Contribution to the construction of the CMS Tracker Endcaps (1)

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Abstract

The Compact Muon Solenoid or CMS detector has been designed as a multipurpose detector to study proton collisions at the Large Hadron Collider. The experiment will allow to extend our understanding of contemporary elementary particle physics, via precise measurements to test the consistency of the Standard Model, the possible discovery of the Brout-Englert-Higgs boson and via searches for new physics beyond the Standard Model. Essential ingredients in obtaining these objectives are the measurement and identification of muons, electrons, photons and jets over a large energy range. Experience has shown that robust tracking and detailed vertex reconstruction within a strong magnetic field are powerful tools to reach these objectives.

The IIHE is involved in the construction of the forward (backward) silicon Tracker. This forward detector consists of about 10000 carbon fibre support frames onto which the silicon sensors of typically 100 cm^2 surface with 512 channels and the readout hybrids are glued. The large number of modules requires an automated procedure which is obtained with a high-precision robotic positioning machine. The accuracy needed for component placement is at the level of 10 μm. The individual detectors are hereafter tested electronically at room temperature for proper functioning before they are integrated onto sectors. As the effective working temperature of the CMS Tracker will be about -10^{0}C, studies are performed to estimate the influence of the temperature on the deformation of the silicon sensors. The subsequent step is to mount the modules on larger detector sectors, azimuthal around the beampipe. Integration tests are in turn peformed, comprising tests of the complete readout chain of the sector, as well as monitoring of the gain, noise and temperature of each silicon detector. An overview of the full forward Tracker construction procedure will be presented.

1 The CMS Tracker Endcaps

The CMS tracking system is designed to reconstruct high-p_t muons, isolated electrons an hadrons with high momentum resolution and an efficiency better than 98% in the range $|\eta| < 2.5$. It is also designed to allow the identification of tracks coming from secondary vertices. Such vertices arise from decays of b-flavoured hadrons, which provide very useful signatures for a broad spectrum of new physics phenomena.

The CMS collaboration decided to use an all-silicon solution for the tracker. In total the CMS tracker implements 25'000 silicon strip sensors covering an area of 210 m^2. Connected to 75'000 APV chips, one has to control 9'600'000 electronic readout channels, needing about 26 million microbonds. This large detector system will be realised applying industrial methods in production and quality assurance.

Two endcaps (TEC) ensure a pseudorapidity coverage of up to η=2.5. The endcap modules are mounted in 7 rings on 2x9 discs consisting of wedge shaped petals, each covering 1/16 of 2π. The detectors of ring 1,2 and 5 are made of double-sided modules. Each one is composed out of two single sided sensors mounted back to back, one tilted by an angle of 100 mrad with respect to the other sensor giving the phi coordinate.

