Real Time Analysis in LHCb

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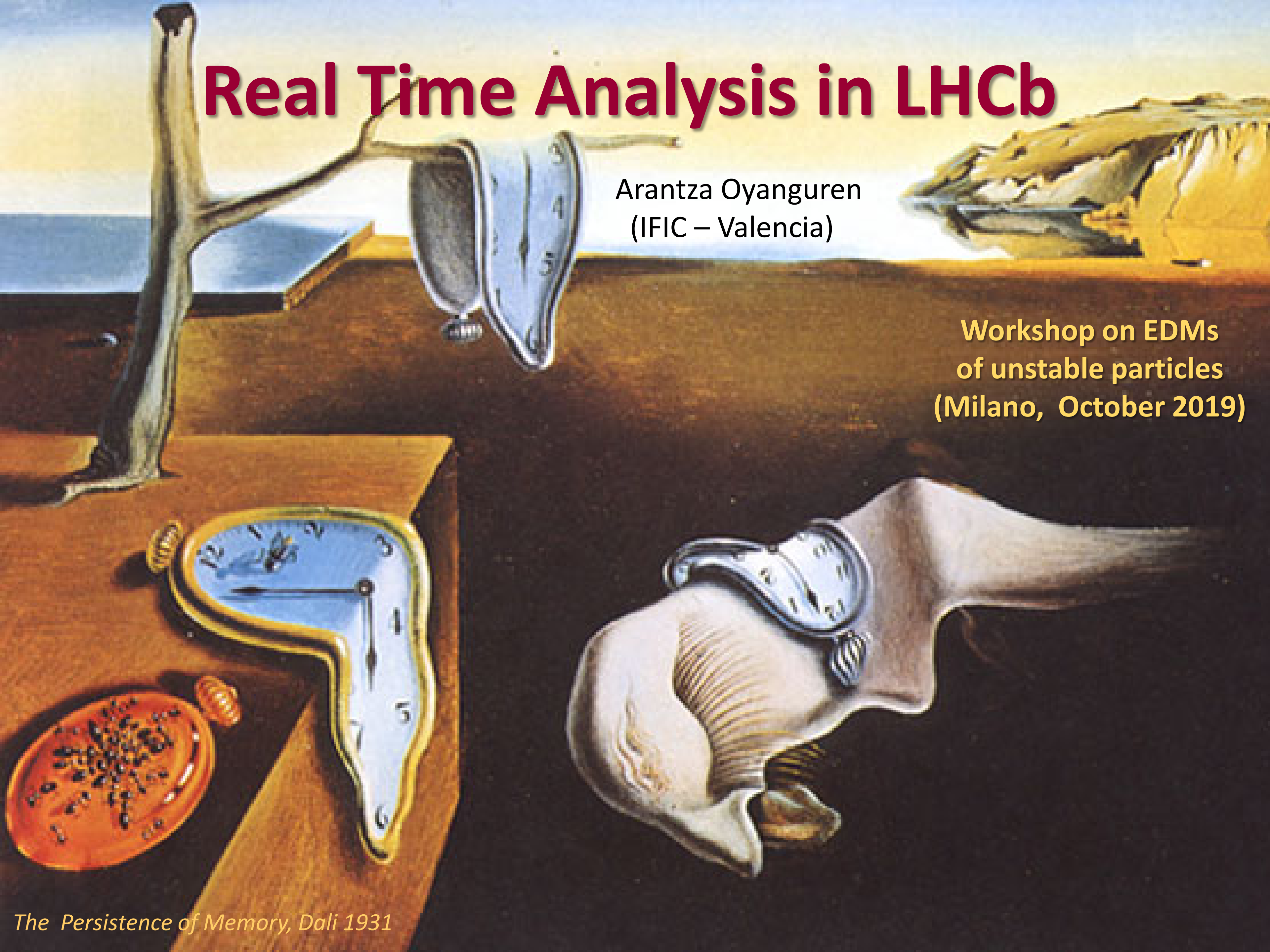
(IFIC – Valencia)

Workshop on EDMs of unstable particles (Milano, October 2019)

