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The CMS Silicon Strip Tracker

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Abstract

With more than 15000 silicon strip modules and an active silicon area of 200 square metres, the CMS silicon strip tracker will be the largest silicon tracker ever built. While module mass production has started in 2004, the detector construction has recently entered its crucial phase with modules being assembled onto larger substructures, which in turn are being integrated into the tracker barrel and end-cap structures.

In this presentation the detector design will be introduced. The challenges and experiences of the silicon module mass production, with focus on the key components such as sensors and hybrids, will be presented. The status of the integration of modules onto the detector substructures, as well as the construction and integration of the large barrel and end-cap structures will be described. Finally an overview will be given on the excellent performance of subsystems of the tracker as demonstrated by system tests and test beam experiments.

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1 Introduction

The Compact Muon Solenoid (CMS) detector is currently under construction and will be installed underground at the LHC collider at CERN, near Geneva. The LHC will provide proton on proton beams (7 TeV each) with 40MHz collision rate. A luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ will produce on average 19 collisions in one single bunch crossing for nominal LHC operation [1]. This enables the CMS physicists to explore new regions of physical interest, conducting precision measurements and searches for new physics at the same time. CMS is one of the two general-purpose detectors with a broad physics programme.

The CMS detector consists of a precise muon spectrometer with a standalone resolution of $\delta p_{\perp}/p_{\perp} \approx 10\%$ at 10 GeV, a sampling brass hadron calorimeter, an electromagnetic lead-tungstate calorimeter with $\delta E/E < 1\%$ for $E > 30$ GeV, a superconducting coil that provides a solenoidal 4 T magnetic field for momentum measurements, and a full silicon tracker [2, 3].

Figure 1. Schematic view of one R-z quadrant of the Silicon Strip Tracker, showing the location of the TIB, TID, TEC, and TOB. The horizontal and vertical axes are in mm; the top axis is in pseudorapidity. The thin lines represent single sided layers; the thick lines represent layers with modules mounted back-to-back for three dimensional space measurements.

2 Detector layout and components

A sketch representing 1/4 of the tracker is shown in Figure 1. The innermost region (at radii below 150 mm) is occupied by the pixel vertex detector (not shown); the Silicon Strip Tracker (SST) covers the radial range between 20 and 110 cm. The barrel region ($|z| < 120$ cm) is split into an Inner Barrel (TIB) made of four layers, and an Outer Barrel (TOB) made of six layers. The TIB is shorter than the TOB, and is complemented by three Inner Disks (TID) made of three rings. The region $120 < |z| < 280$ cm is covered by the nine End-Cap (TEC) disks, each made of seven rings.

In the sketch presented, each line represents a detector module location. Thin lines represent modules made by one single detector with the readout strips oriented along the z axis in TIB and TOB, oriented radially in TID and TEC, therefore measuring the $r\phi$ or ϕ coordinate. Thick lines represent modules composed by two detectors mounted back-to-back, one of which has the strips along z (r), while the other has the sensor tilted by 100 mrad.

Detectors of the TIB, TID, and of the four innermost rings of the TEC have strip lengths around 10 cm and pitch around 100 μm , giving a surface of about 0.1 cm^2 per channel (all strips are read out). These detectors are made of one sensor of 320 μm thickness. In the outer part of the tracker (TOB and three outermost TEC rings), in

order to limit the number of channels, strip length and pitch are increased by about a factor of two, giving a surface of about 0.4 cm^2 per channel. The increase in strip length is realized by bonding together two sensors. To compensate for the increase of noise due to the higher inter-strip capacitance, a silicon thickness of $500 \text{ }\mu\text{m}$ is chosen for these larger detectors.

The entire tracker volume, a cylinder of approximately 2.4 m diameter and 5.4 m length, has to be kept below 0°C all the time, to avoid the “reverse annealing” of silicon sensors[2,4], implying that a dry atmosphere has to be maintained for several years. After the sensors have integrated substantial hadron fluence, the power dissipation due to the leakage current becomes significant, imposing even more stringent requirements on the cooling parameters. It is estimated that after 10 years of operation in the LHC the sensors have to be kept below -10°C to avoid thermal runaway due to increased leakage current from radiation damage in the hostile LHC environment; this sets the nominal running temperature for the tracker (-10°C) and defines the technical requirements for the cooling system. An active thermal shield placed outside of the tracker volume provides isolation, and a cooling system extracts the heat from the 60kW power dissipation generated by the front-end electronics.

