Novel Real-time Alignment and Calibration of the LHCb Detector in Run II

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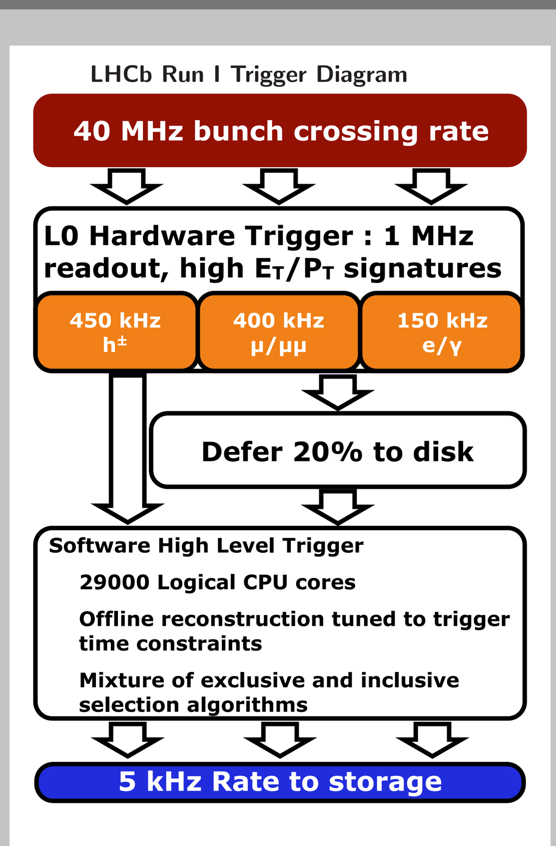
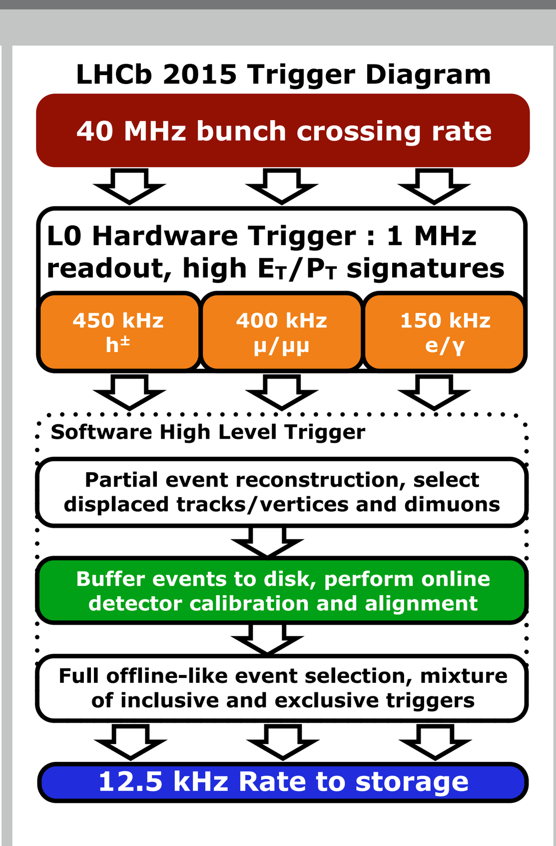
Running Conditions from Run I to Run II

- Higher energy: $\sqrt{s} = 7(8)$ TeV $\Rightarrow$ 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 $\Rightarrow$ 25 ns.
- Similar instantaneous luminosities: $4{\cdot}10^{32}$ cm^{-2}s^{-1}.

