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CMS CR-2008/008

The Compact Muon Solenoid Experiment

Conference Report

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9 April 2008

Status of the Silicon Strip Detector at CMS

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Abstract

The CMS Tracker is the world's largest silicon detector. It has only recently been moved underground and installed in the 4T solenoid. Prior to this there has been an intensive testing on the surface, which confirms that the detector system fully meets the design specifications. Irradiation studies with the sensor material shows that the system will survive for at least 10 years in the harsh radiation environment prevailing within the Tracker volume. The planning phase for SLHC as the successor of LHC, with a ten times higher luminosity at the same energy has already begun. First R&D studies for more robust detector materials and a new Tracker layout have started.

Presented at *10-th INTERNATIONAL CONFERENCE ON INSTRUMENTATION FOR COLLIDING BEAM PHYSICS,February 28 - March 5, 2008, Novosibirsk,Russia*

1 Introduction

The CMS Tracker project was inaugurated more than ten years ago. Only recently the completed Tracker has been inserted underground into the center of the CMS magnet, hence marking the turning point from the construction phase to the actual experiment.

According to the CMS philosophy, the Silicon Strip Tracker is designed as a compact, hermetically closed system. Each track is recorded with at least 10 high resolution space points in the range $\|\eta\| < 2.4$ [1] [2].

The LHC environment, namely the short (25ns) bunch structure and the high luminosity of $10^{34}(s \cdot cm^2)^{-1}$ led to the chosen high granularity of 10M readout channels and special radiation hard $\langle 100 \rangle$-Si sensor material. The Tracker will be operated at a temperature of $-10°C$ to reduce the irradiation induced leakage currents and to permit a stable 10 years of operation.

2 Constituents

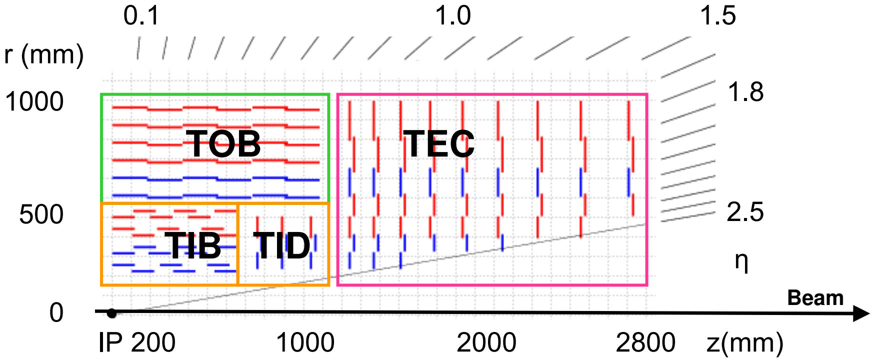

Figure 1: Schematic view of a sector of the Tracker. Each line represents a detector module. The structure is meant to be rotated around the beam axis and mirrored at the interaction point.

The Silicon Strip Tracker consists of 15148 silicon strip detector modules which are grouped in four large substructures: the Tracker Outer Barrel (TOB), the Tracker Inner Barrel (TIB), the Tracker Inner Disk (TID) and the Tracker EndCap (TEC) (see fig. 1).

2.1 The Barrels

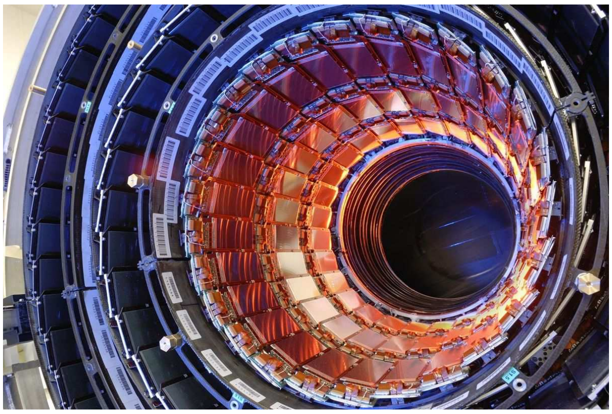

Figure 2: Tracker Inner Barrel

In the two barrel substructures the strips of the modules are oriented parallel to the beam and the prevailing 4T magnetic field. The modules are arranged in four (TIB) respective six (TOB) concentric cylinders “shells” around the beam axis, covering the radial range $25cm < r < 108cm$.

