Real-time alignment procedure at the LHCb experiment for Run 3

The University of Manchester

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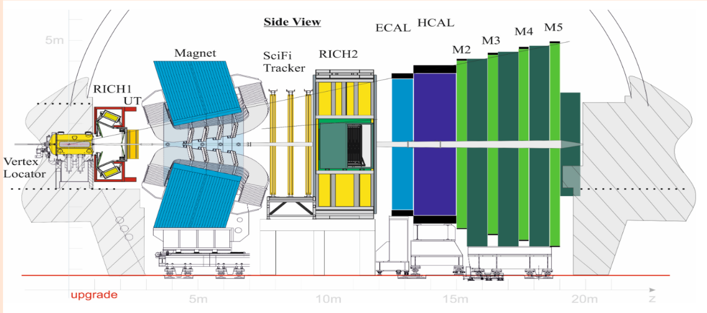
on behalf of the LHCb collaboration

Start here!

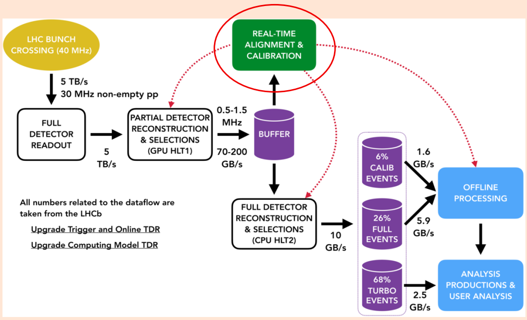
LHCb Upgrade detector


Side View
ECAL
HCAL
M2
M3
M4
M5
Magnet
SciFi Tracker
RICH2
RICH1
UT
Vertex Locator
5m
upgrade
5m
10m
15m
20m
z

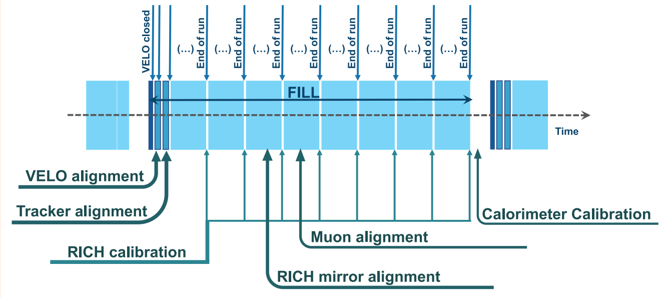
- fully software-based trigger for Run 3
- **real-time alignment and calibration** vital
  - pure selections
  - reduced output bandwidth
  - fully consistent data processing chain

Run 3 data flow

[LHCB-FIGURE-2020-016]

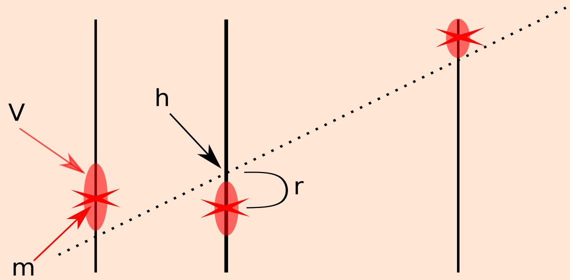

LHC BUNCH CROSSING (40 MHz)
5 TB/s
30 MHz non-empty pp
FULL DETECTOR READOUT
5 TB/s
PARTIAL DETECTOR RECONSTRUCTION & SELECTIONS (GPU HLT1)
0.5-1.5 MHz
70-200 GB/s
BUFFER
REAL-TIME ALIGNMENT & CALIBRATION
FULL DETECTOR RECONSTRUCTION & SELECTIONS (CPU HLT2)
10 GB/s
6% CALIB EVENTS
26% FULL EVENTS
68% TURBO EVENTS
1.6 GB/s
5.9 GB/s
2.5 GB/s
OFFLINE PROCESSING
ANALYSIS PRODUCTIONS & USER ANALYSIS

All numbers related to the dataflow are taken from the LHCb
Upgrade Trigger and Online TDR
Upgrade Computing Model TDR


VELO closed
(…)
End of run
FILL
Time
VELO alignment
Tracker alignment
RICH calibration
RICH mirror alignment
Muon alignment
Calorimeter Calibration

