First experiences with the LHCb heterogeneous software trigger

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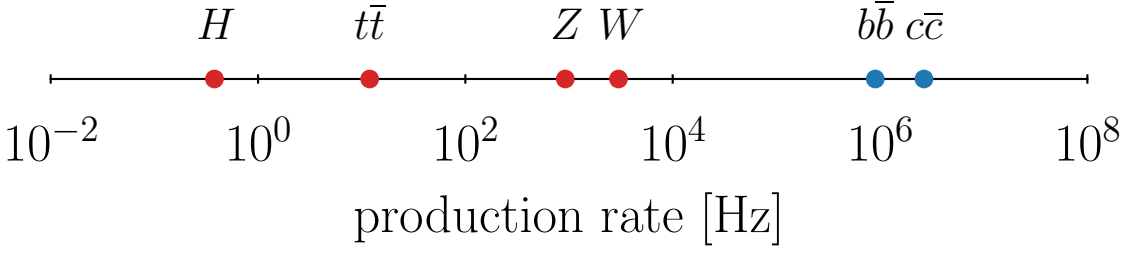
LHCb triggers on MHz signals

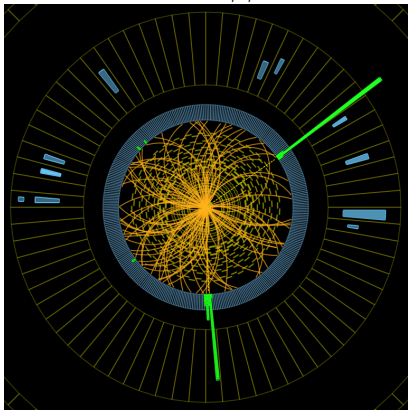
$\mathcal{L} = 2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (ATLAS/CMS) $\sqrt{s} = 13.6$ TeV

$\mathcal{L} = 2 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (LHCb)



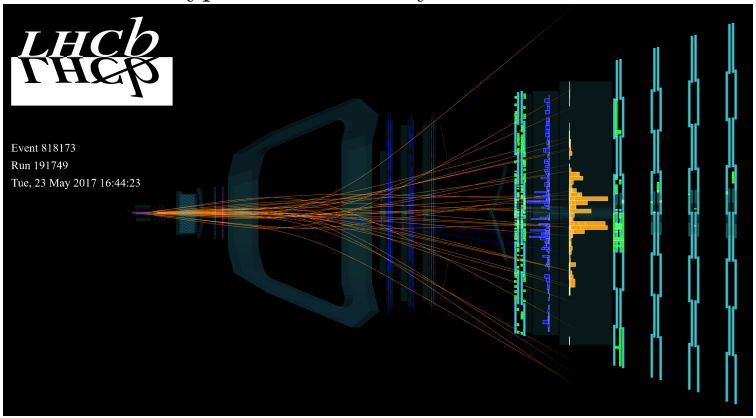
Heavy-flavor events are difficult to trigger with hardware

CMS $H \to \gamma\gamma$ event



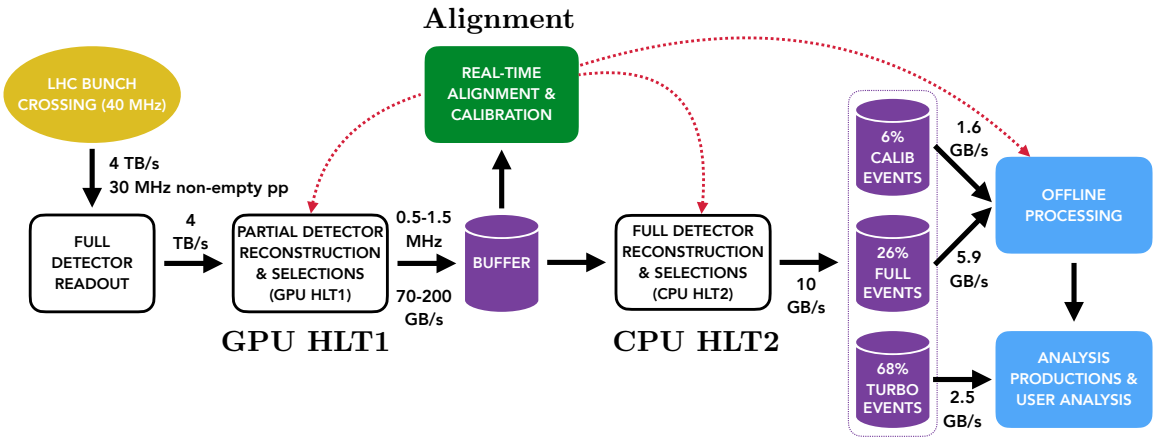
CMS event displays of Higgs to two photon candidate

