Real-time alignment, calibration, and software quality assurance for the LHCb

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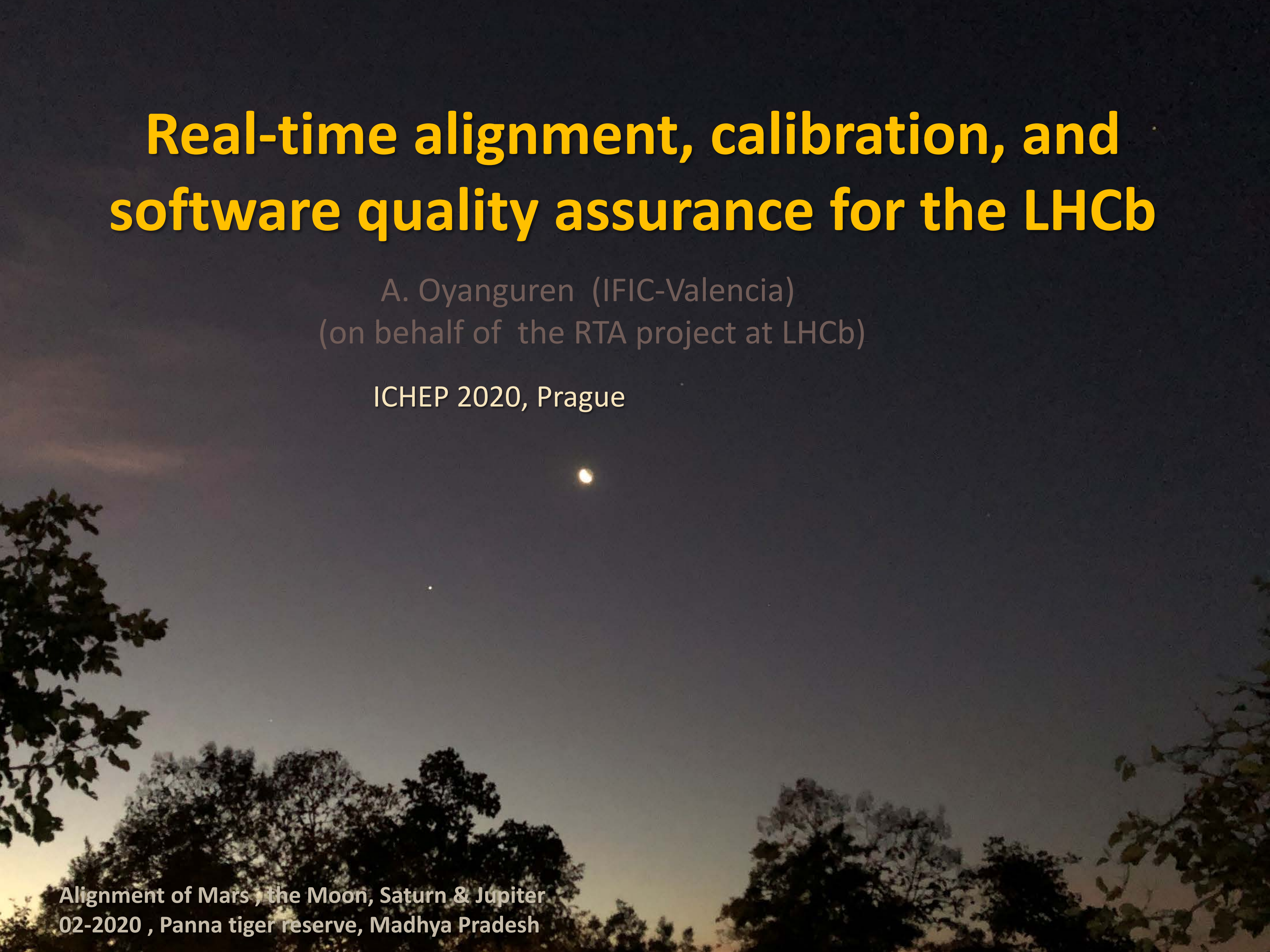
(on behalf of the RTA project at LHCb)