Two of these layers in TID as well as in TOB are “stereo layers”: here modules are mounted in back-to-back pairs, where one module has an axial strip orientation and the second module oriented at an angle of $100mrad$ with respect to the first. The resulting strip crossing leads to an enhancement of the spacial resolution along the strip direction by about two orders of magnitude.

The modules for the TIB subsystem are directly mounted on carbon fiber half shells – two of which combine to a full shell. The four shells of the inner barrel are assembled together and constitute an independent detector unit in the sense of cooling, powering and readout. Figure 2 shows how the TIB modules are mounted so that they overlap on their shells.

For the Outer Barrel system the modules are installed on “rods” (fig. 3), which in turn are used to populate the six layers. A rod is a carbon fiber frame equipped with a cooling tube and a pcb motherboard to enable the operation of six modules (12 modules for stereo layers). The TOB consists of 688 rods mounted in a large carbon fiber support structure.

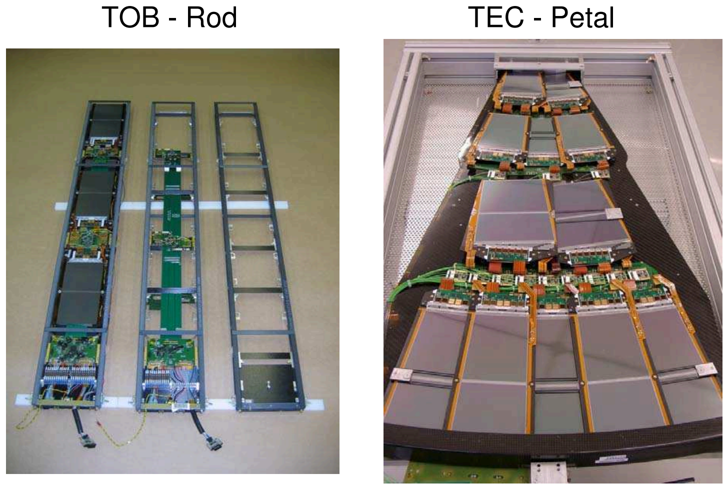

Figure 3: Carbon fiber support structures for TOB and TEC: (left) a rod in three different phases of construction; (right) a fully assembled petal.

2.2 The Disks

In the TID and TEC substructures (fig. 1) the modules are oriented perpendicular to the magnetic field. They are arranged in seven rings (three rings for TID) at different overlapping radii around the beam axis. All strips point radially to the beam axis except for the stereo modules in three rings (numbers #1, #2 and #5). In these cases the strips of one module are rotated by an angle of $100mrad$ with respect to its back-to-back partner. The radial pointing is achieved through a wedge shaped sensor design. Keeping the $width/pitch$ ratio for all strips constant, the signal-to-noise value for particle hits remains independent from the position along the strip. Each ring requires its own sensor, design which led to a large number of different sensors and modules (fig. 4).

On the three TID disks, the modules are mounted in full rings on carbon fiber support structures, three rings per disk.

A Tracker EndCap (fig. 5) consists of 9 large disks. Modules are not directly mounted to these disks, but to intermediate structures called “petals” – wedge-shaped portions of the disk. The production of these structures allowed a reasonable distribution of assembly tasks among the TEC community (fig. 3). Sixteen petals are required for one disk. Eight different types of petals are needed with different numbers of modules, depending on the distance from the interaction point; e.g. the farthest disk need not be equipped with the three inner rings to cover the region $|\eta| < 2.4$ (fig. 1).

After completion and individual testing of these four Tracker substructures, the Tracker was assembled within an aluminum support tube which provides thermal insulation in addition to mechanical stability. Equipped with an insulating foam with cooling pipes on the inner side and an electrical heating outside it acts as a thermal shield against the neighboring electromagnetic calorimeter, which requires a temperature of $18^\circ C$, whereas the silicon sensors of the Tracker are cooled down to $-10^\circ C$.

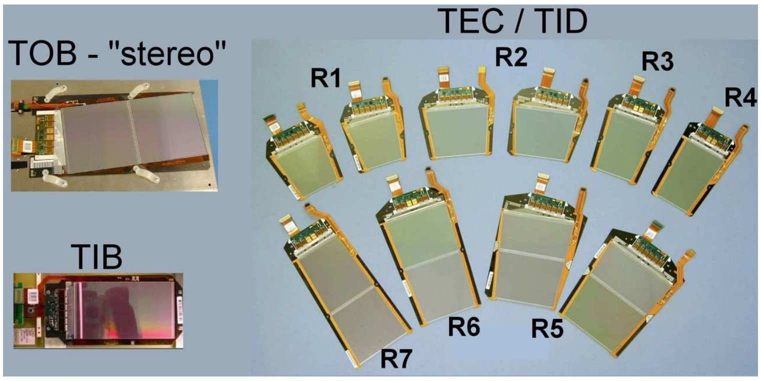

Figure 4: Many different module geometries are needed in the different substructures of the Tracker.

