



# The LHCb trigger system

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In Run 3 scope (2022-2026)  
on behalf of LHCb collaboration

## LHCb in a nutshell:

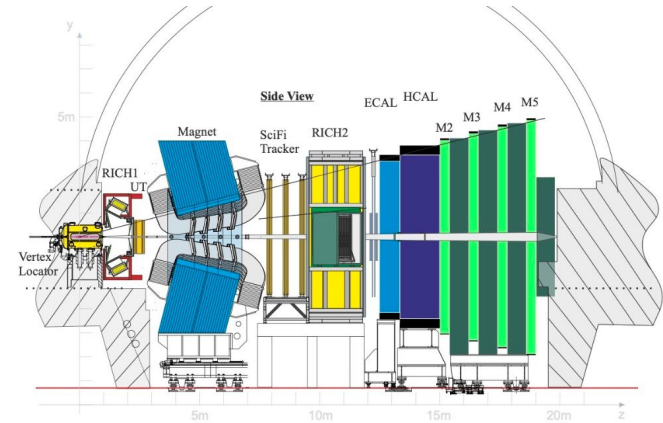
- Precision measurements in Heavy Flavour Physics
- Many research fields - rare decays and CPV (core program), but also spectroscopy, QCD, heavy ions...

*JINST 3 (2008) S08005 – The LHCb experiment*

- Now in the middle of Run 3 (2022 - 2026)

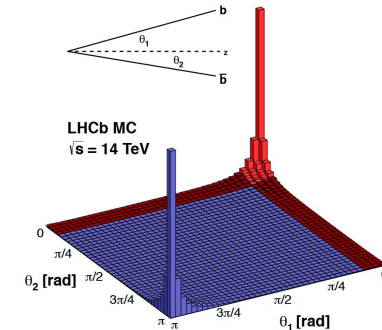
*LHCb-DP-2022-02 – The LHCb Upgrade I*

- Spectrometer well-instrumented in forward region
- Designed to run with 40 MHz readout and at instantaneous luminosity  $L = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- Upgrade II in the scoping phase



**LHCb spectrometer**  
*JINST 19 (2024) P05065*

**Distribution of b-quark pairs**  
How b pairs distribute after produced in collisions and go into the same cone (red color - at least one from the pair seen in LHCb forward acceptance)



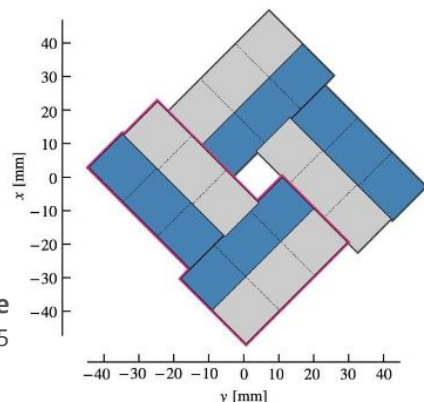
**Vertex Locator (VELO)** - surrounds the beams collision region, primary vertex reconstruction

Upstream Tracker (UT)

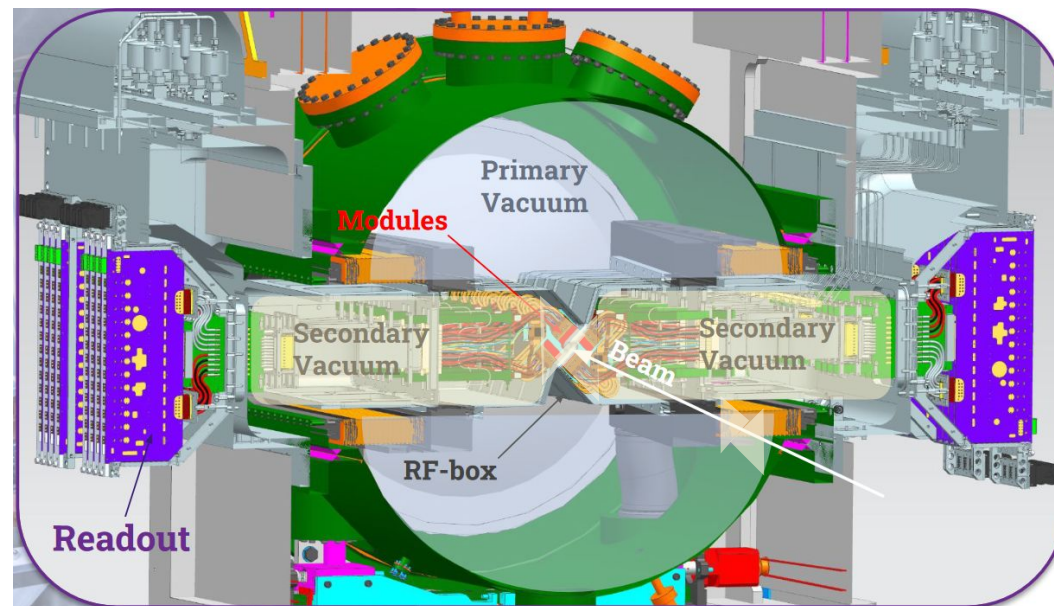
Scintillator Fibres (SciFi)

## Vertex Locator

The scheme of front view of the detector with readout boards and a vacuum tank. CERN-LHCC-2013-021



**VELO aperture**  
JINST 19 (2024) 05, P05065



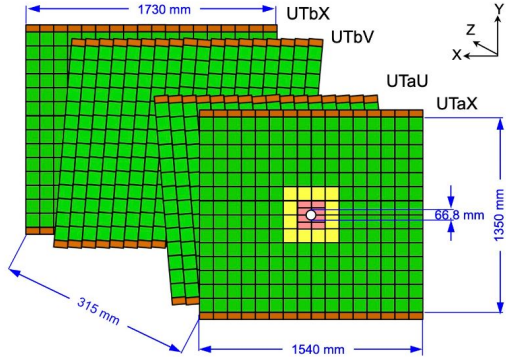
# LHCb tracking detectors

Vertex Locator (VELO)

