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Radiation hardness of 3D pixel sensors up to full HL-LHC fluences

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A new generation of CNM 3D pixel sensors with small pixel sizes of 50x50 and 25x100 μm^2 and reduced electrode distances are developed for the HL-LHC upgrade of the ATLAS pixel detector. For the first time, pixel detectors are irradiated and studied up to the unprecedented fluence of $2.5\times10^{16} n_{eq}/\text{cm}^2$, i.e. for the full expected HL-LHC life time to explore the limits of the 3D technology. Since a readout chip with the desired pixel size is still under development by the RD53 collaboration, first prototype small-pitch pixel sensors were designed to be matched to the existing ATLAS IBL FE-I4 readout chip for testing. Irradiation campaigns with such pixel devices have been carried out at KIT (Karlsruhe) with a uniform irradiation of 23 MeV protons up to a fluence of $1\times10^{16} n_{eq}/\text{cm}^2$, as well as at CERN-PS with a non-uniform irradiation of 23 GeV protons in several steps up to a peak fluence of $2.5\times10^{16} n_{eq}/\text{cm}^2$. The hit efficiency has been measured in several beam tests at the CERN-SPS. The performance of these devices is significantly better than for the previous generation of 3D detectors or the current generation of planar silicon pixel detectors, demonstrating the excellent radiation hardness of the new 3D technology.

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