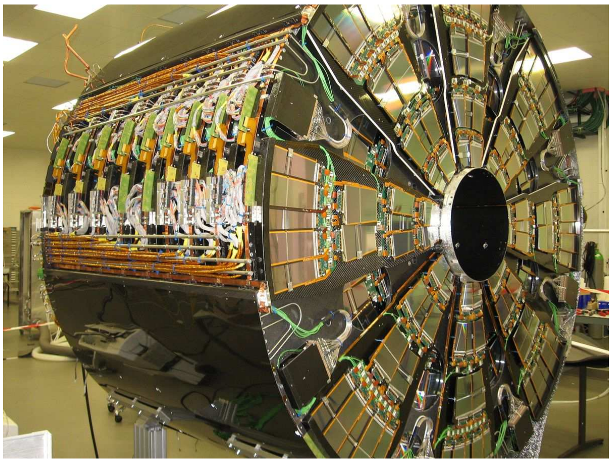

Figure 5: One Tracker EndCap fully equipped with petals.

3 Performance

During all steps of construction every individual part has been carefully tested. Every detector module as well as the larger structures – rods, petals, half shells, TID disks – have been operated and thermally cycled to ensure reliability when used in the collision hall.

Moreover, a large effort has been made with prototypes from both barrel substructures and the endcap to study the system performance in the realistic environment within the 4T magnet during the Magnet Test period, which took place in the summer of 2006 in the CMS surface hall. [3].

The most conclusive test phase however was the assembly period in the Tracker Integration Facility (TIF), a large cleanroom at CERN, where all the substructures were brought together as a unit.

Equipped with about 15% of the final power supplies and readout electronics, a simultaneous study of $25m^2$ of silicon detector area has been done. Cosmic ray data was taken at a rate between 1.5 and 6.5 Hz – depending on the configuration of large plastic scintillator plates above and below the Tracker support tube – at different temperatures down to $(-15°C)$. In fig. 6 it can be seen that the average signal-to-noise is about 30 for all four subsystems. This value is high enough to ensure a good hit efficiency, even when the expected irradiation damage deteriorates the performance. Further studies about tracking efficiency, alignment, data handling and the reconstruction algorithms have been done (see refs [4] [5]). The TIF studies demonstrated, that the Tracker has fewer than 0.2% dead channels and that the expected design performance has been achieved.

4 Upgrade

Despite the fact that the LHC has not yet delivered a single proton bunch, thinking about an upgrade of the accelerator and its consequences for the CMS Tracker has already started.

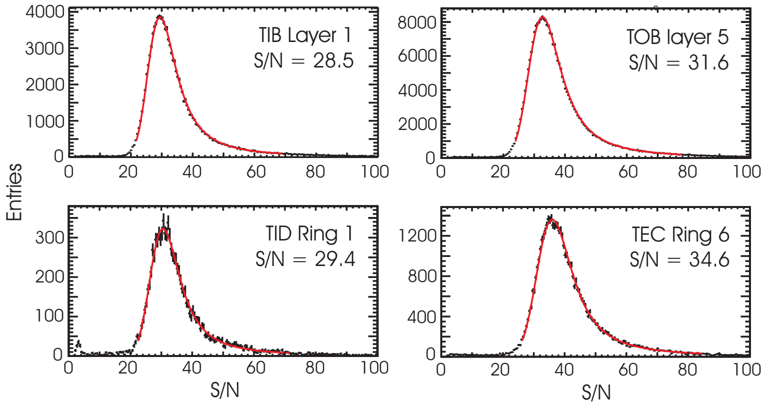

Figure 6: Signal-to-Noise measured for all four subsystems.

Normal LHC operation for ten years was one boundary condition in the design of the Tracker. Consequently, after that time the Tracker very likely will have to be replaced due to severe radiation damage accumulated during operation.

