# Real-time Analysis Project for Run 3 at LHCb


Peilian Li

Heidelberg University


FSP Meeting, Bonn

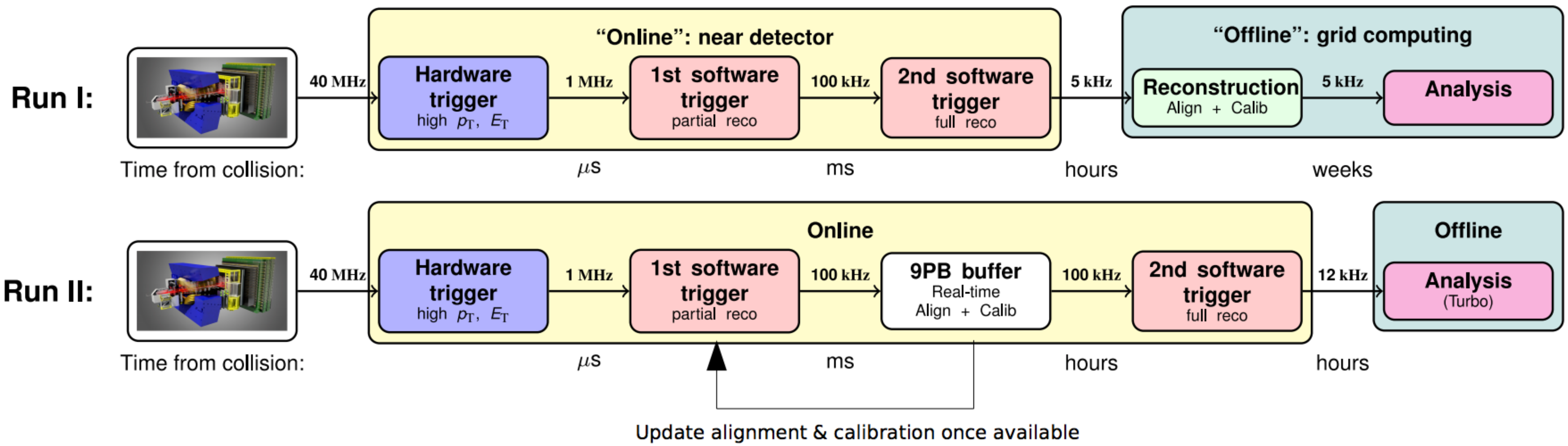
Oct 6st, 2020

# Outline

- Run 1 & 2 trigger at LHCb
- The challenges for upgrade trigger
- The upgrade trigger proposal - RTA
    - First high level trigger (HLT1)
    - Real-time alignment & calibration
    - Second high level trigger (HLT2)
    - Persistency model
- Summary

# Run 1 & 2 Trigger (Conventional)

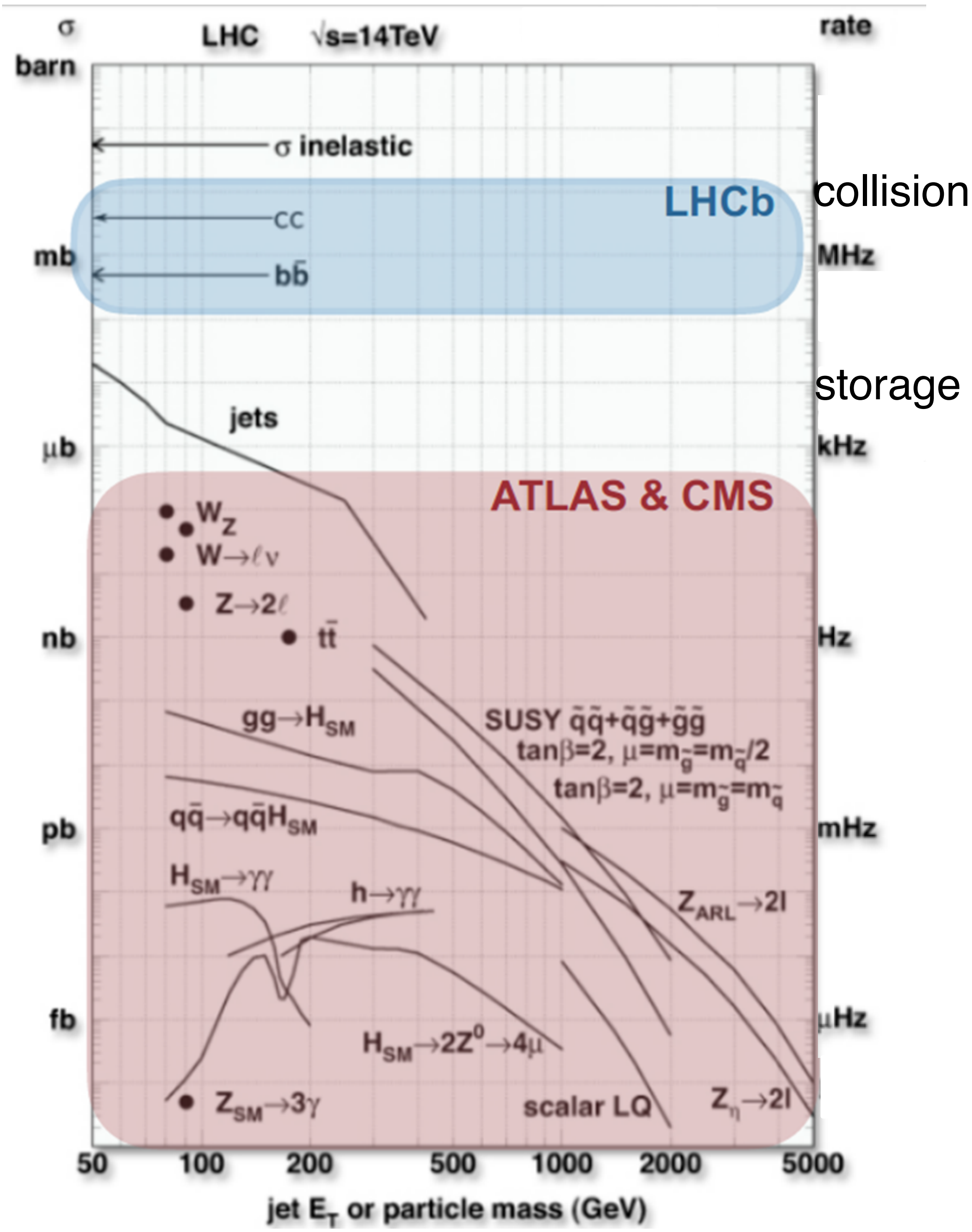
- Hardware trigger: 40→1 MHz read-out limits (fixed-latency trigger)
  - — based on muon detector and calorimeters




- HLT1 (partial) and HLT2 (full) event reconstruction split in Run 2
- Buffer data to disk to perform real time alignment and calibration
- Offline quality reconstruction and selection in the real-time processing

# LHCb Upgrade

- Luminosity of $2 \times 10^{33}$ cm$^{-2}$s$^{-1}$, $\sqrt{s}$ = 14 TeV

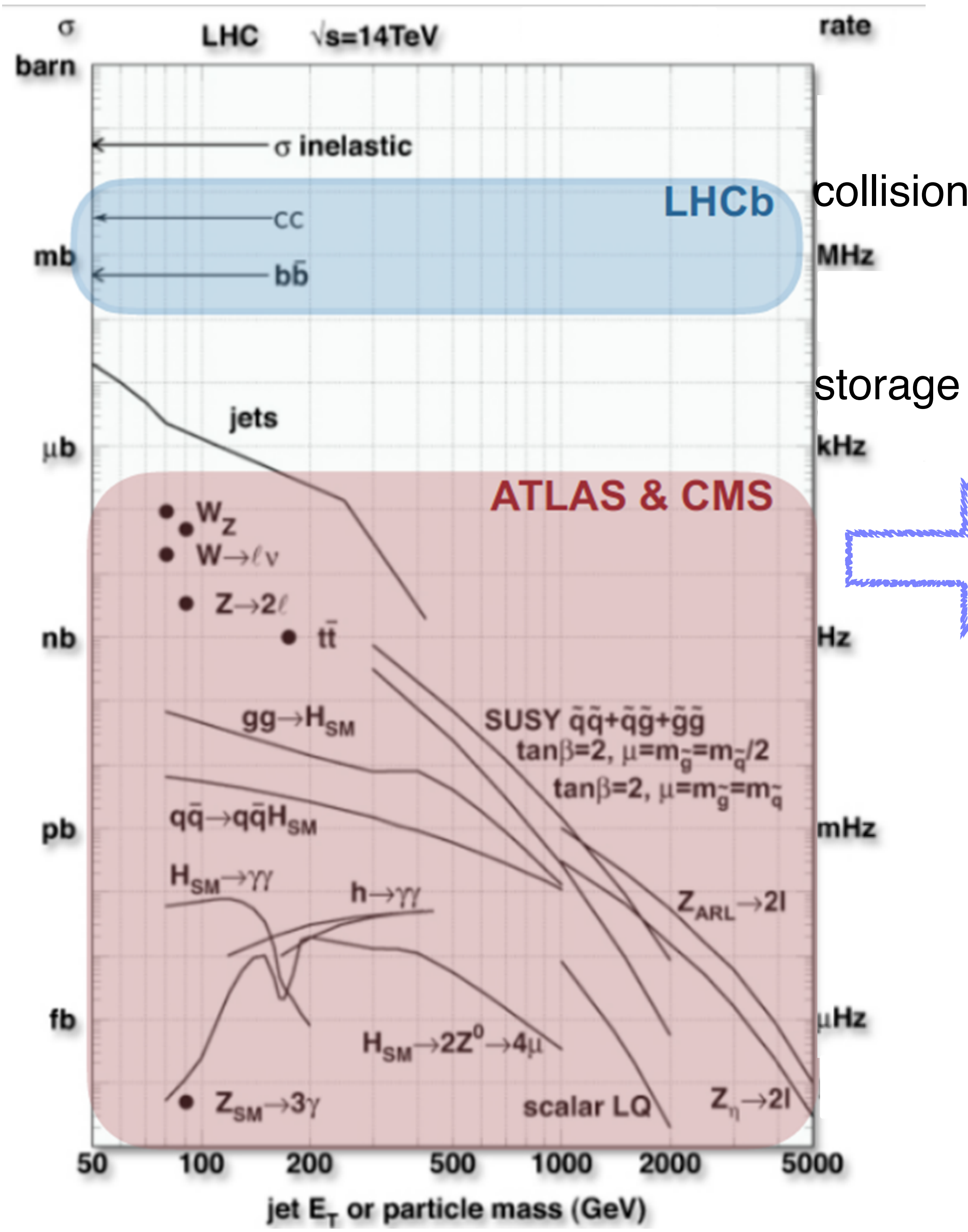



- ATLAS/CMS mainly look at the very rare event → lower event rate
- LHCb is interested in b and c hadrons → much higher event rate

- Pioneering role of LHCb in real time analysis & novel storage concepts

# LHCb Upgrade

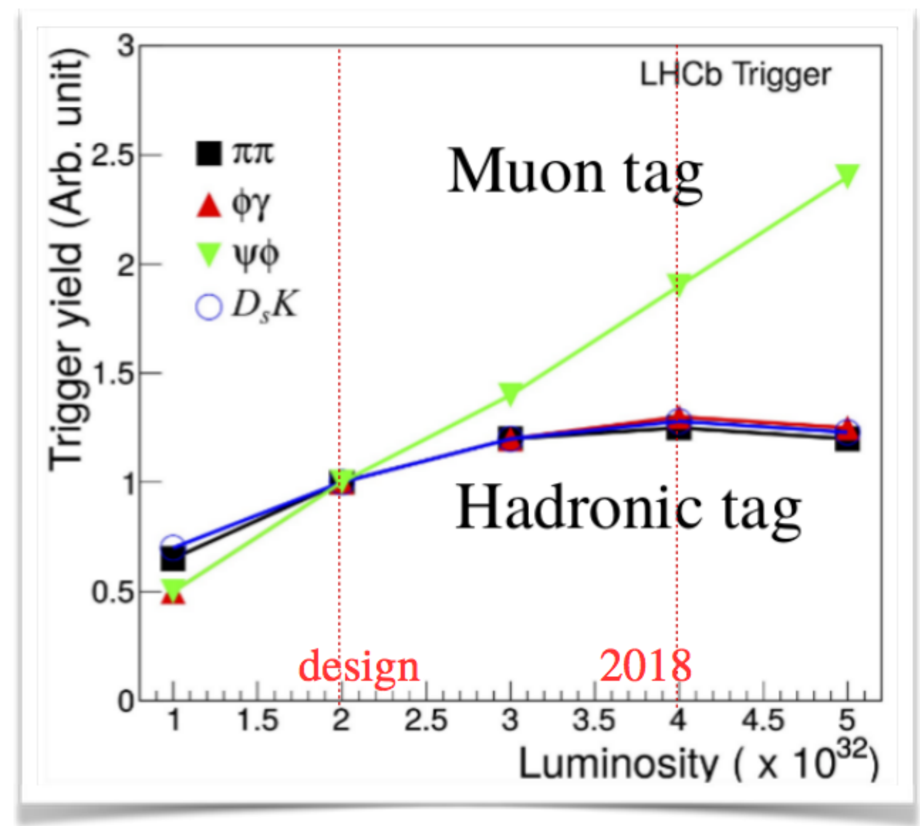
- Luminosity of 2x10$^{33}$ cm$^{-2}$s$^{-1}$, $\sqrt{s}$ = 14 TeV




