Design and performance of the LHCb trigger and full real-time reconstruction in Run 2 of the LHC

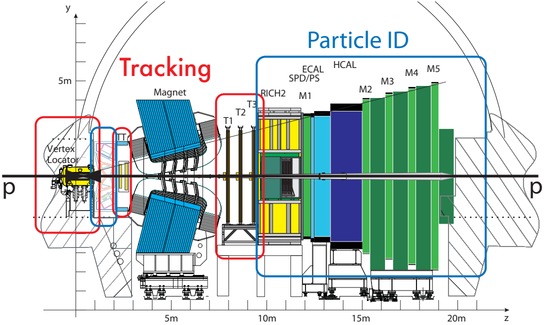
EPS 2019

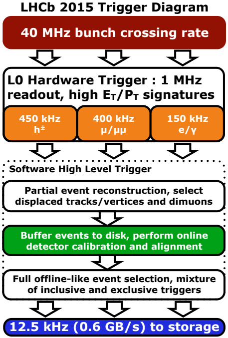
Ghent, July 10 - 17

Michel De Cian, on behalf of the LHCb collaboration

[JINST 3 (2008) S08005]

LHCb detector & trigger in Run II

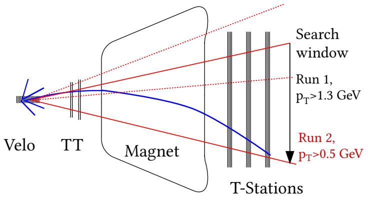


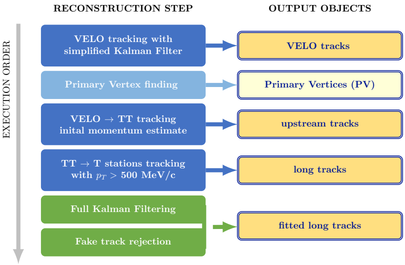


- LHCb detector designed to trigger on decay products of b or c hadrons: moderate p_{T} physics,
- Event Filter Farm in Run II consists of 1700 nodes, almost doubling the capacity compared to Run I.
- High trigger rate (12.5 kHz), but moderate event size (55kB).

[JINST 14 (2019) P04013] [EPJ Web Conf. 127 (2016) 00006]

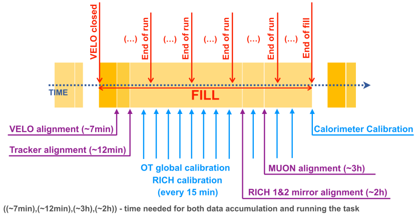
HLT1 software trigger

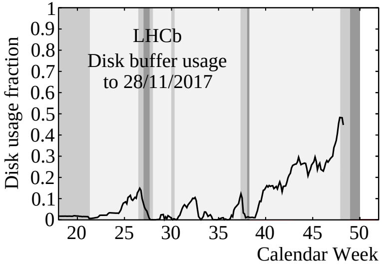




- HLT 1 performs a partial event reconstruction by reconstructing the primary vertex and all long tracks with p_{T} > 500 MeV/c
- Reoptimizing the pattern recognition and track fit allowed to lower the p_{T} threshold from 1300 $\mathrm{MeV}/c \rightarrow$ 500 MeV/c wrt to Run I.
- Low-momentum muons undergo a special reconstruction with a lower p_{T} threshold, to trigger on *e.g.* $K^0_{\mathrm{S}} \rightarrow \mu^+\mu^-$

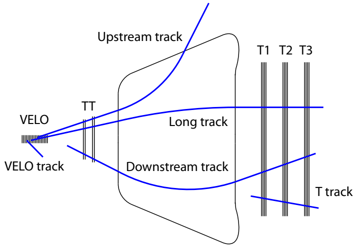
Alignment & Calibration

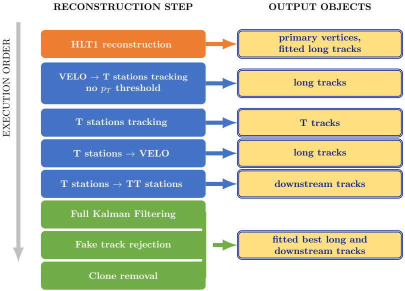




- After HLT1, the event is buffered and an automatic (real-time) alignment and calibration for the subdetectors is performed.
  - Size of buffer: 10PB ($\sim$ 2 weeks of data taking).
- The data for this task is collected with dedicated trigger lines in HLT1.
- Calibration process takes $\mathcal{O}$(min) $\to$ $\mathcal{O}$(h), new constants are put in DB and used for HLT2 processing.
- Inter-fill periods / technical stops are used to empty the buffer.

