Construction of the Forward Pixel Detector

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S Malik

University of Nebraska – Lincoln

CMS Collaboration

E-mail: malik@fnal.gov

Abstract. The Compact Muon Solenoid (CMS) Experiment is scheduled for data taking in 2008 at the Large Hadron Collider (LHC). It has an all-silicon tracking system with a Pixel Detector as the innermost component. The silicon Pixel Detector is made of two disks on each side of the interaction point with three barrel layers in between. It will play a crucial role in realizing the physics potential at LHC by providing a 3D space resolution on the order of ten microns for pattern recognition and track reconstruction. The disks are collectively called the Forward Pixel Detector and are being assembled at Fermilab, U.S.A. The detector modules for the disks alone consist of eighteen million pixels. The design and present status of the Forward Pixel Detector is presented here.

1. Introduction

The CMS (Compact Muon Solenoid) experiment [1] is a major collider detector experiment being built at the LHC (Large Hadron Collider) at CERN. At full luminosity, proton-proton crossings will occur at 14 TeV and at 40 MHz with an average of 20 interactions per crossings. A robust tracking system combined with a precise vertex reconstruction within a strong magnetic field of 4 Tesla will play a key role to address the full range of physics that would be accessible at this energy. This is realized by using an all-silicon tracking system [2], called Tracker, at the center of the CMS detector. The innermost component of the Tracker is the Pixel Detector [3]. With a 3D space resolution on the order of ten microns for pattern recognition and track reconstruction, it will play a key role in offline analysis [4, 5] and online high level trigger [6]. The pixel detector consists of two components – the barrels and the disks. There are three barrel layers complemented with two disks on each side. The disks are collectively called the Forward Pixel Detector and consist of 18 million pixels. Innovative techniques of radiation hard technology and bump bonding have been used to meet the challenge of high radiation environment at LHC and the small space availability, respectively. The Pixel Detector is expected to provide a hit resolution of 10 μm in the ($r\phi$) and 17 μm in ($r\eta$) coordinates and remain functional up to a fluence of $6 \times 10^{14}$ n$_{eq}$/cm$^2$.

2. Design

The Forward Pixel Detector is a very sophisticated device and consists of two disks (see Figure 1) on each side of the pixel barrels at a distance of 34.5 cm and 46.5 cm from its centre. The disks are

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1 Sudhir Malik, MS 310 Fermilab, Batavia, IL 60510, USA
populated with 672 detector modules called plaquettes. A plaquette is a multilayered structure assembled in three steps. First, an array of readout chips (ROCs) is bump bonded to a single silicon sensor and forms a bump bonded module. The bump material is Lead-Tin (PbSn). Then the bump bonded module is glued to a flex circuit called the Very High Density Interconnect (VHDI) laminated on a silicon substrate. Finally, pads on the ROCs and VHDI are connected through wire bonds. There are five different kinds of plaquettes depending on the number of ROCs varying from two to ten. Plaquettes are precisely glued and wire bonded in groups of three or four on another flex circuit called the High Density Interconnect (HDI) laminated to a thin wedge-shaped beryllium substrate and forms a panel. A panel also carries a Token Bit Manager (TBM) [7] chip that orchestrates the readout from the ROCs. The TBM is also wire bonded to the HDI. A panel is mounted on each of the two sides of a U-shaped aluminum cooling channel and forms a blade. One panel on a blade carries four plaquettes and faces the interaction region while the other has three plaquettes. The positioning of plaquettes on panels is constrained by the need to cover up the gaps between the plaquettes. There are 24 blades arranged in a turbine like circular geometry and form a disk. Each blade is rotated by 20° around its axis of radial symmetry. This rotation enhances the spatial resolution by charge sharing among neighbouring pixels. The disk is annular in structure with an inner and an outer radius of 60 mm and 150 mm respectively. This allows a coverage in pseudo rapidity ($\eta$) from 1.5 to 2.4.

The sensor [8,9] and the ROC are designed to be radiation tolerant for the LHC environment. The sensor design is of $n^+$ on n-type. A p-stop isolation technique in which a high dose p-implant surrounds each $n^+$-type region provides explicit electrical isolation between neighboring $n^+$ electrodes. Each sensor is 300 $\mu$m thick and consists of an array of pixels of size 100 $\mu$m x 150 $\mu$m in two dimensions. The sensors are designed to operate up to a bias voltage of 600 V before breakdown and have a set guard rings along its boundary that are kept at a relative ground. When a charged particle enters the biased sensor, the electrons and holes created by its passage, drift in opposite directions. The electrons collected and amplified by the readout chip indicate a hit pixel.

