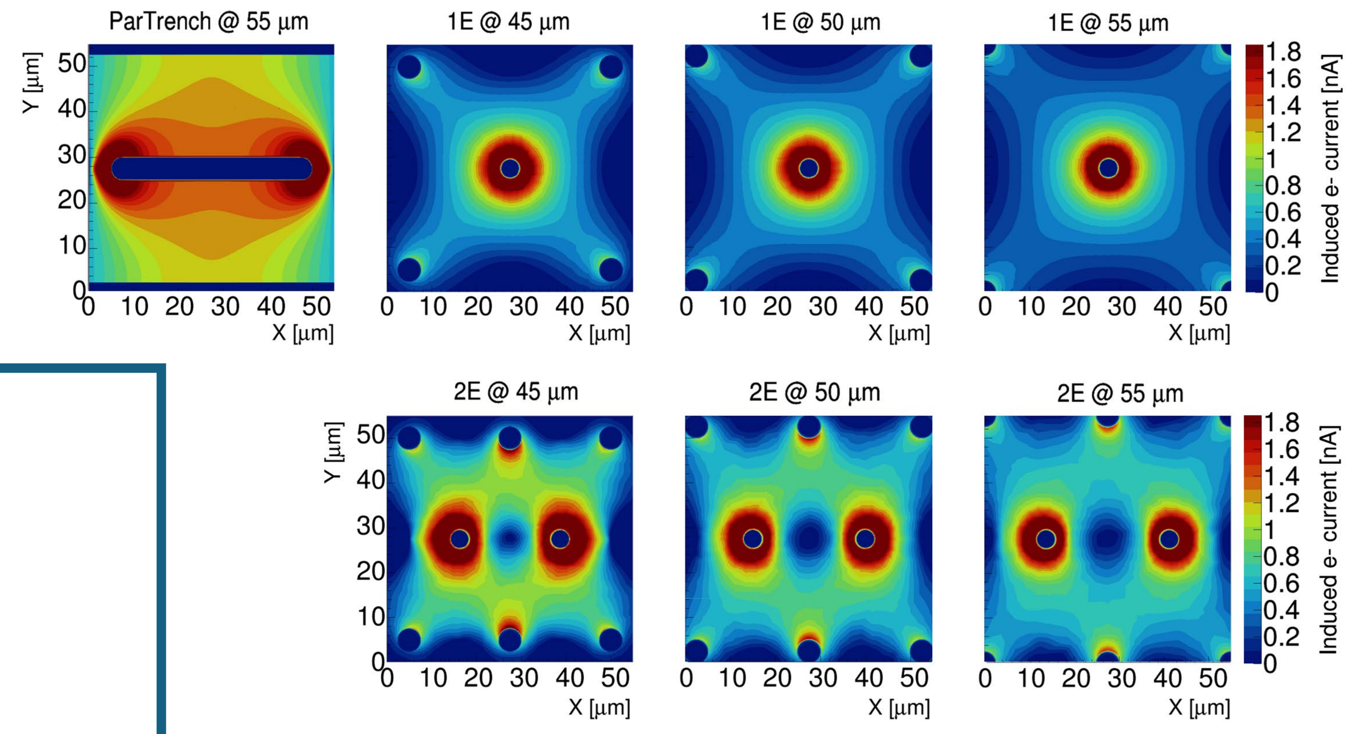
Columnar electrode geometries with single, double and triple readout electrodes are proposed.



AR VIEW

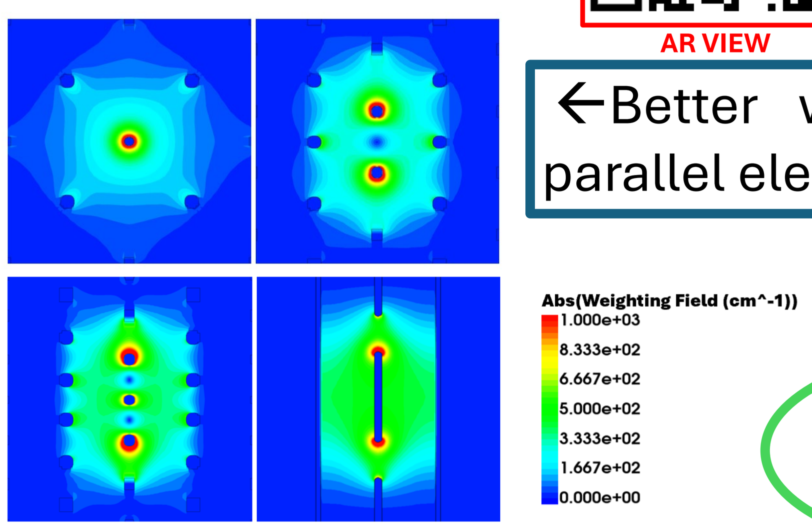
Devices were simulated based on their properties such as weighting field, bulk capacitance and intrinsic current induction (Ramo Map) →

Ramo maps →



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 [1][2].