ICHEP 2020, Prague



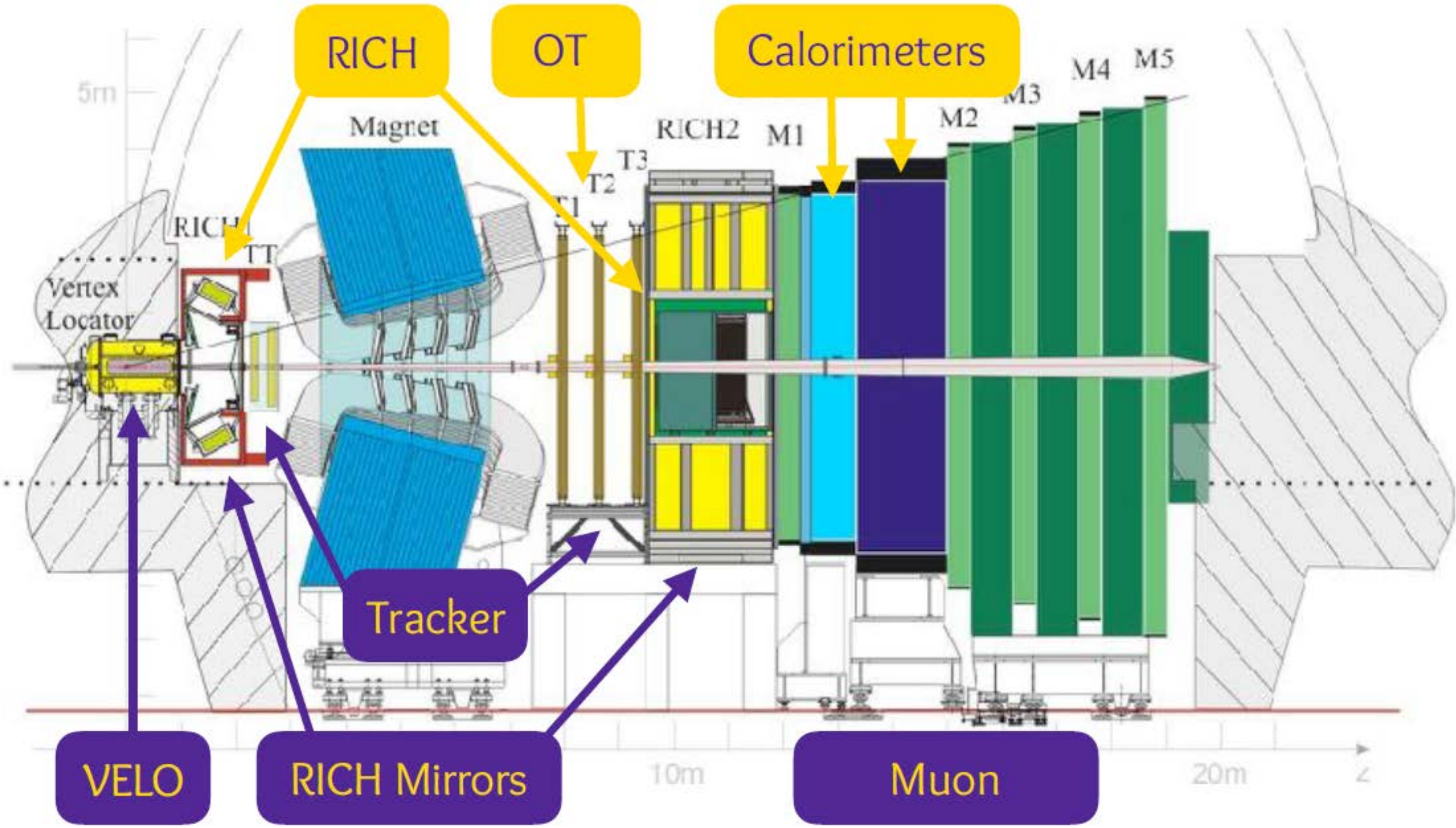
Alignment of Mars , the Moon, Saturn & Jupiter
02-2020 , Panna tiger reserve, Madhya Pradesh

Outline

- The LHCb detector
- The *trigger* system
- Real time analysis
- Alignment and calibration
- Prospects for Run3
- Conclusions

The LHCb detector

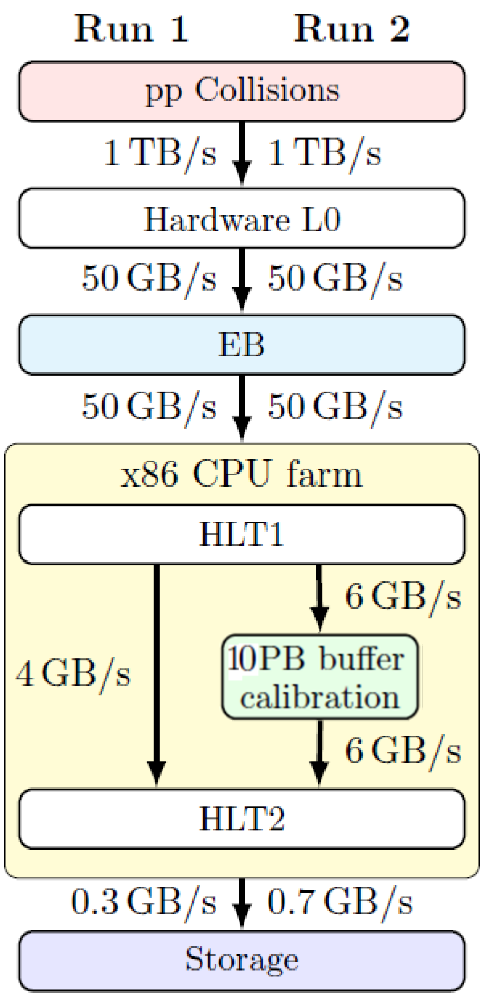
[INT.J.MOD.PHYSA 30 (2015) 1530022], [JINST 3 (2008) S08005]



Very good performance: → tracking resolution Δp/p ~0.5%
→ tracking and PID efficiencies > 95% (90% for electrons)

To achieve this, detectors must be properly **aligned** and **calibrated**

The trigger system



[JINST 14 (2019) P04013]

