CMS automated alignment in Run III

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Why automation?

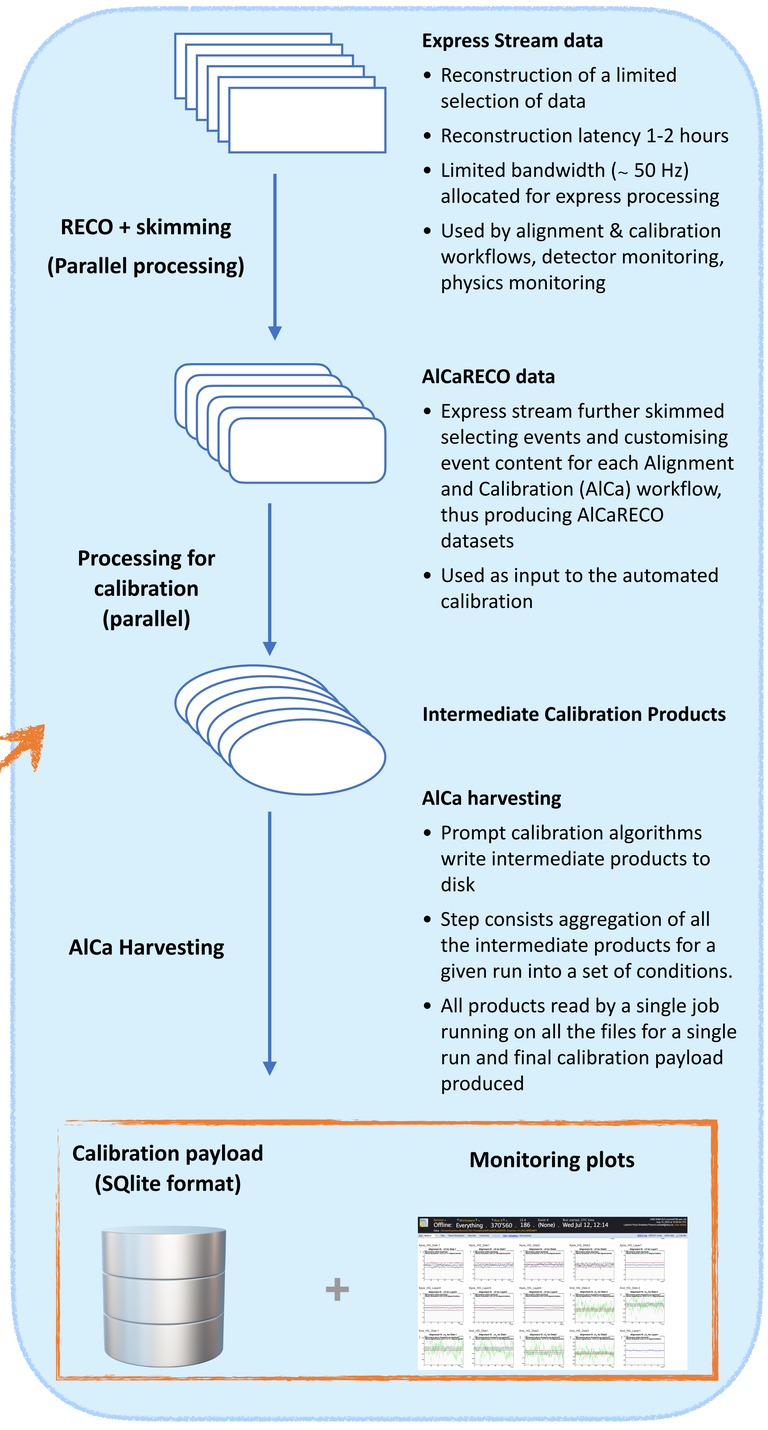
- Calibrations available with short turnaround –> key asset for several aspects of detector operations
- Good quality data, usable for physics analysis, already available 48-72 hours after acquisition
- Reduces need for further reprocessing of data

Prompt calibration loop (PCL)

- Low latency alignment and calibration workflows run immediately after data-taking
- **Run automatically on the Tier0 farm**
- Workflows used to produce conditions which need continuous updates and/or monitoring
- **Update strategy** based on delay between "express reconstruction" of a sub-set of the data (performed within 1-2 hours of data-taking) and "prompt reconstruction" of the bulk of the data (performed after 48 hours since the data was taken)
- Automated workflows executed for each acquired run

Workflow: [1]

- Process a subset of data for each run
- Compute alignment and calibration conditions
- Upload to the CMS Conditions Database (DB)
- Conditions consumed by prompt reconstruction
  - Reconstruction of bulk of the data starts after 48h of data acquisition for the run, profiting of the updated calibrations
  - Offline applications retrieve the conditions data for the Interval of Validity (IoV) corresponding to run-X (already processed by prompt calibration)
  - **Prompt reconstructed datasets used for Physics Analyses**