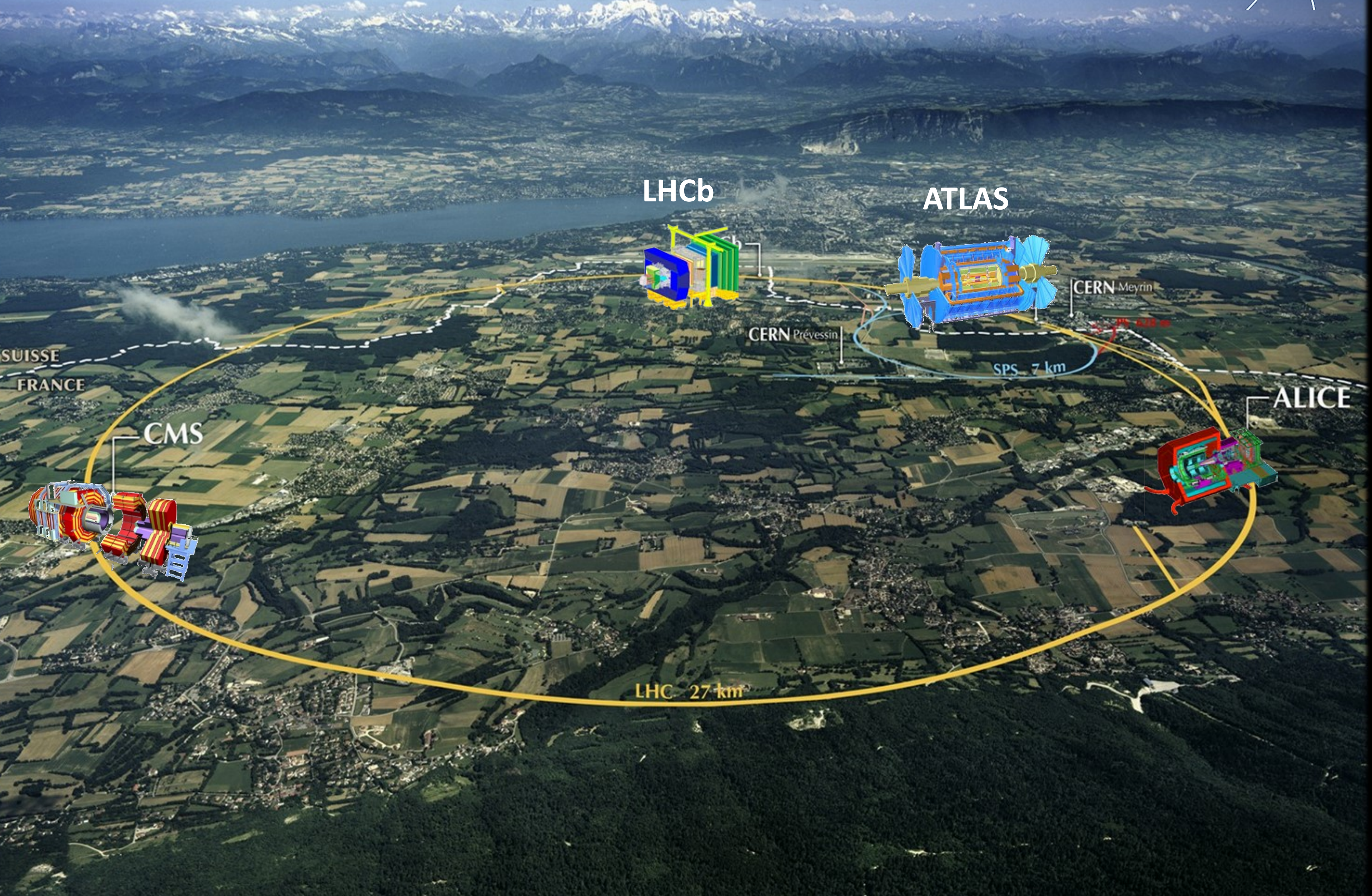


The Persistence of Memory, Dali 1931

Outline

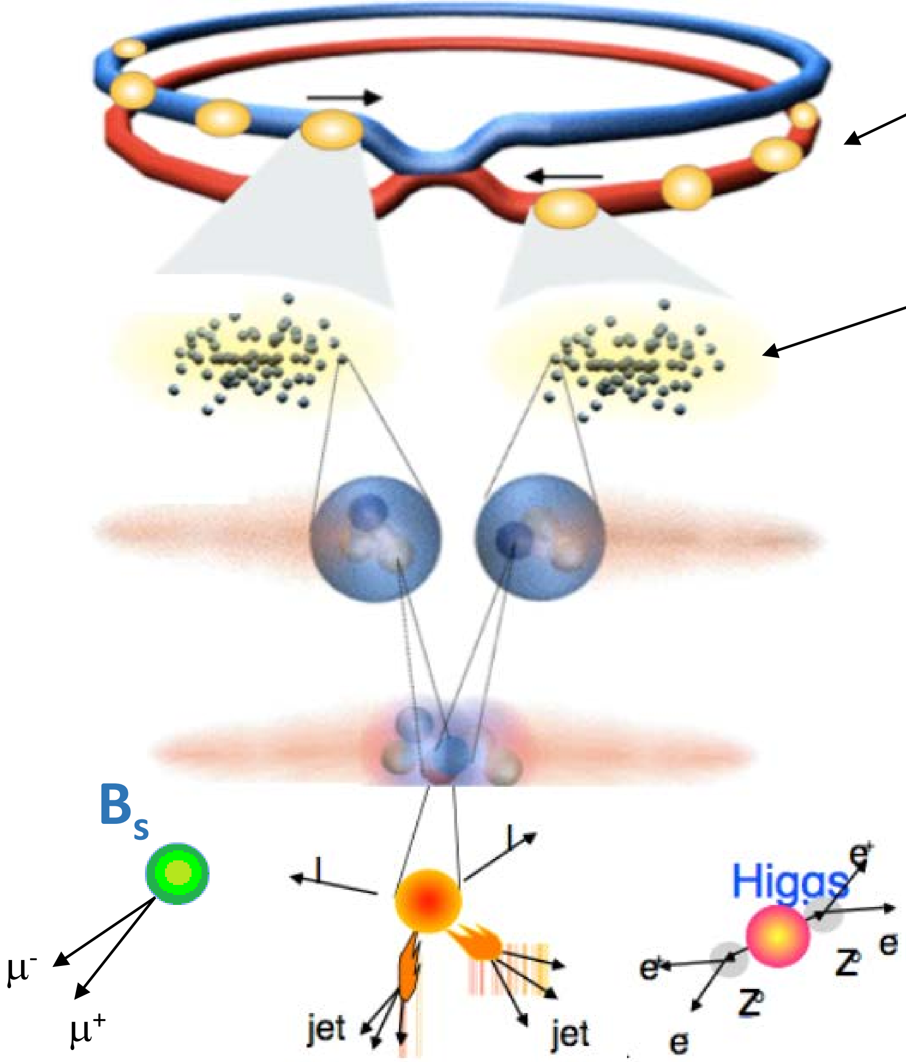
- Introduction
- The *trigger*
- Real time analysis
- Alignment and calibration
- Prospects for Run3
- Long living particles
- Conclusions

Introduction



Introduction

Proton-proton collision



2028 bunch of protons per beam

Beam energy of 6.5 TeV

10^{11} protons per bunch

Luminosity 10^{34} cm^{-2} s^{-1}

Averaged crossing rate ~30 MHz
i.e. 30 M collisions/s

About 1 MB data per collision at ATLAS and CMS
About 0.15 MB data per collision at LHCb

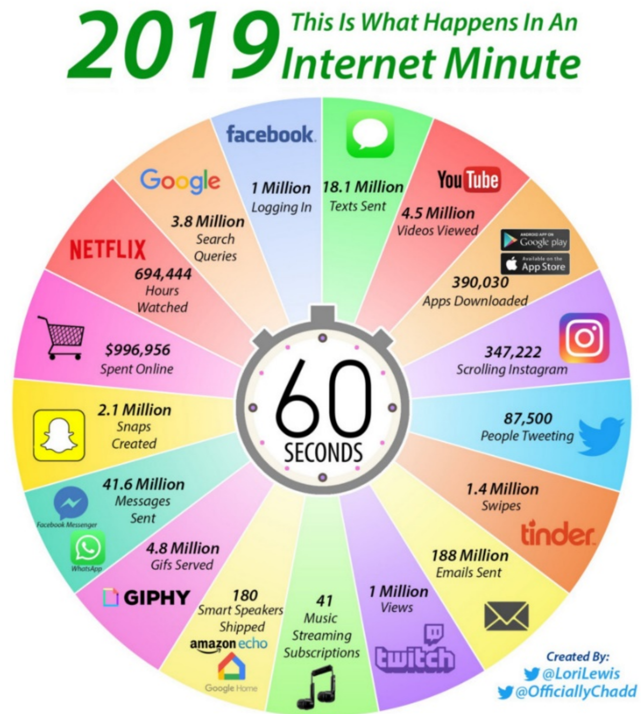
→ **5 TB/s @ LHCb**

Introduction

British Library, London

~ **12 TB**

(25 M books)



Google + + ~

0.3 TB/s

The *trigger*

Impossible to select all the data: need to select the events of interest

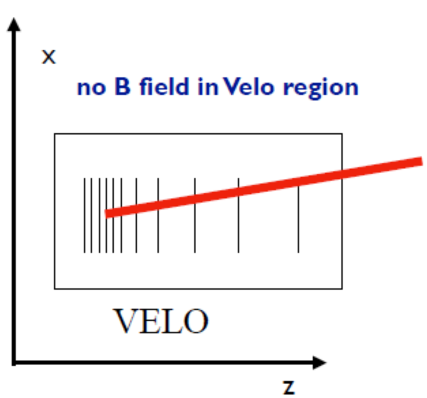
Traditional trigger systems:

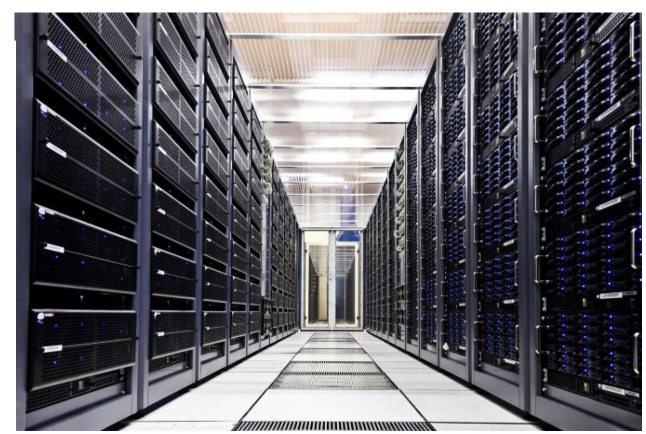
First level (L0/L1) → Y/N → First High Level (HLT1) → Y/N → Second High Level (HLT2) →

