The Alignment of the CMS Silicon Tracker using first 7TeV Collision Data

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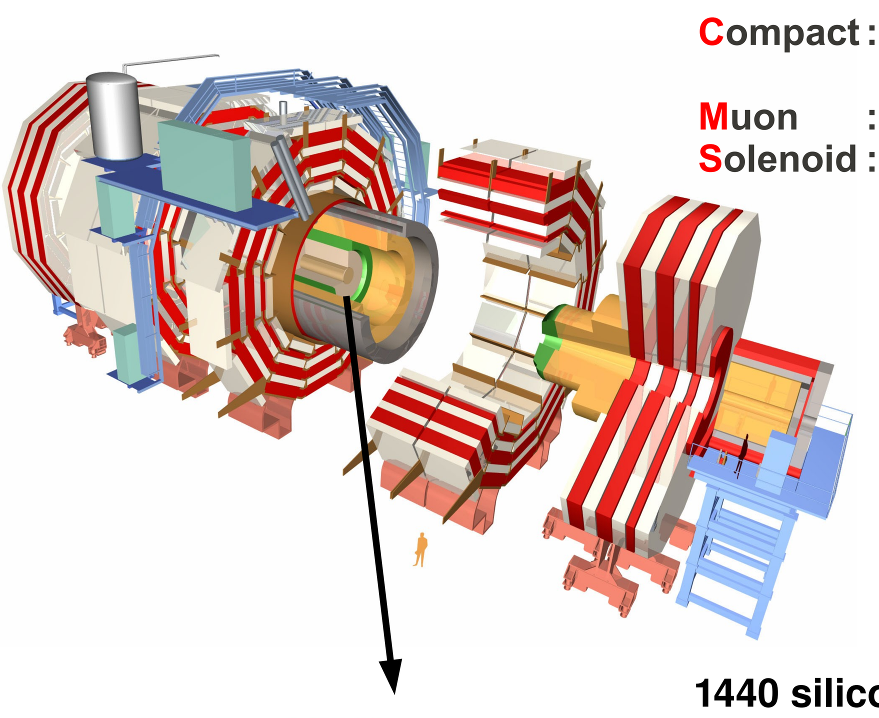
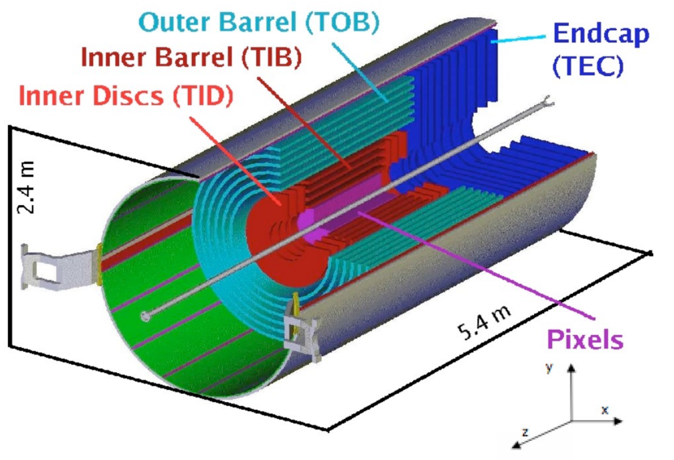
Abstract

The complex system of the CMS all-silicon Tracker, with 15148 silicon strip and 1440 silicon pixel modules, requires sophisticated alignment procedures. In order to achieve an optimal track-parameter resolution, the position and orientation of its modules need to be determined with a precision of few micrometers. We present results of the alignment of the full Tracker, in its final position, used for the reconstruction of the first collisions recorded by the CMS experiment. The aligned geometry is based on the analysis of several million reconstructed tracks recorded during the commissioning of the CMS experiment, both with cosmic rays and with the first proton-proton collisions. The geometry has been systematically monitored in the different periods of operation of the CMS detector. The results have been validated by several data-driven studies. The influence of remaining χ^2-invariant detector movements is estimated by investigating the sensitivity of the alignment procedure to some correlated detector distortions and testing their influence on physics analysis like the B-fraction measurement in J/ψ events.

