Novel Real-time Calibration and Alignment Procedure for LHCb Run II

Claire Prouve, on behalf of the LHCb collaboration
University of Bristol

New challenges in Run II

- Increase in energy: √s = 7(8) TeV ⇒ 13 TeV
- 15% increase of inelastic collision rate
- 20% increase of multiplicity per collision
- 60% increase of $\sigma_{b\bar{b}}$ and $\sigma_{c\bar{c}}$
- Reduced bunch spacing: 50 ns ⇒ 25 ns

Real Time Alignment and Calibration

- Particle identification useable in HLT2
- Overall improved HLT2 efficiency
- Stable quality of alignment
- No more differences between online and offline

LHCb Trigger Schemes

LHCb 2012 Trigger Diagram

40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz $h^\pm$ | 400 kHz $\mu/\mu\mu$ | 150 kHz e/γ

Software High Level Trigger
29000 Logical CPU cores
Offline reconstruction tuned to trigger time constraints
Mixture of exclusive and inclusive selection algorithms

5 kHz (0.3 GB/s) to storage

2 kHz Inclusive Topological | 2 kHz Inclusive/ Exclusive Charm | 1 kHz Muon and DiMuon

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

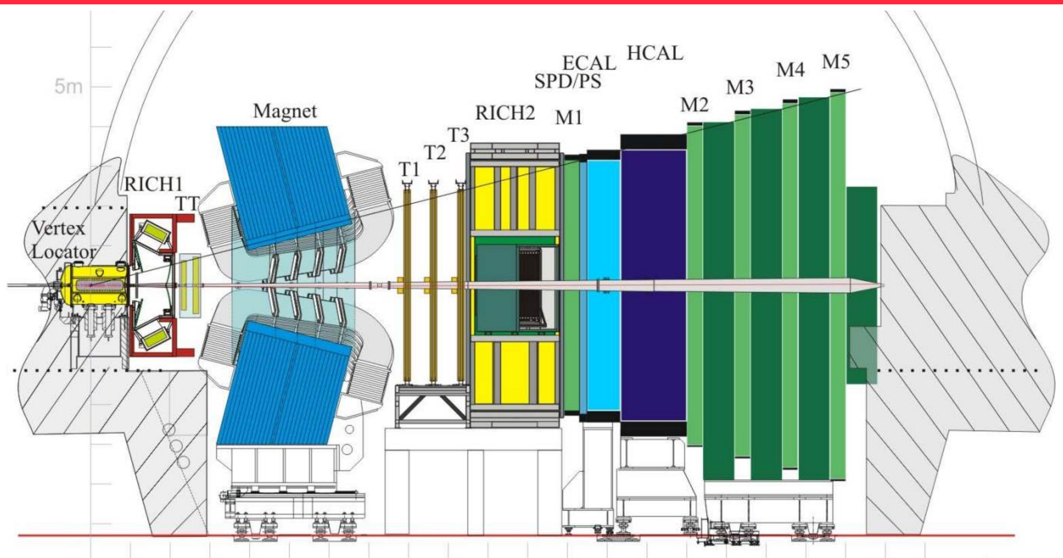
L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz $h^\pm$ | 400 kHz $\mu/\mu\mu$ | 150 kHz e/γ

Software High Level Trigger
Partial event reconstruction, select displaced tracks/vertices and dimuons
Buffer events to disk, perform online detector calibration and alignment
Full offline-like event selection, mixture of inclusive and exclusive triggers