- collision events selected using partial reconstruction (HLT1)
- selected events stored on buffer
- **real-time alignment and calibration** is executed
- alignment constants updated if limits are surpassed
- second software stage (HLT2) uses the fully calibrated detector
- tracking alignment can be promptly used in HLT1

Tracking alignment



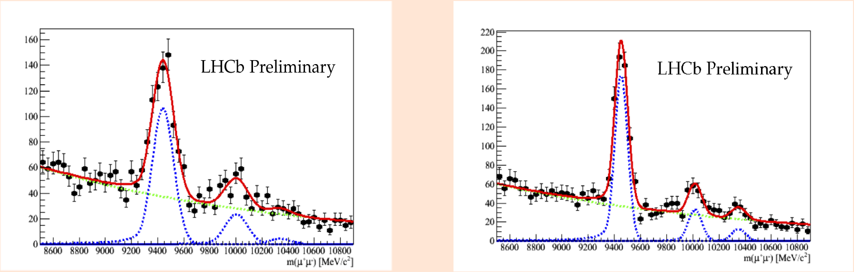
$$\chi^2 = r^T V^{-1} r$$
$$r = m - h(x, \alpha)$$
$$\frac{d\chi^2}{d\alpha} = 2 \sum_{tracks} \frac{dr}{d\alpha}^T V^{-1} r$$
$$\frac{d^2\chi^2}{d\alpha^2} = 2 \sum_{tracks} \frac{dr}{d\alpha}^T V^{-1} R V^{-1} \frac{dr}{d\alpha}$$
$$\alpha_1 = \alpha_0 - \left(\frac{d^2\chi^2}{d\alpha^2}\right)^{-1}\Bigg|_{\alpha_0} \frac{d\chi^2}{d\alpha}\Bigg|_{\alpha_0}$$

with r: track residual, V: measurement covariance matrix, m: measurement
h: track model R: covariance matrix of residuals

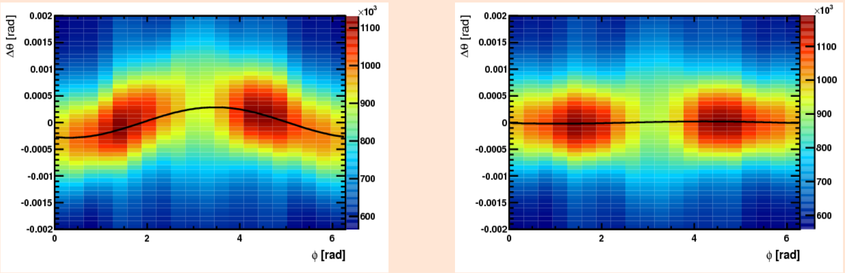
- tracking detector aligned using reconstructed tracks
  - fitted with Kalman filter [Nucl.Instrum.Meth.A 600 (2009) 471-477]
  - using initial alignment parameters α_0
- new alignment parameters obtained by χ^2 minimisation
- repeated until convergence criterion is reached

Impact of the alignment

[2015 J. Phys.: Conf. Ser. 664 082010]

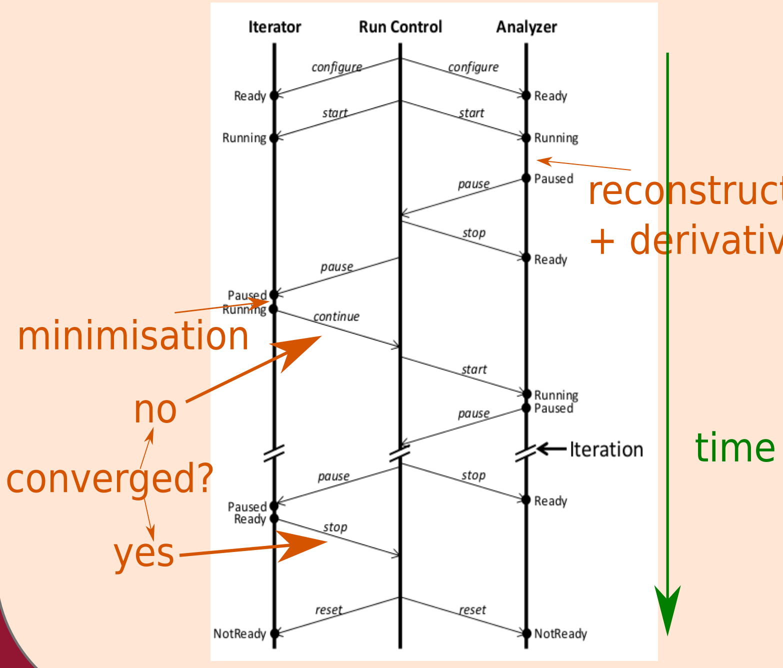


[Eur. Phys. J. C 73 (2013) 2431]