The CMS Tracker



Compact : 12500 t, Ø15m, length 21.5 m
Muon : Drift/RPC/CSC
Solenoid : B = 3.8T @ 4K



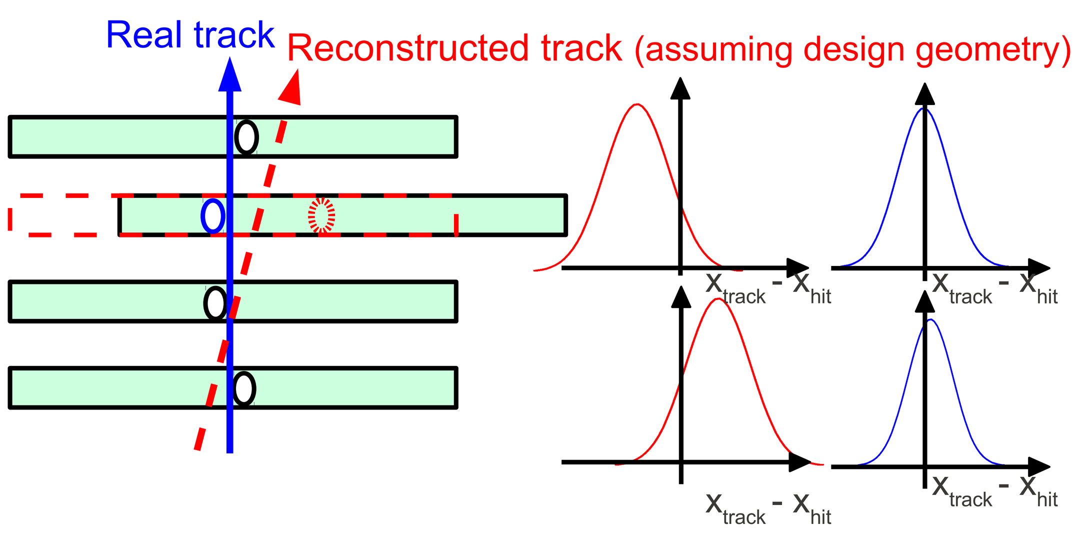
1440 silicon pixel modules

- 3 layers in the barrel
- 2x2 disks (endcaps)

15148 silicon strip modules

- TIB 4 layers
- TOB 6 layers
- TID 2x3 disks
- TEC 2x9 disks

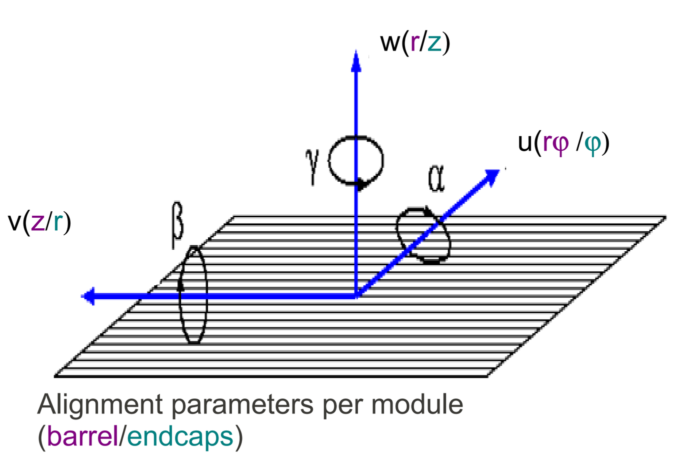
Track-based Alignment



Use tracks to determine 'real' module position by minimisation of track residuals ($r = x_{track} - x_{hit}$)

$$\chi^2(\mathbf{p},\mathbf{q}) = \sum_j^{tracks} \sum_i^{hits} \mathbf{r}_{ij}^T(\mathbf{p},\mathbf{q}_j)\mathbf{V}_{ij}^{-1}\mathbf{r}_{ij}(\mathbf{p},\mathbf{q}_j)$$

Global χ^2 depends on local track parameters q and global alignment parameters (module positions) p



Independent from the global orientation of the module the alignment parameter u is always pointing orthogonal to the strips and is thus the most sensitive coordinate (rφ in the barrel and φ in the endcaps).

