Real-time alignment and calibration in Run 3 at LHCb

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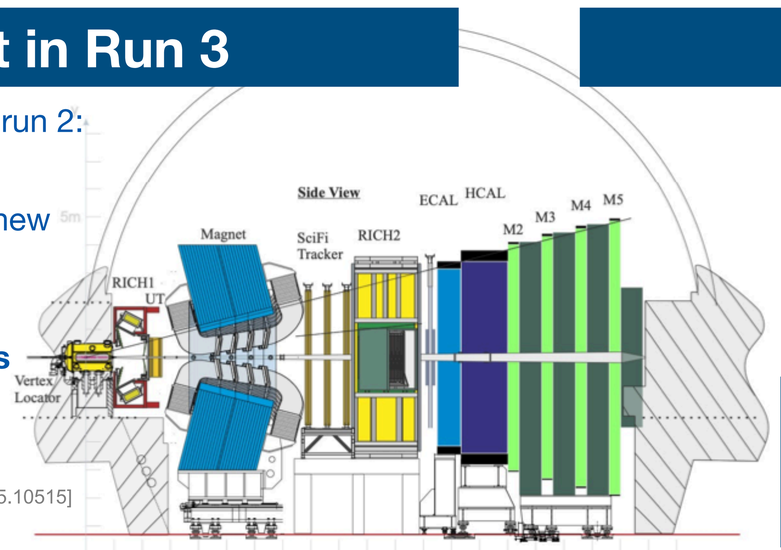
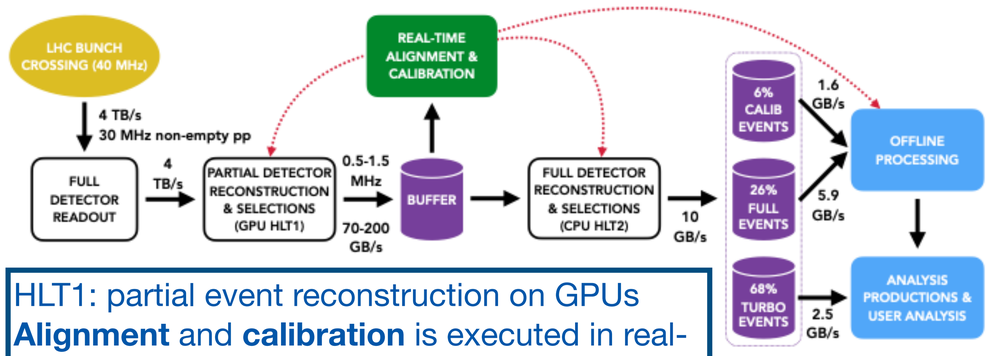
The LHCb experiment in Run 3

- Instantaneous luminosity about 5x higher than in run 2: $\mathscr{L}_{\text{inst.}} = 2 \cdot 10^{33}\text{cm}^{-2}\text{s}^{-1}$
- **Tracking detectors** (VELO, UT, SciFi) are brand new to handle higher track multiplicity and radiation
- Fully **software-based trigger system**
- Larger event rate: **DAQ** and **read-out electronics** have been upgraded



[arXiv:2305.10515]

LHCb trigger system in Run 3



HLT1: partial event reconstruction on GPUs
Alignment and **calibration** is executed in real-time using HLT1 data
HLT2: **full event reconstruction** on 4400 CPUs

[LHCB-FIGURE-2020-016]