▶ Proton-proton collisions at 40MHz

▶ A hardware trigger (L0) using information from calorimeters and muon systems

▶ Events built at 1MHz sent to 27k CPU cores.
Two software trigger stages:

- HLT1: fast tracking, inclusive selections (1MHz $\rightarrow$ 100kHz)
- HLT2: ~ 500 dedicated lines (100 kHz $\rightarrow$ 12.5kHz)

▶ **Run I:** Alignment & Calibration of the detector performed “offline”, several weeks after data taking

▶ **Run 2:** Alignment & Calibration performed in real-time before HLT2 (up to few weeks) thanks to the addition of a 10PB buffer

▶ 0.3 $\rightarrow$ 0.7 GB/s to storage, thanks to data processing in real time

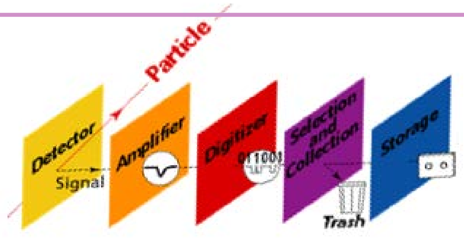
Real Time Analysis

- Our storage capacity is limited. The trigger bandwidth is given by:

Bandwidth [GB/s] ~ Trigger output rate [kHz] x Average event size [MB]

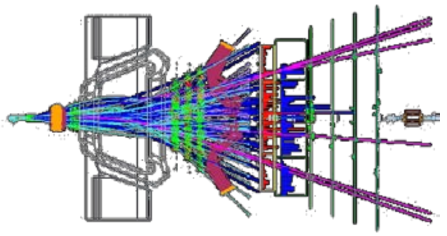
~ 1 GB/s

and increasing
in the next periods
of data taking

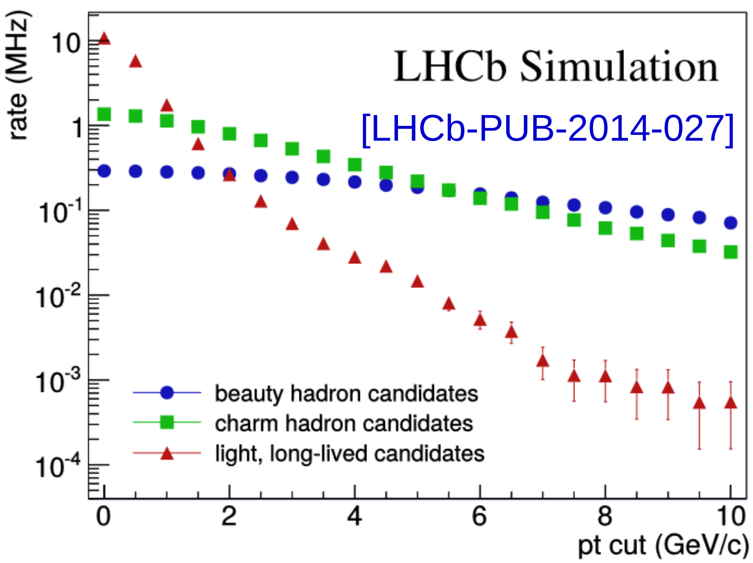


12.5 kHz at LHCb

Raw event data size



~0.1 MB at LHCb

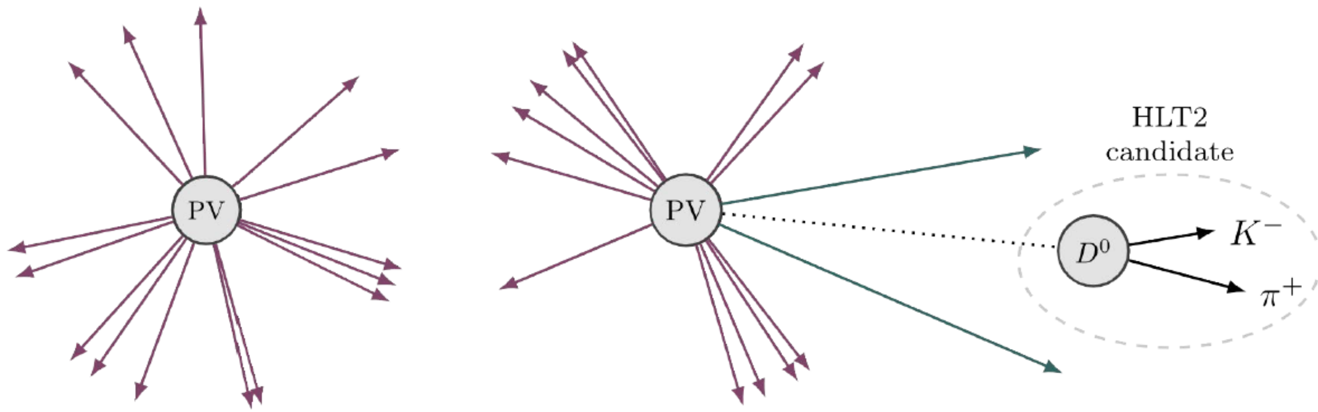


▶ The **trigger rate saturates:** all our selected events are interesting signals

