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Radiation tolerance of the readout chip for the Phase I upgrade of the CMS pixel detector

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For the Phase I upgrade of the CMS pixel detector a new digital readout chip (ROC) has been developed. An important part of the design verification are irradiation studies to ensure sufficient radiation tolerance. The presentation summarizes results of the irradiation study on the final ROC design for the detector layers 2 - 4. Samples have been irradiated with 23 MeV protons to accumulate the expected lifetime dose of up to 1.2 MGy. Additionally, very high doses of up to 4.2 MGy have been tested to explore the capabilities of the current chip design on 250 nm CMOS technology.

Summary

As the LHC's center of mass energy and instantaneous luminosity will increase in several development stages also the detectors around the accelerator have to be upgraded to maintain or even improve their performance. For the CMS experiment, especially the pixel detector is affected by degraded performance as a consequence of increased track multiplicity and radiation damage. Therefore, the present pixel detector which is designed for luminosities of up to $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ will be replaced by an upgraded version to ensure precise tracking at luminosities twice as high. This replacement is referred to as Phase I upgrade and is scheduled during the winter shutdown 2016/17.

Several new features such as an additional detector layer, the smaller distance between interaction point and first layer, and a lower material budget improve the tracking performance. For this talk, the most important change is that the readout of the detector will be fully digitized in order to transmit higher data rates. Therefore a new readout chip (ROC) with on-chip digitization of the data has been developed. Other changes in the ROC such as an additional readout buffer and the extension of data and time stamp buffers aim to minimize data losses. Moreover, the new ROC targets for a lower threshold of less than 2000 electrons. This improves the radiation tolerance of the detector since it allows to readout weaker signals which occur due to charge collection inefficiencies in the sensor after irradiation. The lower threshold also requires a small timing difference between small and large signals in the ROC's comparator (timewalk).

The study aims to verify that the ROC for the pixel detector layers 2 - 4 is fully functional after receiving a total ionizing dose as it is expected for the detector's lifetime. FLUKA simulations show that layer 2 of the detector will accumulate up to 0.6 MGy assuming $500\ \mathrm{fb}^{-1}$ of proton-proton collisions. A dose of 1.2 MGy corresponds to the maximum dose expected for the innermost detector layer where the so-called layer 1 ROC will be used. This ROC was under development when this study has been performed and results have been used to optimize its radiation tolerance. Finally, samples irradiated up to 4.2 MGy have been tested to explore the capabilities of the current chip design on 250 nm CMOS technology after heavy irradiation.
Samples of the ROC have been irradiated with 23 MeV protons at the Zyklotron AG Karlsruhe, Germany and have been qualified before and after irradiation to compare possible changes in the optimal operation parameters and in important performance parameters, such as timewalk, threshold, noise, and pixel hit efficiency. The results confirm excellent radiation tolerance of the CMS pixel ROC for layers 2 - 4 up to the expected total ionizing dose the detector will accumulate during its lifetime. Moreover, it could be shown that the ROC can be operated efficiently with binary readout after irradiation of up to 4.2 MGy.

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