Alignment of the CMS Tracker and latest results from 2018.

Patrick L.S. CONNOR on behalf of the CMS Collaboration

The CMS tracker

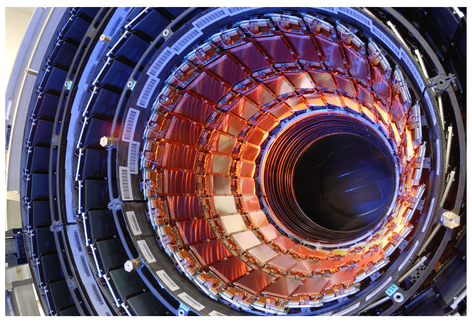


Figure from [1]

History

> *Phase-0*: Run-I & Run-II 2016 [2]
> *Phase-I*: Run-II 2017-2018 & Run-III [3]
> *Phase-II*: Run-IV [4]

Phase-I

> *Inner pixel detector*: PXF + PXB
> *Outer strip detector*: TIB + TID + TOB + TEC

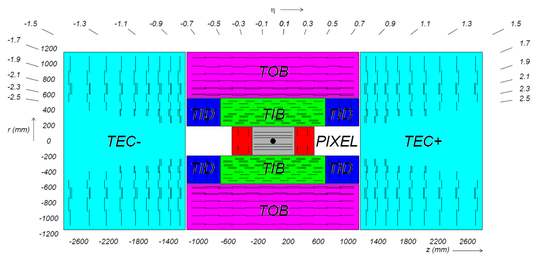
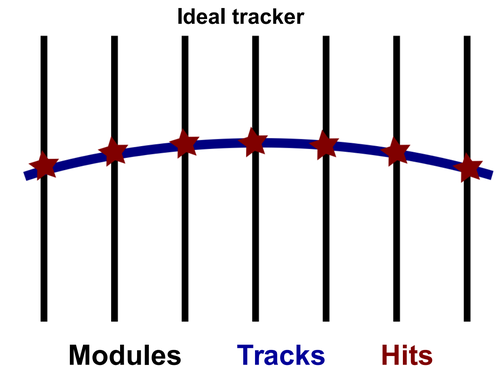
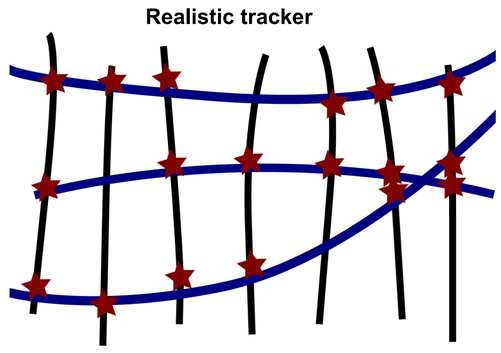


Figure from [8]

Purpose





Tracking performance is reduced due to misalignment

Challenge

At mounting

Mechanical alignment is performed but performance is still limited:

$$\sigma_{\text{align}} \gg \sigma_{\text{hit}}$$

~ 0.1 mm

~ 10 µm (pixel)
~ 20-60 µm (strip)

Goal

Compute a correction for each module in order to improve the tracking performance:

$$\sigma_{\text{align}} \approx \sigma_{\text{hit}}$$

> Each sensor has to be aligned
> 3+3+3 parameters for **position**, **orientation** and **curvature**
> Some modules are made of two sensors

→ **~ 200k parameters** to determine!

+ keep constant performance over time

Track-based alignment [5]

$$\chi^2(\mathbf{p},\mathbf{q}) = \sum_j^{\text{tracks}} \sum_i^{\text{hits}} \left(\frac{m_{ij} - f_{ij}(\mathbf{p},\mathbf{q}_j)}{\sigma_{ij}} \right)^2$$

> module and track parameters **p** and $\mathbf{q}_j$
> measured and predicted position m_{ij} and f_{ij}
> measurement uncertainty σ_{ij}

→ linearisation of the χ² allows to treat the problem with linear algebra

Global χ² minimisation with MillePede-II [6]

> global fit of **p** and $\mathbf{q}_j$, including all correlations
> takes advantage of the different nature of **p** and $\mathbf{q}_j$
→ global vs local parameters
> very demanding in terms of memory (~100 GB of RAM)

Note: MillePede-II is a project independent from CMS

Local χ² minimisation with HipPy [7]

> iterative procedure, where
1) fix track parameters $\mathbf{q}_j$ to fit module parameters **p**,
2) *vice versa* & iterate
> reasonable memory consumption