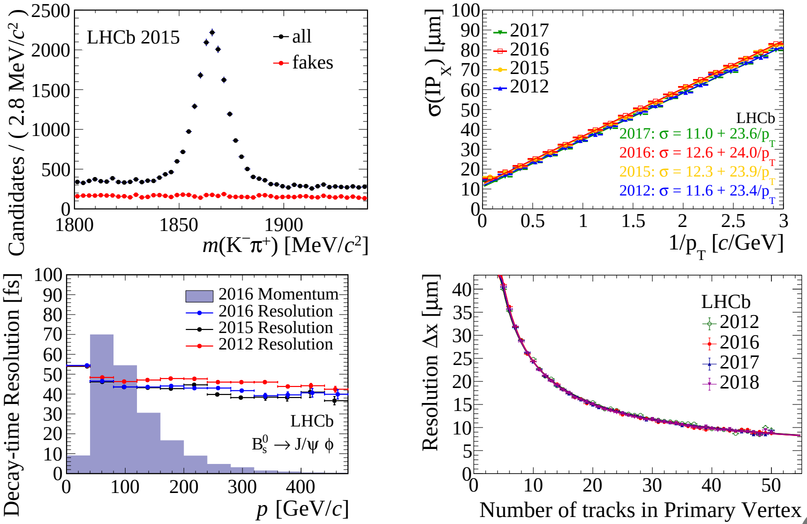
HLT2 software trigger





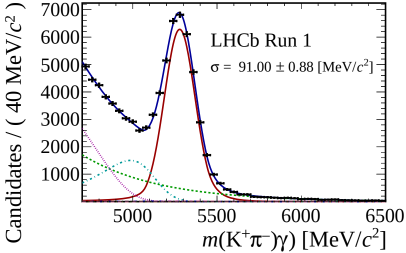
- HLT 2 performs a full event reconstruction, without p_{T} thresholds, including all detectors (tracking & PID).
- Improvements in reconstruction speed / more CPUs available / automatic alignment & calibration allow to run offline-like event reconstruction.
  - 100% overlap between offline and triggered candidates.
- LHCb introduced the Turbo framework to perform an analysis on the output of HLT2 $\longrightarrow$ See talk by B. Mitreska.

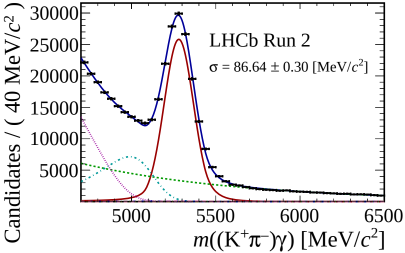
HLT reconstruction performance



- Run 1: Offline performance vs. Run 2: HLT/Offline performance.

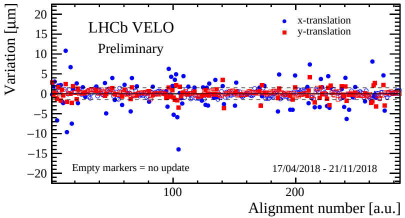
Calorimeter calibration performance

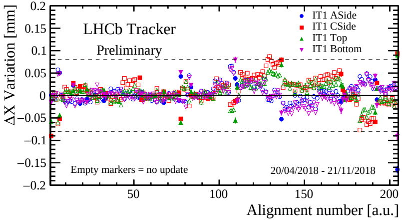


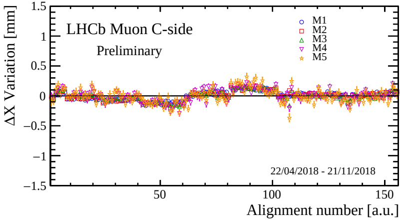


- Frequent calibration needed due to ageing of calorimeters.
- After every fill: Compare value from LED monitoring system to reference value, update voltage if needed.
- Once a month:
  - ECAL: Calibration with $\sim$ 300M minbias events, using the known π^0 mass.

Tracker alignment







- Kalman Filter based alignment for alignment of tracking detectors + muon chambers.
- Constants for Velo updated every few fills, for tracker mainly after magnetic field flip.
- Muon alignment for monitoring only, as variations are too small to have an impact.
- See poster by B. Mitreska.

