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CMS Tracker alignment and its influence on the b-tagging performance

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Abstract

Tagging of b jets is of fundamental importance for the top physics at LHC and only an efficient and aligned tracker detector can offer the possibility to increase the precision in the detection of tagging vertexes. At the Compact Muon Solenoid (CMS) experiment, the alignment of the Tracker is an important goal in the determination of the robustness of the b-tagging algorithms performance: many studies and tests about possible alignment strategies have been carried out during these years, using different algorithms on sets of real (cosmic muon tracks) and simulated data (muon tracks from Z and W decays).

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1 Importance of b-jets for physics at CMS

Many physics processes containing top quark, Higgs or supersymmetric particles produce b-jets in the final state. The top quark, for example, decays almost 100% into a W and a b-quark. The identification of the jets containing b quarks relies on the properties of B hadrons, that have a lifetime of $\sim 1.6\,\mathrm{ps}$ and decay producing five charged tracks, on average. One of the charged tracks is often a lepton, with a branching ratio of $\sim 10\%$ for each lepton family. Different algorithms have been implemented [1] to identify b-jets using lifetime properties and the presence of a lepton in the jet:

- *Lifetime based algorithms*. Those algorithms exploit the fact that B hadrons decay on average $\sim \mathrm{mm}$ away from the primary interaction vertex (method based on impact parameter and secondary vertex reconstruction).
- *Soft lepton algorithms*. Those algorithms are based on the presence of a lepton with a low p_T relative to the beam line (hereafter referred as *soft*), but a high p_T with respect to the closest jet axis to be distinguished from other leptons coming from ligther quark flavours decay.

The most relevant observables in the b-jets tagging are tracks with high impact parameters with respect to the primary vertex and a displaced secondary vertex: they can be measured only by a detector with high spatial resolution, and for this reason calibration and alignment of the inner tracking system become one of the most important goals.

2 Strategy for a CMS Tracker alignment

The CMS silicon Tracker [2] [3] covers the cylindrical volume limited by $r < 110\,\mathrm{cm}$, $|z| < 275\,\mathrm{cm}$. The inner part (*Tracker Pixel Barrel and Endcap (TPB, TPE)*) is composed of 1440 pixel detectors, with a pixel size of $100(r\phi) \times 150(z)\,\mu\mathrm{m}^2$, which give a resolution of 9 $\mu\mathrm{m}$ along $r\phi$ and and of 20 $\mu\mathrm{m}$ along z direction. In the outer part (*Tracker Inner and Outer Barrel (TIB, TOB) and Tracker Inner Disks and Endcaps (TID, TEC)*) there are 15148 silicon strip modules (pitch: $80 - 205\,\mu\mathrm{m}$) each with a resolution of $20 - 60\,\mu\mathrm{m}$. For each possible track trajectory, at least four *2D*-measurements are obtained by assembling two modules back-to-back with a stereo angle of $100\,\mathrm{mrad}$ (stereo modules). The large number of rigid-body parameters leads to an alignment procedure performed at different levels:

1. High precision in module assembly and survey measurements. During construction and assembly of the CMS Tracker, a vast number of measurements have been performed, e.g. by coordinate measurement machines (the precision of sensors with respect to the carbon-fibre support is $25 - 180\,\mu\mathrm{m}$) or photogrammetry (this step leads to a spatial resolution of about $100\,\mu\mathrm{m}$), to verify and to correct the desired mechanical accuracy for most of the Tracker components.
2. Laser Alignment System. This system is used to align *TIB, TOB* and *TEC* relatively to each other. The goal of the system is to generate alignment information on a continuous basis, providing geometry reconstruction of the Tracker substructures at the level of $100\,\mu\mathrm{m}$.
3. Track based alignment. In this step different kinds of tracks are used to reach the precision on the modules position of $10\,\mu\mathrm{m}$ along their sensitive coordinates: muons from Z and W decays, cosmic ray muons , beam halo muons (to compensate the low cosmic ray statistics in the endcaps), minimum bias tracks, primary vertex constrained tracks and mass constrained tracks from Z, Y and J/ψ.
   The common principle of track based alignment is the minimisation of χ^2. Currently three algorithms are available in CMS:
   - *HIP*. The Hits and Impact Point algorithm [4] minimises the sum of the residuals of each aligned object, independently from the others. Since only the *local module* track χ^2 is minimized in each iteration, the track fit is repeated iteratively until convergence is reached.
   - *Kalman*. This algorithm [5] is an extension of the Kalman filter used in track fitting by including alignment parameters: these are updated after each processed track. The computational complexity of the algorithm is reduced by restricting the update to detectors which are close according to a certain metric.

