Abstract Ph.D. Project in Physics, XXXII Cycle

Ph.D. Student: Merve İnce

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. Operation of the accelerator started in 2009. The 2010-2012 running period is referred to as Run 1. In 2010 and 2011 the LHC operated at a centre-of-mass energy, √s, of 7 TeV, and delivered to the CMS experiment data volumes of 45 pb^{-1} and 6.1 fb^{-1}integrated luminosity, respectively. The centre-of-mass energy was increased to 8 TeV in 2012 and an integrated luminosity of 23.3 fb^{-1} was delivered to CMS during that year. Run 1 was followed by a two-year long shutdown, referred to as Long Shutdown 1 (LS1), during which the accelerator and the experiments were consolidated. This allowed starting Run 2 in 2015 at a centre-of-mass energy of 13 TeV. The integrated luminosities delivered to CMS were 4.2 fb^{-1} in 2015 and 41.1 fb^{-1} in 2016. Run 2 will continue until the end of 2018, when the Long Shutdown 2 (LS2) will start. The LS2 will be followed by Run 3. It is expected that about 300 fb^{-1}will have been collected by 2024. The Long Shutdown 3 (LS3), scheduled to last from 2024 to 2026, will see the preparation of the accelerator and of the experiments for the High Luminosity phase of the LHC (HL-LHC).

The CMS detector needs to be substantially upgraded during LS3 in order to exploit the increase in luminosity provided by the HL-LHC. This upgrade is referred to as the CMS Phase-2 Upgrade. The increase in radiation levels requires improved radiation hardness, while the large number of pileup events leads to an increase in particle density, requiring higher detector granularity, the ability to handle higher data rates and readout bandwidths, and improved trigger capabilities, in order to keep the trigger rate at an acceptable level. Before the start of the HL-LHC both the strip tracker and the Phase-1 pixel detector will have to be replaced due to the significant damage and performance degradation they would suffer during operation at the HL-LHC, and to cope with the more demanding operational conditions.

The Phase-2 tracker will consist of an Inner Tracker (IT) based on silicon pixel modules and an Outer Tracker (OT) made from silicon modules with strip and macro-pixel sensors. The main requirements and guidelines for the tracker upgrade can be summarized as follows.

- Radiation tolerance,
- Increased granularity,
- Improved two-track separation,
- Reduced material in the tracking volume,
- Robust pattern recognition,
- Contribution to the level-1 trigger,
- Extended tracking acceptance.

The Inner Tracker will be equipped with pixel modules. The detector comprises a barrel part with four layers (referred to as Tracker Barrel Pixel Detector or TBPX), eight small double-discs per side (referred to as Tracker Forward Pixel Detector or TFPX) and four large double-discs per side (referred to as Tracker Endcap Pixel Detector or TEPX). In the TBPX the pixel modules are arranged in “ladders”, while in TFPX and TEPX the pixel modules are arranged in concentric rings. Each double-disc is physically made of two discs, which allows to mount modules onto four planes.

In total the pixel detector will have an active surface of approximately 4.9m^2. The acceptance extends to |η|≈ 4. It is designed to maintain or improve the tracking and vertexing capabilities under the high pileup conditions of the HL-LHC. The Inner Tracker has to cope with an ionizing radiation dose of up to 1.2Grad and a hadron fluence of up to 2.3×10^{16} n_{eq}/cm^2, a pileup of 140 (or even 200) collisions per bunch crossing, and hit rates approaching 3GHz/cm^2 in the inner layers. The following requirements have been taken into account for the design of the Inner Tracker:

- a narrower pitch than the present pixel detector, for better transverse and longitudinal impact parameter resolution;
- increased granularity to limit the occupancy under high pileup conditions and to improve track separation in jets;
- geometrical coverage up to |η|≈ 4 to provide large forward acceptance and to mitigate pileup;
- capability to withstand the demanding hit rates and radiation environment with negligible inefficiencies;
- simple installation and removal to allow for a potential replacement of inefficient parts;
- capability to contribute to real-time instantaneous luminosity measurement by hit counting or simple track counting

Good results with respect to the aforementioned requirements can be obtained by using thin planar silicon sensors (of thickness 100-150 µm^2), segmented into pixel sizes of 25×100 µm^2 or 50×50 µm^2 , that allow for a detector resolution that is relatively stable with respect to radiation damage. The resulting factor-of-six reduction in the pixel area compared to the present and Phase-1 pixel detectors will allow to achieve low occupancy and improved track separation in dense environments like high p_T jets. An alternative option that is being actively pursued is the possibility to use 3D silicon sensors, offering intrinsically higher radiation resistance because of the shorter charge collection distance. Since the production process is more expensive and thus not suitable for large volumes, the use of 3D sensors could be limited to the regions of highest particle fluences.

My PhD activity will focus on:

- R&D on silicon sensors for the inner layers of the Phase-2 CMS Tracker (2017-2018): Characterization of sensors prototypes, both planar and 3D, in the Bari Clean Room. Development of detector prototypes to be tested on beam test (FNAL, CERN) and data analysis
- Preliminary performance studies of the Phase-2 CMS Inner Tracker (2019) on the specific channel $B_s^0 \rightarrow \varphi\varphi \rightarrow K^+K^-K^+K^-$.