Custom electronics (FPGAs), Information from calorimeters and muon stations

Processors farm, fast Information from tracking

Processors farm, detailed information to reconstruct the event





The *trigger*

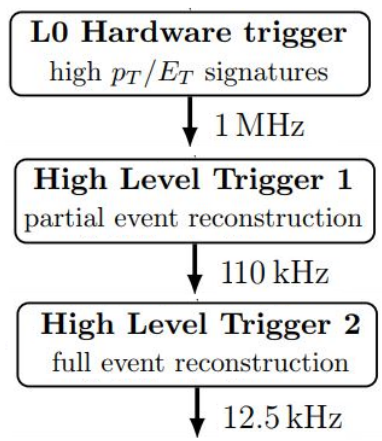
How many data can we record?

The need of storage is given by the trigger bandwidth:

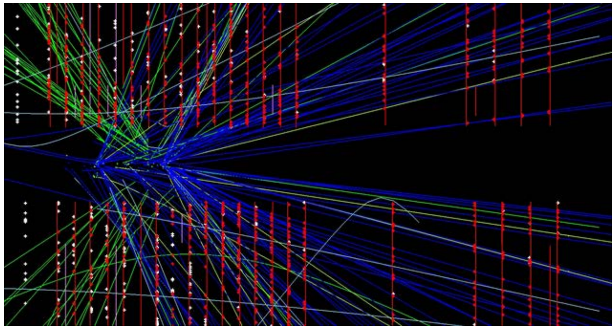
Bandwidth [MB/s] ~ Trigger output rate [kHz] x Average event size [kB]

~ 0.8 GB/s (Run2)

and increasing for Run3



12.5 kHz (Run2)

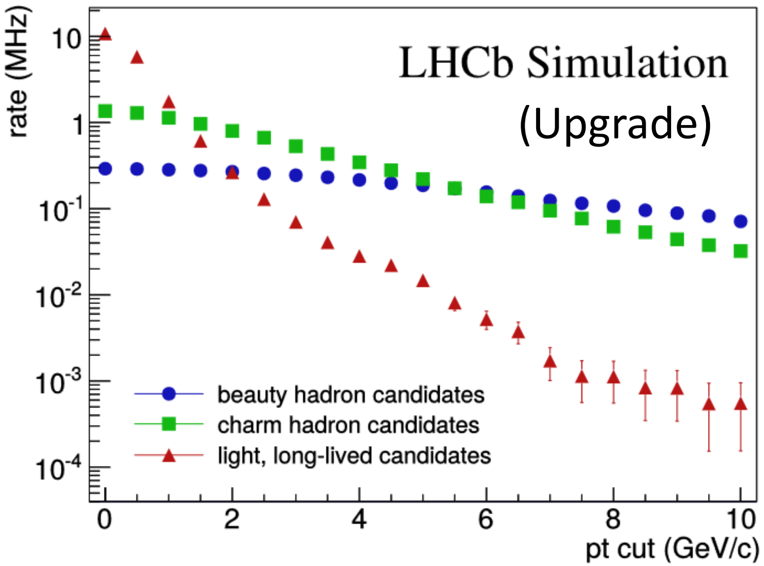


Raw event data size
60 kB (Run2)

Note: For the Upgrade (Run 3) the raw event size is ~150 kB

Real time analysis

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



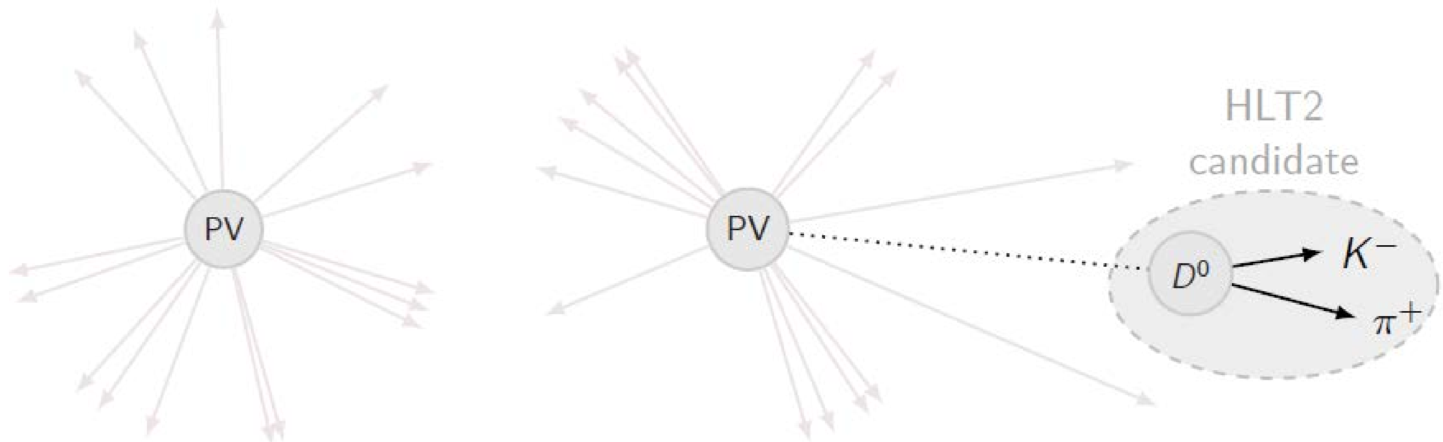
[LHCb-PUB-2014-027]

- The **trigger rate saturates**: we cannot reduce the trigger output, all our selected events are signals!
- We need then to **reduce the event size**: Instead of taking the raw data, store only the relevant information

→ Need to reconstruct and analyse the event to select them in **real time**, and keep the important data

Real time analysis

Turbo*: 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:



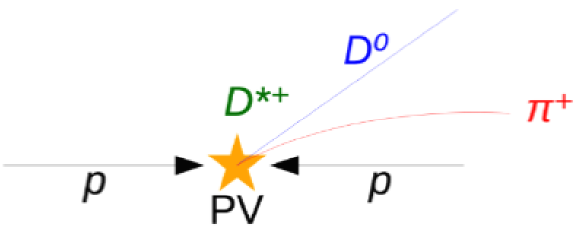
Persistence method	Average event size (kB)
Turbo	7
Selective persistence	16
Complete persistence	48
Raw event	69

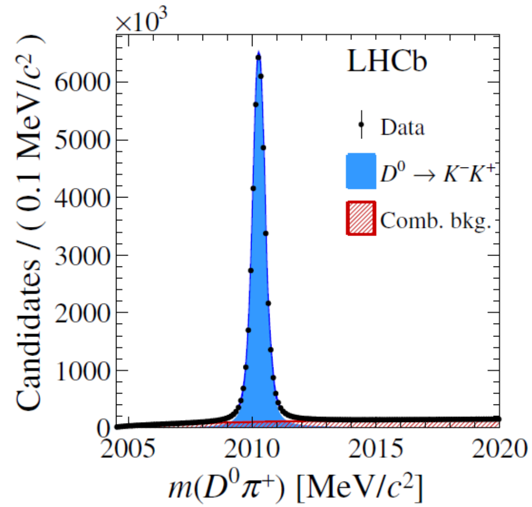
* Comput.Phys.Commun. 208 (2016) 35, applied in LHCb since 2015

