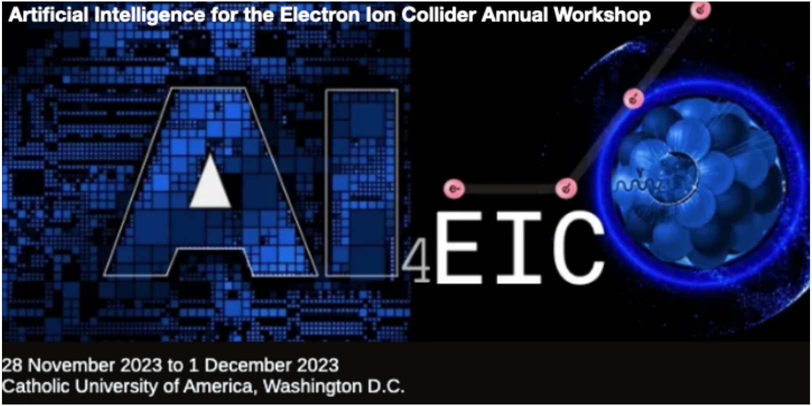
Bundesministerium
für Bildung
und Forschung

technische universität
dortmund

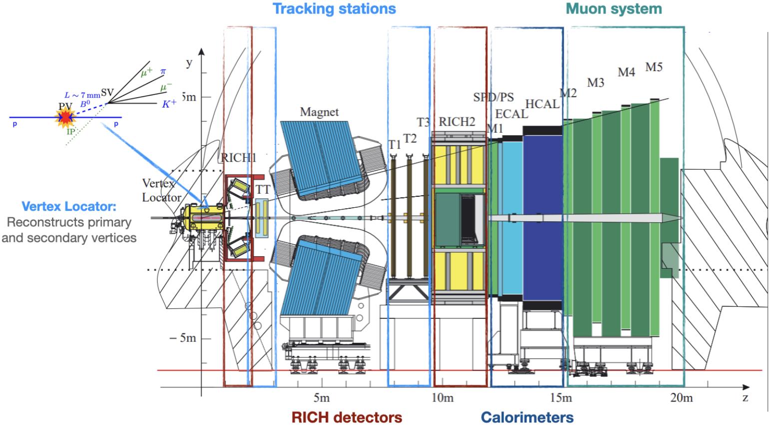
LHCb

Real-time alignment and calibration at the LHCb experiment

Biljana Mitreska



The LHCb experiment



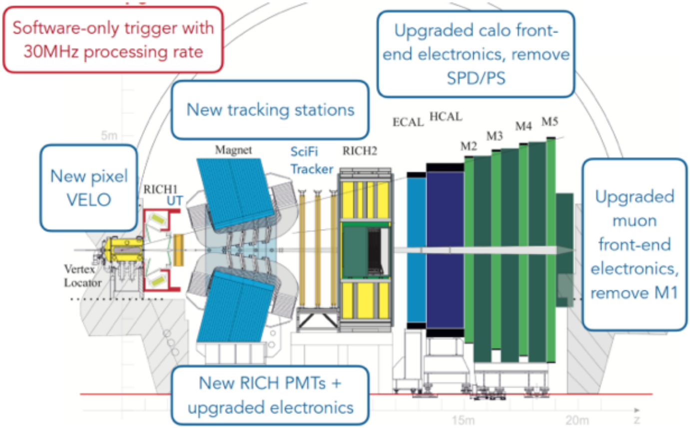
- Forward detector specialised in measuring properties of *b* and *c* hadrons
- Run 1 [2011-2012]: 7-8 TeV and 3 fb^{-1}
- Run 2 [2015-2018]: 13 TeV and 6 fb^{-1}

JINST 3 (2008) S08005

The LHCb experiment in Run 3

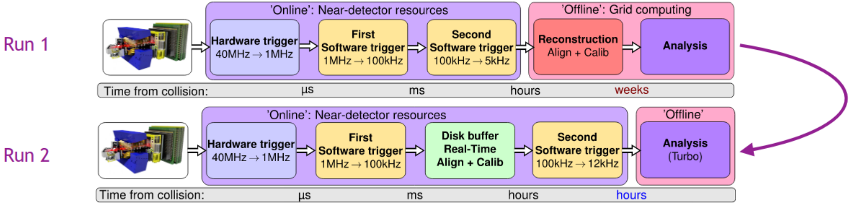
Brand new detector: Maintain the physics performance at harsher environment (5x higher luminosity)