LHCb Trigger Schemes





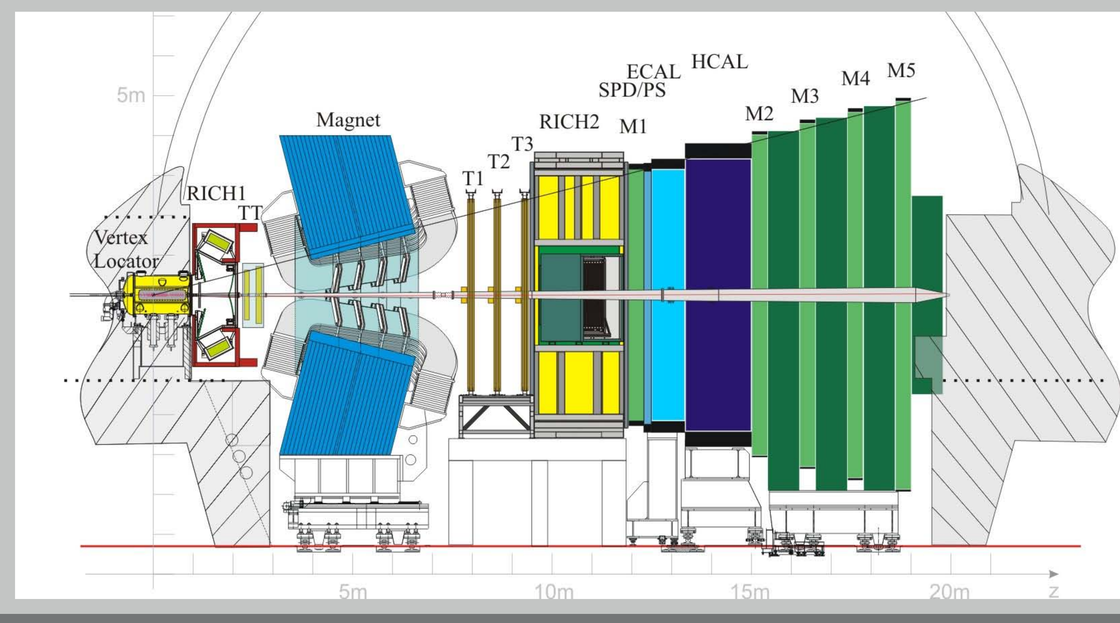
Advantages of Real-time Align. and Calib.

- Improves trigger selection.
- Minimises the difference between online and offline performances.
- Ensures the stability of the alignment quality.
- Enables physics analyses directly on the trigger output.

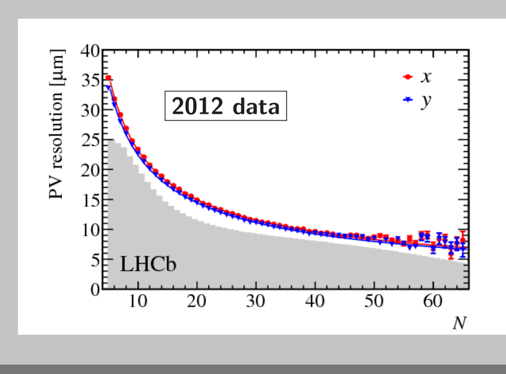
Degrees of Freedom for Alignment

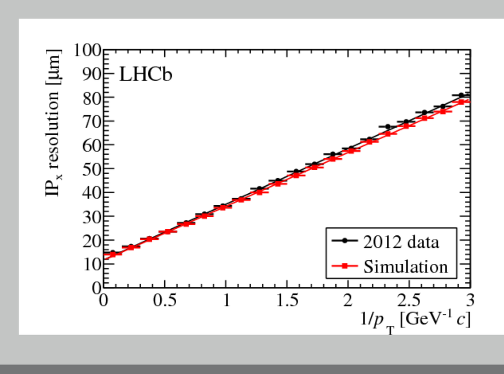
- 3 translations and 3 rotations for each element
- Number of elements to be aligned:
  - VELO: 86
  - TT: 135
  - IT: 64
  - OT: 496
- Constrained to nominal, survey or previously aligned position