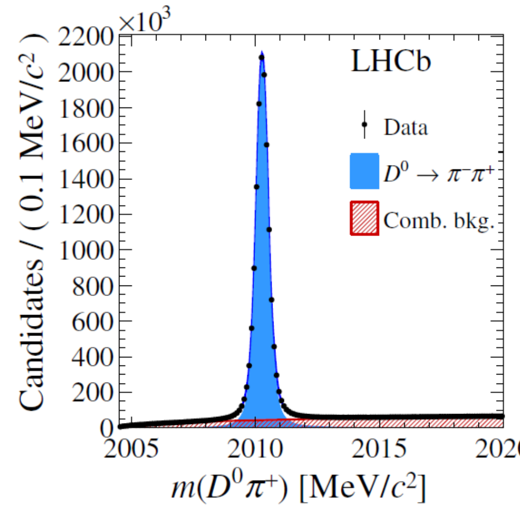
Real time analysis

★ **Observation of CP Violation in Charm Decays**

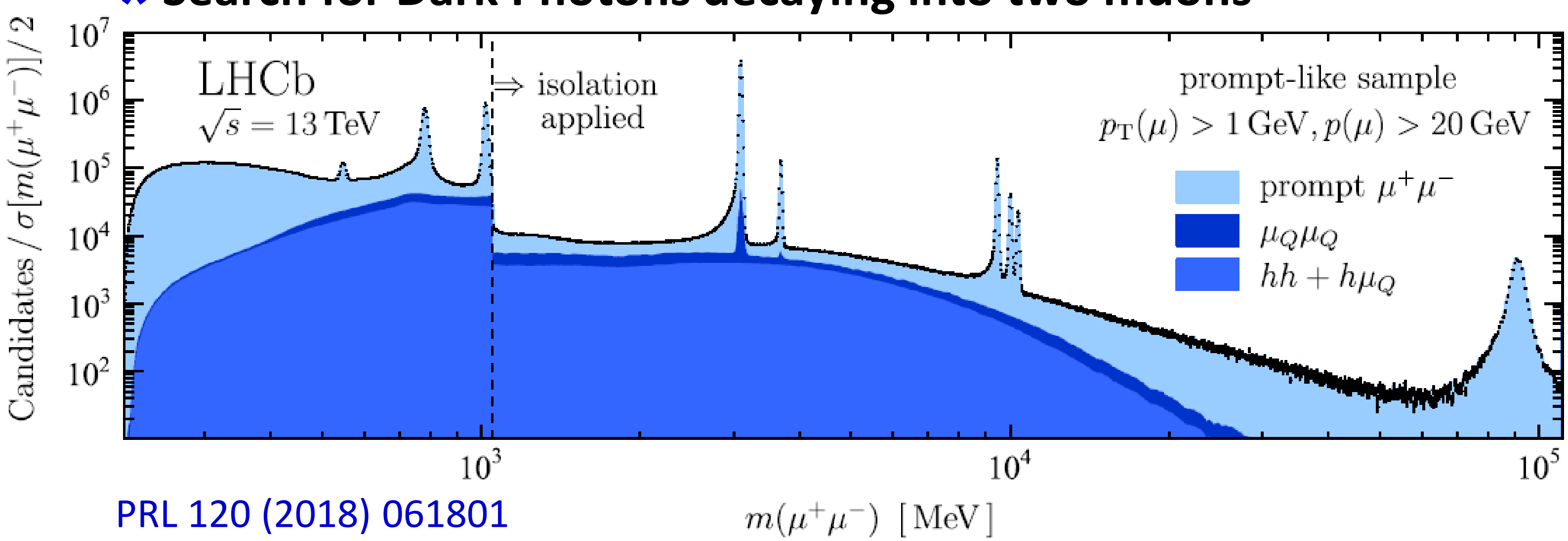
PR 122 (2019) 211803







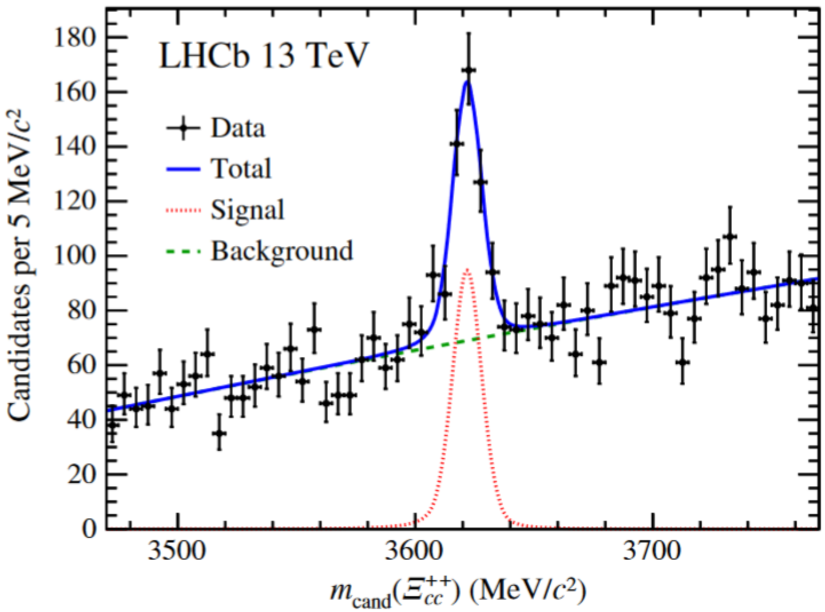
★ **Search for Dark Photons decaying into two muons**