▶ We need then to **reduce the event size**: Instead of taking the raw data, store only the relevant information

Real Time Analysis

- At LHCb The TURBO model exploits the event topology and saves only a subset of the objects which are relevant for a posterior analysis. One can use several persistence levels:



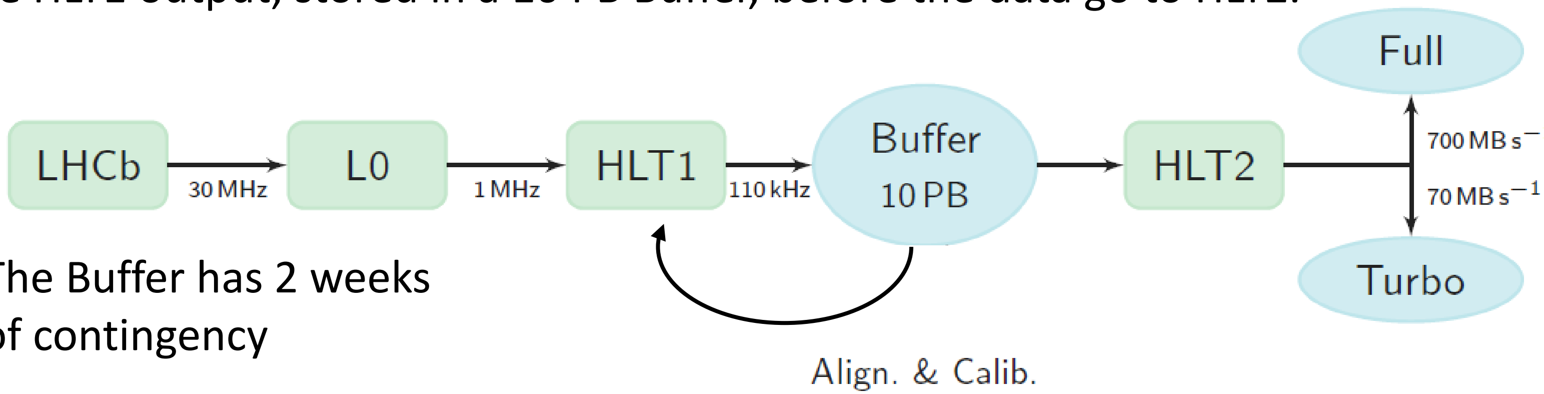
[Comput.Phys.Commun. 208 (2016) 35], applied in LHCb since 2015

Persistence method	Average event size (kB)
Turbo	7
Selective persistence	16
Complete persistence	48
Raw event	69

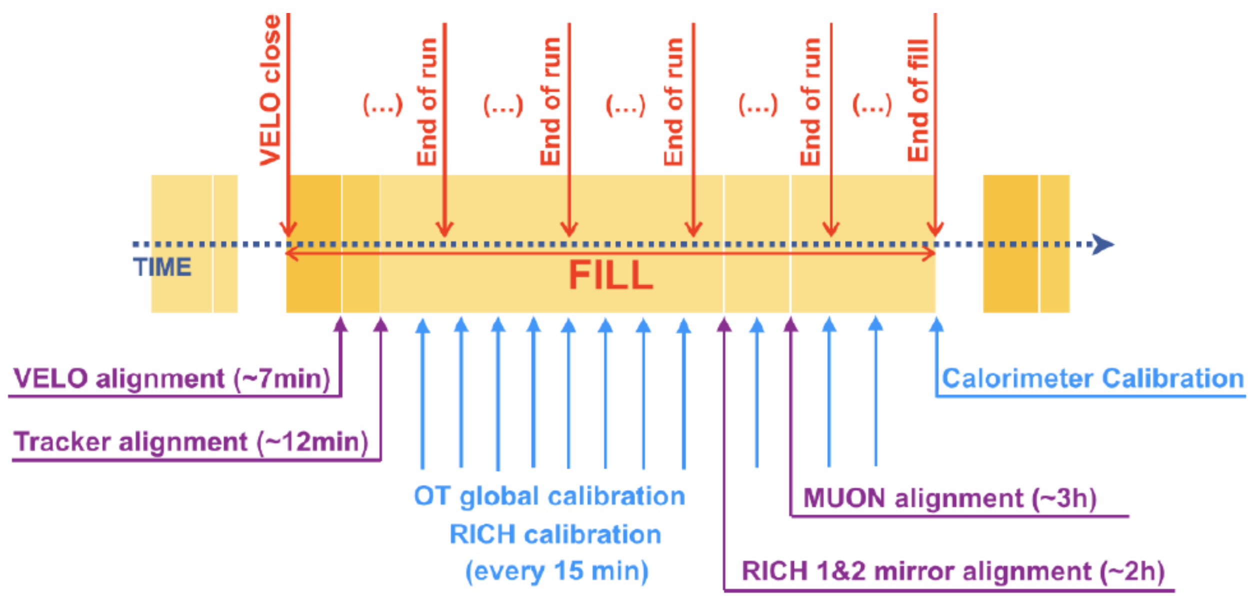
For this we need **alignment and calibration in real-time**

Alignment and calibration

- All detectors are **aligned & calibrated online** using a selected set of events from the HLT1 output, stored in a 10 PB Buffer, before the data go to HLT2.