Algorithms

Global method Millepede II (V.Blobel)[1]:

- Matrix size reduction to only the number of global parameters preserving correlations and precision O(10^5)
  + only a few iterations necessary (internal outlier rejection)
  - use of survey information not implemented yet

Local method 'Hit and Impact Point' (HIP)[2]:

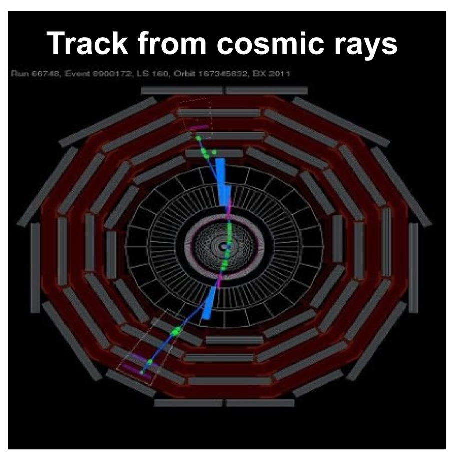
- Local solution for each module O(10^1)
  + primary vertex constraint implemented
  - large number of iterations necessary to converge for modules with large misalignment

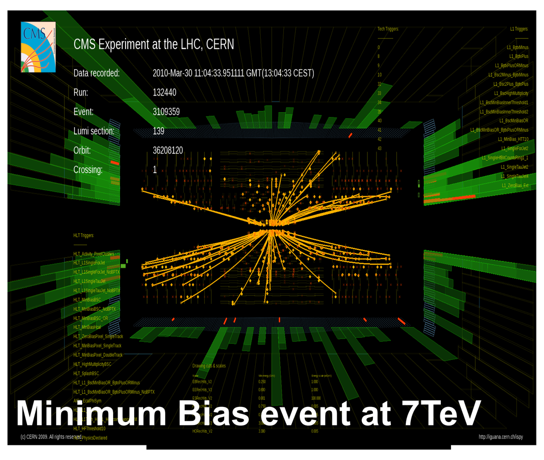
Data Selection & Alignment Strategy

Data selection: Combination of an equal amount of data from cosmic rays and $\sqrt{s}$=7GeV collisions to profit optimally from their different topology to constrain module positions in the best way:

- Cosmic rays (taken at 5kHz): long tracks connecting top and bottom half of the detector
- MinimumBias: good illumination of forward region and pixel