PRL 120 (2018) 061801

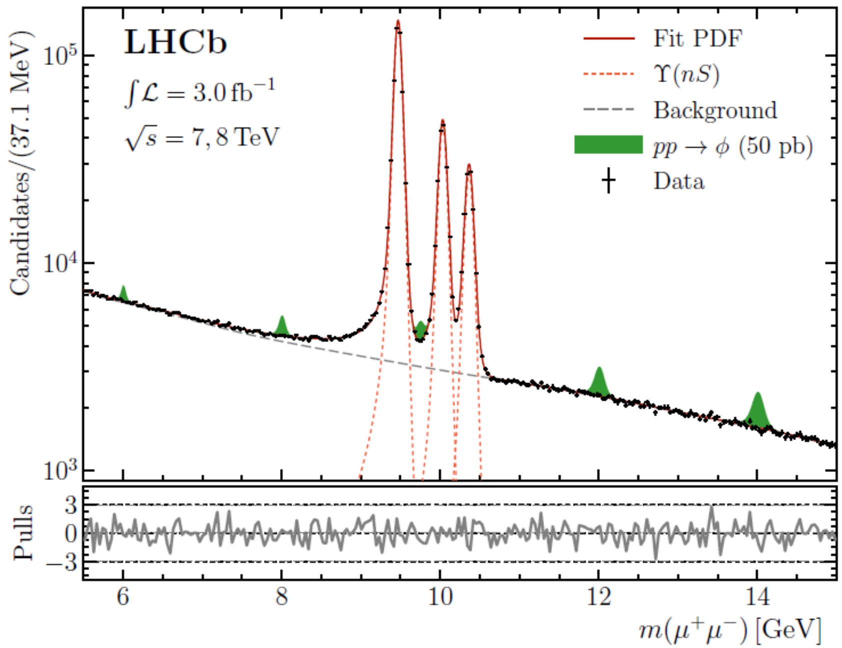
Real time analysis

* Observation of the Doubly Charmed Baryon Ξ^{++}_{cc}



PRL 119 (2017) 112001

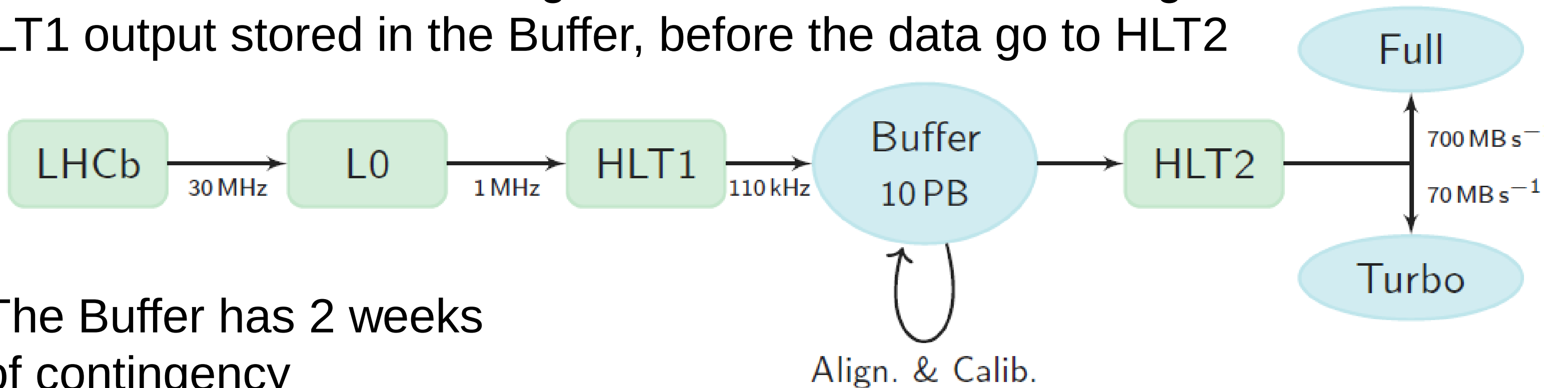
* Search for dimuon resonances (new spin-0 bosons)



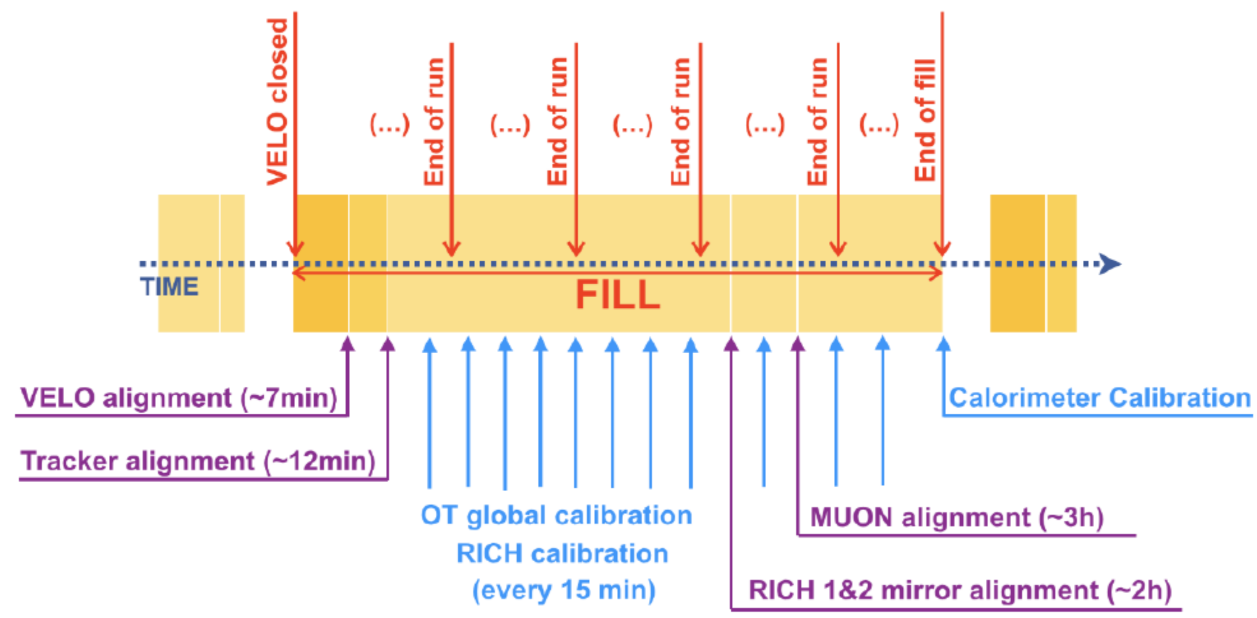
JHEP 08 (2018) 147

Alignment & calibration

In Run2 all detectors are aligned & calibrated online using the HLT1 output stored in the Buffer, before the data go to HLT2