Extensive studies have been done in the past years to guarantee high efficiencies for highly irradiated detectors. Test beam runs [10-12] with un-irradiated and irradiated detectors have shown that the Forward Pixel sensors maintain an efficiency of greater than 99% after a fluence of $8 \times 10^{14}$ along with other electronic components. This is above the total dose of about $6 \times 10^{14}$ neq / cm$^2$ that the innermost pixel layer would receive at 4 cm from beam line 4-5 years into running of LHC.
The ROC has been fabricated in 0.25 µm CMOS technology [13] and designed by collaborators from the Paul Scherrer Institute (PSI). To align and bump bond with the sensor pixels, each ROC consists of an array of 4160 pixels arranged in 52 columns and 80 rows. A total of 4320 ROCs are used to construct four disks. This puts the number of channels to be readout around 18 million. Each ROC pixel consists of an amplifier, shaper, programmable discriminator, storage capacitor and a charge injection circuitry for calibration purposes. The ROC has thirty two data buffers and twelve time stamp buffers for low dead time during operation in the CMS trigger.

The TBM chip on each panel organizes the readout in the front end. Through a token bit mechanism it controls the access of each column in a ROC to the readout link. It also formats the data packets and signals any errors. The data is readout in two steps [14]. When a pixel is hit the corresponding information about its time, address and analog signal is stored in the ROC. In the next step, when a trigger arrives, a token is generated and passed to all the ROCs on a panel. Then the analog data of the triggered event stored in the ROC is read out. An optical readout is used to reduce electrical interference among the analog signals. The analog signal is converted to an optical signal using an opto-hybrid and is sent via optical links to the counting room. Here a front-end digitizer converts the signal back from optical to electrical, performs the digitization, formats the event and sends it to the CMS DAQ.

3. Current Status

As of September 2007, testing [15] of 90% of the Forward Pixel modules is complete and three disks have been delivered to CERN. The fourth disk is expected to be ready by October 2007. This year several tests were done in order to facilitate the integration and operation of the final Forward Pixel detector. In May 2007, a rehearsal of the final installation procedure of the Forward Pixel detector at CERN was performed. This was successfully followed there by an extensive physical and electronic integration test of a subsystem of the detector with the rest of the Tracker. In parallel we also tested a similar subsystem at Fermilab in a 4T magnetic field to check the performance. No electronic or mechanical effects were observed due to the magnetic field. We are confident that a full installation of the Forward Pixel Detector will occur in early 2008 for the first CMS physics run.

References

[1] The CMS Collaboration 1998 CMS Tracker Technical Design Report, CERN/LHCC 1998-6
[2] Hartmann F 2002 Nucl. Instr. Meth. A 478 285
[3] Kotlinski D 2002 Nucl. Instrum. Meth. A 477 446
[4] CMS Collaboration 2006 CMS Physics TDR Volume 1, CERN-LHCC-2006-001
[5] CMS Collaboration 2006 CMS Physics TDR Volume 2, CERN-LHCC-2006-021
[6] CMS Collaboration, “The TriDAS Project, Technical Design Report: Data Acquisition and High-Level Trigger”, CERN-LHCC-02-26 (2006)
[7] Bartz E “The token bit manager chip for the CMS pixel readout”. Prepared for 11th Workshop on Electronics for LHC and Future Experiments (LECC 2005), Heidelberg, Germany, September 2005 12-16
[8] Arndt K et al 2003 Nucl. Instrum. Meth. A 511 106
[9] Bolla G et al 2002 Nucl.Instrum.Meth. A 485 89
[10] Bolla G et al 2003 Nucl.Instrum.Meth. A 501 160
[11] Atac M et al 2002 Nucl.Instrum.Meth. A 488 271
[12] Rohe T et al 2005 Nucl. Instr. Meth. A 552 232
[13] Kaestli H C et al 2006 Nucl. Instr. Meth. A 565 188
[14] Barbero M et al 2004 Nucl. Instr. Meth. A 517 349
[15] Menasce D et al 2007 Nucl. Instr. Meth. A 579 1141