A comprehensive real-time analysis model at the LHCb experiment

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Wednesday 20th March 2019

2019 Joint HSF/OSG/WLCG Workshop

The paper

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCb-DP-2019-002
March 6, 2019

A comprehensive real-time analysis model at the LHCb experiment

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Abstract

An evolved real-time data processing strategy is proposed for high-energy physics experiments, and its implementation at the LHCb experiment is presented. The reduced event model allows not only the signal candidate firing the trigger to be persisted, as previously available, but also an arbitrary set of other reconstructed or raw objects from the event. This allows for higher trigger rates for a given output data bandwidth, when compared to the traditional model of saving the full raw detector data for each trigger, whilst accommodating inclusive triggers and preserving data mining capabilities. The gains in physics reach and savings in computing resources already made possible by the model are discussed, along with the prospects of employing it more widely for Run 3 of the Large Hadron Collider.

Submitted to JINST

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arXiv:1903.01360v2 [hep-ex] 5 Mar 2019

- LHCb-DP-2019-002 released this month
- Describes evolution of our RTA model during Run 2
- LHCb has profited enormously from RTA
  - But how?
  - Was it necessary?
  - What did we learn?
  - Can it be improved?
  - What are the implications for Run 3?

What is real-time analysis, exactly?

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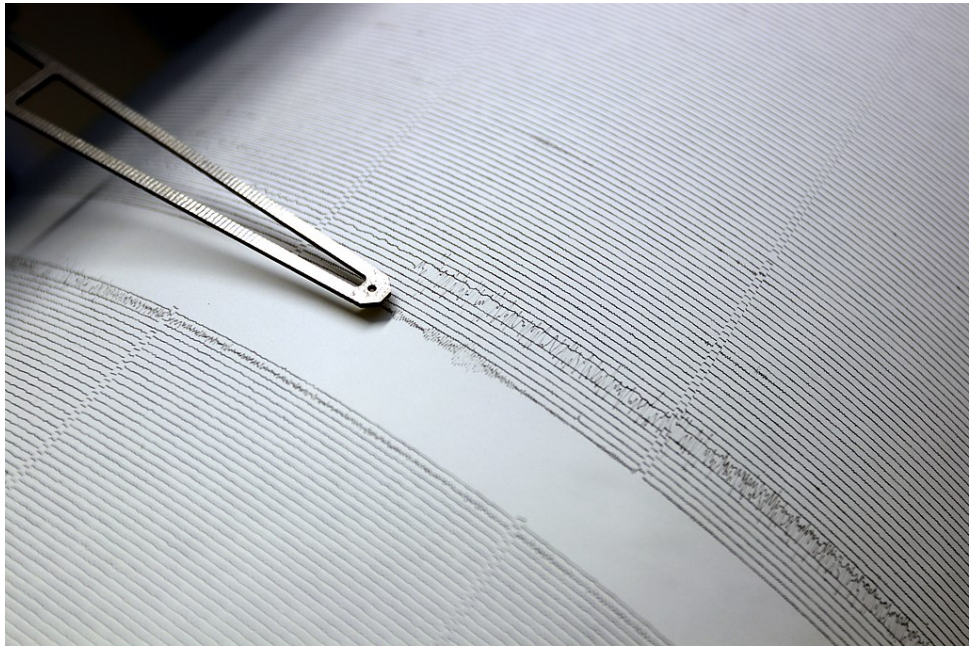

Source: Petr Brož

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- ***Hard**: Missing a deadline is a total system failure.*
- ***Firm**: Infrequent deadline misses are tolerable, but may degrade the system's quality of service. The usefulness of a result is zero after its deadline.*
- ***Soft**: The usefulness of a result degrades after its deadline, thereby degrading the system's quality of service.*

— Wikipedia: Real-time computing

The LHCb definition

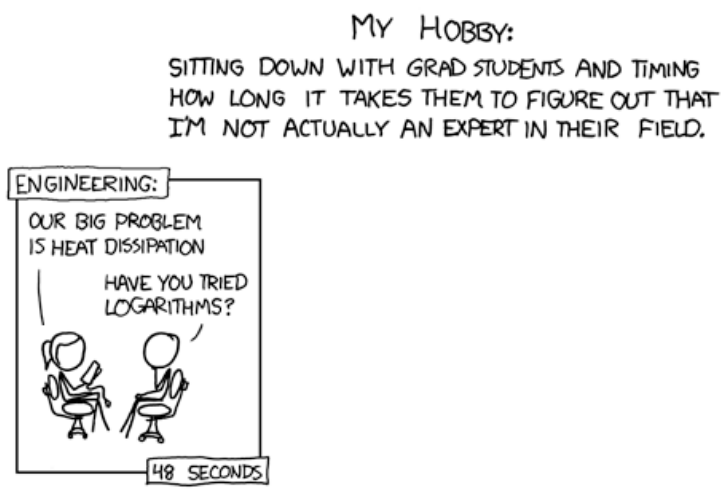
Here, 'real time' is defined as the interval between a collision occurring and the point at which the corresponding event must be either discarded forever or sent offline for permanent storage.

— LHCb-DP-2019-002

Let’s agree to disagree

1. Real time analysis is the **set of actions we apply to events that may later be discarded forever**.
2. Can also be the **analysis of that information later**, i.e. “offline”.