Automated alignment and calibration system in place since LHC Run I

- A general consolidation effort put in place during Run II and Run III to integrate new alignment and calibration algorithms
- Several calibration workflows running currently, covering a wide-range of calibrations including:
  - Determination of the Lorentz Angle in the barrel region of the SiPixel tracker
  - Identification of transient problematic channels in the SiStrip tracker for each run
  - **Track-based alignment of the different structures in the SiPixel detector**

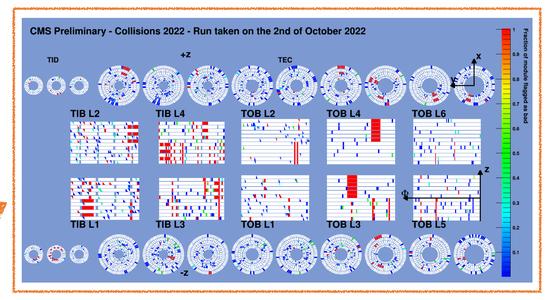
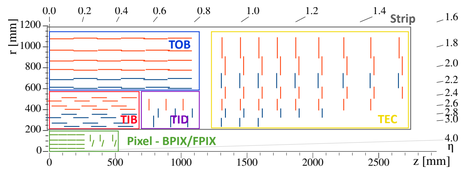


Image Source: [2]

Alignment of the CMS Tracker

The CMS Tracker:

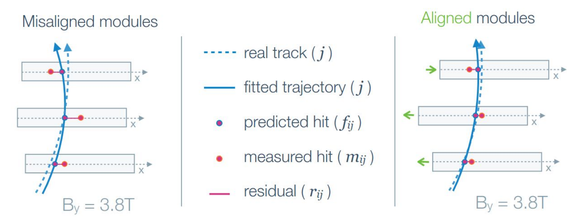
- **Innermost detector**, closest to the interaction point
- Estimates p_T, impact parameter etc, of charged particles (tracks)



Phase 1 tracker (since Run II 2017): Pixel (1856 modules) + Strip (15,148 modules) [3]

Tracker Alignment

Goal: Determine the position and orientation of the modules such that the **alignment precision < intrinsic hit resolution** (~10 μm)



Need to frequently realign the tracker due to several sources of time variation: magnet cycles, temperature variations, change in Lorentz drift caused by radiation

Track-based alignment [4]

Following a least-square approach, minimising the χ^2

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

Where p : alignment parameters
q : track parameters
m : measurements (e.g. hits)
f_{ij} : predictions
σ^m : measurement uncertainty

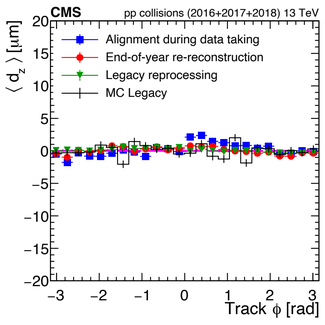
Two independent algorithms

MillePede - II
- Global χ^2 minimisation
- Global fit of p and q_j including all correlations

HipPy
- Local χ^2 minimisation
- Iterative procedure

Automated alignment in Run II [4]

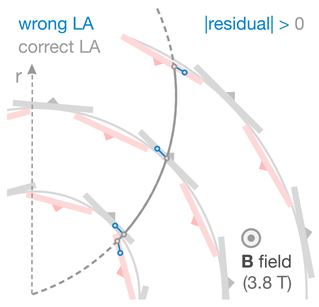
- **Automated workflow for alignment of pixel half-barrels and half-cylinders** (6 structures) run during data-taking as part of the PCL
- 36 alignment parameters in total (6 degrees of freedom x 6 structures)
- Workflow (referred to as LG-PCL), using MillePede - II algorithm, designed specifically to deal with large movements associated with magnet cycles

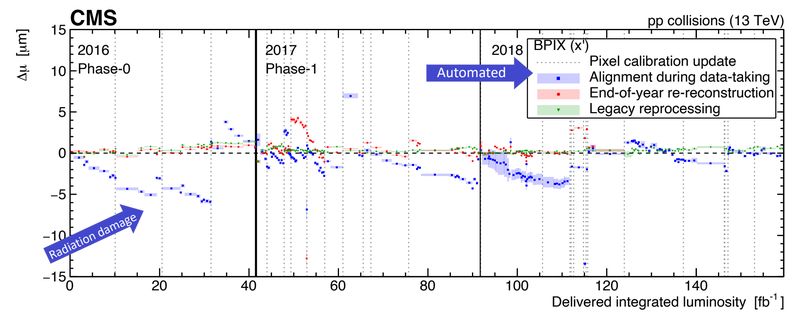


Mean track-vertex impact parameter in the longitudinal plane d_z as a function of track ϕ
In blue: mostly covered by automated alignment