Figure 2. Shapes and dimensions of all the silicon module types of the tracker.

2.1 The modules

The fundamental active detector element of the SST is a module. Each module is made up of a carbon fibre support structure, a front-end hybrid circuit, and one or two single-sided silicon sensors. The shapes and dimensions of all tracker modules are represented in Figure 2, while the sketch of its various components is showed in Figure 3.

Figure 3. Sketch of a module with various components

2.2 The Front-End hybrids

The front-end hybrid provides filtering, and distributes power and control lines for the various ASIC chips used for signal readout and monitoring. Each front-end hybrid houses chips for amplifying and buffering the data (APV) [5], multiplexing data lines (MUX) [6], decoding the trigger and clock signals (PLL) [7], and monitoring the temperature, currents, and voltages of the module (DCU) [8]. After an extensive R&D program [9], the kapton flex circuit technology produced by Cicorel was chosen for the final hybrid. The flex circuit is laminated onto a ceramic substrate to provide a good thermal management. The components on the hybrids are mounted and wire bonded at Hybrid SA.

2.3 The Silicon Sensors

All CMS silicon sensors, designed based on the results of an extensive R&D program [10], use p^+ -on-n implantation. The final design uses simple guard ring and strip geometry. The Aluminum coupling strips are wider than the p^+ implants, moving the high field region near the implant from the bulk silicon into the SiO_2 . Thus, the metal-overhang increases the breakdown voltage of the device. The design also utilizes $\langle 100 \rangle$ silicon crystals, which minimize the effects of surface damage after irradiation. In total, suppliers deliver 24244 tested silicon sensors with 6" wafer technology.

Hamamatsu Photonics (HPK) produced the thin 320 μm sensors. The sensors have been of exceptional quality with over a 99% acceptance in internal testing and have been fully delivered by July 2005. SGS Thompson Microelectronics (STM) produced 15% of the thick 500 μm sensors for CMS which have been delivered and qualified; the remaining fraction (85%) of the production has been moved to HPK in order to meet the production schedule; the delivery so far (August 2005) has been 70% of the total with excellent quality.

3 Production chain

The production procedure is executed as follows. The companies qualify the sensors and the good ones are sent to the Control & Distribution Centre (CERN). There they are registered in the database and distributed to 4 Quality Test Centres (QTC). These centres perform optical inspections and electrical tests of the sensors. During production, tests will be done on 5-10 % of the sensors. A fraction (around 1%) of the sensors is sent to the Irradiation Qualification Centres in Karlsruhe (Germany) and Louvain-la-Neuve (Belgium), where they are irradiated with 26MeV-protons (Karlsruhe) or with fast neutrons (Louvain-la-Neuve). After the irradiation with a fluence corresponding to 10 years operation at LHC the sensors are tested again to test the radiation hardness [11]. All sensors accepted by the QTC are shipped to 7 Module Assembly Centres using fully automatized robots to assemble the modules. For bonding these modules are sent to 12 Bonding Centres equipped with industrial machines. These centres are also responsible for module quality assurance. During production of the first 200 modules, the different test centres were calibrated by shipping the same sensors and modules around and comparing measurement results. Complete module production is expected for early 2006, with a final production yield greater than 95% and typically 0.1-0.3% or less of bad strips per module.

4 Substructure construction, integration and test

TOB (rods) and TEC (petals) segments will be built and tested to qualify design and to check functionality during a full sub-system test. Integration of modules on petals, rods and shells has recently started while the integration of large structures into the detector will last until spring 2006. The TID disks and TIB cylinders are almost completed and fully integrated. On the other hand, the construction of the mechanical support structures has already been finished.

A Test Beam performed in June 2004 proved the excellent performance of several components (2 petals and 6 rods) and stable readout at all temperatures, allowing a successful tracking with official CMS reconstruction software (ORCA), obtaining the expected spatial resolution. TIB test beams have been successfully performed in years 2003 and 2004. A last readout test of 25% of the tracker with final DAQ system is foreseen for 2006 while the final integration into the CMS detector is expected in autumn 2006.

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