Real-time analysis makes everything amazing



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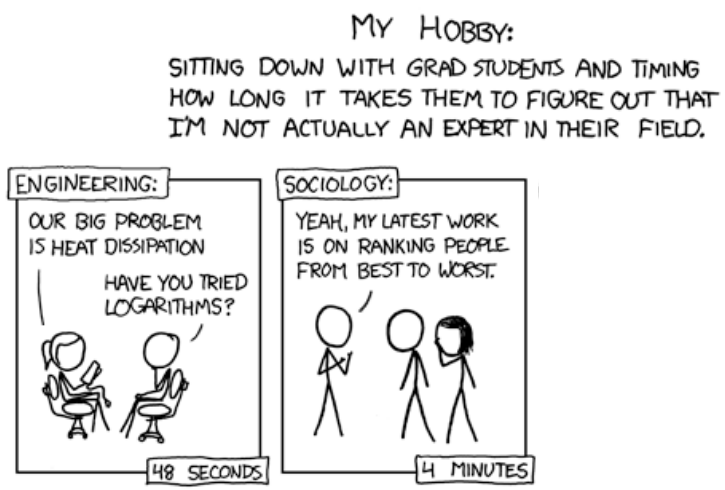

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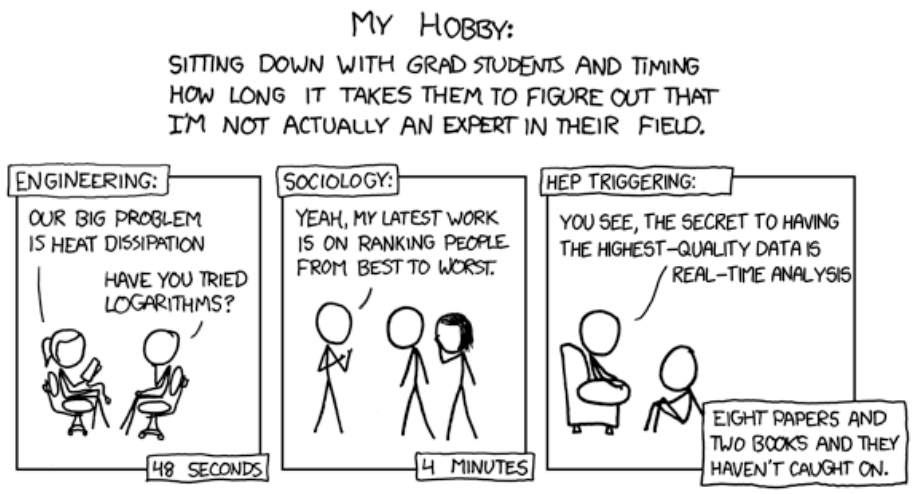

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Motivation

- Triggering is expensive; must fit within computing constraints

$$\text{Bandwidth}\,[\text{GB/s}] \propto \text{Accept rate}\,[\text{kHz}] \times \text{Event size}\,[\text{kB}]$$

- Want highest accept rate high to maximise $\varepsilon_{\text{Sig.}}$ and reduce bias
  - Balanced against maximising $1 - \varepsilon_{\text{Bkg.}}$
- Can't do much to reduce the raw event size; it's all or nothing!

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If event size is reduced, there's room for more physics!

The idea

- We design our trigger systems to compute useful information
- We do analysis in real-time to compute the trigger decision
- What if that information is *good enough* to also use directly ‘offline’?

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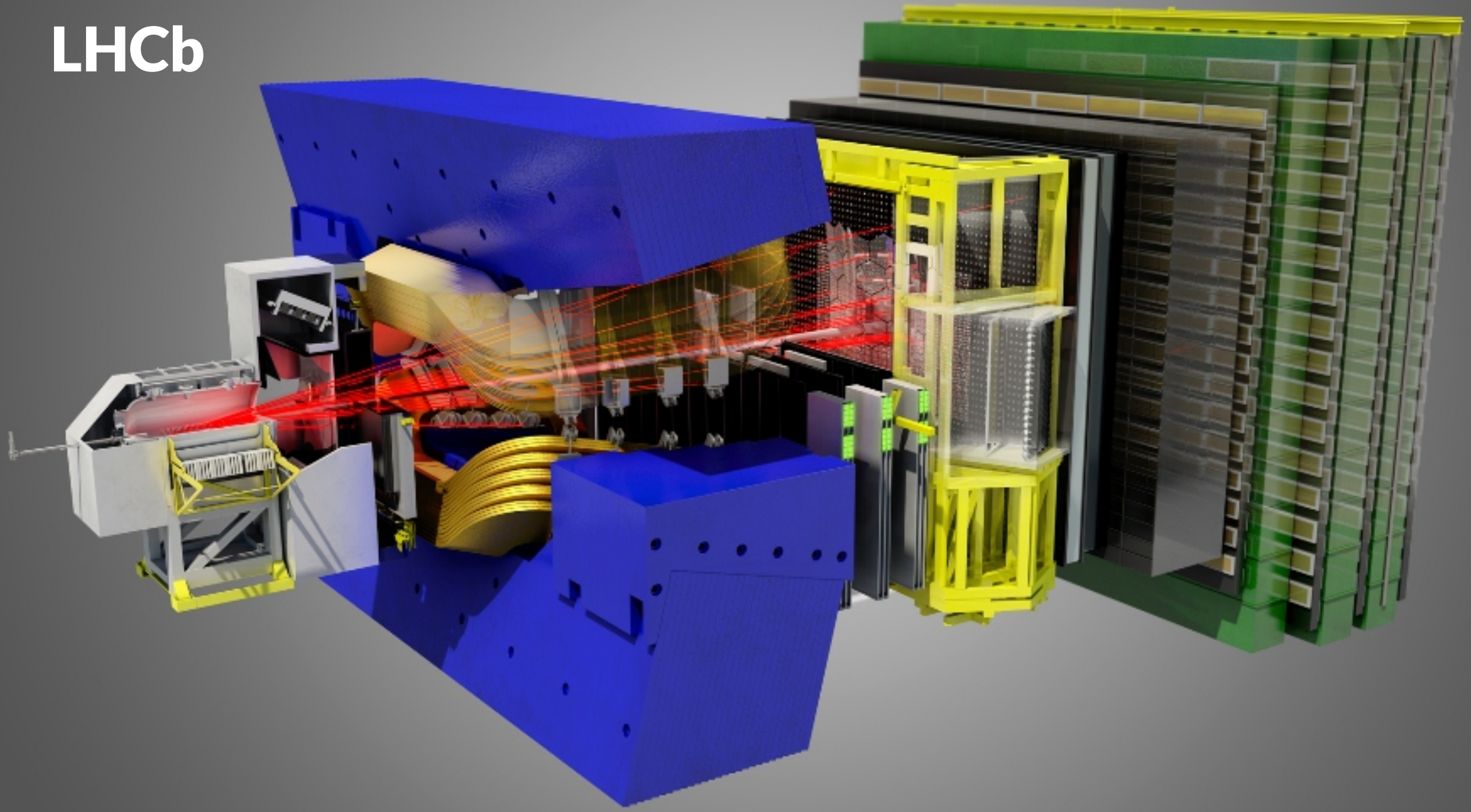
Save only what you need, as computed in the trigger!

