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Simulation and Characterization of fast and radiation hard 3D sensors

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The High-Luminosity LHC will subject vertex detectors to unprecedented radiation levels, requiring sensors that can withstand fluences up to 10^{17} n_{eq}/cm^2 while maintaining excellent spatial and temporal resolution. This work presents the development of 3D silicon pixel sensors for the second upgrade of the LHCb Vertex Locator (VELO). Unlike planar sensors, 3D sensors feature columnar electrodes etched through the silicon bulk, significantly reducing charge collection distances. This geometry provides both enhanced radiation tolerance and faster charge collection times, making them ideal candidates for high-rate, high-radiation environments.

To identify optimal 3D sensor geometries that meet the VELO upgrade requirements, an automated simulation pipeline is being developed to explore the large parameter space of sensor designs. Key design parameters under investigation include column diameter and spacing, sensor thickness, doping profiles, isolation structures (p-stop vs. p-spray), and electrode geometry variations for both single-sided and double-sided fabrication processes. Studies have focused on optimizing breakdown voltage, capacitance, and electric field distributions to maximize timing performance when coupled to the PicoPix fast-timing ASIC. In this talk, the results so far obtained, as well as ongoing and future studies will be discussed.

The simulation pipeline integrates multiple software tools and is currently halfway through completion, linking sensor geometry optimization, charge transport modeling, and readout electronics response. First comparisons between testbeam data and simulation results are expected soon. Once completed, the full pipeline will predict the complete hybrid sensor response when coupled to the PicoPix ASIC, enabling comprehensive optimization of the sensor-ASIC system. Experimental validation is performed through laboratory measurements as well as testbeam campaigns at CERN's SPS using the Timepix4 telescope.

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