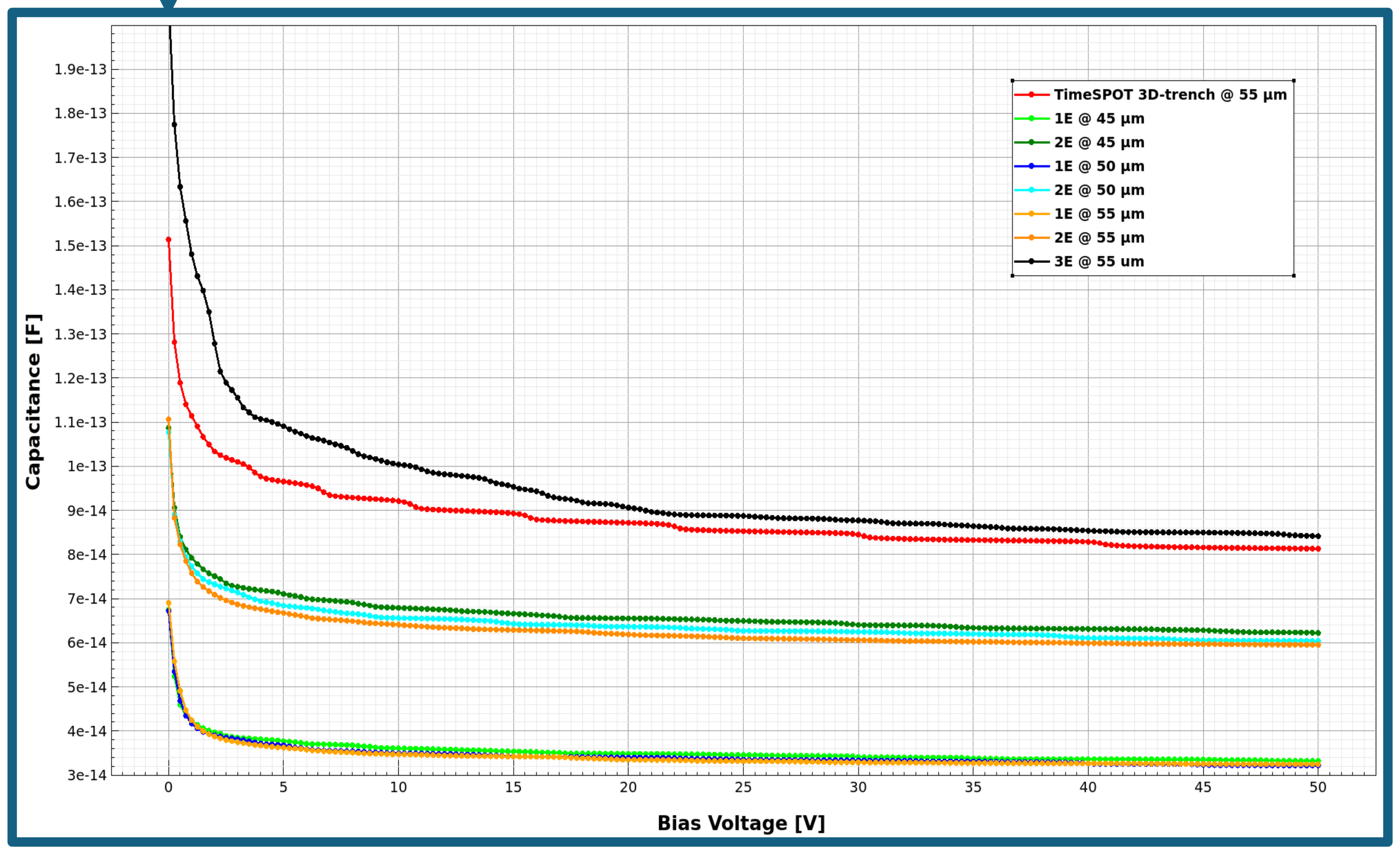
3E excluded due to large capacitance and complicate fabrication process.



