LHCb prompt calibration and detector performance

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on behalf of the LHCb collaboration

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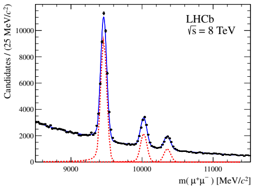
outline

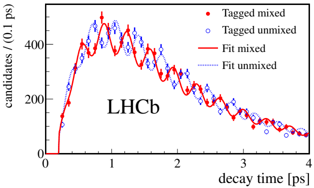
- Introduction
- Improved LHCb trigger in Run II
- Real-time alignment and calibration
- Improvements in track reconstruction
- Conclusion

introduction

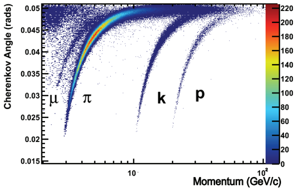
- LHCb is heavy flavour experiment at the LHC
- goal: indirect search for New Physics in CP violation and rare decays of beauty and charm
- requirements:
  - excellent tracking (momentum, impact parameter and primary vertex resolution – $dp/p \sim 0.5\%$)
  - excellent decay time resolution ($\mathcal{O}(45\,\mathrm{fs})$ for B mesons, depending on decay)
  - excellent particle identification



[J. High Energy Phys. 06 (2013) 064]

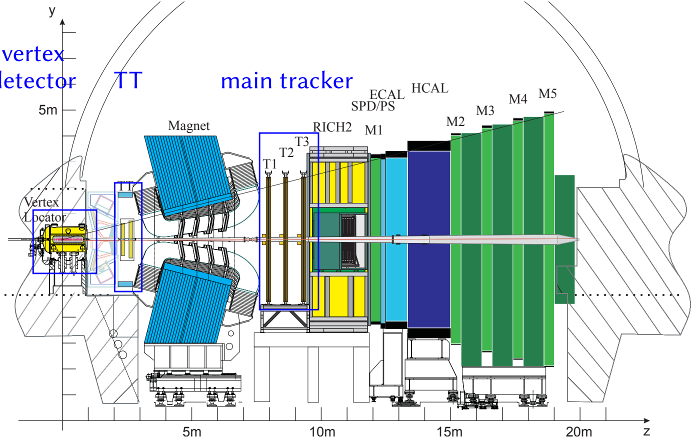


[New J. Phys. 15 (2013) 053021]



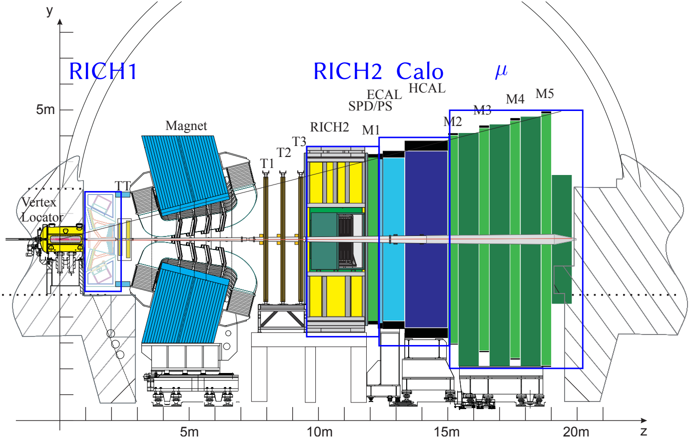
[Eur. Phys. J. C 73 (2013) 2431]