- tracking alignment improves momentum resolution
- RICH mirror alignment to improve particle-identification

Online alignment


Iterator
Run Control
Analyzer
configure
configure
Ready
Ready
start
start
Running
Running
pause
Paused
stop
Ready
pause
Paused
Running
continue
start
Running
Paused
pause
Iteration
pause
stop
Paused
Ready
Ready
stop
reset
reset
NotReady
NotReady

reconstruction + derivatives

minimisation

no

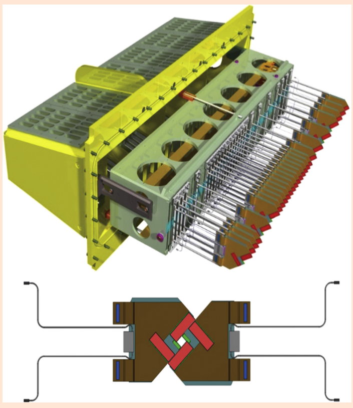
converged?

yes

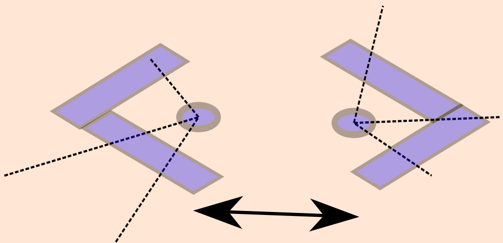
time

- **Analyzer** task
  - reconstruct tracks
  - calculate and write out derivatives
- **Iterator** task
  - collect derivatives
  - perform minimisation
- Analyzer tasks can be distributed over multiple threads/nodes
- similar timing to Run 2 expected

first VELO alignment on Run 3 data



[2019 IEEE NSS/MIC, 2019, pp. 1-5]

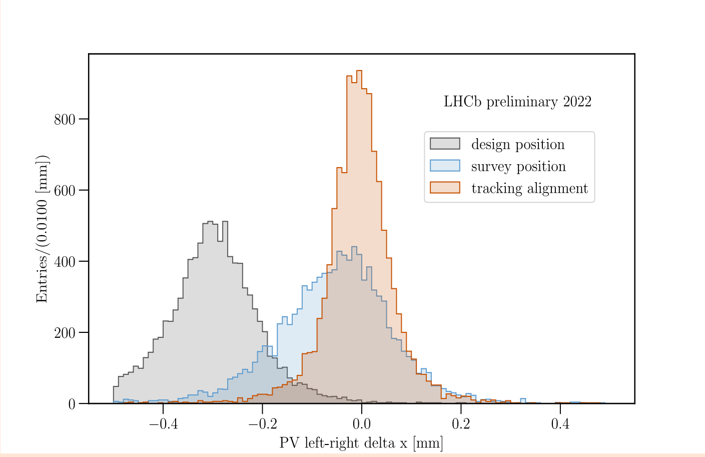


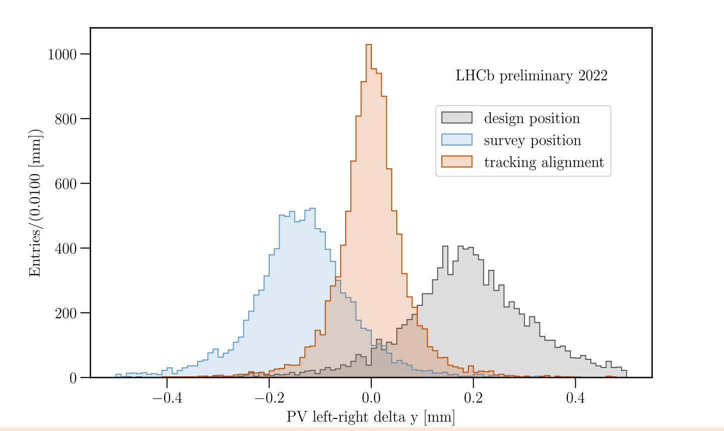
PV(left)-PV(right)

