



Real-time analysis @ (from ansichsein to fürsichsein)



Economic conditions had first transformed the mass of the people of the country into workers. The combination of capital has created for this mass a common situation, common interests. This mass is thus already a class as against capital, but not yet for itself. In the struggle, of which we have noted only a few phases, this mass becomes united, and constitutes itself as a class for itself. The interests it defends become class interests. But the struggle of class against class is a political struggle.

Karl Marx, The poverty of philosophy



V. V. Gligorov
LPNHE/CNRS

Seminar @ Uni Bonn, 24.07.2025



LHCb – a forward detector @ LHC

JINST 19 (2024) P05065

Key detector physics drivers
(for upgraded detector)

Vertex resolution

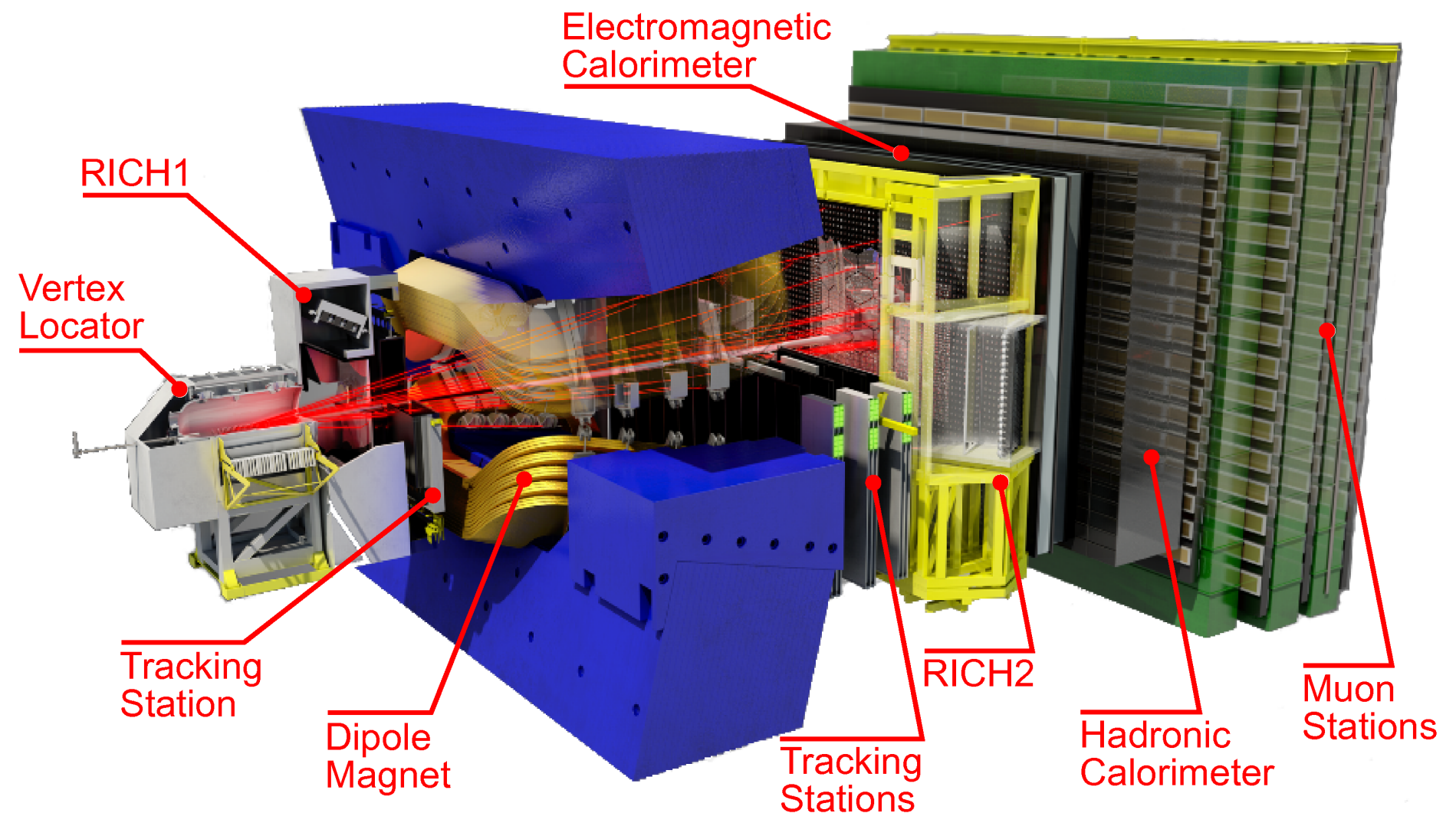
$$\sigma_{IP} \sim 19 \mu\text{m} @ p_T = 2 \text{ GeV}$$

Particle ID

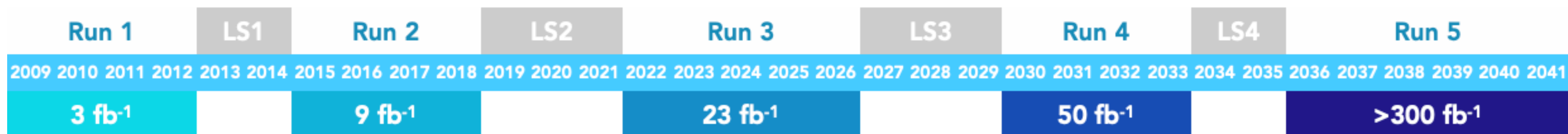
$$\varepsilon(K \rightarrow K) \sim 95\% @ 4\% \text{ misID}$$

Momentum resolution

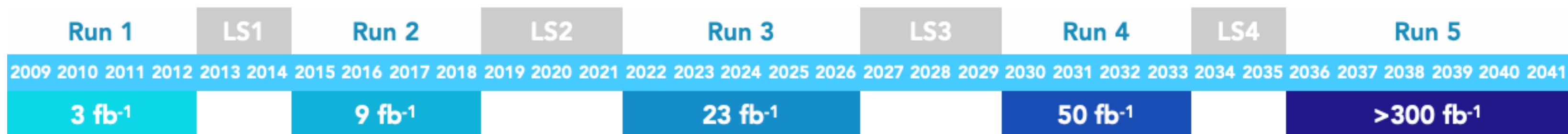
$$\sigma_p/p \text{ 0.45\%} - 1.1\% @ p = 2 - 200 \text{ GeV}$$



LHCb – past, present, and future



LHCb – past, present, and future



The forward flavour detector concept works! Many world-best measurements. Pioneering use of quantised and unbiasing ML algorithms in real time and offline.

LHCb – past, present, and future

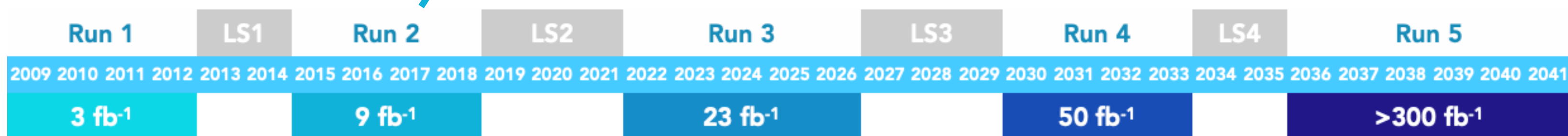
Align and calibrate detector in quasi-real time, full detector reconstruction and pileup suppression in trigger



The forward flavour detector concept works! Many world-best measurements. Pioneering use of quantised and unbiasing ML algorithms in real time and offline.

LHCb – past, present, and future

Align and calibrate detector in quasi-real time, full detector reconstruction and pileup suppression in trigger



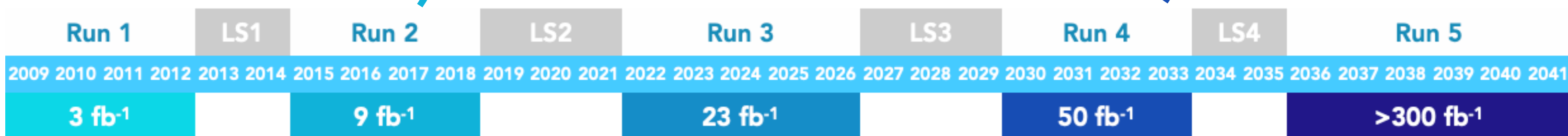
The forward flavour detector concept works! Many world-best measurements. Pioneering use of quantised and unbiasing ML algorithms in real time and offline.

Greatly improved tracker & PID granularity, 30 MHz detector readout & GPU trigger performing a near-full detector reconstruction

LHCb – past, present, and future

Align and calibrate detector in quasi-real time, full detector reconstruction and pileup suppression in trigger

Enhance PID with precise timing and improved granularity, explore enhanced readout boards with fast tracking



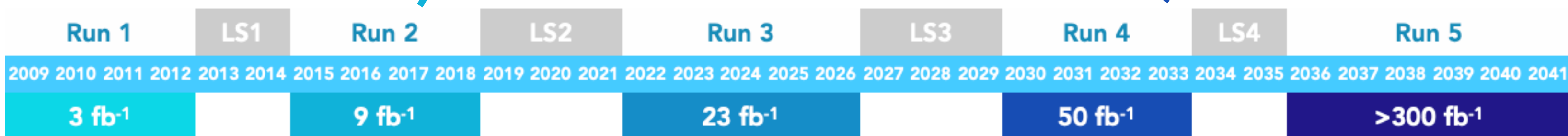
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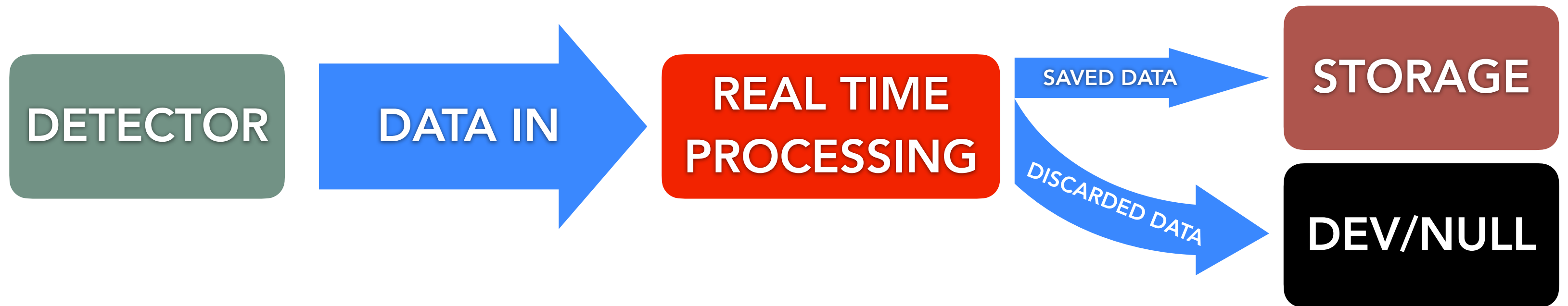
The forward flavour detector concept works! Many world-best measurements. Pioneering use of quantised and unbiasing ML algorithms in real time and offline.

Greatly improved tracker & PID granularity, 30 MHz detector readout & GPU trigger performing a near-full detector reconstruction

Deploy 4D tracking, PID, and calorimetry + a highly granular pixel tracker to be processed by a heterogenous trigger

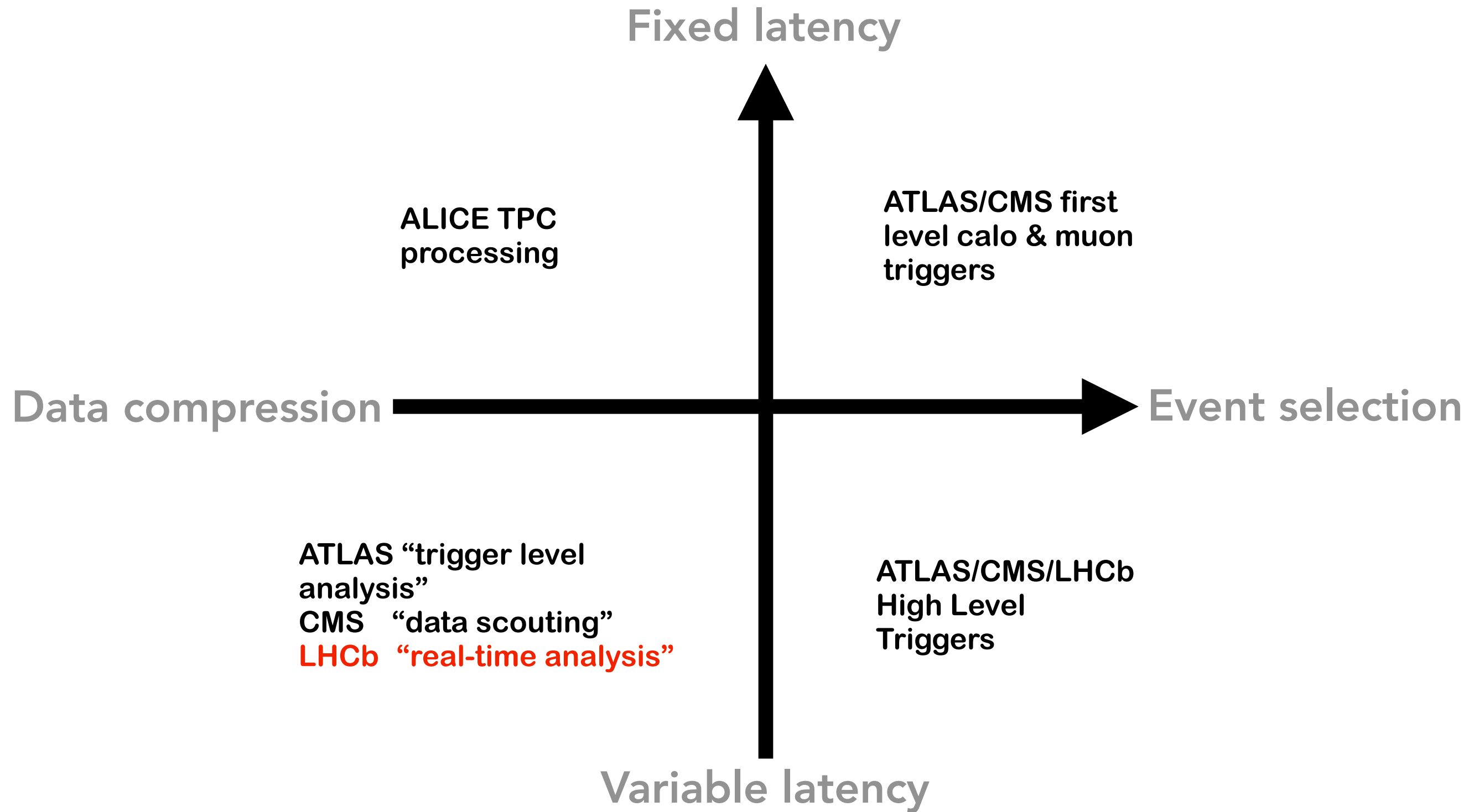
What is real-time
analysis?

Q : What is real-time?



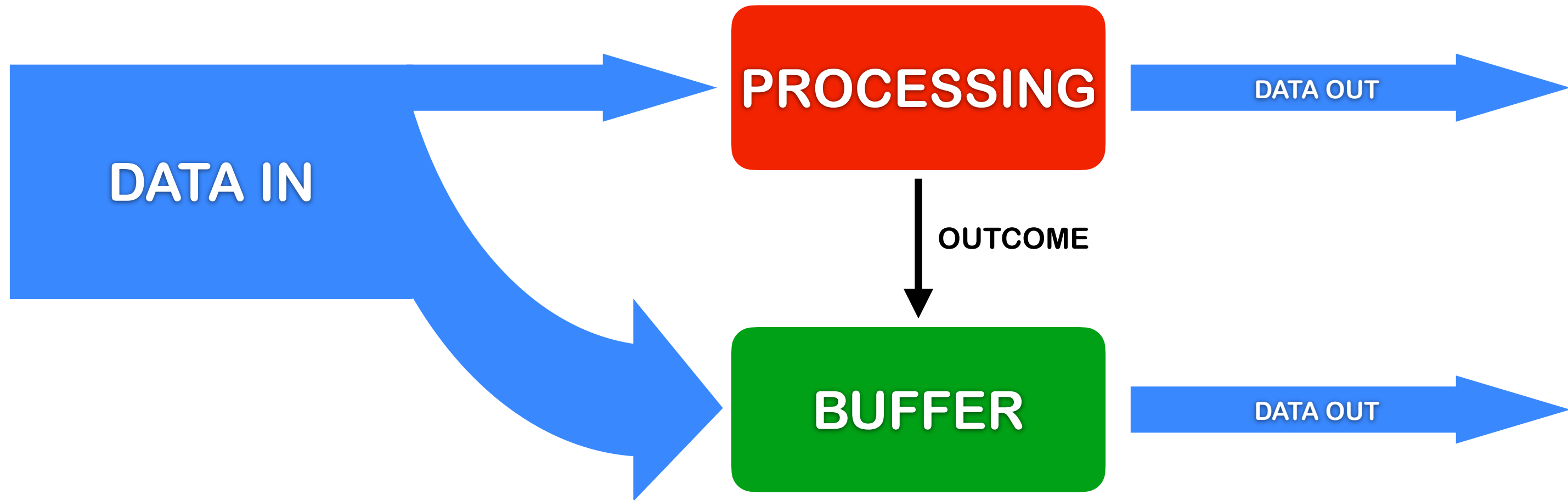
A : Any processing of data before it is permanently recorded

Types of real-time data processings



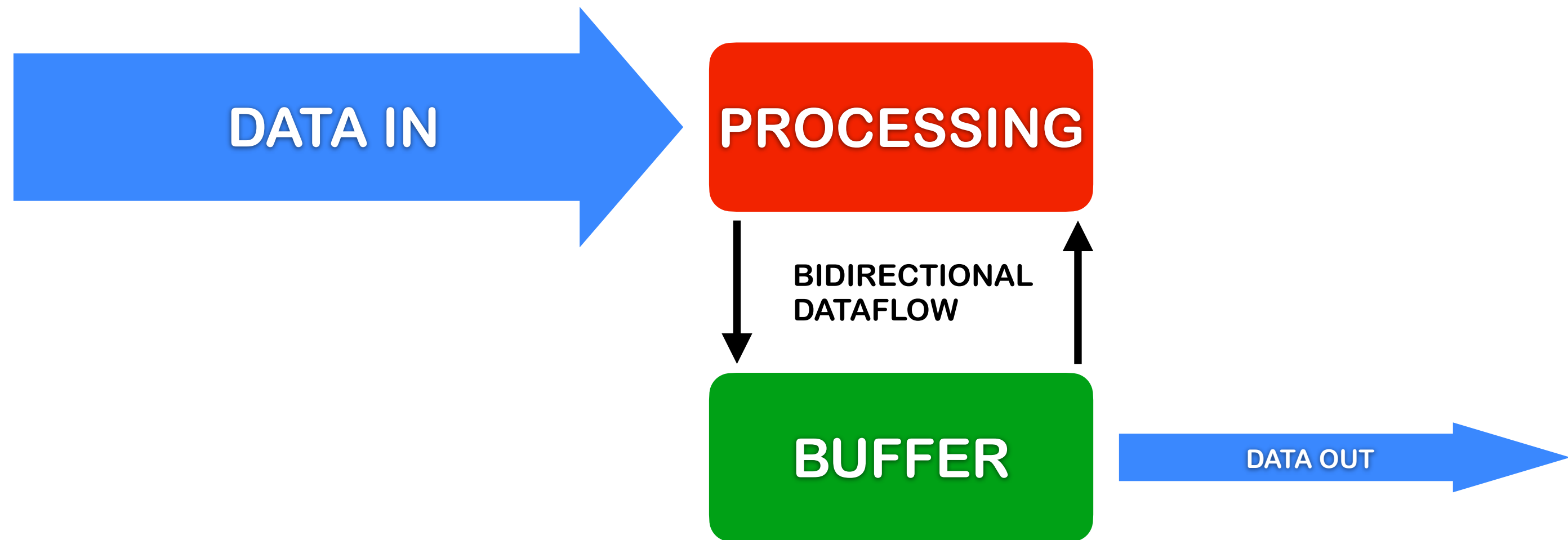
Distinguish fixed & variable latency, selection & compression

Fixed latency processing



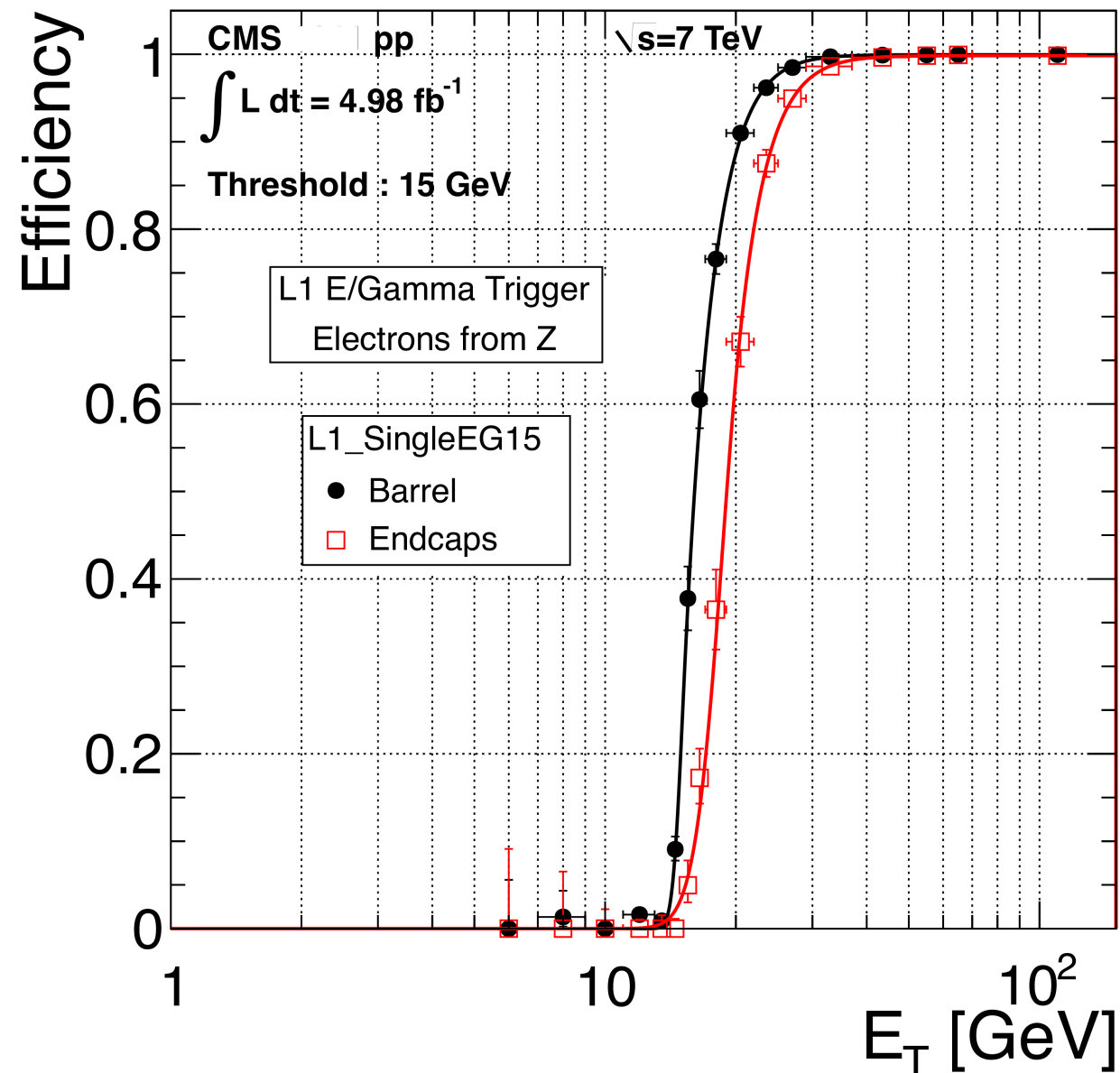
Typically used when processing controls detector readout

