Overview and Present Status of the CMS Phase 1 Pixel Upgrade

Martin Lipinski for the CMS Collaboration

Abstract

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Presented at Elba2015 13th Pisa Meeting on Advanced Detectors
Overview and Present Status of the CMS Phase 1 Pixel Upgrade

M. Lipinski\textsuperscript{a,}\textsuperscript{*}, on behalf of the CMS Collaboration

\textit{a}1. Physikalisches Institut B, RWTH Aachen University, Aachen, Germany

Abstract

During Run 2 of the LHC a significant luminosity increase to $2 \times 10^{34}$ cm$^{-2}$s$^{-1}$ is foreseen. As the innermost tracking device of CMS, the silicon pixel detector has to cope with large particle fluxes and radiation damage. To maintain the present high tracking efficiency, the current pixel detector will be replaced during an extended winter shutdown in 2016/2017. The design of the new detector is described, with a special focus on the construction and testing of the pixel modules.

Keywords: Tracking detectors, CMS, Phase 1

PACS: 29.40.Cs, 29.40.Gx

1. Introduction

The silicon pixel detector is the innermost part of the CMS experiment \cite{1} at the CERN Large Hadron Collider. It provides space point measurements of charged particle trajectories within a pseudorapidity$^{1}$ up to $|\eta| = 2.5$. The pixel detector has been designed to withstand an instantaneous luminosity of $1 \times 10^{34}$ cm$^{-2}$s$^{-1}$ with a bunch spacing of 25 ns, which was almost achieved in 2012 (with 50 ns bunch spacing). It is anticipated that before 2018 the LHC will provide a peak luminosity of twice the design value. The number of pileup events will then increase to 50 or more which, together with ongoing radiation damage, will potentially lead to a loss in tracking efficiency. To maintain the current performance, CMS has decided to replace the pixel detector with a new one during an extended winter shutdown in 2016/2017. The new detector is hereafter referred to as the Phase 1 pixel detector.

The Phase 1 pixel detector will consist of four layers in the barrel (BPIX), which represents an additional layer compared to the current detector. The radius of the innermost layer will be reduced from 44 mm to 30 mm \cite{2}. In the endcap region (FPIX) a third disk will be added per side. The new detector will therefore allow a four-point coverage in the whole tracking region and the number of channels will almost double from 66 million to 124 million. A comparison of the current and upgrade designs is shown in Figure 1.

An ultra-light carbon fiber support structure, together with a new two-phase CO$_2$ cooling system and shifting of electronic services outside the active volume, will allow the material budget to be significantly reduced. Together with the number of channels, the power consumption will grow by a factor of about 1.9, leading to higher currents and an increased loss on the power cables. To overcome this problem, a new powering scheme using DC-DC converters has been developed \cite{3}. A voltage of 10 V is supplied to the DC-DC converters that provide the required voltages of 2.4 V and 3 V. The converters are placed on the service structures inside CMS and close to the pixel detector.

2. The CMS Pixel Module

The design of the Phase 1 pixel modules is very similar to the ones used in the current detector. It features a n$^+$-in-n type silicon sensor with 66560 pixels, each 100$\mu$m x 150$\mu$m in size. There are two rows with eight readout chips, each connected to the sensor via bump bonds. The total length of a module is about 65 mm.

The readout chip (ROC) is the psi46dig \cite{4}, which is an evolved version of the psi46 chip \cite{5} used in the current detector. The readout is organized in double columns that consist of 80 pixels each. To reduce data losses, the number of hit buffer cells in each double column has been increased from 32 to 80 and the time stamp buffers have been increased from 12 to 24. An additional readout buffer stage per ROC has been added to

Figure 1: Comparison of the Phase 1 pixel detector (top) and the current detector layout (bottom).

\footnotetext{*}Corresponding author

\textit{Email address: m.lipinski@physik.rwth-aachen.de (M. Lipinski)}

\footnotetext{1}The pseudorapidity $\eta$ is defined as $\ln[\tan(\theta/2)]$, where $\theta$ is the polar angle of the particle with respect to the anticlockwise beam direction.
During each stage of production components are tested either electrically, mechanically or by optical inspection. For example, the sensor leakage current is tested at wafer level and after the production of the bare module. A completed module will undergo a final qualification to decide if it can be used in the detector. Every module will be tested at temperatures of $+17^\circ$C and at $-25^\circ$C for electrical functionality and the sensor leakage currents will be measured. These tests make use of the ROC’s internal charge injection mechanism to check for defective pixels and missing bump bonds, to unify the signal thresholds for all pixels and to optimize settings of the different digital to analog converters (DAC) on the module. The tests are done using software common to all production centers and the results uploaded to a global database. Every module will undergo thermal cycling with 10 cycles between $+17^\circ$C and $-25^\circ$C after which it is tested again for functionality. In a second series of tests the module will be tested using X-Rays. A high rate test is foreseen to check for efficiencies and readout uniformity at hit rates up to 120 MHz/cm$^2$, which are expected for layer 2 modules in the detector. Furthermore, an energy calibration of the internal charge injection mechanism will be carried out with fluorescence photons, using the $K_\alpha$ lines of different elements. After all these tests are done, the module will receive a grade of A, B or C, depending on whether there are issues that may prevent that module from being used in the detector.

Up to now all production centers have successfully built grade A preproduction modules and the test procedures and software are well advanced. The delivery of the required parts is ongoing and mass production is about to start or has recently started. It is anticipated that all required modules will have been produced by the start of 2016. The production of power distribution boards and DC-DC converters has started, with the first quarter having already been delivered. The mechanical design of the support structure and the cooling loops is being finalized.

4. Summary

The CMS pixel detector is going to be replaced in 2016/2017 because of increased LHC luminosity and radiation damage. The new detector will have almost twice the number of channels and features a more lightweight design. Furthermore, a new readout chip has been developed to reduce data losses. The series production of pixel modules is about to start and will be finished by early 2016.

References