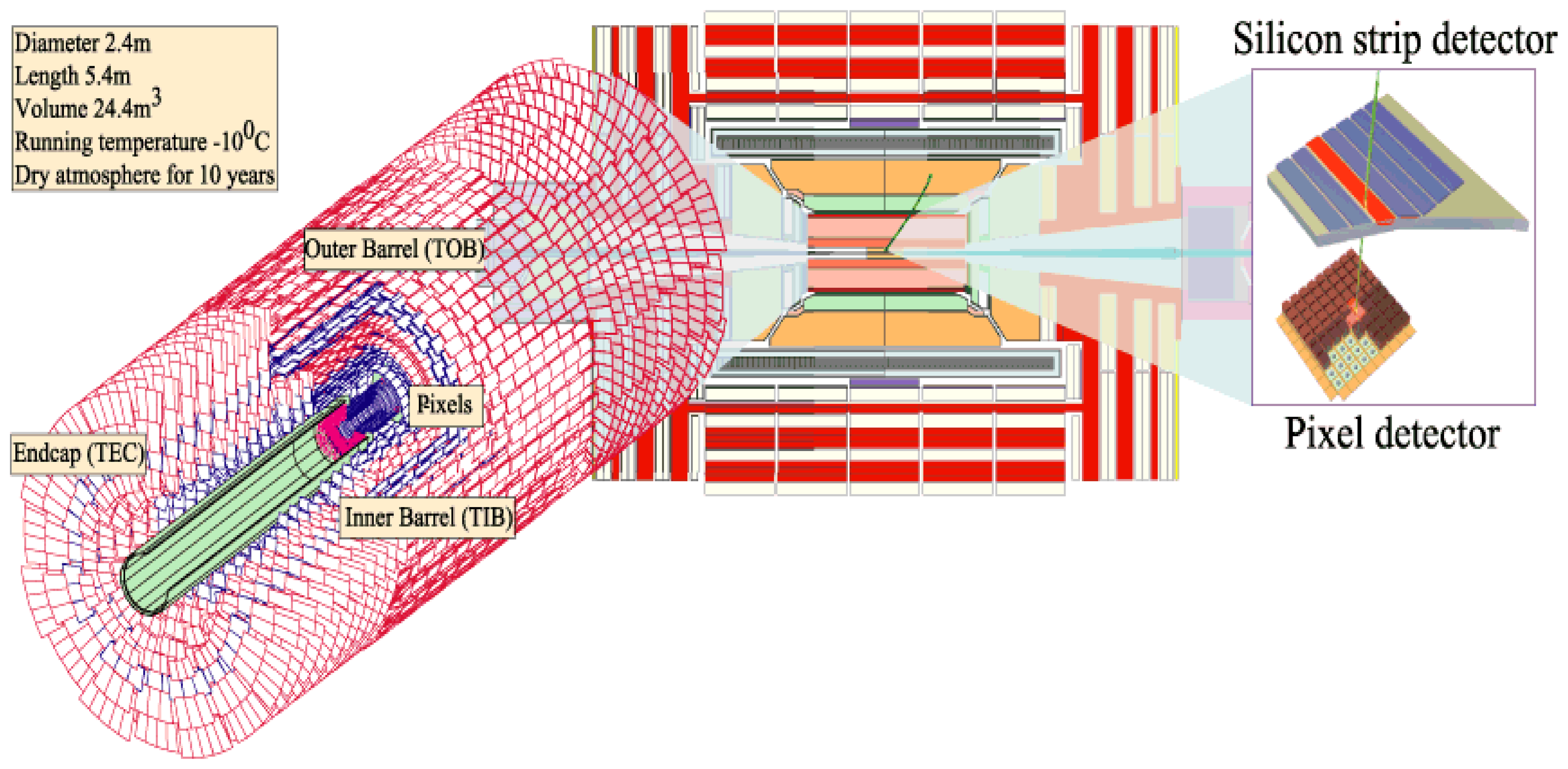

Figure 1: Schematic overview of the CMS Tracker showing all detector modules.

2 Silicon sensors, readout circuits and support frames

The CMS silicon strip detectors are composed of 1 or 2 silicon sensors and a readout circuit with integrated amplifiers, glued onto a lightweight carbon support frame. These components are designed by members of the CMS collaboration and produced by industrial partners.

2.1 Silicon sensors

The CMS sensors consist of 350 and 500 μm thick n-type silicon of about 50 cm^2 surface, implanted with $p+$-type strips about 100 μm apart from each other. The principle of silicon detectors is to collect the electron-hole pairs released by ionizing particles in silicon. The diodes formed by the $p+$-type implant strips and the n-type bulk are reversely polarized in order to deplete the bulk from majority charge carriers. This depletion prevents recombination of the ionization released by the particles to be detected.

High energy charged particles produce about 35000 electron-hole pairs per 500 μm of pathlength in silicon. This amount of charge can be detected by low noise readout amplifiers, here connected to the implant strips. The point of passage of the particles into the detector is measured with a precision of 10 μm by interpolation of the charge collected on a few neighbouring strips.

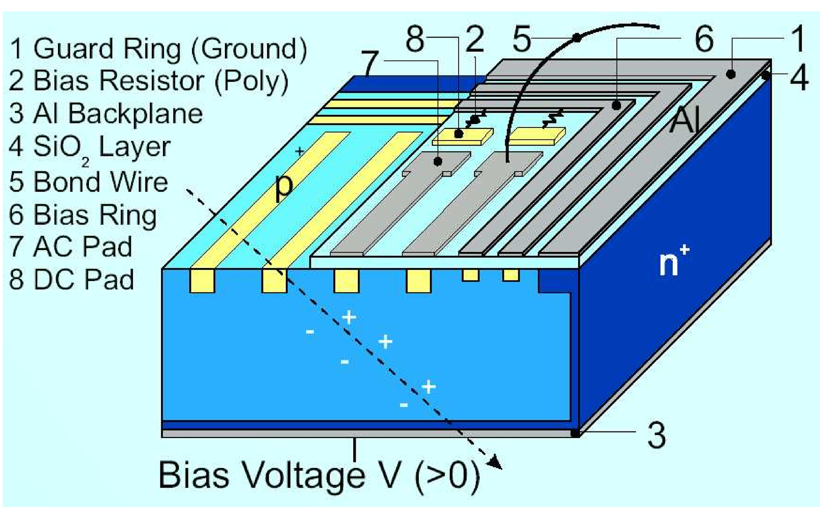

Figure 2: Illustration of the silicon detection technique.