**Upstream Tracker (UT)** - covers the plane before LHCb Magnet

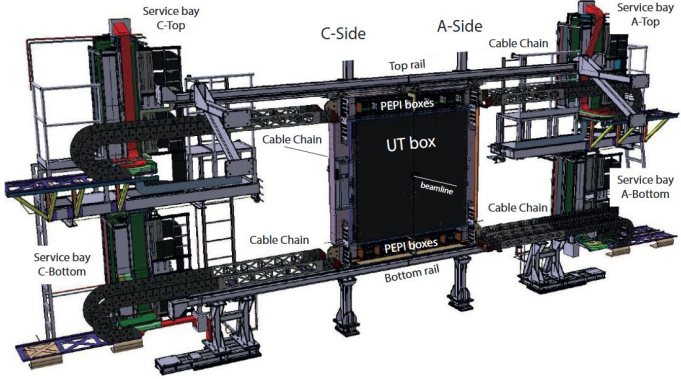
**Scintillator Fibres (SciFi)** - covers the wide plane after the LHCb Magnet

**Silicon planes of Upstream Tracker**  
JINST 19 (2024) 05, P05065



**Scintillator Fibres**  
The front and profile view of detector planes  
JINST 19 (2024) 05, P05065

**Upstream Tracker**  
The detector together with mechanical setup  
JINST 19 (2024) 05, P05065

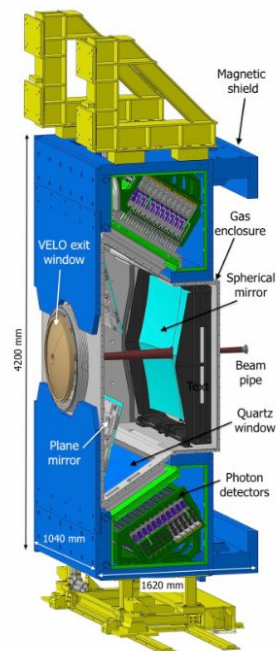
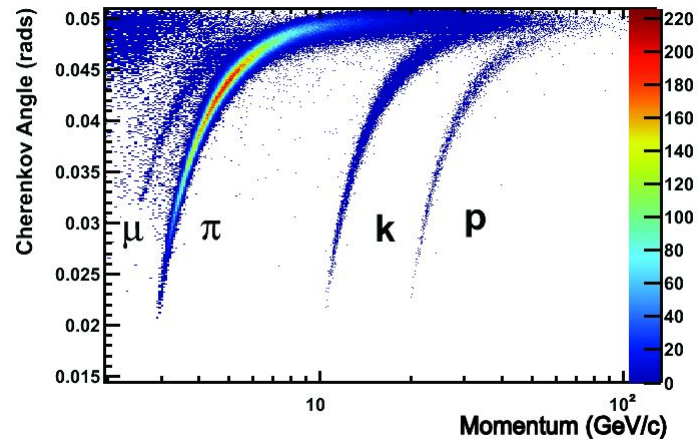


## 2 Ring-Imaging Cherenkov detectors (RICH1 & RICH2)

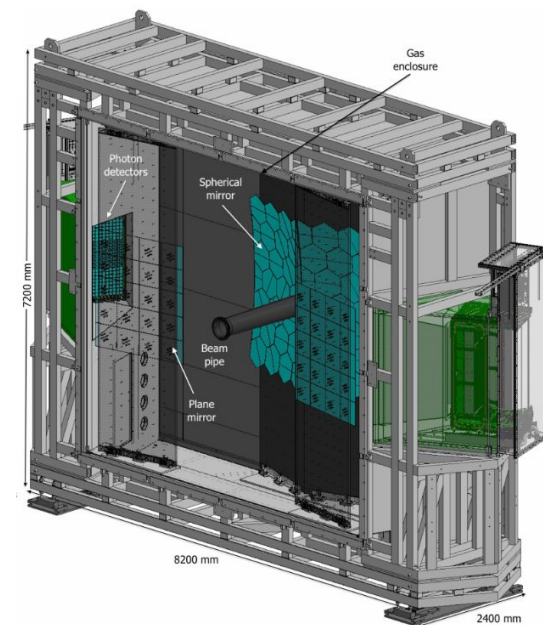
Calorimeters (ECAL and HCAL)

Muon system

Reconstructed Cherenkov angle as a function of track momentum in the C4F10 radiator in RICH1  
LHCb-DP-2012-003



**RICH detectors**  
Schematic view of RICH1 (left) and RICH2 (right)  
from JINST 17 (2022) C11006





2 Ring-Imaging Cherenkov (RICH1 & RICH2)

Calorimeters (ECAL and HCAL)

Muon system

**Muon chambers**

Floor view between M1 and M2  
LHCb-PHO-BEPI-2009-001-1

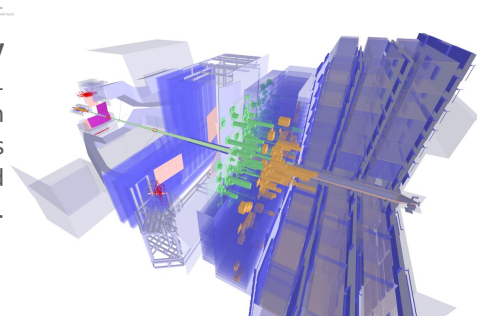


**Calorimeters**

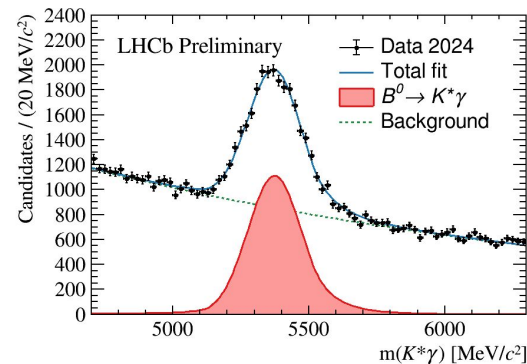
ECAL (front) and HCAL (back)  
view after installation



**LHCb Event Display**  
LHCb-PHO-GEN-2022-001  
A 13.6 TeV pp-collision  
event in LHCb, red chunks  
for RICH light, green and  
yellow for ECAL and HCAL.