Typical LHCb heavy-flavor event

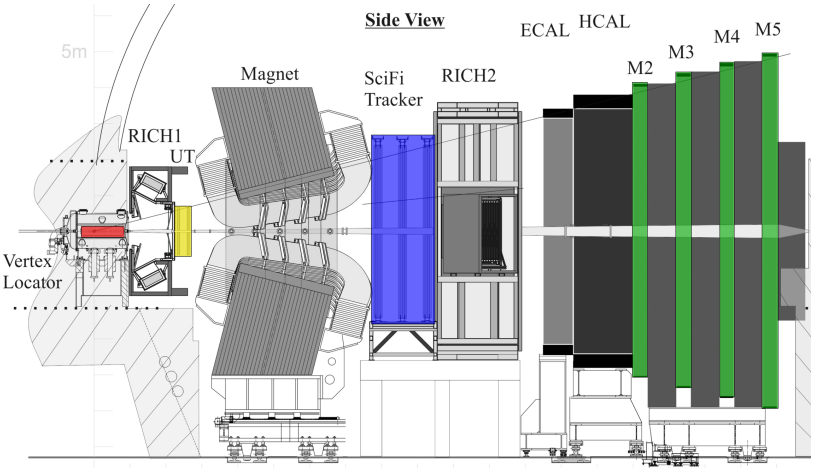


LHCb online event display

The LHCb dataflow (LHCb-TDR-016, LHCb-TDR-018)



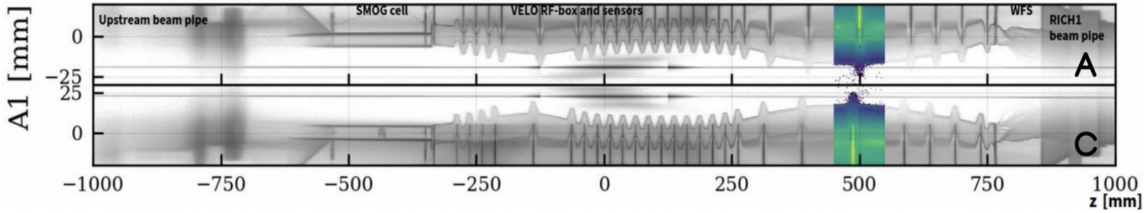
The upgraded LHCb detector (The LHCb upgrade I)



LHCb is a fully instrumented spectrometer in the forward region at the LHC.
Recently upgraded detector and increased instantaneous luminosity by $\sim 5\times$.

2023 was a challenging year

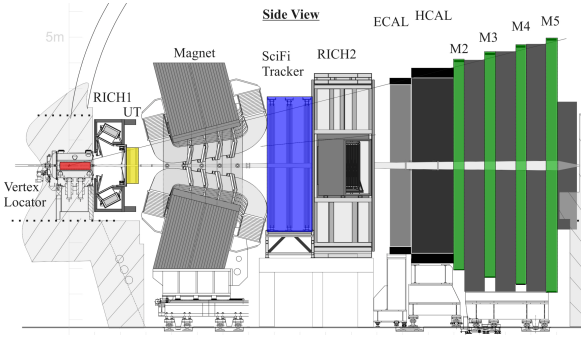
January 10, 2023: An issue with the vacuum safety system created a 200 mbar pressure differential between the VELO and LHC vacuums (safe $\Delta P < 10$ mbar).



- The RF foils separating the vacuum deformed by ~ 14 mm.
- The VELO was retracted to 24.5 mm in 2023 instead of 5 mm.
- UT commissioning still in progress after installation finished at the end of 2022.

The trigger had to adapt.