▸ LHCb Upgrade TDR

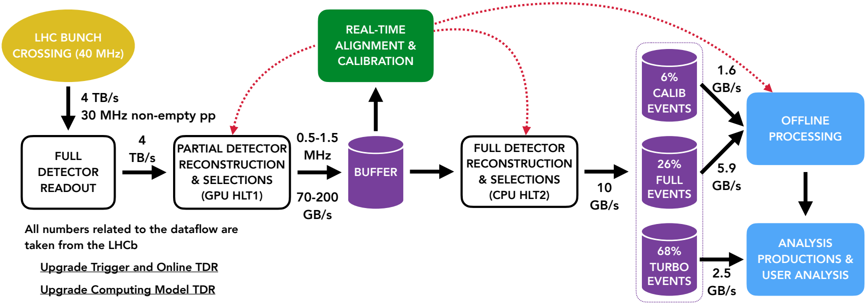


Data taking strategy

- Run 2 real time analysis model developed by LHCb → new trigger model
- Events buffered on disk while performing real-time alignment and calibration
- Physics analysis performed directly from the trigger output
- No offline processing in Run 2



The LHCb trigger in Run 3



All numbers related to the dataflow are taken from the LHCb

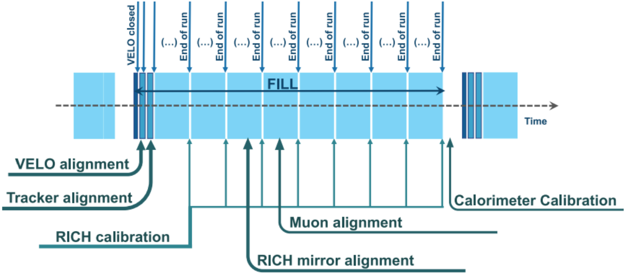
Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

1. Collision events selected with partial reconstruction (HLT1)
2. Selected events stored in a buffer
3. **Alignment and calibration** are executed
4. Alignment constants are updated if above threshold
5. Second software stage (HLT2) applies the full reconstruction

Alignment and Calibration

- Run automatically at the start of each fill
- Automatic update if the variations are significant



- Tracking alignment (VELO, UT, SciFi, Muon)
  - VELO ∼ few min
  - rest of the tracking system ∼ 10 min
- RICH mirror alignment ∼ 10 min
- RICH and CALO calibration ∼ hours

Alignment and Calibration

General strategy

- Data sample to perform alignment or calibration collected with a specific trigger selection line for each task
- Automatic evaluation within minutes
- Automatic update if variations of the constants is significant
- Monitoring plots for alignment quality produced for each subdetector: reconstruction and alignment quantities per iteration
- The new alignment and calibration constants are used by the trigger and the offline reconstruction

Advantages

- Have the same performance offline and online
- Stable alignment quality $\rightarrow$ better physics performance
- Effective trigger selections

Tracking alignment

- Method based on Kalman filter track fit ‣ NIM A 600.2 (2009)
- Takes a sample of reconstructed tracks
- Minimum χ^2 algorithm → determine the position of the detector elements

Reconstruct the tracks using the current alignment constants

$$\frac{d\chi^2}{d\alpha} = 2 \sum_{\text{tracks}} \frac{dr}{d\alpha}^T V^{-1} r$$

$$\frac{d^2\chi^2}{d\alpha^2} = 2 \sum_{\text{tracks}} \frac{dr}{d\alpha}^T V^{-1} R V^{-1} \frac{dr}{d\alpha}$$

Compute a new set of alignment constants (α) minimizing a global χ^2:

$$\alpha = \alpha_0 - \left(\frac{d^2\chi^2}{d\alpha^2}\right)^{-1}\Bigg|_{\alpha_0} \frac{d\chi^2}{d\alpha}\Bigg|_{\alpha_0}$$