- ATLAS/CMS mainly look at the very rare event → lower event rate
- LHCb is interested in b and c hadrons → much higher event rate

First challenge

Hardware trigger is not an option

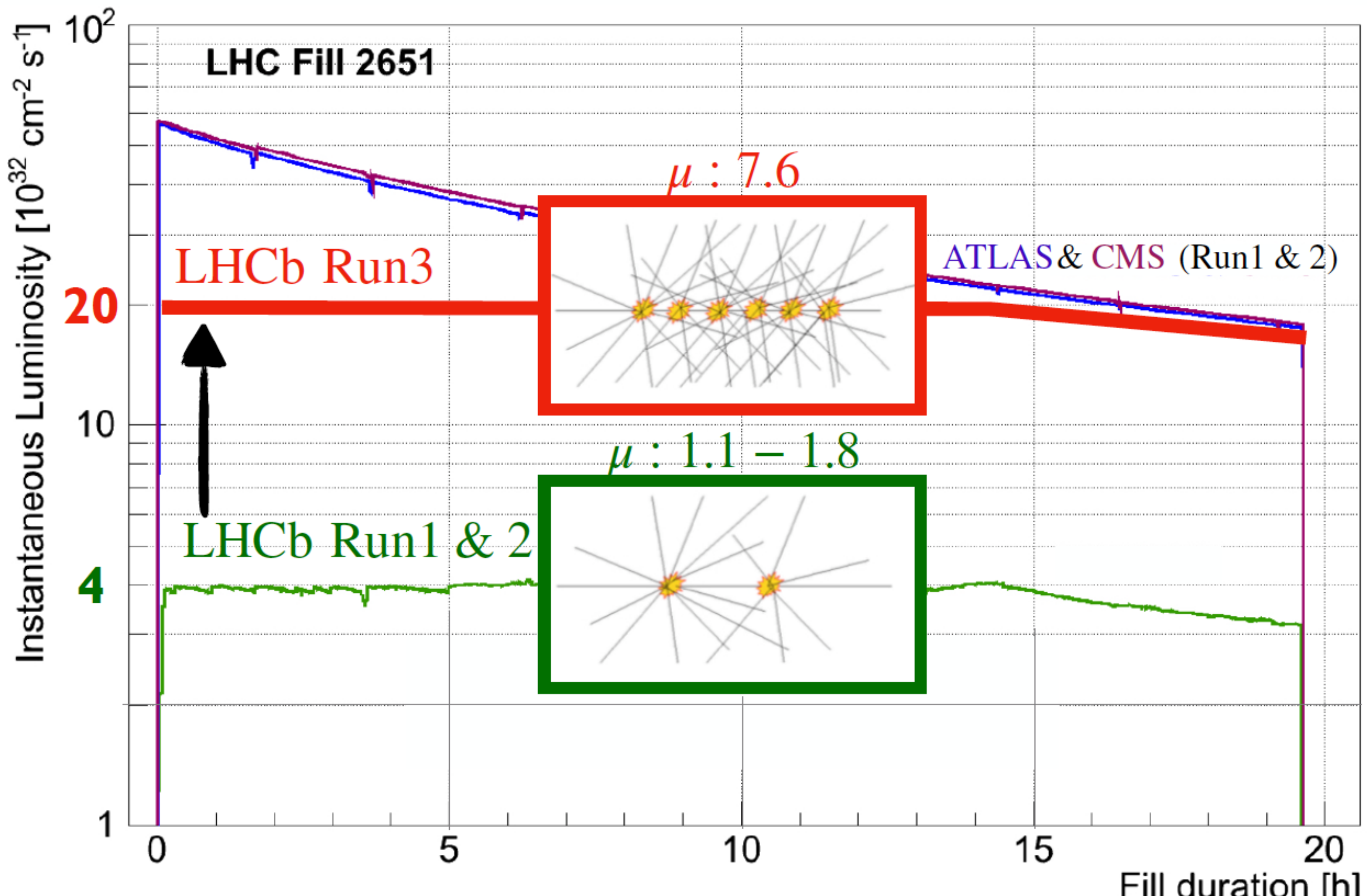



- L0 rate limit of 1 MHz saturates fully hadronic modes already in Run 2

# LHCb Upgrade

LHCb-PUB-2014-027

- Luminosity of $2 \times 10^{33}$ $cm^{-2}s^{-1}$, $\sqrt{s}$ = 14 TeV
- More PVs, more tracks, almost all events will have b or c hadron
- Signal rates up to ~ MHz, hardware trigger is not an option

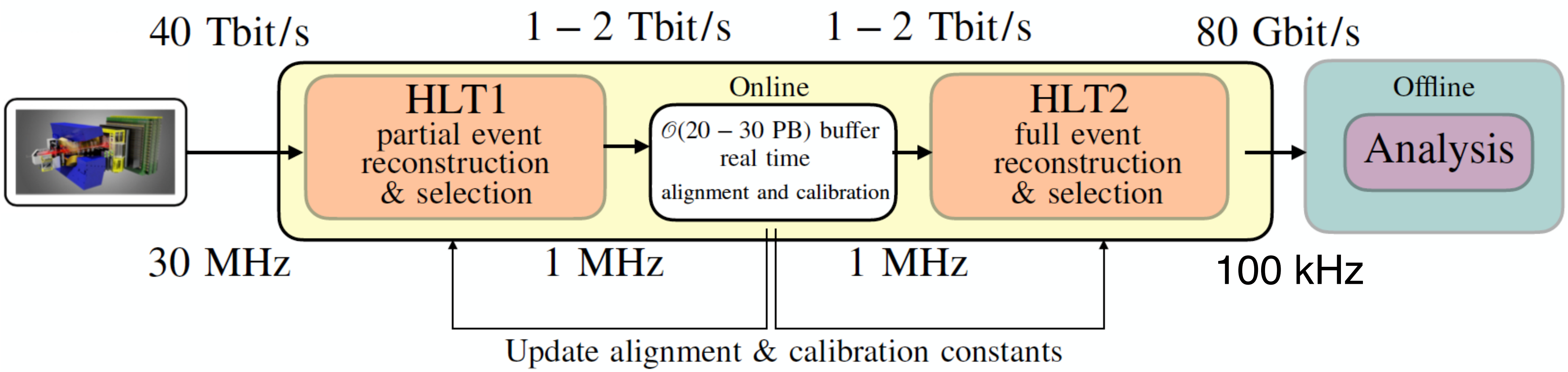



* μ is the average visible collision per bunch

Second challenge

How to select the interested beauty and charm hadrons from the large mount of b or c hadrons

# LHCb Upgrade Trigger




- Remove L0 trigger, read out the full detector at 30 MHz and make all data available for variable latency processing

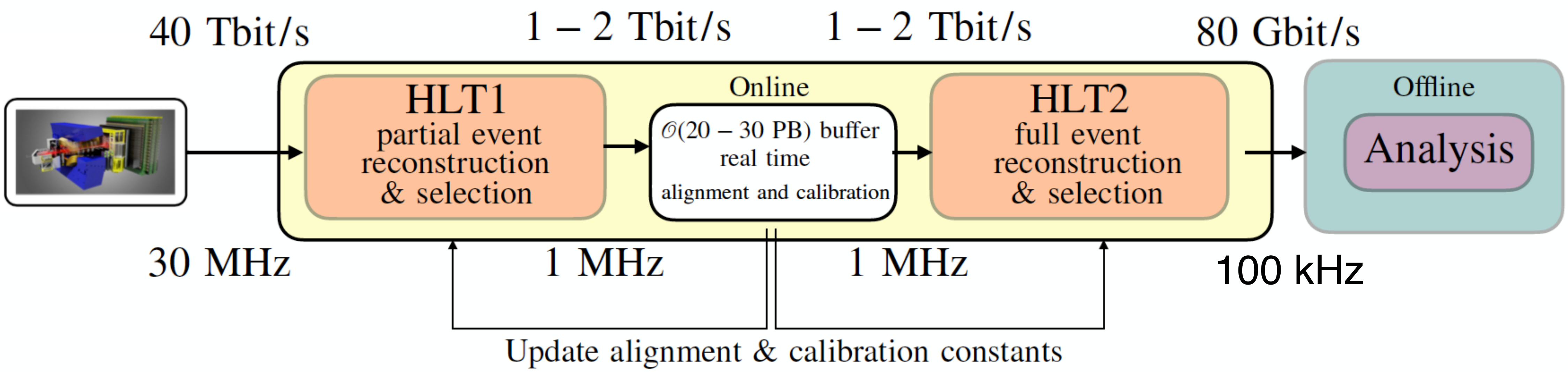
  Earlier & less money

  → Workload of ATLAS/CMS in their high-level HL-LHC trigger in 6 years

- Real time alignment and calibration & Full offline-quality reconstruction

  → Have best resolution for HLT2 selections

# LHCb Upgrade Trigger




- Remove L0 trigger, read out the full detector at 30 MHz and make all data available for variable latency processing

  Earlier & less money

  →Workload of ATLAS/CMS in their high-level HL-LHC trigger in 6 years

- Real time alignment and calibration & Full offline-quality reconstruction

  → Have best resolution for HLT2 selections

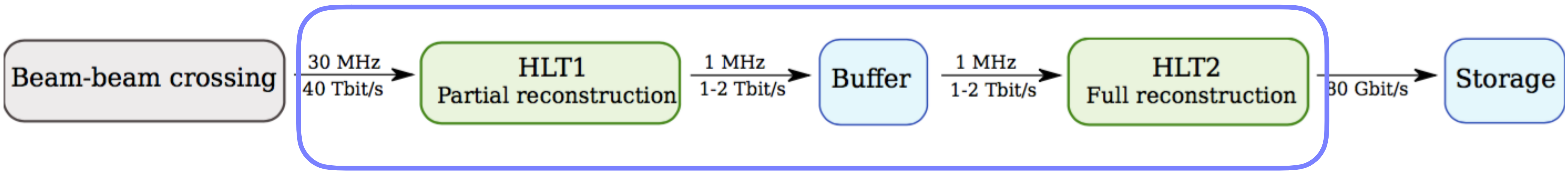
Comparison with Run 2:

Huge computing challenge

→ 5 × higher pileup

→ 30 × higher event rate into HLT1

→ Same disk buffer with 10x more data, requiring time for data processing to be reduced from O(weeks)→O(days)