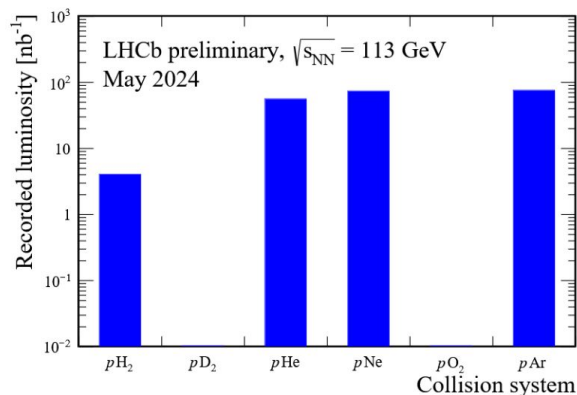
ECAL performance on a benchmark  $K^*\gamma$  mass  
distribution for up to July 2024  
LHCb-FIGURE-2024-017



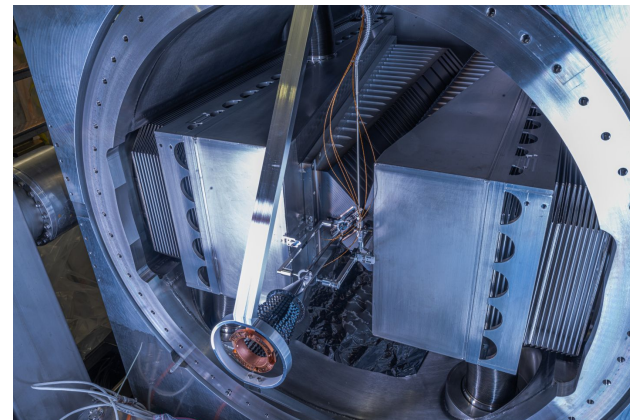
## SMOG2 (System for Measuring Overlap with Gas)

- Injects noble gases into beam pipe
- LHCb is highest-energy fixed-target experiment

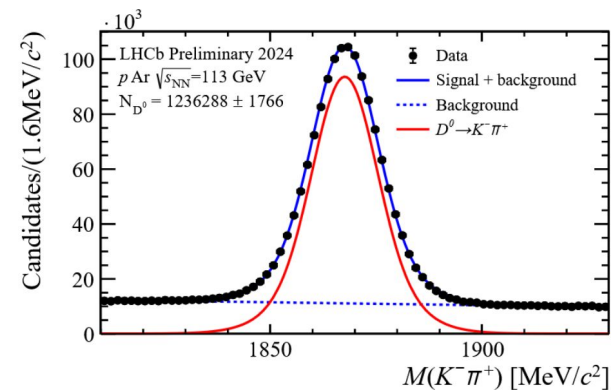
Collected online luminosities with SMOG2 in the different collision systems in May 2024  
LHCb-FIGURE-2024-005



SMOG2 cell  
VELO vacuum tank and box  
in the background  
CERN-PHOTO-202008-103

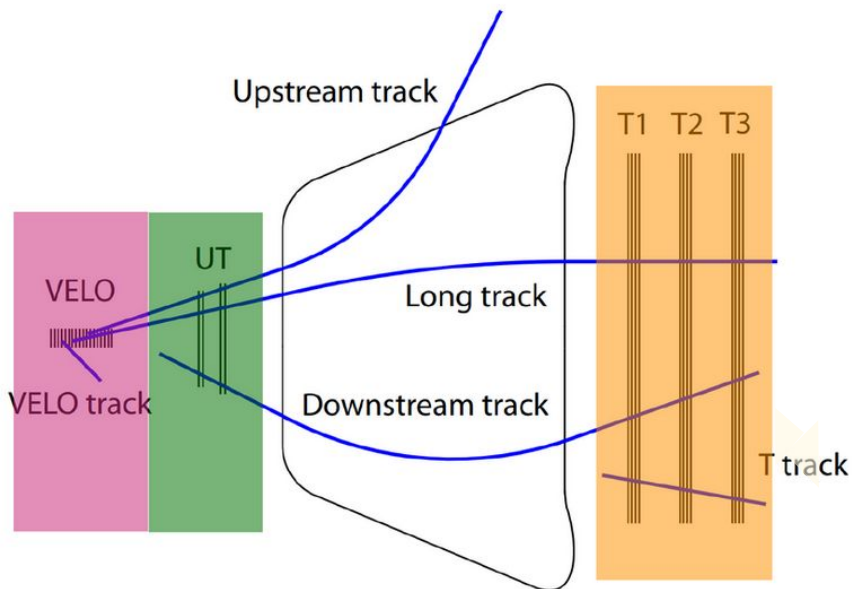


Invariant mass distribution for  $K^- \pi^+$  candidates in collisions, collected during 88 hours of Argon injection.  
LHCb-FIGURE-2024-023



Depending on which tracking detectors the charged particle goes through, the LHCb distinguishes the following types of tracks:

- VELO track
- Upstream track
- Long track
- Downstream track
- T track





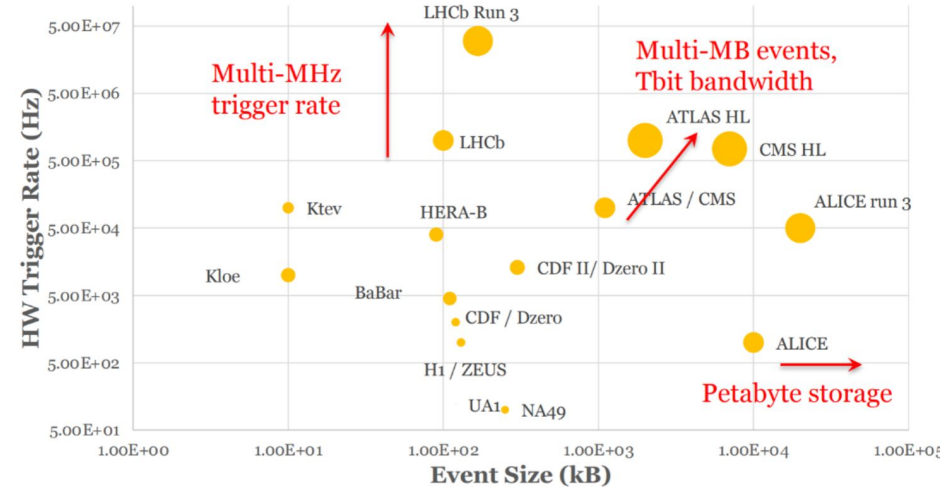
# Challenges for trigger

Motivation:

- Physics program of LHCb needs a fully software trigger (multi-MHz trigger rate)

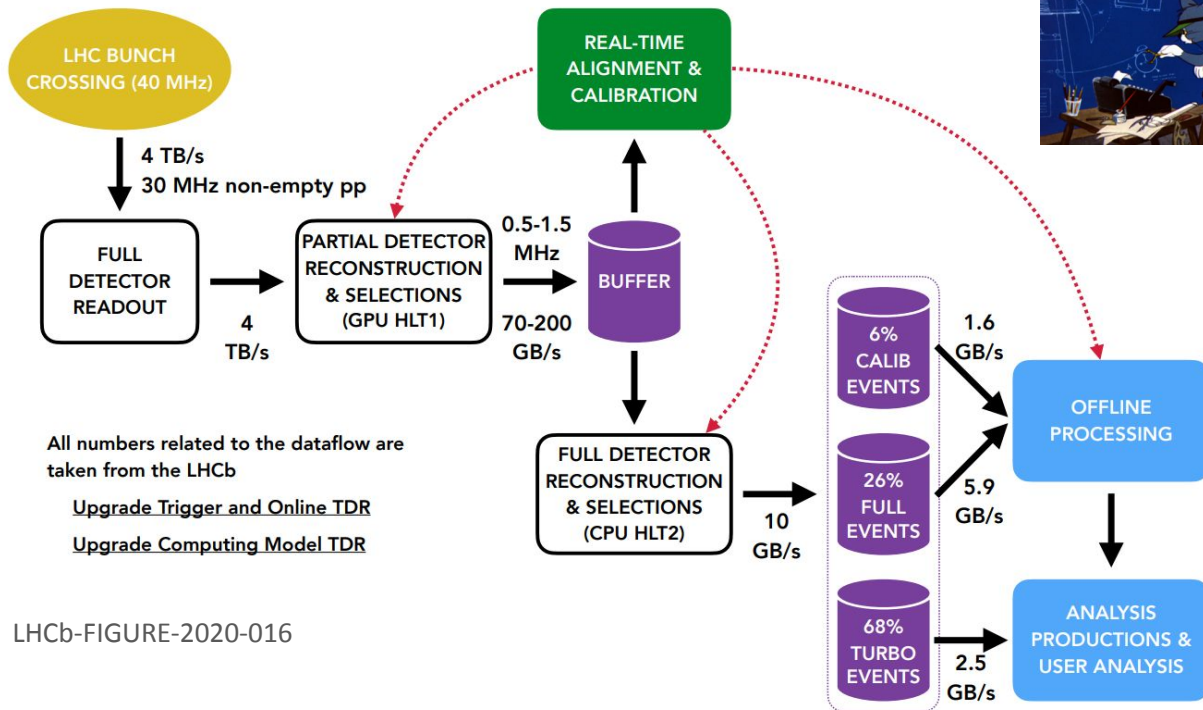
Challenges for the trigger system:

- Trivial case: trigger on interesting events
- Online detector calibration and alignment
- Flexible trigger lines
- Hardware budget and limited storage
- Software quality



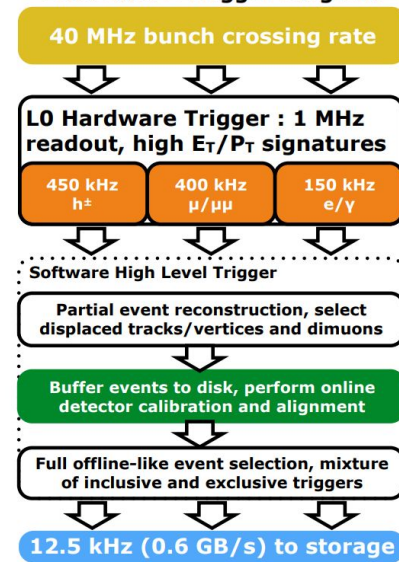
A. Cerri LHCP 2022

# Trigger overview



**A previous (Run 2) trigger scheme:**  
Hardware trigger (L0) before GPU successor in Run 3.  
Main con of that trigger was saturation of many hadronic channels when increasing instantaneous luminosity.

## LHCb Run 2 Trigger Diagram



LHCb-FIGURE-2020-016

Event readout @ 30 MHz (40 MHz LHC but intervals between trains of collisions)

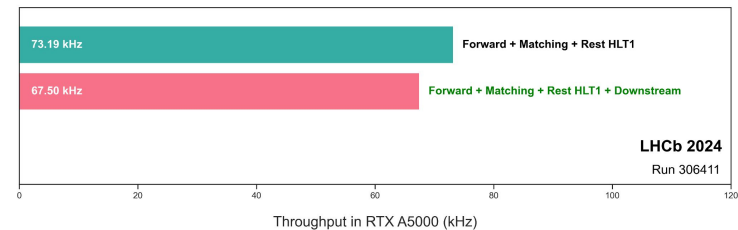
Reduces data rate 30 MHz -> 1 MHz

Performs partial event reconstruction (track and primary vertex reconstruction, ...) and primary selection (single displaced tracks, ...)