Variable latency processing

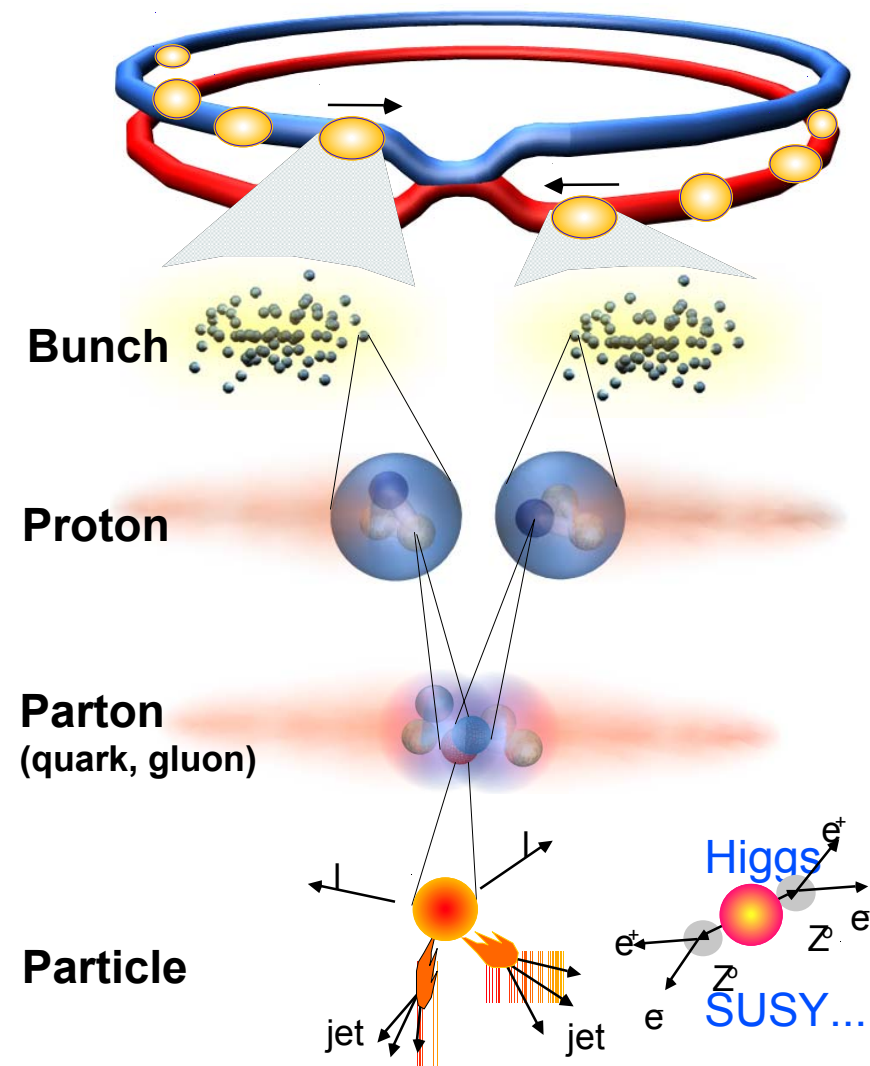


Typically used when data has already been read out

Traditional “triggering”



Collisions at the LHC: summary



Proton - Proton 2804 bunch/beam
 Protons/bunch 10^{11}
 Beam energy 7 TeV (7×10^{12} eV)
 Luminosity $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

Crossing rate 40 MHz

Collision rate $\approx 10^7 - 10^9$

New physics rate $\approx .00001$ Hz

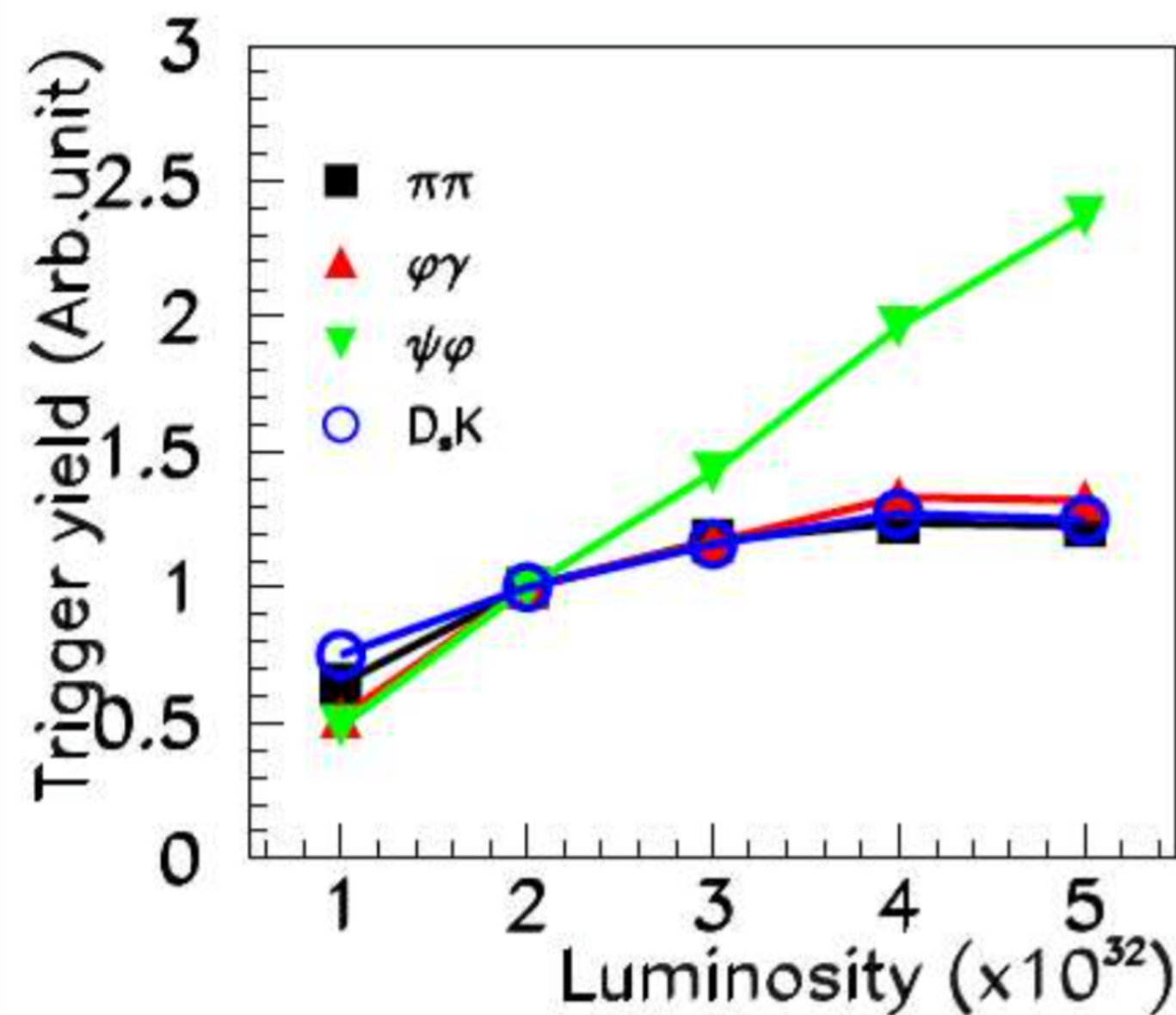
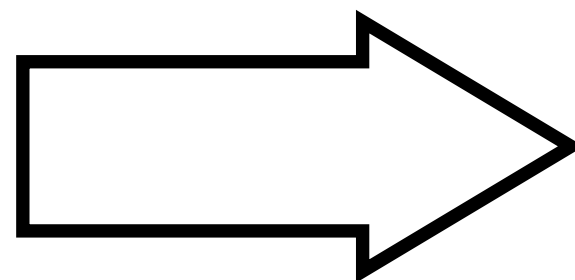
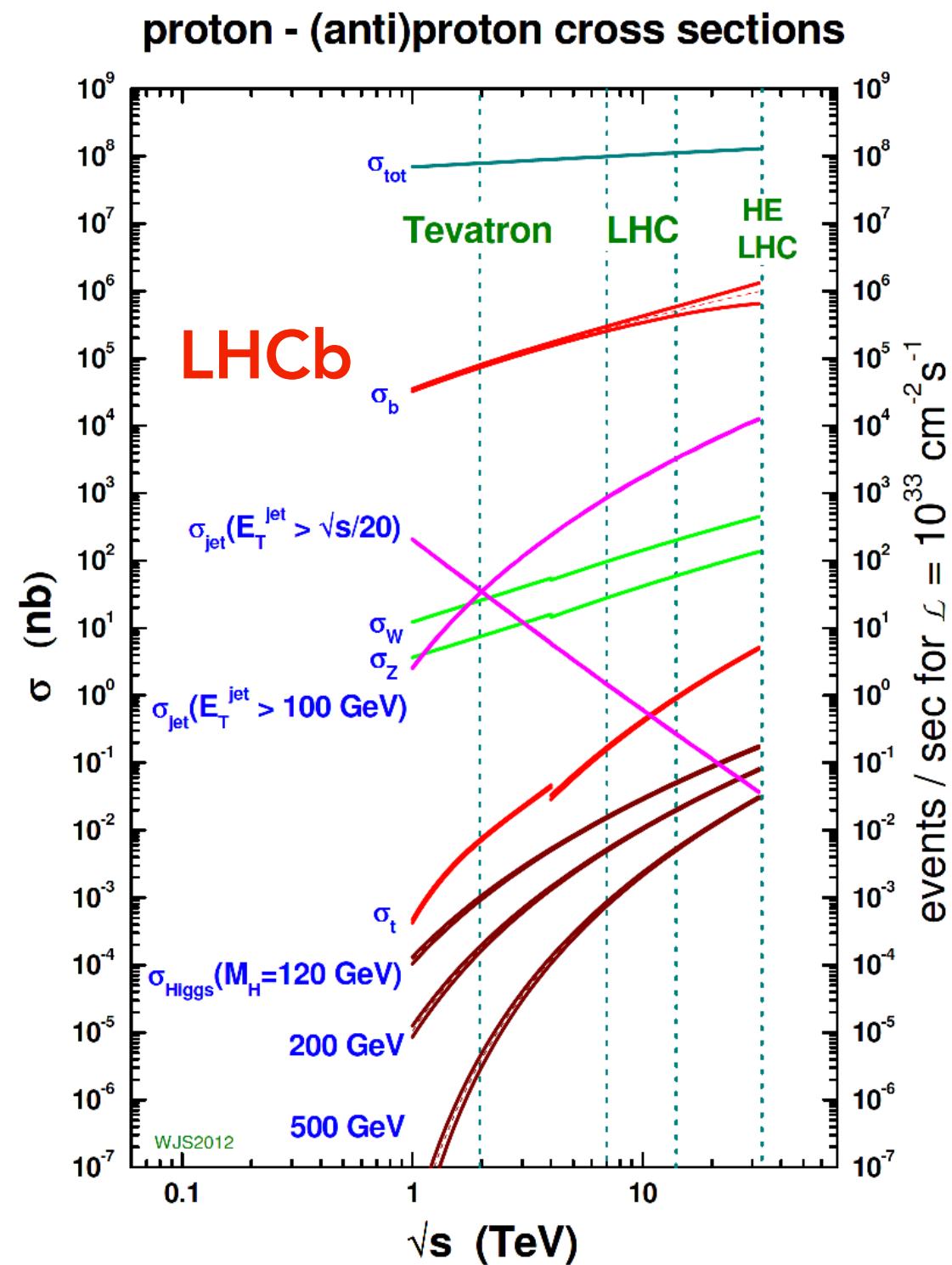
Event selection:
1 in 10,000,000,000,000

P. Spicas
 Triggering

SSI 2006
 July 2006

Driven by fixed-latency selection, analysis on efficiency plateau

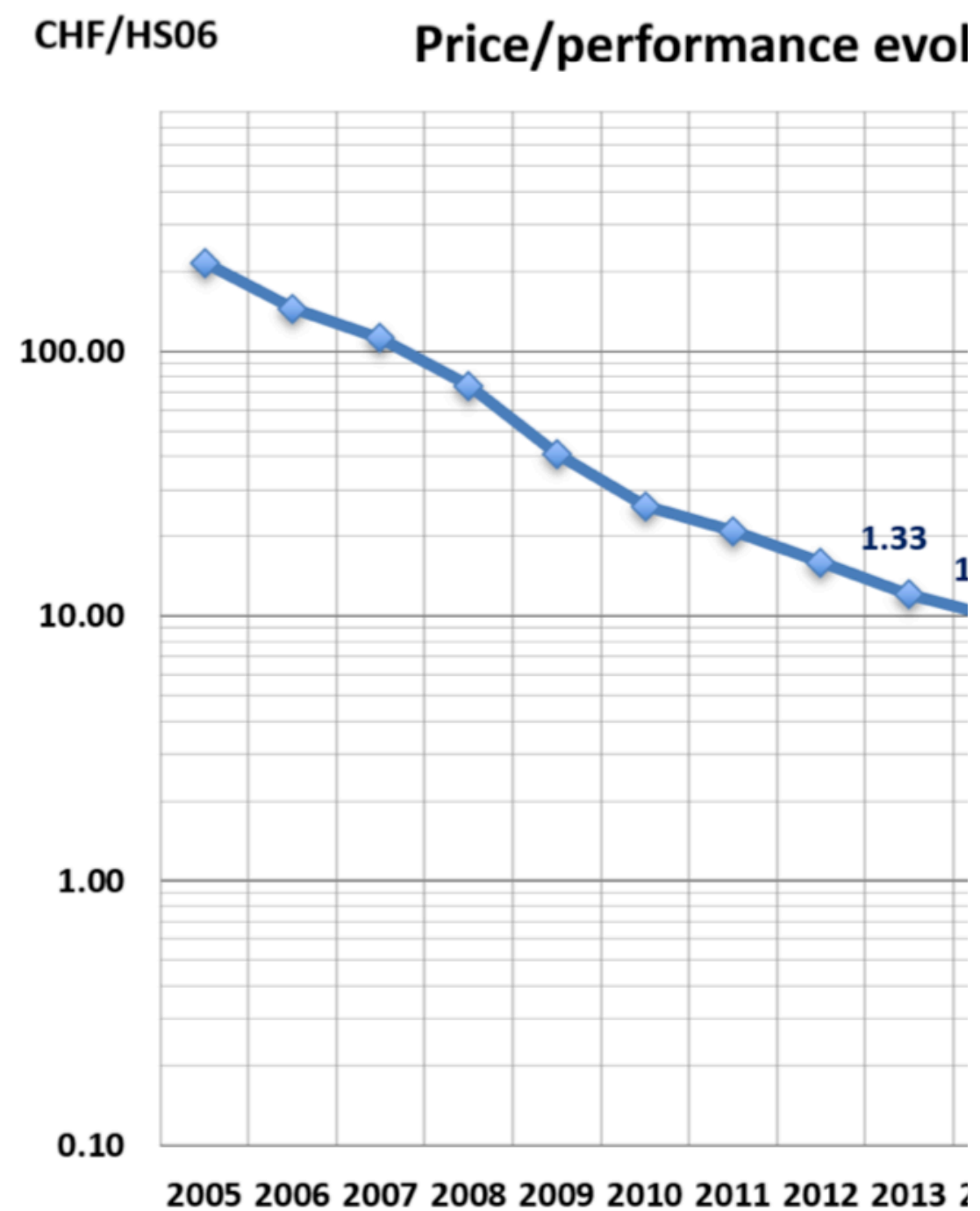
Modern “real-time analysis”



Largely compression not selection, variable latency by necessity

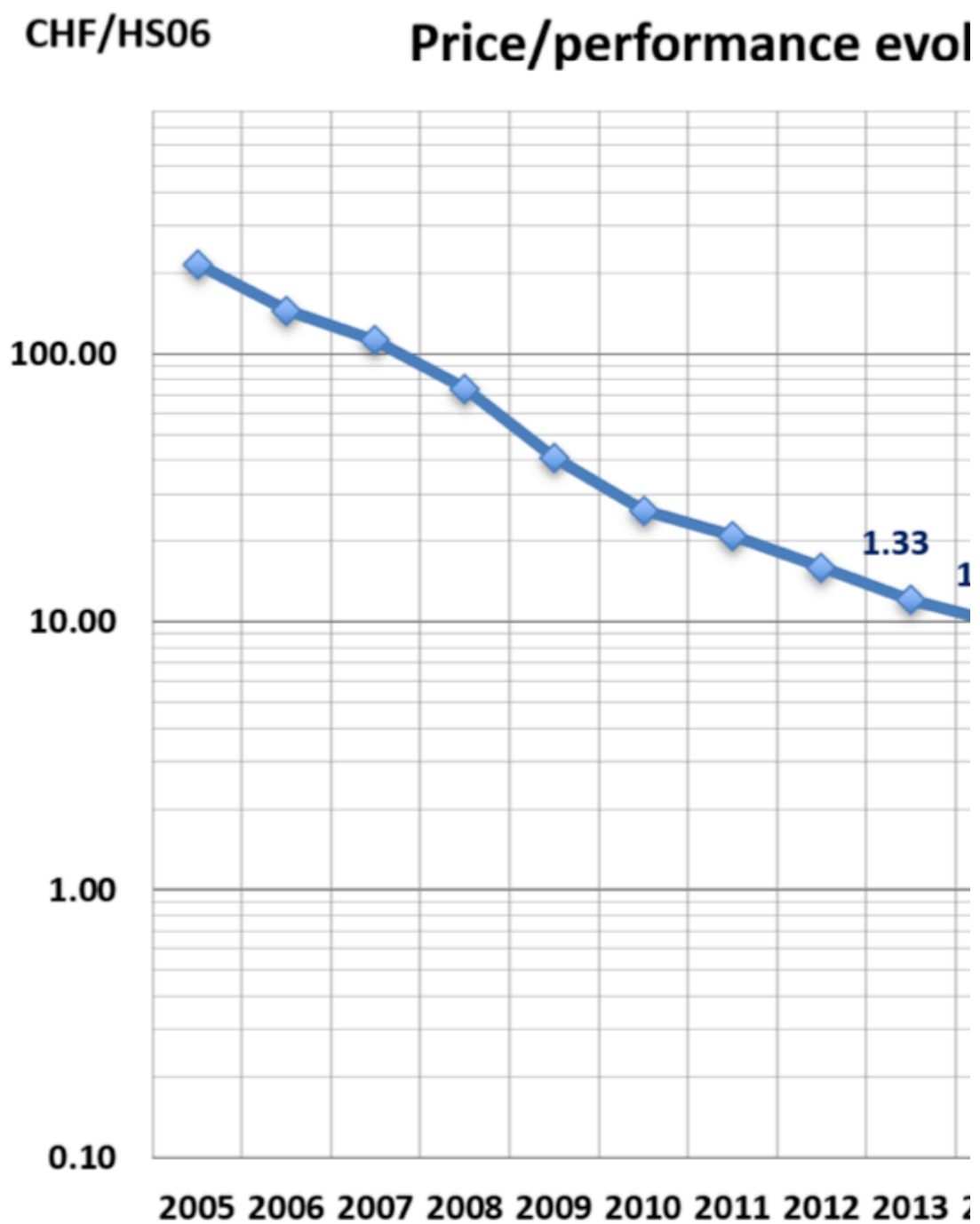
The origins of real-time analysis @ LHCb