Iterate until the χ^2-difference is below a threshold

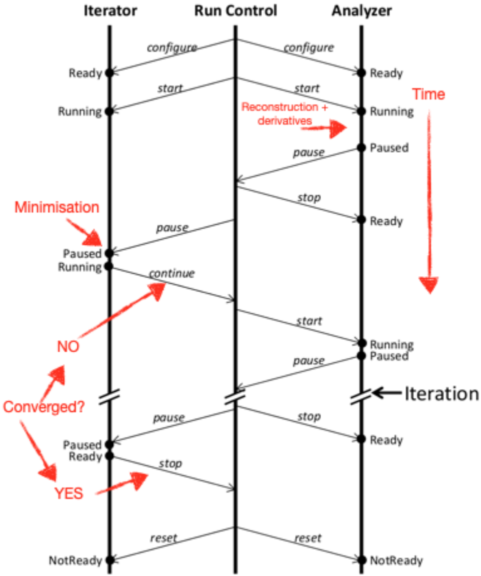
r: tracks residuals, V: covariance matrix, R: residuals' covariance matrix

- Alignment for 6 degrees of freedom: translations $(\mathrm{T_x}, \mathrm{T_y}, \mathrm{T_z})$ and rotations $(\mathrm{R_x}, \mathrm{R_y}, \mathrm{R_z})$
- Vertex and mass constraints are used ‣ NIM A 712 (2013)

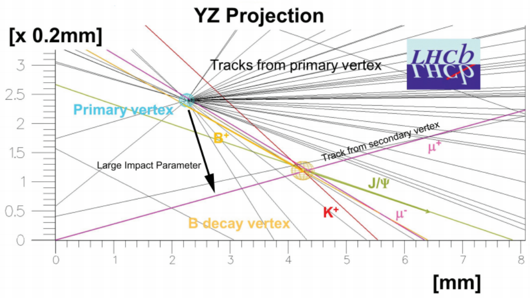
Real-time tracker alignment

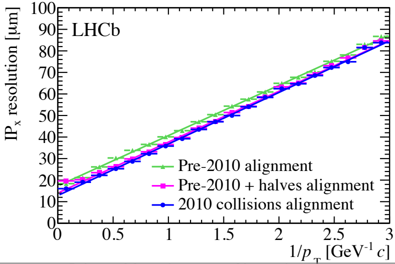
Tracker alignment is split in two parts:

- **Analyzer**
    - read current constants α_i
    - run reconstruction
    - calculate and store derivatives
- **Iterator**
    - collect derivatives
    - perform minimisation
    - write new constants α_{i+1}
    - update constants (if necessary)
- **repeat the procedure**



Importance of alignment & calibration





- Correctly distinguishing primary and secondary vertices
- Improves the quality of the impact parameter

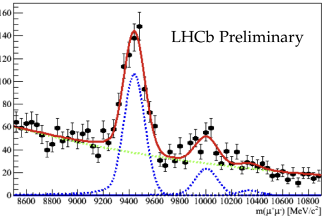
▸ Int. J. Mod. Phys. A 30, 1530022 (2015)

▸ LHCb-TDR-13

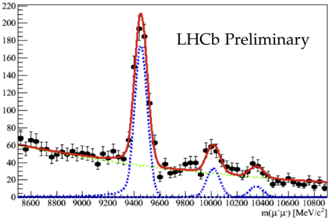
Importance of alignment & calibration

- Better alignment of the tracking system improves the mass resolution

First alignment
$\sigma_{\Upsilon} = 92\ \mathrm{MeV/c^2}$



Better alignment
$\sigma_{\Upsilon} = 49\ \mathrm{MeV/c^2}$

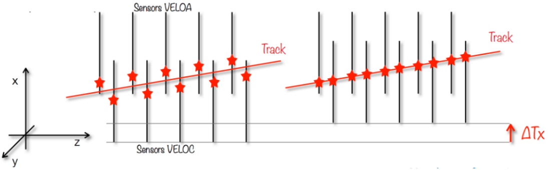


Invariant mass distribution for $\Upsilon \to \mu\mu$

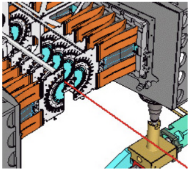
- Complete calibration of the RICH detector needed for exclusive selection using hadron particle identification criteria