HLT1 runs two track reconstruction approaches, which perform better for different region of momentum:

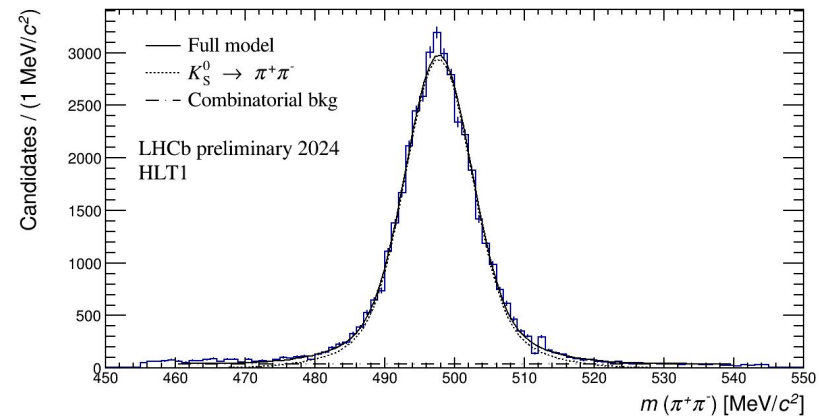
- Seeding and matching
- Forward tracking

LHCb-FIGURE-2024-035



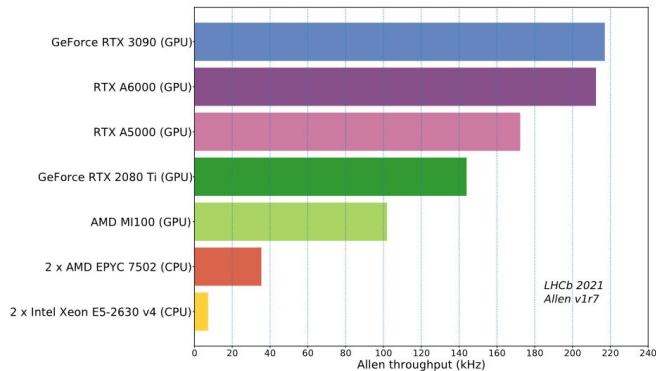
TwoTracksKs HLT1 line, early 2024 data taking,  $1.4 \text{ nb}^{-1}$

LHCb-FIGURE-2024-013



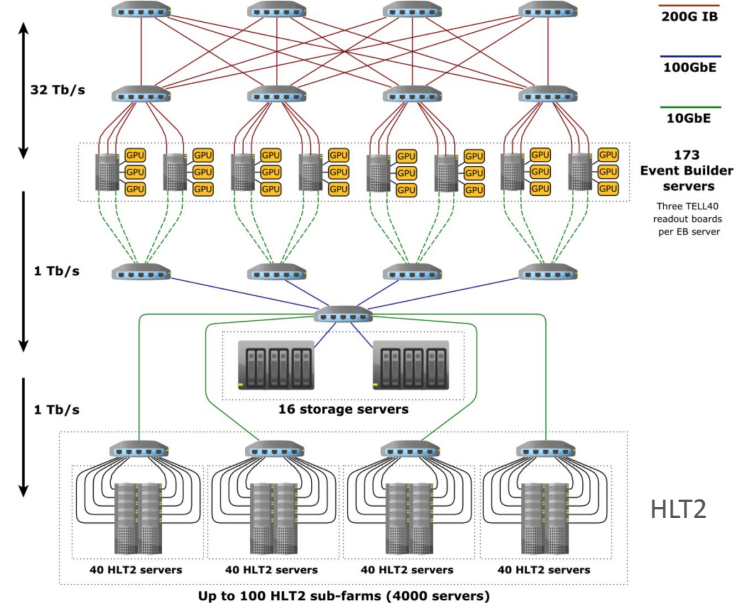
## HLT1 is GPU based

- Use-case matches parallelism paradigm
- Events are independent (however batches of events are processed together)
- Combines well with LHCb Event Builder
- About 500 GPUs NVIDIA RTX A5000 (300 in TDR)



Allen (next slide)  
throughput  
for the entire HLT1  
sequence  
LHCb-FIGURE-2020-014

## Data Acquisition System



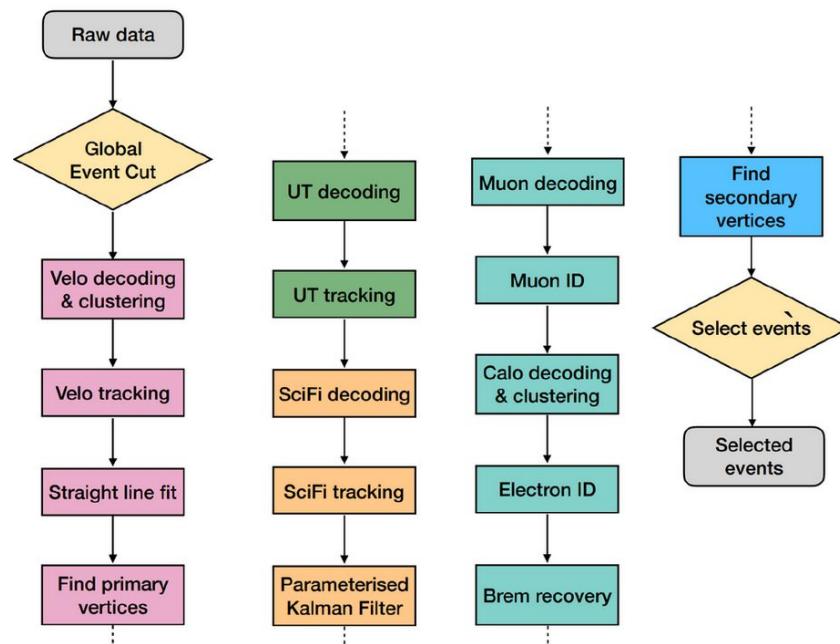
LHCb computing farm LHCb-DP-2021-003

Software for HLT1 is Allen

- Written mostly in CUDA
- <https://allen-doc.docs.cern.ch/index.html>
- Publication: Comput. Softw. Big Sci. 4, 7 (2020)

Trigger lines are python configurables

- Described by Trigger Configuration Key (TCK)
- Flexible to change or develop new conditions
- Possible to change TCK in the same software release
- Integrated/partly automated in GitLab pipelines



**Block scheme of HLT1 algorithms**

From Comput. Softw. Big Sci. 4, 7 (2020)

Rhomb block reduces the data rate, rectangle block is an algorithm block.