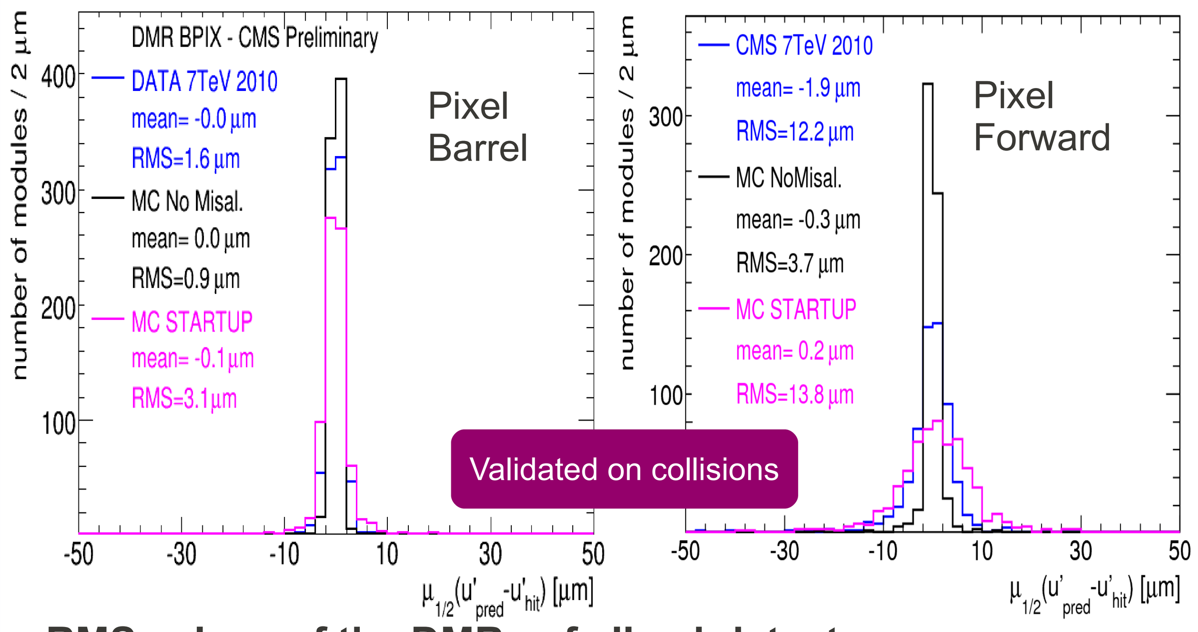
The alignment was started from a prealigned detector (February 2010) using cosmic rays only. For the alignment with MinimumBias a primary vertex constraint was used.





Alignment Results with First Collisions

The alignment results are shown for collision data at 7TeV, and compared to simulated data without any misalignment (MC No Misal.) and with the expected alignment at startup (MC STARTUP) which is based on an alignment using tracks from cosmic rays only[3]. As the residuals are dominated by random effects (multiple scattering & hit error) the **D**istribution of the **M**edian of the **R**esiduals (**DMR**) is used to judge on the quality of the alignment.



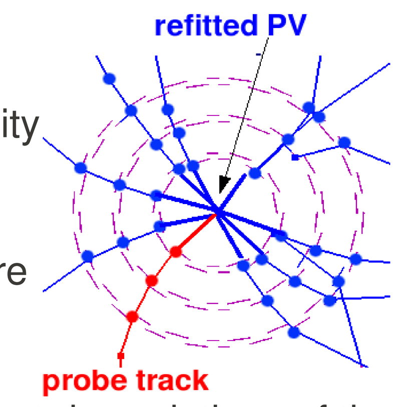
RMS values of the DMRs of all subdetectors :

Subdetector	Data 7TeV [µm]	MC startup [µm]	MC no misal. [µm]
Pixel Barrel u	1,6	3,1	0,9
Pixel Barrel v	5,5	8,9	1,8
Pixel Forward u	5,7	10,7	2,5
Pixel Forward v	7,3	14,4	6,1
TIB	5,1	10,1	3,2
TOB	7,5	11,1	7,5
TID	4,3	10,4	2,4
TEC	10,1	22,1	2,9

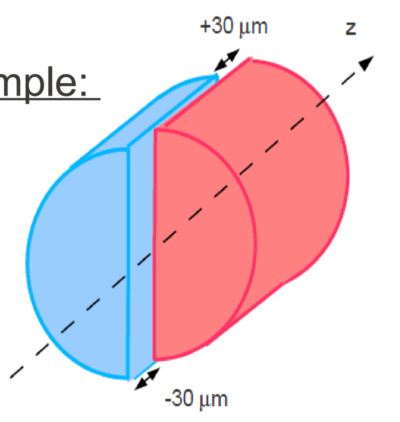
The alignment using tracks from cosmic rays and collisions shows a clear **improvement** especially in the **forward direction** and the **pixel** compared to the expected alignment at startup.