LHCb Detector

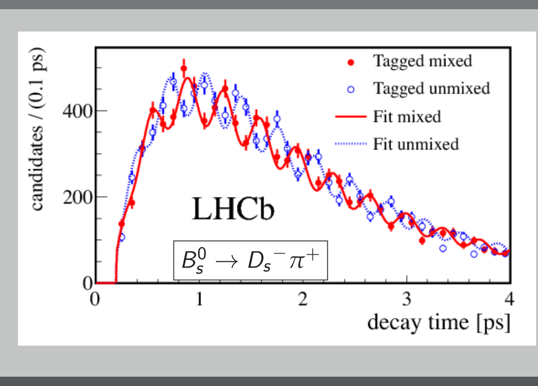


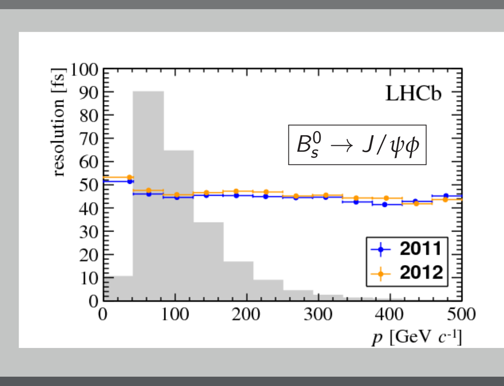
Vertex Reconstruction



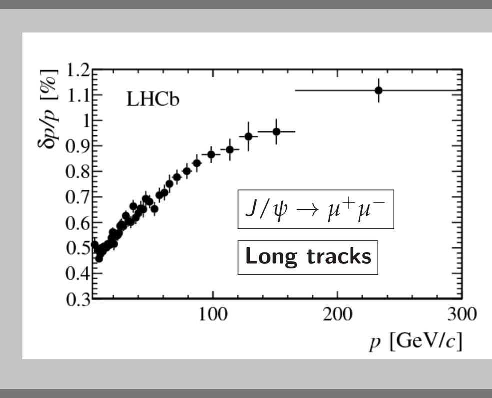


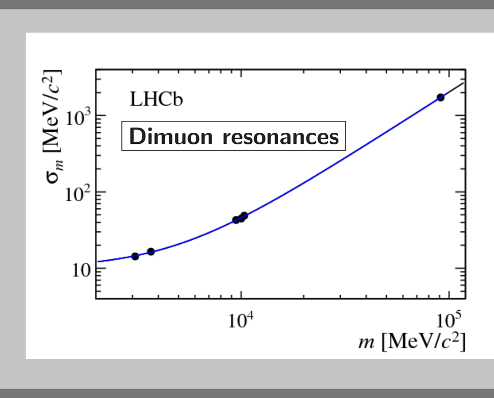
Decay Time Resolution



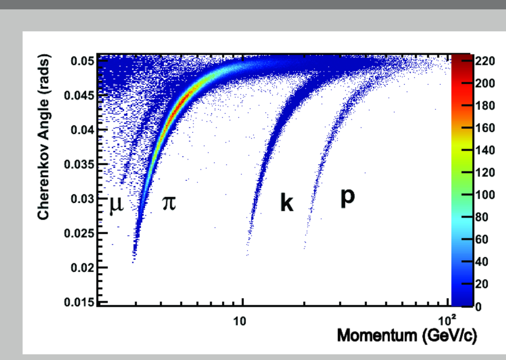


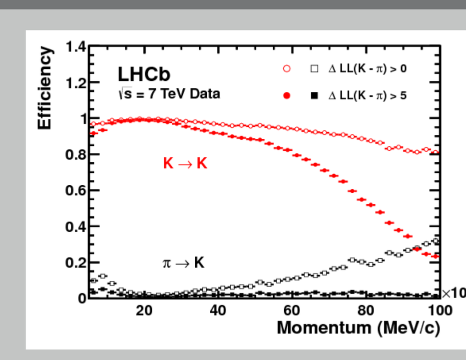
Mass and Momentum Resolution



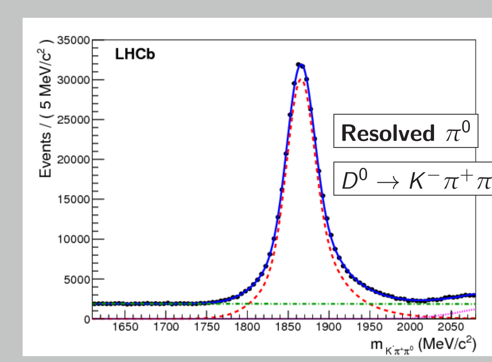


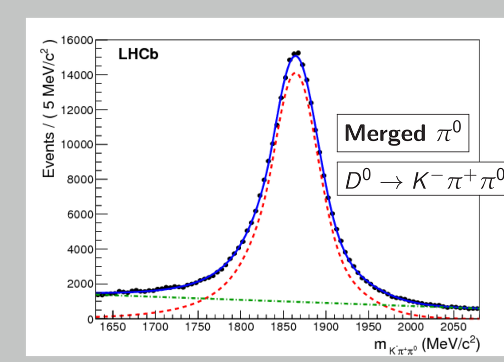
PID Performance





Neutral Pion Reconstruction

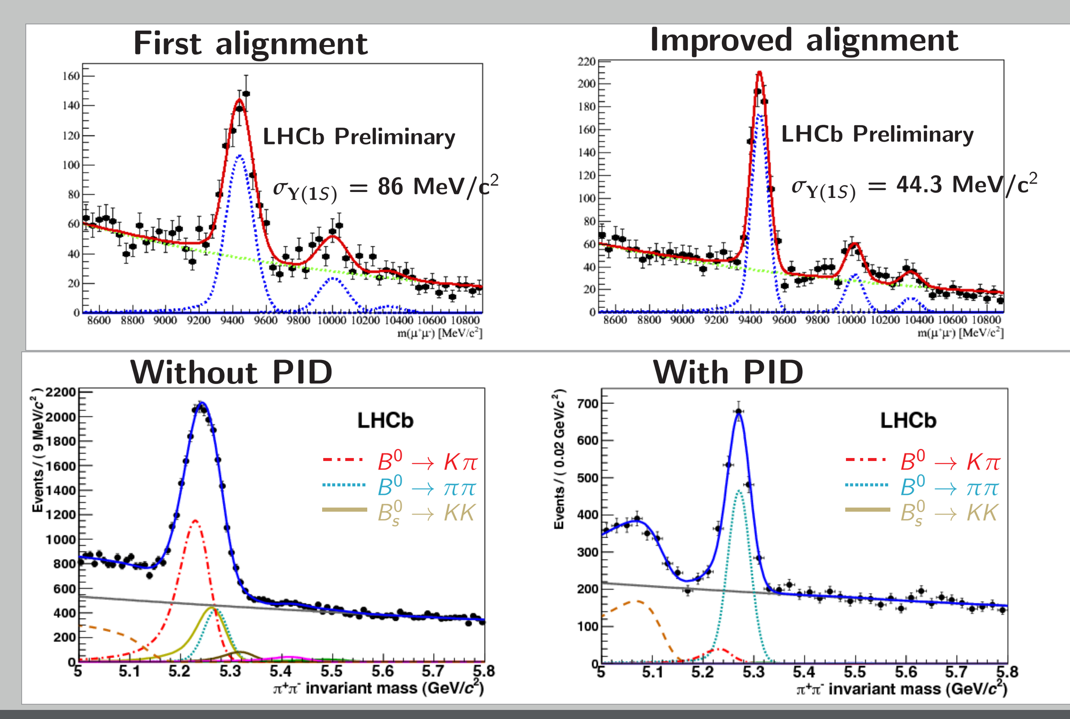




DAQ data volume 1.5 TBytes/second in Run II

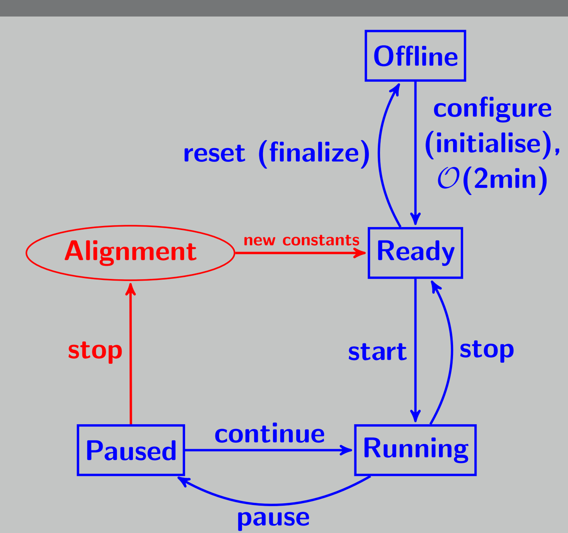
Alignment and Calibration Impact on Physics Performance

- The spatial alignment of the detector and the accurate calibration of its subcomponents are essential elements to achieve the best physics performance.
