PROCEEDINGS OF SCIENCE

Overview of the Compact Muon Solenoid Phase 1 Forward Pixel Upgrade

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During Run II of the LHC, the instantaneous luminosity will increase to near $2.5 \times 10^{34} cm^{-2} s^{-1}$. This increase in luminosity will create a high-pileup environment with a large charged particle flux near the interaction point. Operating in such challenging conditions requires high-efficiency tracking and vertexing in order to maintain the physics performance of Run I. The Phase 1 Pixel Upgrade will meet these challenges by incorporating new digital readout chips and front-end electronics for higher data rates, DC-DC powering, and dual-phase CO2 cooling, which will achieve performance exceeding that of the present detector with a lower material budget. The upgraded detector will be installed during the extended technical stop between 2016 and 2017, and it will increase the number of barrel layers from 3 to 4 and the number of forward disks from 2 to 3. The design of the new forward detector will be presented along with status of system tests, module assembly, and module qualification.

38th International Conference on High Energy Physics
3-10 August 2016
Chicago, USA

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PoS(ICHEP2016)1097

1. Introduction

The Compact Muon Solenoid [1] tracker uses silicon as active material. It consists of two subcomponents: the pixel detector which is located closest to the beam pipe, and the microstrip detector surrounding it. The current pixel detector was designed for a peak luminosity of $1 \times 10^{34} cm^{-2} s^{-1}$. Beyond this the pixel read out chip (ROC) suffers from significant dynamic data loss. With more interactions per bunch crossing, also known as pile-up, the tracking efficiency lowers and consequently the fake rate increases.

The Phase 1 Pixel Upgrade [2] will consists of four layers in the barrel (BPIX), adding one more layer compared to the current, also the forward region of the detector (FPIX) will have an additional third disk. This reflects in the number of channels almost doubling in this updagrade from the former 66 million to 124 million channels. This work explains in more detail the upgrade of the FPIX component.

A big improvement to reduce the passive material of the detector was the employment of ultra-light carbon fiber support structures, a two-phase CO_2 cooling system and by shifting the electronic service outside the active volume.

2. FPIX Modules

FPIX is a modular component that consists of four half-cylinders each with three half disks. Each half disk has an inner and outer part that contains 22 and 34 modules respectively. Each module features an n^+-in-n type silicon sensor, with 66560 pixels each of 100 $\mu m \times$ 150 μm in size, that is bump-bonded to 16 ROCs. This is then glued and wire-bonded to a high-density interconnect flex printed circuit (HDI) that distributes signals and voltages.

Since the replacing all the cables or adding new cables would present a very challenging procedure, the existing infrastructure that powers the system will be reused as much as possible. However, the increase in the number of readout channels leads to a higher front-end power consumption that surpasses the current power capacity of the existing system. To overcome this problem we employ DC-DC step-down converters.

3. Module Testing

There are a total of 672 modules required for the upgraded FPIX detector. During each stage of the production the components are tested either electrically, mechanically or by optical inspection. Some of the quality assurance tests that the modules undergo include:

- Measuring the sensor's leakage current.
- Testing the ROCs programability and functionality.
- Performing thermal stress tests, where the module goes trough several thermal cycles between 17 °C and -20 °C.
- Module calibration, where the signal thresholds for all pixels in a module are unified and the settings of the different digital-to-analog converters (DACs) of the ROCs are optimized.

- Checking the bump-bond quality.
- X-ray testing for energy calibration and for checking readout inefficiencies at high fluxes.

4. FPIX Assembly

The pixel modules passing the quality assurance tests will be mounted on ultra-light-weight support structures integrated with the cooling distribution system which are mounted on a service half cylinder (HC).

The half-disks consist of two turbine-like mechanical support structures with the inner assembly providing a sensor coverage from radius = 45 mm to 110 mm while the outer assembly covers from radius = 96 mm to 161 mm. The modules are arranged radially on a light-weight substrate made out of thermal pyrolytic graphite that has excellent thermal conductivity. The introduction of CO_2 two-phase cooling is a major innovation because it greatly contributes to the reduction of passive material in the tracking volume. In addittion, the choice of CO_2 as refrigerant is particuarly advantageous due to its excellent themoconductivity and low density that allow the use of very small stainless steel tubes which are embedded in the outer and inner assembly rings made of light-weight carbon fiber reinforced carbon material.

The light but stiff HC is made of carbon-fiber reinforced plastic. The cooling tubes and the readout electronics will be placed in this service component, shifting away the passive material from the active volume.

5. Conclusion

The conclusion of the production and testing of the modules is expected to happen in the fall of 2016. The FPIX upgrade is expected to occurr during the 2016 winter shut down of the LHC. If completed it will be a more efficient detector that will cope with higher luminosities.

References

[1] The CMS Collaboration, *The CMS Experiment at the CERN LHC*, *JINST* **3** 2008 (S08004)

[2] The CMS Collaboration, *CMS Technical Design Report for the Pixel Detector Upgrade*, *CERN-LHCC*-2012-016