Embedded into the trigger system

- Uses a subset of data after HLT1
- Performs tasks online with 5 dedicated lines
- Feeds HLT2 and ex-post HLT1
- Eliminates differences between online and offline reconstruction and efficiencies

Essential during data taking ...

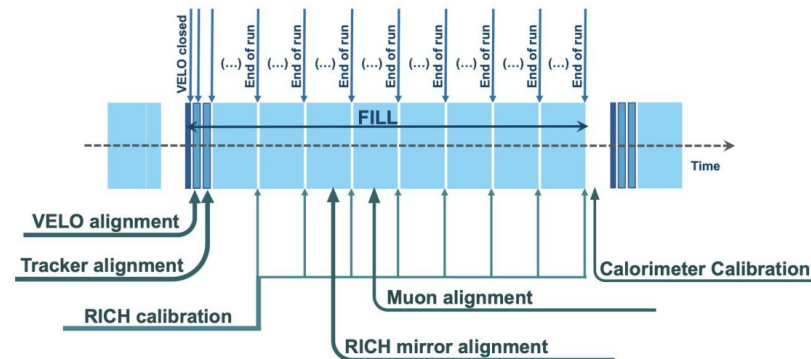
- Calibration for PID detectors
- Spatial alignment for trackers

... and for the detector monitoring!

## Alignment and calibration

A scheme as a function of LHC fill.

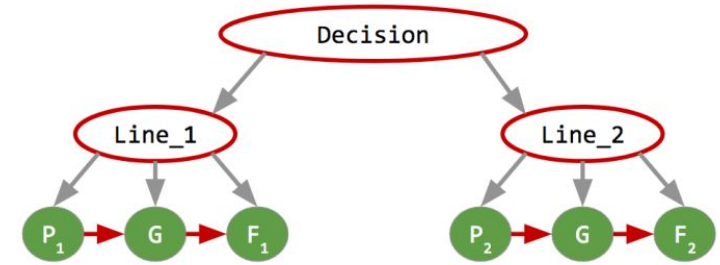
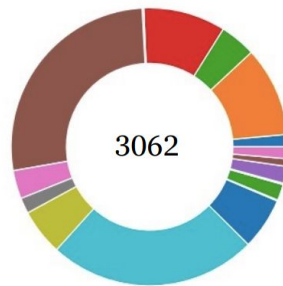
After VELO is closed, the alignment of trackers is (repeatedly) done, followed by alignment or calibrations of other LHCb detectors.



## Full event reconstruction and selection on CPU farm

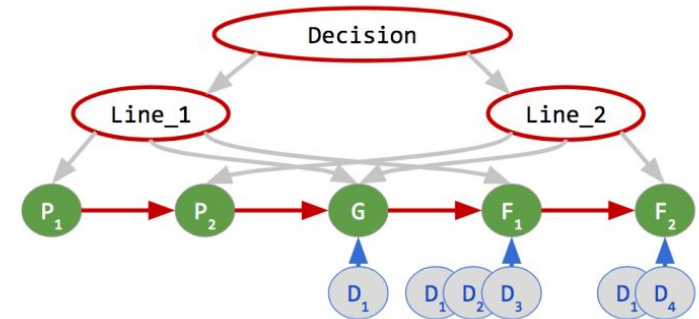
- Inclusive and exclusive selection with  $O(3000)$  physics lines
- Reduces data rate to 20 kHz - the limiting factor is bandwidth of HLT2 output (next slide)
- Physics lines are written in Python, and get converted into C++ code -> flexibility

Number of Hlt2 lines per WG



HLT2 Event Scheduler

Not optimized (above) and optimized (below) for node sharing  
2020 J. Phys. Conf. Ser. 1525 012052

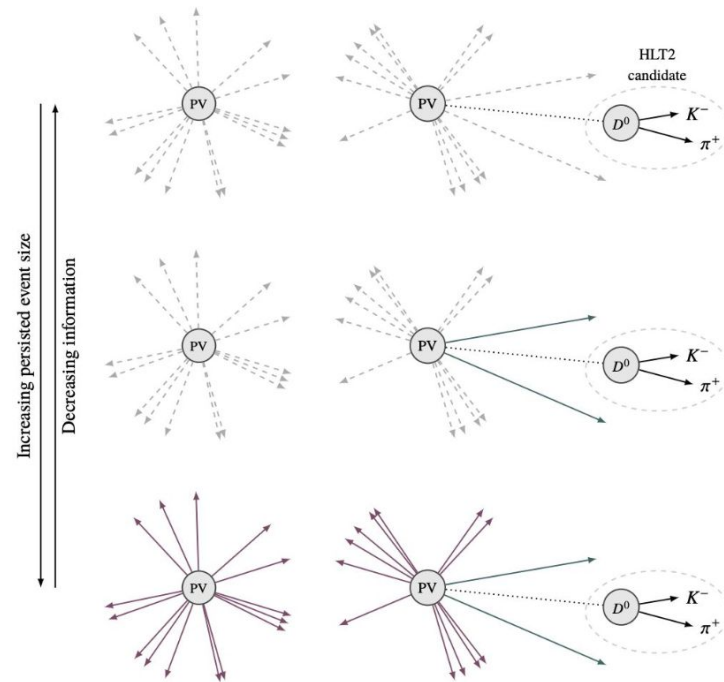


Bandwidth (GB/s, Event Size x Rate) is hardware-limited to 3.6 GB/s for save-to-disk (10 GB/s save-to-tape)

- Solution: smart reduction of event size may reduce bandwidth with no impact on Physics

LHCb defines various models of events:

- Full event - all reconstructed objects
- Turbo event - essential information (signal) for a requested analysis (e.g. Primary Vertex, ...)
- Selective event with flexible definition
- TurCal event



