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Lessons learned during CMS tracker end cap construction

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On behalf of the CMS Tracker Collaboration

Abstract

With more than 15 000 silicon strip modules and a silicon area of about 200 m^2, the CMS silicon strip tracker will be the largest silicon strip tracker ever built. More than half of the volume is occupied by the two end caps, which comprise about 42% of the silicon strip modules. Construction of the end caps is far advanced. In this article the experience from module production, integration of medium-sized substructures, the so-called petals, and from the integration of the end caps themselves is summarized.

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Keywords: LHC; CMS; Tracker; Silicon strip

1. The CMS tracker end caps

The CMS silicon strip tracker [1], comprising of more than 15 000 silicon strip modules and a silicon area of about 200 m^2, will be the largest silicon strip tracker ever built. To avoid reverse annealing and to limit the leakage current in the harsh radiation environment expected at the LHC, the tracker will be operated at a temperature of below $-10\,^\circ$C. A cross-section through one-quarter of the tracker in the R–z view[1] is shown in Fig. 1. It is composed of four subdetectors: the inner barrel (TIB) with four cylindrical layers of modules; the inner disks (TID) consisting of three disks per side; the outer barrel (TOB) with six cylindrical layers; and the two end caps (TECs) which are composed of nine disks each. The end caps occupy more than half of the tracker volume and carry about 42% of all modules.

The TECs cover the pseudorapidity region between 0.9 and 2.5, with the disks located at distances between 1.2 and 2.8 m from the interaction point. The end caps, called TEC+ and TEC− according to their location in the z (beam) direction, feature a modular design. Up to 28 modules are mounted in seven radial rings on both sides of carbon fibre support structures called petals [2]. Eight petals are mounted on each side of a disk. These so-called front and back petals differ in geometry and the number of modules mounted. A technical drawing of one TEC is shown in Fig. 2.

2. End cap module production

The CMS silicon strip sensors are single-sided, AC-coupled p-on-n devices. Sensors with a nominal thickness of 320 μm and a resistivity of 1.55–3.25 kΩ cm are used within a radial distance of less than 0.6 m to the beam axis because of their radiation hardness. Further outside, larger sensors with up to 20 cm long strips and a strip pitch of up to 200 μm are being used for reasons of cost and to limit the number of readout channels. To compensate for the increase in noise due to the increased sensor capacitance, sensors with a nominal thickness of 500 μm are used in the outside region. One or two daisy-chained sensors are glued onto a carbon fibre/graphite support frame, together with the front-end hybrid and the Kapton strip that delivers the bias voltage.

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[1] In the CMS coordinate system the x-axis points towards the centre of the LHC ring, the y-axis points upwards, and the z-axis completes the right-handed coordinate system. The azimuthal angle in the xy-plane is denoted as ϕ.

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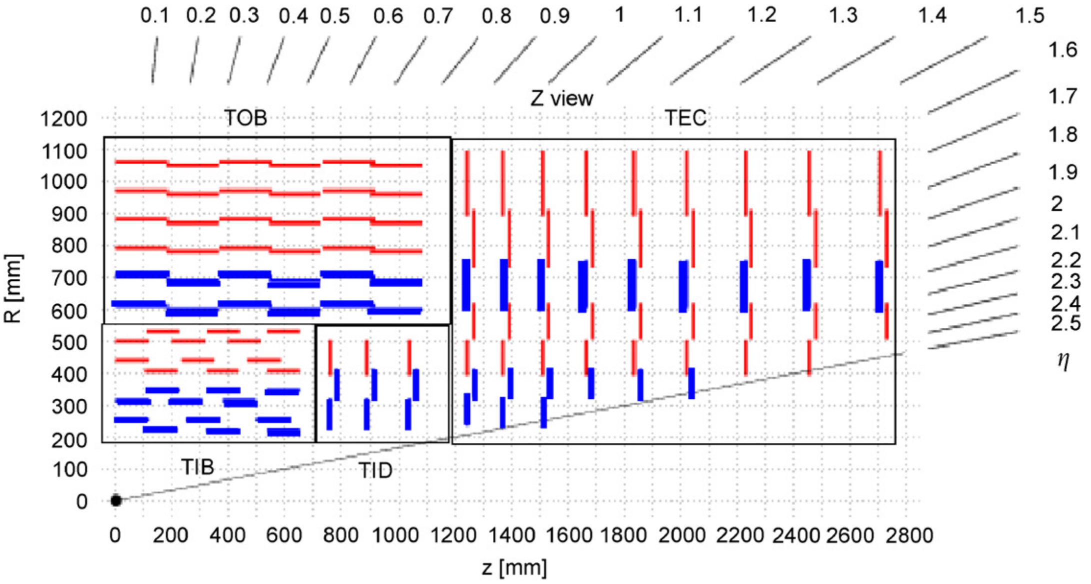