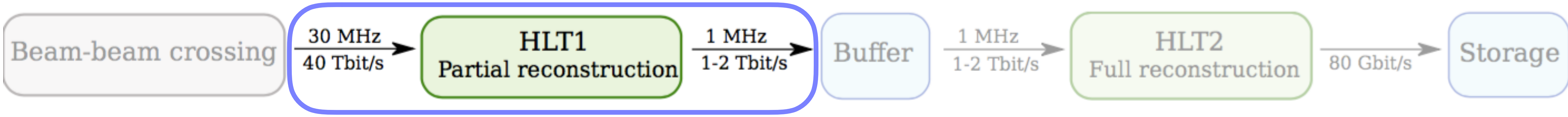



Conventional trigger: **background rejection**

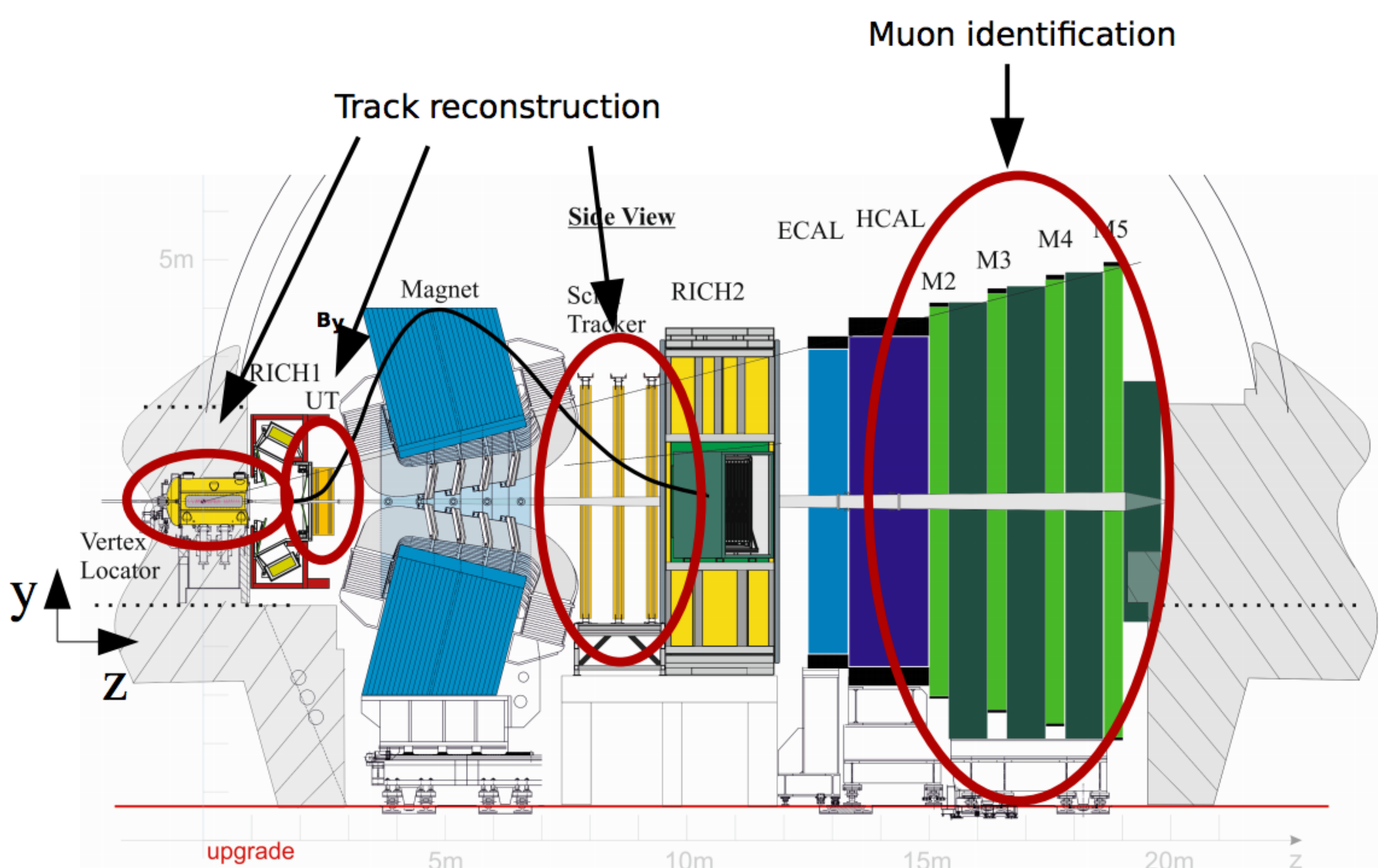

→

Upgrade trigger: **background rejection & classify signals**

# First High Level Trigger (HLT1)



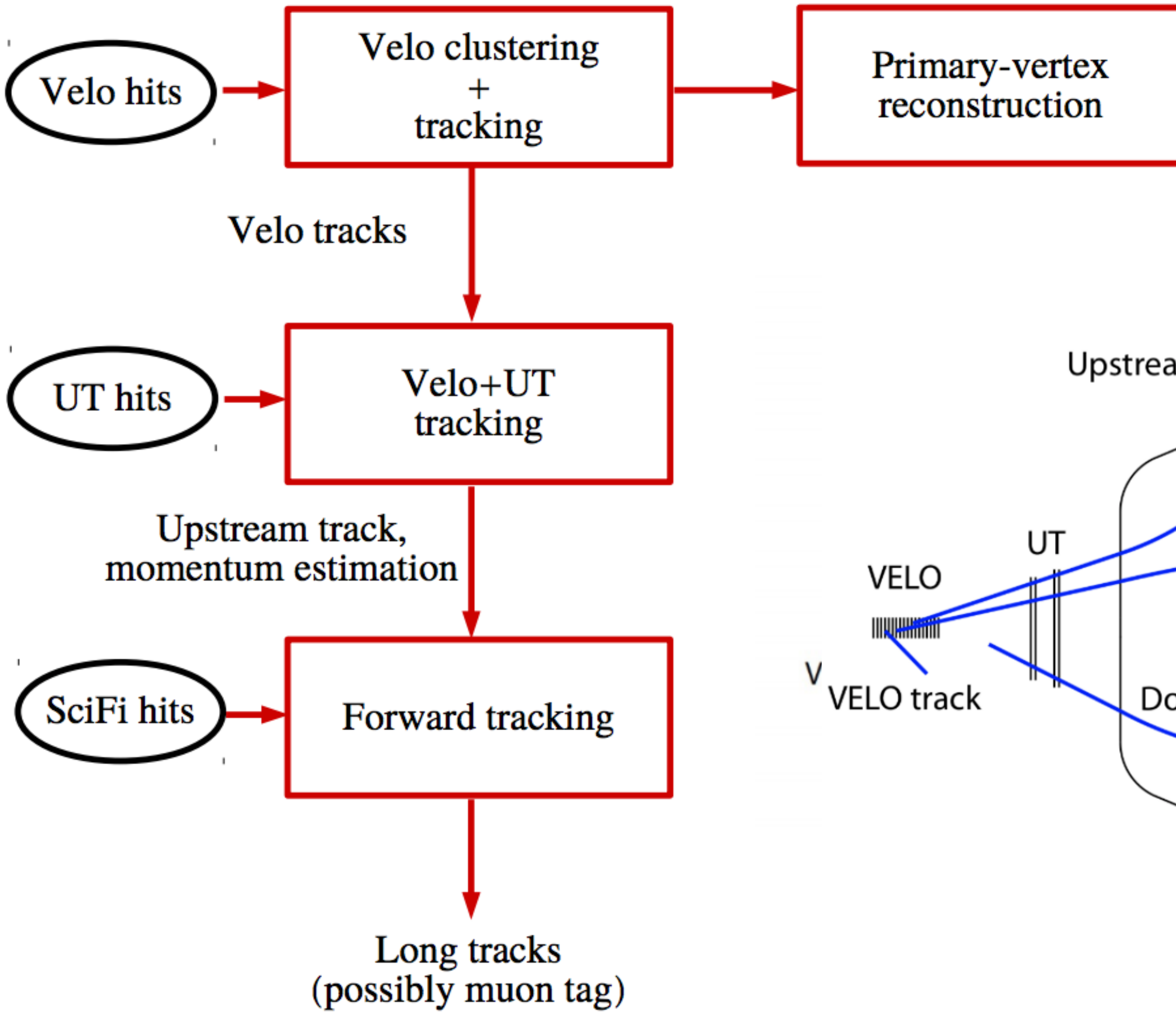

- Filter the 30 MHz pp collision to 1 MHz, must be fast and efficient
- Partial reconstruction
  - → Full charged track reconstruction
  - → Few inclusive single and two-track selections on bunch crossings

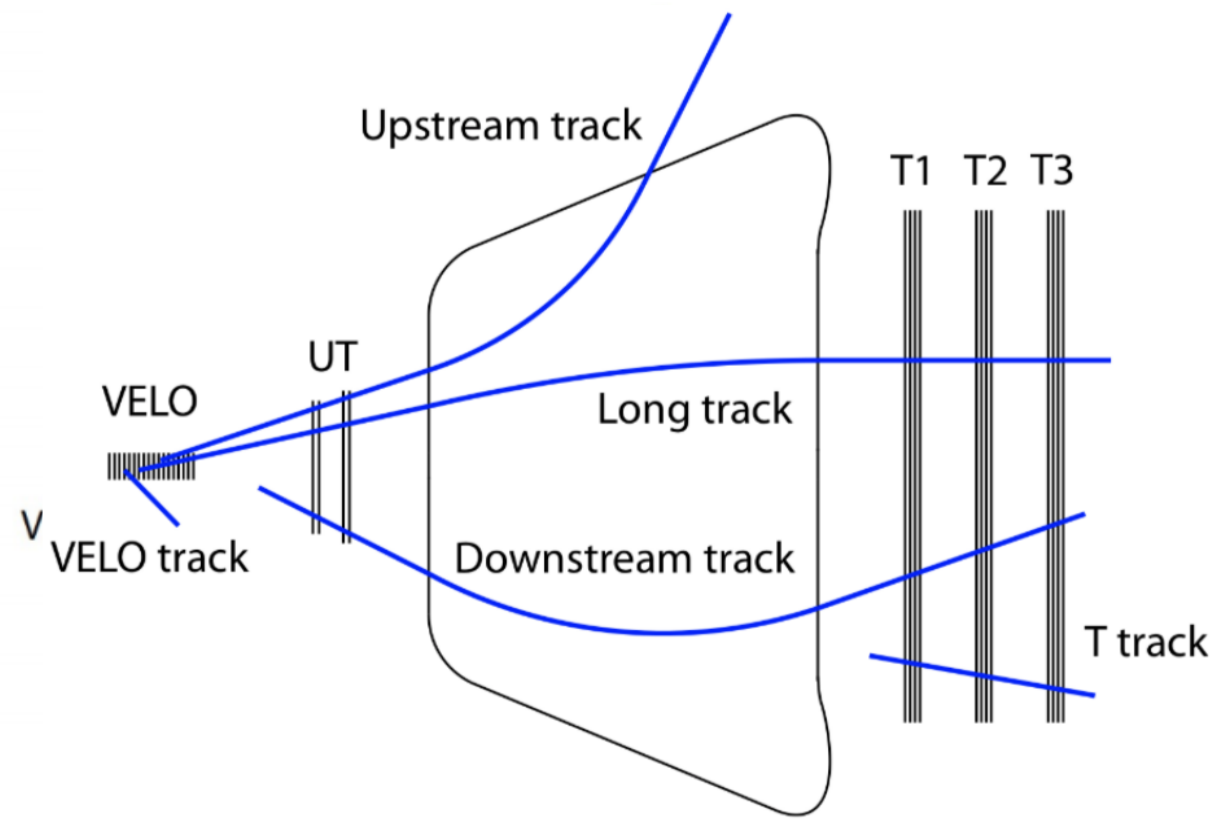


# First High Level Trigger (HLT1)

- Filter the 30 MHz pp collision to 1 MHz, must be fast and efficient
- Partical reconstruction