LHCb detector



- very good vertex and decay time resolution
- excellent momentum resolution

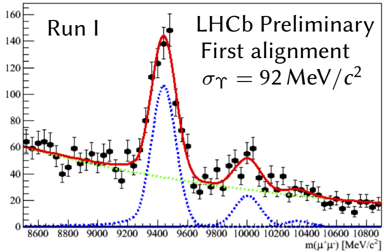
LHCb detector

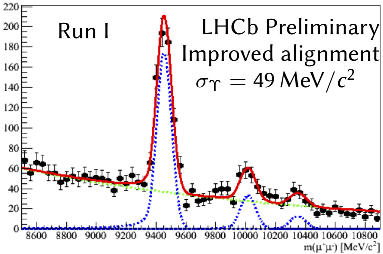


- excellent particle identification from interplay of RICHes, calorimeters and muon system

importance of alignment

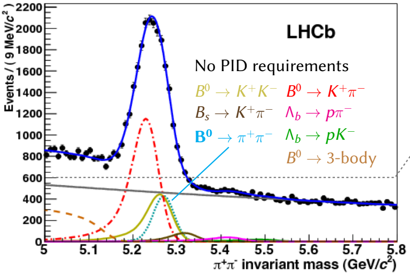
- spatial detector alignment crucial for physics performance
- vertex detector alignment needed to isolate secondary vertices from *b* and *c* hadrons
- optimal tracking system alignment for best dp/p and mass resolution

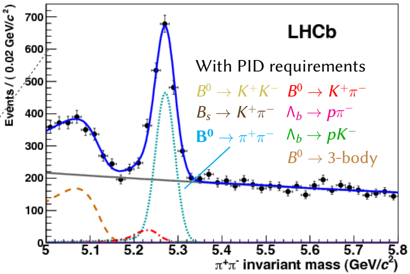




importance of calibration

- tight selection criteria in hadronic channels require proper RICH calibration

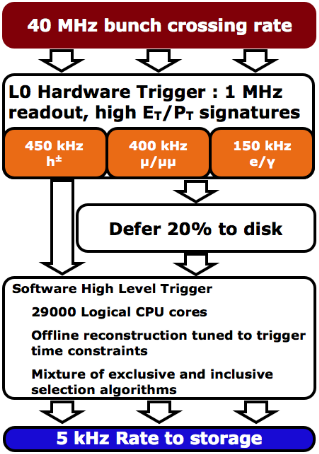




[Eur. Phys. J. C 73 (2013) 2431]

LHCb trigger in 2012

- L0 trigger (hardware)
  - high E_T or p_T signatures in muon or calorimeter system
  - 1 MHz detector readout
- HLT trigger (software)
  - flexible software trigger
  - two stages (HLT1 and HLT2)
  - simplified track and vertex reconstruction
  - use inclusive and exclusive selections
  - defer 20% of data to HLT farm node disk, use inter-fill time for processing



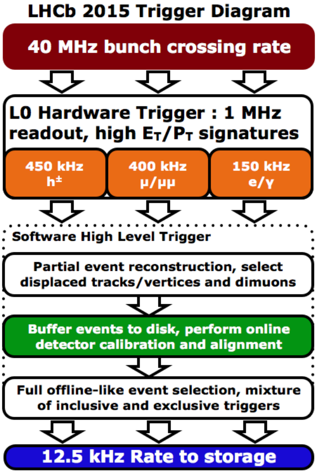
LHCb trigger for Run II

- larger farm and faster tracking allow offline quality reconstruction
  - defer everything between HLT1 and HLT2
  - can do near real-time alignment and calibration before HLT2 runs

→ offline quality reconstruction already in HLT2 (incl. RICH PID)

- new feature: TURBO stream: perform offline-quality analysis directly with HLT output (∼5 kHz)

→ more efficient and pure selections (for details, see talk by Roel Aaij on Friday)



Online alignment framework

- HLT1 selects special events for alignment and calibration at start of fill
- parallel processing on $\sim$ 1700 HLT farm nodes

- tracker alignment details
  - analyser (multiple nodes): massively parallel track reconstruction
  - iterator (single node): combine analyser output, minimise χ^2, extract alignment constants

- RICH alignment details
  - analyser (multiple nodes): photon reconstruction, fill histograms
  - iterator (single node): fit histograms, extract alignment constants