Fig. 1. Cross-section through one-quarter of the CMS silicon strip tracker in the *R–z* view. Thin and thick lines represent single- and double-sided silicon strip modules, respectively. The individual subdetectors are labelled.

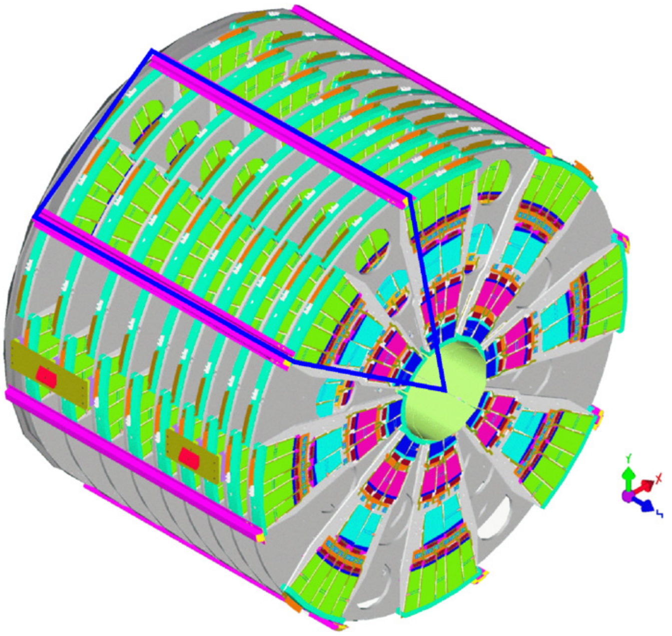

Fig. 2. Technical drawing of one tracker end cap (TEC). The interaction point is located to the right. The eight front petals mounted on the front side of disk 1 are visible. The modules of rings 1, 3, 5, and 7 can be seen as well; the individual rings are shaded in different grey tones. The rings 2, 4, and 6 are mounted on the back side of the petals. One sector, corresponding to one-eighth of a TEC in ϕ, is indicated.

In the TECs on rings 1, 2, and 5 double-sided modules are mounted. These are made of two single-sided modules that are mounted back to back with a stereo angle of 100 mrad, and provide information in both azimuthal (ϕ) and radial coordinates (thick module lines in Fig. 1).

Modules with 512 or 768 strips exist. The signals of the 512 or 768 silicon strips of a module are processed by four or six APV25 readout chips [3] that are mounted on the front-end hybrid. The APV25 is built in radiation hard 0.25 μm CMOS technology. It is a 128 channel chip which samples at a frequency of 40 MHz and implements a charge-sensitive amplifier, a shaper with a time constant of 50 ns, and an analogue pipeline memory. After arrival of a first level trigger the signals are processed by an analogue circuit, for which two operation modes can be chosen: in peak mode only one data sample is used, while in deconvolution mode three consecutive data samples are reweighted and summed up [4], which leads to a much shorter pulse and thus to correct bunch crossing identification in the high-luminosity running phase of the LHC. The analogue electrical signals are converted to optical signals in dedicated electro-optical converters, the Analogue Opto-Hybrids (AOHs).

Modules are assembled with precision pick-and-place robots, the so-called gantries. The sensors are bonded to each other and to the pitch adapter with the wire wedge bonding technique, using standard commercial wire bonding machines. In addition to the already mentioned variety of module types (number of strips, single- or double-sided, one or two sensors), the geometry of the wedge-shaped TEC modules has been optimized individually for each ring for optimal geometrical coverage using 6″ wafers while maintaining cost-effectiveness. This has led to 10 different module types in the TEC, each of which needed specific custom precision jigs for assembly and wire bonding. The TEC modules were produced by four gantry centres and seven bonding centres, which typically assembled/bonded three and one or two module types, respectively. This distributed production with a high level of specialization of the centres made the production very inert and inflexible. In addition, the ramp-up time and learning curve within each centre has to be accounted for.