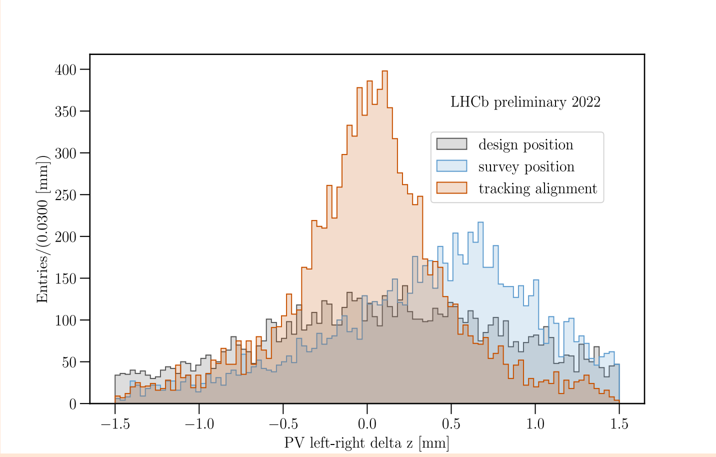
Upgrade **Vertex Locator** [LHCB-TDR-013]

- **two halves** of **26 silicon pixel modules** each
- close to the beam line for precise **primary vertex reconstruction**
- relative half misalignment studied by comparing PVs reconstructed using either half
- first alignment performed on early data

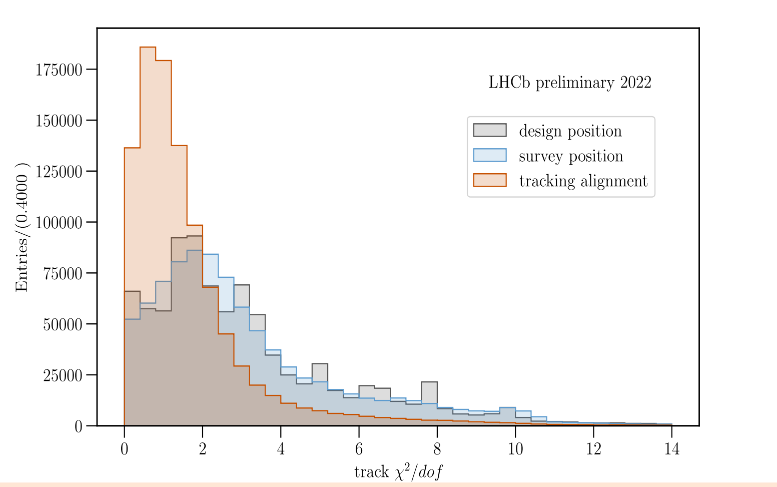
[LHCb-FIGURE-2022-029]

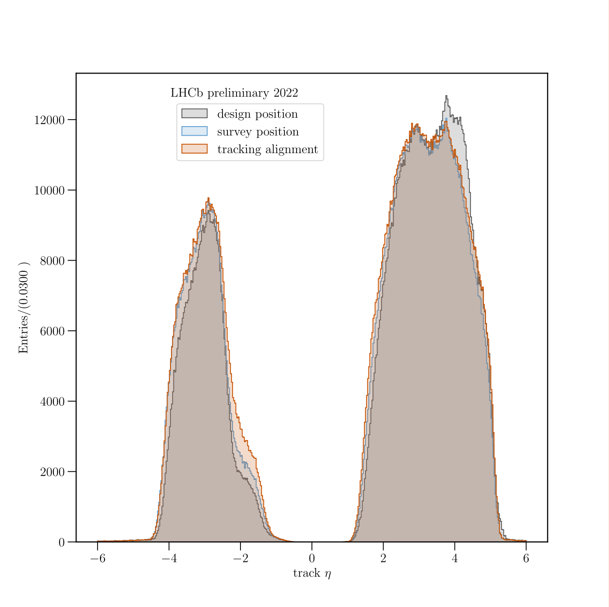






- **design** description of geometry
- corrections from **survey** measurements
- corrections from **alignment**





- already good performance using survey information
- alignment procedure works well on early data
- performance expected to further improve over time