VELO alignment

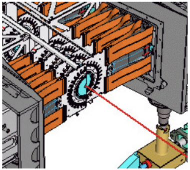
- VELO centered around the beam for each fill when the beam is declared stable



Opened at injection



Closed when stable beam declared

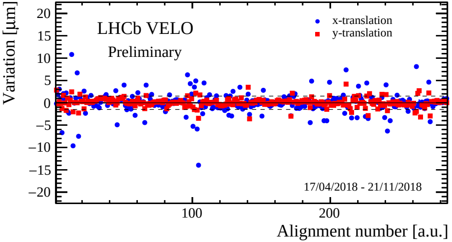


VELO alignment update tresholds

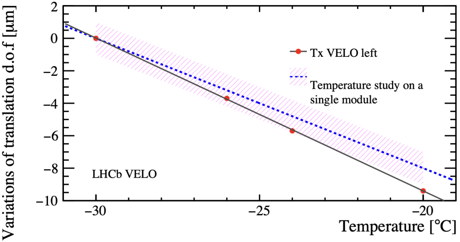
dof	Threshold
$T_x, T_y (\mu m)$	1.5
$T_z (\mu m)$	5
$R_x, R_y (\mu rad)$	4
$R_z (\mu rad)$	30

VELO alignment: Run 2 performance

Alignment Stability



Temperature dependency

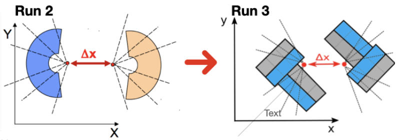


- Each point shows the difference between the initial and the new alignment constants
- Stable VELO alignment with update of constants every few fills
  LHCb-FIGURE-2019-015
- Variations of alignment constants describe well the temperature shrinkage (laboratory measurements)
  JINST 18 P10003 (2023)

VELO alignment: look at Run 3

Simulation studies

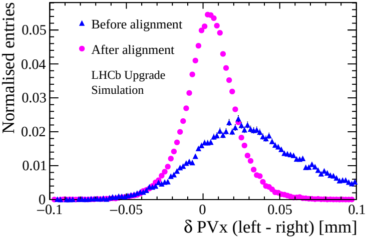
- Pixel detector with new geometry

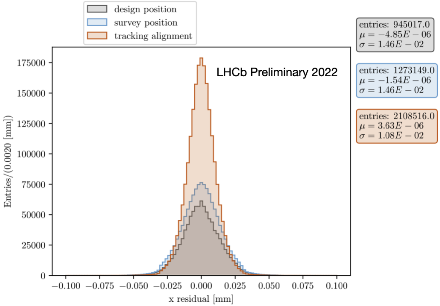


- Starting from misaligned detector (blue points)

Look at the new data

- **Survey position**: as measured during VELO commissioning
- VELO alignment procedure improves residual distribution, 10 % more PVs reconstructed





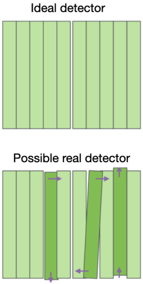
LHCB-FIGURE-2022-016

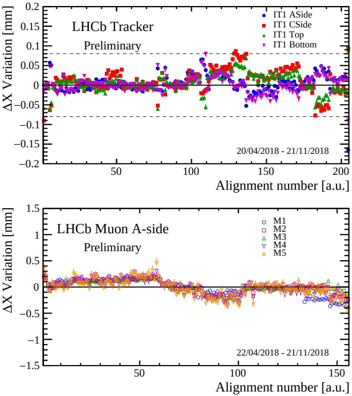
Tracker alignment

- Alignment of the tracking stations and its detector elements ($\sim$ 200 elements)
- Positions of tracking stations is affected by change of magnet polarity: variations of a few mm

- Misalignment in the tracking system affects the mass resolution and the momentum scale