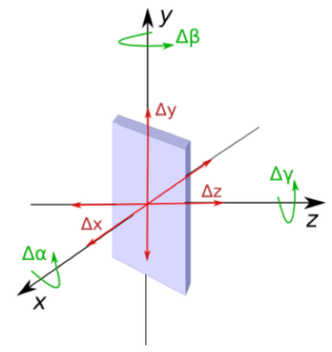
Alignment and Calibration

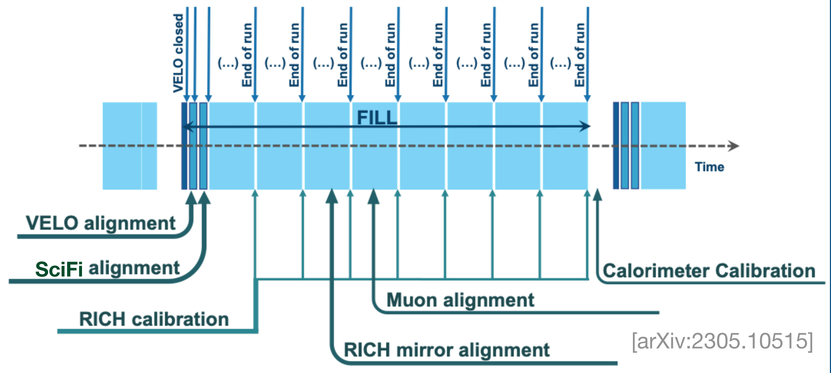
During a fill, the different subdetectors (VELO, UT, SciFi, RICH) are **aligned** and **calibrated**

Procedure: Use same **Kalman Filter** as in **track reconstruction** for potential corrections to detector positions

$$\chi_i^2 = r_i^T(x)\ V_i^{-1}\ r_i(x) \rightarrow x^{(1)} = x^{(0)} - \left(\frac{\partial^2\chi^2}{\partial x^2}\right)^{-1}\frac{\partial\chi^2}{\partial x}$$ [NIM A 600.2 (2009)]

$\mathbf{r_i}$: residuals between measurement model and measured coordinates
$\mathbf{V_i}$: measurement covariance matrix from kalman filter
$\mathbf{x}$: alignment parameters



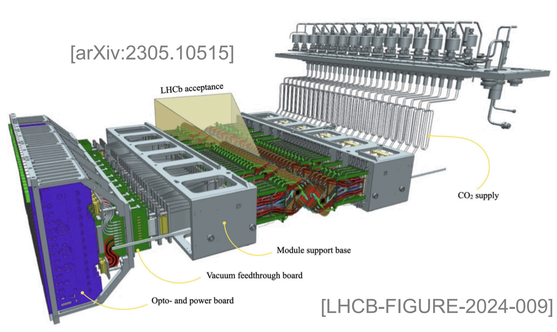


[arXiv:2305.10515]

Alignment constants: transformations such as translations in and rotations of the detector components around the x, y and z axis
Minimisation of the **global track** χ^2 yields optimal **alignment constants** x_i ➞ Update the alignment constants if they yield better performance

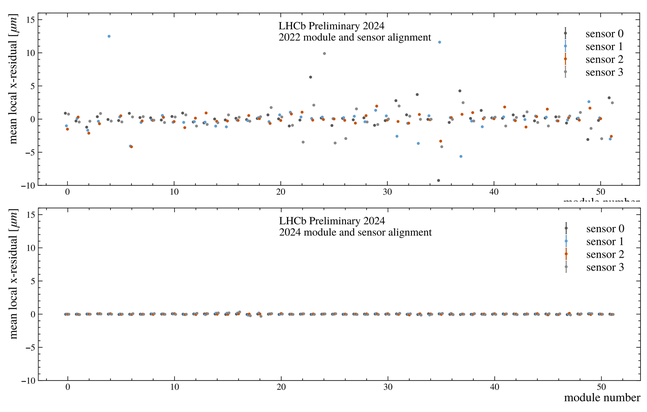
Alignment of the Vertex Locator

- The Vertex Locator (VELO) is the tracking system closest to the interaction point
- The starting point of the VELO alignment is the survey for the VELO halves and modules
- At the beginning of stable beams the VELO is closed
- The **primary vertex** position is reconstructed by each VELO half and is monitored in **real-time**



[arXiv:2305.10515]

[LHCB-FIGURE-2024-009]