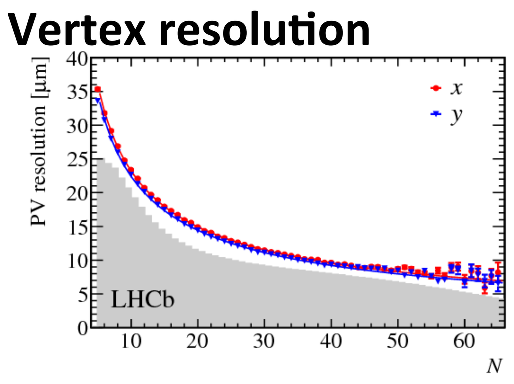
12.5 kHz (0.6 GB/s) to storage

The LHCb Detector

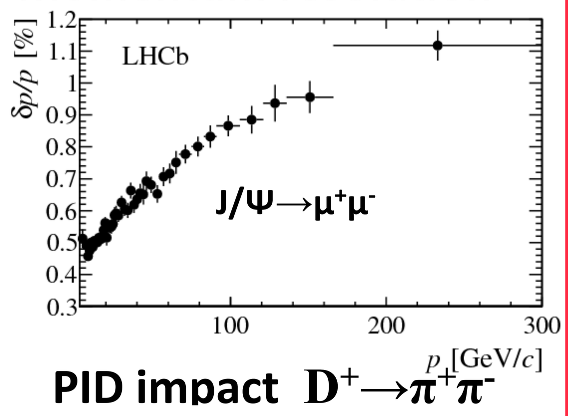


2.4 · 10^{12} B hadrons in LHCb detector acceptance in 2011 + 2012

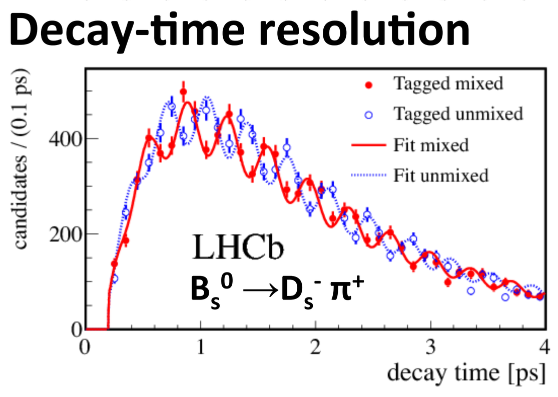
Vertex resolution



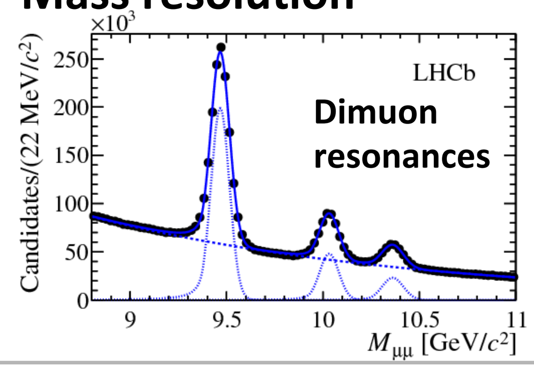
Momentum resolution



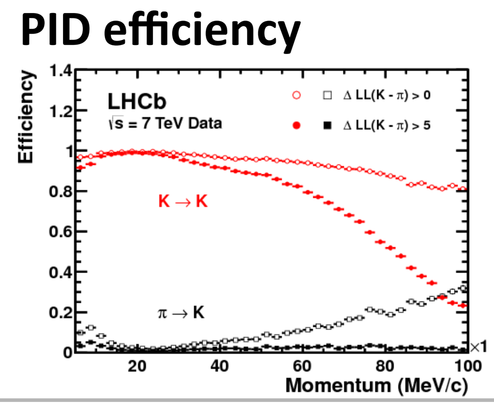
Decay-time resolution



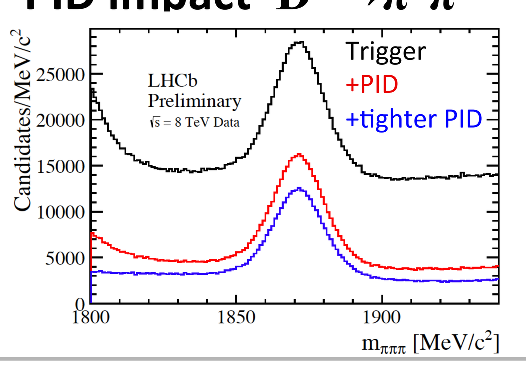
Mass resolution