GPU HLT1: Allen (CSBS 4, 7 (2020), LHCb-TDR-021)

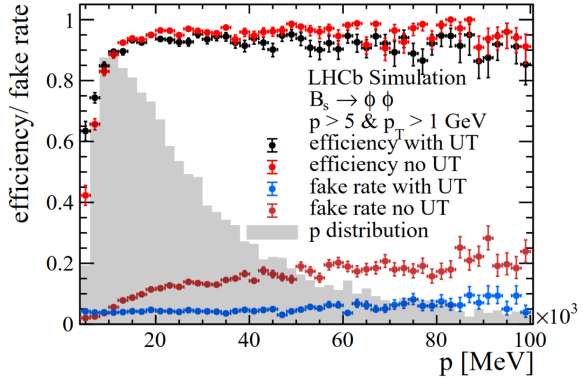


- Decode subdetector data
- Build tracks
- Find primary vertices
- Identify muons and electrons

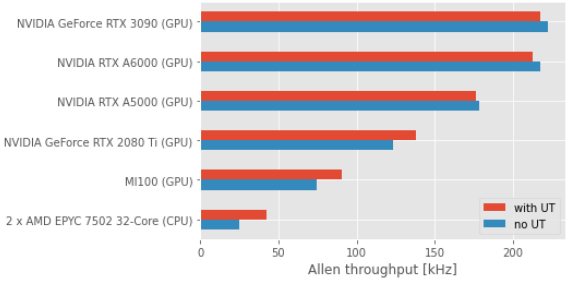
Can be compiled for CPU and GPU (CUDA or HIP).
Works as a standalone application or as part of LHCb's software stack.

Adapting HLT1 to new conditions

arXiv:2402.14670

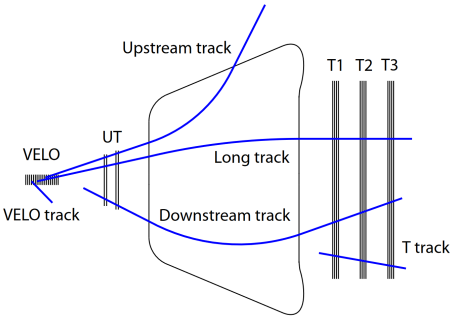


LHCb-FIGURE-2022-007

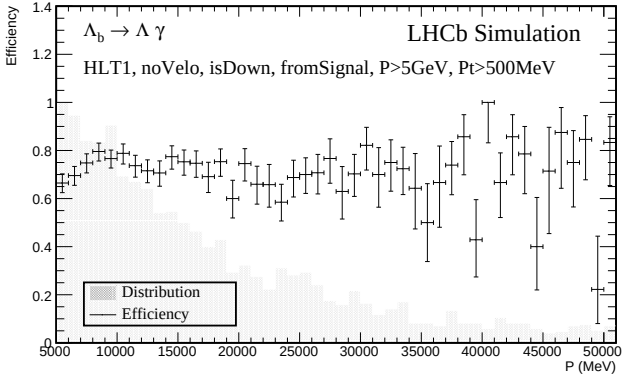


Adapted algorithms to work without the UT with minimal loss of physics performance.

Downstream tracking in HLT1



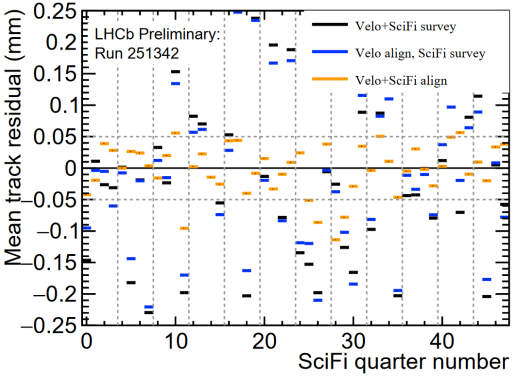
LHCb-FIGURE-2023-028



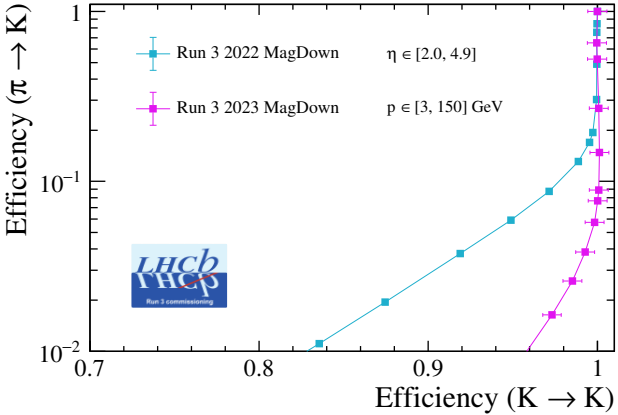
Implemented in HLT1 for the first time in 2023. See Volodymyr's talk from Monday.