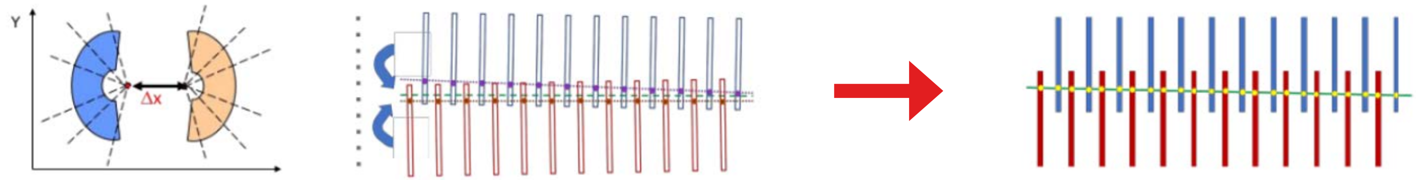
The Buffer has 2 weeks of contingency

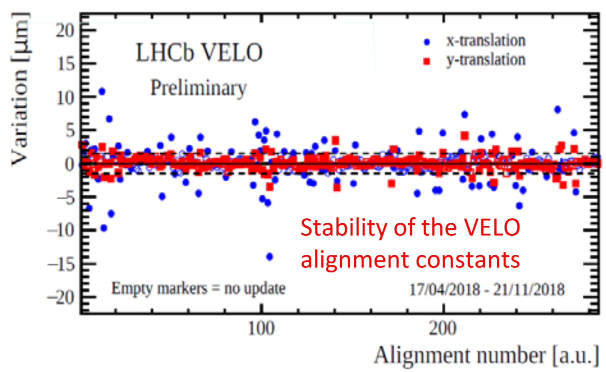


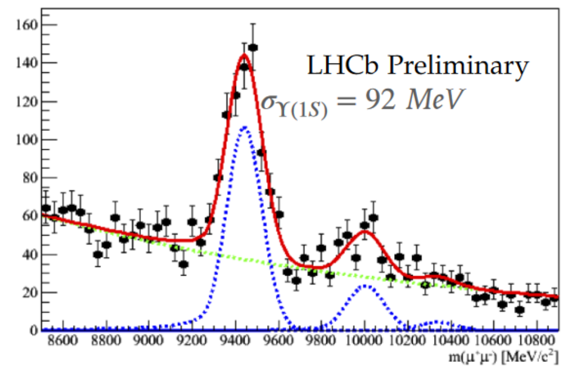
(...) - time needed for both a data accumulation and running the task

Alignment and calibration

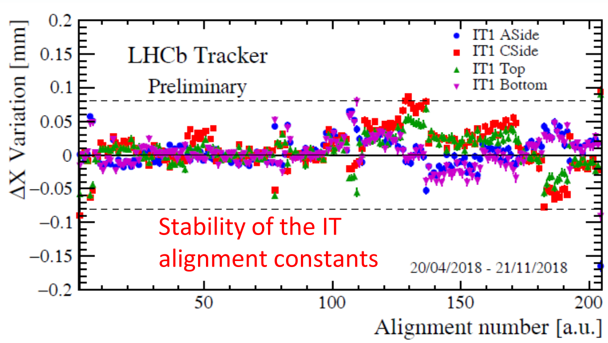
- The VELO detector centers itself around beam at start of each fill, and it is aligned with a Kalman filter using track hit residuals with PV constraints.