Contributors from Germany group:
L. Funke, C. Hasse, J. Hu, M. Saur



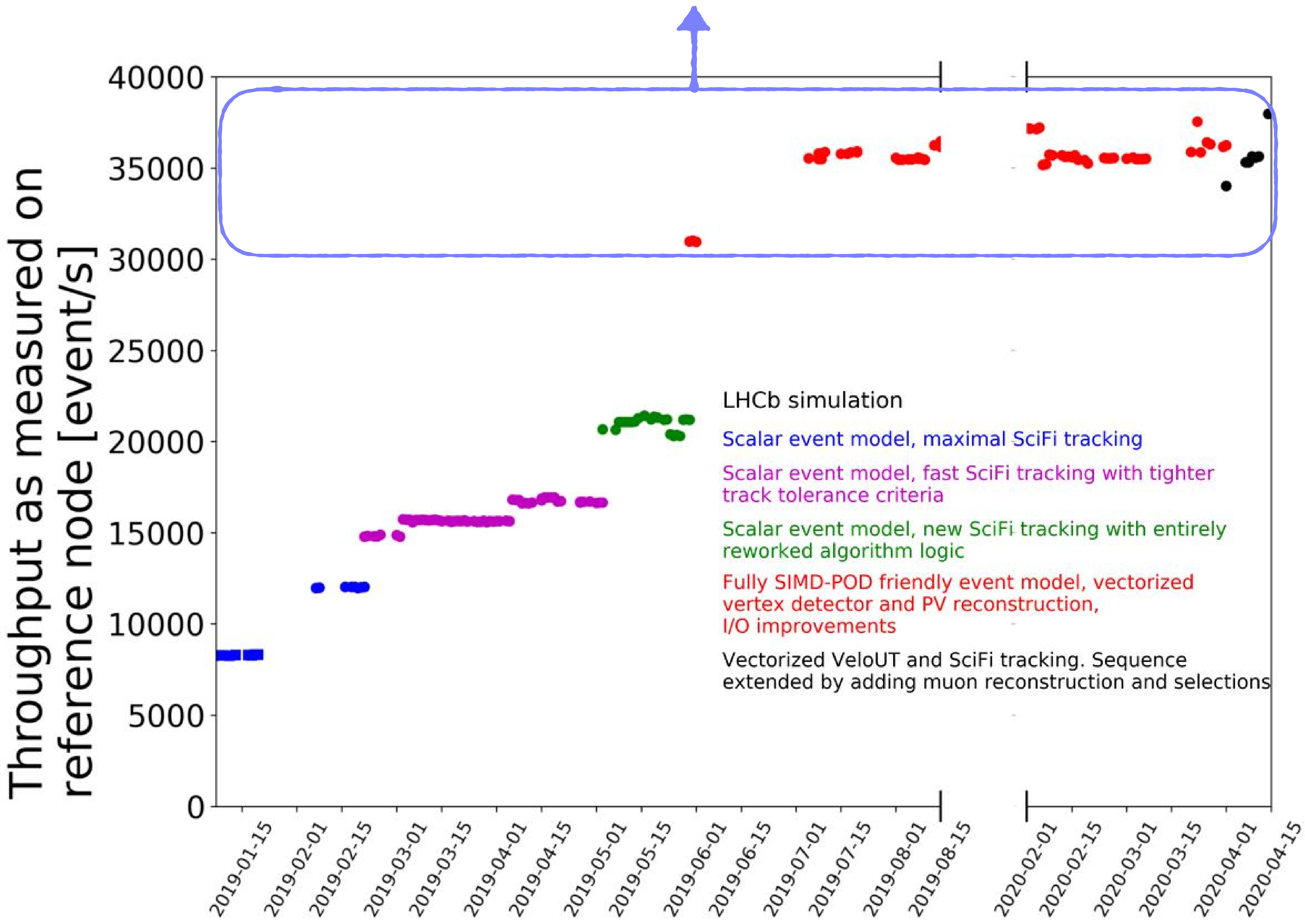




* Every task is individually parallelizable

# HLT1 Throughput

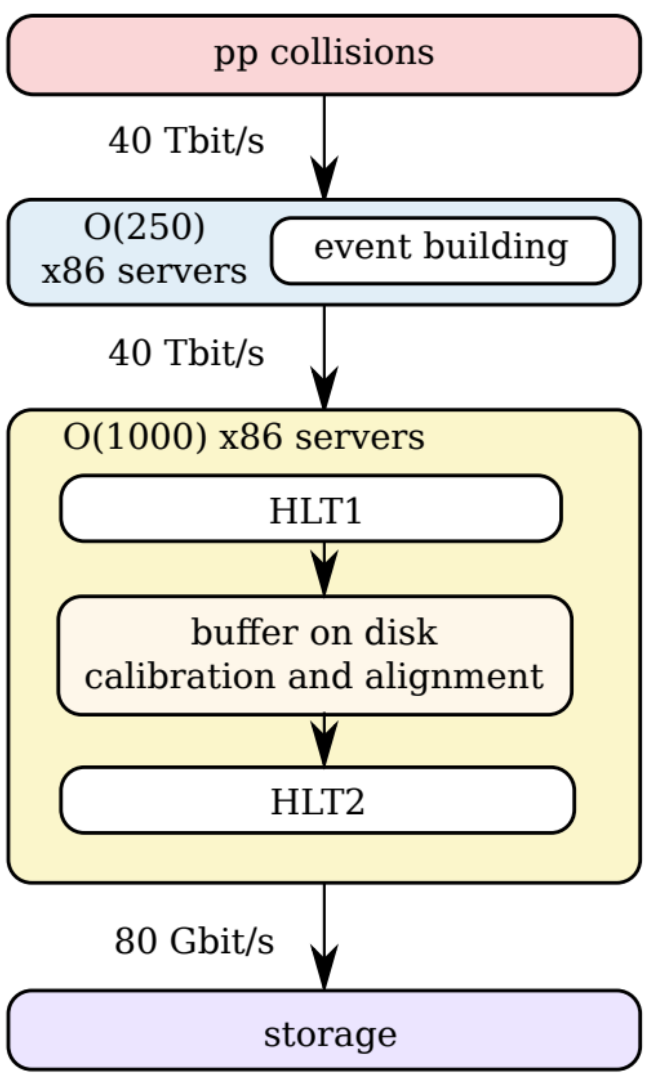
LHCb-FIGURE-2020-007

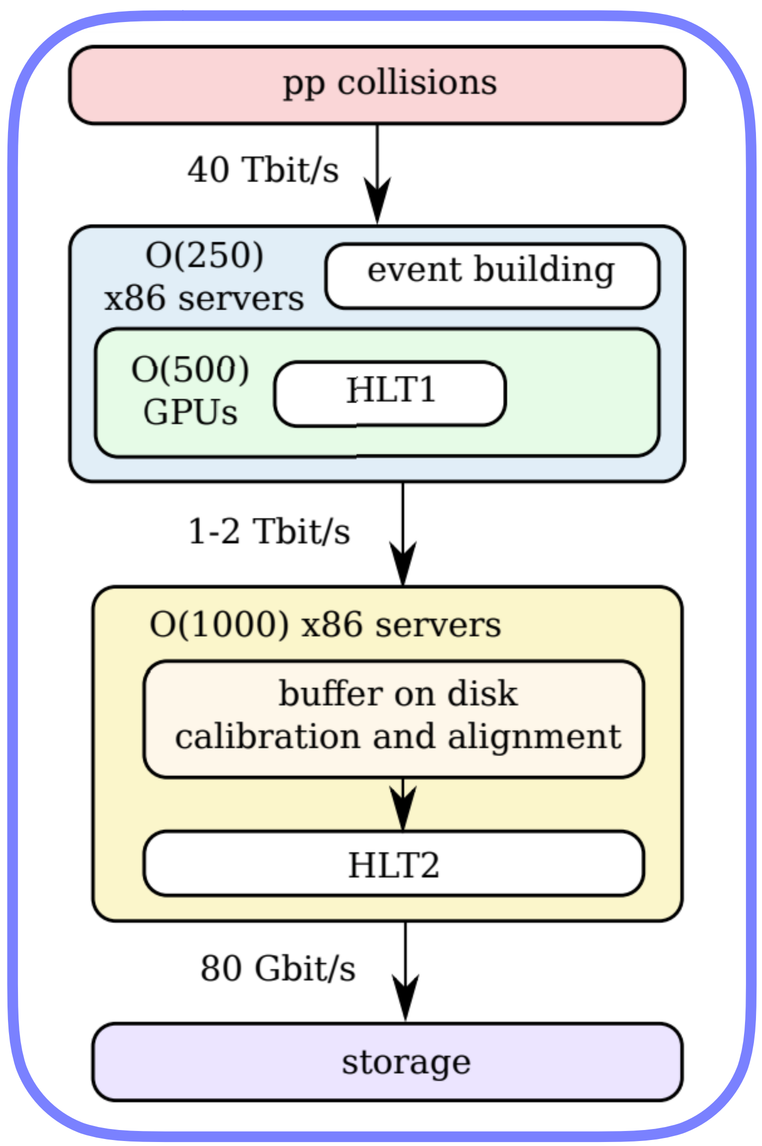
- Achieved the requirement in 2019! More improvements afterwards



# GPU & CPU HLT1

- Both GPU & CPU HLT1 achieved the designed performance successfully
  → Extensive studies and developments on both GPU & CPU architectures
  → Brand new algorithms and ideas on pattern recognition developed on both architectures
  → Final decision to take GPU for HLT1 in April 2020
  →All the work and experience gained for HLT1 reconstruction using CPUs crucial to achieve large speed-up for the HLT2 reconstruction



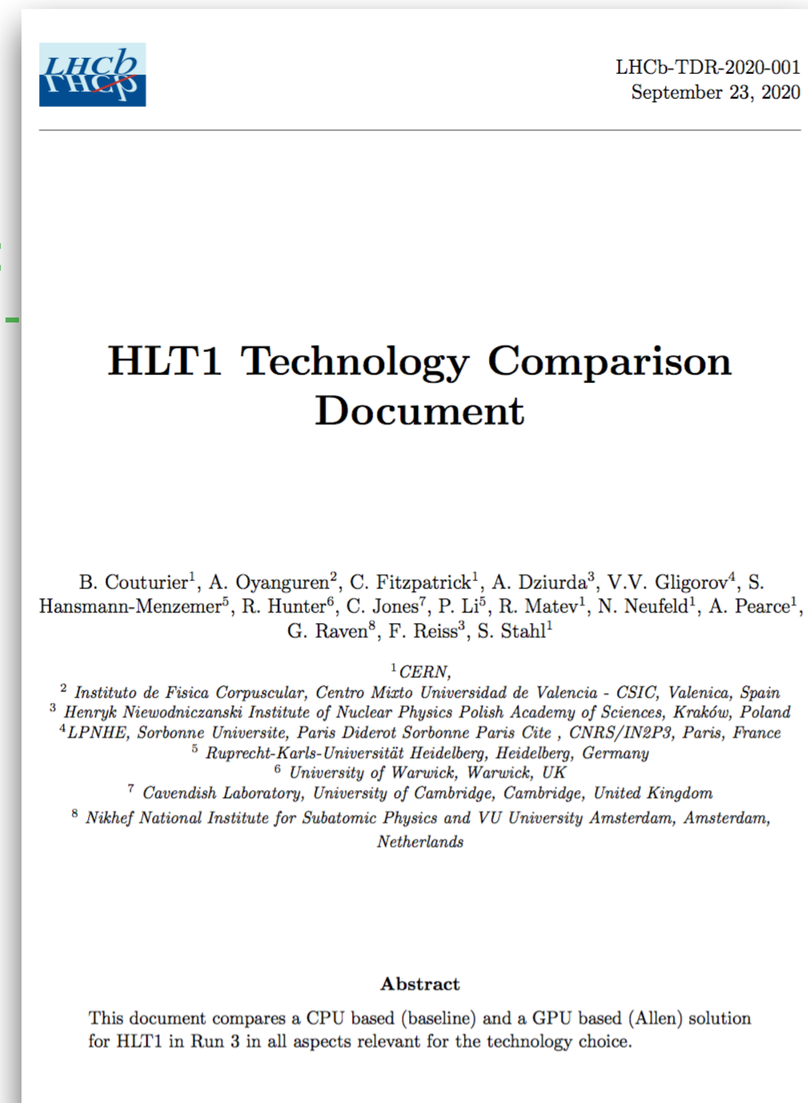




- Reduce network bandwidth between EB and filter farms
- Free up filter farm CPU for HLT2 only

# GPU & CPU HLT1

- Both GPU & CPU HLT1 achieved the designed performance successfully
  - → Extensive studies and developments on both GPU & CPU architectures
  - → Brand new algorithms and ideas on pattern recognition developed on both architectures
  - → Final decision to take GPU for HLT1 in April 2020
  - →All the work and experience gained for HLT1 reconstruction using CPUs crucial to achieve large speed-up for the HLT2 reconstruction

Contributors: S. Hansmann-Menzemer, P. Li



LHCb-TDR-2020-001
September 23, 2020

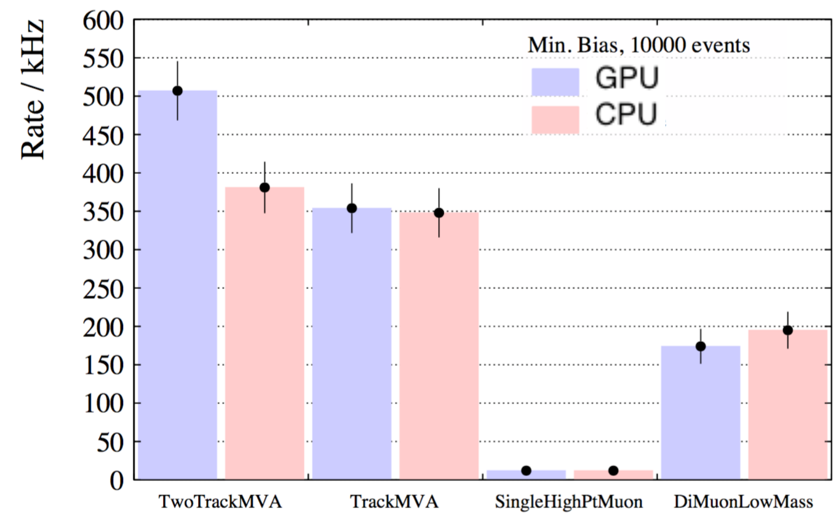
## HLT1 Technology Comparison Document

B. Couturier[1], A. Oyanguren[2], C. Fitzpatrick[1], A. Dziurda[3], V.V. Gligorov[4], S. Hansmann-Menzemer[5], R. Hunter[6], C. Jones[7], P. Li[5], R. Matev[1], N. Neufeld[1], A. Pearce[1], G. Raven[8], F. Reiss[3], S. Stahl[1]

