Alignment of the CMS Tracker and latest results from 2022

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The CMS tracker

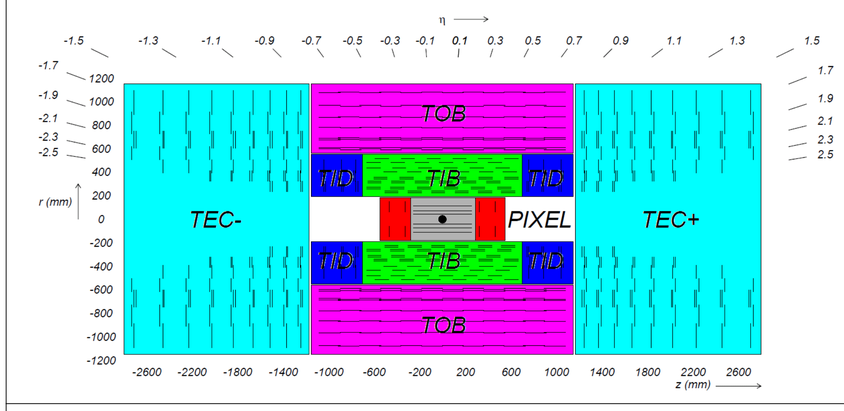


Figure from [4]

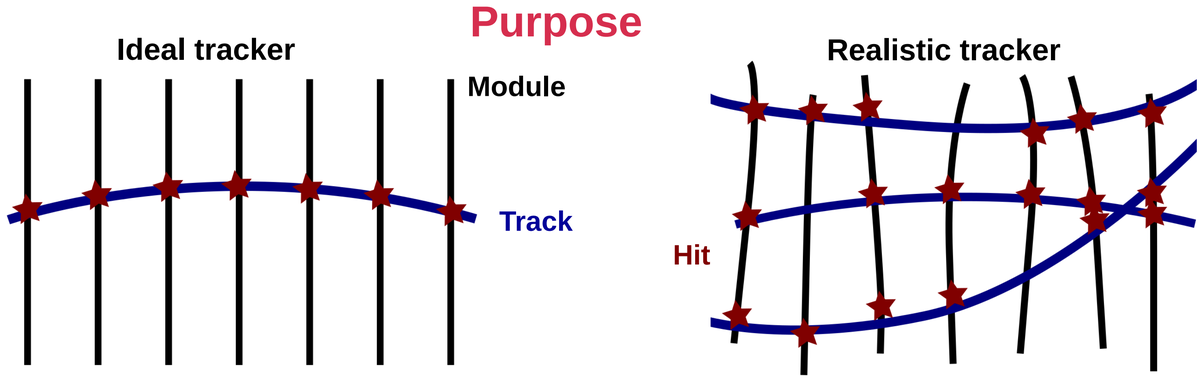
History

***Phase-0*: Run-I & Run-II [1]**
***Phase-I*: Run-II & Run-III [2]**
***Phase-II*: Run-IV [3]**

Phase-I

***- Inner pixel detector*:**
BPIX + FPIX
***- Outer strip detector*:**
TIB + TID + TOB + TEC

Purpose



Tracking performance is affected by misalignment

The Challenge

At mounting

The tolerance of **mechanical alignment** cannot guarantee design **single hit resolution:**

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

~ 0.1 mm **~ 10 µm (pixel)** **~ 20-60 µm (strip)**

Aim

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

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

- Each sensor must be aligned: **9 parameters** **6 rigid body** and **3+ curvature**
- Some **modules** are made of two **sensors**

>200k parameters to determine & preserve 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 **p** and track parameters $\mathbf{q}_j$
> measured $\mathbf{m}_{ij}$, expected position $\mathbf{f}_{ij}$
> measurement uncertainty $\boldsymbol{\sigma}_{ij}$

→ linearisation of χ² allows treatment with linear algebra

Global χ² minimisation: MPII [6]