Sensitivity to Lorentz Drift

- **Sign of Lorentz Angle (LA) shift –> dependent on orientation of E field**
- **In barrel pixel** –> modules arranged in ladders, **alternatively facing inward or outward w.r.t the beam line**
  - Thus opposite shift in hit position for inward and outward modules
- **Impact of radiation damage evident in $\Delta\mu$** = difference in the mean (μ) of the Distribution of Mean (track-hit) Residuals (DMRs) of inward and outward facing modules





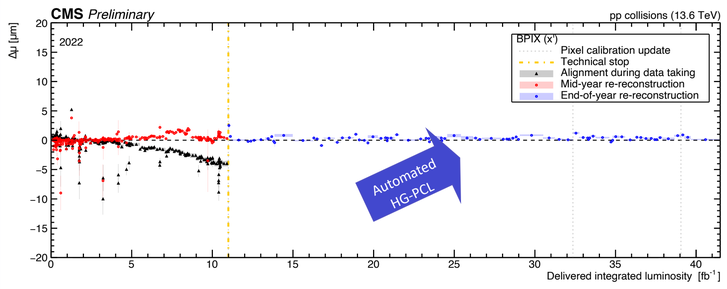
The DMR trends for the barrel pixel for the years 2016–2018, as functions of the delivered integrated luminosity [4]

Deviation from zero -> Shift in LA -> indication of radiation damage

- Automated alignment in Run II not granular enough to absorb radiation effects!

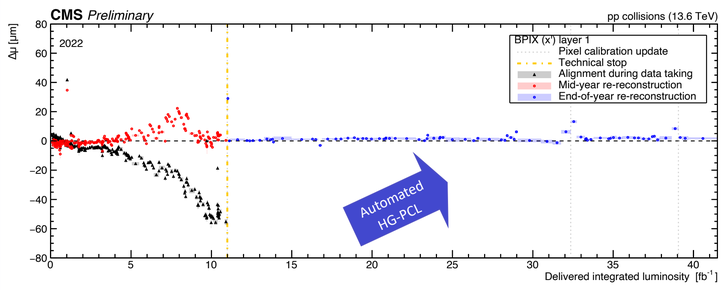
Automated high-granularity alignment for LHC Run III

- Increase granularity from high-level structures to "almost" module level: align the barrel pixel ladders and forward pixel panels
- Number of alignment parameters increased from 36 to over 5000!
- Automated workflow running as part of the PCL - workflow referred to as HG-PCL
- Deployed in the middle of 2022 after a technical stop of LHC



The DMR trends for the barrel pixel for 2022, as a function of the delivered integrated luminosity [5]

Online HG-PCL corrects positional bias developed during data-taking



The DMR trends for the barrel pixel layer 1 for 2022, as a function of the delivered integrated luminosity [5]

BPIX layer 1 more affected since its closer to the interaction point

Outlook

- **Automated alignment with high granularity** helps:
  - counteract degradation of performance from irradiation
  - reduce the effort while reprocessing the data
- Does this make offline calibration obsolete? **NO!**
  - Strip tracker not automatically aligned → need offline alignment
  - Due to exclusive usage of collision tracks by the automated alignment, limited capability to constrain systematic deformations ("weak modes")
    - ✦ Work in progress to include a larger kinematic variety of tracks used by HG-PCL
  - Alignment conditions used for reconstruction at HLT-level provided by performing manual offline alignments
    - ✦ Efforts ongoing to develop a PCL workflow to provide alignment conditions for HLT

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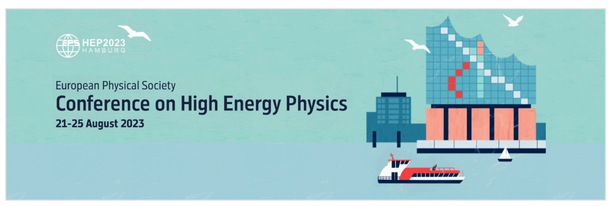

References

[1] Cerminara G et al, "Automated workflows for critical time-dependent calibrations at the CMS experiment", J. Phys.: Conf. Ser. 664 072009
[2] The CMS Collaboration, SiStrip Bad components 2022, https://twiki.cern.ch/twiki/bin/view/CMSPublic/SiStripBadComponents2022
[3] The CMS Collaboration, "The Phase-2 Upgrade of the CMS tracker", CERN-LHCC-2017-009
[4] The CMS Collaboration, "Strategies and performance of the CMS silicon tracker alignment during LHC Run 2", doi:10.1016/j.nima.2022.166795
[5] The CMS Collaboration, "Tracker alignment performance in 2022 (addendum)", CERN-CMS-DP-2022-070