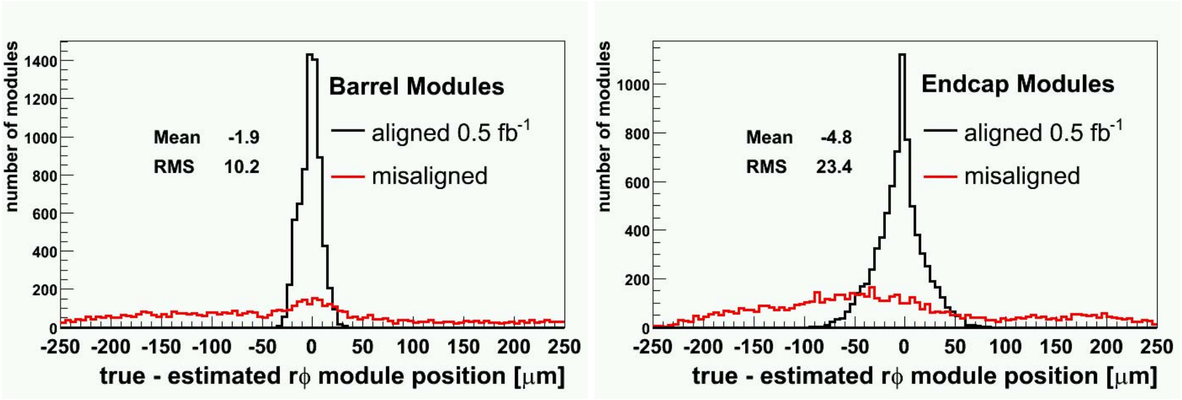

Figure 1: Precision of the resulting module positions in the precisely measured coordinate reaches $\sigma_{r\phi} = 10\,\mu\mathrm{m}$ in the strip barrel. Due to missing cosmic ray tracks in the endcaps (*TID* and *TEC*) and to the topolgy of the radial strips, the position of their modules is known with a precision $\sigma_{r\phi} = 23\,\mu\mathrm{m}$.

Table 1: Expected uncertainity in the $r\Delta\phi$ detector position for the Tracker barrel subsystem for two different misalignment scenarios [1].

	Short Term scenario (μm)	Long Term scenario (μm)
Tracker Pixel Barrel	10	10
Tracker Inner Barrel	100	20
Tracker Outer Barrel	70	20

- *Millepede*. The basic principle [6] is the minimisation of the objective function, which is performed simultaneously taking into account track and alignment parameters. This allows to compute an optimal solution to the alignment problem where all correlations are properly taken into account.

2.1 A first full Tracker alignment study with Monte Carlo samples

A study with the Millepede algorithm has shown that the full CMS tracker could be aligned with such samples [7]. Starting with a pixel system pre-aligned to about $15\,\mu\mathrm{m}$, it utilises single muon tracks and mass/vertex constrained pairs of muon tracks from W and Z decays, respectively, corresponding to an integrated luminosity of $L = 0.5\,\mathrm{fb}^{-1}$.

The alignment parameters taken into account for all modules are a shift along the precisely measured coordinate (close to parallel to the $r\phi$ direction), a shift perpendicular to the sensor plane and a rotation around the sensor normal. In addition, the shift along the coarsely measured coordinate is aligned for the pixel modules and for the stereo modules in the strip detectors. This amounts to about 45000 free parameters. Achieved results are shown in Fig. 1.

3 Impact of the Tracker misalignment on b-tagging performance

The b-tagging performance studies often have been carried out assuming a complete and perfectly aligned detector. However, in reality, the alignment will always be somewhat limited accuracy. The efficiency ϵ_q to tag a q-flavoured jet as a b-jet (b-tagging efficiency for b-jets, or mistag efficiency for *non* b-jets) is defined as:

$$\epsilon_q = \frac{\mathrm{nr.\,jets\,q\,flavoured\,tagged\,as\,b}}{\mathrm{nr.\,jets\,q\,flavoured}} \tag{1}$$

The goal of a b-tag algorithm is to have a high efficiency to correctly identify as b, originally produced b-jets and a low efficiency for a lighter flavoured jets.

The performance in the tagging efficiency is certainly influenced by the assumed accuracy of the alignment of the tracker, that affects the track's impact parameter resolution as well as the vertex resolution. Fig. 2 shows the performance for b-tag in different alignment conditions. The *short term* and *long term* scenarios are meant to illustrate the effects of the residual tracker misalignment after collecting the first fb^{-1} data and $10\,\mathrm{fb}^{-1}$, respectively. The average values of the residual misalignment are given in Tab. 1.

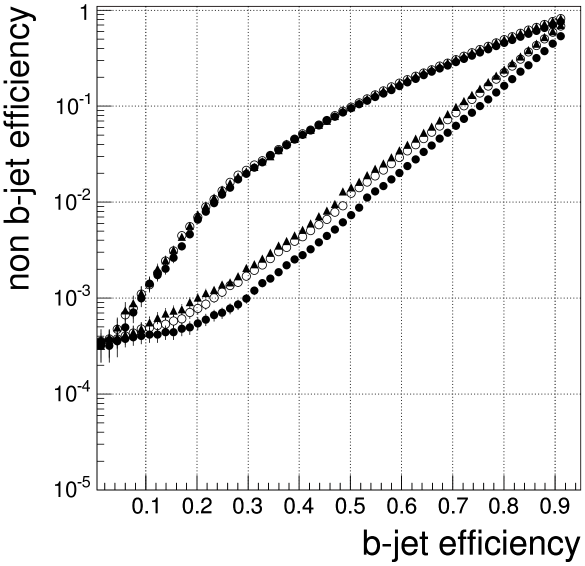

Figure 2: Algorithm performance with the assumption of perfectly aligned detector (full circles), Short Term misalignment Scenario at $L_{int} = 1\,\mathrm{fb}^{-1}$ (triangles) and Long Term misalignment scenario at $L_{int} = 10\,\mathrm{fb}^{-1}$ (open circles). Expected uncertainty for the two scenarios are presented in tab. 1. The upper and lower set of curves correspond to c-jets and uds-jets, respectively[1].

4 Conclusions

The results of the study of the full Tracker alignment using simulated samples (sect. 2.1) show that the tracker can be aligned to a high precision level and also shows that it could be done simultaneously in one step.
These results, together with the ones coming from Tracker commissioning and from the CMS global run, provide the basis for the full scale Tracker alignment, which will be carried out with the first $p-p$ collisions.

References

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