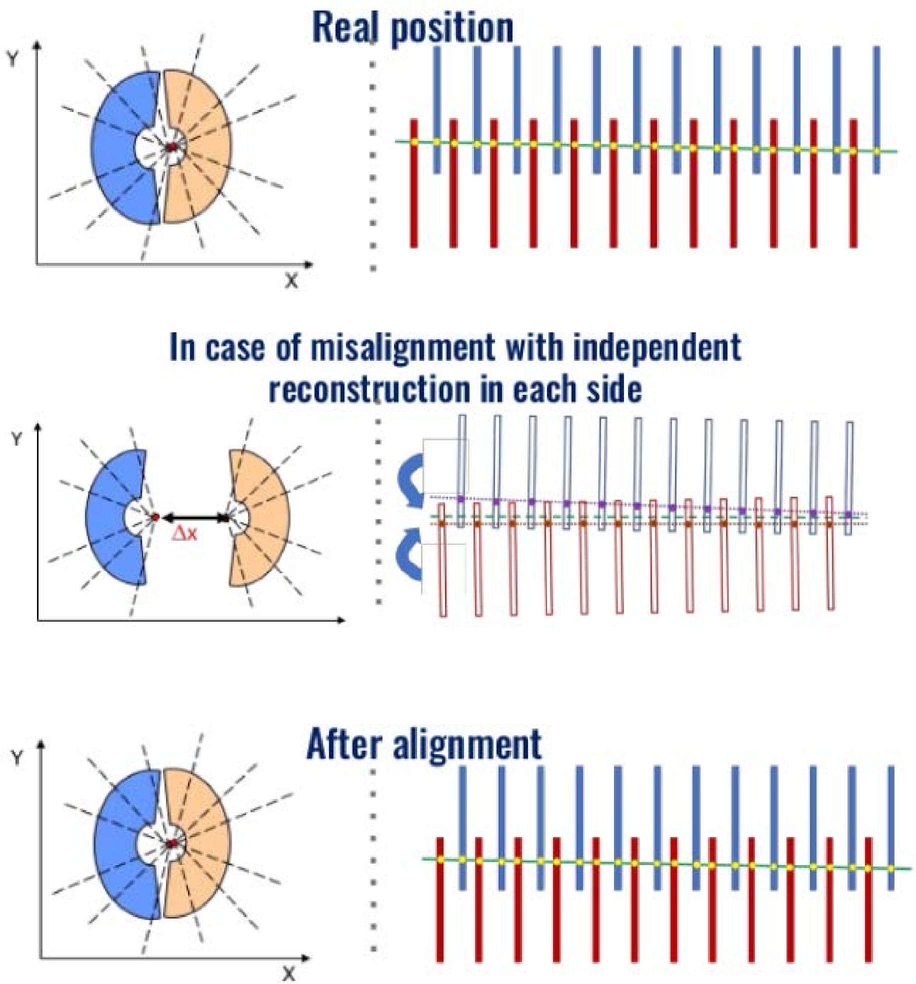


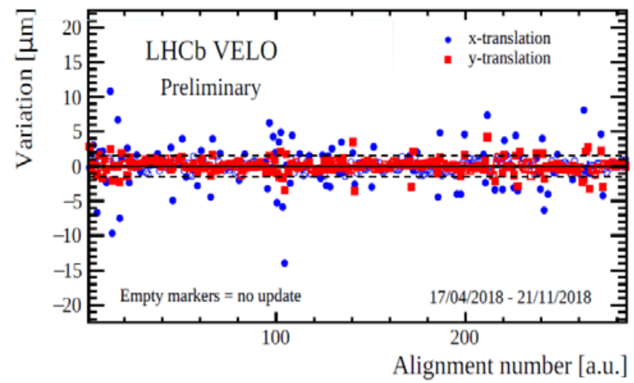
The Buffer has 2 weeks of contingency

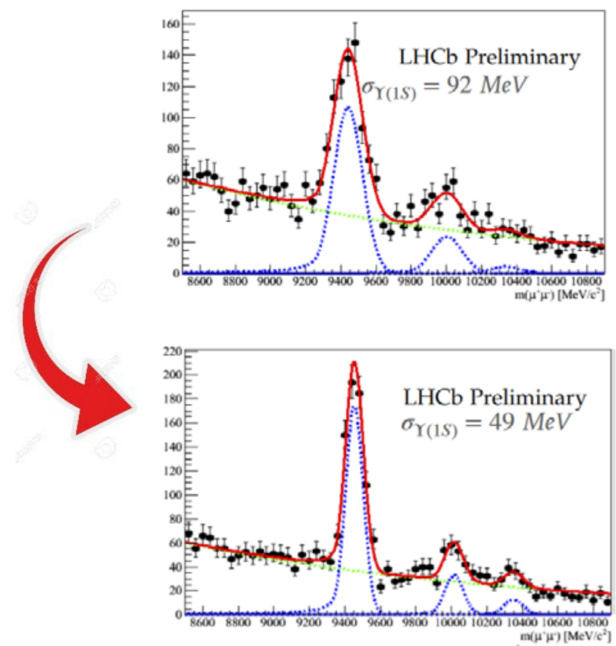


Alignment & calibration

Ex: VELO centers itself around beam at start of each fill, aligned with a Kalman filter using track hit residuals with PV constraints



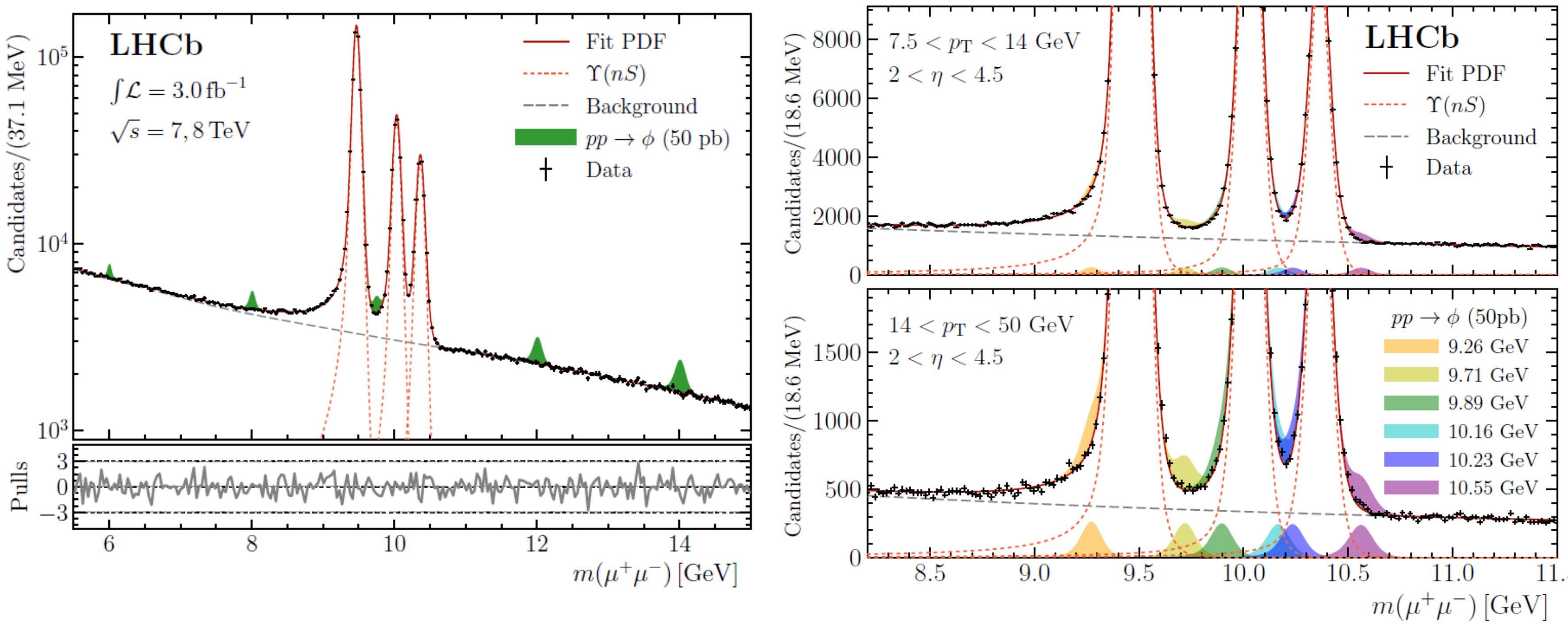




Alignment & calibration

Search for dimuon resonance (new spin-0 bosons)