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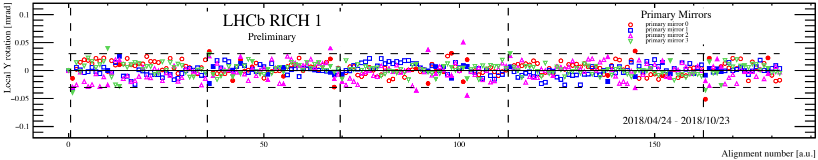
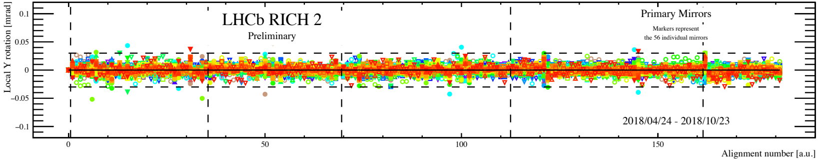
RICH mirror alignment





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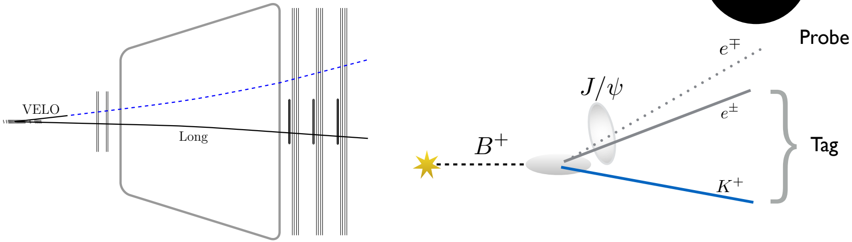
One more thing...

[JINST 10 (2015) P02007]

Electron tracking efficiency (I)

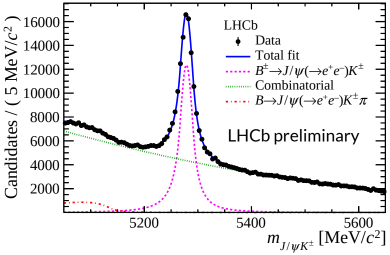
New

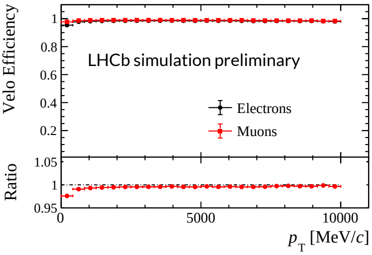


- See talks by M. Santimaria and V. Lisovskyi for LHCb analyses with electrons.
- Tracking efficiency for muons was determined with $J/\psi \to \mu^+\mu^-$.
- Electrons behave differently than muons (bremsstrahlung).
- Use tag-and-probe technique with $B^+ \to (J/\psi \to e^+e^-)K^+$.
  - Fully reconstruct K^+ and one electron.
  - Reconstruct Velo track for other electron, constrain momentum using known J/ψ mass.

Electron tracking efficiency (II)

New





- Use invariant B^+ mass to separate signal from background.
- Determine efficiency by finding the long track with the same Velo segment.
- Velo reconstruction efficiency almost identical for muons and electrons.
  - Energy loss happens mostly when crossing the magnetic field region.

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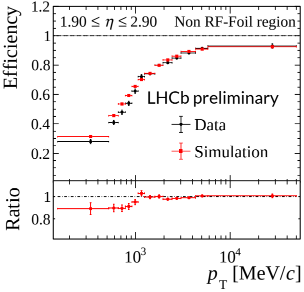
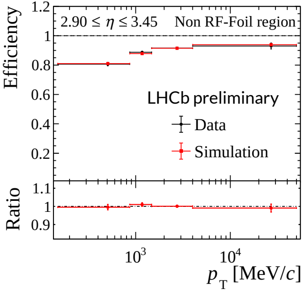
Electron tracking efficiency (III)

New





- Determine efficiency as a function η and p_{T}.
  - Need to consider tracks going parallel to RF foil differently.
- Generally very good agreement between data and simulation.
- Correction factors can be derived to correct for efficiencies in simulation.
  - Will profit precision of analyses with electrons.
- Systematic uncertainty on ratio on average 0.6% (but depending on kinematic region).