Spatial alignment

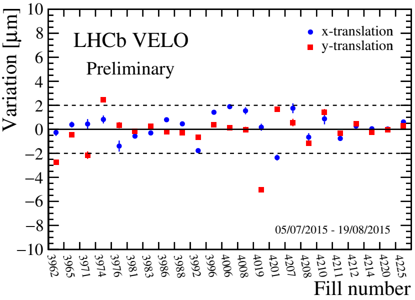
- use tracks in vertex detector, tracker and muon stations
- iterative procedure:
    1. reconstruct tracks using current alignment constants (Kalman filter fit)
    2. derive new alignment constants by minimisation of global χ^2 (uses (some) particle masses and vertex positions as global constraints)
    3. iterate until $\Delta\chi^2$ below threshold

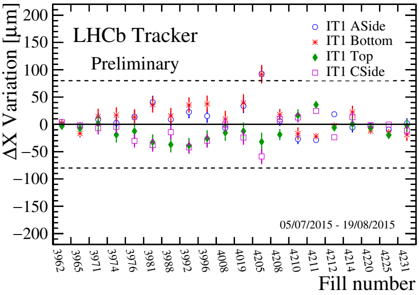
→ alignment constants available for HLT2 within minutes, magnetic field and multiple scattering taken into account

(for a much more detailed treatment of the subject, see Varvara Batozskaya's poster)

Online alignment stability

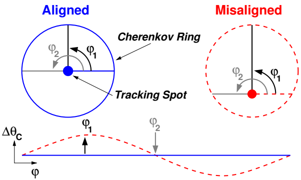
- update alignment constants only when above threshold (dashed lines)
  - VELO opens and closes each fill (protect sensors during injection): expect updates every few fills
  - tracking system (TT, IT, OT): expect updates every few weeks

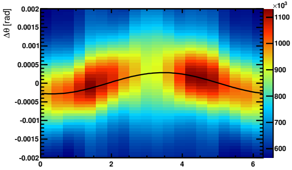




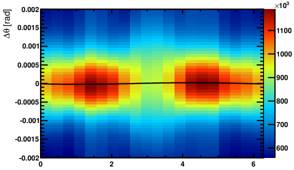
RICH mirror alignment

- framework also used to monitor muon and RICH mirror alignment
- misalignment between tracker and RICH leads to shift of track projection point on photodetector plane from centre of Cherenkov ring
- Cherenkov angle $\Delta\theta$ shows sinusoidal shift with angle around projection point ϕ
- iterative procedure in online alignment framework (filling histograms, fit for alignment constants)





Misaligned

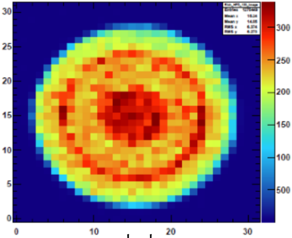


Aligned

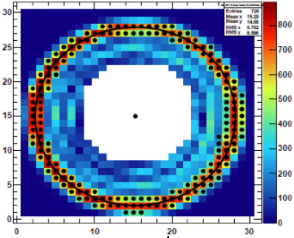
[Eur. Phys. J. C 73 (2013) 2431]

RICH calibration

- RICH gas refractive index
  - depends on temperature, pressure, composition of gas (changes with time)
  - fit difference between expected and measured Cherenkov angle to extract scale factor
- HPD images
  - electric and magnetic fields distort drifting charges inside HPDs
  - calibrate/correct anode image to give nice Cherenkov ring



bad

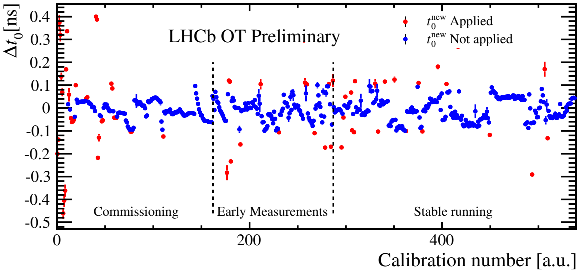


good

- calibration run and updated automatically for each run

Outer tracker drift time calibration

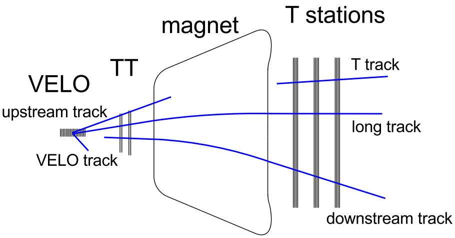
- measured drift times can be compared to estimated ones (drift radius estimate known from tracking)
- most common cause of discrepancies: time shift between proton collision time and LHCb clock
- evaluated each run, and global drift time offset corrected for next run if above threshold