Global tracker alignment

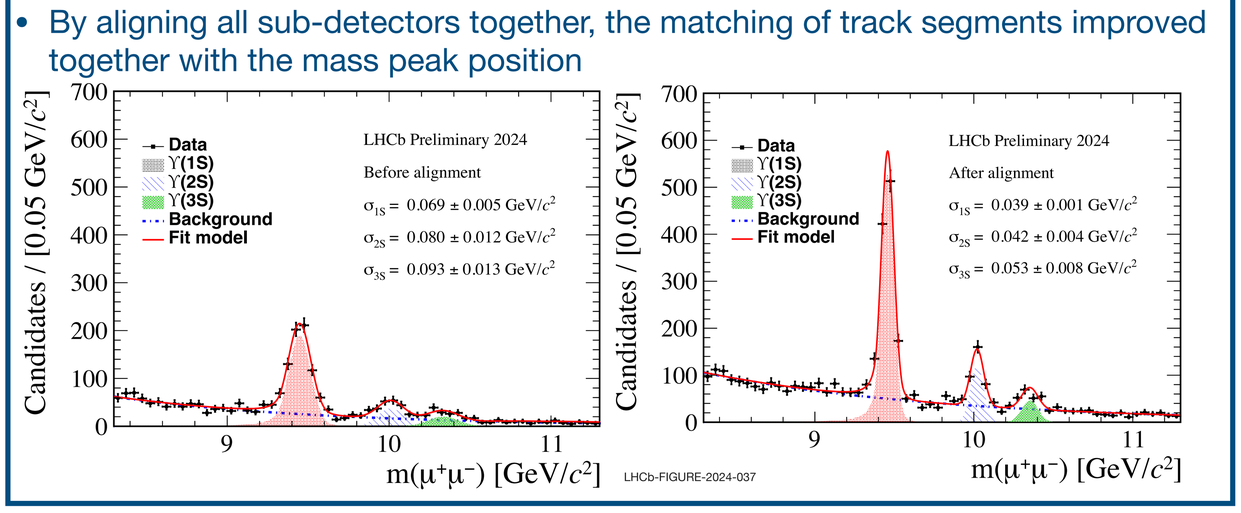
- Simultaneous alignment of the **VELO**, **UT** and **SciFi** with updated magnetic field map description

Why is this important?

- Improvements to mass width and position
- Better understanding relation between the tracking detectors
- More accurate Run 3 magnetic field map description is a more accurate description of the material in the cavern ➞ yield masses closer to the known values

Results from 2024 global alignment

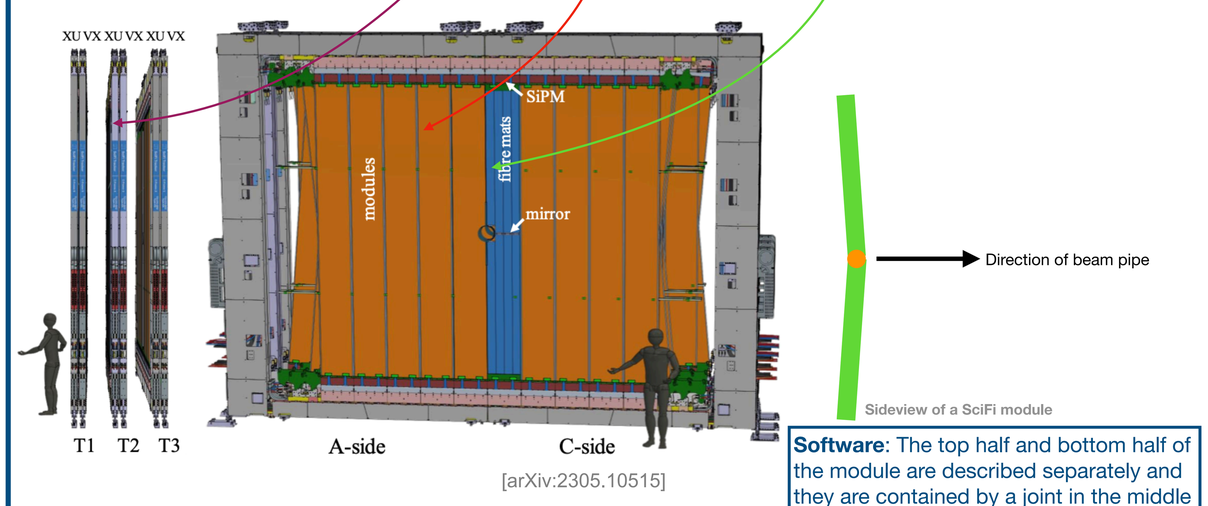
- First time to perform a full detector alignment
- Achieved similar performance on mass resolution and mean mass position as in Run 2
- By aligning all sub-detectors together, the matching of track segments improved together with the mass peak position



