Novel pixel sensors for the Inner Tracker upgrade of the ATLAS experiment at HL-LHC

ATLAS-ITk Collaboration

Abstract

The High-Luminosity Large Hadron Collider (HL-LHC) is a major upgrade of the existing Large Hadron Collider (LHC) at CERN. The HL-LHC aims to significantly increase the luminosity allowing for more precise measurements of known particles and the discovery of new physics phenomena. The HL-LHC will provide up to 200 proton-proton interactions per bunch crossing allowing the ATLAS experiment to collect about 4000 fb^{-1} of data over 10 years of operation.

The inner tracking detector plays a crucial role in particle tracking and vertexing, providing precise measurements of charged particle trajectories and interaction points. To meet the challenges posed by the increased luminosity and particle collision rates at the HL-LHC, the present inner detector of the ATLAS experiment will be replaced by a completely new Inner Tracker (ITk).

Being closer to the proton interaction point in the extremely dense particle environment of HL-LHC, the pixel detector of the new ITk will have to maintain excellent tracking capabilities facing the highest radiation levels of the whole ITk (up to a particle fluence of $2{\times}10^{16} n_{eq}/cm^2$). To operate in such a harsh particle environment the ITk pixel modules feature an increased number of readout channels employing small pixel cells of $25{\times}100$ µm^2 in the innermost barrel layer and $50{\times}50$ µm^2 in the rest of the detector.

Moreover, different sensor technologies will be implemented depending on the distance from the proton interaction point and the consequent radiation levels expected:

- The innermost layer and rings will be instrumented with 3D silicon sensors. This sensor technology has been selected due to its outstanding radiation hardness which is enhanced in these novel small pitch designs and is expected to meet the most demanding requirements of ITk.
- The second innermost layer and rings are instead instrumented with n-in-p planar sensors with 100 µm thick active substrates. While the radiation hardness of planar sensors may not match that of 3D sensor technology, their manufacturing process is simpler and thus more suitable to instrument a larger area. Additionally, due to the thin active substrate, this design can still ensure radiation hardness up to a particle fluence of $5{\times}10^{15} n_{eq}/cm^2$.
- The outermost layers of ITk will utilise n-in-p planar sensors with 150 µm thick active substrates. This technology offers a cost-effective solution for covering the largest areas of the pixel detector in a region where radiation levels are comparatively lower.

Pre-production sensors and modules have been already delivered and are being evaluated by the ATLAS Collaboration. Following the positive outcome of such evaluation the first production orders of both 3D and planar sensors have been issued.

This contribution will provide an overview of the current status and results obtained from the evaluation of pixel sensors for ITk. We will showcase various designs and capabilities of both 3D and planar sensors developed specifically for ITk. Additionally, we will discuss the performance of the first fully assembled modules, incorporating the latest revision of the final readout chip, known as the ITkPix.

To assess the sensor reliability for long-term operation within the ATLAS detector at HL-LHC, we exposed bare sensors and modules to proton and neutron radiation, simulating the expected doses at the end of their operational life in ITk. The electrical performance of the sensors and modules was thoroughly analyzed in the laboratory. This involved comparing IV characteristics and power dissipation before and after irradiation, enabling us to assess any potential effects caused by radiation exposure.

To evaluate the tracking capabilities and hit efficiency of the full modules, we conducted beam test campaigns at CERN SPS using high-energy pion beams and precise tracking telescopes. These experiments allowed to comprehensively assess the performance of the modules under realistic conditions.