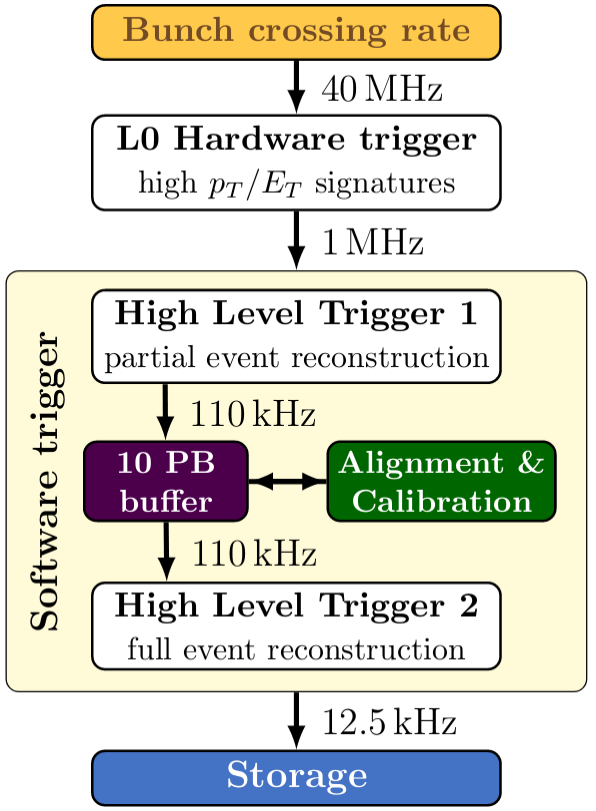
LHCb



The Run 2 trigger

Formidable challenge

- Production rate of around 45 kHz for $b\bar{b}$ events, 1 MHz for $c\bar{c}$
  - Must operate quickly but was high fidelity and selectivity
- Filters proton-proton collision rate down to around 12.5 kHz
  - Bandwidth of around 0.7 GB/s
- Events buffered between split software stages
- Buffered data **aligned and calibrated online**
- **Offline-quality reconstruction** in final stage