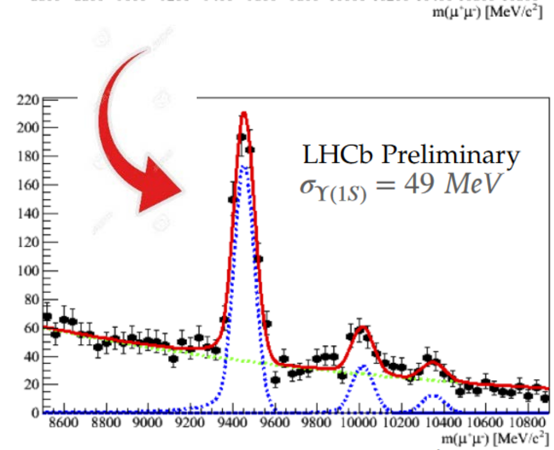






- Alignment of the full tracker system:
  + TT, IT, OT and Muon chambers



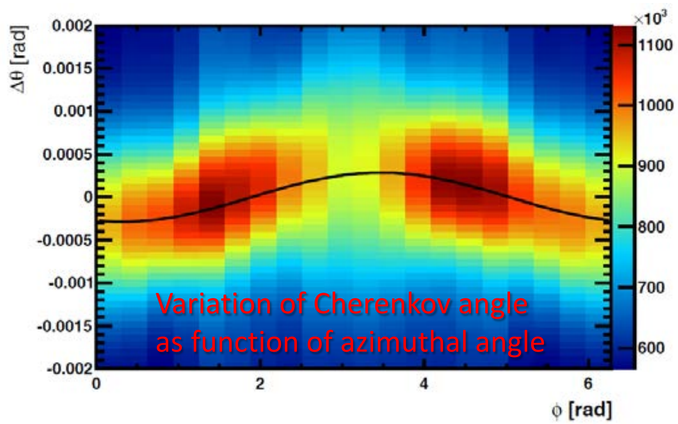


Alignment and calibration

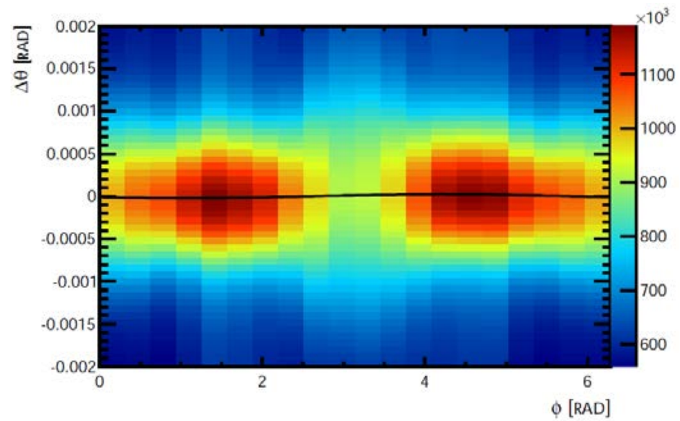
- The refraction index of gas radiators of RICH detectors change with temperature, pressure and composition. It is calibrated by fitting the difference between reconstructed and expected Cherenkov angle.

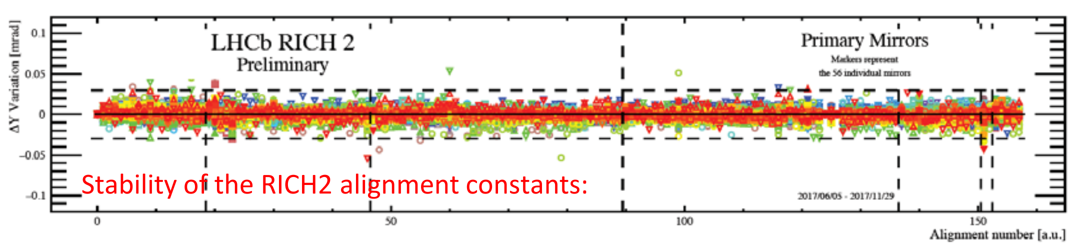
- In addition the RICH mirrors (20 segments for RICH1 and 96 for RICH2) are automatically aligned using rotations around local axes and fitting the variation of the Cherenkov angle.

Before alignment



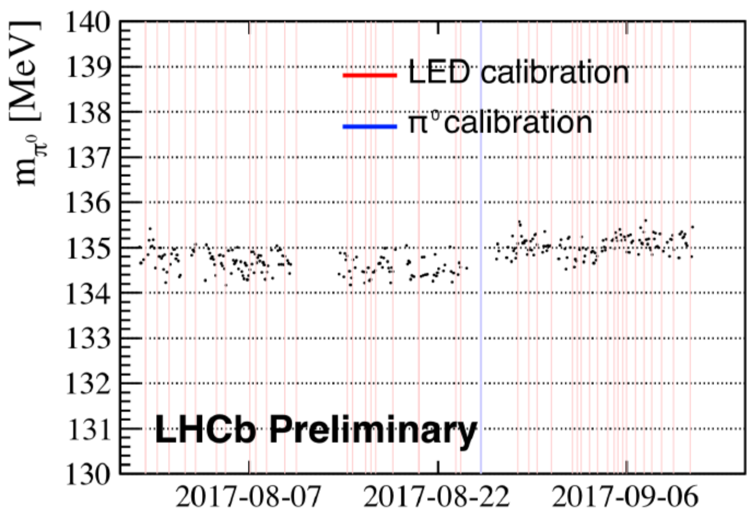
Aligned

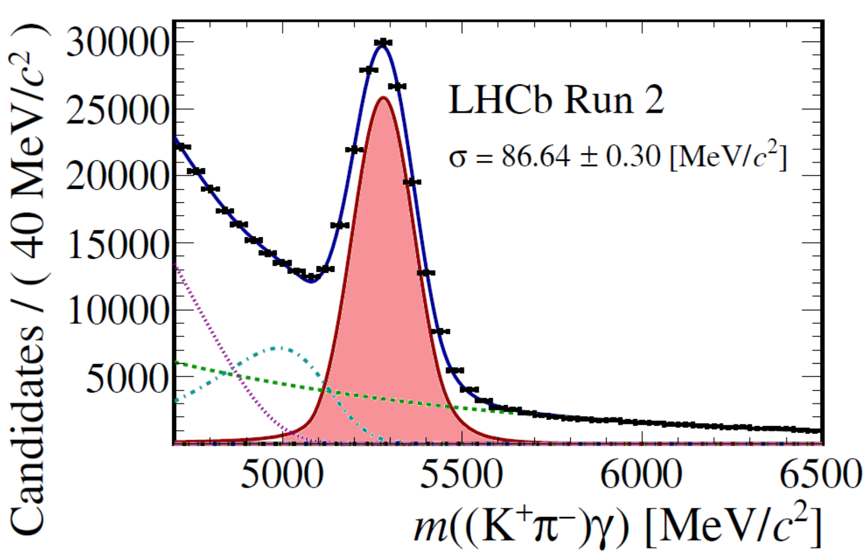




Alignment and calibration

- The calorimeters are automatically calibrated:
  - → At the end of each long fill LED amplitudes are compared with the references and High Voltages are updated accordingly if needed.
  - → Once per month an absolute π^0 calibration is performed with large data samples.