PID efficiency



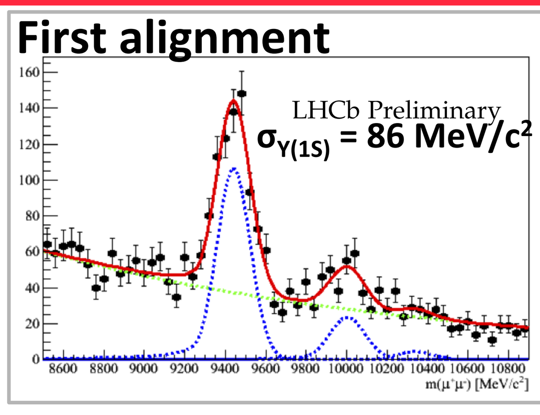
PID impact $D^+ \to \pi^+\pi^-$



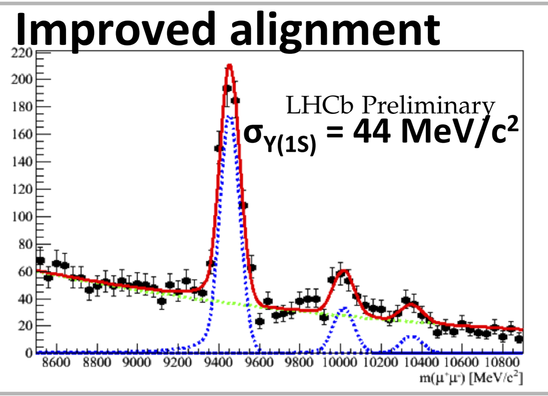
References:
[1] R. Aaij et al., Int.J.Mod.Phys. A30, 1530022 (2015).
[2] R. Aaij et al., JINST 9, 09007 (2014).
[3] J. Amoraal et al., Nucl.Instrum.Meth. A712, 48 (2013).
[4] M. Adinolfi et al., Eur.Phys.J. C73, 2431 (2013).
[5] W. Hulsbergen, Nucl.Instrum.Meth. A600, 471 (2009).
[6] R. Arink et al., LHCb-DP-2013-003.