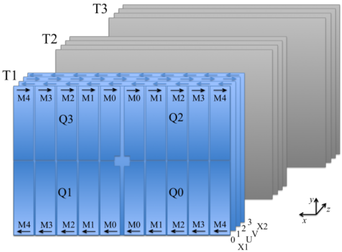
Stability in Run 2

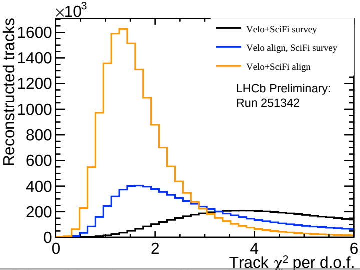




LHCb-FIGURE-2019-015

Scintillating Fibre Tracker alignment in Run 3





- Three stations (T1, T2, T3)
- Each station with 4 layers attached in pairs
- Each layer with 5 modules (10 half modules)

Out from Run 3

- Aligning the SciFi tracker improves the quality of reconstructed tracks

LHCb-FIGURE-2022-016

RICH mirror alignment

- Cherenkov photons focused on photon-detector plane by spherical and flat mirrors
- Track reflected through the RICH mirrors should be in the center of the ring

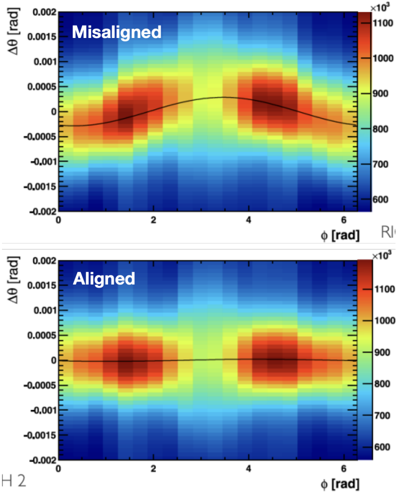
- $\Delta\theta =$ Difference in measured and expected Cherenkov angle
- When misaligned $\Delta\theta$ vs ϕ results with sinusoidal distribution

- Fit the distribution to calculate alignment constants

$$\Delta\Theta = T_x \cos(\phi) + \mathrm{T_y} \sin(\phi)$$

RICH mirror alignment: procedure

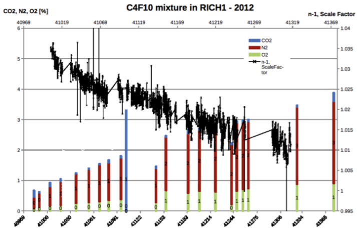
- Same real-time procedure as tracking
- Analyser: perform photon reconstruction
- Iterator: Fitting the $\Delta\theta$ distribution
- Evaluated each fill for the two RICH detectors $\sim$ 1090 alignment parameters
- Variations not expected each fill but procedure checked

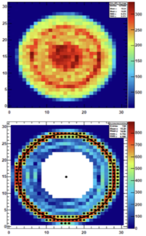


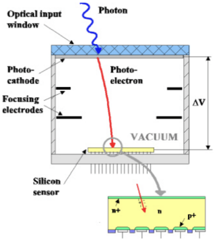
RICH calibration

- RICH gas refraction index calibration accounting for temperature and pressure changes and varying gas composition
- Extracted from the fit of the Cherenkov angles

- Hybrid photon detector calibration to correct for electrostatic effects
- Evaluated and updated every run

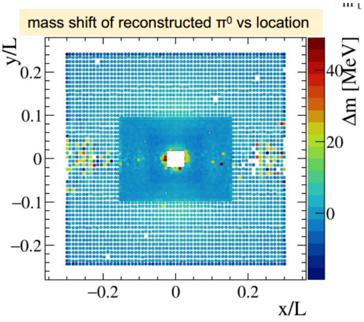






Calorimeter calibration

- Uses $\pi^0 \to \gamma\gamma$
- Calibration based on the π^0 mass peak
- Fitting di-photon mass distributions
- Requires an iterative procedure and it is run on the HLT farm
- Takes several hours to run and performed offline few times per year



Challenges for Run 3:

- severe pileup brings more background
- Selections and monitoring optimized for the new conditions

Summary

- LHCb has an established real-time alignment and calibration starting as of Run 2
- Alignment task parallelise the alignment task running multi threaded in the computer farm for the trigger
- Crucial for good physics and detector performance
- Run 3 has brought a new detector geometry that alignment needs to handle
- We are looking forward to more collisions!

Thank you!