Alignment Monitoring: PV validation

A primary vertex (PV) validation is used to monitor the alignment quality in the pixel detector over time. For tracks of good quality an unbiased PV is refitted using all tracks except the probe track.
Residuals with respect to the refitted PV are evaluated and finally plotted vs the probe track parameters in different bins of η, ϕ and the transverse momentum to spot degradations of the alignment.

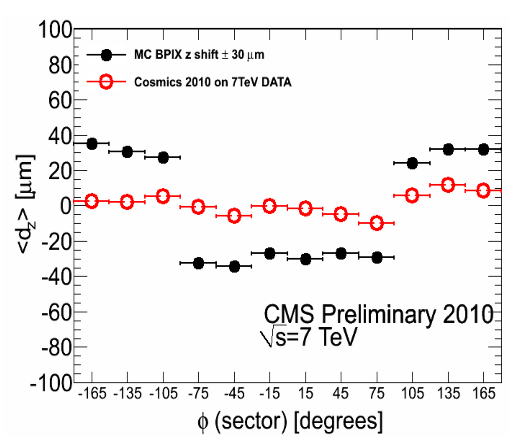


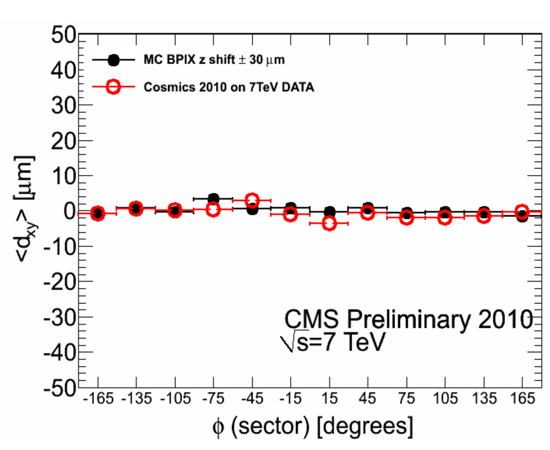
Example:



A z-shift of the two pixel half-shells by 30 micron in opposite directions would result in a shift of d_z of 30 microns for different regions in ϕ as shown below.

DATA points (open red circles): obtained using a geometry from March on tracks collected in April shows no big structures. Pixel geometry has no biases > 10 microns. Geometry stable over time