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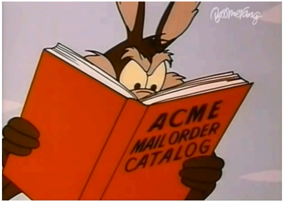
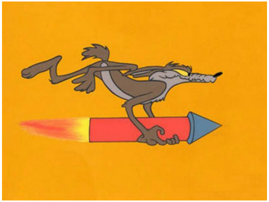
That's all, folks





- LHCb sucessfully implemented a real-time alignment & calibration in the software trigger.
- Consistently high performance of the detector, allowing to perform analyses on output of HLT.
- Upgrade of LHCb builds on this idea, removing the L0 trigger, implemeting a all-software trigger running at 30 MHz.
- First measurement of electron track reconstruction efficiency performed, good agreement with simulation.

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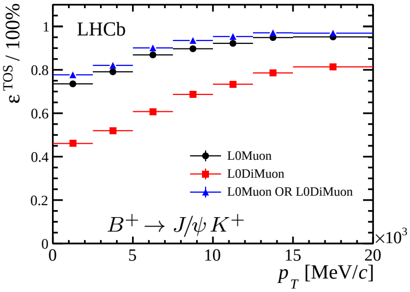
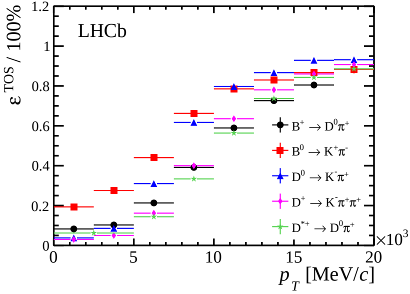
//Backup//

L0 hardware trigger

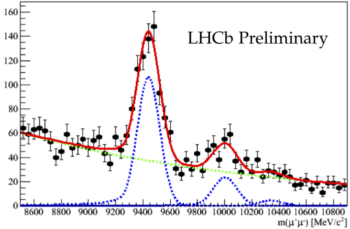




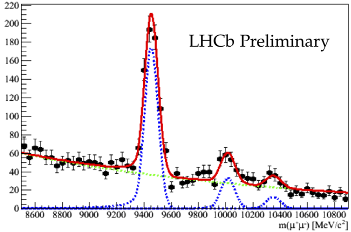
- Hardware-based trigger, implemented on FPGAs.
- Trigger on p_{T} of muons, or E_{T} in calorimeters.
- Good efficiency for muons, but high occupancy in calorimeters necessitates high thresholds to reduce rate to 1 MHz (at which the detector can be read out).

Impact of alignment

before alignment

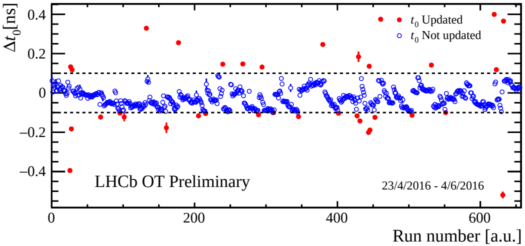


after alignment



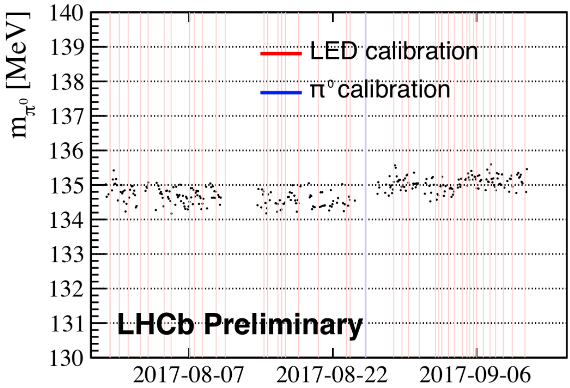
- Clear impact of performing an alignment visible
- Before alignment: $\sigma = 92\,\mathrm{MeV}/c^2$
- After alignment: $\sigma = 49\,\mathrm{MeV}/c^2$

OT global time calibration

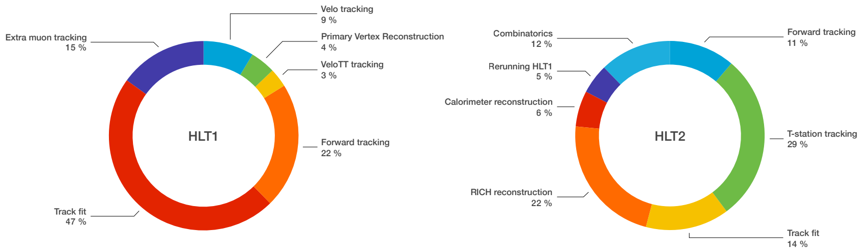


- OT is a drift-tube detector, need to calibrate a global time in order to translate drift time into position measurement.
- Fit difference between expected arrival time and measured time $\rightarrow$ difference is global time offset.

