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Extremely radiation-hard technologies: 3D sensors

3D sensors have emerged as the most radiation-hard silicon-based technology for vertex detectors. Their radiation tolerance is due to their structure, where vertical electrodes penetrate the substrate for most or all of its thickness. The inter-electrode separation is therefore determined by the layout and can be made much smaller than the substrate thickness. As a result, sensors can be operated at relatively low bias voltages even after large radiation fluences (~200 V at most), leading to significant savings in terms of power dissipation and strongly mitigating charge trapping effects. Remarkably good results have so far been reported for 3D sensors fabricated at different processing facilities, achieving a comparable performance level, evidence of the intrinsically geometrical nature of the radiation hardness properties.

As the technology has progressed through the years, it has been possible to steadily improve the device characteristics by downscaling the electrode geometries. As an example, the 3D pixels installed in the ATLAS Insertable B-Layer have an inter-electrode separation of ~67 μm: they were qualified for the benchmark fluence of 5×10^{15} n_{eq} cm^{-2}, but were also proved to be fully efficient up to ~1×10^{16} n_{eq} cm^{-2}. Conversely, the 3D pixels designed for the innermost tracking layers at the High Luminosity LHC (HL-LHC) have high granularity (e.g. 50×50 μm^2 pixel size) and an inter-electrode separation as small as ~35 μm. In a beam test, after irradiation at the extreme fluence of 3×10^{16} n_{eq} cm^{-2}, they exhibit an efficiency greater than 97% at just 150 V.

This talk will provide a comprehensive and up-to-date overview of 3D sensor performance in terms of radiation hardness. Selected results from the electrical and functional characterization of sensors from different manufacturers will be discussed, as well as the main design and technological issues relevant to the new generation of small pitch 3D sensors for the HL-LHC. The potential advantages in terms of radiation hardness and timing performance attainable by implementing trenches rather than cylindrical electrodes will also be addressed.

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