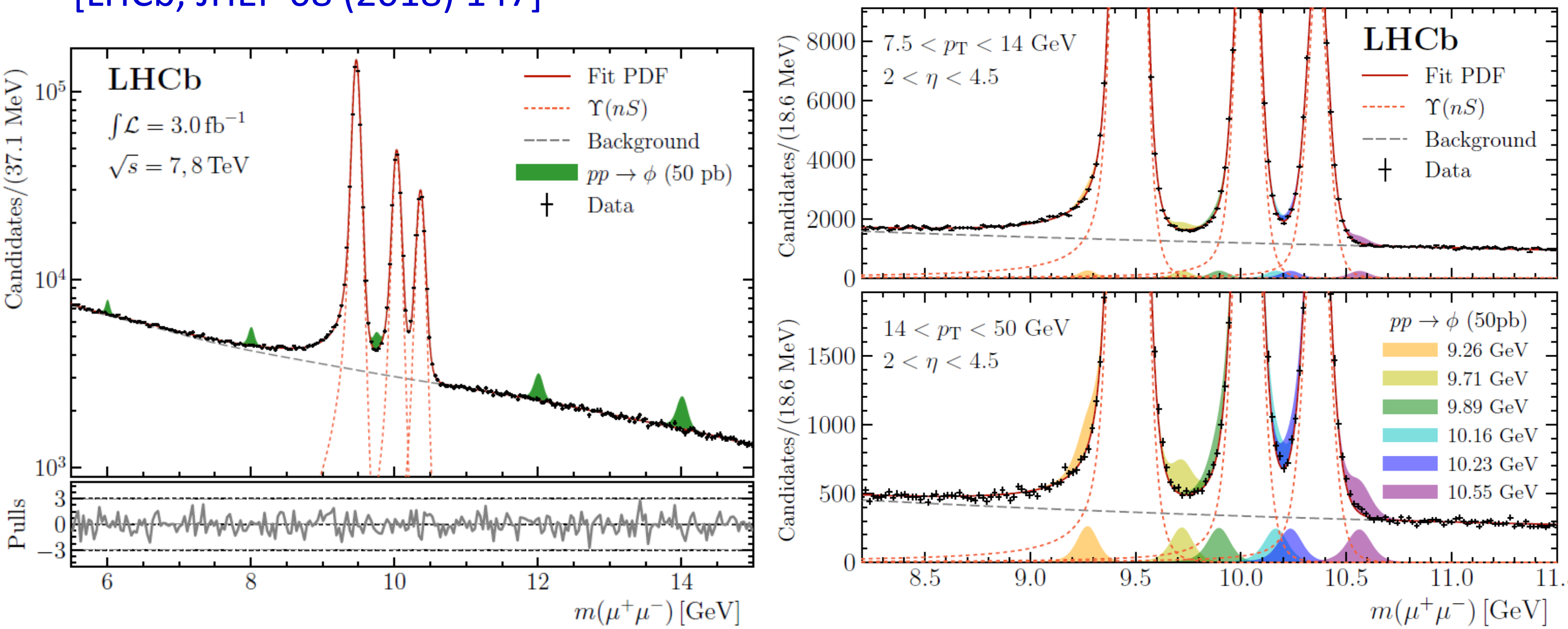


Alignment and calibration

- Outcome in physics:

Ex: Search for dimuon resonance (new spin-0 bosons)

[LHCb, JHEP 08 (2018) 147]

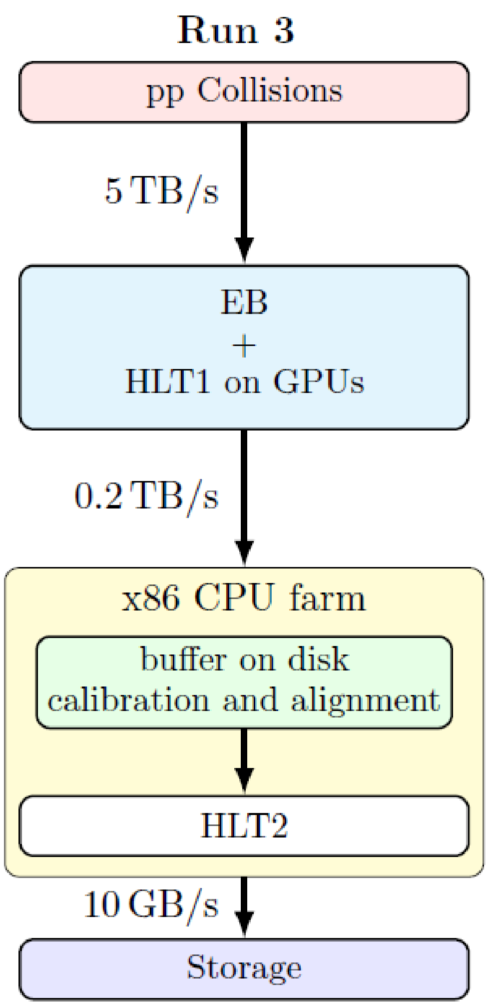


→ Fully aligned and calibrated physics objects in real time allow to perform analysis at the same level that the offline

