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CMS Silicon Strip alignment and monitoring with the Laser Alignment System

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For this, 434 of the Silicon Strip modules (3%) are illuminated by the laser beams, assuring a continuous surveillance during the collisions and cosmics data taking. In this contribution the status and the preliminary results of monitoring and alignment parameters during the 2011 data taking period at the Large Hadron Collider (LHC) are presented.

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1. Introduction

The Compact Muon Solenoid (CMS) detector has two concentric tracking sub-detectors built out of Silicon. The inner detector uses a pixel structure, while the outer one is made out of strips. The CMS Silicon Strip detector has an inner radius of 20 cm and an outer radius of 116 cm. Its length along the z -axis is 564 cm. It has 9.3 million silicon strips and covers an active area of $198\ \text{m}^2$ [1].

Figure 1: The geometry of CMS Silicon Strip detector and the Laser Alignment System.

The components of the CMS Silicon Strip detector are the Tracker Inner Barrel (TIB), Tracker Inner Discs (TID), Tracker Outer Barrel (TOB) and two Tracker Endcaps (TEC+ and TEC-), as presented in Fig. 1. In order to monitor the stability and the alignment of its mechanical structure the Laser Alignment System (LAS) was built-in.

2. Laser Alignment System

The LAS uses 434 Silicon modules (3%) that are also used for track reconstruction. These are illuminated by 8 laser beams that are passing between TIB and TOB, and enter both endcaps. They allow the alignment of the sub-detectors with respect to each other. In addition to this, in each of the endcaps the 9 discs are monitored by 16 laser beams. They are placed in two concentric rings, as shown in Fig. 2, perpendicular to the strip direction. The rings are called Ring 4 and 6. The laser beams have a wave length of 1075 ± 4 nm. At this wave length the silicon modules have a transmission of up to 20% for Ring 4 and up to 18% for Ring 6. The reflectivity is less than 6% [2], [3].

Figure 2: The LAS Rings and Beam geometry in TEC and TOB/TIB.

The laser light, generated by laser diodes, is coupled into optical fibres that enter the Silicon Strip detector volume. At the end of these fibres there are beam splitters that produce pairs of collimated, back-to-back oriented beams. These beams pass several layers of modules in TEC. The silicon sensors have a hole in the back-plane metallization and are covered with an anti-reflective coating. In TIB, outermost layer, and TOB, innermost layer, the light is coupled out by semi-reflecting glass plates.

In order to achieve a good signal on every module used by LAS, the beam intensities and the firing time delays need to be properly adjusted. Like a crossing particle, the Laser light absorbed inside the Silicon sensors generates a signal. The Laser signals are 3-20 strips wide and the Laser pulse intensity is adjusted to be inside the dynamic range of the frontend amplifiers.

Figure 3: The laser beam profiles in (a) TEC+ for Ring 4 Beam 0 of various discs and (b) TOB for Beam 0 corresponding to the alignment tubes.

In Fig. 3(a) the TEC laser beam profiles are presented. Due to the fact that each beam has to travel over 4 modules a diffraction pattern is observed. The beam position is given by the main maximum. In TOB, as well as in TIB, the beams illuminate only one module, as illustrated in Fig. 3(b). The number of ADC counts is proportional to the beam intensity. In order to exploit also the signals that are close to the saturation of the frontend amplifiers, the position of the Laser spot is computed with an algorithm which uses the profile slopes.

The same acquisition system as for physics data is used to collect alignment data during pp collisions and cosmic runs, using the calibration triggers. The Lasers fire 2000 pulses at 100 Hz every 5 minutes. The pulses are syn-

chronised with the LHC clock and fall into the orbit gap to avoid interference with physics events produced in pp collisions.

The relative movements of the sub-detectors with respect to each other are monitored with these beams to a precision better than $10\ \mu\text{m}$. Another goal is to measure the absolute alignment parameters with a precision better than $100\ \mu\text{m}$, which can be used as input for the tracking alignment. The movements and the deformations of the CMS Silicon Strip detector structure are described in the alignment algorithm by a linear model. The parametrization allows the laser beams to change orientation and offset, but they are constrained to straight lines. The algorithm uses the χ^2 fit minimization. In this model are aligned the internal parameters, Δx_k , as well as the global parameters, Δx_0 , of the TEC structure, as illustrated in Fig. 4(a). For TEC internal discs, three alignment modes are solved, the displacements along the x - and y -axis, as well as the rotation around the z -axis, as highlighted in Fig. 4(b).

Figure 4: The alignment method (a), e.g. TEC can be aligned with respect to TOB (Δx_0 - global parameters) and TEC discs relative to each other (Δx_k - disc parameters). The CMS coordinate system and the alignment modes (b) that can be solved with LAS. Because a misaligned fibre plugged into the beam splitters (c) may cause a kink between the beams, this is also taken into account in the alignment algorithm.