The most stringent design constraint comes from the radiation dose that will be accumulated at the LHC, 1 MRad/year at 20 cm from the beam pipe. This constraint has lead to the following design parameters: low resistivity (1-4 kΩ.cm) silicon, capacitive coupling of the readout electronics to the implant strips, readout electrode shapes reducing the electric field intensity inside the coupling oxide layer. The conformity to the design parameter values is checked in industry and cross-checked by members of the CMS collaboration (Louvain-la-Neuve, Karlsruhe and Vienna for the sensors of the tracker end-caps).

2.2 Readout circuits

The readout circuits consist of integrated amplifiers mounted onto multilayer polyimide hybrids and connected by ultrasonic microbonding. Each hybrid carries 4 or 6 APV25 amplifier chips with 128 readout channels each, a multiplexing chip and a control chip which monitors the sensor temperature and the electronics bias voltages and currents. The chips are addressed using the I2C protocol. For radiation hardness the chips are produced using a 0.25 μm submicron process. The fan-in circuit used to connect the sensor strips to the APV25 channels is designed at the Interuniversity Institute for High Energies in Brussels.

The hybrids tests include checks of the chip addressing and of the gain and noise of all channels. They are performed in the industry using a system made in collaboration between Aachen and Louvain-la-Neuve. The same tests are performed in Brussels before assembly into modules, to detect possible damages during transportation.

2.3 Support frames

The sensors and hybrids are glued onto frames made of two carbon fiber legs and one graphite cross-piece. This material is rigid and prevents in-plane displacements of the components by more than few tens of microns. It also has a high thermal conductivity in order to transmit the heat generated by the electronics to the detector cooling circuit. On one of the carbon fiber legs a kapton circuit is glued, that carries the high voltage to the sensor backplane. For the tracker endcaps Brussels is responsible of assembling 6000 frames.

3 Assembly of the modules

The IIHE is committed to assemble about 3500 tracker modules of four different types : Ring 3, Normal Ring 5, Stereo Ring 5 and Ring 6. An automated Silicon Module assembly system for the CMS Tracker is been used to ensure the quality. The setup consists of a high-precision robotic positioning machine (Aerotech AGS 10000 Gantry) which provides a large static area, 4 separate coordinate positioning motors (X, Y, Z and ϕ rotation), and control hardware and software. The Gantry robot is illustrated in Figure 3 together with an assembled Ring-3 module.

The effective area of the Gantry is calibrated by a 2D grid of points measured with a high precision Mitutoyo machine. This grid is remeasured with the Gantry and used as the coordinate reference system. Several independent grids were used and the local systematic effect was estimated to be of the order of 5 μm.

A pattern recognition of a CCD camera image is used to measure the position of the sensors and the hybrids. Each carbon frame itself is positioned on the assembly plate by 2 precision 3H7 steal pins of which the position is precisely estimated. The nominal positions of the module components are calculated relative to these pin positions.

Depending on the dimensions of the modules, we can assemble 3 or 4 modules of a particular type at a time. All components are first placed within the active area of the gantry robot : the sensors, the hybrids (including the pitch adaptor) and the frames. Three different glues are used during the assembly : silicone based glue for the sensors, araldite for the hybrids and conductive epoxy for the sensor backplane connection. The procedure is programmed to dispense these glue types on the correct places on the carbon fibre frames and then to position the module components in their (X,Y) nominal places. The proper handling of the delicate sensors during the pick and place operations is assured by means of flat teflon-coated vacuum pickup tools with built-in pressure sensors that prevent any large forces from being applied to the sensor surfaces. Once the components are positioned, vacuum valves are enabled which secure the detectors into place on the vacuum chucks under each of those components.

The repeatability of the positioning of the assembled modules is good, an RMS of 4 μm is obtained for the fiducial markes on the sensors. Remeasuring the module on a different place within the calibrated region of the Gantry and using therefore different pins and their asigned position, results in difference of the order of 5 μm. A set of 6 assembled modules is remeasured on an independent measuring machine at the CERN Metrology Service and found to be in agreement with the measurements on the Gantry.