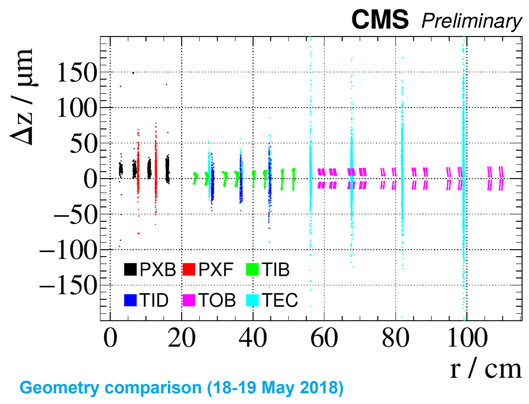
The precision of the alignment depends on the statistics used to perform the minimisation. → **alignment in data taking** / → **aligned tracker**

Re-alignment in 2018 [8]

Strategy

> Pixel tracker very sensitive to intense radiation
> Larger samples after several months of data taking
> Improve performance for physics analysis

→ ~ 80 sets of calibration constants covering first half of the year's data taking

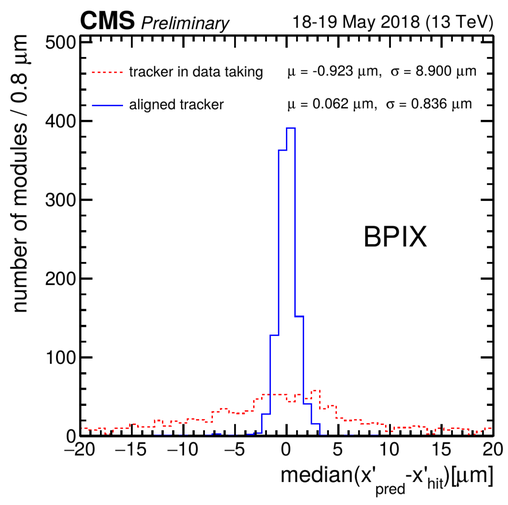


Geometry comparison (18-19 May 2018)

> Each point represents a module.
> X-axis: Old position.
> Y-axis: Difference in the position of the module between the two sets of alignment constants.

→ PXB and PXF in the tracker in data taking are shifted w.r.t. the aligned tracker

Performance [8]



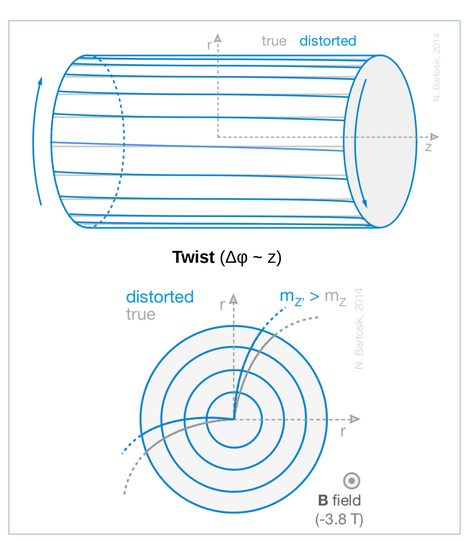
Distribution of the median of the residuals

> Residuals are computed for each module
→ track fit is performed with N-1 hits
> The median of the residuals per module is histogrammed
→ shown here for local x' coordinate in PXB
> μ and σ are the parameters of a Gaussian fit

→ local precision of the tracker in data taking is improved with a factor of 10 in the aligned tracker

Weak modes

Symmetric detector + **Symmetric track topology** → **Certain transformations have Δχ² ~ 0** → **Tracks from resonance** / **Cosmic rays**



Figures from [9]

Time variations

Magnet cycles | **Temperature variations** | **Ageing and calibration of the modules**

But **limited statistics** from **cosmic rays** and **resonance products**

Align separately

> *absolute* positions of the large mechanical structures with time dependence
> *relative* position of the sensors to the large mechanical structures without time dependence

Primary-Vertex validation [8]

Mean track-vertex mpact parameters

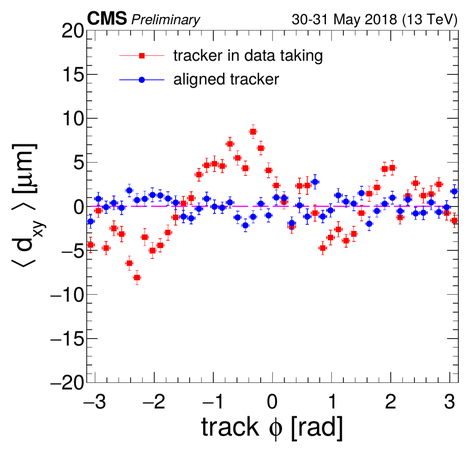
> Refit a vertex with N-1 tracks
> Investigate impact parameter distributions of the excluded track
> Very sensitive to misalignment, especially in pixel