What this buys us

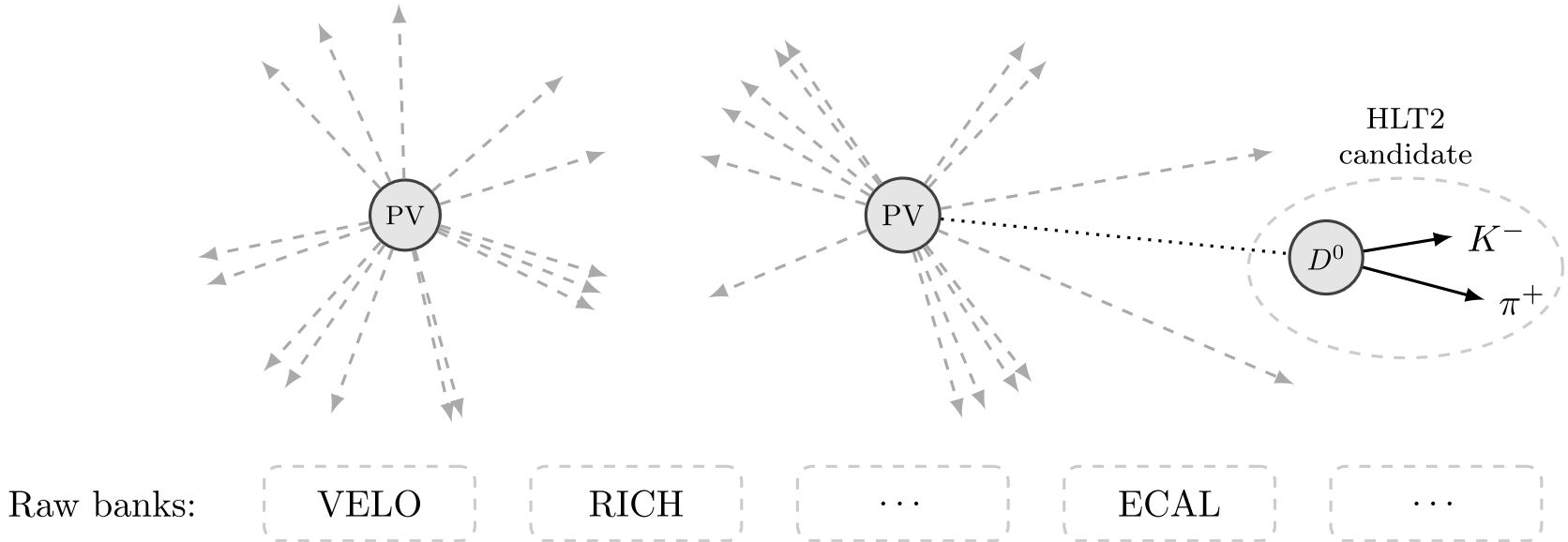
- Offline-equivalent, fully aligned and calibrated physics objects in HLT2
- Can include offline selections in the trigger with no associated systematic effects
- Offline reprocessing of the raw data is not *necessary* to recover information

Real-time analysis with offline-quality physics objects

Enter: Turbo

- Persist **objects from HLT2** directly, analyse only these offline
- Individual trigger selections have **complete control** over what objects are saved
  - Evolved over time to meet increasing needs

Persistence granularity



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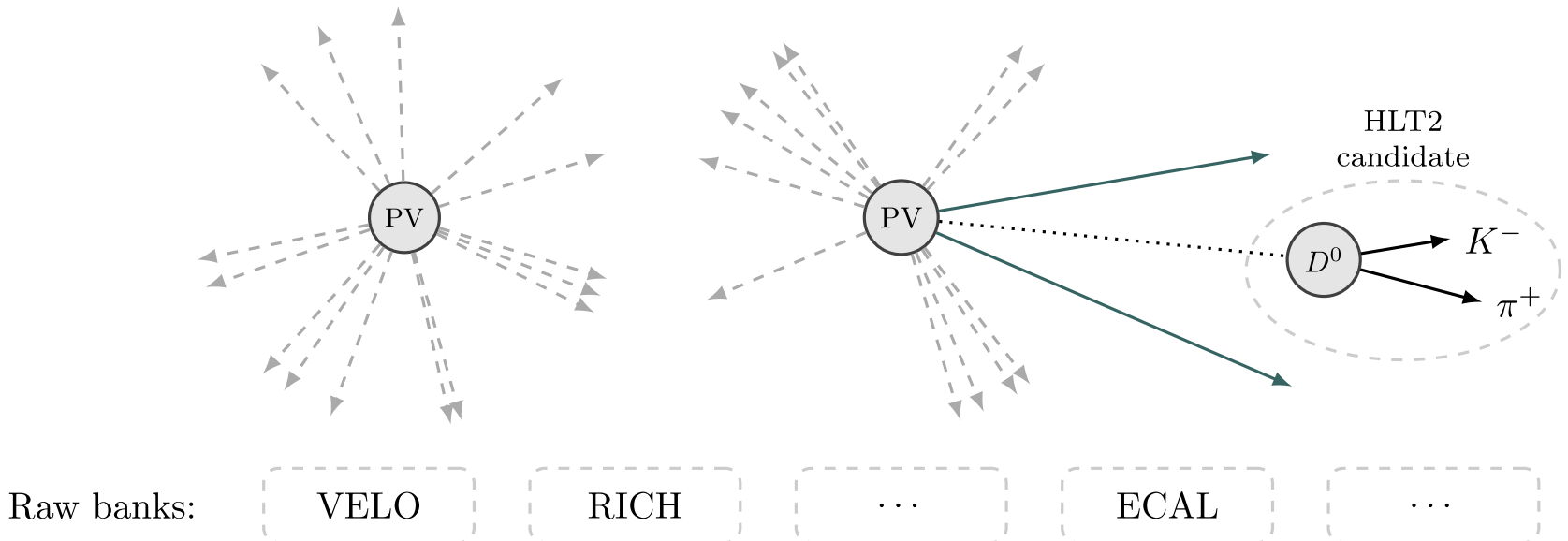

