

# Allpix<sup>2</sup> simulations of irradiated 3D columnar-electrode sensors for 4D tracking

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## Abstract

3D silicon sensors have demonstrated excellent radiation hardness since their first deployment in the Insertable B Layer (IBL) at ATLAS, paving the way for their integration into the innermost layers of ATLAS and CMS for the high luminosity upgrade. Besides being extremely radiation-hard, they also promise excellent timing performance. A timing resolution of about 30 ps has been reported for 3D columnar-electrode test structures [1], while 3D-trench electrode sensors can achieve resolutions as low as  $\sim 10$  ps even after the exposure to very high fluences [2].

Despite the remarkable results, the fabrication technology for 3D-trench electrode sensors is still under development. In contrast, the fabrication of 3D columnar-electrode sensors has reached its maturity, with the capability of producing large-area sensors ( $\sim 4$  cm<sup>2</sup>) with high yield. To fully exploit this advantage, we have conducted an extensive study of 3D columnar-electrode sensors with various configurations—specifically, different pixel sizes and numbers of readout electrodes (i.e., 1E or 2E structures)—aimed at improving radiation hardness, enhancing timing performance, and reducing dead area [3]. Simulation results show the timing performance of the sensors can be significantly improved by downscaling the pixel size and/or introducing additional electrodes. These advancements could be important for the VELO Phase-2 upgrade at LHCb, which requires 4D tracking capabilities under extreme radiation damage.

Based on the study, a new batch has been scheduled for production at FBK in 2025; dedicated irradiation and characterization campaigns will follow after on-wafer electrical tests. However, to support future layout optimization, it is crucial to study how different structures respond to radiation damage in the meantime. Through the help of TCAD and Monte-Carlo simulations (Allpix<sup>2</sup>), this work focuses on evaluating the charge collection properties and timing resolution of various 2E structures, with particular attention paid to their performance after irradiation.

**Keywords:** 3D silicon sensor, timing resolution, 4D tracking, TCAD simulation, Monte-Carlo simulation

## References

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