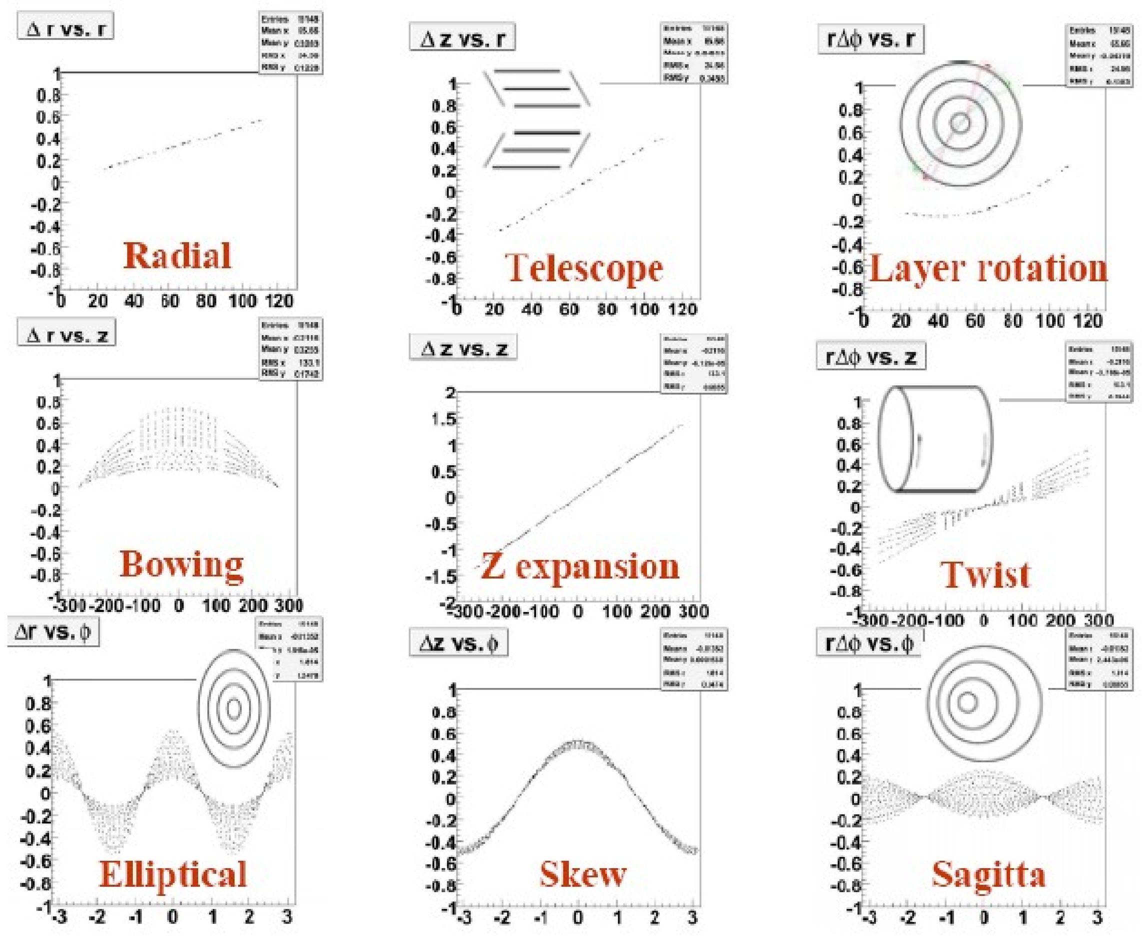




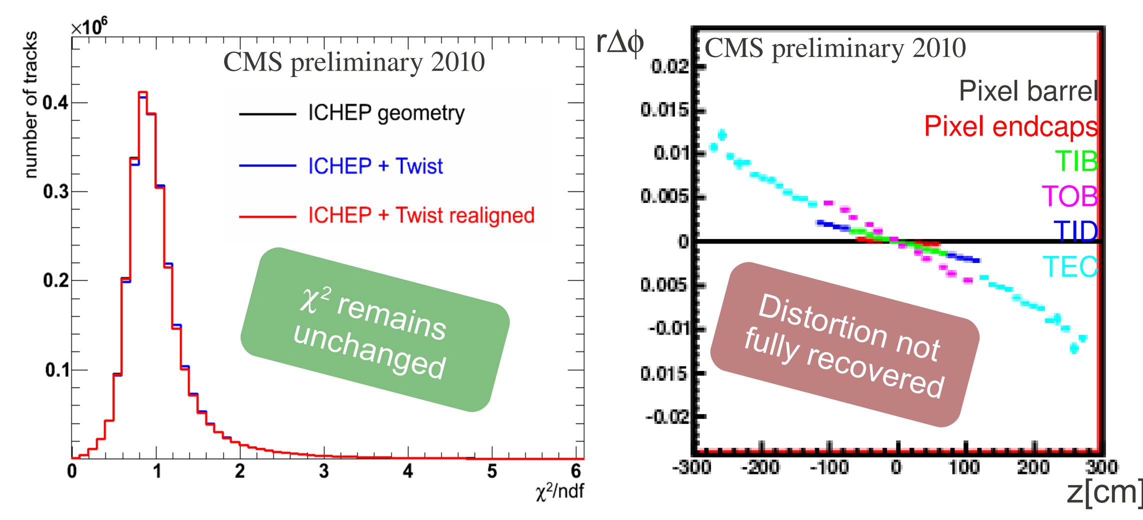
MC points (black squares): perfectly aligned MC with barrel pixel half-shells shifted along z by 30 microns in opposite directions.