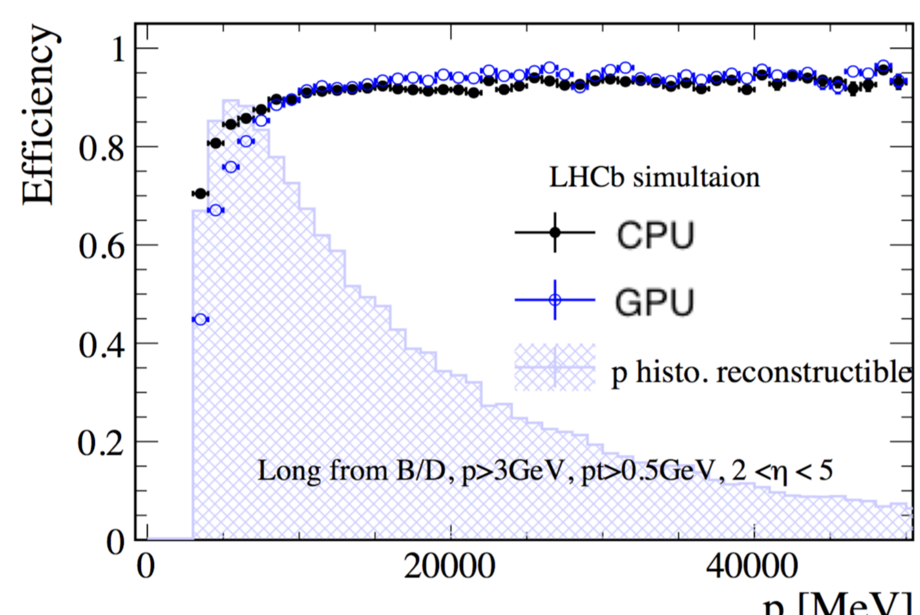
[1] CERN,
[2] Instituto de Fisica Corpuscular, Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain
[3] Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland
[4] LPNHE, Sorbonne Universite, Paris Diderot Sorbonne Paris Cite , CNRS/IN2P3, Paris, France
[5] Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[6] University of Warwick, Warwick, UK
[7] Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[8] Nikhef National Institute for Subatomic Physics and VU University Amsterdam, Amsterdam, Netherlands

**Abstract**

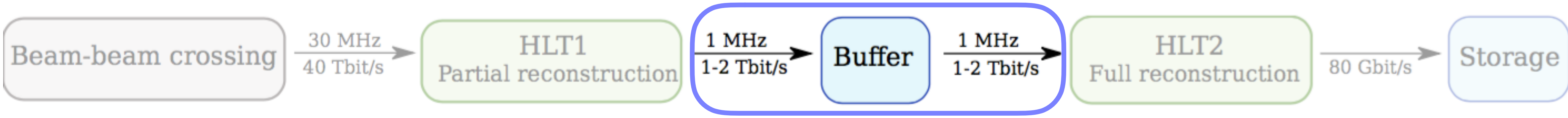
This document compares a CPU based (baseline) and a GPU based (Allen) solution for HLT1 in Run 3 in all aspects relevant for the technology choice.




*Comparable performance



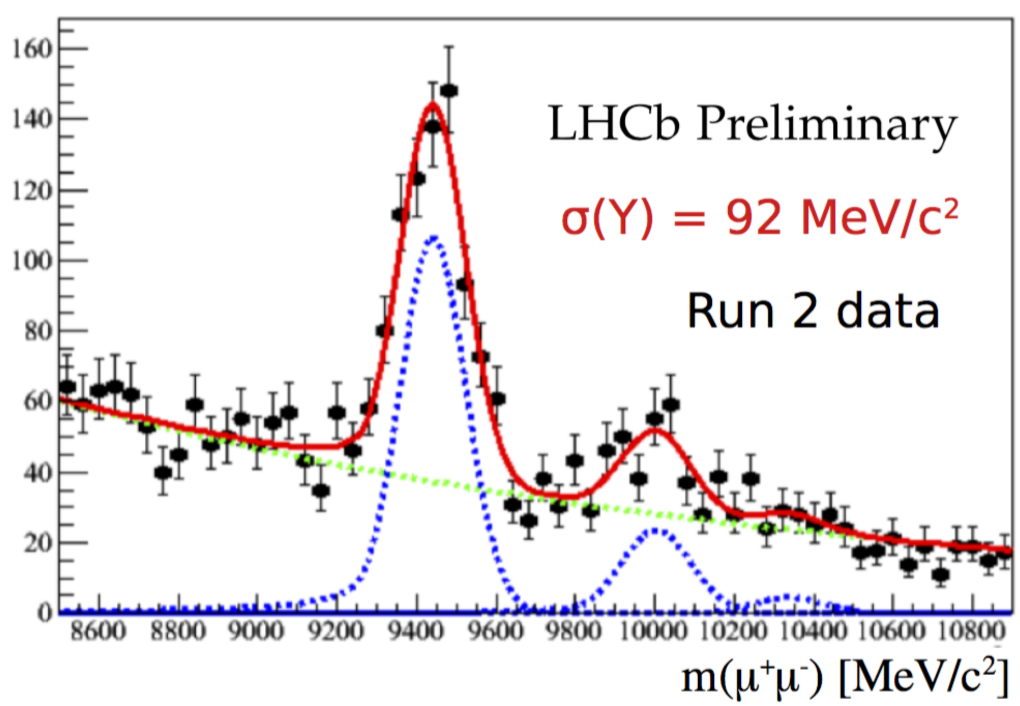
# Real-time Alignment & Calibration



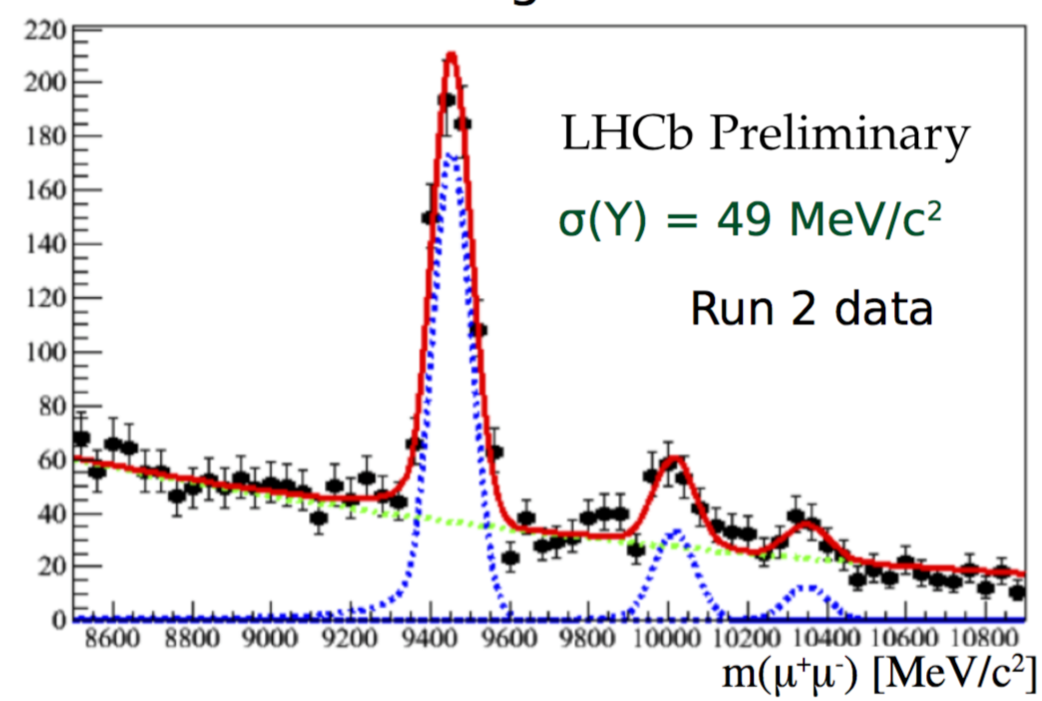

- Efficient and pure selections require offline-quality reconstruction at the HLT2 level → Aligned and calibrated detector
- Use output bandwidth more efficiently
  - Better mass resolution
  - Better particle identification
  - Less background

Journal of Physics:
Conference Series, 664 (2015)

Before alignment




After alignment

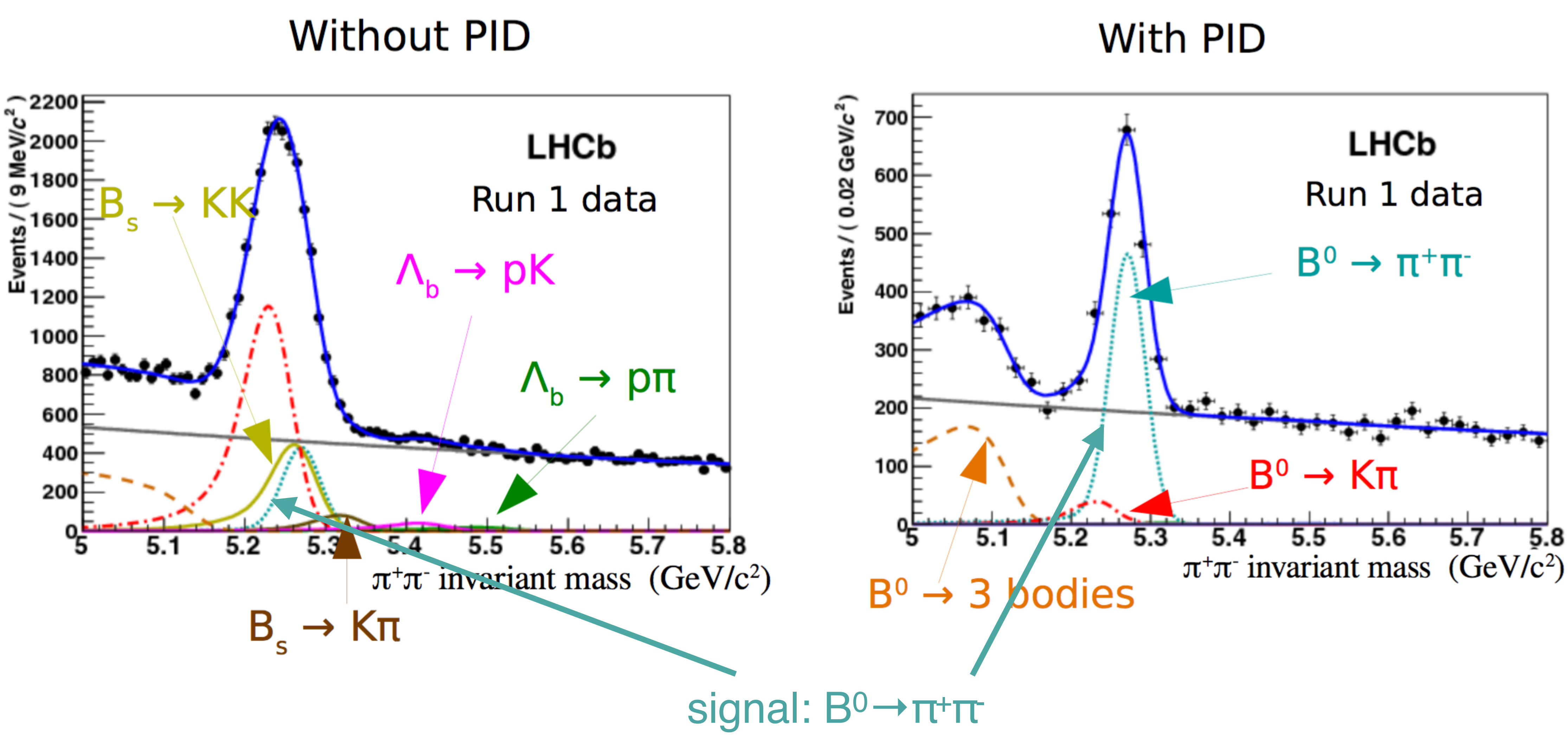


# Real-time Alignment & Calibration

- Efficient and pure selections require offline-quality reconstruction at the HLT2 level ⟵ Aligned and calibrated detector
- Use output bandwidth more efficiently