Run 1: exploiting the headroom

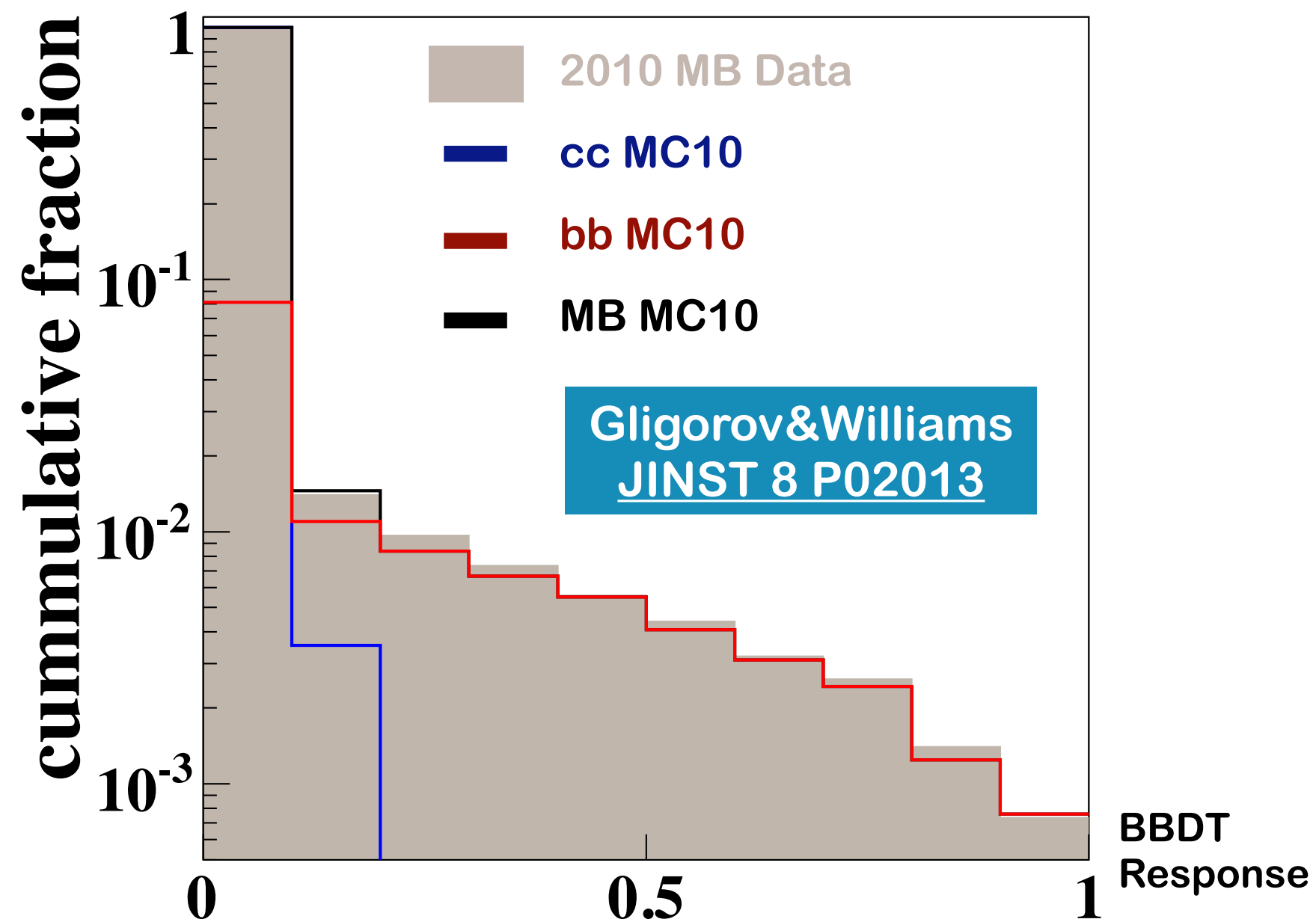


Bernd Panzer-Steindel, CERN IT

Run 1: exploiting the headroom

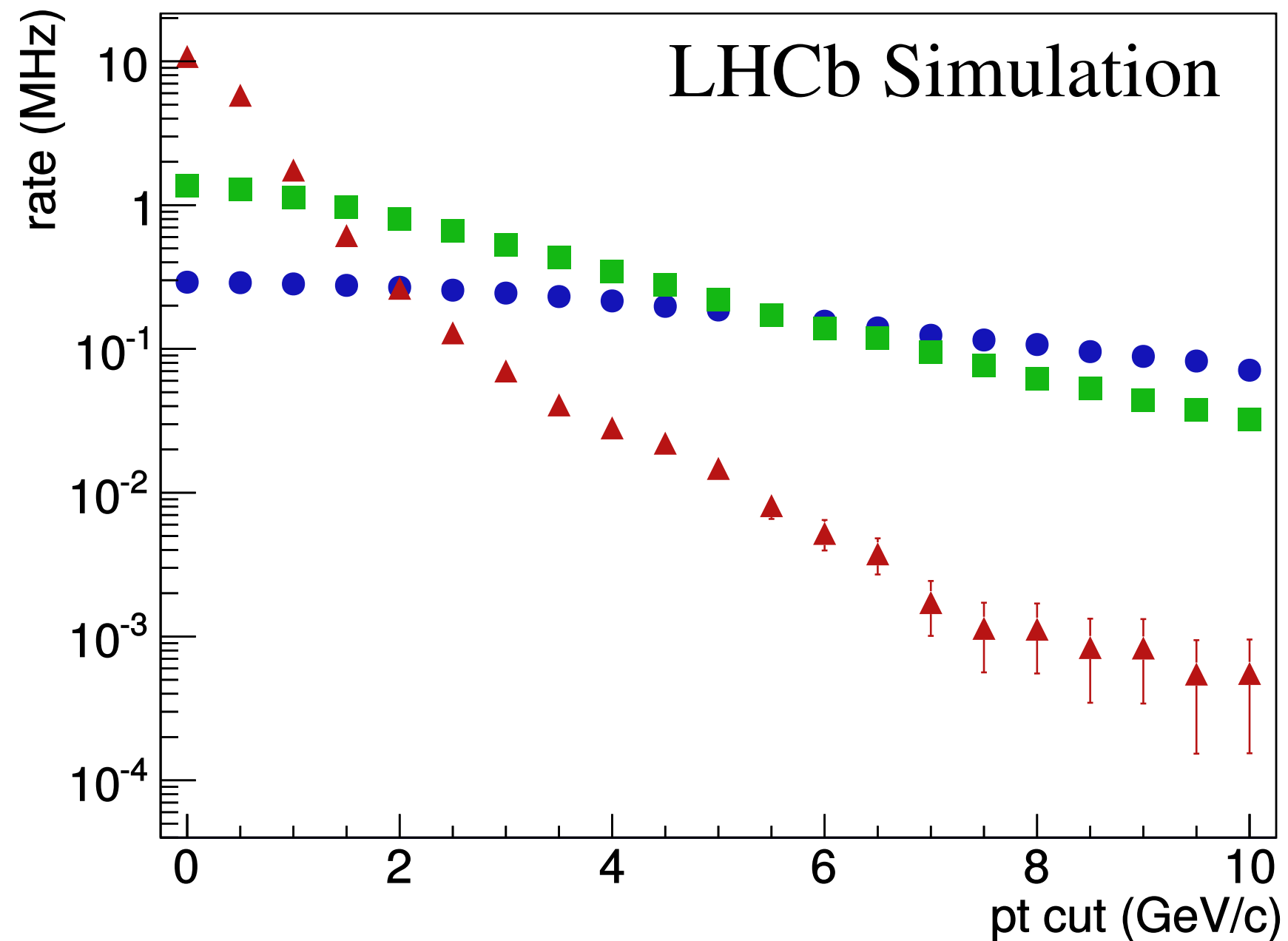


Bernd Panzer-Steindel, CERN IT

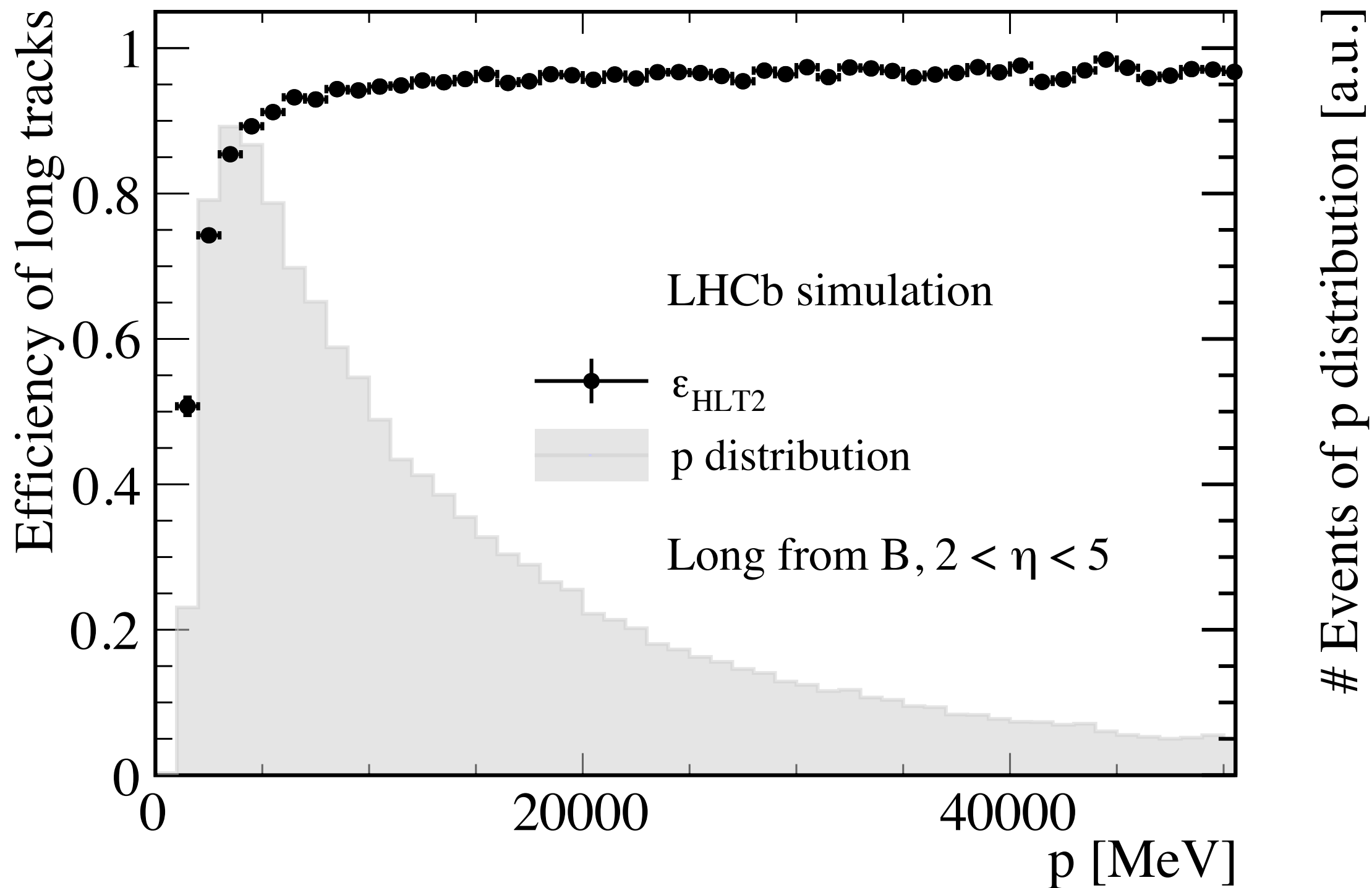


The physics case for real-time analysis

Rates as a function of pT cut for part. reco. candidates

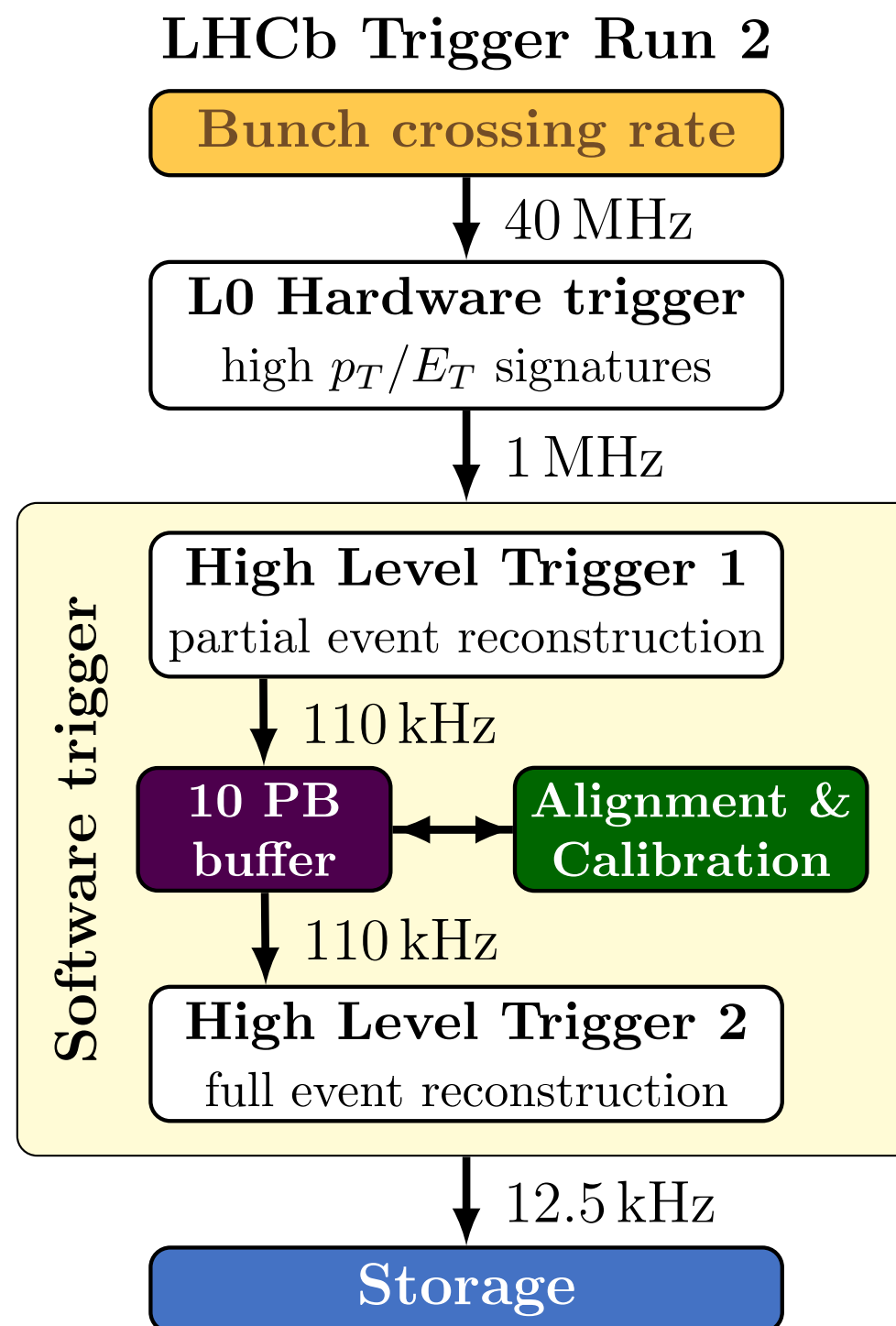


The physics case for real-time calibration



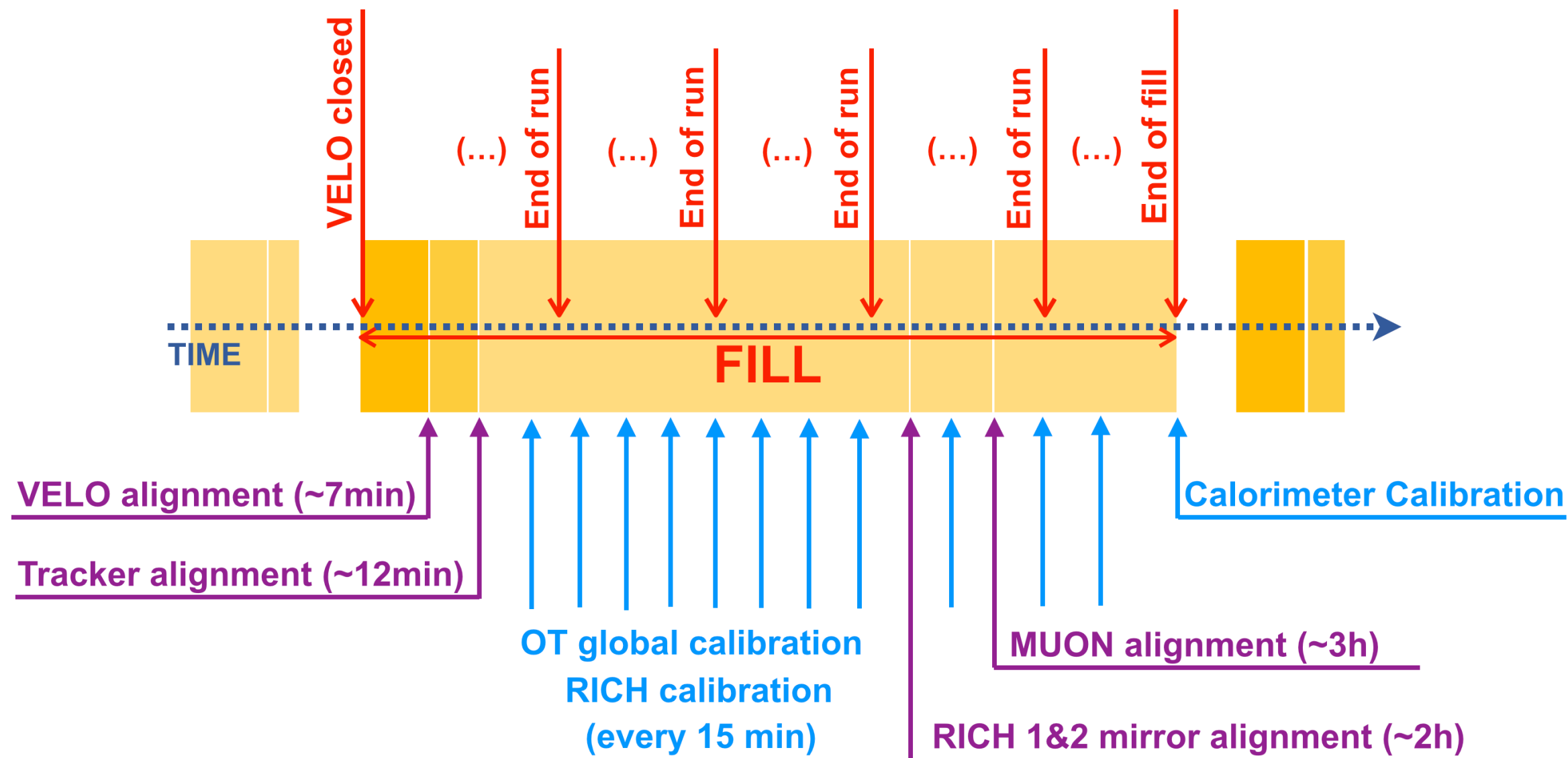
Run 2: the future, yesterday

[LHCb-DP-2019-001](#)



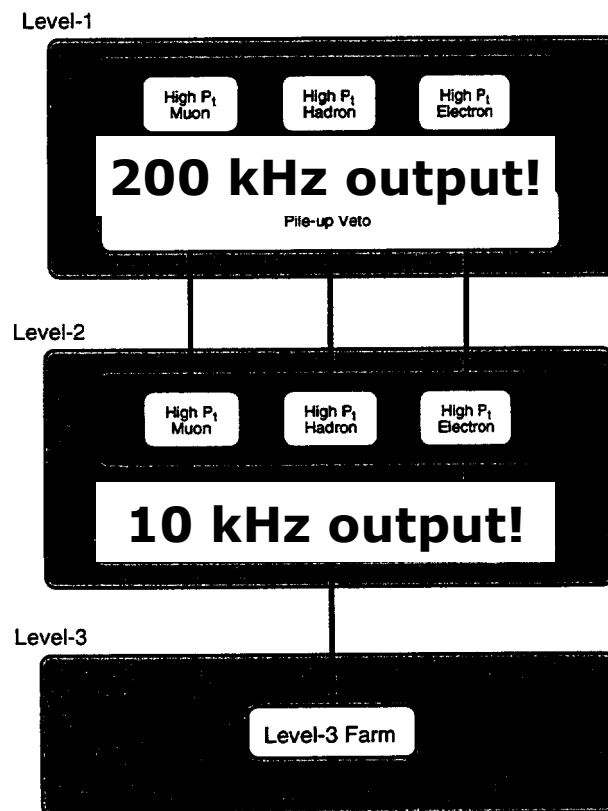
Run 2: the future, yesterday

[LHCb-DP-2019-001](#)

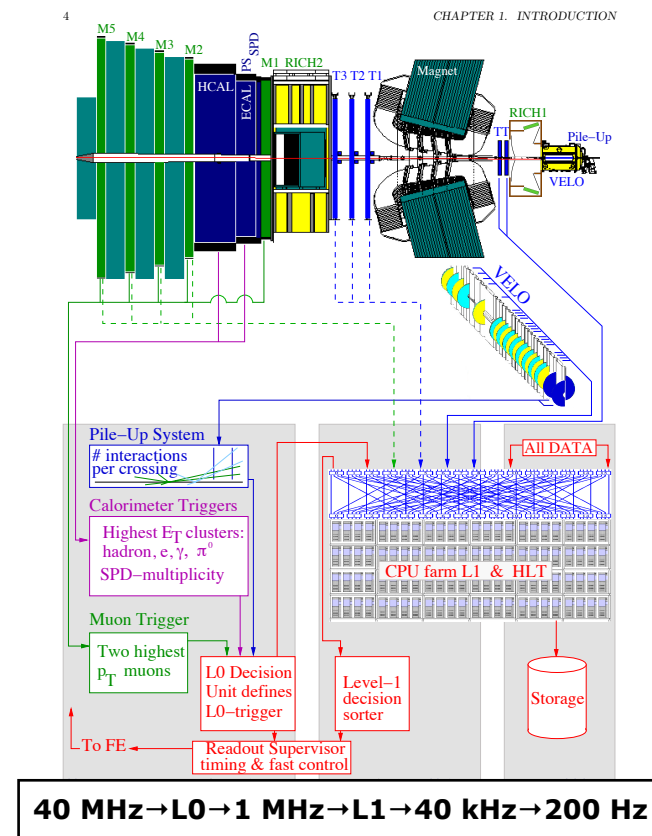


((~7min),(~12min),(~3h),(~2h)) - time needed for both data accumulation and running the task

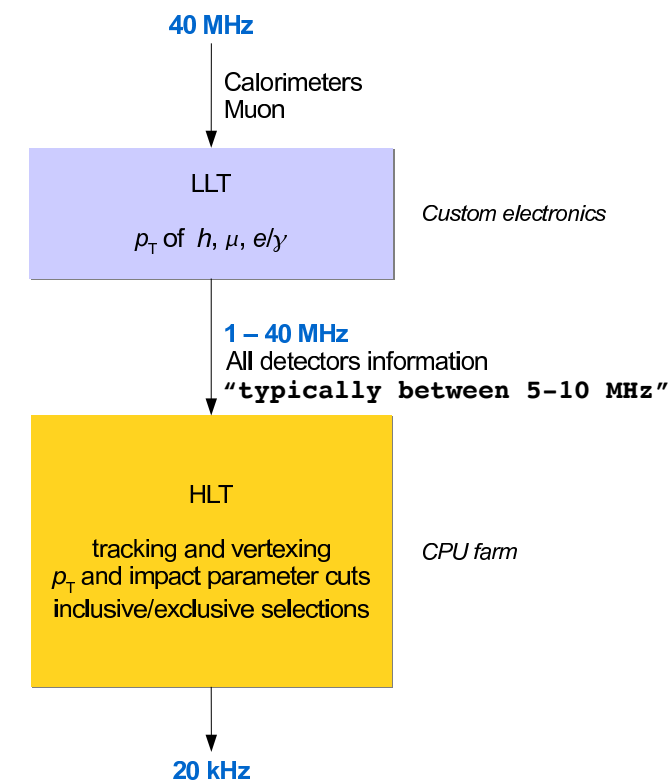
Certum est, quia impossibile



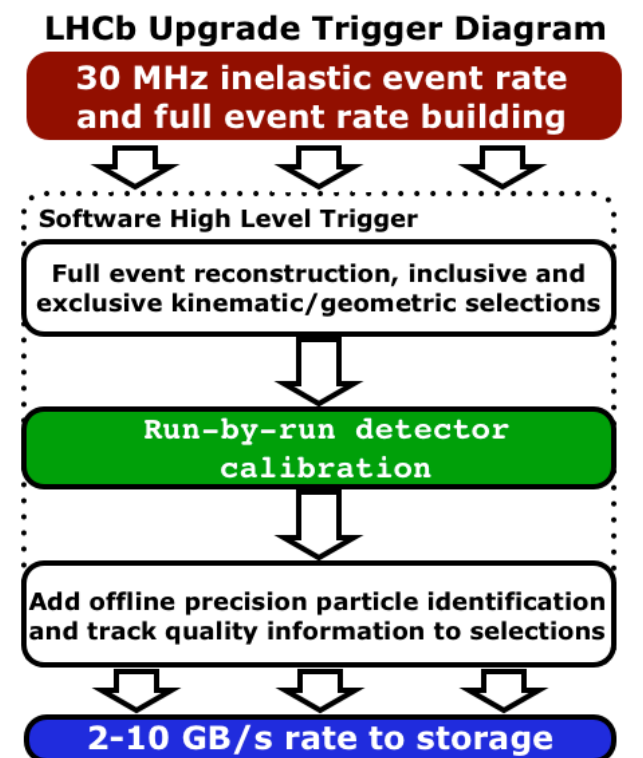
LHCb LOI (1995)



Trigger TDR (2003)



Upgrade LOI (2011)



Run 3

A community existing
for itself

Software & hardware co-design now!



Ask yourselves: what would Jensen do?

BUSINESS INSIDER

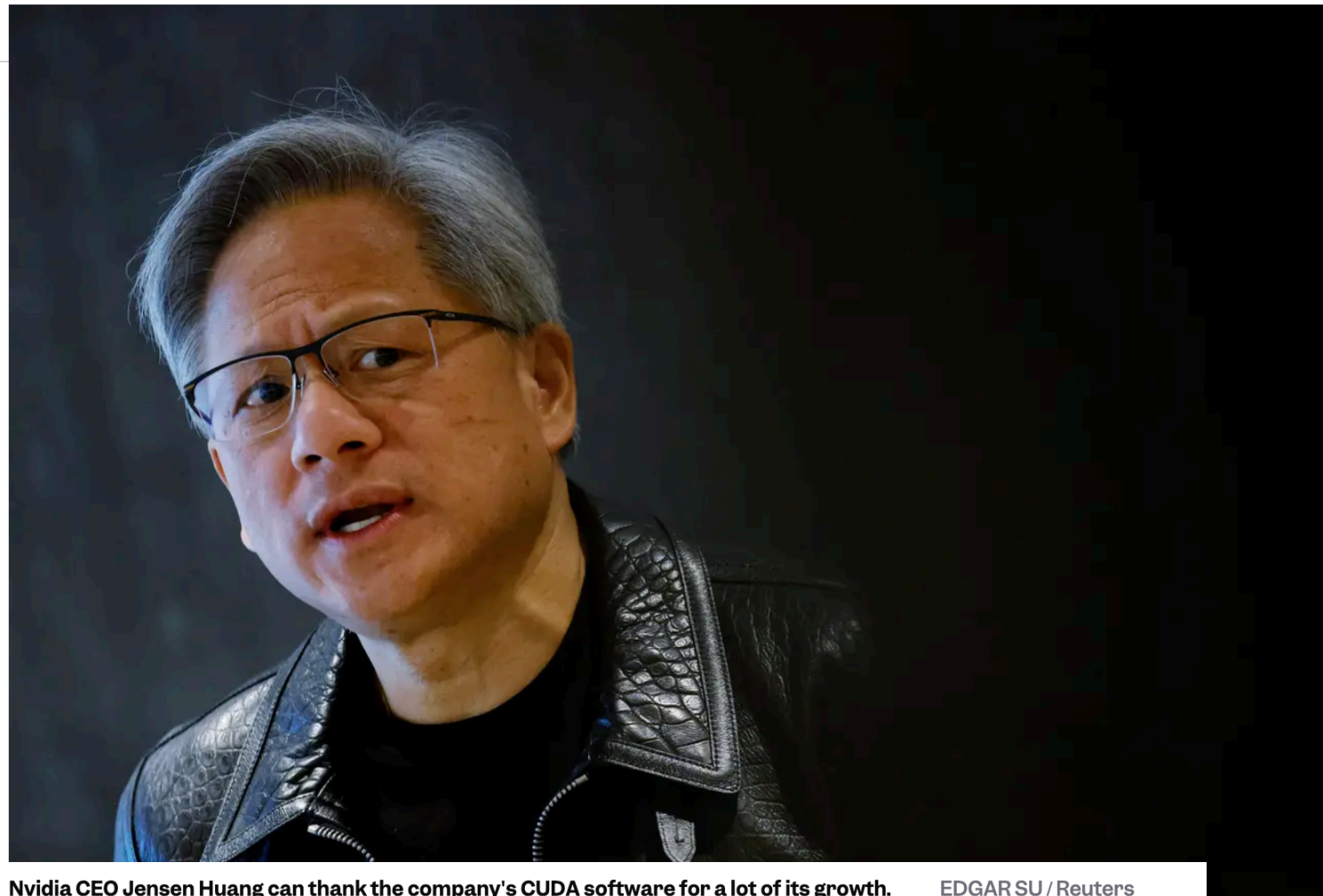
[Subscribe](#)

DOW JONES ▲ +0.4% NASDAQ ▼ -0.5% S&P 500 ▲ +0.06% AAPL ▲ +1.33% NVDA ▼ -1.8% MSFT ▼ -0.6% AMZN ▼ -0.58% META ▼ -0.66% TSLA ▲ +1.28%

AI

CUDA is Nvidia's secret sauce — and now it's in the sights of European regulators

By [Hasan Chowdhury](#)



Nvidia CEO Jensen Huang can thank the company's CUDA software for a lot of its growth.

EDGAR SU / Reuters

Now spot the missing topic

Implementation of the ECFA Detector R&D Roadmap

After the publication of the ECFA Detector R&D Roadmap, CERN Council requested ECFA to develop the plan for its implementation.