JHEP 08 (2018) 147



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

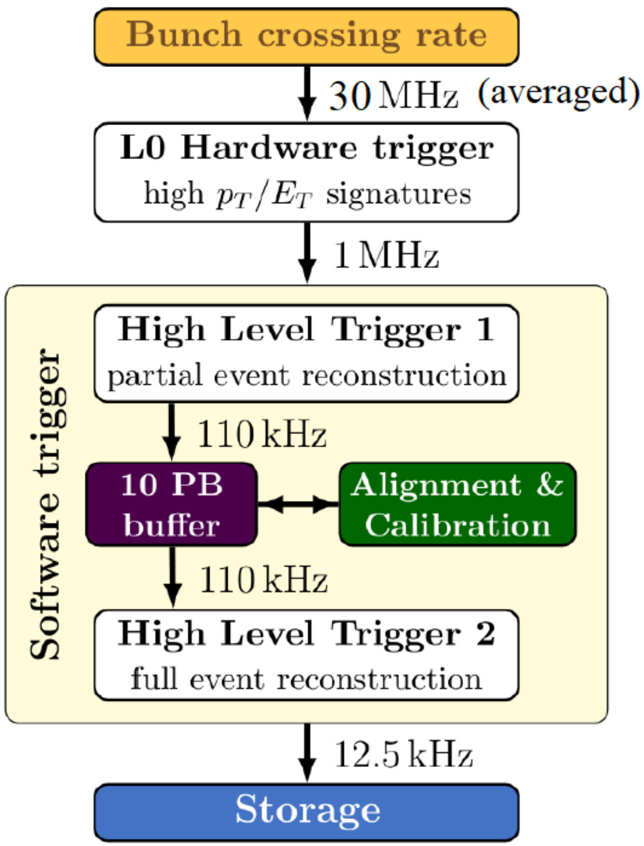
Data reprocessing not needed → fast and fresh analyses, results delivered in few days

Reduced systematics in HLT2 selections

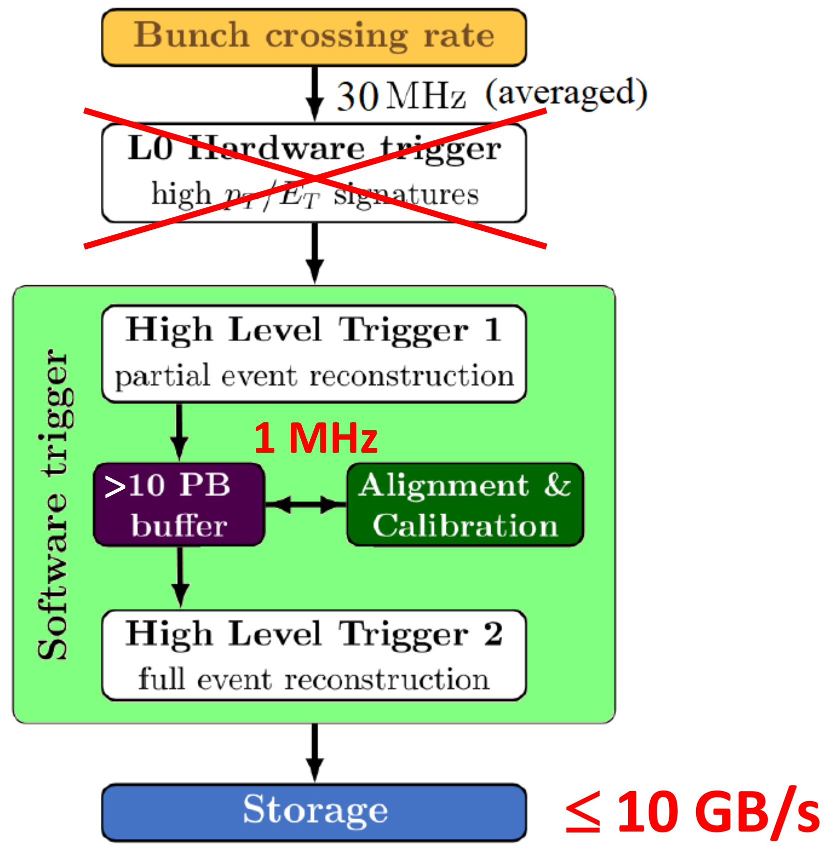
Prospects for Run3

Increasing the instantaneous luminosity x 5 + triggerless readout

Run 2



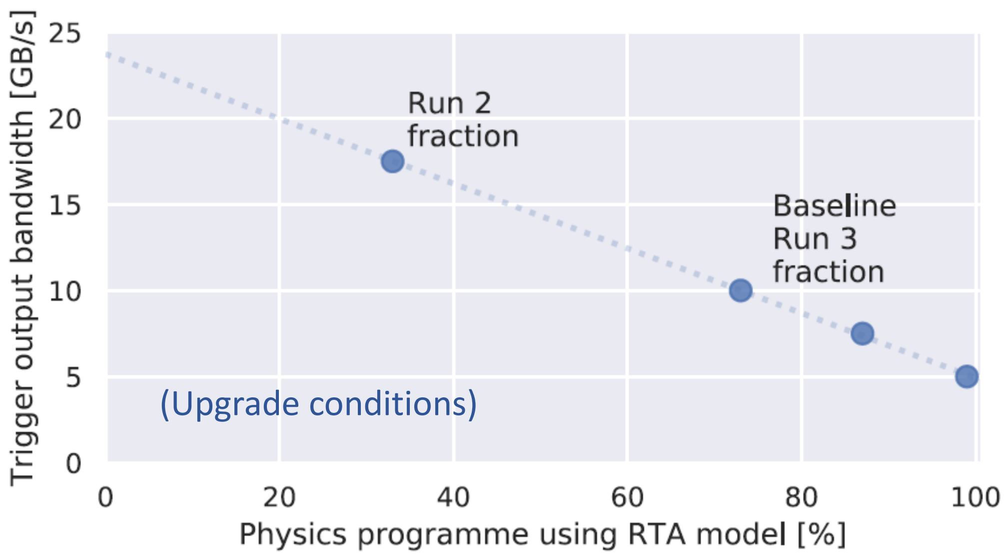
Run 3

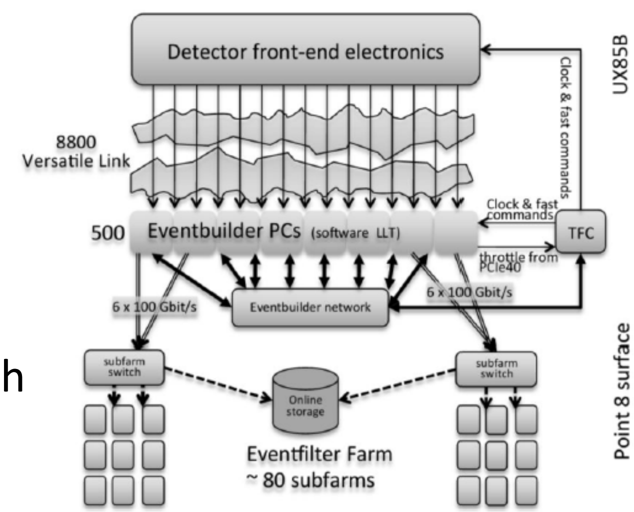


For the Upgrade (Run 3) the raw event size is ~150 kB

Prospects for Run3

Need to migrate most of trigger lines to RTA





Caveats:

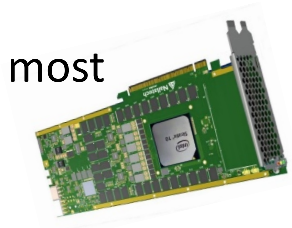
- Risk of not recording relevant information
- One can discard objects from PV not compatible with the signal
- Inclusive triggers: need rejection of tracks/objetcs
- New and unexpected events?