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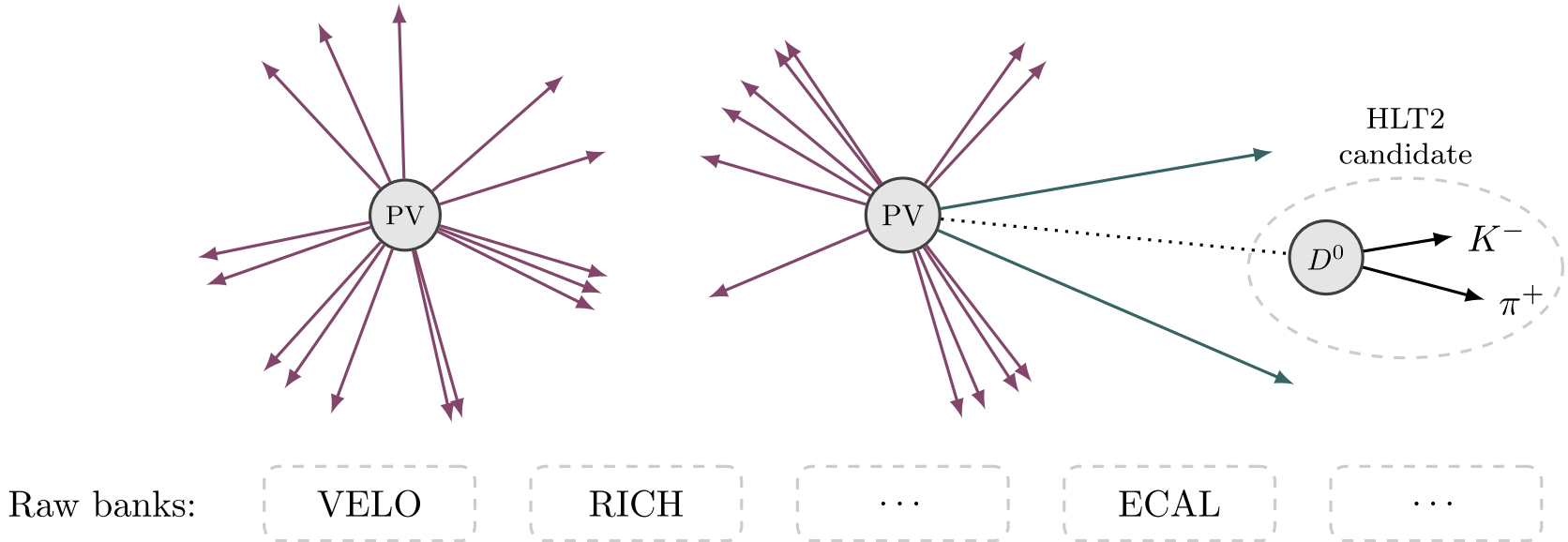

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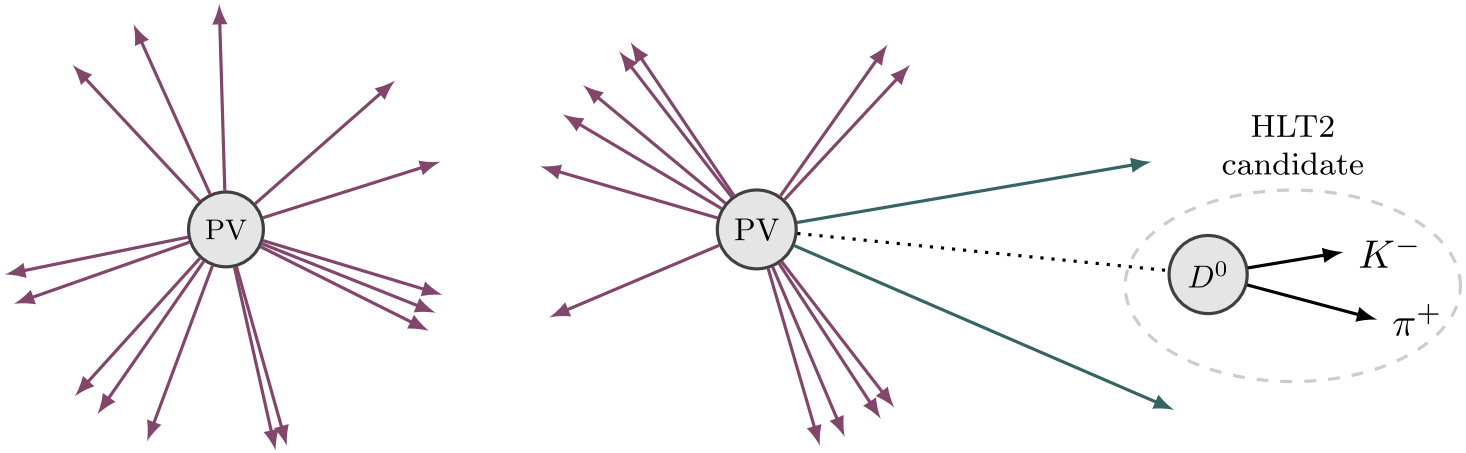
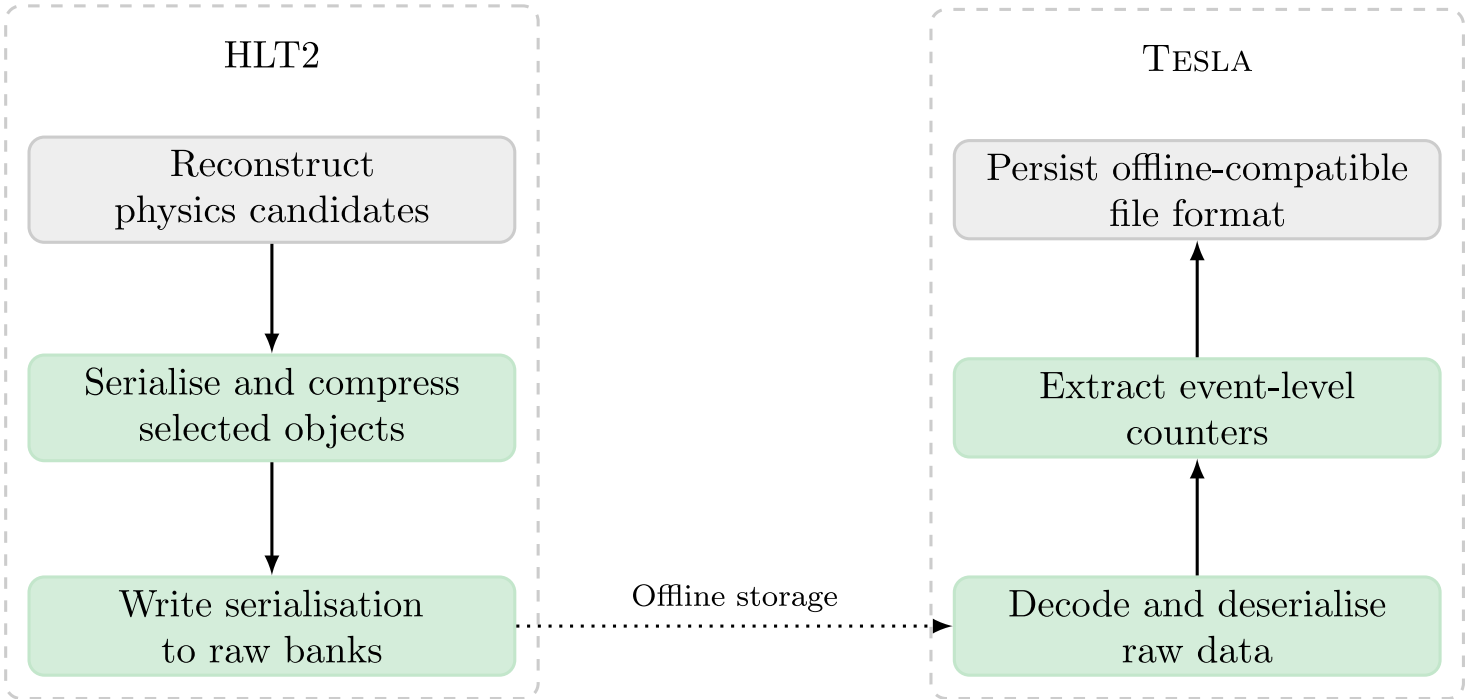