ECAL calibration with π^0 mass

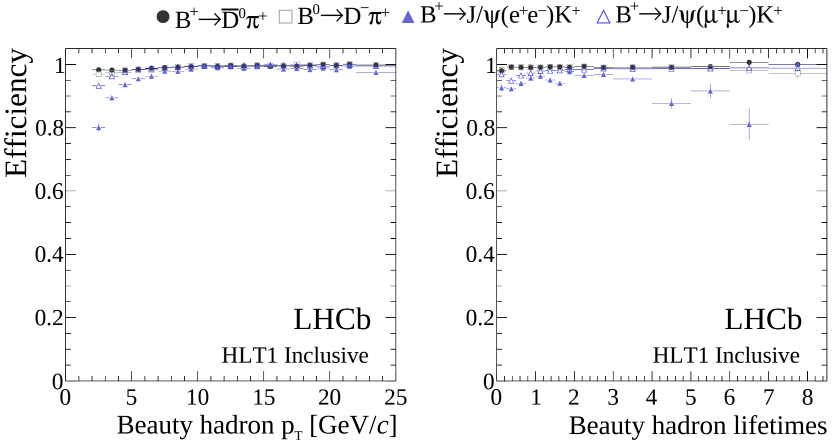


HLT timing breakdown



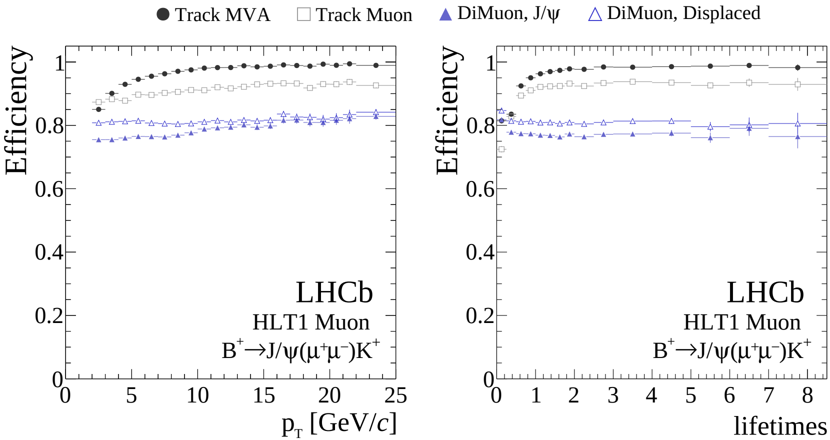
- HLT1: $\sim$ 35ms
- HLT2: $\sim$ 650ms

HLT1 efficiency (I)



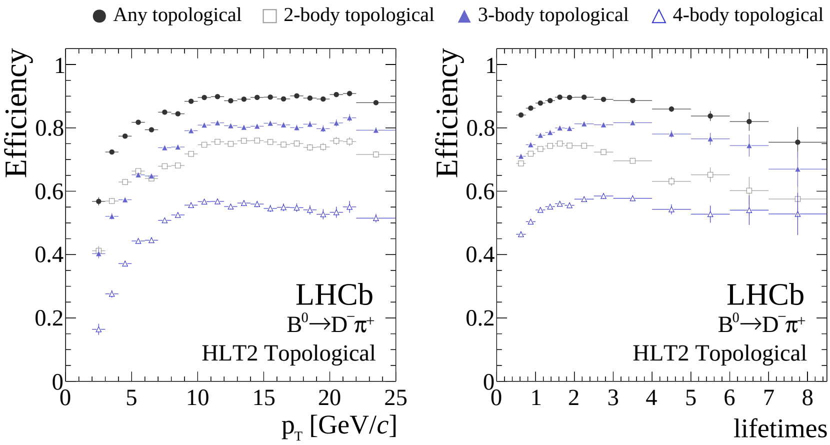
[JINST 14 (2019) P04013]

HLT1 efficiency (II)



[JINST 14 (2019) P04013]

HLT2 efficiency (I)



HLT2 efficiency (II)