Alignment

Positions and orientations of detector elements can differ from their nominal values. The detector is aligned in real time using buffered data.



LHCb-FIGURE-2022-018

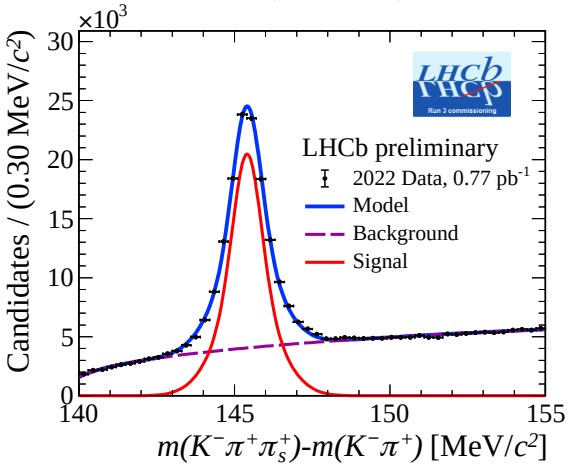


LHCb-FIGURE-2023-019

Better RICH mirror alignment in 2023 contributed to big improvements in PID.

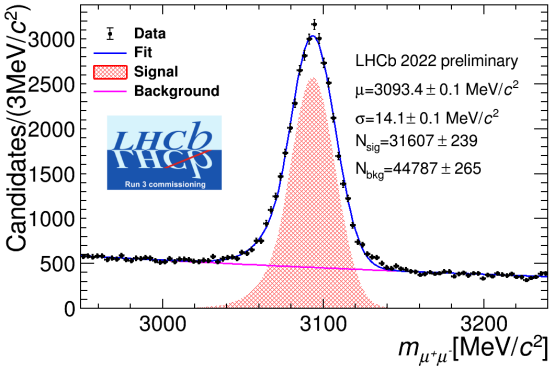
HLT2: *pp* collisions

$D^{*+} \to D^0(\to K^-\pi^+)\pi^+$



LHCb-FIGURE-2023-011

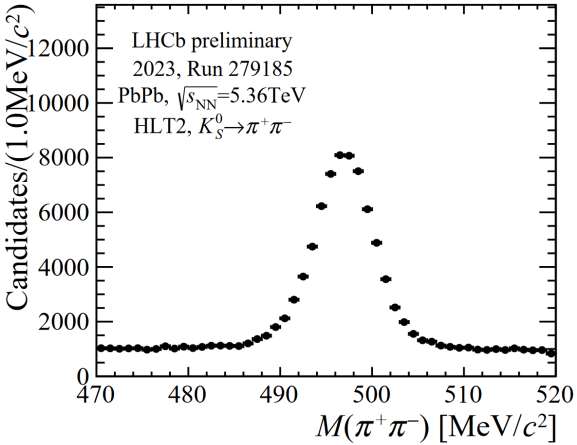
$J/\psi \to \mu^+\mu^-$

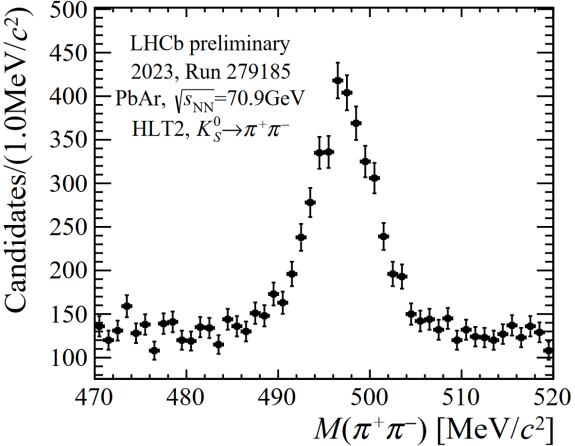


LHCb-FIGURE-2023-015

HLT2: 2023 PbPb collisions

Simultaneously triggered on PbPb and fixed-target PbAr collisions in 2023!





LHCb-FIGURE-2023-030

Final thoughts...

- 2023 was a challenging year for LHCb.
- The heterogeneous trigger system performed extremely well under adverse conditions.
- We gained a lot of experience that we can use to take great data in 2024.

Thank you!