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CMS tracker alignment validation with electron tracks

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The CMS tracker is the largest silicon detector ever built. Its purpose is the reconstruction of charged particles tracks, from a collection of hits in the different tracker layers. To take advantage of the good resolution provided by the silicon sensors, we need to know precisely the position of all the tracker modules. For this purpose, minimization algorithms are used to estimate possible misalignments of these modules. Nevertheless, some global deformations may exist that are almost invisibles to these classical methods. The presented tool is sensitive to some of these *Weak Modes* deformations, and is used to detect the eventual presence of one of these misalignments in the tracker geometry. The principle of the tool is explained. The results on Monte Carlo events reconstructed with a simulation of misaligned detector are shown. Finally, results on 2012 data are presented.

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1. The CMS tracker alignment

The Compact Muon Solenoid (CMS) is one of the four main experiments at the Large Hadron Collider (LHC). The detector has the shape of a 21 m long cylinder with a diameter of 15 m. The tracker is the innermost subdetector, followed by the electromagnetic and the hadronic calorimeters, all placed inside the solenoid magnet, and finally the muon system, placed outside [1].

The CMS tracker is a 540 cm long cylinder with a radius of 110 cm, fully composed of silicon detectors. Two technologies of silicon sensors are used: pixels, in the innermost layers, and microstrips, in the rest of the tracker. Its goal is the reconstruction of charged particles trajectories, from which charge and momentum are estimated.

Positions of tracker's sensitive areas must be precisely known, not to spoil the intrinsic single-hit resolution of the silicon detectors (typically 10-60 μm). However, misalignments of modules, due to gravity, thermal variations or magnetic field are unavoidable, and are time-dependent. The goal of alignment is therefore to determine the real positions of modules over time, to take them into account in track reconstruction. Track parameters measurements are significantly improved.

To estimate modules positions with an accuracy of 1 to 10 μm, a *track based* alignment technique is used. It exploits the impact of misaligned modules on track measurement. Indeed, if the assumed and the true positions of modules differ, track-hit *residual* distributions will be degraded, where the term *residual* refers to the difference between the *measured* hit position and the *expected* hit position obtained from track fit. By minimizing a sum of residuals over millions of tracks, modules positions can be estimated. More details can be found in [2].

2. Motivations and principle of the developed tool

Nevertheless, some global deformations (*Weak Modes*) may exist that let the χ^2 of the tracks unchanged, as illustrated in figure 1. Therefore, minimization algorithms presented before are only weakly sensitive to such misalignments. We need additional tools to detect them. The tool described here is sensitive to two particular Weak Modes: Twist and Curl. Twist (Curl) consists in coherent rotations of groups of modules whose amplitude depends on the z (r) coordinate[1], and is parametrized by $\Delta\phi = z \times c_{twist}$ ($\Delta\phi = r \times c_{curl}$). The goal of alignment validation is to estimate the value of the parameter c, in rad/cm.

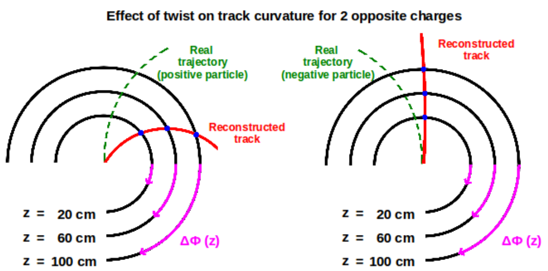

Figure 1: Illustration, in the transverse plane ($x-y$), of the effect of a twist deformation ($\Delta\phi \propto z$) on track reconstruction for two tracks having the same real transverse momenta, but opposite charges.

[1]CMS uses a right-handed coordinate system taking the nominal interaction point as origin. The x axis points toward the center of the LHC, the y axis points up, and the z axis lies along the beam direction. The azimutal angle ϕ and the radial coordinate r are measured in the $x-y$ plane. The pseudorapidity is defined as $\eta = -\log(\tan(\theta/2))$.

The tool exploits the fact that these two Weak Modes will introduce a systematic bias in the transverse momentum measurement provided by the tracker. Indeed, they modify the reconstructed track curvatures, from which the momentum is estimated. Furthermore, this effect is opposite depending on the charge of the considered particle. This is again illustrated in figure 1. For two tracks having the same real transverse momenta but opposite charges, an analytical expression of the $\Delta\phi$ misalignment with respect to the measured p_T can be obtained. Nevertheless, as the tracker measurement is biased, it cannot be used to regroup tracks with equal real p_T.

Calorimeters, however, provide a transverse energy measurement that, in ultra-relativistic conditions, is equivalent to p_T. This measurement does not depend on charge, nor on tracker alignment. The $\Delta\phi$ misalignment can then be retrieved using the differences that arise in the mean of the E/p distributions in the presence of a Twist or a Curl misalignment. This is illustrated in figure 2.