Internals


HLT2
Reconstruct physics candidates
Serialise and compress selected objects
Write serialisation to raw banks
Offline storage
Tesla
Persist offline-compatible file format
Extract event-level counters
Decode and deserialise raw data

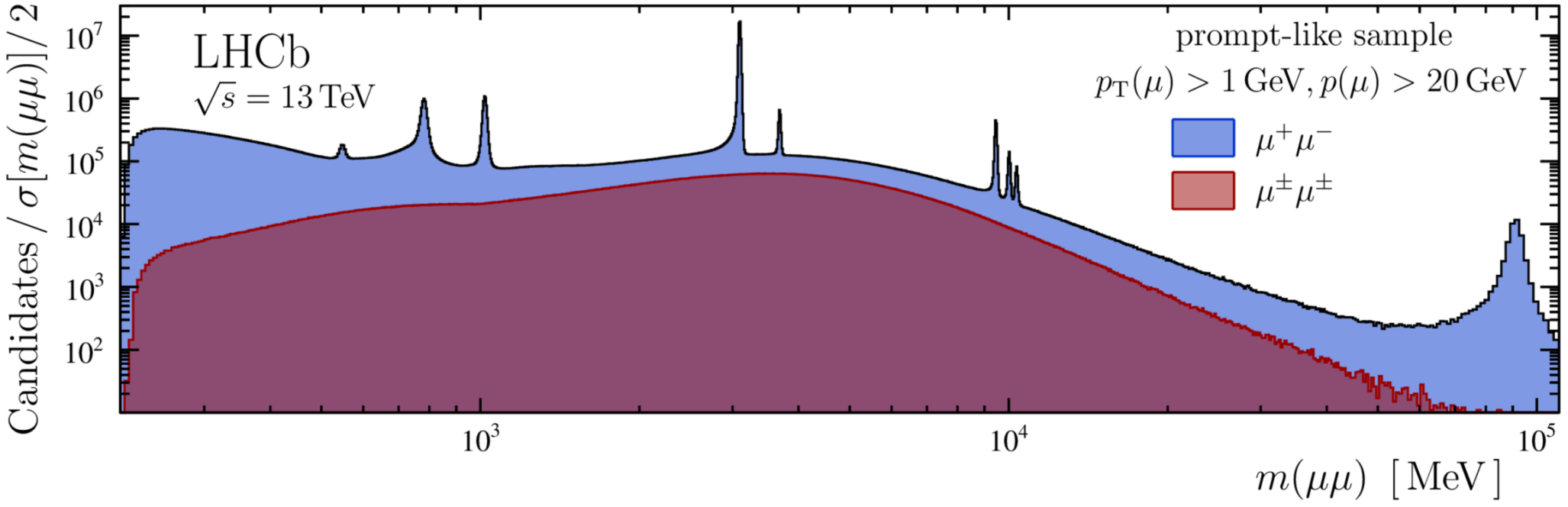
Rewards

- Much smaller average event size → **more physics** within our resources

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

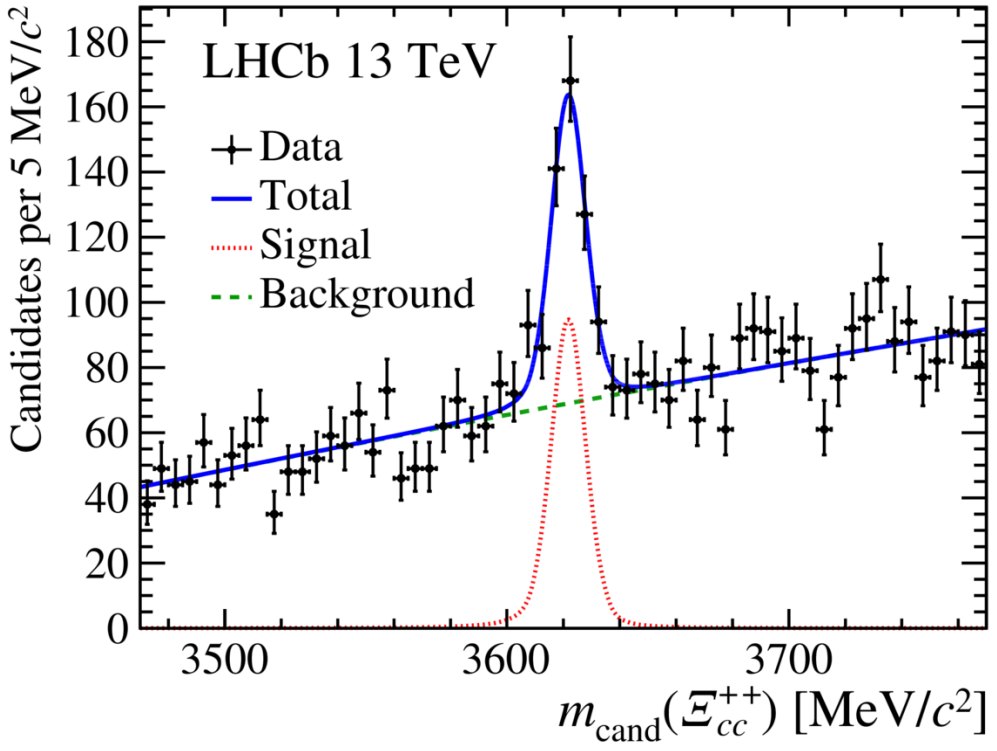
- Accounted for around **one quarter** of the trigger rate in Run 2
  - For one tenth of the bandwidth!

What we're able achieve



Source: LHCb Collaboration, Phys. Rev. Lett. 120 (2018) 061801

What we're able achieve