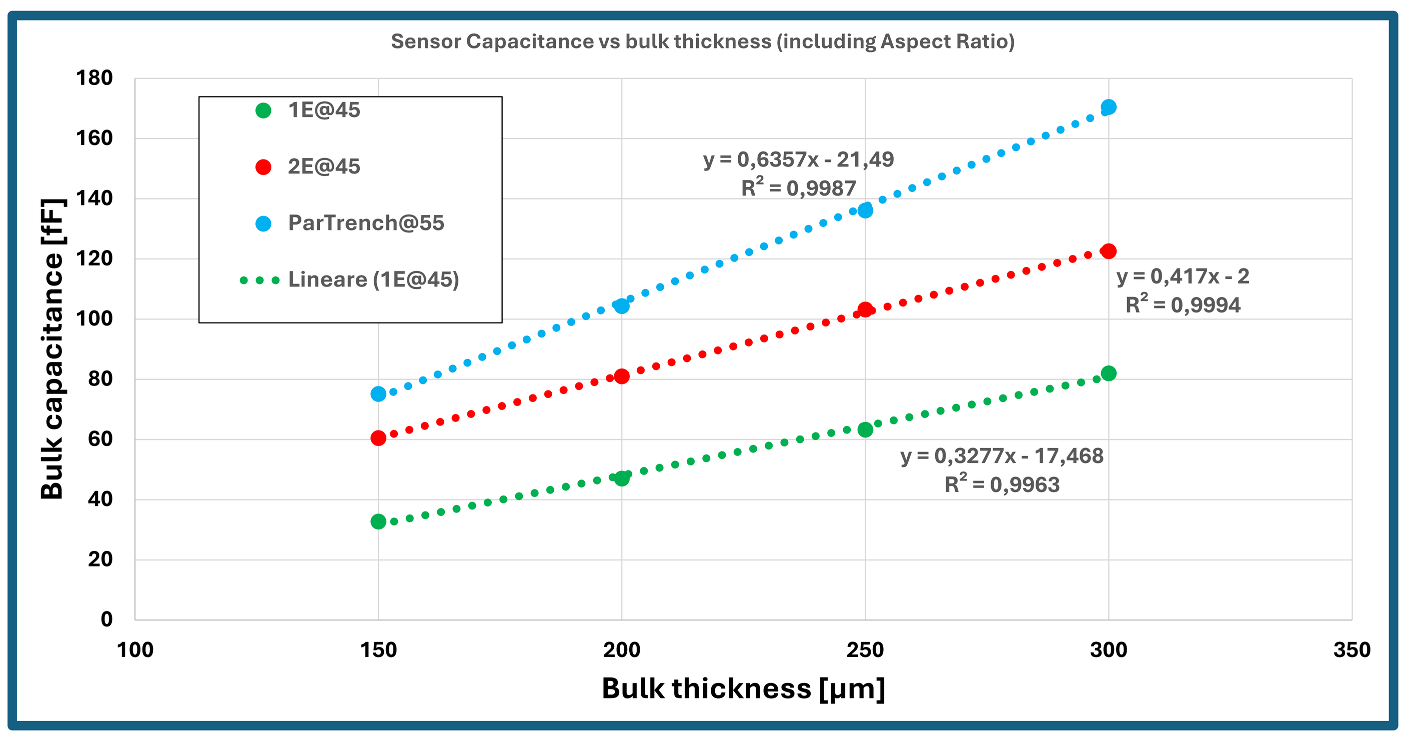
↑ Weighting field maps

←Better weighting field confinement in parallel electrode geometries

@150 µm thickness, the capacitance increases proportional to the number of readout columns used (40 fF for every single RO column). →