The planned increase of the luminosity by a factor of ten necessitates a complete redesign of the Tracker:

1. The granularity has to be increased by a factor of at least five in order to cope with the higher occupancy due to the much higher number of underlying events per bunch crossing.
2. The sensor material has to be more radiation tolerant, especially in the region of small radii ($r < 40cm$)
3. A contribution of the Tracker to the L1 trigger is desirable to reduce the expected much higher data rate to a reasonable level. The only reasonable trigger criterion that the Tracker can provide is the transverse momentum of charged particles. However, the determination of p_t in real time requires new electronics that can combine the data of two or more neighboring detector layers.
4. Another important issue for the Tracker is the reduction of the material budget. The existing Tracker exhibits already a radiation length of above $1.6X_0$ for certain regions of η. The sensor material itself represents only about $\approx 10\%$ of the material budget, so reducing sensor thickness is not a high priority, at least as far as the material budget is concerned. On the other hand, there would be a large gain if the material required by the services could be reduced.

The first item can be met with a threefold strategy: for small radii add an additional pixel layer; for large radii use short strip; and for intermediate radii use “strixels”, a series of very short strips on a sensor. The technical problem of the connection of the frontend electronics could be solved with an additional metallization layer on top of the readout strips.

For the second item much profit can be taken from the results of the RD50 collaboration. There is a clear indication that n-on-p magnetic Czochralski silicon is more radiation tolerant than the float zone material used to date. This could be the material of choice for the outer radii ($r > 40cm$). Only for the innermost region more exotic candidates like 3D-structures or CVD diamond are under discussion.

The third item leads to the wide field of R&D for electronics which is ongoing for all aspects of the module readout: New readout chips with more than 128 channels but less power consumption are desired. Frontend digitizers are needed as well as logic chips to make trigger decisions. Fast switches are required to get the tremendous amount of data out. Since all these elements are within the Tracker volume, they have to be radiation hard.

The fourth item triggers two independent directions of studies:

- DC-DC couplers for each module are investigated. Feeding the Tracker with higher voltages could result in a reduction of cables and hence reduce material.
- Replace the existing low pressure C_6F_{14} cooling system with a high pressure, two phase CO_2 system, which is much more efficient. The latter scheme would lead to a significant savings in pipe material. Moreover, the cooling pipes should simultaneously serve as power lines so that the number of reqired cables as well as pipes could be substantially reduced.

R&D studies on all these aspects have only just begun. The necessity for an upgrade of LHC is unquestioned, but still it is an open question if or how the bunch structure of the accelerator will change. The answer to this question has consequences for the new Tracker layout.

5 Status

The completion of the Tracker was a common effort of about 600 people in 50 institutes distributed all over the world. It took more than ten years from the R&D phase to the end of the construction. Unique methods of quality assurance had to be established in order to guarantee a uniform behavior of the system. The full Strip Tracker was completed on surface some month before access was given to its underground destination. This allowed an intensive period of data taking with first performance studies of the system as well as all aspects of data handling and analysis. It took three months following the insertion of the Tracker (16-dec-2007) to connect all of the optical fibers, cooling pipes, and cables.

Now, while waiting for the accelerator team to finish with machine comissioning, the Tracker is ready to accept cosmic data, with and without the solenoid field (fig. 7).

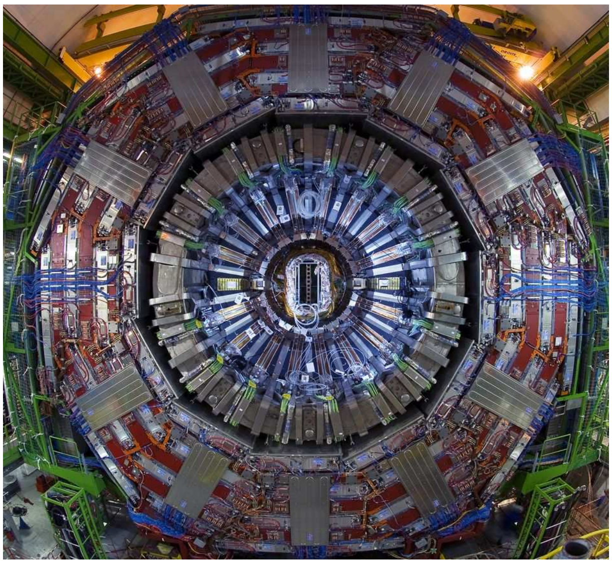

Figure 7: The Tracker positioned in the center of CMS.

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