Performance and Impact on Physics

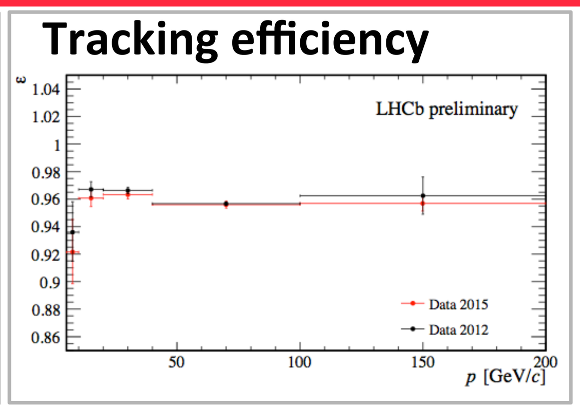
First alignment



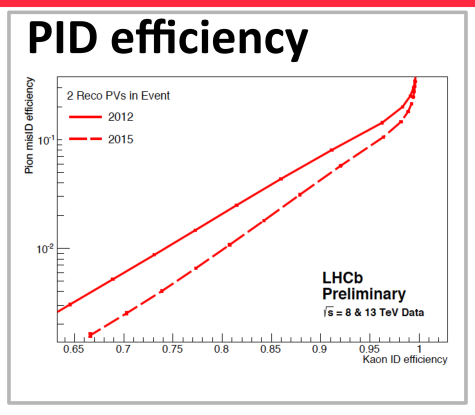
Improved alignment



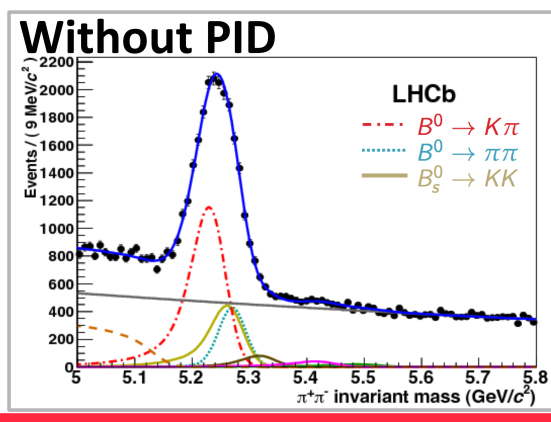
Tracking efficiency



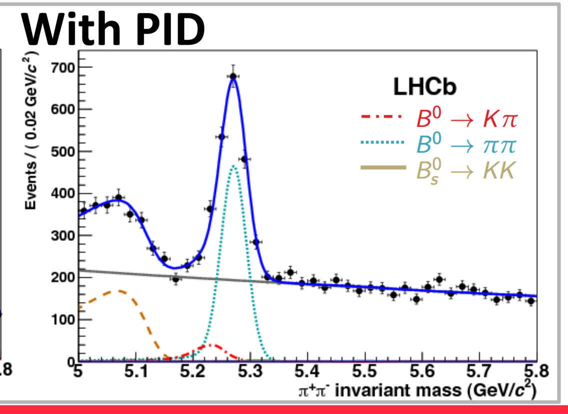
PID efficiency



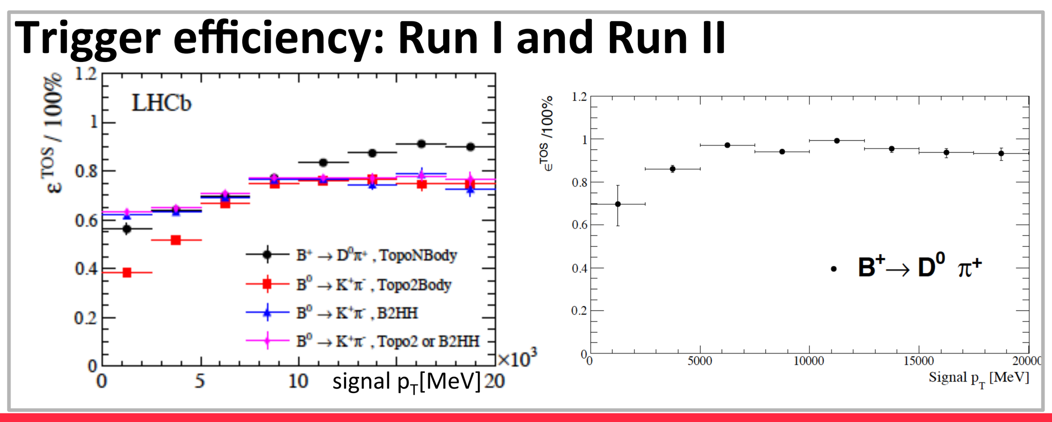
Without PID



With PID



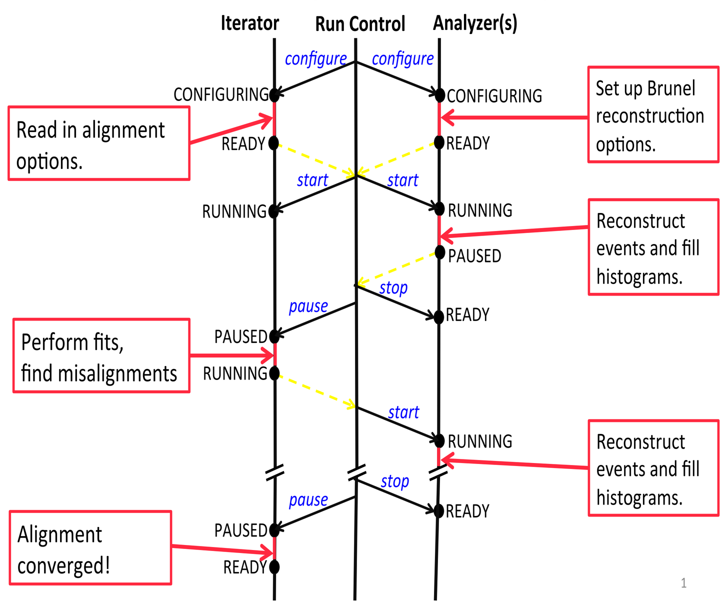
Trigger efficiency: Run I and Run II



Alignment Farm and Framework

- Alignments performed for each fill
- HLT1 line for each task
- Event reconstruction parallelised on *analysers* (1700 nodes), computing of alignment constants by *iterator* (1 node)
- Steered by the run control using a Finite State Machine
- VELO, Tracker & calibrations: automatic update of the constants if they differ by a given value
- RICH alignment & Muon System: monitoring mode

Example of alignment sequence



Tracker Alignment: VELO, Tracker, Muon System