- Better mass resolution
- Better particle identification
- Less background

JHEP 2012, 37 (2012)

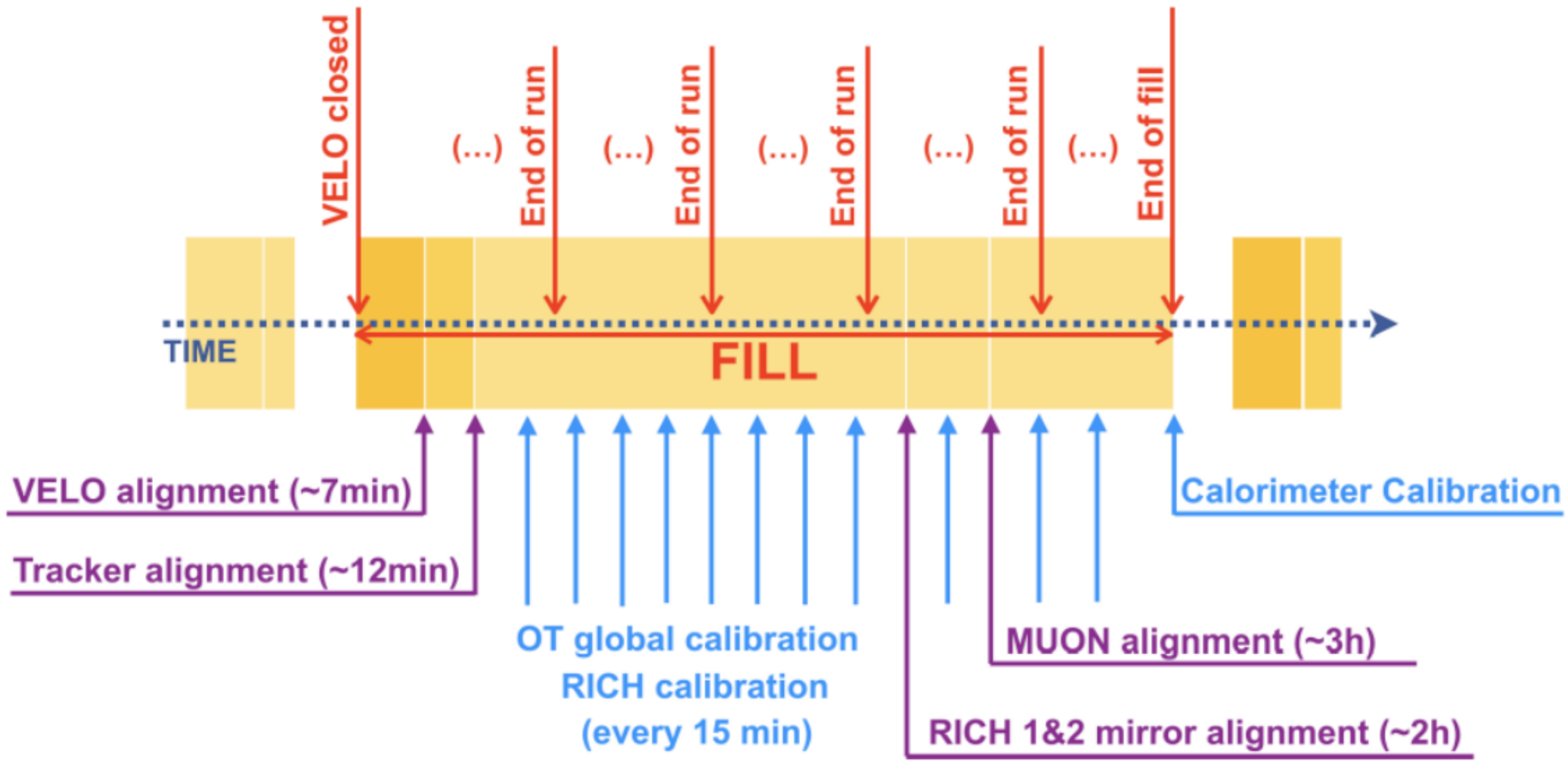



PID helps to remove lots of backgrounds

# Real-time Alignment & Calibration

- Same strategy as Run 2
- Same disk buffer as Run 2 but 10x more data
  - Alignment not only trackers but also RICH, MUON, Calo
  - Should be very fast!
  - Several minutes in Trackers & several hours for RICH & MUON

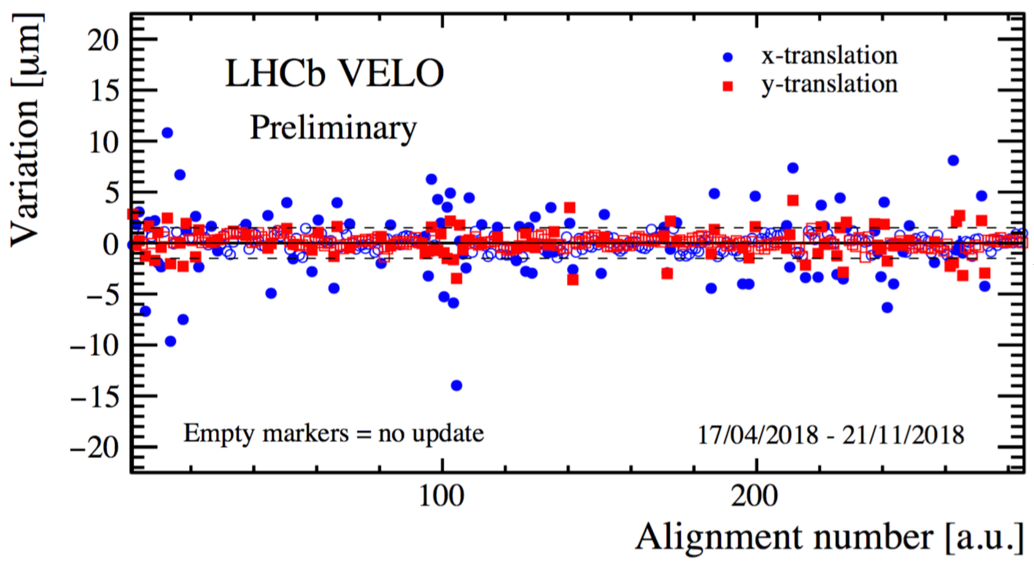
Contributors:
F. Archilli, G. Frau,
R. Kopecna



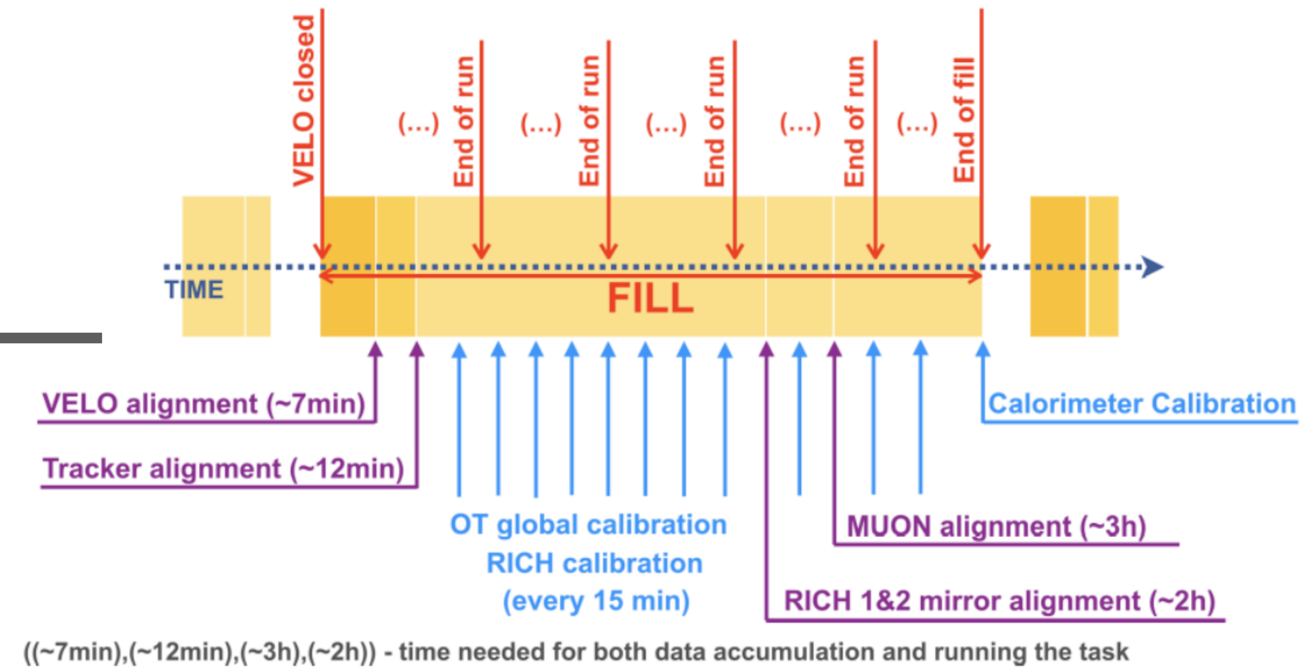

((~7min),(~12min),(~3h),(~2h)) - time needed for both data accumulation and running the task

# Real-time Alignment & Calibration

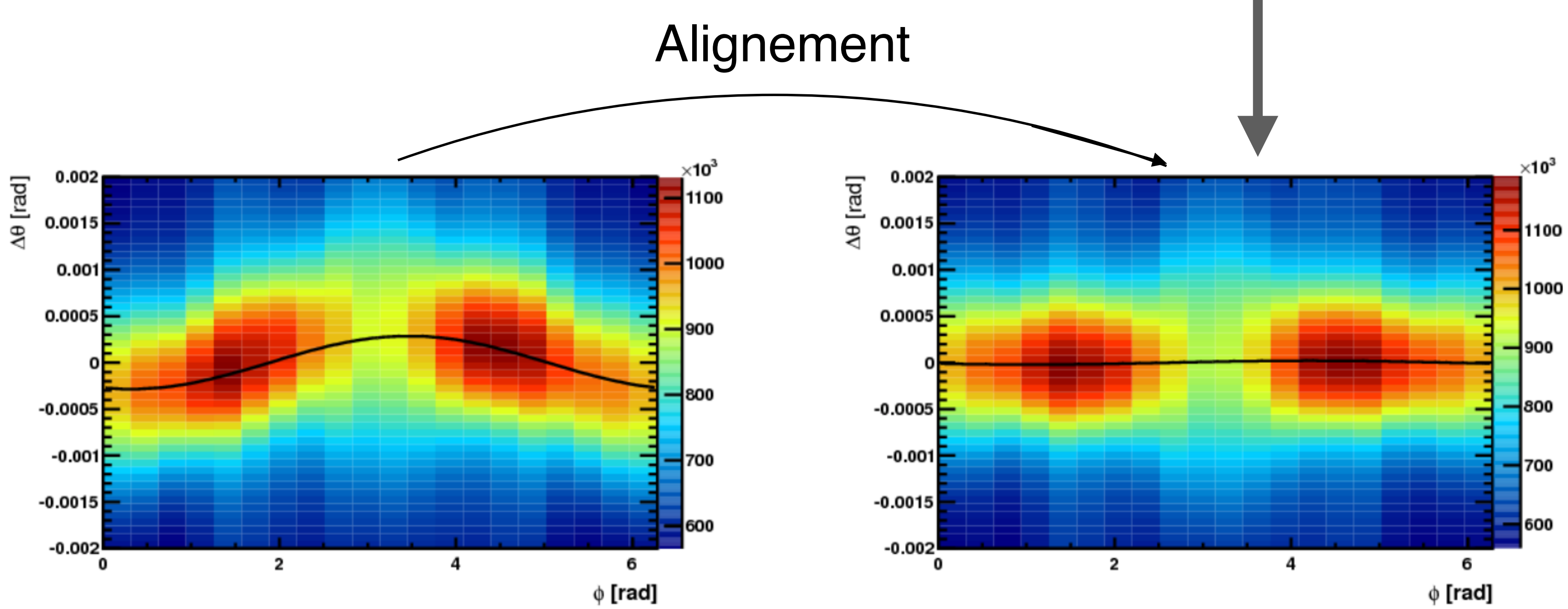
- Same strategy as Run 2
  - Alignment in each dedicated sample