- An exclusive selection using hadron particle identification criteria relies on the complete calibration of the RICH detectors.



Alignment and Calibration Framework in Run II

- Automatic evaluation at the beginning of each fill.
- Track reconstruction parallelised on several nodes of the HLT farm.
- Alignment constants computed single node.
- Only a few minutes needed to run all alignment tasks.
- Special HLT1 selection line enriched with well known particle decays (e.g. $D \to K\pi$, $J/\psi \to \mu\mu$ etc).
- Two different alignment tasks (same state diagram):

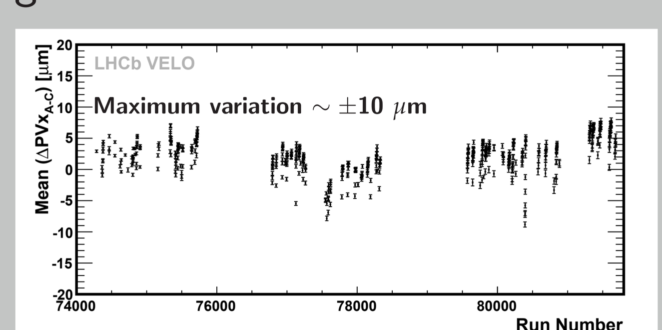


Analyzer performs the track reconstruction based on the alignment constants provided by the iterator.

Iterator collects the output of the analyzers and minimizes χ^2 computing the alignment constants for the next iteration.

