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Radiation-tolerant Silicon Detectors for the LHC Phase-II Upgrade and Beyond: Review of RD50 Activities

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The inner tracking layers of all LHC experiments were designed and developed to cope with the environment of the present Large Hadron Collider (LHC). At the LHC Phase-II Upgrade foreseen for 2026, the particle densities and radiation levels will increase by roughly an order of magnitude compared to the present LHC conditions, and the silicon-based inner tracking systems have to be able to withstand fluences of up to 2e16 neq/cm2.
Within the CERN RD50 Collaboration, a large R&D program has been underway for more than a decade across experimental boundaries to develop silicon sensors with sufficient radiation tolerance for HL-LHC tracker detectors. This challenge is approached simultaneously from different angles: Collaboration activities range from defect characterization and modeling to sensor development and the integration of sensors into full detector systems.
One of the main objectives of the RD50 collaboration is to gain a deeper understanding of the connection between the macroscopic sensor properties, such as radiation-induced increase of leakage current and trapping, and the microscopic properties at the defect level. With increasing fluence, radiation-induced phenomena on a sensor level become increasingly complex, and call for advanced techniques and strategies to identify the mechanisms behind the observed changes in material properties. Furthermore, at very high radiation levels the differences in radiation damage caused by different types of radiation are highlighted, which poses a challenge for the scaling of radiation damage.
Experimental results are complemented by simulation studies, e.g. to obtain predictions of the electric field distributions and trapping in the silicon sensors and to assist device structure optimization, using both open-source and commercial TCAD simulation tools.

This talk will present an overview of research activities within the RD50 Collaboration, with an emphasis on the characterization and current understanding of radiation-induced effects corresponding to HL-LHC fluences. We will comment on considerations for silicon detectors in future collider experiments, where tracker detectors may be exposed to fluences of up to 7e17 neq/cm2.
We will also discuss recent developments in novel silicon detector technologies and fabrication, for example 3D detectors and low-gain avalanche detectors, as far as they are not covered in dedicated presentations.

Primary author: OTT, Jennifer (Helsinki Institute of Physics (FI))

Presenter: OTT, Jennifer (Helsinki Institute of Physics (FI))

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