The document approved by the SPC and CERN Council in September 2022 can be found at https://indico.cern.ch/event/1197445/contributions/5034860/attachments/2517863/4329123/spc-e-1190-c-e-3679-Implementation_Detector_Roadmap.pdf.

As proposed in the document, topic specific community meetings have been held throughout 2023 with sign up for more information in the links listed below.

- TF1 Gaseous Detectors <https://indico.cern.ch/event/1214405/>
- TF2 Liquid Detectors <https://indico.cern.ch/event/1214404/>
- TF3 Solid State Detectors <https://indico.cern.ch/event/1214410/>
- TF4 Photon Detectors and PID <https://indico.cern.ch/event/1214407/>
- TF5 Quantum and Emerging Technologies <https://indico.cern.ch/event/1214411/>
- TF6 Calorimetry <https://indico.cern.ch/event/1213733/>
- TF7 Electronics and On-detector Processing <https://indico.cern.ch/event/1214423/>
- TF8 Integration <https://indico.cern.ch/event/1214428/>
- TF9 Training <https://indico.cern.ch/event/1214429/>

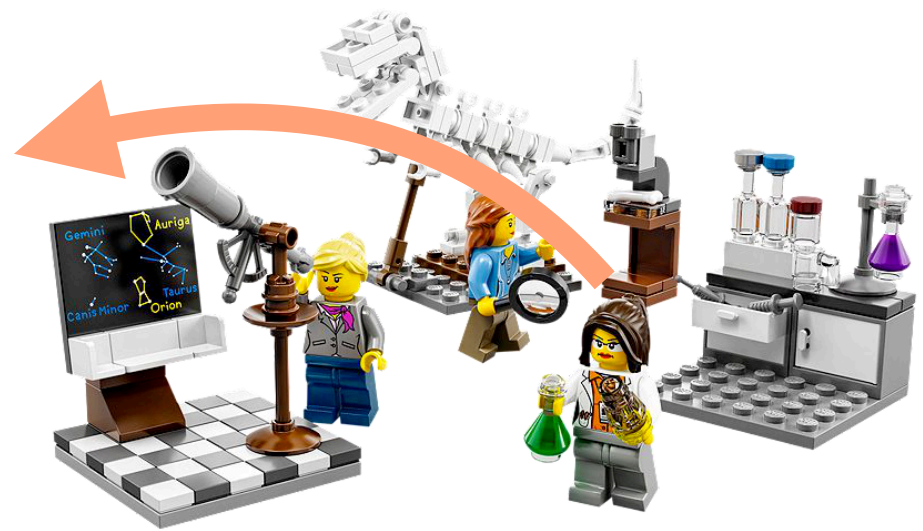
The reviewing process for the proposals is now well underway, with the DRDC now set up at <https://committees.web.cern.ch/drdc> supported by the ECFA Detector Panel (<https://ecfa-dp.desy.de>).





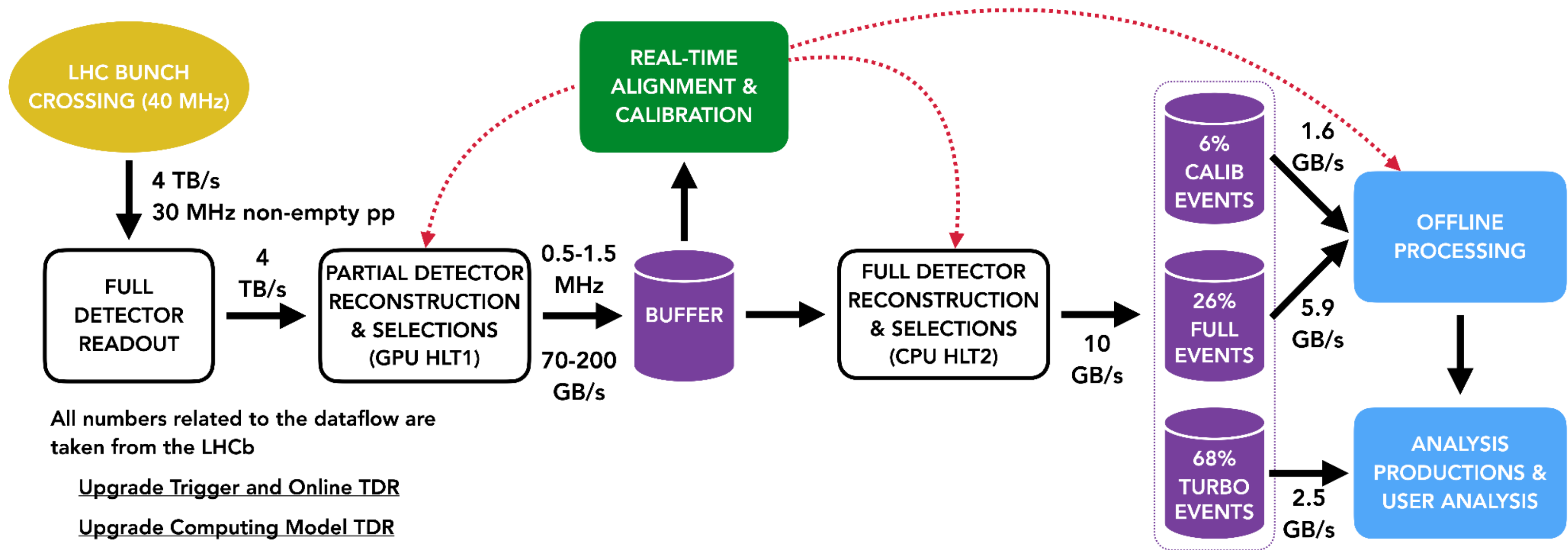




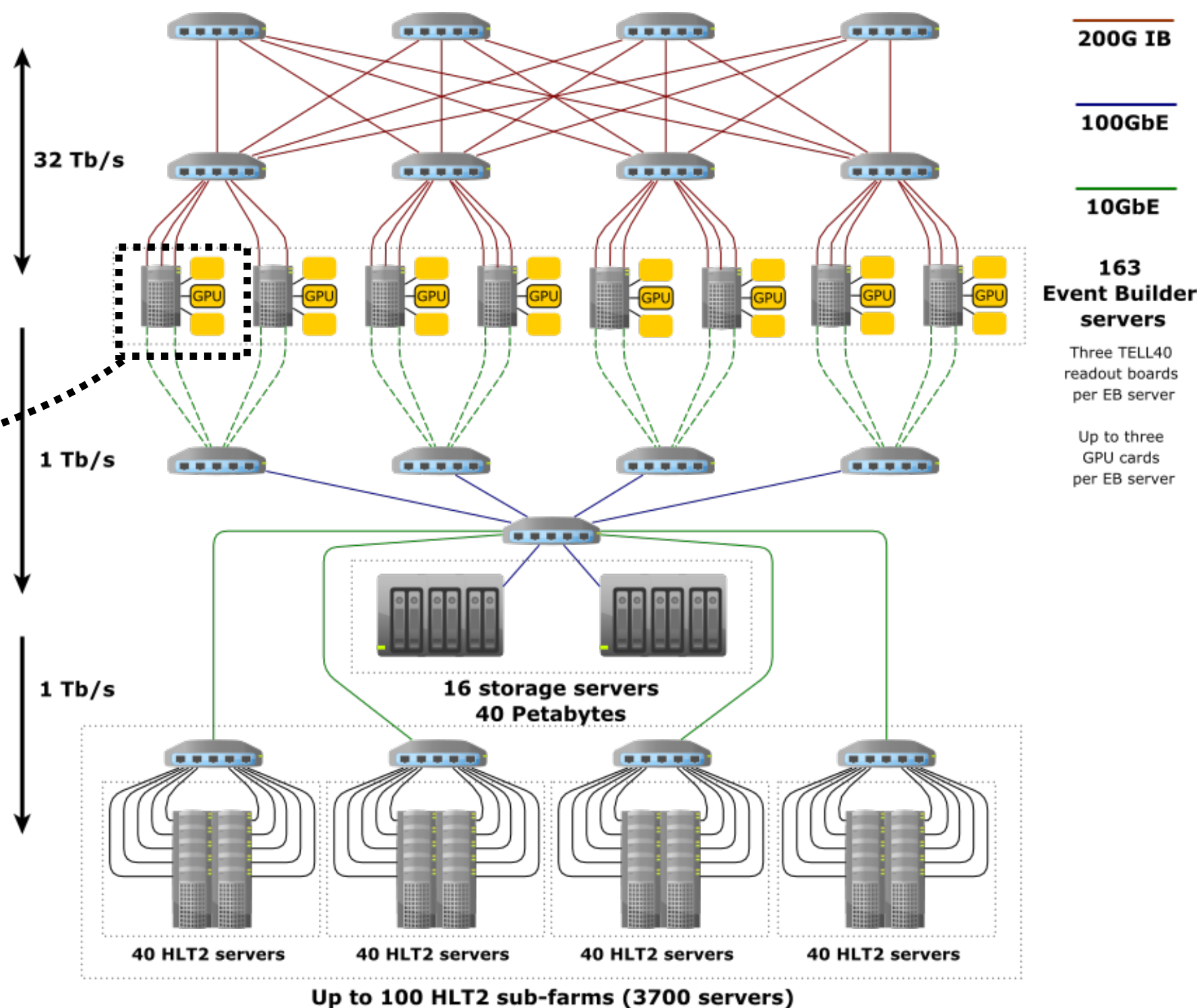
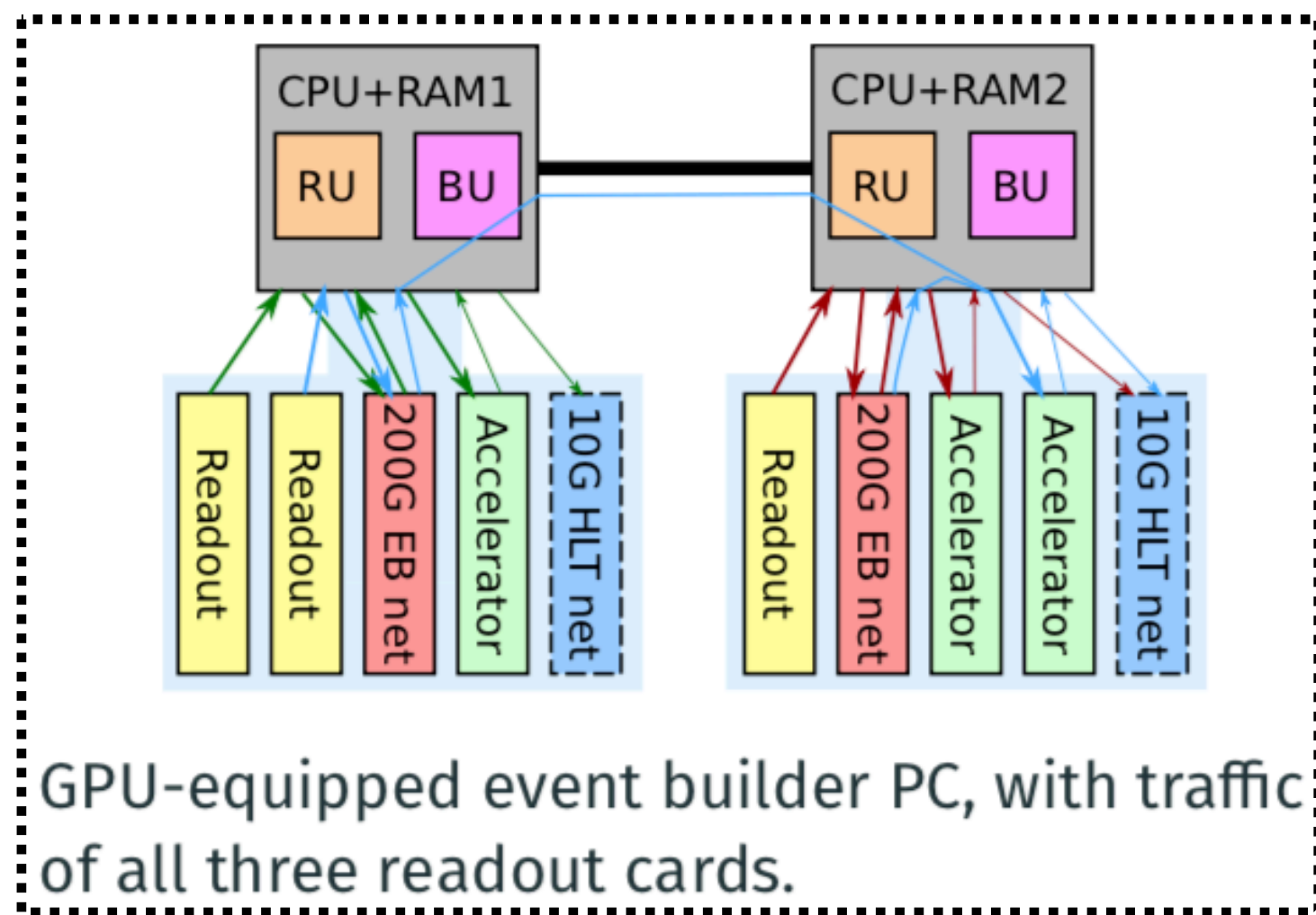


Real-time analysis @ LHCb in Run 3

LHCb Run 3 dataflow

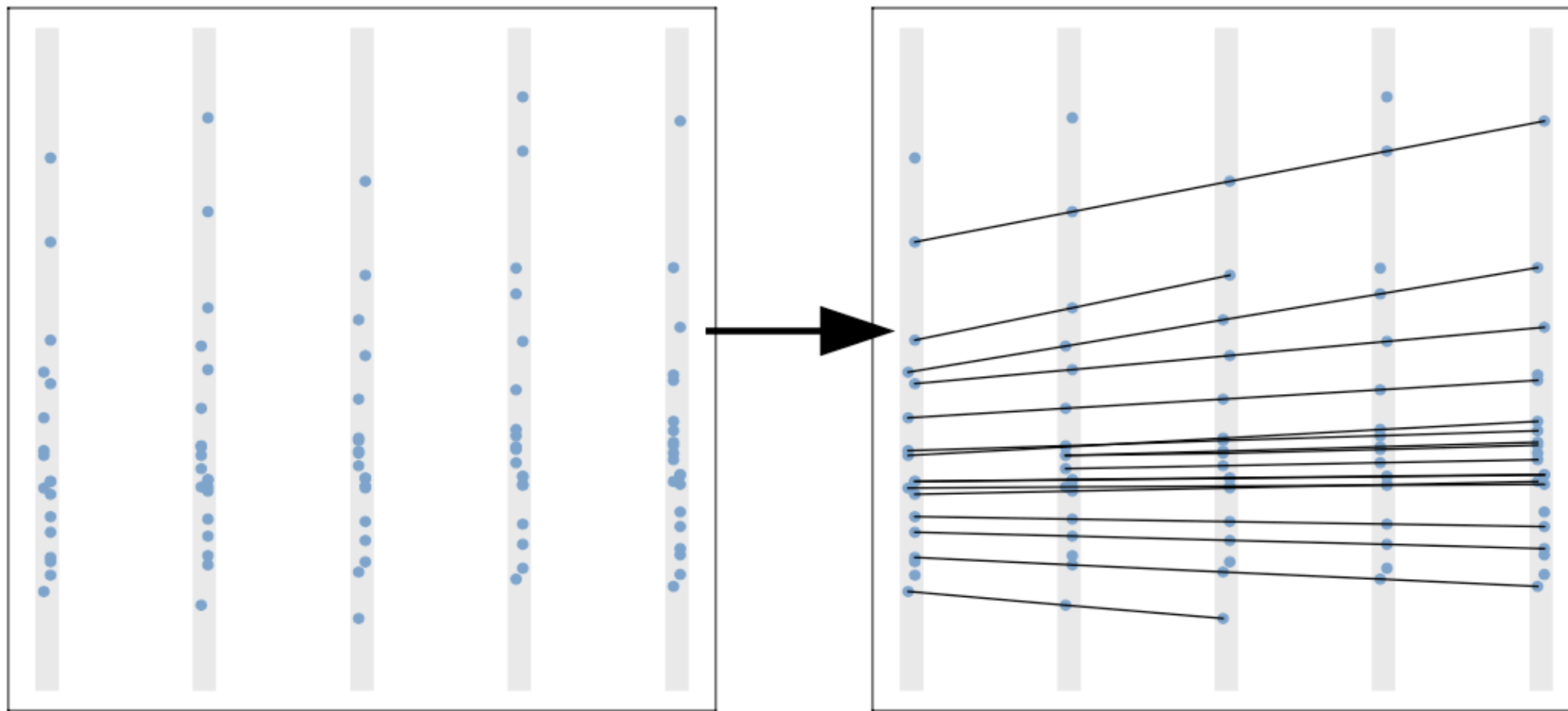


LHCb Run 3 online processing

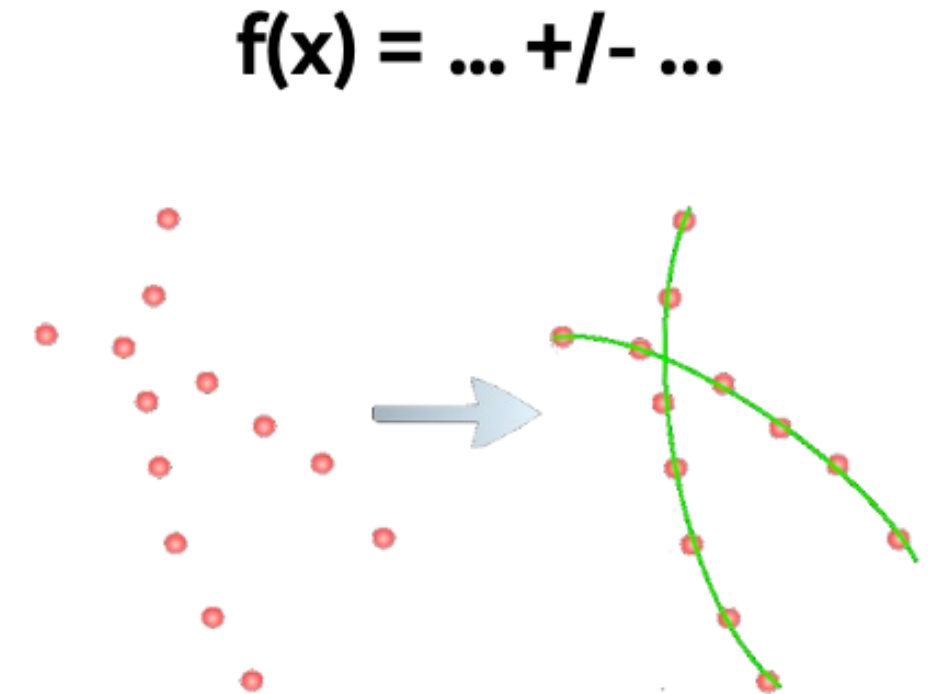


Why a GPU tracking trigger?

Pattern recognition: inherently parallel!



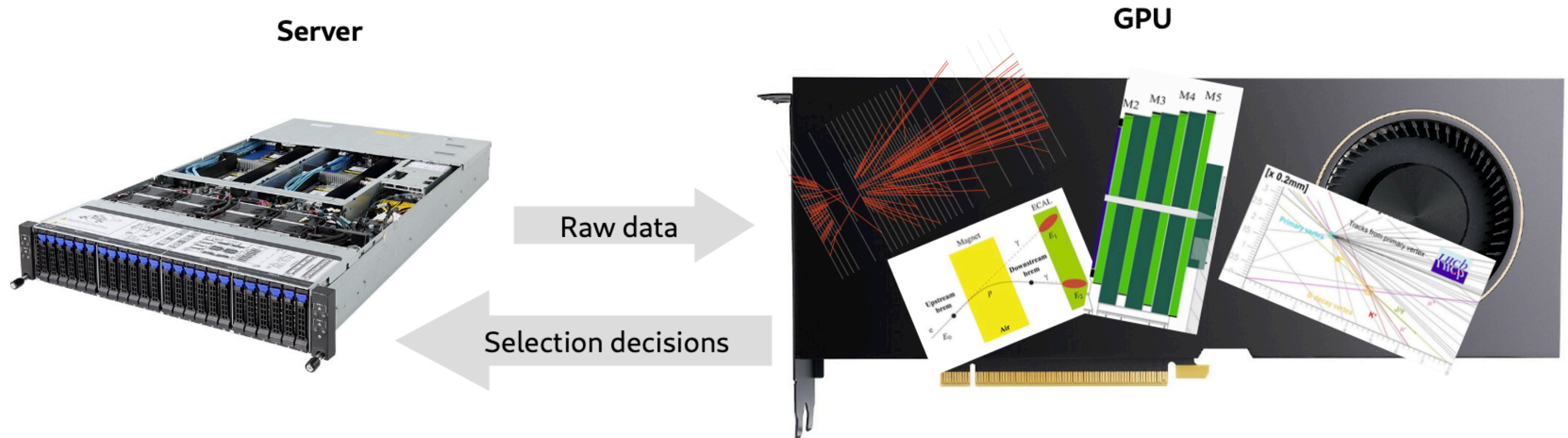
Track fit: mix of serial and parallel



Why is HLT1 a good fit for GPUs?

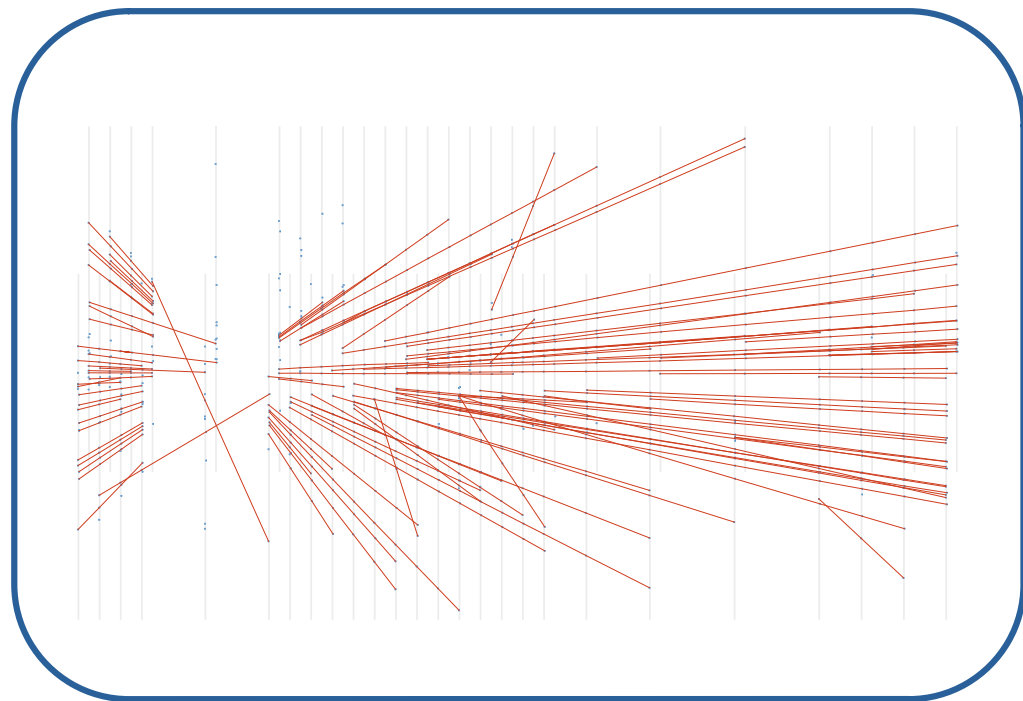
Characteristics of LHCb HLT1	Characteristics of GPUs
Intrinsically parallel problem: - Run events in parallel - Reconstruct tracks in parallel	Good for - Data-intensive parallelizable applications - High throughput applications
Huge compute load	Many TFLOPS
Full data stream from all detectors is read out → no stringent latency requirements	Higher latency than CPUs, not as predictable as FPGAs
Small raw event data (~100 kB)	Connection via PCIe → limited I/O bandwidth
Small event raw data (~100 kB)	Thousands of events fit into O(10) GB of memory