→ Data reprocessing not needed → fast and fresh analyses, results delivered in few days

→ Reduced systematics in HLT2 selection

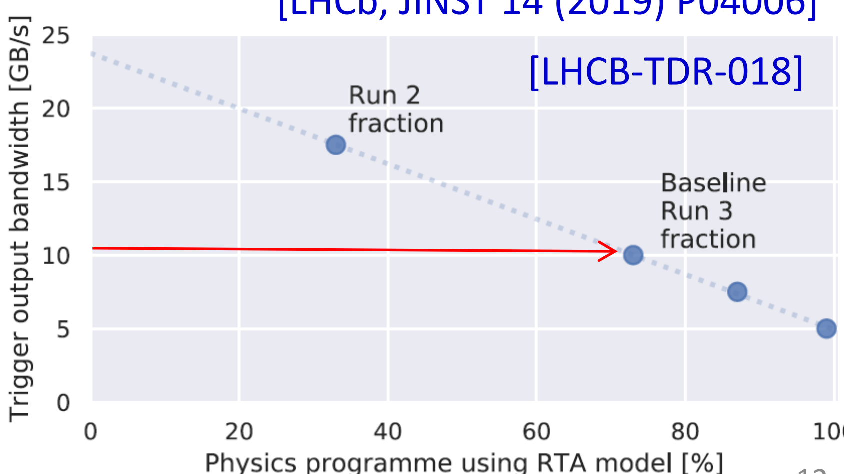
Prospects for Run 3



- Running at x5 higher luminosity
- New vertex locator and outer trackers
- **Full software trigger at 40 MHz**
- **Full HLT1 selection stage on GPUs**
  - Reduced data transfer to 0.2 TB/s
  - Improved physics performance
- Improved buffer → reduced time for A&C
- Large part of the physics program in real time

[LHCb, JINST 14 (2019) P04006]

[LHCB-TDR-018]



Prospects for Run 3

Software quality assurance:

- **Online integration and monitoring**
  Essential for the proper trigger operation

  Ex: new HLT1 will be processed on GPUs
  - high throughput,
  - very good physics performance

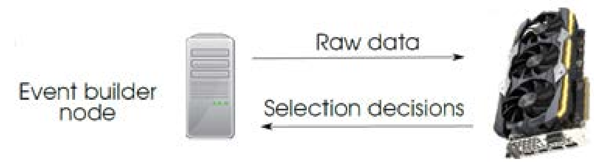
  [LHCB-TDR-021]

- **Development of the software infrastructure**

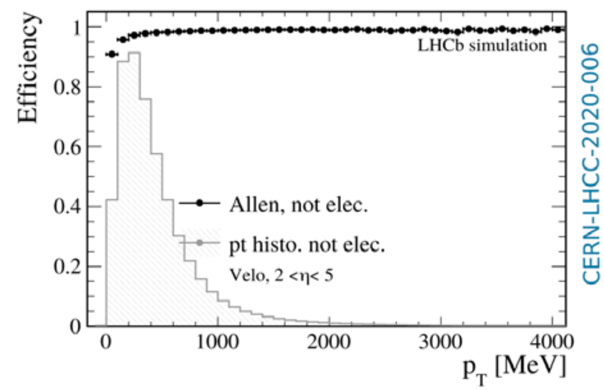
  Improvement of the workflow thanks to the collaboration with the computing group

- **Distributing software maintenance**

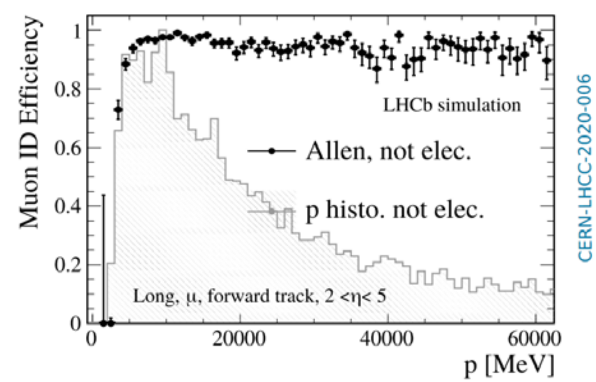
  Shift based system: training people
  to help in the validation of software projects



Tracking efficiency for tracks in the VELO



Muon identification



Conclusions

- **Excellent performance** in reconstruction at LHCb during Run1 and Run2

- It comes from the full **Alignment & Calibration** of detectors, now online and entirely automatized

- **A&C** is crucial for Run3 since a large part to the physics program will be processed on **real time**

Thanks!