**Illustration of event size reduction**

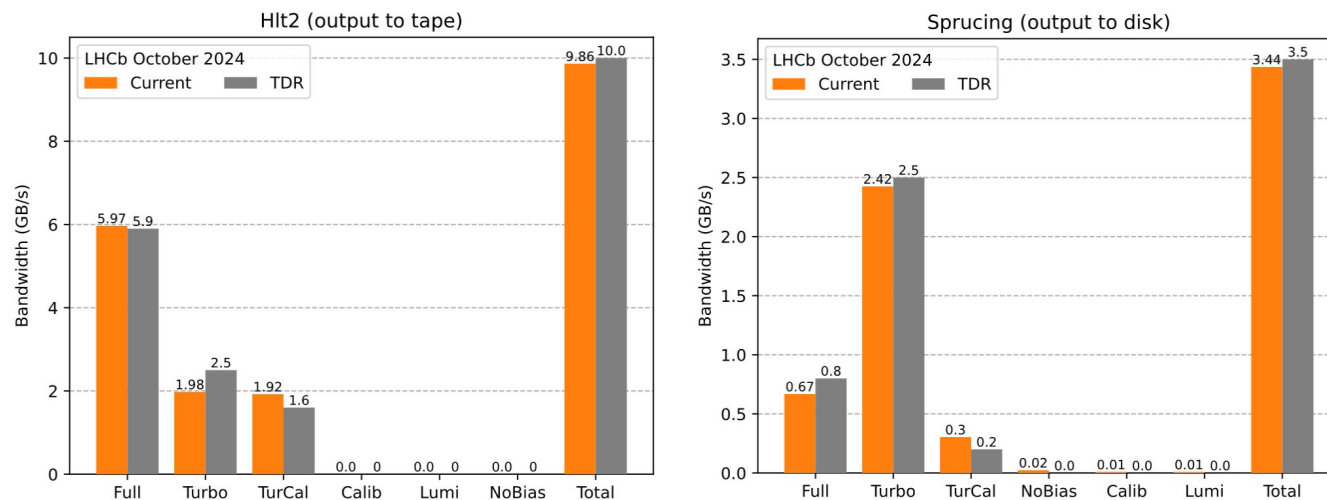
In Turbo stream (top) not essential data is discarded

JINST 14 P04006

HLT2 achieved performance from TDR

- Graphs below come from October 2024
- For these, HLT1 had an output rate of around 1.2 MHz (20% higher than TDR)
- Taken at nominal LHCb Run 3 pile-up

LHCb-FIGURE-2024-034



## Production software

- A stack of Gaudi-based projects with backward dependencies
- Automatic daily testing - LHCb Nightly Builds
- Many-platform test suite scheduled by Jenkins
- Tests executed for current and legacy slots
- The stack of projects includes not only production software for Triggers, also Alignment, Simulation, ...

### LHCb Nightly Build

For many platforms, a full test suite from all software projects that aim to be used in production



lhcb-head/4038 (today) [View](#)  
 head of everything against Gaudi/v3r1 and LCG\_100c

build 100% failinp: 25 errors tests 95% ✓ 13438 | ✗ 1117

Project	Version	x86_64_v4-eh-gcc13-opt		x86_64_v2-eh-gcc13-dbg		x86_64_v4-eh-gcc13-opt+g		x86_64_v4-eh-gcc13-ehetesc-opt		x86_64_v4-eh-gcc13-ehetesc-dbg		x86_64_v4-eh-gcc13-ehetesc-opt+g		x86_64_v4-eh-clang16-opt		x86_64_v4-eh-clang16-dbg	
		build	tests	build	tests	build	tests	build	tests	build	tests	build	tests	build	tests	build	tests
Gaudi	v3r1	0/0	322/1	0/0	324/0	0/0	322/0	0/0	322/1	0/0	324/0	0/0	322/0	0/0	323/0	0/0	324/0
Detector	HEAD	0/0	83/0	0/0	83/0	0/0	83/0	0/0	83/0	0/0	83/0	0/0	83/0	0/0	83/0	0/0	83/0
LHCb	HEAD	0/0	247/1	0/0	246/1	0/0	247/1	0/0	254/2	0/0	263/2	0/0	254/2	0/0	247/1	0/0	246/1
Lbcom	HEAD	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	
Rec	HEAD	0/0	45/6	0/0	45/6	0/0	50/1	0/0	40/8	0/0	40/8	0/0	45/3	0/0	45/6	0/0	45/6
Allen	HEAD	0/0	17/0	0/0	17/0	0/0	16/1	0/0	14/1	0/0	14/1	0/0	14/1	0/0	17/0	0/0	17/0
Moore	HEAD	0/0	206/7	0/0	205/6	0/0	207/6	0/0	181/16	0/0	181/14	0/0	183/14	0/0	201/6	0/0	192/11
Alignment	HEAD	0/0	6/2	0/0	6/2	0/0	8/8	0/0	3/2	0/0	3/2	0/0	3/8	0/0	6/2	0/0	3/1
Online	HEAD	0/0	346/0	0/0	345/1	0/0	346/0	0/0	346/0	0/0	346/0	0/0	345/1	0/0	346/0	0/0	346/0
MooreOnline	HEAD	0/0	27/11	0/0	26/12	0/0	23/15	0/0	17/6	0/0	17/6	0/0	17/6	0/0	27/11	0/0	25/12
Panoplies	HEAD	0/0	3/0	0/0	3/0	0/0	3/0	0/0	2/1	0/0	3/0	0/0	3/0	0/0	3/0	0/0	3/0
Dafnic	HEAD	0/0	64/13	0/0	64/13	0/0	63/14	0/0	62/17	0/0	63/24	0/0	63/16	0/0	64/13	0/0	64/13
LHCbIntegrationTests	HEAD	0/0	21/1	0/0	21/1	0/0	21/1	0/0	51/7	0/0	51/7	0/0	52/6	0/0	21/1	0/0	21/1
Run2Support	HEAD	0/0	45/0	0/0	45/0	0/0	45/0	0/0	6/0	0/0	6/0	0/0	6/0	0/0	45/0	0/0	45/0
Boole	HEAD	0/0	3/6	0/0	3/6	0/0	3/6	5/0	8/6	5/0	8/6	5/0	8/6	0/0	3/6	0/0	3/6
Geant4	HEAD	84/0	53/0	0/0	82/0	0/0	84/0	0/0	83/0	0/0	82/0	0/0	806/0	0/0	802/0	0/0	802/0
GaussinoExtLibs	HEAD	633/0	0/0	633/0	0/0	633/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	2/68	0/0	2/68
Gaussino	HEAD	0/0	15/0	0/0	15/0	0/0	15/0	0/0	15/0	0/0	15/0	0/0	15/0	0/1	0/1	0/1	0/1
Gauss	HEAD	0/0	20/0	0/0	20/0	0/0	20/0	0/0	13/2	0/0	13/6	0/0	13/2	0/1	0/1	0/1	0/1