LHCb-FIGURE-2019-059

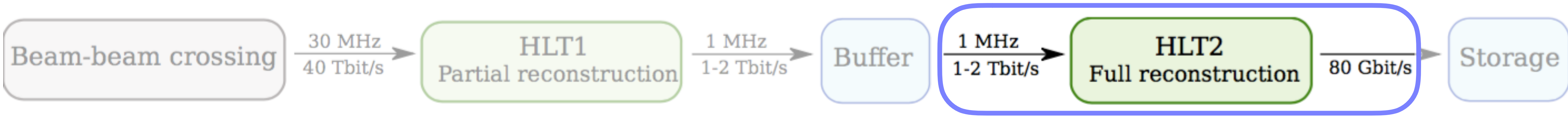



- Difference between measured and expected Cherenkov angle Δθ




EPJC 73, 2431 (2013)

# Second High Level Trigger (HLT2)




- HLT2 reconstruction is critical to both physics output and physics quality
  - → Full, offline-fidelity event reconstruction on at least 1 MHz
  - → Charged track reconstruction with no momentum selection

Charged particle reconstruction:
VELO, UT, SciFi

↓

Full track fit:
best resolution, background rejection

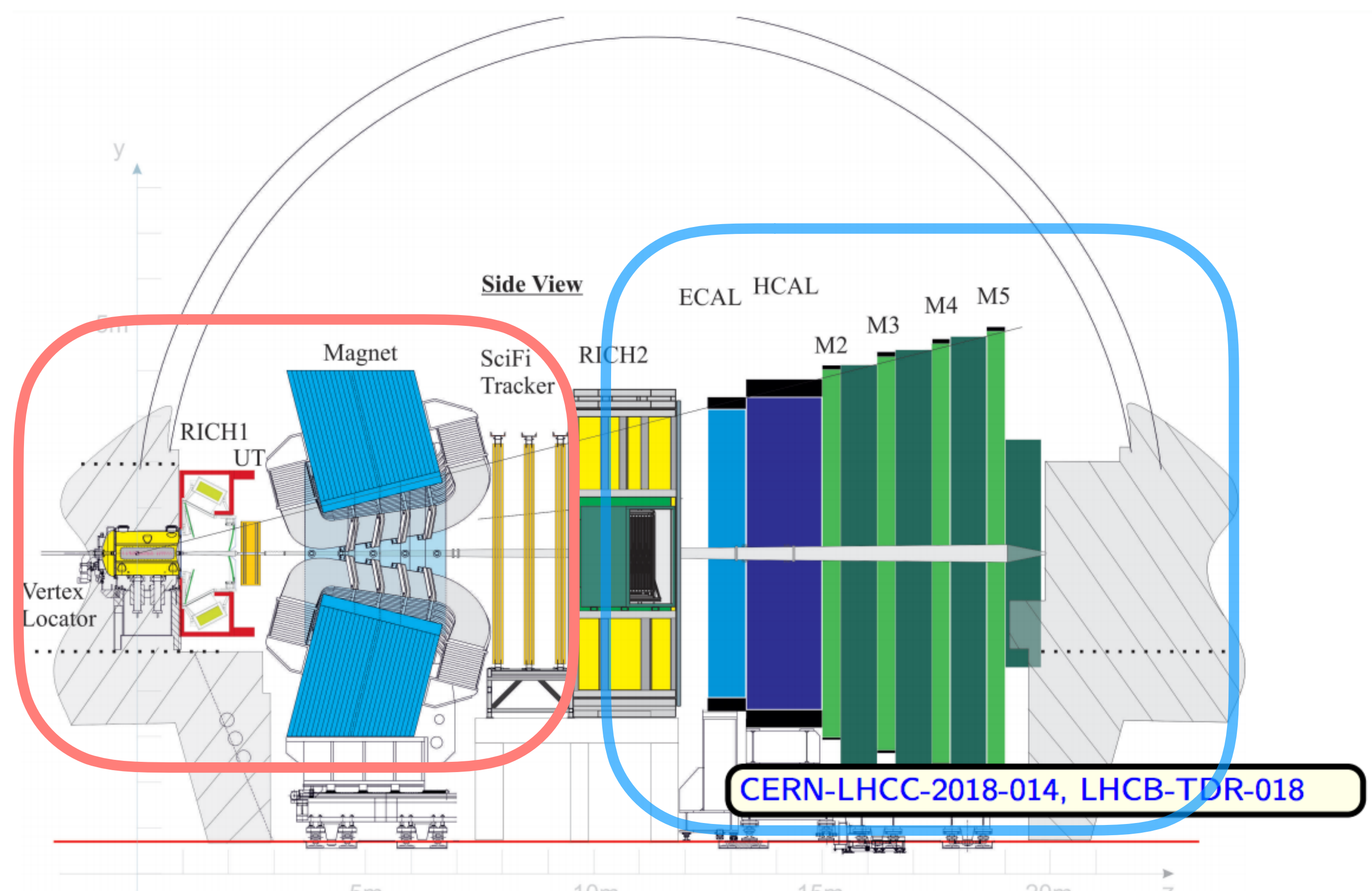
↓

Particle identification:
RICH, MUON, ECAL

↓

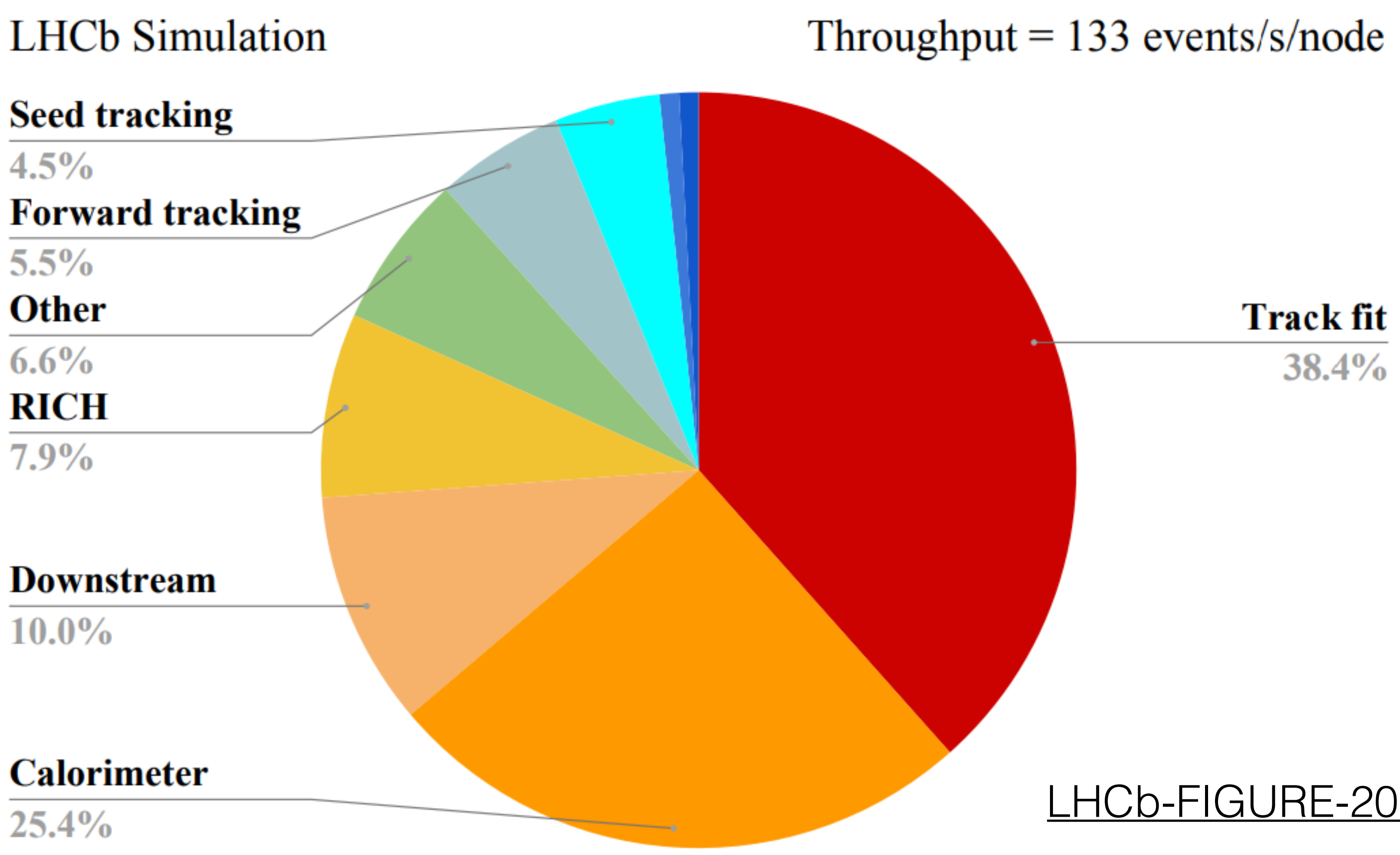
Neutral reconstruction:
ECAL

Contributors:
A. Gunther, P. Li



# Current HLT2 Throughput

- Far from the requirement but several solutions have been implemented
  → Remove the redundancy in the track reconstruction / apply track fit only to the tracks used in physics analyses
  → More optimizations/rewriting of the algorithms are in good progress
  → Monitor both the speed and the quality of outputs
  → Concentrated effort shifts from HLT1 to HLT2 now



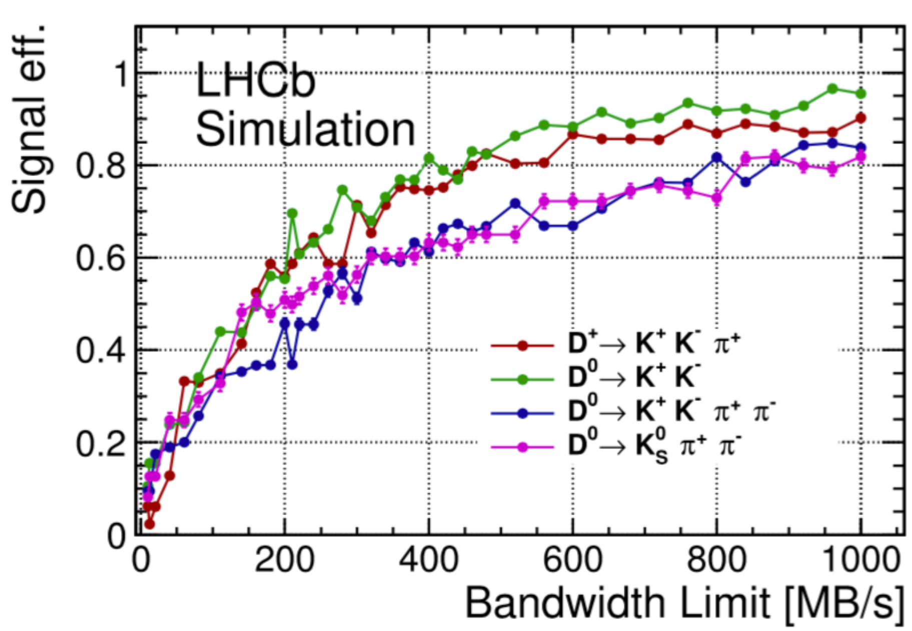

LHCb-FIGURE-2020-007

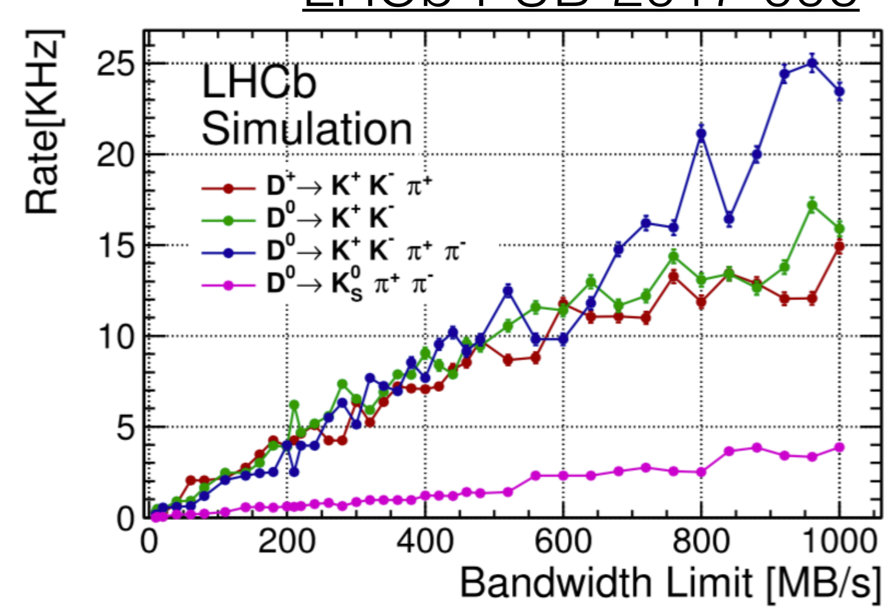
# HLT2 Selection

Contributors:
N. Nolte, P. Li, G. Meier, etc

- O(1000) inclusive and exclusive selections (O(400) implemented)
  - Bandwidth sharing optimized using a genetic algorithm
- Framework:
  - Data flow: Configurable algorithms properties & user defined inputs/outputs
  - Control flow: what should be run and when to stop
- Fixed output bandwidth of 10 GB/s
- New combination algorithms implemented to speed up the selection
- Studies on bandwidth & efficiency for various decay channels ongoing