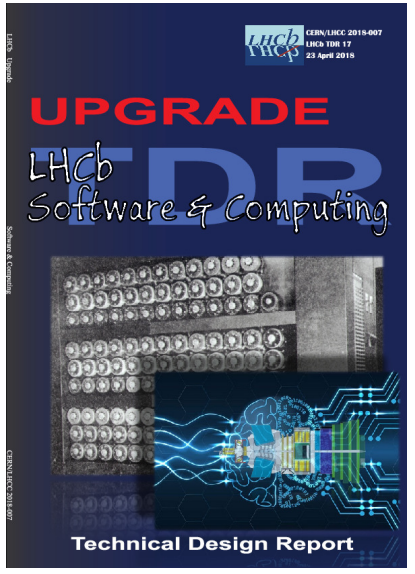
Source: LHCb Collaboration, Phys. Rev. Lett. 119 (2017) 112001

Looking back

- Must **overcome fear** of losing information
- There's **always room for improvement**
  - Selective persistence allowed us to reduce Turbo bandwidth, then added *new* inclusive charm baryon lines
- Must **support users** in transitioning to any new features
- Turbo isn't a great name…

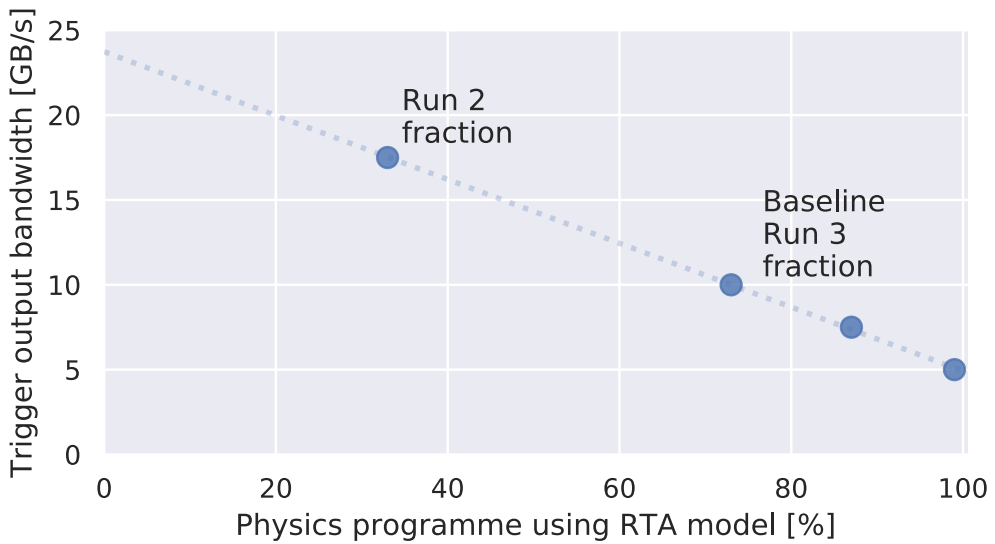
Looking forward: Run 3

- Instantaneous luminosity increases **5x**
- Triggerless readout, full software trigger
  - Removal of hardware trigger increases efficiency of hadronic signals > **2x**
- Huge increase in signal rate!