The stability of the entire Silicon Strip detector is monitored using TOB as reference. Relative to TOB the TEC is aligned along the x - and y -axis and for rotations around the z -axis. For TIB two more alignment modes are solved, the rotation around the x - and y -axis. For global alignment parameters additional corrections are applied for misaligned fibres plugged in the beam splitter, as pictured in Fig. 4(c). They may cause a kink between the beams.

3. LAS Calibration and Monitoring

Before each data taking period, the LAS is calibrated and commissioned. In Fig 5(a) the intensity and time delay scans, which are performed during this phase, are shown. The first scan is a coarse time delay scan, which ensures

Figure 5: Calibration of the laser beams intensity and time delay (a). Online monitoring (b) of the LAS modules and beams. The white colour indicates that the modules are not read out (known problems). For certain modules only half of the signal beams can be recorded (yellow colour).

that the laser beams are synchronized with the trigger. Then for each beam group the intensity and fine delay time are varied and the signal is checked on each module in order to find optimal settings.

During data taking periods the laser beams and the modules are monitored online, Fig 5(b), to spot possible problems. The simple color code shows green for modules where the expected number of events is seen, yellow for modules that are illuminated only half of the time or for which the beam intensity is not above the ADC reading threshold. Because of the LAS redundancy the yellow label is not considered critical. For certain modules only one quarter of total events are expected, they will be colored in red.

The critical modules are displayed in white. In this case no event is reported either because the laser beam is not active or the module are not read out. In this case immediate action is taken. The 3 modules seen in beam 6 in TIB are part of 7 known modules that are not read out.

4. CMS Silicon Strip Detector Stability

The stability of the Silicon Strip detector structure monitored over the 2011 year is presented in Fig. 6. The positions of TIB, TEC+ and TEC– are computed relative to TOB. The stability is calculated with respect to the last measurement in each run. In this approach the effect of the changes in temperature settings, low and high voltage or pedestals of Silicon Strip modules are minimized and the intrinsic resolution can be determined. Changes and fluctuations in between runs are not visible in this approach, they would add 2 to 5 μm to the spread of the parameters.

Figure 6: The stability of CMS Silicon Strip detector in 2011. The TIB (up), TEC+ (middle) and TEC– (down) are monitored within each run with respect to TOB.

For every single measurement the changes of the laser beam spot positions are determined, and from these the LAS alignment parameters are computed.

The achieved intrinsic resolution is better than 3 μm (μrad) for displacements along the x - and y -axis as well as for TIB rotations. The TEC+ rotation resolution is 3.1 μrad while for TEC– 3.2 μrad is obtained. In Table 1, the resolutions of the solved alignment modes are presented.

During the 2011 data taking period a few significant deviations of LAS alignment parameters are observed. These deviations are related to non stabilized temperature periods. In Fig 7 one of these cases is presented. The CMS Silicon Strip detector

Figure 7: The few significant deviations of LAS alignment parameters seen during 2011 are related to temperature, e.g. in runs 161473/74.

was switched off and on, giving raise to jumps in temperature. This had as result the deviations in the alignment parameters which vanish once the temperature plateau is reached.

5. Lorentz Angle

The deflection/drift angle of a moving particle in an electric field is changed by the magnetic field. This needs to be corrected for in the track reconstruction [4], [5]. During the CMS magnet ramp from 0 to 3.8 T the Lorentz angle, translated in the laser beam shift, Lorentz shift, as it is depicted in Fig 8(a), can be measured with LAS independent of tracking. The effect is seen only in the barrel region due to the magnetic field orientation.

Figure 8: The LAS can also measure the Lorentz shift independently from tracking reconstruction (a). In TOB (b) the measured shift is from 4 to 7 μT , while for TIB from 2 to 4 μT .

The measured Lorentz shifts for TOB are 4 to 7 μT , while for TIB 2 to 4 μT . The difference is due to the different thickness of the silicon sensors (500 μm and 320 μm , respectively).

6. Summary

The mechanical structure of the CMS Silicon Strip detector is monitored by its own built-in Laser Alignment System which uses 3% of the modules. LAS ran stably during the 2011 pp collisions and cosmics data taking periods, taking data at 100 Hz in the orbit gap every 5 minutes. The achieved intrinsic resolution of LAS for misalignment of TIB and TEC with respect to TOB is better than the design goals:

	$\sigma_{\Delta x} [\mu\text{m}]$	$\sigma_{\Delta y} [\mu\text{m}]$	$\sigma_{R_x} [\mu\text{rad}]$	$\sigma_{R_y} [\mu\text{rad}]$	$\sigma_{R_z} [\mu\text{rad}]$
TIB	0.8	0.9	2.1	1.8	1.0
TEC+	2.6	2.6	—	—	3.1
TEC-	2.4	2.6	—	—	3.2

Table 1: The achieved intrinsic resolution of LAS for misalignment of TIB and TEC with respect to TOB.

The CMS Silicon Strip detector geometry was essentially stable over the 2011 data taking period, within LAS resolution. Few deviations of the alignment parameters were observed. These deviations are related to unstable temperature conditions and they vanish once the stability plateau is reached.

LAS can also measure the Lorentz shift providing an independent measurement from track reconstruction.

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