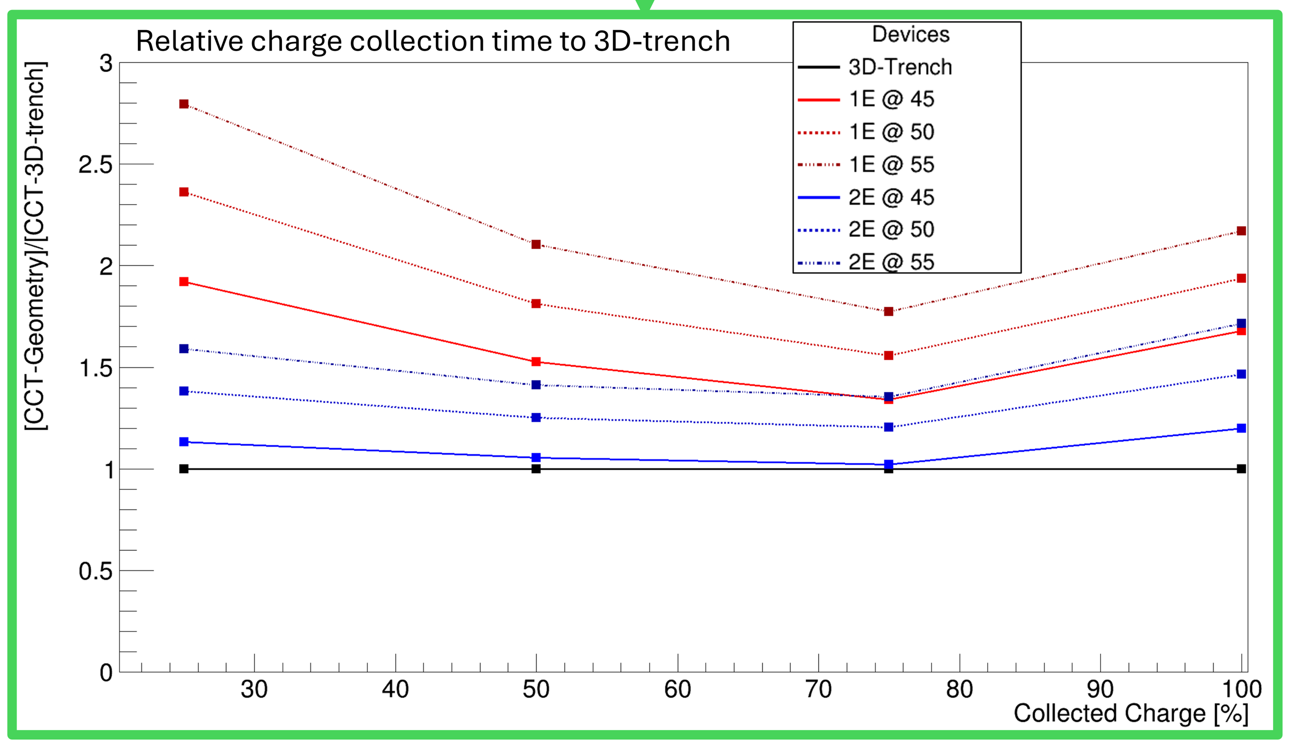


A parallel study considered also capacitance related to wafer thickness, showing an increment of 0.5 fF/µm including aspect ration. →



Transient simulation:

Sensor geometries simulated at 3 different angulations (0°, 10° and 20°). Collected charge as well as Charge Collection time at thresholds of 25 %, 50 %, 75% and 100 %, has been analyzed and compared to 3D-trench device.

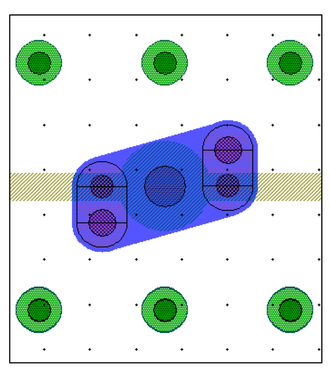


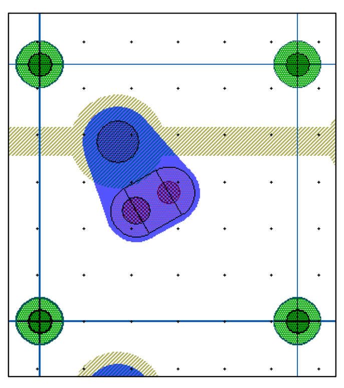
← The performances of the 2E design @ 45 µm pitch are the closest to the 3D-trench. The smaller pitch allows faster charge collection time and the columnar shape electrodes reduces capacitance by 25%. →

Layout:

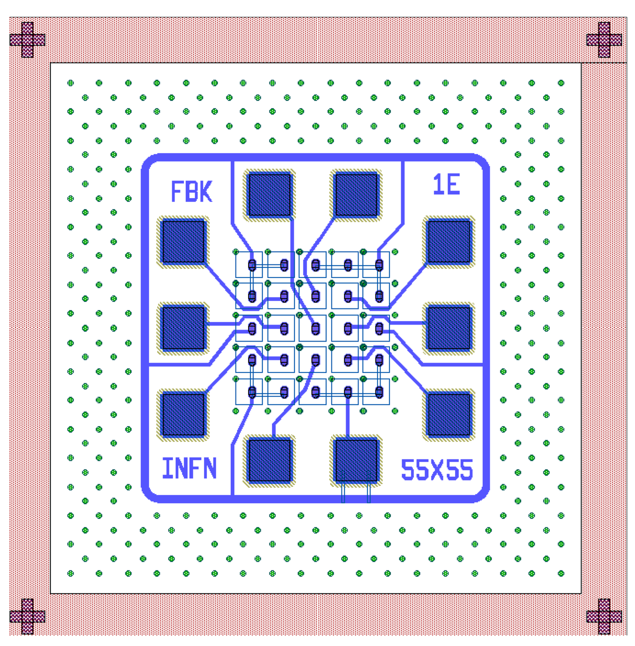
Layout has been defined based on choices made after the design study and the development of the incoming IGNITE-ER and PicoPix ROCs.

2E@45um layout →





← 1E@45um layout



3x3 pixel structure for charge sharing studies

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

← Pixel geometries will include 1E and 2E geometries to compare the best tradeoff capacitance/CCT. Dedicated 3x3 pixel matrices have been designed.

Batch expected back at latest for 2026. Future activities involving charge sharing studies and beam test comparison are currently under preparation

Simulation tools used:

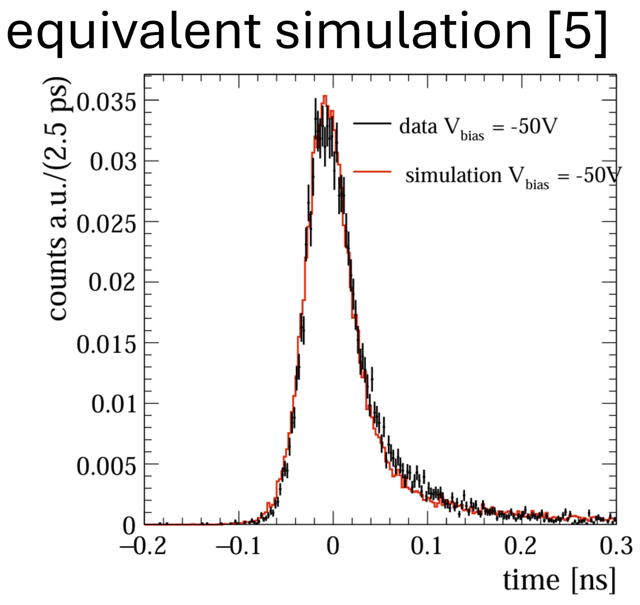
The simulation framework developed for these studies involve different tools, including commercial, open source and custom made.

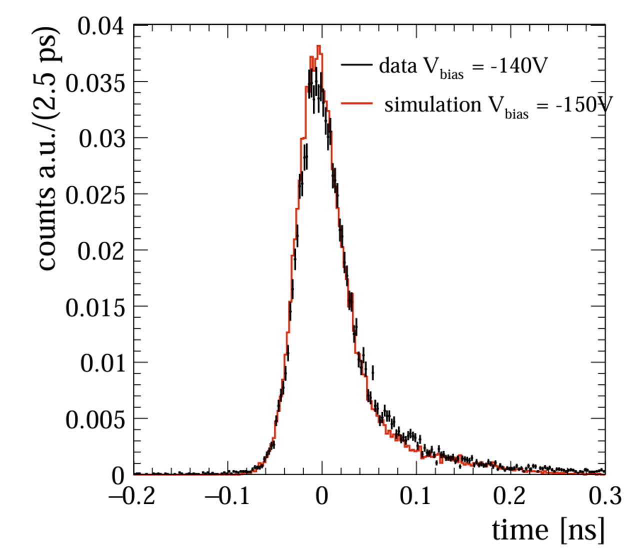
Device modelling and stationary simulation → SYNOPSYS TCAD

Particle-matter interaction with: Geant4

Charge drift, diffusion and signal generation with TCoDe. → TCoDE

The simulation framework has been used and validated for the first time in 2021, comparing test beam data with equivalent simulation [5]





References

[1] TimeSPOT 3D trench sensor

[2] results after irradiation

[3] TimeSPOT test-beam results

[4] Recent developments in the IGNITE project

[5] Accurate simulation vs measurement