LHCb-PUB-2017-006



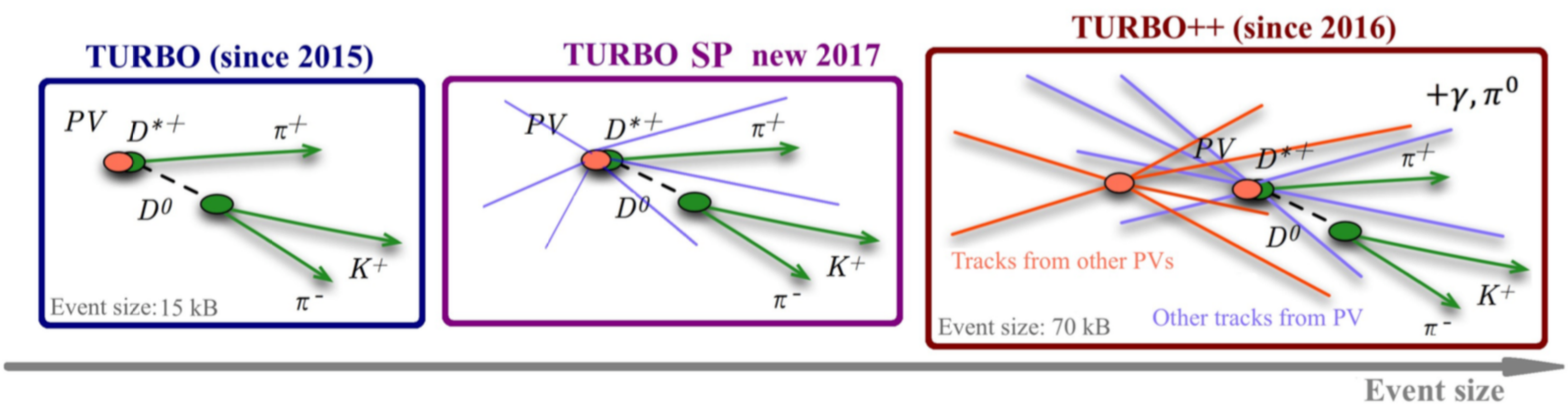



# Persistency Model: what is saved to disk

- Bandwidth [MB/s] ~ Trigger output rate [kHz] × average event size [kB]
  - → Trigger bandwidth is crucial, not only trigger rate but also event size
  - → Real-time selection occurs with offline quality
  - → Only store high-level objects reconstructed in real-time
  - → Reduced event format: reduction of event size

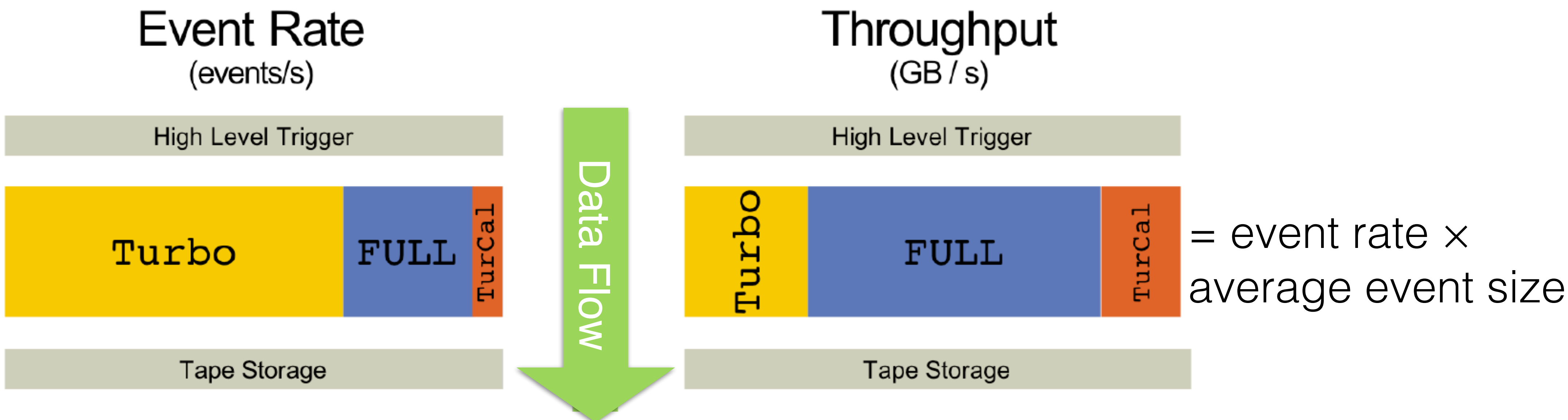
    Higher efficiency for the same bandwidth

- Turbo stream developed and commissioned in Run 2 as Baseline for Run 3



# Persistency Model

LHCB-TDR-018

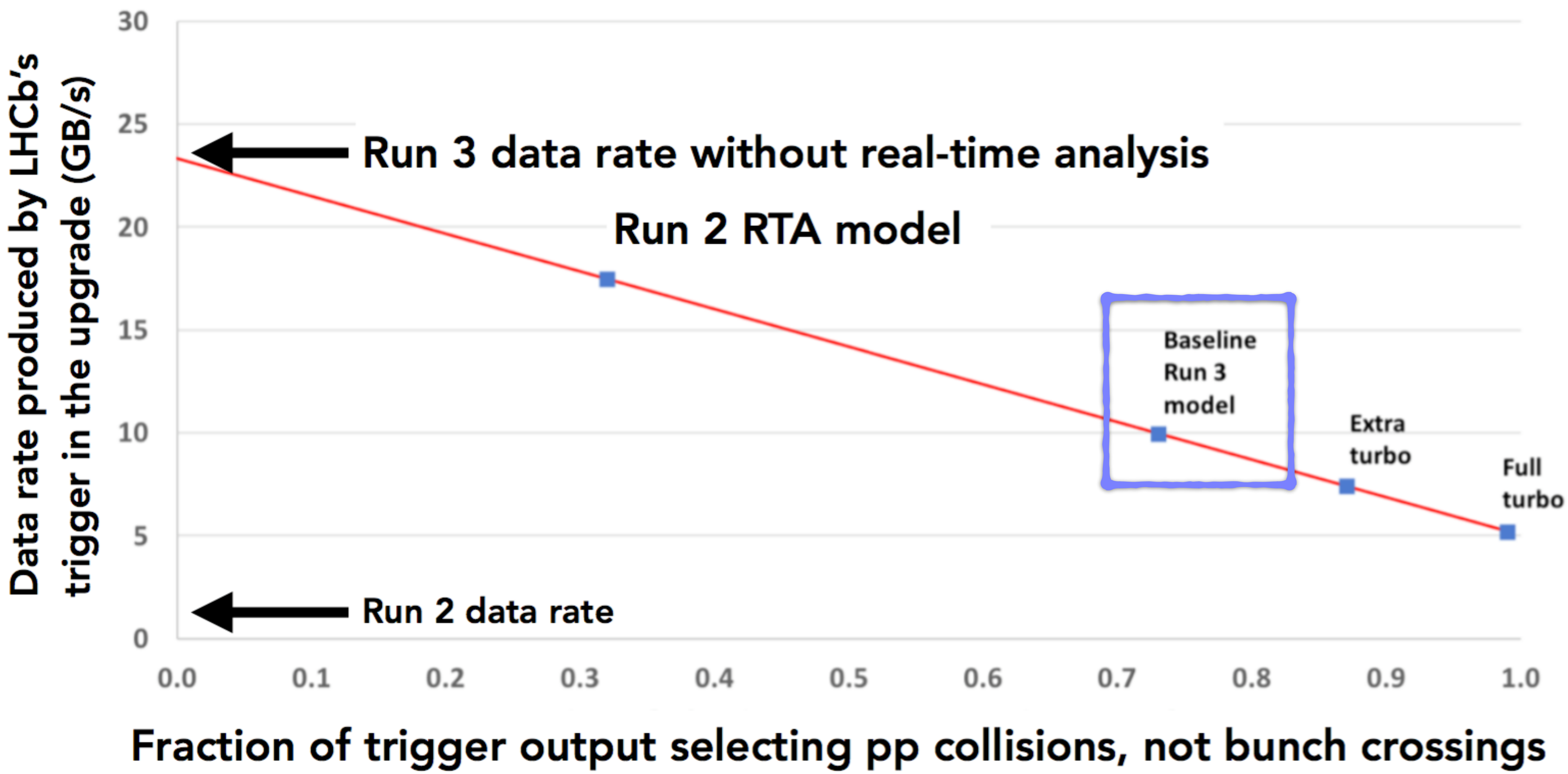



| stream | rate fraction | throughput (GB/s) | bandwidth fraction |
|---|---|---|---|
| FULL | 26% → | 5.9 | 59% |
| Turbo | 68% → | 2.5 | 25% |
| TurCal | 6% | 1.6 | 16% |
| total | 100% | 10.0 | 100% |

- Turbo stream: only HLT2 signal candidates (minimum output)
  - Optionally: (parts of) pp vertex (e.g. “cone” around candidate for spectroscopy)
  - Limitations: cannot refit tracks and PVs offiline, rerun flavor tagging etc.
  - Advantage: Event size O(10) smaller than RAW
- Full stream: all reconstructed objects in the event + selected RAW banks
- TurCal stream: HLT2 candidates and RAW banks
  - Used for offline calibration and performance measurement

# Persistency Model

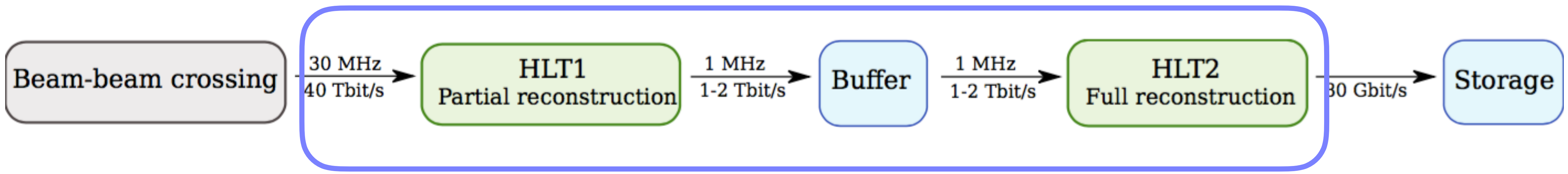
- Real-time analysis reduces required resources by more than 2




- Reduced event size and no offline rerun are risky, requiring more careful evaluations and studies for the HLT2 selections
- Faster reconstruction algorithms would make more rooms for the selections, keep improving both

# Summary

- ✓ LHCb is almost ready to face the MHz signal era, changing the trigger paradigm to RTA, pioneer in the real time processing
- ✓ From background rejection → signal selection and characterization
- ✓ Partial event reconstruction (HLT1) at 30 MHz input rate using GPUs
- ✓ Full event reconstruction (HLT2) at 1 MHz input rate using CPUs
- ✓ Event rate & size reduction → bandwidth reduction
- ✓ Turbo-mode selective persistency will be dominated in the upgrade




In the long term:

- Hybrid architecture in Run 3 would prepare us better for future upgrade
- R&D studies on optimal use of hybrid architectures (GPU/CPU/FPGA), remain flexible

Thanks for your attention!