Minimising copies to and from the GPU

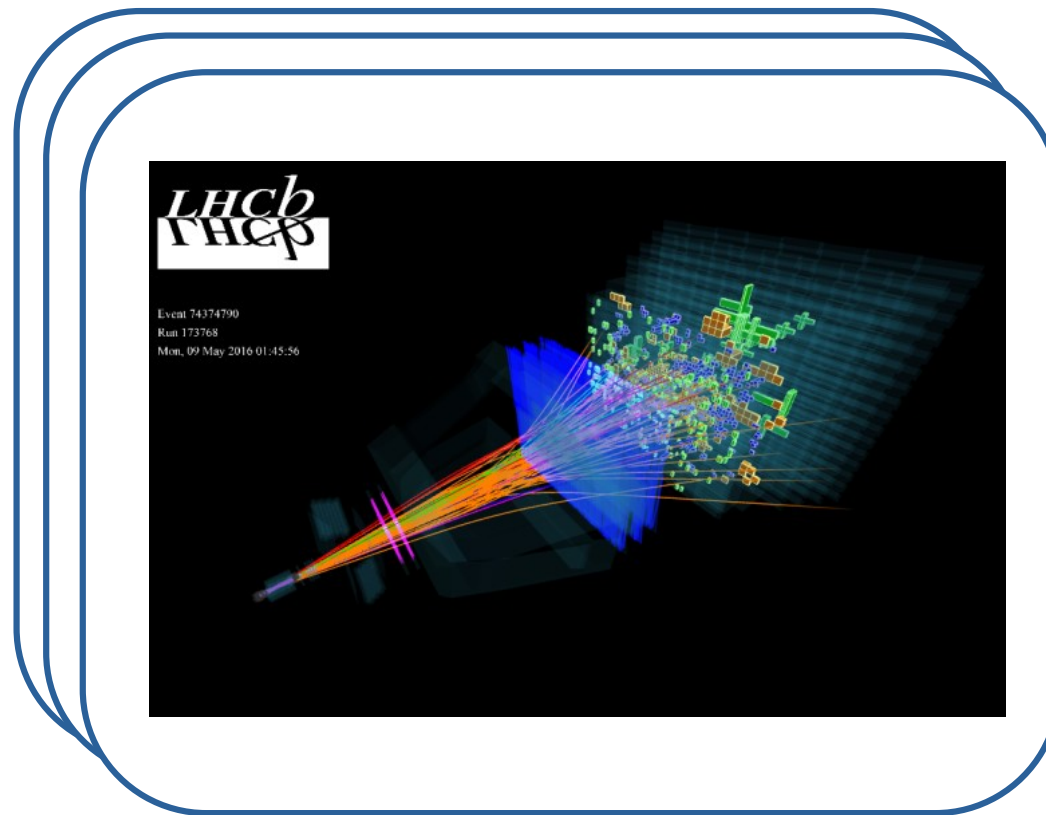


Three levels of parallelisation

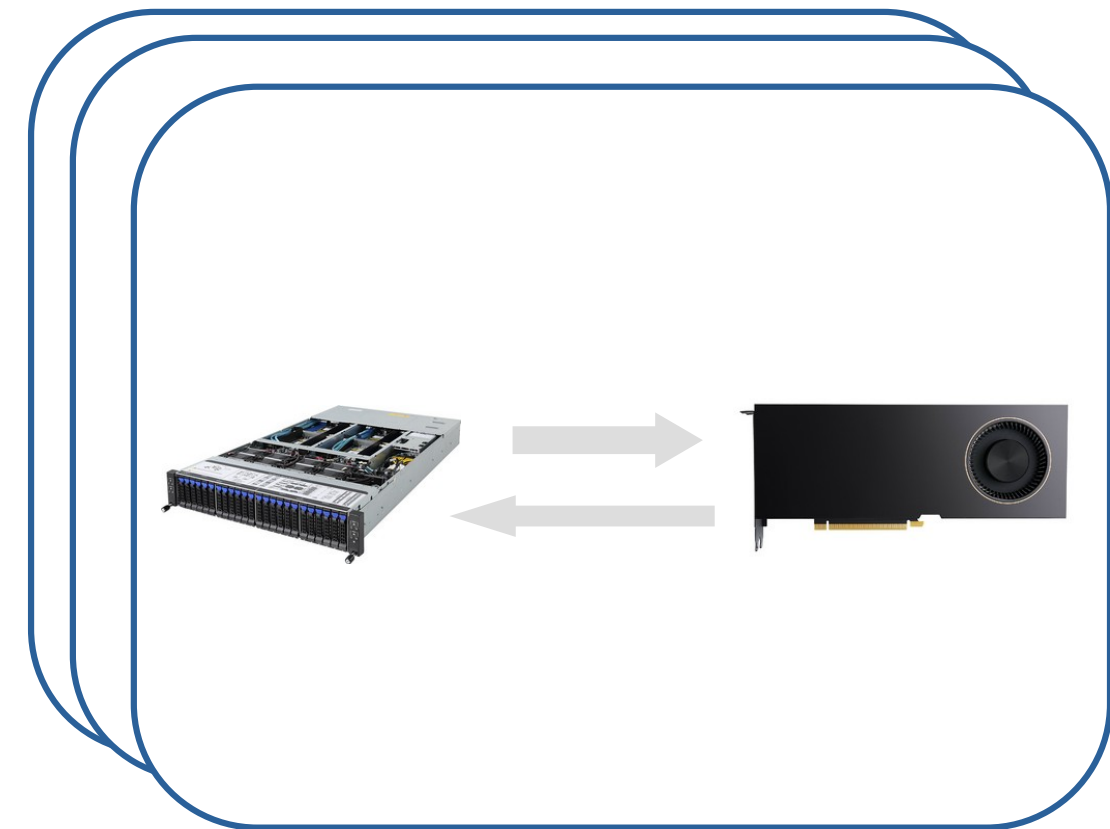
Intra-event: Tracks, vertices, ...



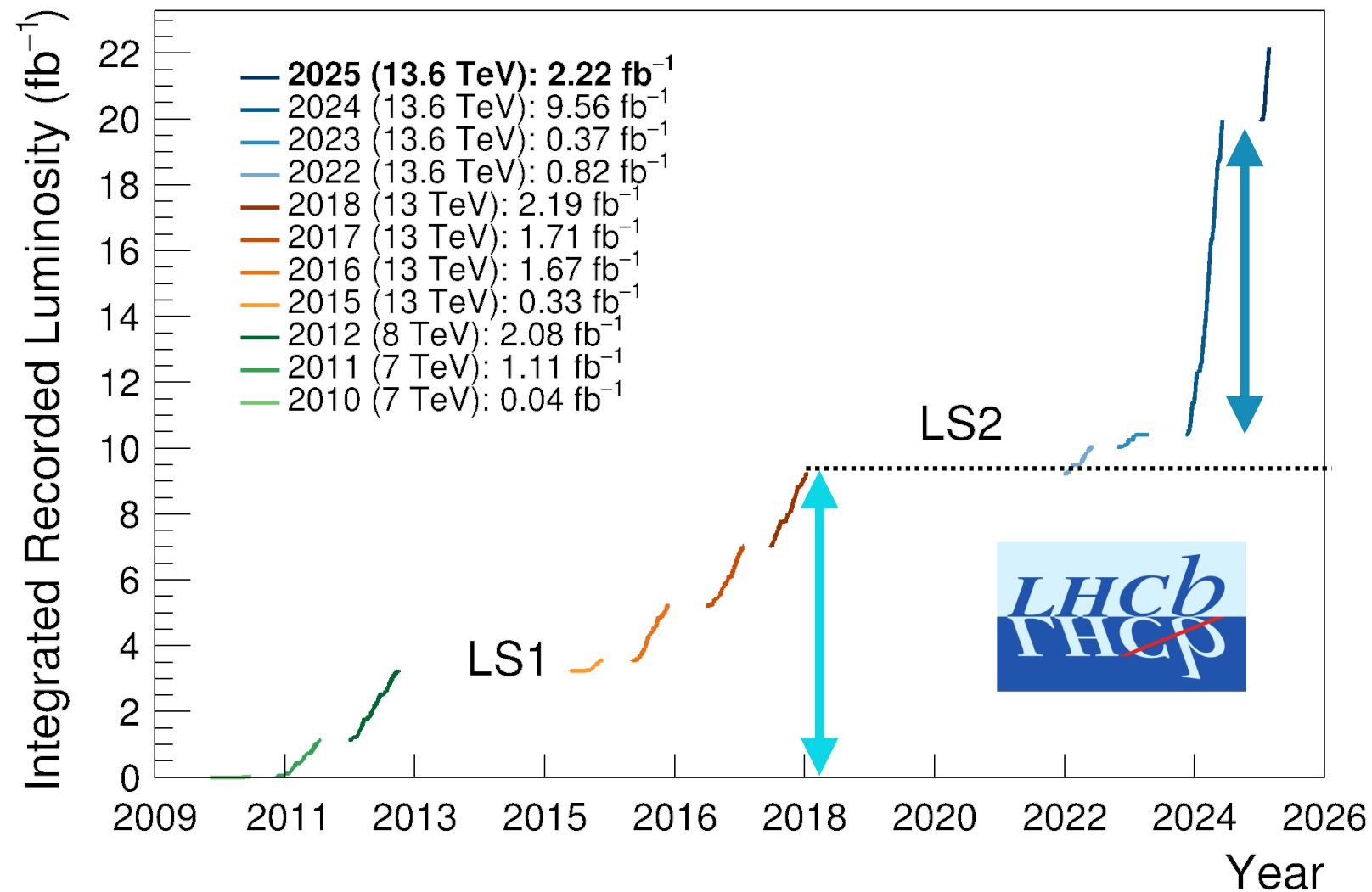
Events



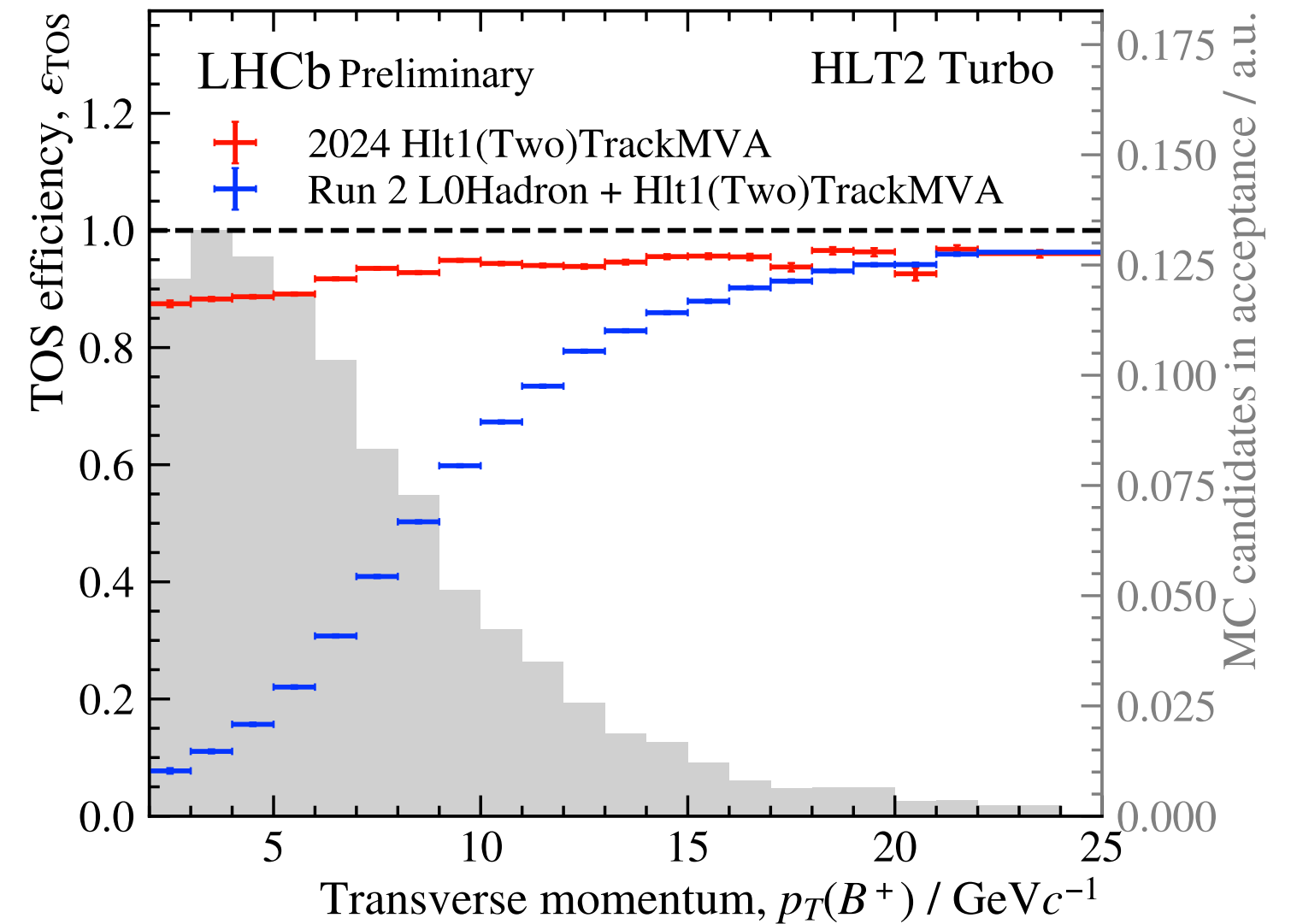
Event batches



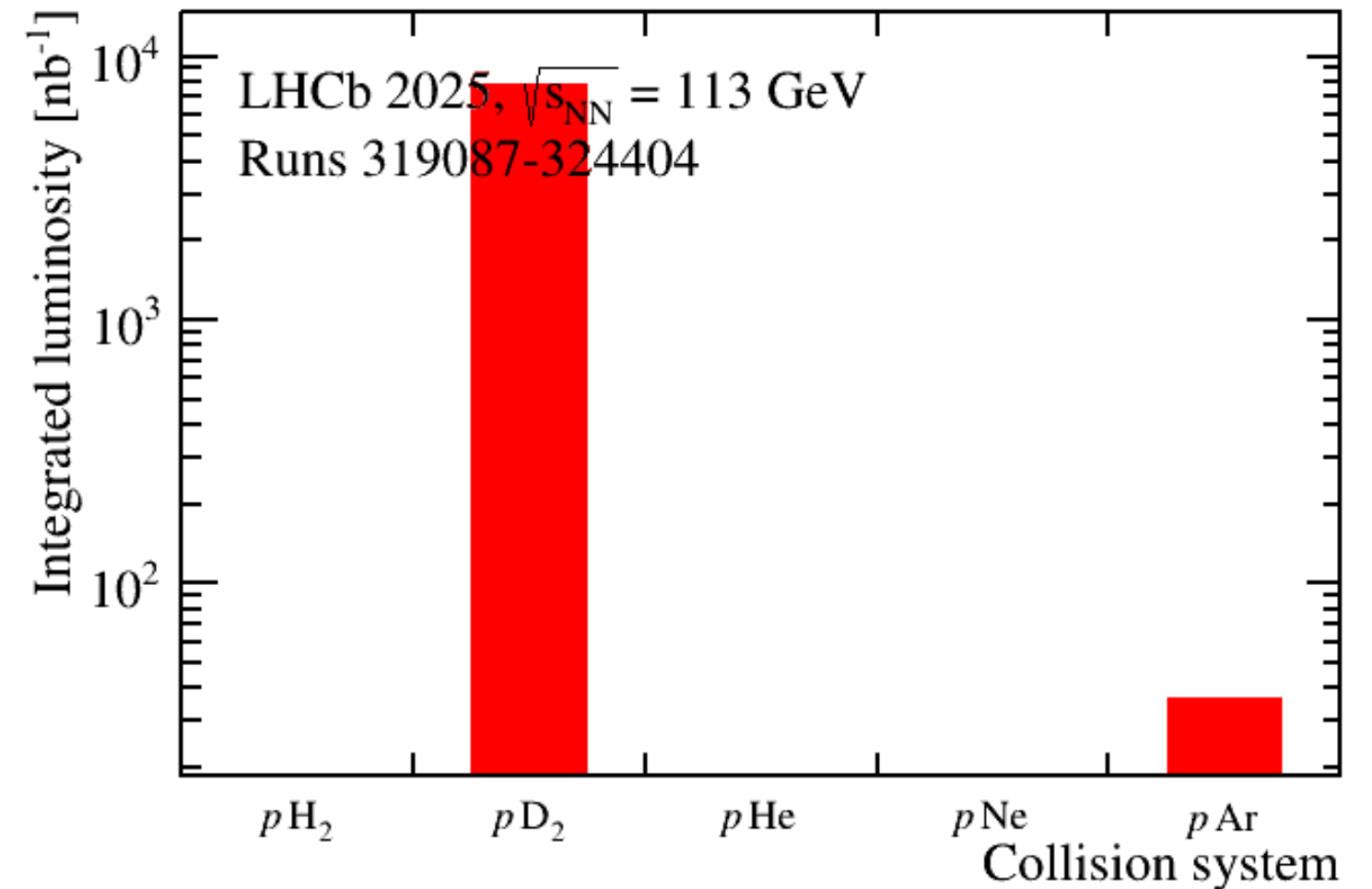
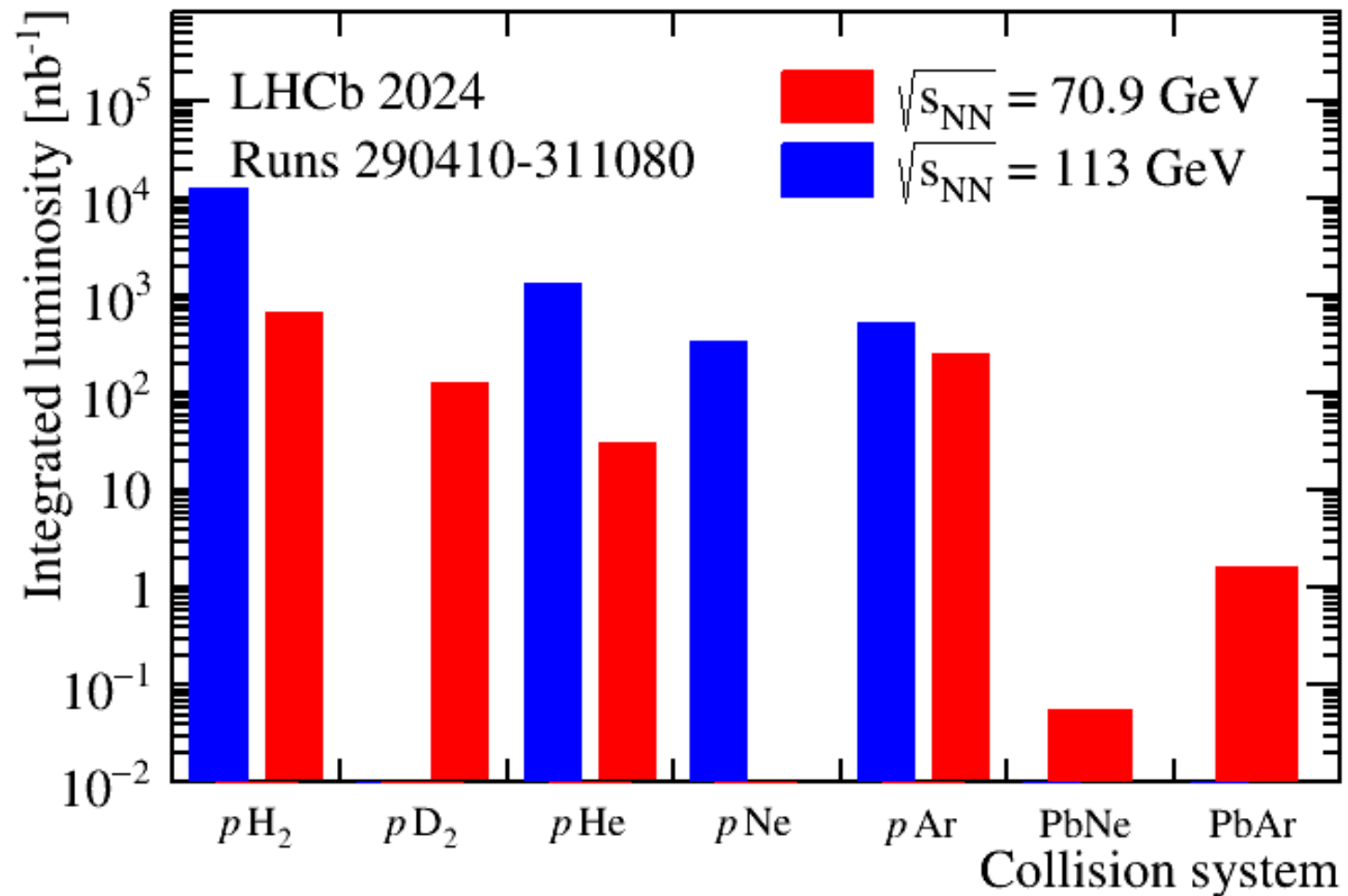
LHCb in Run 3: twice doubled data



LHCb-FIGURE-2024-030



LHCb in Run 3: collider and fixed target!

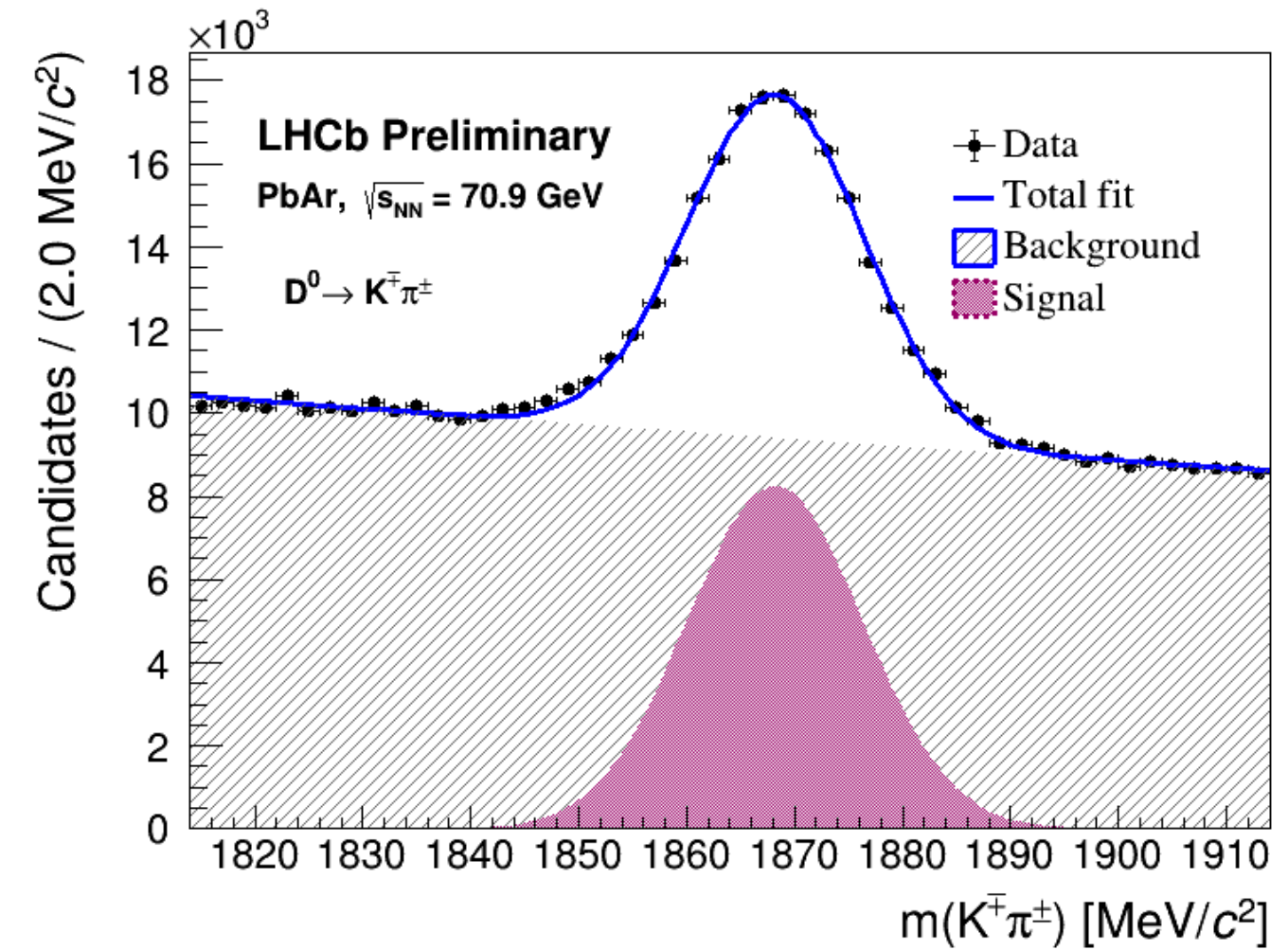
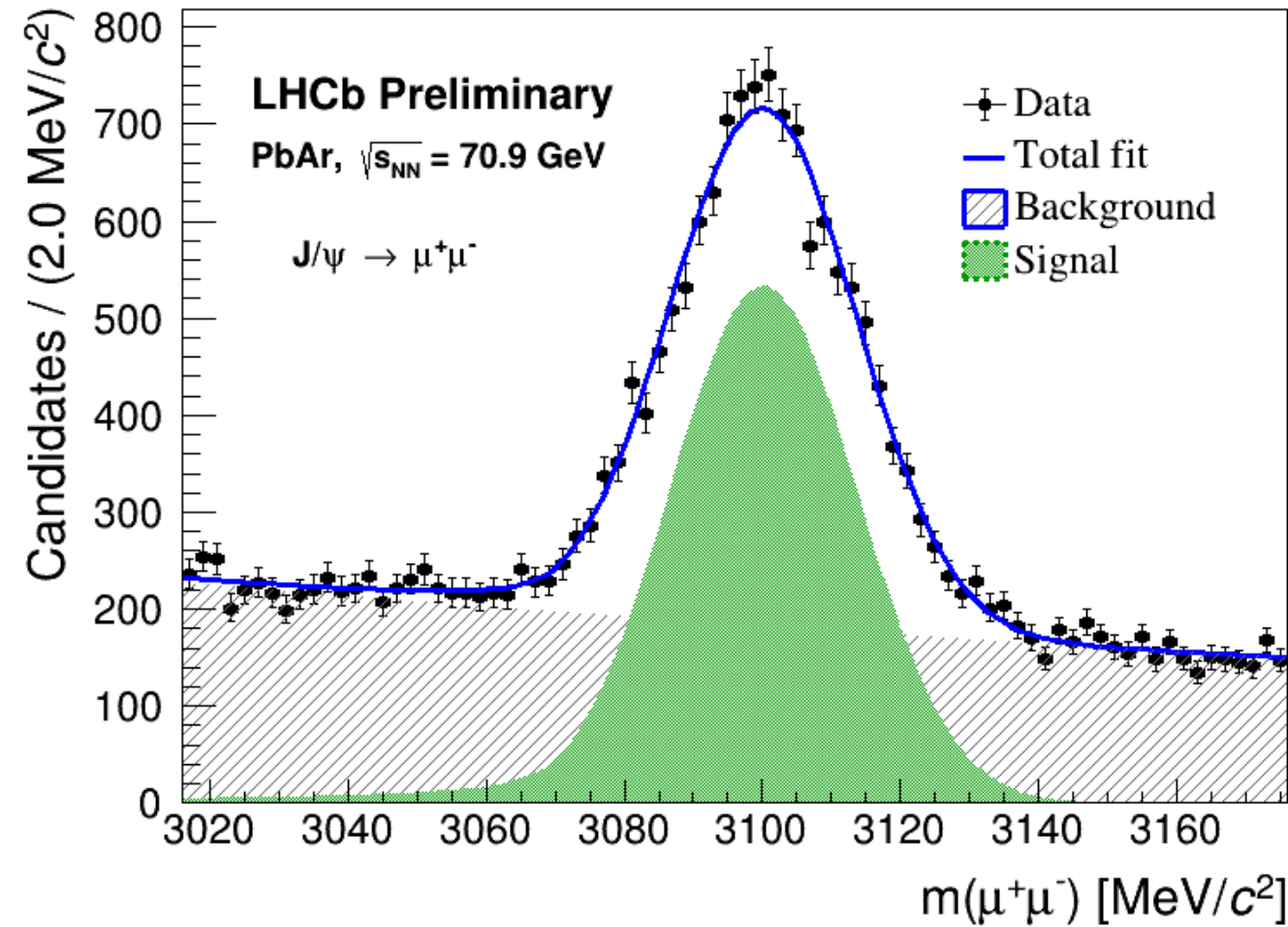


LHCb is both a collider-mode and a fixed target experiment!