Calorimeter calibration

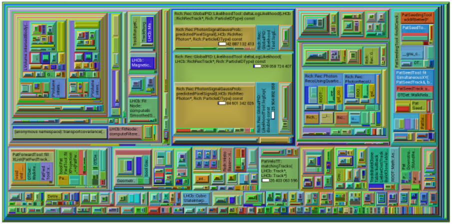
- occupancy method
  - compare per-cell occupancy to reference sample
  - occupancy ratio is proportional to HV ratio
  - compensate gain variations by adjusting HV based on occupancy ratio
    (e.g. if $\left|\left(\frac{occ}{occ_{ref}}\right)_{cell} - 1\right|$ is above threshold)
- calibration using π^0:
  - use π^0 mass peak position to obtain a per-cell calibration coefficient
    (such that the π^0 mass peak appears at the nominal mass)
  - define PMT high voltage tuning per cell
  - run on HLT farm as alignment tasks
- both calibration methods in place, and running routinely

tracking

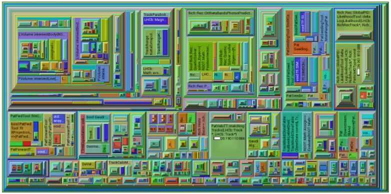


- run exactly same track reconstruction as offline in HLT in Run II
- to maintain high tracking efficiency, need speed improvements to fit in time budget
  - need some new ideas
    - use momentum information from upstream tracks to speed up long track reconstruction in HLT1
    - fast Kalman track fit (uses simplified geometry)
  - optimise, optimise, optimise

tracking improvements



March 2014



August 2015

- identify hot spots by profiling
  - vectorisation (track fit, magnetic field)
  - caching (material description)
  - fast approximations (e.g. various corrections in the Outer Tracker)
  - replace a few pattern recognition algorithms with new implementations
  - algorithm tuning

$\Longrightarrow$ vast speedup realised (34% overall, more in code used in HLT)

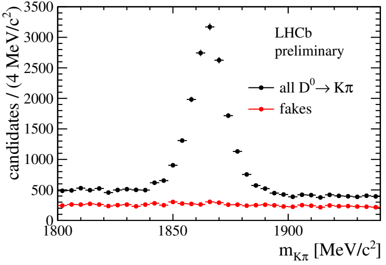
tracking: new ideas

- have NN classifier for fake tracks

→ very powerful quality metric, hence cleaner track sample

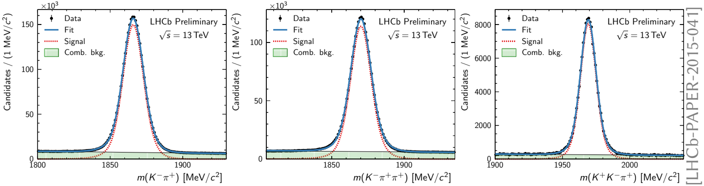
  - saves combinatorics (and thus CPU)
  - hence lower HLT output rate (see plot!)

- can loosen χ^2 cut in turn: higher efficiency



conclusion

- first experiment of this scale to perform alignment and calibration online
- works extremely well; get beautiful peaks out of the trigger (TURBO stream)



$D^0 \to K^-\pi^+$ $D^+ \to K^-\pi^+\pi^+$ $D_s^+ \to K^+K^-\pi^+$

(for details, see talk by Alex Pearce on Monday)

- tremendous improvements in track reconstruction (time)
- offline track reconstruction now also used in HLT