Systematic misalignment studies

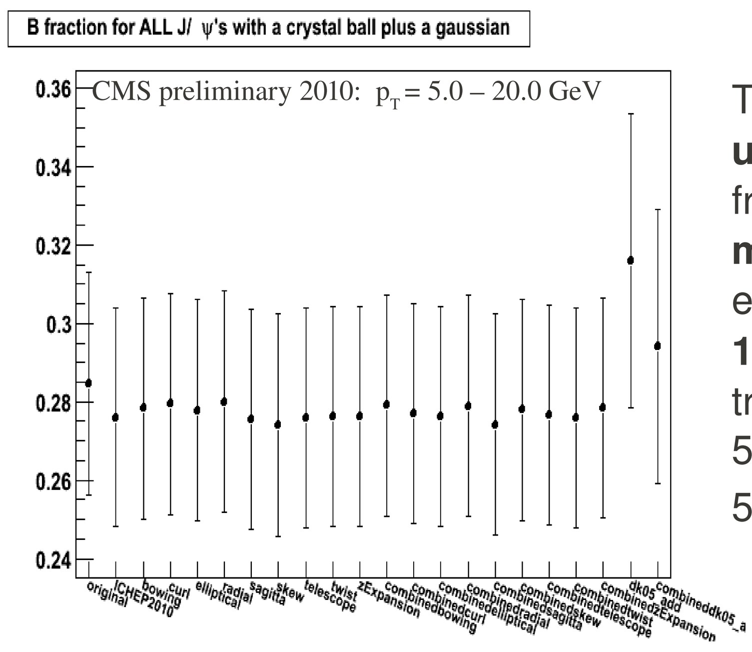
The future alignment challenge will be the detection and constraint of tracker distortions which do not or only weakly influence the χ^2 ('weak modes') but still effect the track parameters like d_0 or the curvature.



To detect and investigate the influence of possible weak modes the above correlated detector deformations were applied on top of the latest tracker geometry, then aligned back following the same strategy as before and compared to the starting geometry.



Impact on physics analysis:
To estimate the influence of correlated misalignments on physics analysis (example: B-fraction measurement in J/ψ analysis[4]) the analysis was repeated for all 9 geometries and the difference in the B-fraction was compared.



The **systematic uncertainties** arising from possible correlated **misalignment** is overall estimated to **1%** for J/ψ with a transverse momentum of 5 – 20GeV (4% for p_T 0-5GeV)

Summary & Outlook

Summary:

- Good performance of the alignment algorithms using information from collisions and cosmic ray data
  - Largest improvements in the forward region and the pixel
- Monitoring of the alignment over time (Primary vertex validation etc.) shows a stable behaviour

Ongoing/Future challenges:

- Determining and constraining χ^2-invariant deformations of the tracker in close cooperation with physics groups (Onia, b-tagging, Z→ µµ)
- Usage of additional datasets (beam halo, isolated muons, laser alignment data) and constraints (mass constraint Z→ µµ)

References

[1] V. Blobel, “Software alignment for tracking detectors”, Nucl. Instrum. Meth. A566, 2006
[2] V. Karimaki, T. Lampen, and F. P. Schilling, “The HIP algorithm for track based alignment and its application to the CMS pixel detector”, CMS Note 2006/018, 2006
[3] CMS Collaboration, “Alignment of the CMS Silicon Tracker during Commissioning with Cosmic Rays”, arXiv:0910.2505v2, JING_S_T, 2010
[4] CMS Collaboration, “Inclusive total and differential production cross sections of J/ψ and b-hadron production in pp collisions at $\sqrt{s}$ = 7 TeV with the CMS experiment”, CMS PAS BPH-10-002, 2010