The success of the SMOG2 cell and the operational flexibility of the full software trigger enable LHCb to conduct a tremendously broad program of fixed-target physics

Lead fixed-target signals in Run 3 data

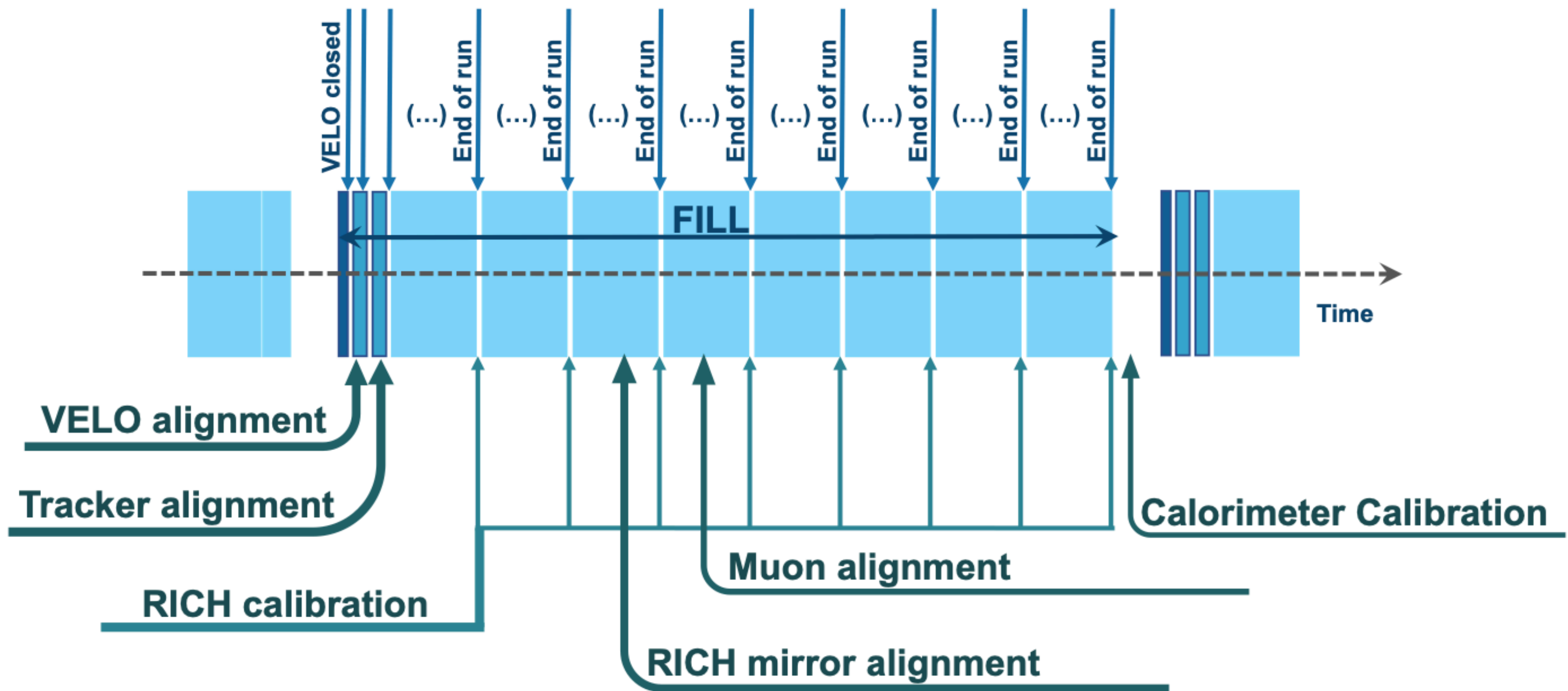
LHCb-FIGURE-2025-014



Efficient reconstruction of PbAr signals at $\sqrt{s}=70.9$ GeV

Cross-section measurements with this and other configurations are on their way

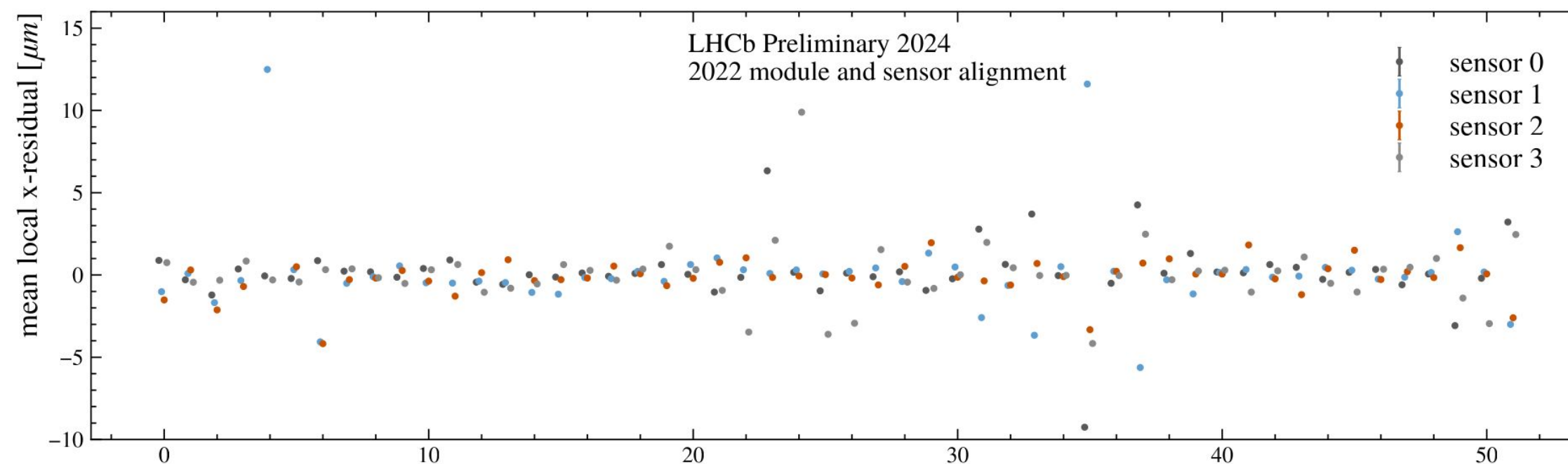
LHCb calibration in Run 3



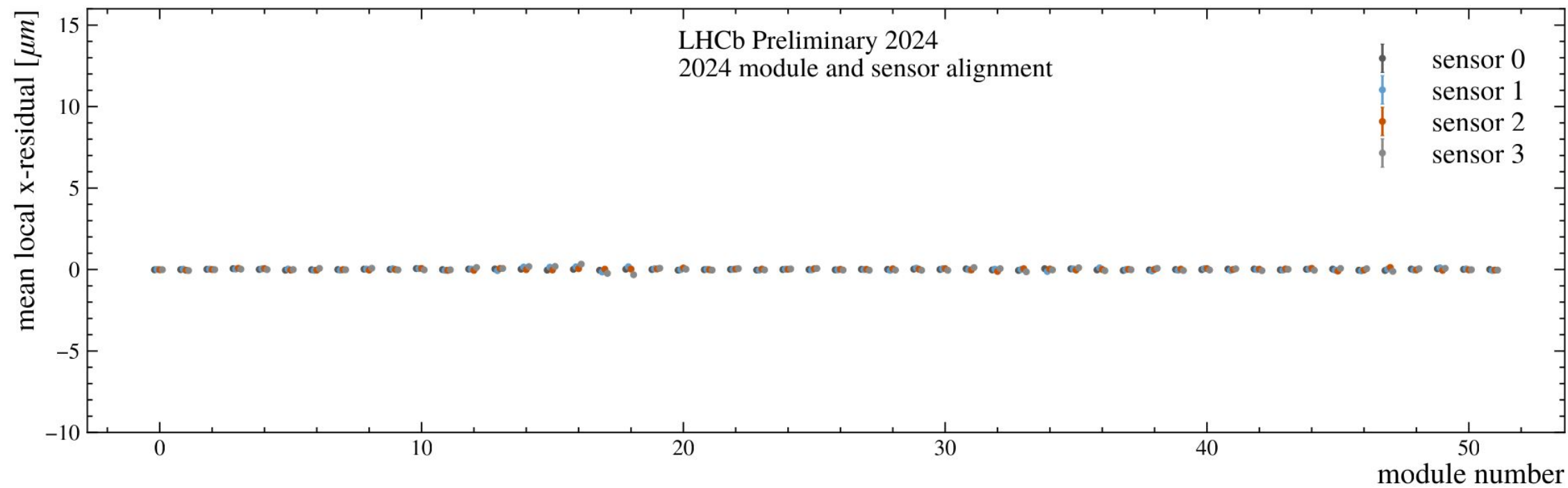
VELO alignment in Run 3

LHCb-FIGURE-2024-009

Before alignment



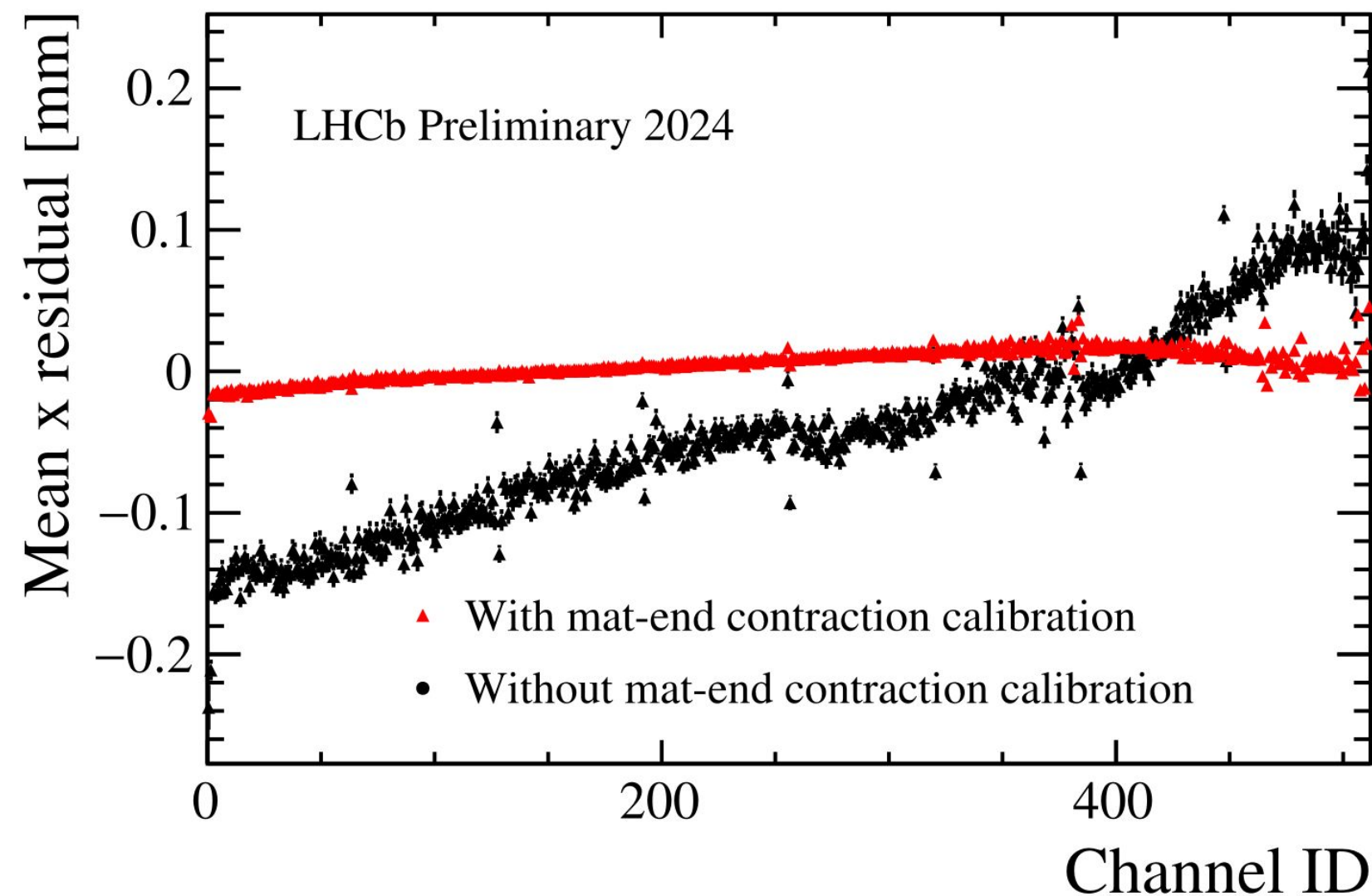
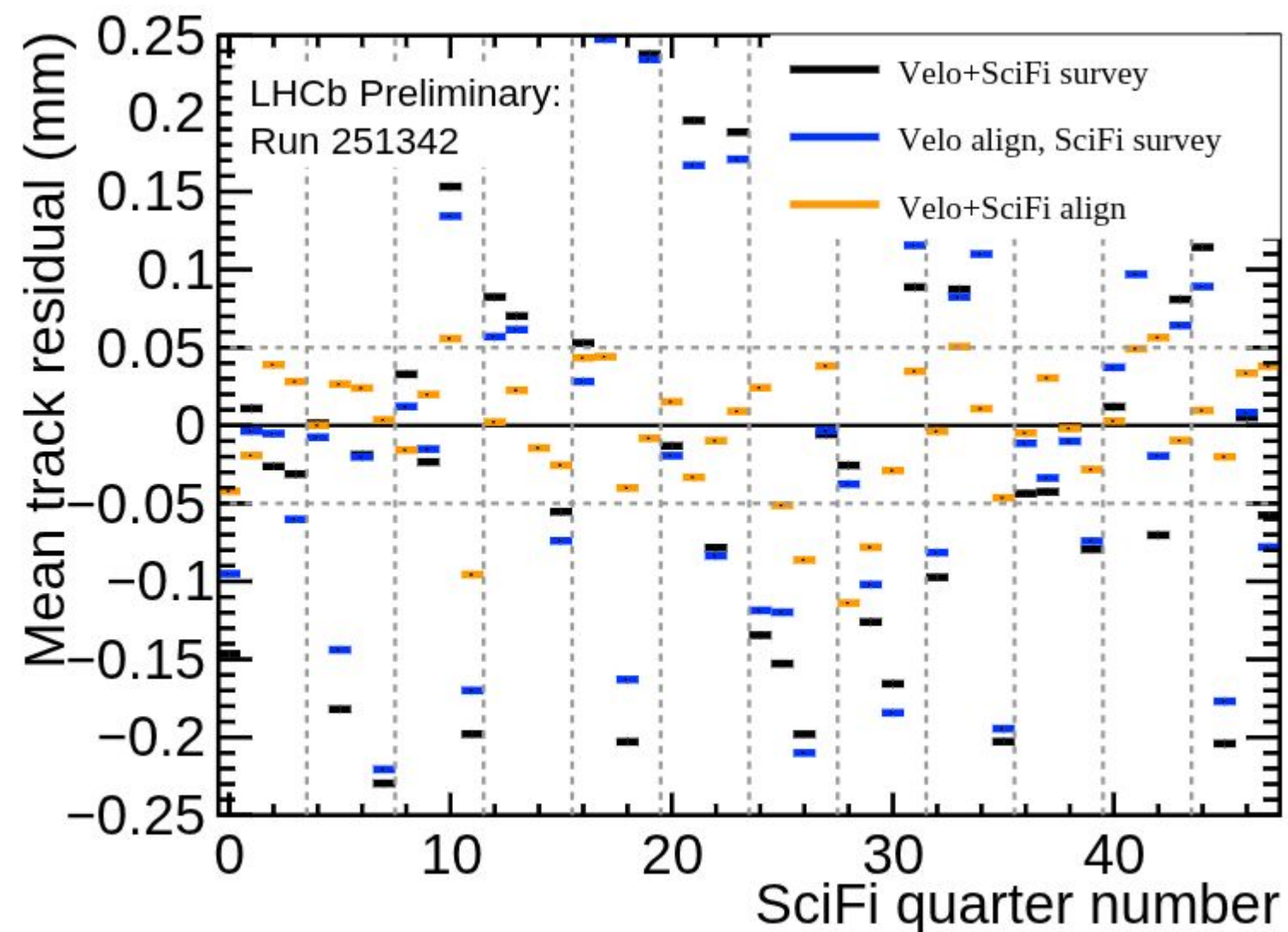
After alignment