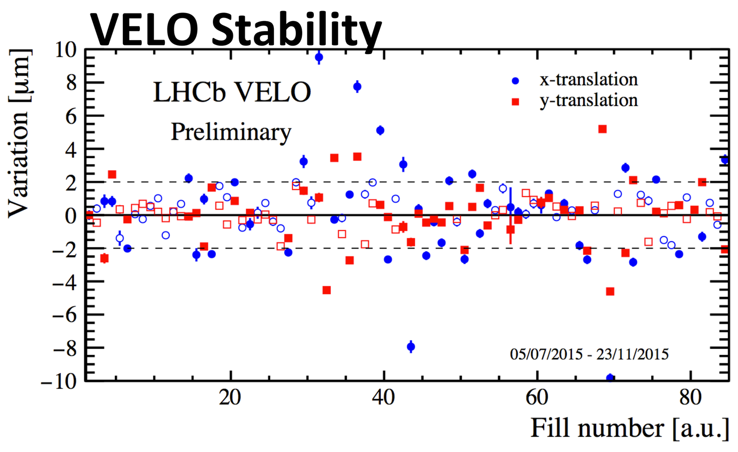
Position of the tracking elements in *x* and *y*

- Minimisation of residual of Kalman track fit using additional constraints

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

- Independent alignments:
- VELO & Tracker: updated every $\mathcal{O}(1)$ fills
- Tracker: updated every $\mathcal{O}(1)$ weeks
- Muon system: updated $\mathcal{O}(1)$ per year
- ~7 minutes for each task

VELO Stability



Outer Tracker Calibration

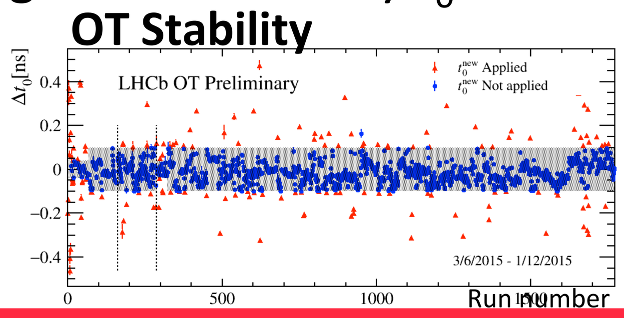
Global time alignment for all modules

- Fit the residual of the drift time to extract the global time delay t_0 caused by readout electronics

$$t_{meas} = t_0 + t_{flight} + t_{drift} + t_{prop}$$

- Updated every $\mathcal{O}(10)$ runs

OT Stability



RICH Mirror Alignment

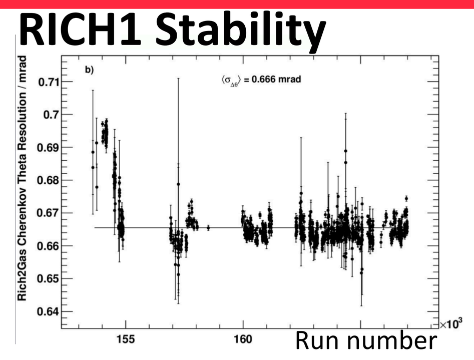
Orientation of the RICH mirrors in *x* and *y*