Challenges

- Run 3 physics programme is **bandwidth-constrained** like charm was in Run 2



- **Turbo fraction must increase** 3 if the programme is to prosper; baseline is **70%**
- Must migrate some **inclusive triggers** to the RTA model
- What if we cannot achieve **online/offline parity** in HLT2?

Summary

- Real-time analysis is what we can do with **information computed in the trigger**
- LHCb has **profited enormously** from it in Run 2
- Must work hard to **convince ourselves** we're discarding things we will never need
- Now have tools we need for **Run 3**

End

References

- LHCb Collaboration, *The LHCb Detector at the LHC*, 2008 JINST 3 S08005
- R. Aaij et al., *Performance of the LHCb trigger and full real-time reconstruction in Run 2 of the LHC*, arXiv:1812.10790
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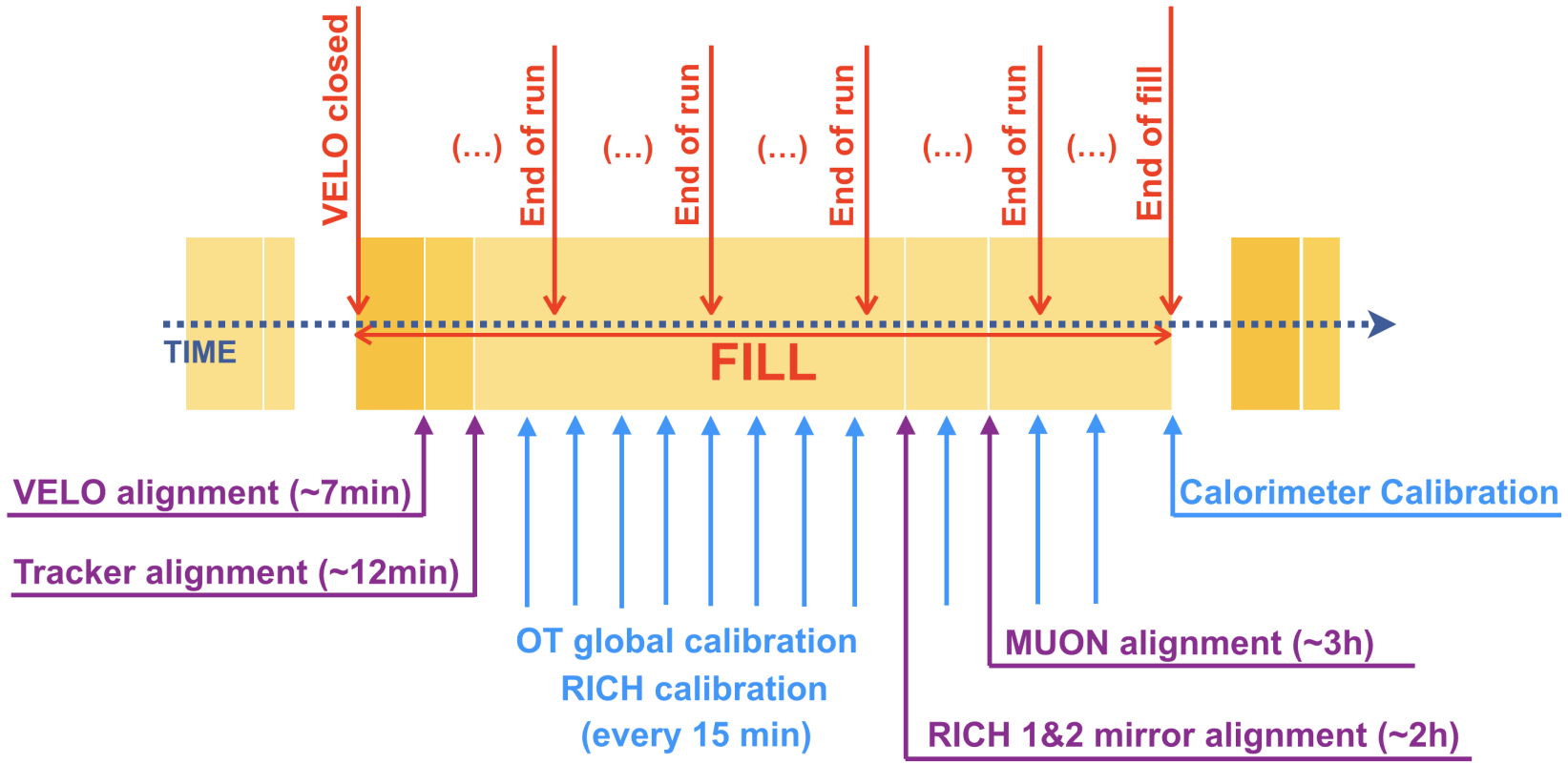
Online alignment and calibration



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

Online alignment and calibration stability