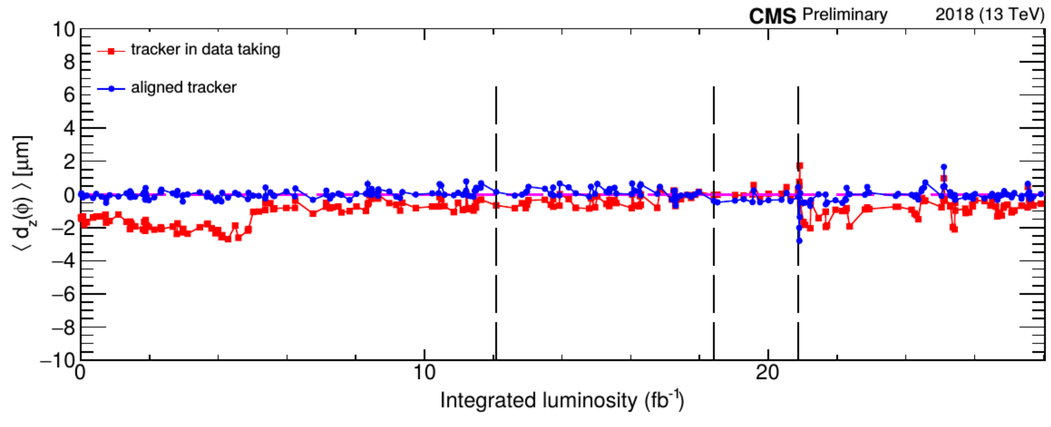
→ modulations are improved with the aligned tracker

Trends

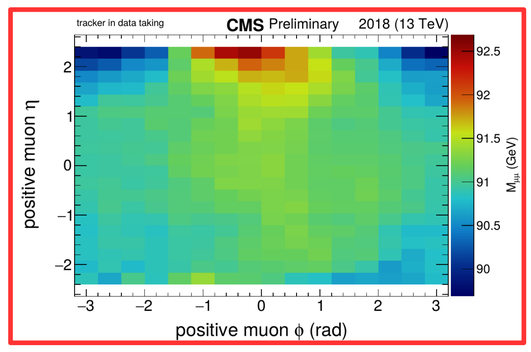
> Perform similar validation for each period
> Extract mean bias and investigate evolution w.r.t. integrated luminosity
> Vertical lines correspond to changes in the calibration of the pixel local reconstruction

→ aligned tracker is more stable than tracker in data taking



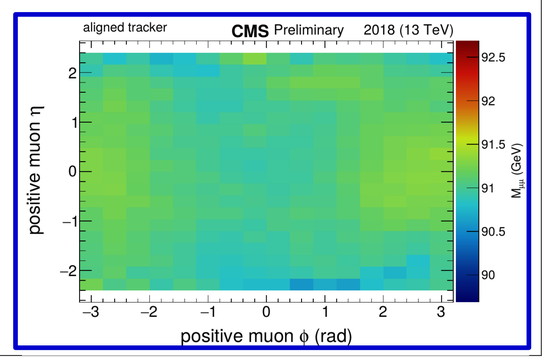


Zμμ validation [8]



> Compute $m_z(\varphi_\mu, \eta_\mu)$
> Data from throughout 2018 are used

→ misalignment of PXF in tracker during data taking is cured after re-alignment



References
[1] http://cms.web.cern.ch/news/tracker-detector
[2] The CMS tracker system project : Technical Design Report, CMS Collaboration, CERN-LHCC-98-006, CMS-TDR-5
[3] CMS Technical Design Report for the Pixel Detector Upgrade, CERN-LHCC-2012-016, CMS-TDR-011
[4] The Phase-2 Upgrade of the CMS Tracker, CMS Collaboration, CERN-LHCC-2017-009, CMS-TDR-014
[5] The CMS collaboration. "Alignment of the CMS tracker with LHC and cosmic ray data". In: Journal of Instrumentation 9.06 (2014), P06009.
[6] Volker Blobel and Claus Kleinwort. "A New Method for the High-Precision Alignment of Track Detectors". In: Proceedings of the Conference on Adcanced Statistical Techniques in Particle Physics (2002).
[7] CMS Collaboration. The HIP Algorithm for Track Based Alignment and its Application to the CMS Pixel Detector. http://lib.tkk.fi/Diss/2007/isbn9789521037115/article6.pdf.
[8] Tracker Alignment performance in 2018: https://twiki.cern.ch/twiki/bin/view/CMSPublic/TkAlignmentPerformanceMid18
[9] Nazar Bartosik. "Associated top-quark-pair and b-jet production in the dilepton channel at s = 8 TeV as test of QCD and background tt+Higgs production". PhD thesis. Hamburg: U. Hamburg, Dept. Phys., 2015.