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TCAD simulation of Radiation Damage Effects on LHCb Velo and Operations in Run-II

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The primary goal of the LHCb experiment at the LHC is to search for indirect evidence of new physics via measurements of CP violation and rare decays of beauty and charm hadrons. The VErtex LOcator (VELO) is a silicon-strip detector located around the interaction region. It has active sensing elements as close as 8 mm from the LHC beams, and for this reason it undertakes a very high radiation damage.

The non-uniform exposure of the VELO sensors makes it an ideal laboratory to study radiation damage effects in silicon detectors. The VELO sensors are exposed to fluences of the order of 5×10^{13} 1-MeV neq/cm^2 per fb^{-1}, and it is planned to operate up to 10 fb^{-1} integrated till the end of Run II. Several different methods are used to monitor the radiation damage. In particular, regular High Voltage scans are taken which allow a precise measurement of the Charge Collection Efficiency (CCE), and Cluster Finding Efficiency (CFE) as function of the applied voltage. These analyses are used to determine the operational voltages, and to monitor the degradation of the detector performance.

The detectors are constructed with two metal layers in order to cover the particular design of the R/ϕ strips and to route the signal to the outer region where the front-end chips are located. A loss of signal amplitude and hence efficiency has been observed with a strong dependency on the distance to the routing lines. A complete TCAD simulation was implemented with the full detector geometry in order to investigate these effects in detail. Using the Perugia n-type bulk model and the Peltola surface damage model it is shown that, for the worst case particle hit position and angle, up to 60% of the deposited charge is picked up by the routing lines. It is argued and shown in simulation that this is caused by trapping of the otherwise mobile electron accumulation layer at the oxide-silicon interface. As the inversion layer is trapped and made immobile, its shielding effect on the routing lines is removed. Additionally, it is found that the observed drop in CFE, which is largest in the outer radial regions of the sensors far away from the interaction point, can be explained by the angular dependence of charge loss to the second metal layer. By combining 2D and 3D simulations of up to five strips in TCAD with the global geometry of the sensors, efficiency drop as function of sensor radius and angle is qualitatively reproduced.

The overall performance of the VELO during Run-2 will be presented. The results of the latest high voltage scans will be shown, and measurements of the effective depletion voltage will be compared with the expected values that are calculated using the Hamburg model. Several fits to the model will be shown that illustrate different annealing scenarios, related to maintenance activities of the cooling system that are envisaged in Run-2, and their impact on the operation of the detector during the remaining Run-2 data taking. An explanation for the observed charge loss to the routing lines will be presented, backed up by the results from the simulation.

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