- Fit the variation of the Cherenkov angle Δθ as a function of the polar angle φ to extract the misalignments on the detector plane (Θ_x, Θ_y):

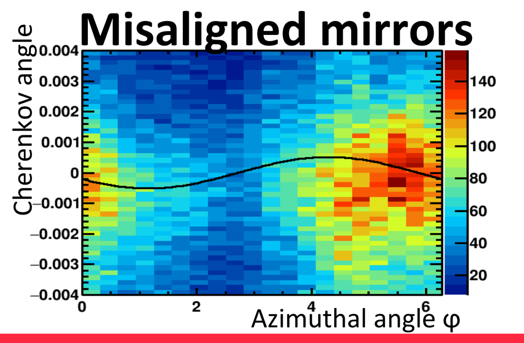
$$\Delta\theta = \Theta_x \sin\varphi + \Theta_y \cos\varphi$$

- Monitoring mode, updated $\mathcal{O}(10)$ times a year
- ~30 minutes per task

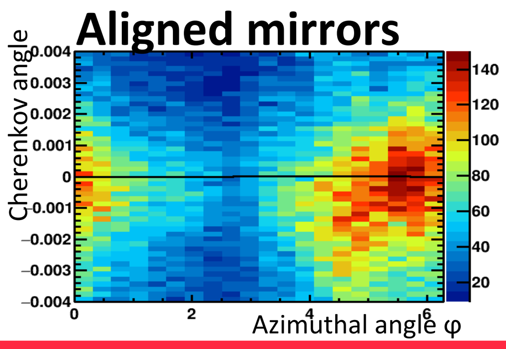
RICH1 Stability



Misaligned mirrors



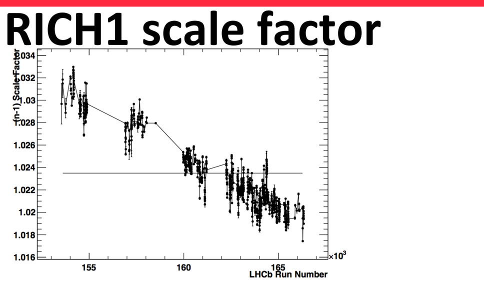
Aligned mirrors



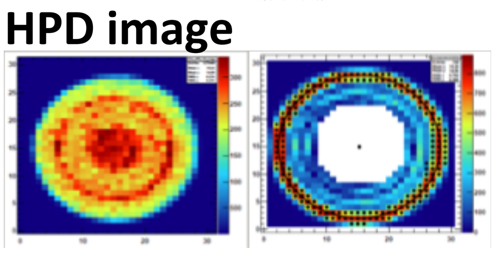
RICH Calibration

- Refractive index calibration: Fit to the reconstructed-expected Cherenkov angle yields scale factor for the refractive index
- HPD image calibration: Sobel filter applied to each HPD and used to provide calibration
- Updated every run

RICH1 scale factor



HPD image



Calorimeter Calibration

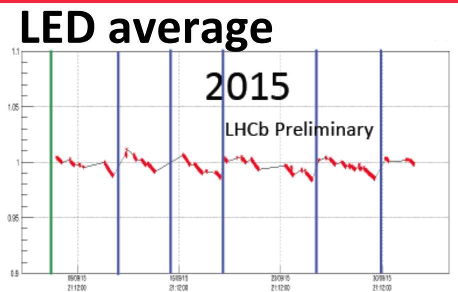
Relative calibration for each cell

- Scale the High Voltage by factor α to keep the gain stable by evaluating the variation of the occupancy
- LED monitoring system to detect ageing of the Photo Multiplier Tubes
- Updated per fill

Calibrate to the neutral π mass

- Fit the π^0 mass distribution for each cell for $\pi^0 \to \gamma\gamma$, where one γ has its seed in the cell
- Run on the HLT-farm during TS

LED average



π^0 calibration