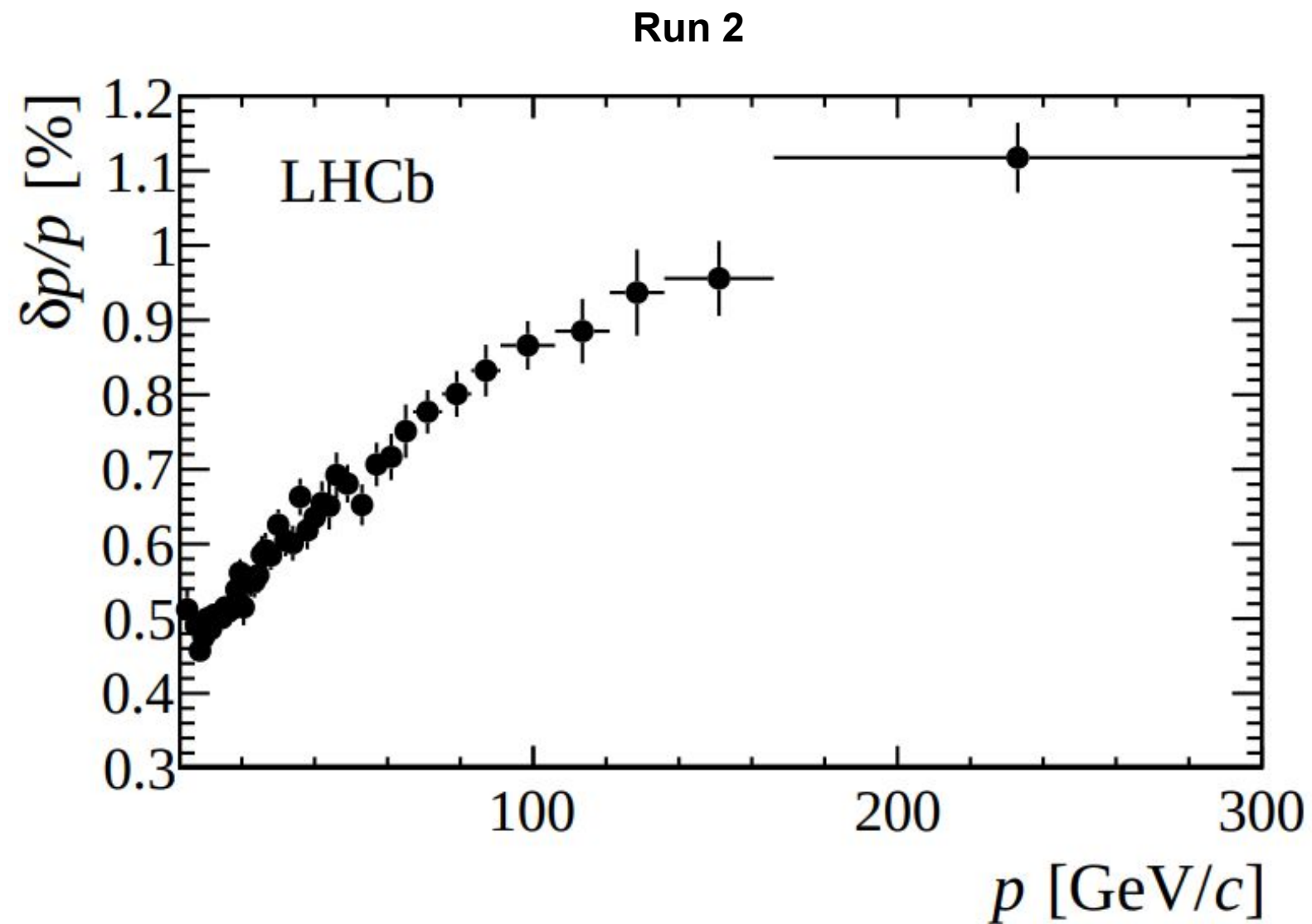
Tracker alignment in Run 3

LHCb-FIGURE-2022-018

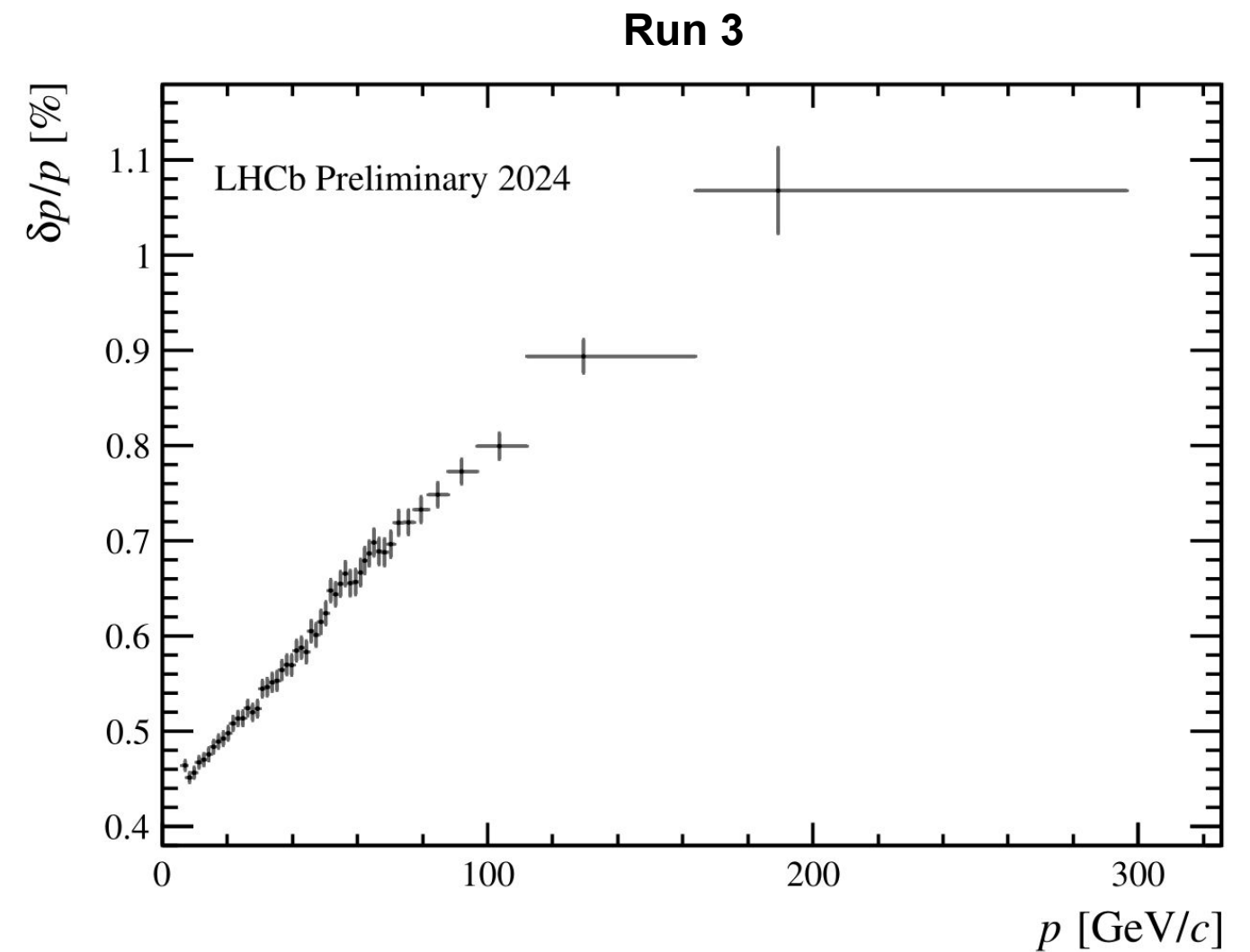
LHCb-FIGURE-2024-009



Aligned momentum resolution in Run 3



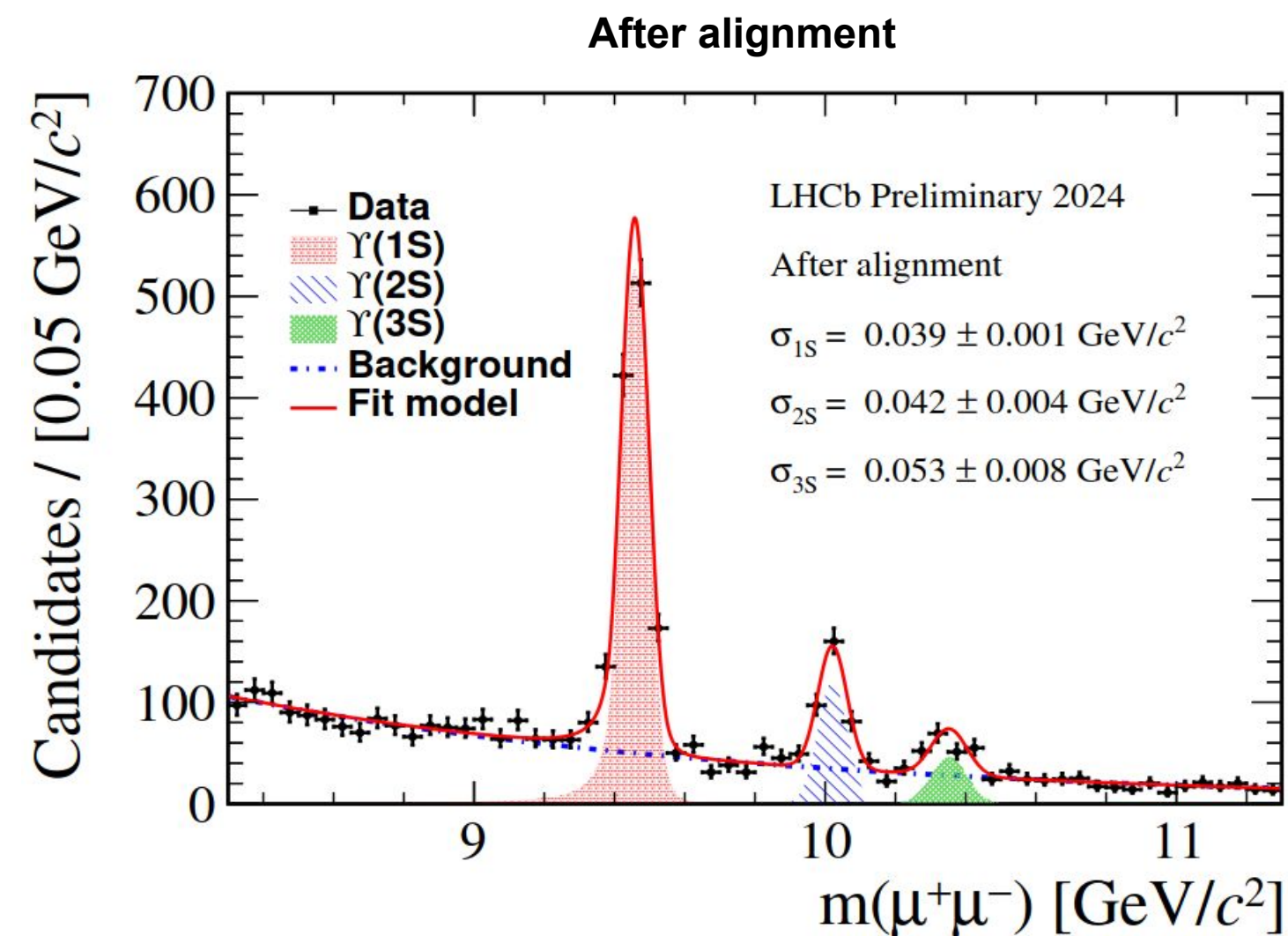
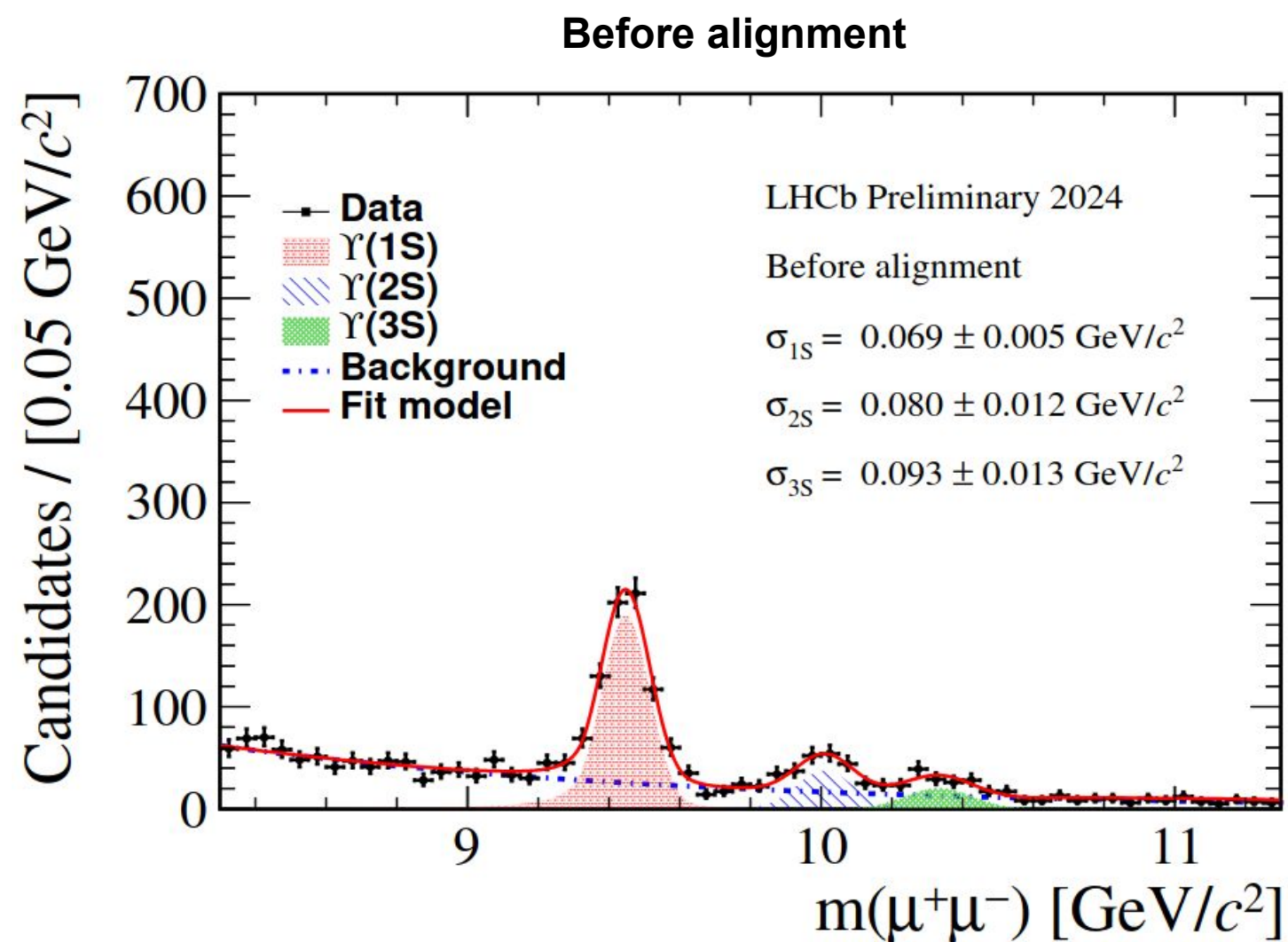
[Int. J. Mod. Phys. A 30 1530022 (2015)]



[LHCb-FIGURE-2024-040]

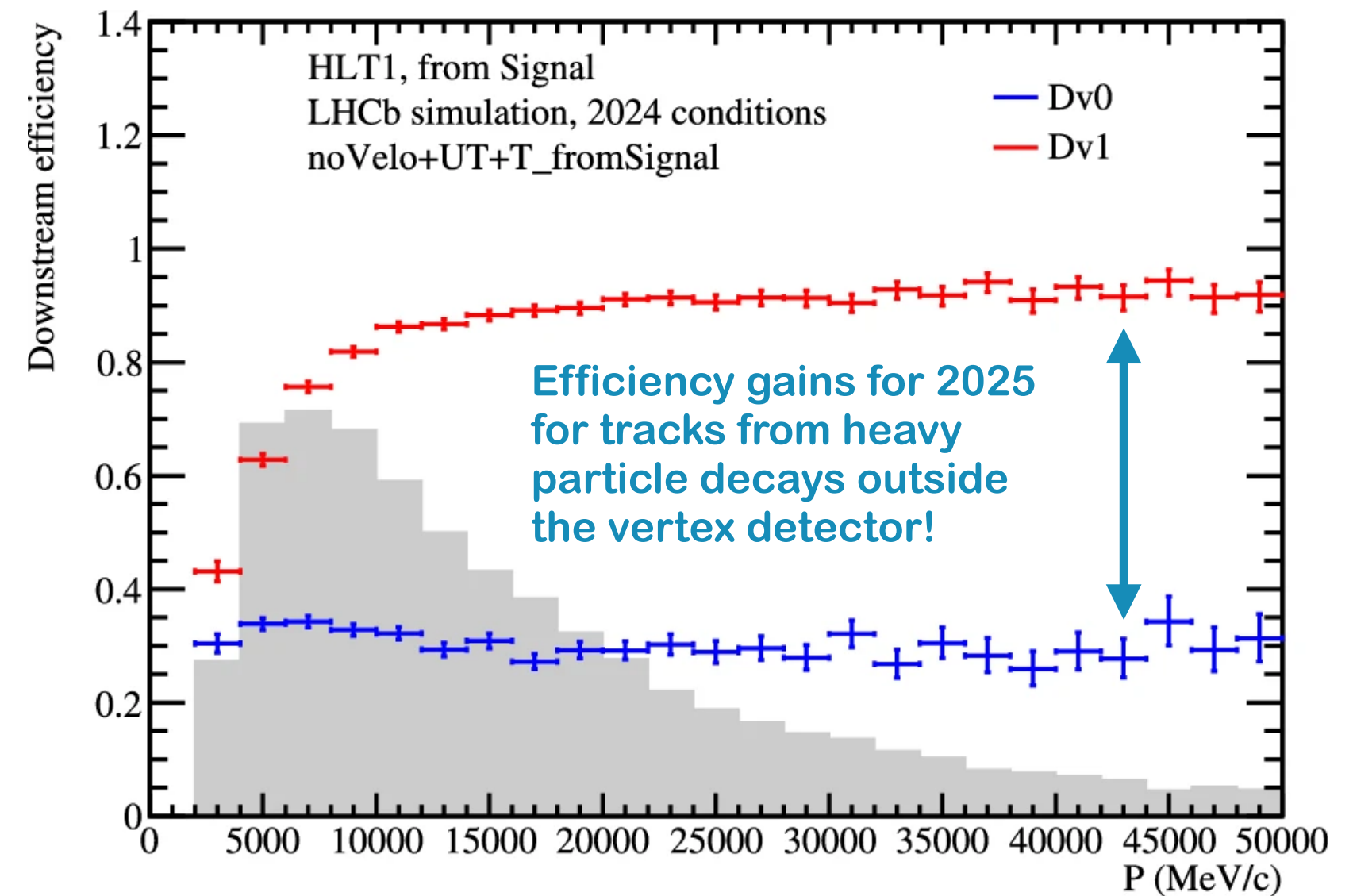
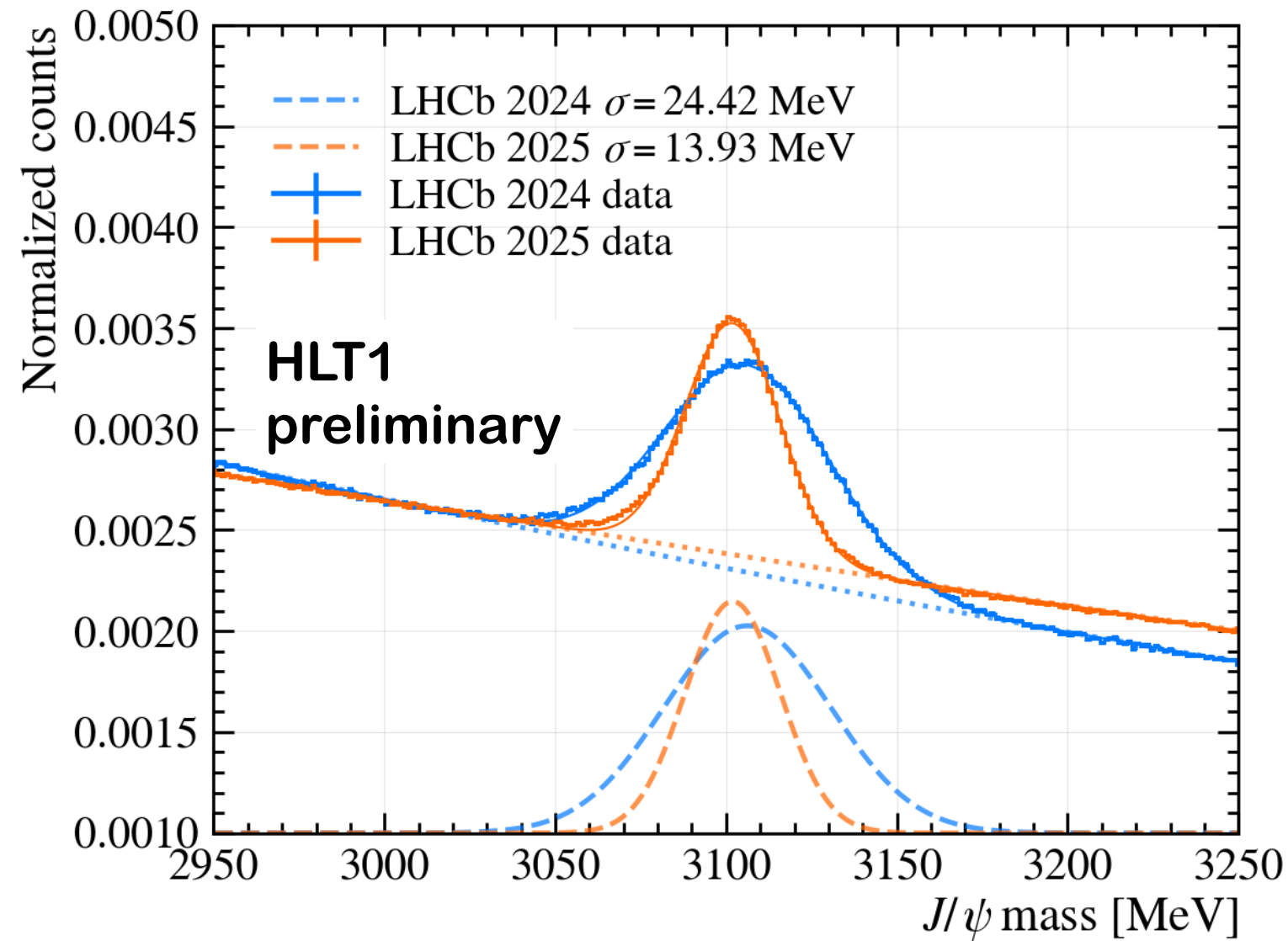
Impact on mass resolutions

LHCb-FIGURE-2024-037



Towards a full 30 MHz reconstruction

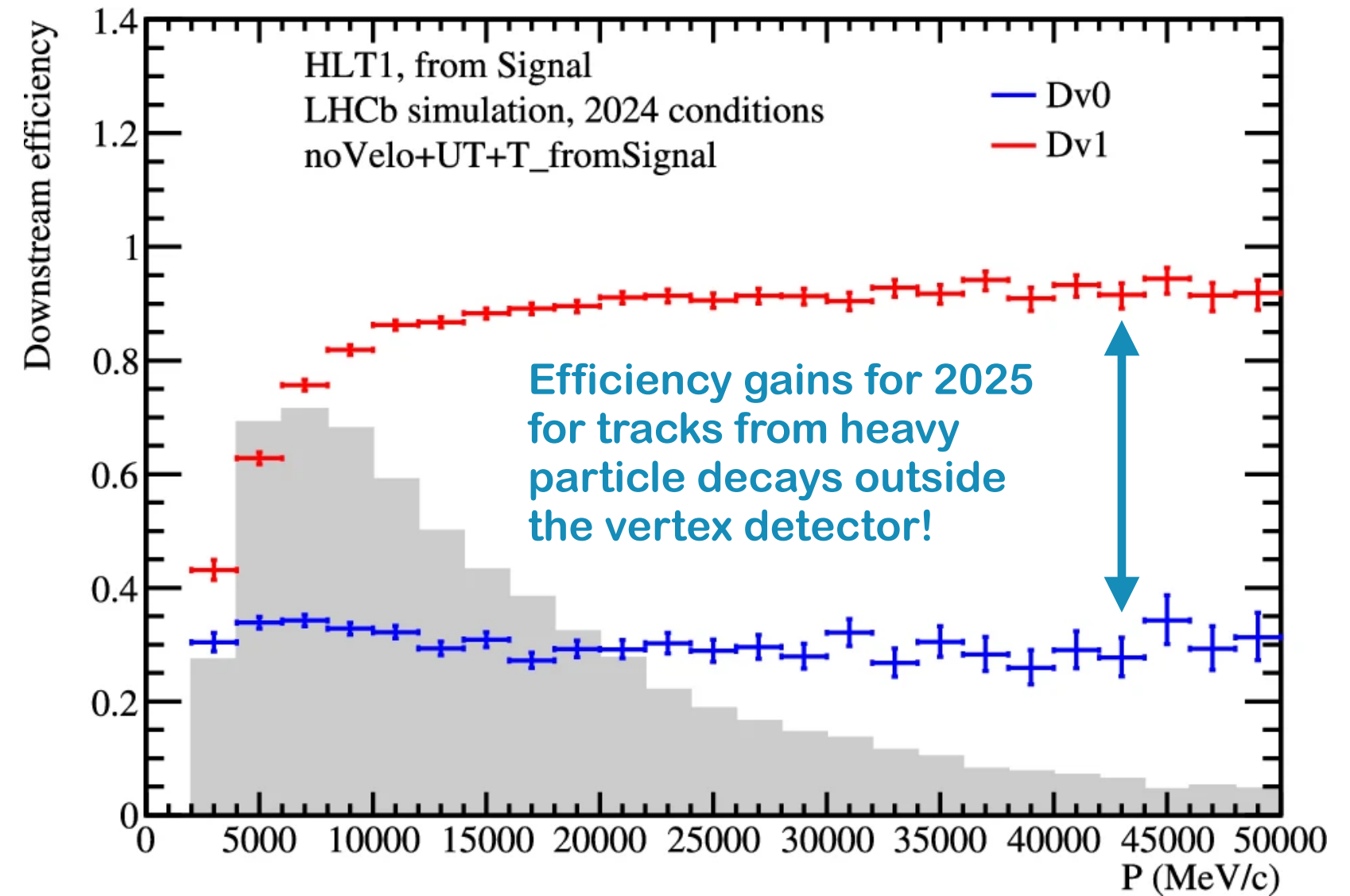
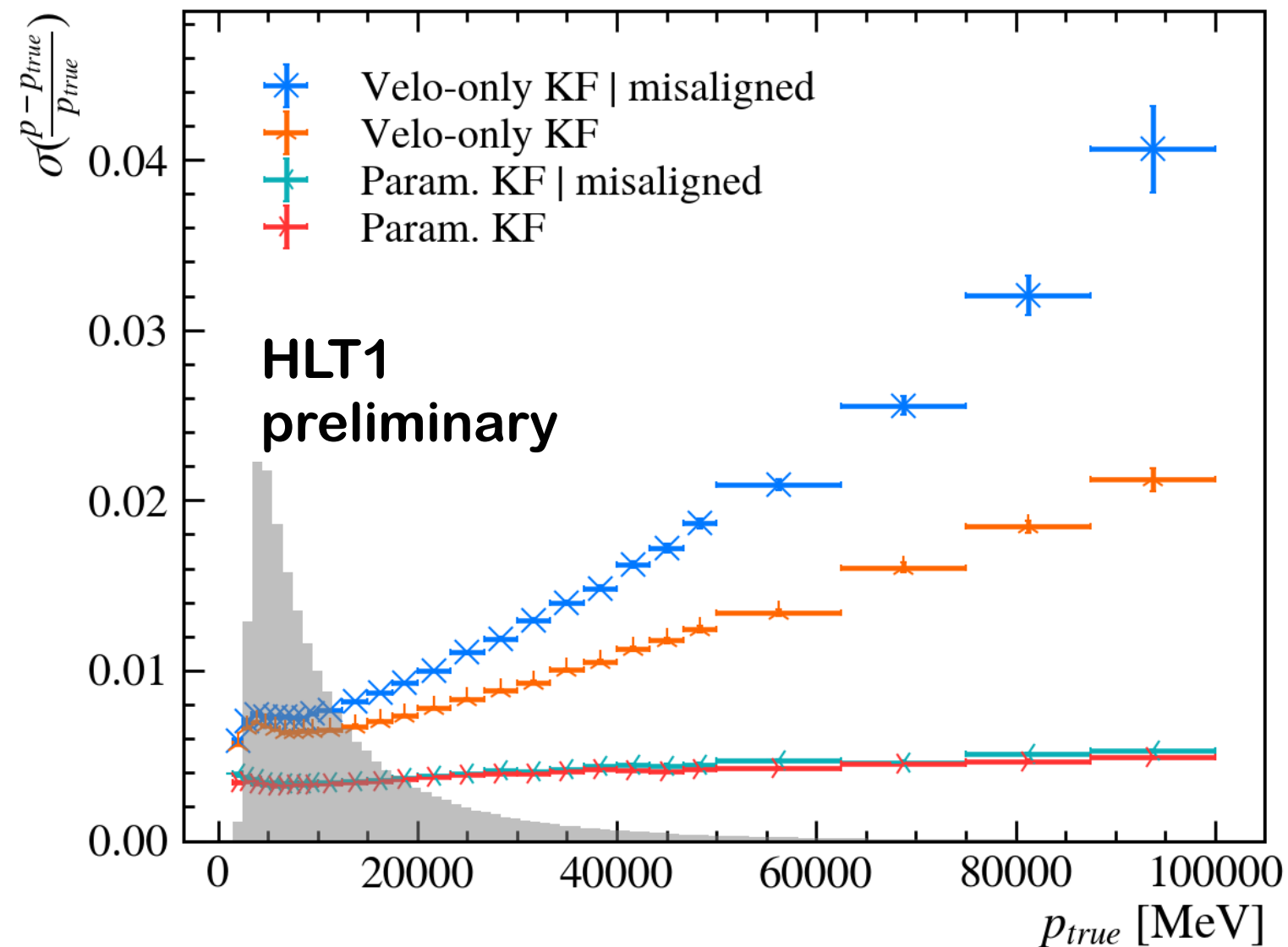
[Kholoimov et al. CSBS Volume 9, article number 10, \(2025\)](#)



We now reconstruct tracks originating anywhere in the detector and Kalman fit them at 30 MHz
Together with CALO and Muon ID goes far beyond TDR design! Cost neutral because of GPUs.
Achieved by delivering a production-grade heterogeneous framework from scratch in 4 years.