- global fit of **p; $\mathbf{q}_j$**, and **correlations**
- differentiates between **global** vs **local** parameters
- high memory consumption ~O(100 GB)

Local χ² minimisation: HipPy [7]

- iterative procedure:
1) fix $\mathbf{q}_j$ to fit module parameters **p**
2) *vice versa* & **iterate**

Strategy

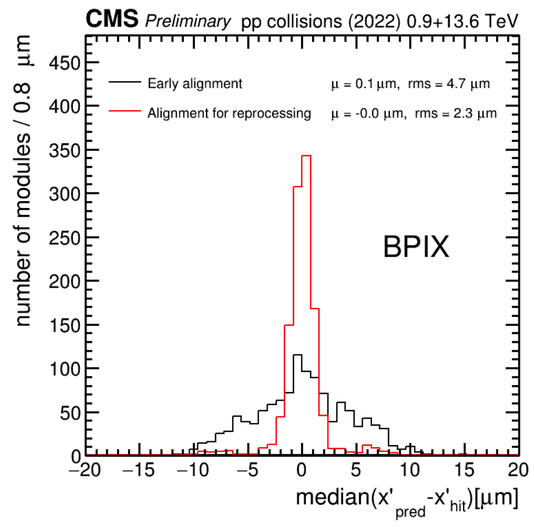
> Position bias of **single pixel hit** depends on **calibrations**
> Affected by **large irradiation**
> Maximise precision of **tracker alignment** using different **track topologies: collision + cosmic-ray**

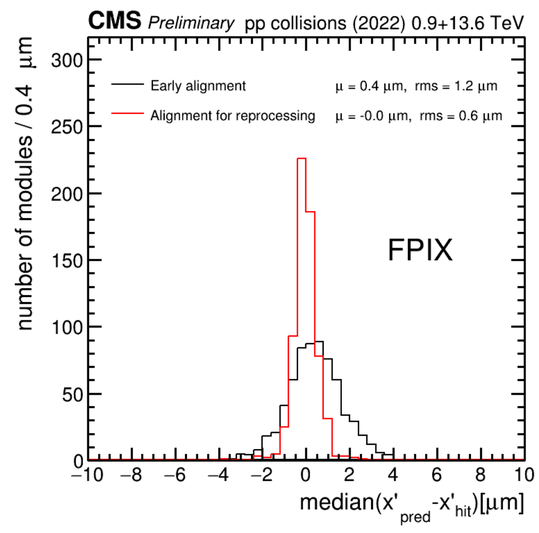
Performance in 2022 [8]

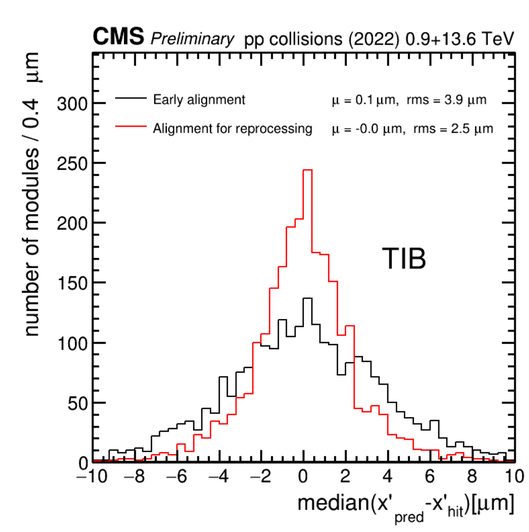
Distribution of the median of the residuals

