LHCb prompt calibration and detector performance

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- Introduction
- Improved LHCb trigger in Run II
- Real-time alignment and calibration
- Improvements in track reconstruction
- Conclusion
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 ($\mathcal{O}(45\text{ fs})$ for $B$ mesons, depending on decay)
  - excellent particle identification

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

Run I  
LHCb Preliminary  
First alignment  
$\sigma_{\Upsilon} = 92$ MeV/$c^2$

Run I  
LHCb Preliminary  
Improved alignment  
$\sigma_{\Upsilon} = 49$ MeV/$c^2$
importance of calibration

- tight selection criteria in hadronic channels require proper RICH calibration

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)
HLT1 selects special events for alignment and calibration at start of fill

parallel processing on ∼ 1700 HLT farm nodes

tracker alignment details

analyser (multiple nodes): massively parallel track reconstruction
iterator (single node): combine analyser output, minimise $\chi^2$, 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 $\chi^2$
     (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

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**LHCb VELO**

Preliminary

**LHCb Tracker**

Preliminary

M. Schiller (CERN)
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 $\phi$
- iterative procedure in online alignment framework (filling histograms, fit for alignment constants)
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

- calibration run and updated automatically for each run

![HPD images: bad and good](attachment:image.png)
## 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.

![Graph showing drift time calibration](image)

**Legend:**
- $t_0^{\text{new}}$ Applied
- $t_0^{\text{new}}$ Not applied

**Phase:**
- Commissioning
- Early Measurements
- Stable running

**Calibration number [a.u.]**

**Time [ns]:**
- 0
- 0.1
- 0.2
- 0.3
- 0.4
- 0.5

**LHCb OT Preliminary**
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
    
    \[ \left| \left( \frac{\text{occ}}{\text{occ_{ref}}} \right)_{\text{cell}} - 1 \right| \text{ is above threshold} \]

- calibration using $\pi^0$:
  - use $\pi^0$ mass peak position to obtain a per-cell calibration coefficient
    (such that the $\pi^0$ 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
- 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
March 2014

- 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

⇒ 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 $\chi^2$ cut in turn: higher efficiency
first experiment of this scale to perform alignment and calibration online

works extremely well; get beautiful peaks out of the trigger (TURBO stream)

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

\[ D^0 \rightarrow K^− \pi^+ \]
\[ D^+ \rightarrow K^− \pi^+ \pi^+ \]
\[ D_s^+ \rightarrow K^+ K^− \pi^+ \]

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