Towards a full 30 MHz reconstruction

[Kholoimov et al. CSBS Volume 9, article number 10, \(2025\)](#)

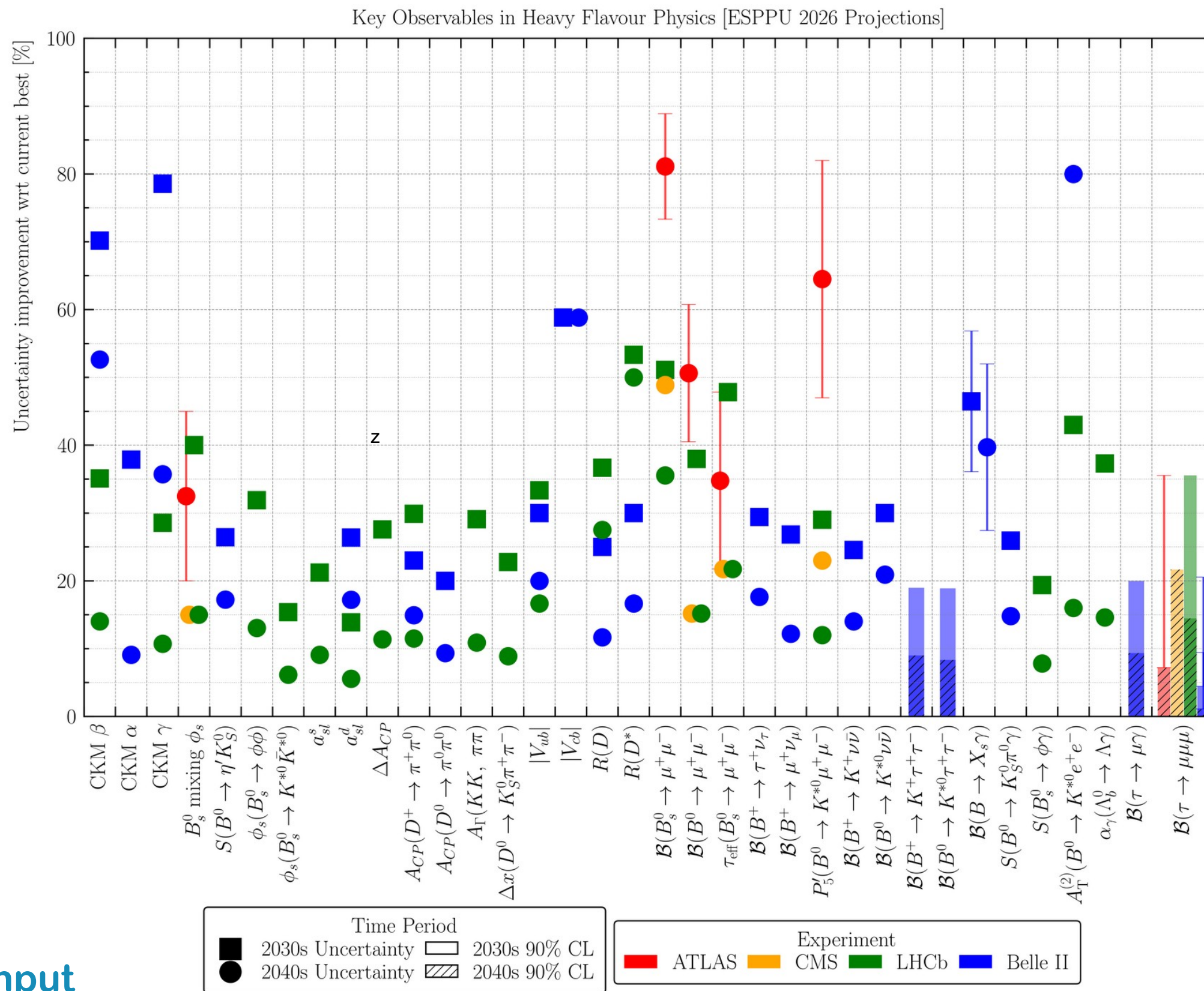


The parametrised Kalman filter also makes HLT1 more robust against detector misalignments

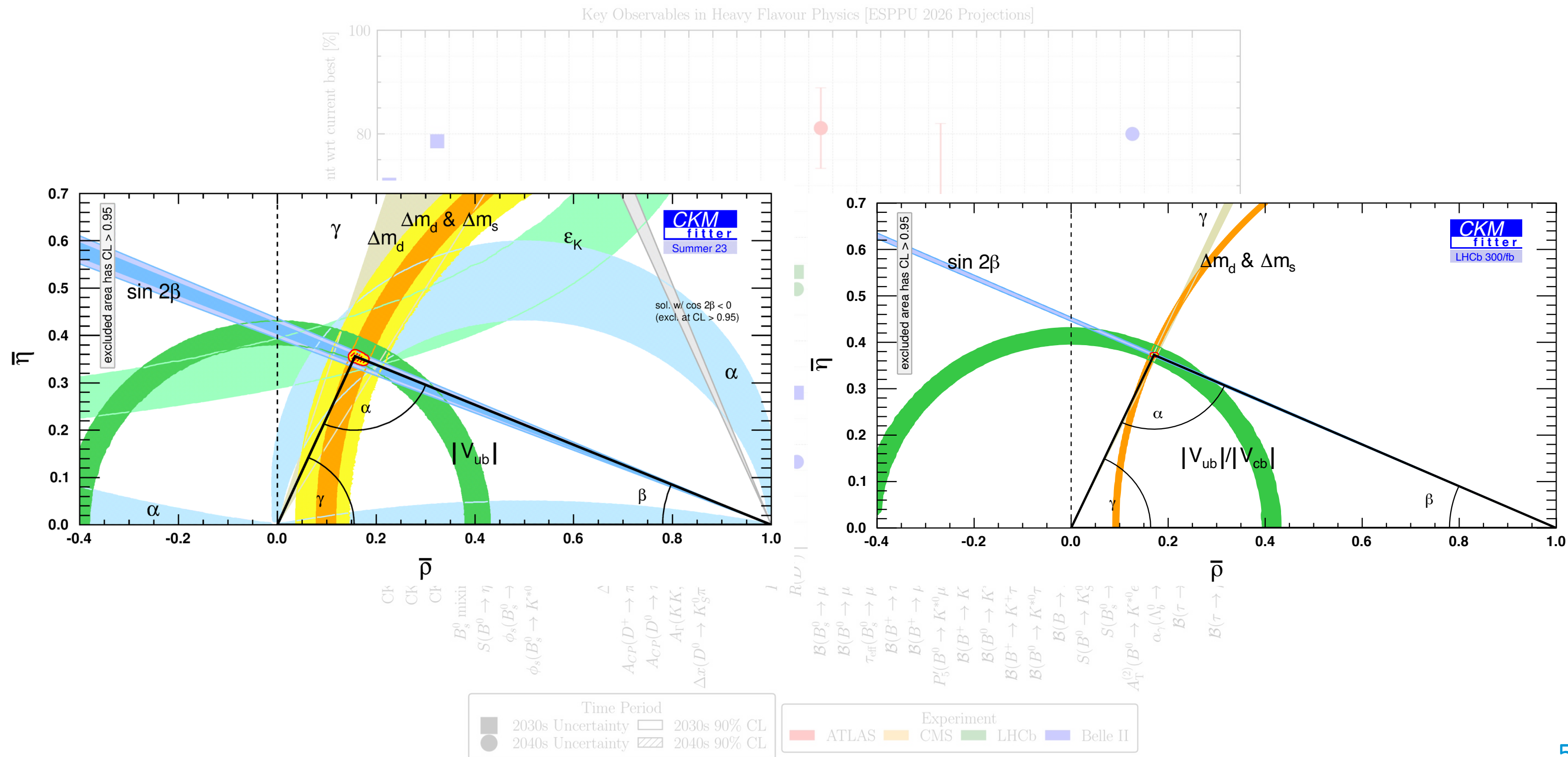
In continuity with a focus on robustness against changing detector conditions which has been a hallmark of LHCb's reconstruction and real-time processing since Run 1

Real-time analysis @ LHCb beyond Run 3

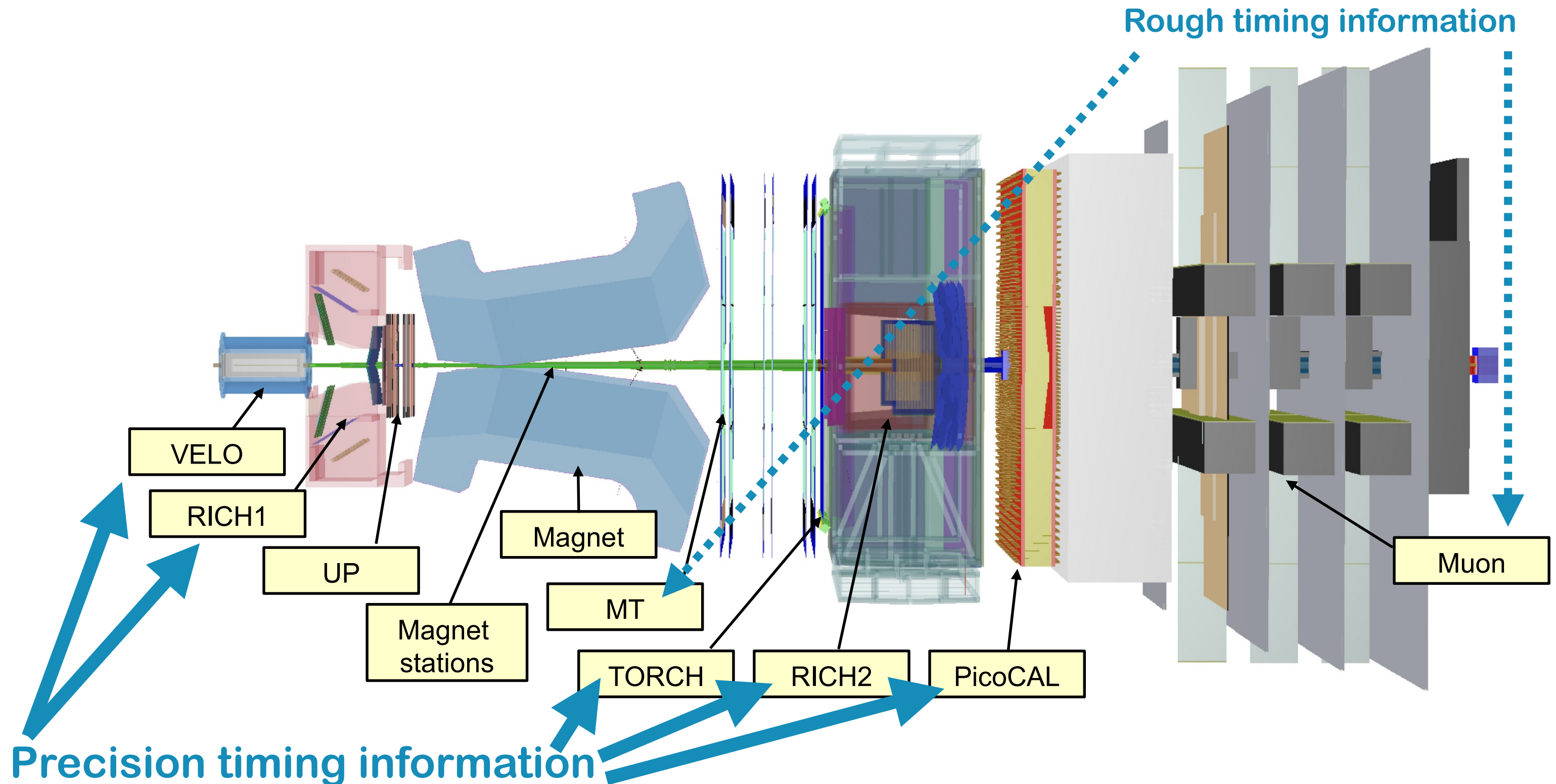
Why another LHCb upgrade?



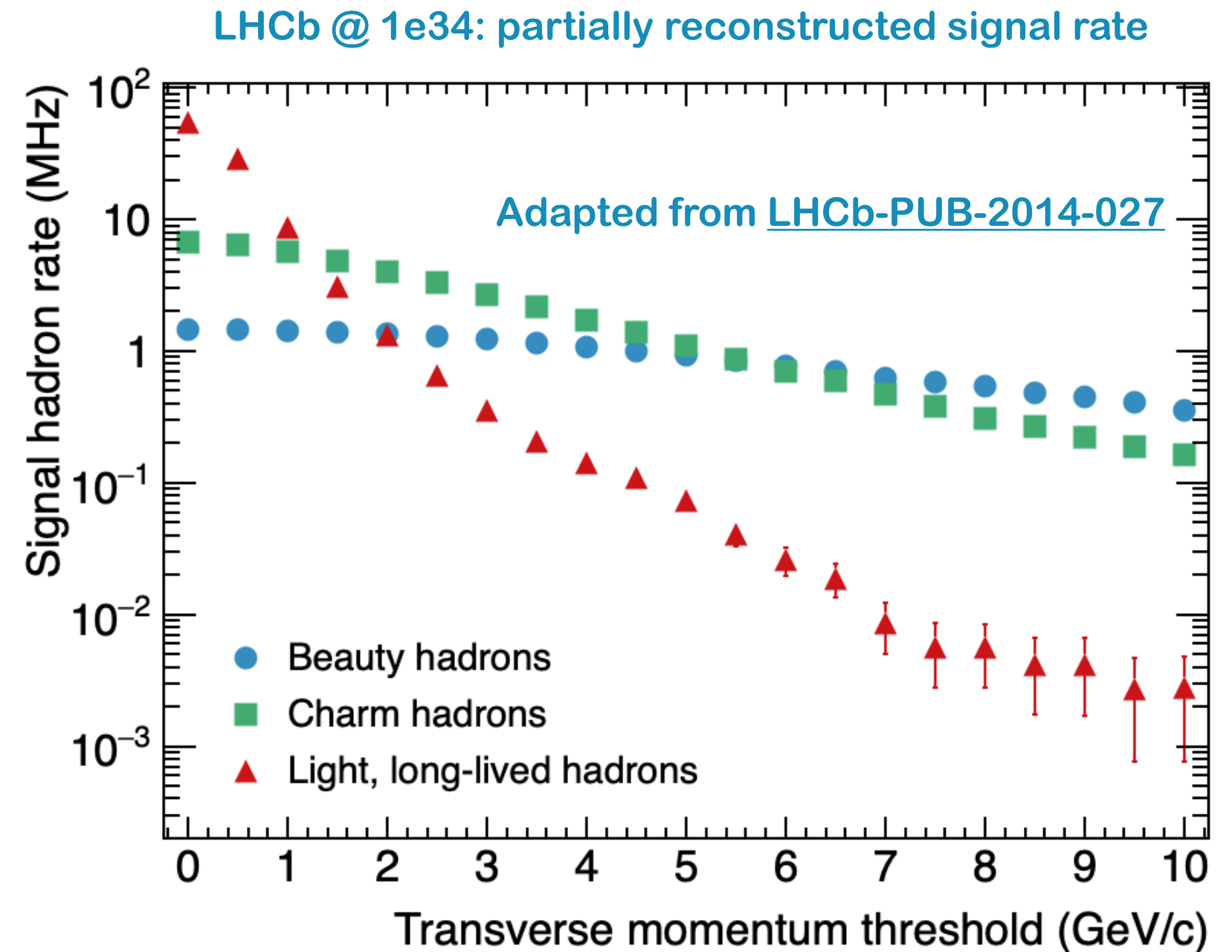
So why another LHCb upgrade?



LHCb U2: a four-dimensional detector



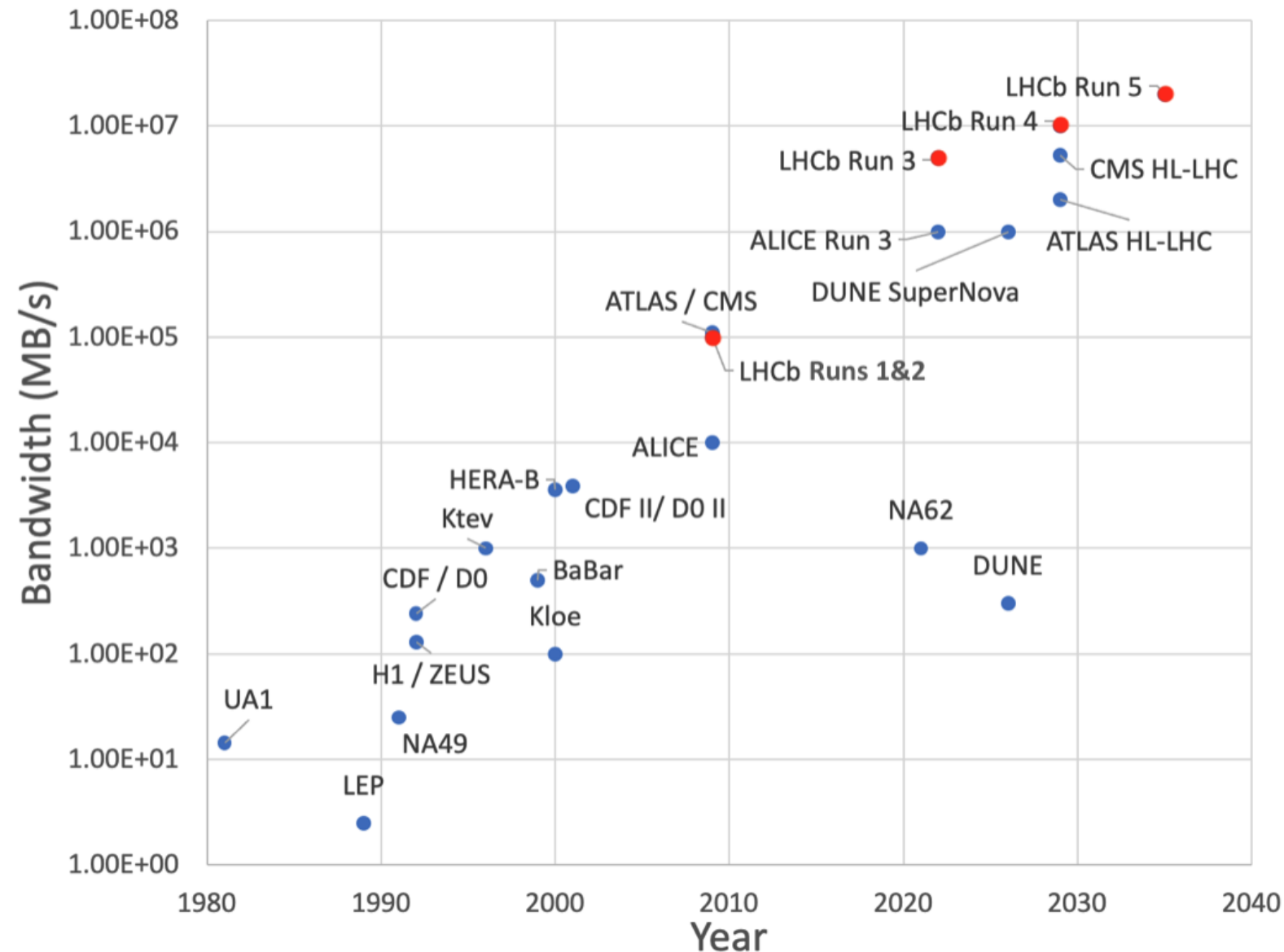
LHCb U2: DAQ & real-time analysis



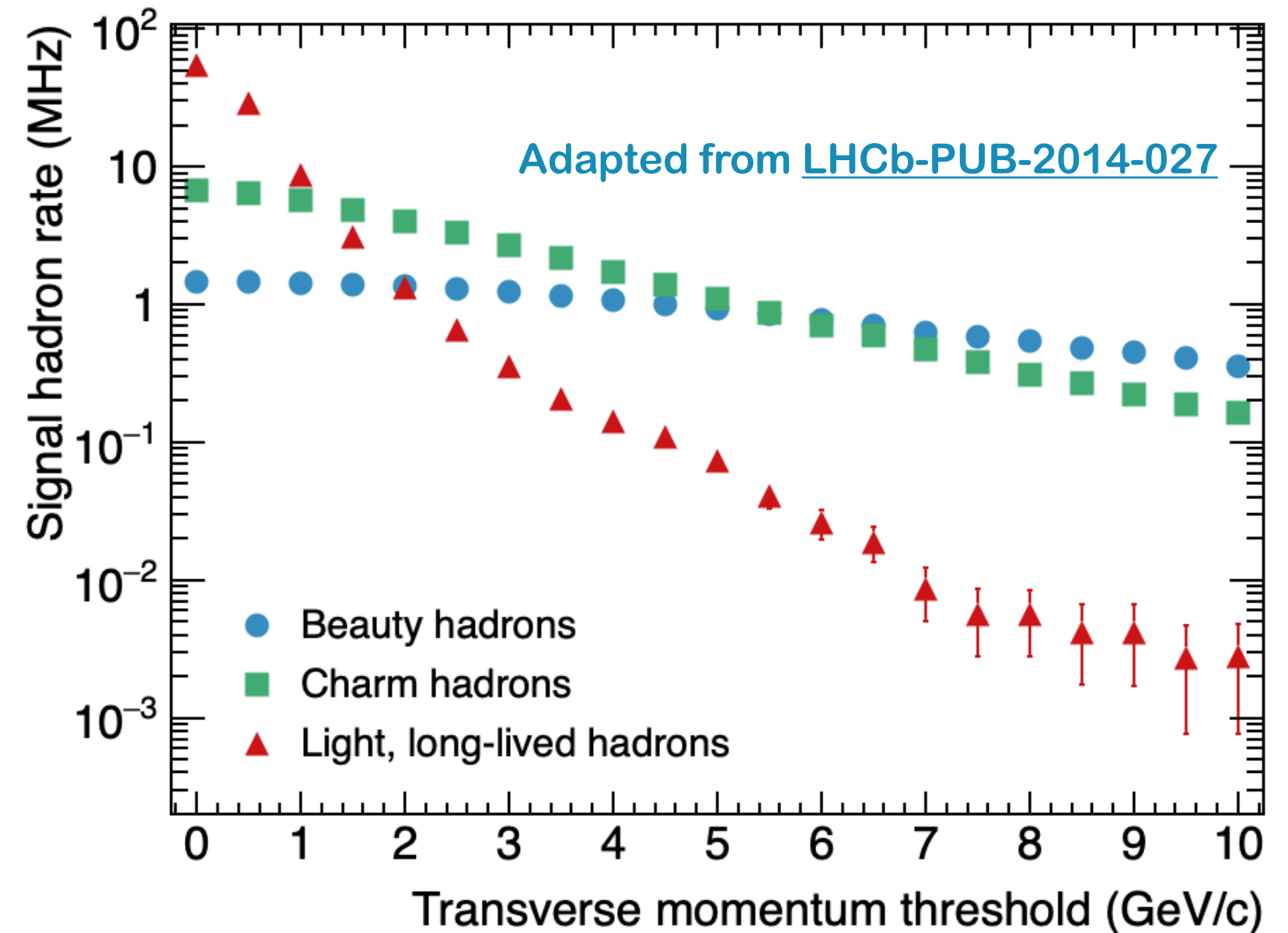
Trigger saturated by signal – must perform real-time analysis!

LHCb U2: DAQ & real-time analysis

A. Cerri, University of Sussex



LHCb @ 1e34: partially reconstructed signal rate



LHCb Upgrade 2 will be the biggest data processing challenge attempted in HEP

The full real-time reconstruction, calibration, and alignment of LHCb U2 is a key technology pathfinder for HEP. If successful will lead to a permanent paradigm shift for high-throughput experiments.

BACKUP