LHCb-FIGURE-2024-037

SciFi tracker alignment

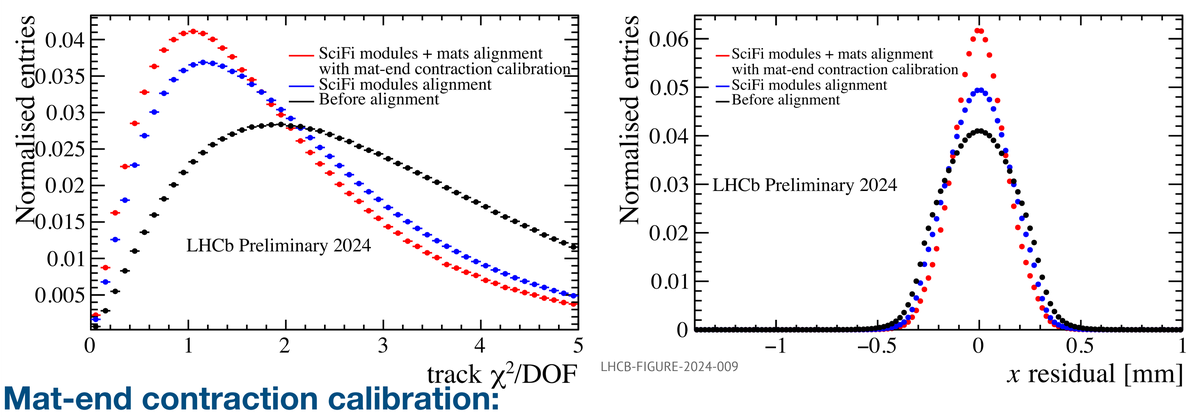
- **Data sample:** Track samples from D^0, J/Ψ and Z decays
- Corrections to the momentum scale of the tracks during the alignment by adding constraints on the mass and the vertex position
- Alignable objects are e.g. **CFrames**, **modules** or **fibre-mats**



[arXiv:2305.10515]

Software: The top half and bottom half of the module are described separately and they are contained by a joint in the middle

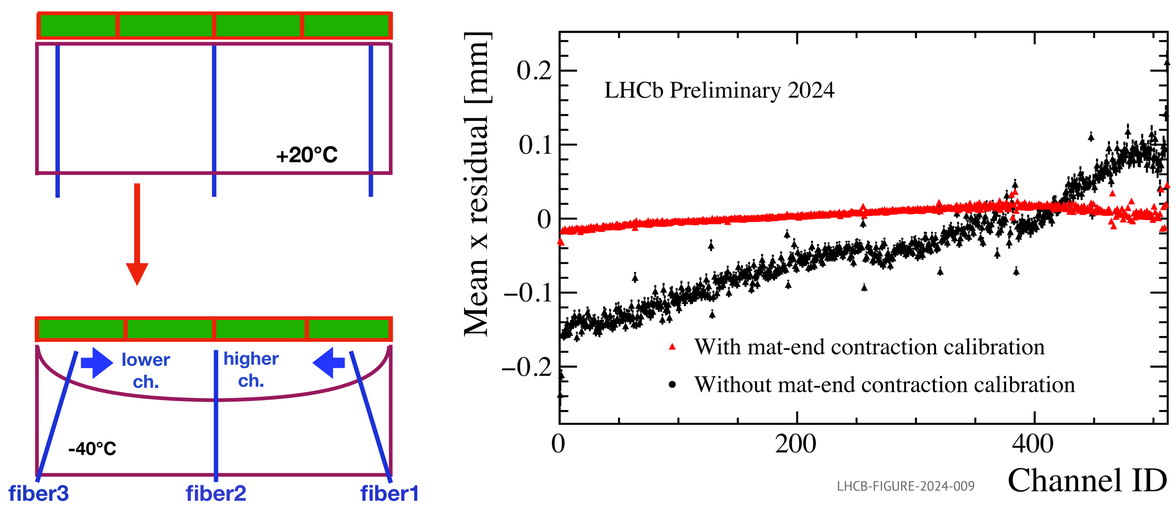
The SciFi modules are slightly bent around x-axis which the alignment has to account for



LHCB-FIGURE-2024-009

Mat-end contraction calibration:

Each fibre-mat contains four SiPMs which are placed in cold boxes cooled down to -40°C ➞ This influences the mapping of hits in the detector in x direction



LHCB-FIGURE-2024-009