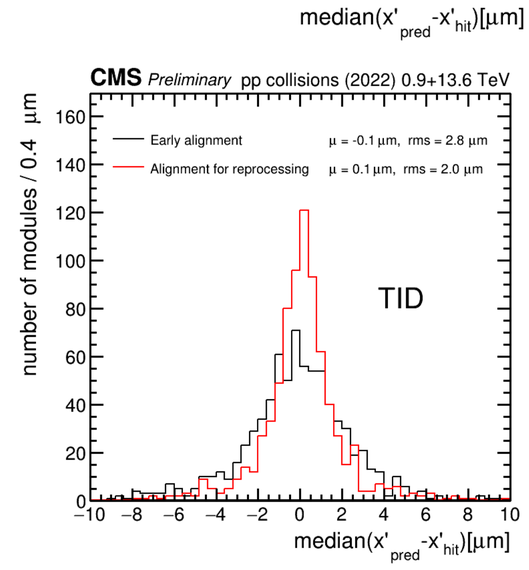
> Residuals for **each module**
> Evaluated in **track refitting** after removing **associated hit**
> Median of residuals per module for **local x'** coordinate of the modules **in pixel & strips**
> μ and **σ** parameters of **Gaussian fit**

→ local precision largely improved in alignment for reprocessing







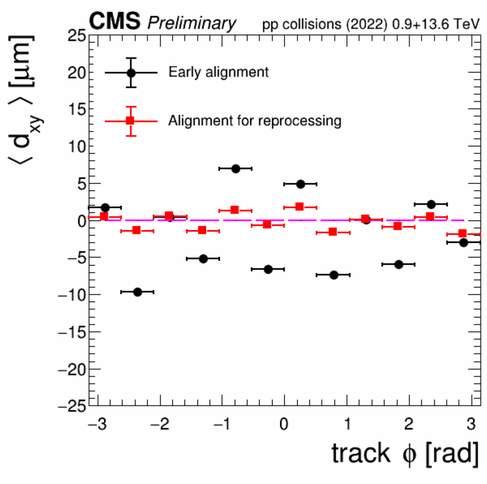


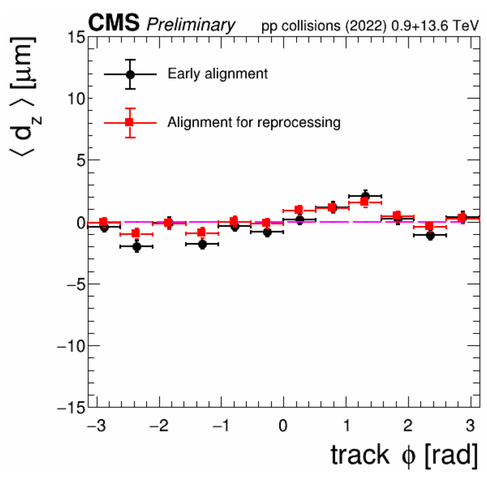
Primary-Vertex validation [8]

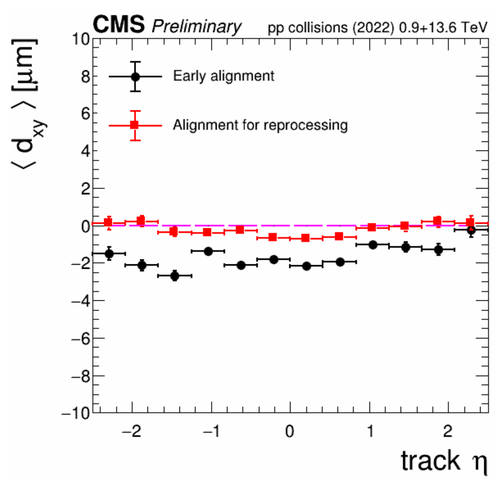
Mean track-vertex impact parameters

> Refit a **vertex** with **N-1 tracks**
> Investigate i**mpact parameter distributions** of **excluded track**
> Very sensitive to **misalignment** in pixel

→ modulations greatly **reduced in alignment for reprocessing**







References
[1] The CMS tracker system project : Technical Design Report, CMS Collaboration, CERN-LHCC-98-006, CMS-TDR-5
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[1] The CMS tracker system project : Technical Design Report, CMS Collaboration, CERN-LHCC-98-006, CMS-TDR-5
[4] http://cms.web.cern.ch/news/tracker-detector
[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.
[8] Tracker Alignment performance in 2022 Approval : https://indico.cern.ch/event/1210643/