The above studies have proven that both the random uncertainties and the systematic biases introduced by the setup are under control. Hence we remain only with the positioning precision of the machine and the sensor or hybrid pick-up tools themselves. For the dilution introduced by these assembly steps the CMS Collaboration has defined limits. The position of the sensors and hybrid on the frame should not deviate too much from the nominal or foreseen position. Figure 3 show the deviations from this nominal position for the **XX** Ring-3 modules we have assembled and demonstrate that the obtained precision is adequate.

Figure 3: Illustration of an assembled module on the left and the Gantry robot at work on the right.

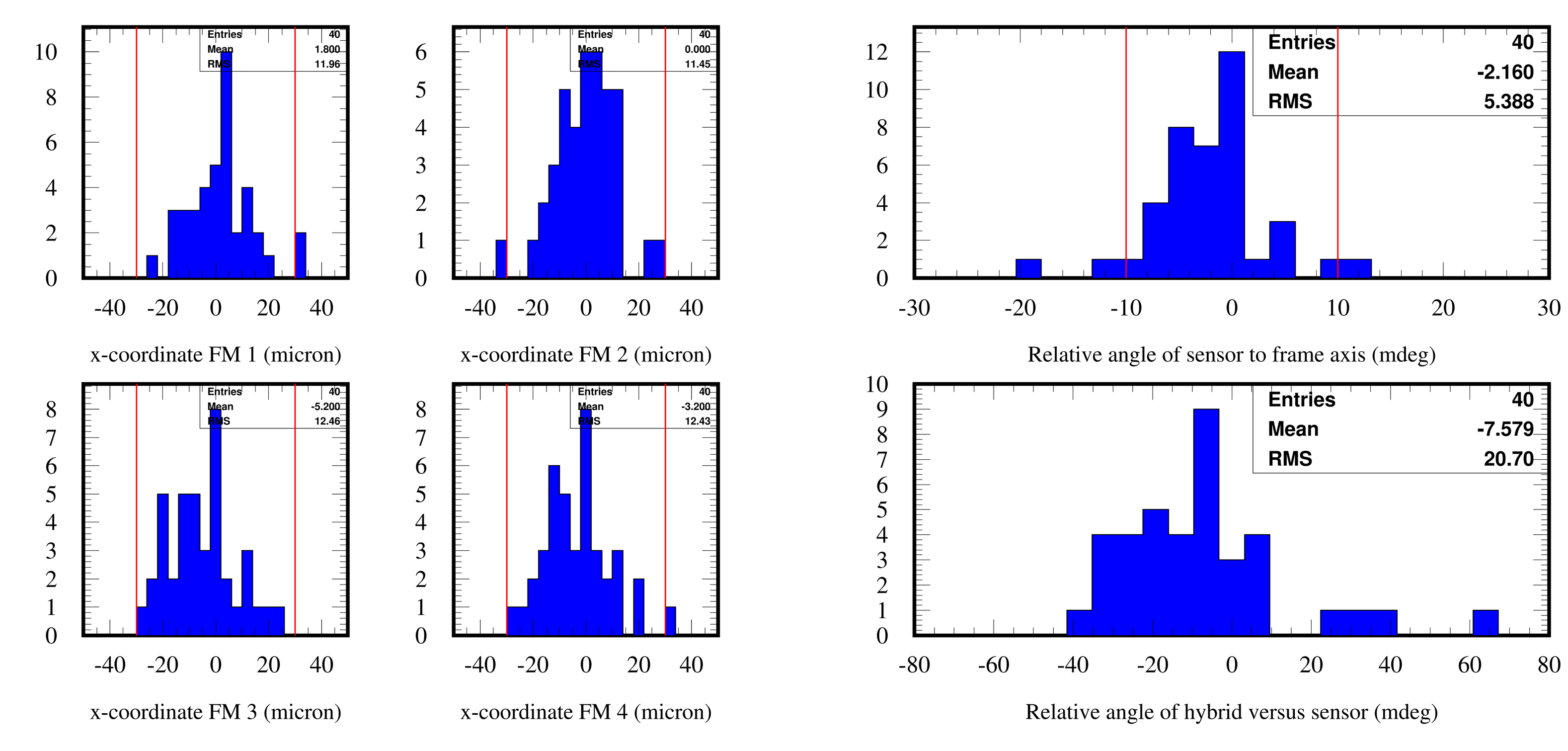

Figure 4: Achieved precision for Ring-3 module assembly. All spatial residuals are indicated in μm and angular ones in mdeg. The labels are defined in the above illustration, while the CMS specified precision limits are indicated by the red borderlines. *(To be updated)*