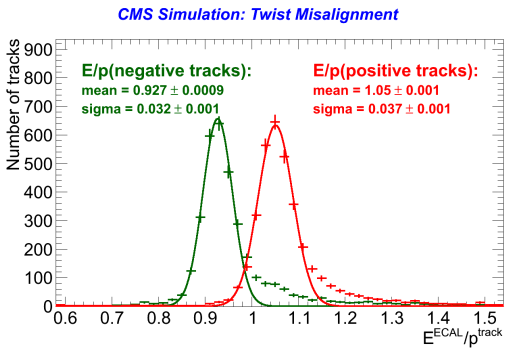

Figure 2: E/p distribution obtained from simulated electrons and positrons of 50 GeV transverse energy, and reconstructed with a detector simulation in which a 10 µrad/m Twist has been introduced. The outermost hit coordinate of the tracks used is $-80<z<-100$ cm.

Successive gaussian fits of the central part of these distributions are performed until a convergence criterion is reached. The mean of the last fit is used, and the $\Delta\phi$ misalignment is estimated on different z intervals and bins of compatible energy, using the formula:

$$\Delta\phi = \frac{1}{2}\left(\arcsin\left(\frac{0.57r}{\langle E_T^+\rangle}\left\langle\frac{E}{p}\right\rangle^+\right) - \arcsin\left(\frac{0.57r}{\langle E_T^-\rangle}\left\langle\frac{E}{p}\right\rangle^-\right)\right)$$

More detail can be found in [3]. This tool has been designed to work with electron tracks. The main reason is that a clear signal can be obtained via a selection of electron pairs coming from the decay of a Z^0 boson, with large yield. However, electrons can loose a significant fraction of their energy by bremsstrahlung radiation, and the sensitivity of the tool is so far limited to the barrel part of the tracker, where the material budget is lower.

3. Results on Monte Carlo and 2012 Data

The tool has been tested using the CMS detector simulation, in which we introduce Twist and Curl deformations, with various amplitudes. Monte Carlo events with electrons of fixed transverse energy (50 GeV) are produced, and reconstructed using the misaligned detector. Biases are checked, measuring the reconstructed $\Delta\phi$ as a function of z at outermost hit. Results are shown in figure 3. Measured biases are compatible, within the errors, with the input misalignments. The tool is sensitive down to an amplitude of 1 µrad/cm with an amount of data of only 250 pb^{-1}.

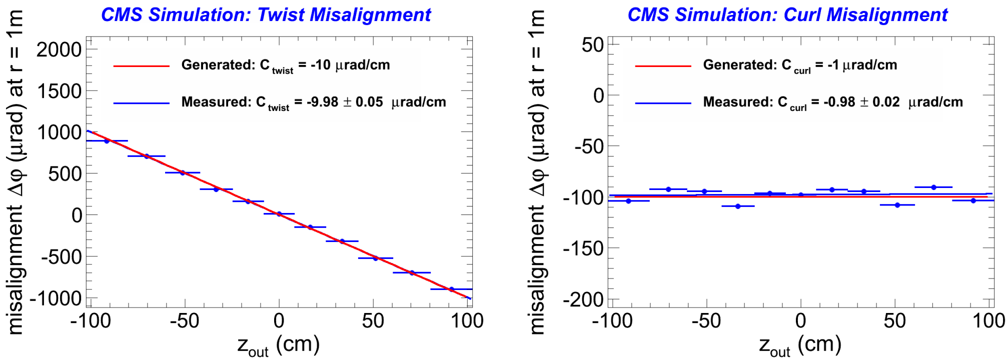

Figure 3: Measurement of Twist (left) and Curl (right) misalignment introduced in detector simulation. The amplitude of the deformations are retrieved within the errors.

Finally, the 2012 data have been validated with the tool: no significant Twist or Curl was observed. The result on the last data taking period of 2012 (Run 2012 D) is presented in figure 4.

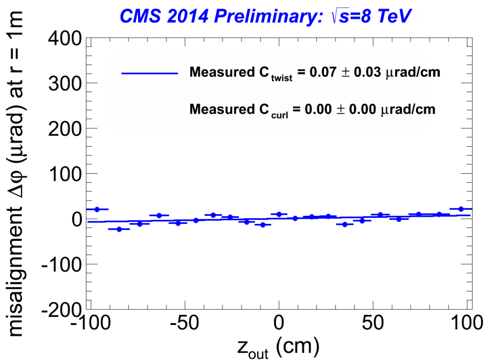

Figure 4: Measurement of $\Delta\phi$ misalignment as a funtion of z for the Run D of 2012 data. No significant Twist or Curl is observed.

4. Conclusions

We have developed a tool that allows the detection of deformations to which standard alignment algorithms are only weakly sensitive. It has been validated with the detailed detector simulation and 2012 Data, and integrated in the official CMS alignment software. The tool will be used at the restart of the LHC in 2015 to monitor the tracker geometry during LHC Run 2.

References

[1] The CMS Collaboration, *The CMS experiment at the CERN LHC* , *JINST* **3** (2008) S08004 [doi:10.1088/1748-0221/3/08/S08004]

[2] The CMS Collaboration, *Alignment of the CMS tracker with LHC and cosmic ray data*, [arXiv:1403.2286]

[3] The CMS Collaboration, *CMS Tracker Alignment Validation with Electron Tracks*, [http://cds.cern.ch/record/1706195/files/DP2014_019.pdf]