## Developing software

- Via GitLab Merge Requests
- A CI-test is available to call at any moment, for Jenkins to schedule the full test suite
- Managed by software shifters and maintainers
- Very detailed code review
- Tests include throughput and bandwidth to check the impact on triggers

### Software development

Continuous development (in this case Moore) with new merge requests appearing hourly.

[RTADPA BW Tests] Minor doc change following !4073

!4133 · created 4 minutes ago by Luke Grazette

RTA

[QEE] Collection MR for 2025 First Reoptimisations 0 of 3 checklist items completed

!4033 · created 4 weeks ago by Luke Grazette ◊ Reoptimised Hit2 selections for 2025: "lossless" first pass

DPA-WP1 PR/Moore\_hit2\_and\_spruce\_bandwidth RTA RTA WP3 ci-test-triggered qee

Draft: B2OC Hit2 updates for 2025 5 of 5 checklist items completed

!4089 · created 1 week ago by Alessandro Bertolin ◊ Reoptimised Hit2 selections for 2025: "lossless" first pass

B2OC PR/Moore\_hit2\_and\_spruce\_bandwidth PR/full\_throughput\_test RTA ci-test-triggered

SLB Nov24 Hackathon: Tune BToXuTauNu lines (Hadronic and Muonic Tau)

!4128 · created 1 day ago by Abhijit Mathad 📄 SLB-Nov24-hackathon

SLB Builder SLB Line

Draft: SLB Nov Hackathon: Add selective persistence (charged particles) + neutral to all spruce lines

!4107 · created 1 week ago by Abhijit Mathad

PR/Moore\_hit2\_and\_spruce\_bandwidth RTA SLB Builder SLB Line ci-test-triggered

Draft: Synchronize master branch with 2024-patches

!4088 · created 1 week ago by Marco Clemencic

RTA Synchronise master with 2024-patches

Manual ref update based on lhcb-master 2521

!4132 · created 3 hours ago by Miroslav Saur

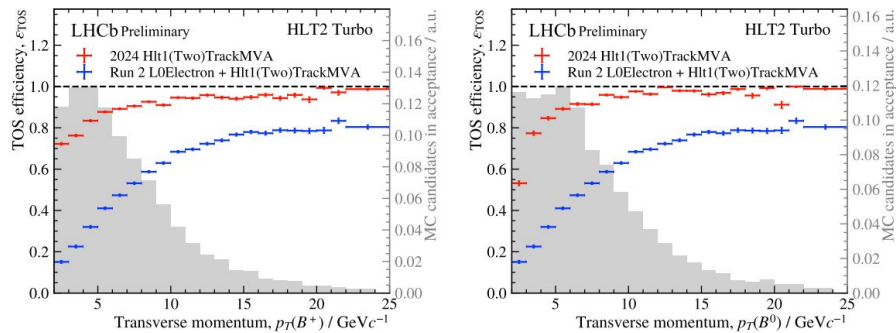
RTA reference update

# Summary of 2024 operation

LHCb did great this year!

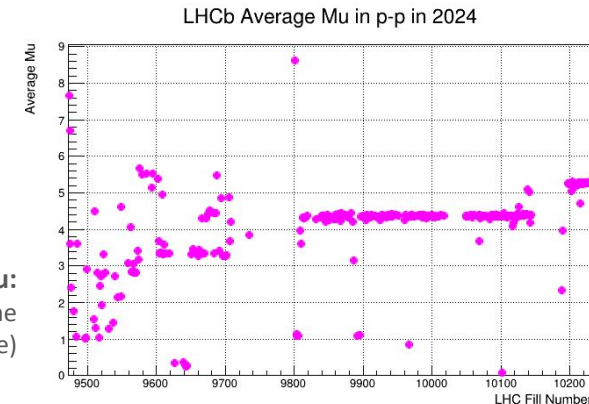
- Expected integrated luminosity for proton-proton recorded by LHCb was achieved
- And first time PbPb data taken with full detector!

Efficiency compared to Run2  
LHCb-FIGURE-2024-030

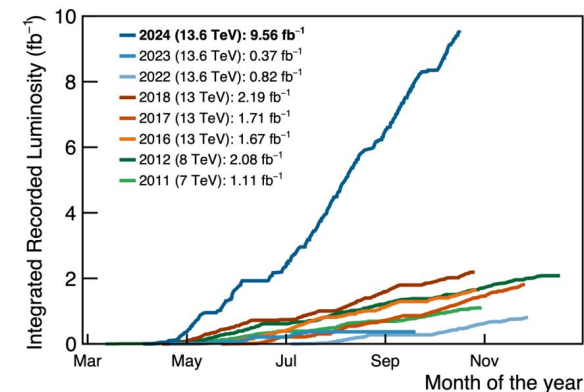


LHCb average mu:

How LHCb increased mu during the year (LHC's fill 9800 is 19 of June)



Data collected by LHCb  
Summary plot for all Runs  
since LHCb start in 2011.



# Thanks for attention!

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The LHCb RTA group