VELO, Tracker and Muon System Alignment

- Kalman filter fit to minimise the χ^2, based on residuals of reconstructed tracks.
  - Takes into account multiple scattering and energy loss.
  - Uses magnetic field information.
  - Applies mass and vertex constraints.
- Independent jobs for VELO, Tracker and Muon system alignment.
  - VELO: performed at the beginning of each fill and updated immediately if required.
  - Tracker: run after VELO for each fill, update expected every few weeks.
  - Muon system: run after Tracker for each fill, variation not expected but used as monitoring.

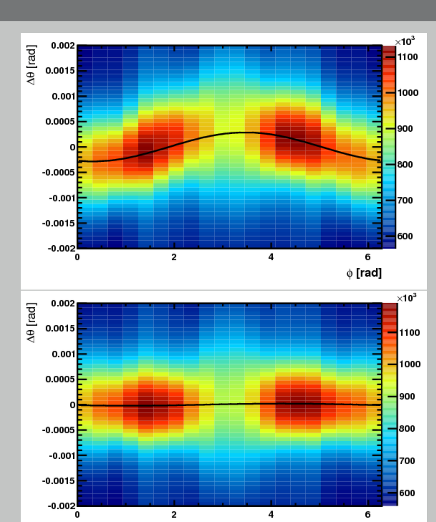


RICH Mirror Alignment

- Fit the variation of the Cherenkov angle as function of the polar angle to extract the misalignments (θ_x, θ_y):

$$\Delta\theta = \theta_x \cos\phi + \theta_y \sin\phi$$

and θ_x and θ_y are on the HPD detector plane.
- The alignment constants (1090) are determined at the beginning of each fill.



OT and RICH Calibration Strategy in Run II

- Online analysis task running on single CPU.
- New parameters evaluated from fits to monitoring histograms.

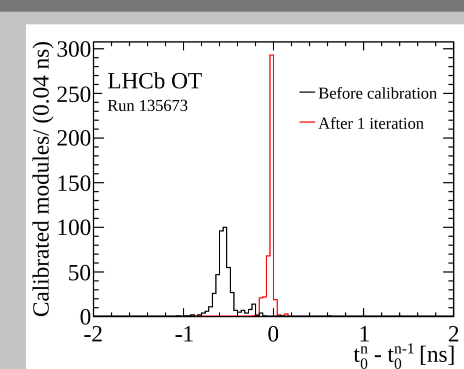
Global Time Alignment for OT

- Drift-time t_{TDC} measurement:

$$t_{\mathrm{TDC}} = t_0 + t_{\mathrm{tof}} + t_{\mathrm{drift}} + t_{\mathrm{prop}},$$

$$\text{with } t_0 = t_{\mathrm{collision}} - t_{\mathrm{clock}} + t_{\mathrm{module}} - t_{\mathrm{gate}}$$

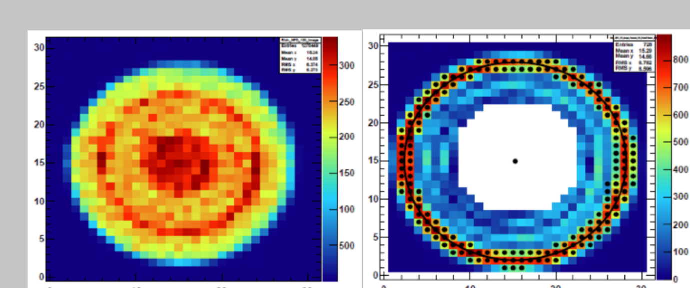
- A single condition which accounts for the time alignment between the collision time and the LHCb clock.



- Run the job for every run and update the constant if above a certain threshold.

RICH Calibration

- Refractive index calibration (1940 constants):
  - Depends on the gas mixture, temperature and pressure.
  - Fit on the Cherenkov angle differences $\Delta\theta$.
  - Corrections calculated and updated every run.
- HPD calibration (2 constants):
  - Electrostatic effect (probably) due to switching off the HV for every injection.
  - Fit a circle to the HPD image.
  - Corrections calculated and updated every run.



Anode images, before and after cleaning and Sobel filter.

CALO Calibration

- A relative calibration online using occupancy method.
  - Occupancy for each cell defined as $O(x,y,I_{\mathrm{th}},K) = \sum_{i>I_{\mathrm{th}}} F(x,y,i,K) / \sum_i F(x,y,i,K)$.
  - Ratio of occupancies proportional to changes in hardware characteristics.
- HV adjusted on a per fill basis based on the gain changes calculated from the occupancy profiles.

References

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[3] J. Amoraal et al., Nucl.Instrum.Meth. A712, 48 (2013).

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