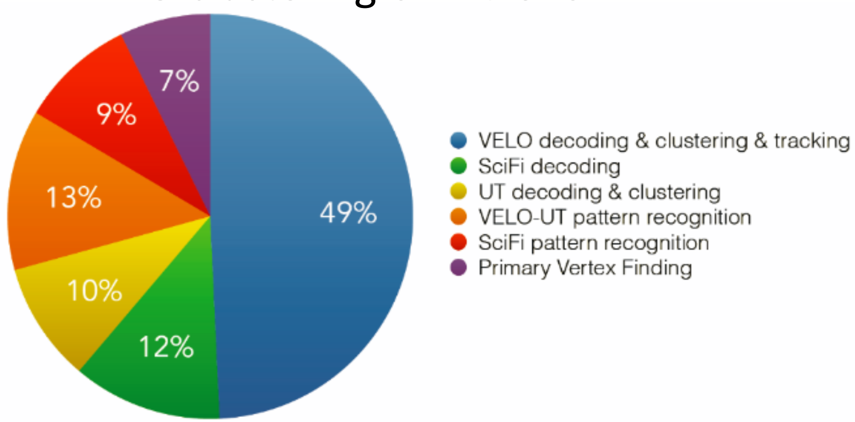
Prospects for Run3

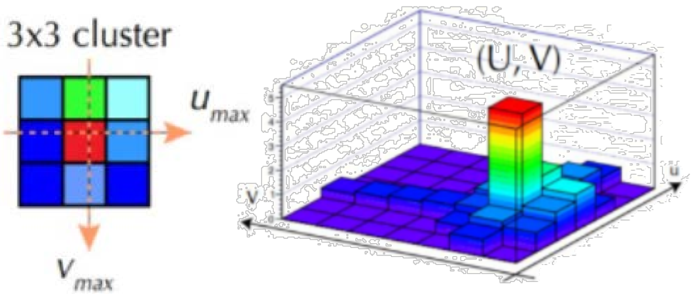
R&D: using computing accelerators (FPGAs, GPUs) ?

Several projects are ongoing at LHCb aiming to improve the trigger capabilities

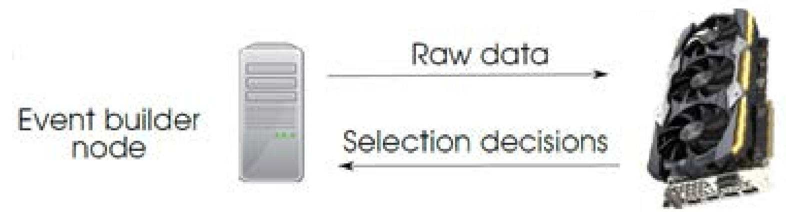
Retina: aiming to implement the most repetitive sequences on FPGAs before the HLT decision
Ex: VELO clustering on PCIe40

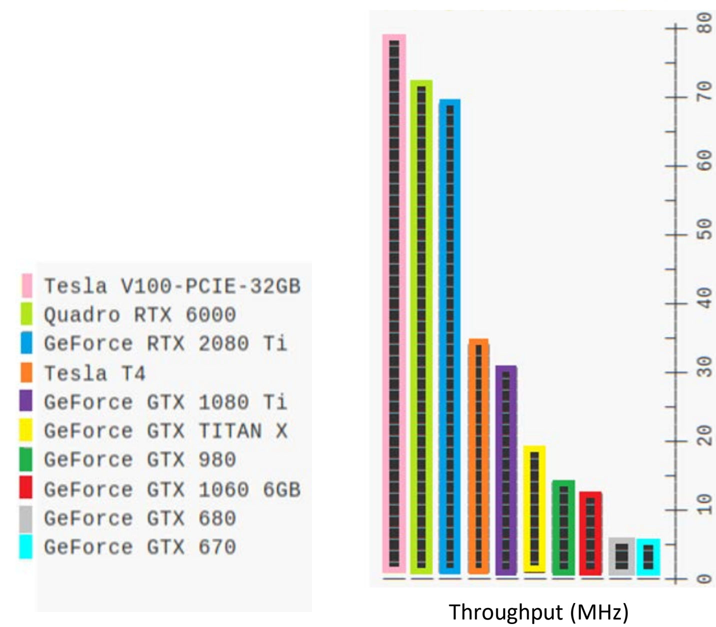






Allen: running the entire LHCb HLT1 software on GPUs

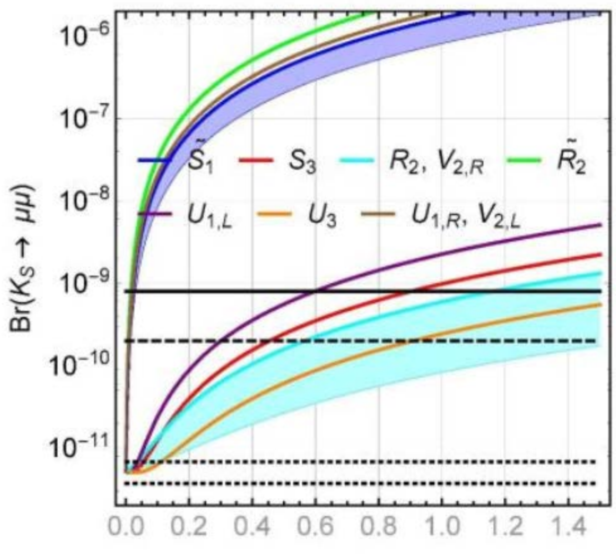




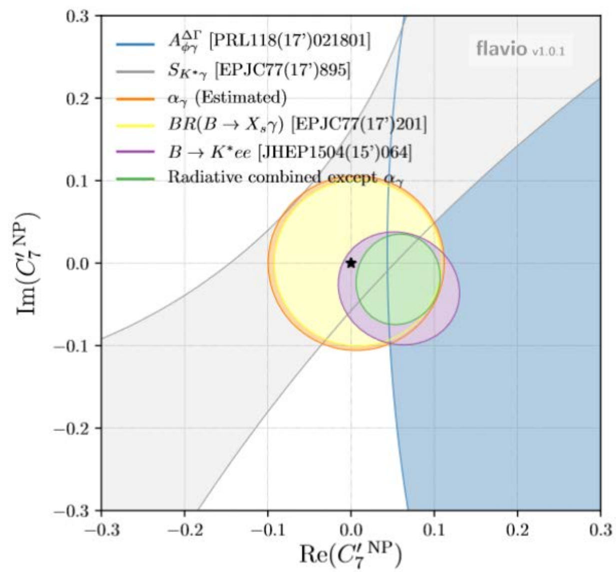
Prospects for Run3

The case for long living particles

Strong Physics case for K_s and strange baryons at LHCb



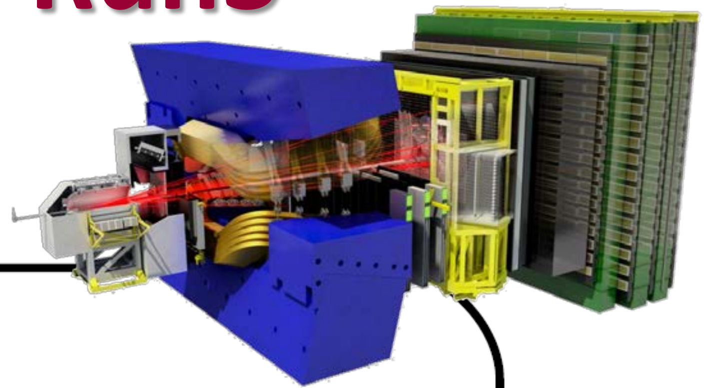
Leptoquark scenarios from Bobeth & Buras, JHEP02(2018)101



Photon polarization from b-baryon decays [Eur.Phys.J. C79 (2019) 634]

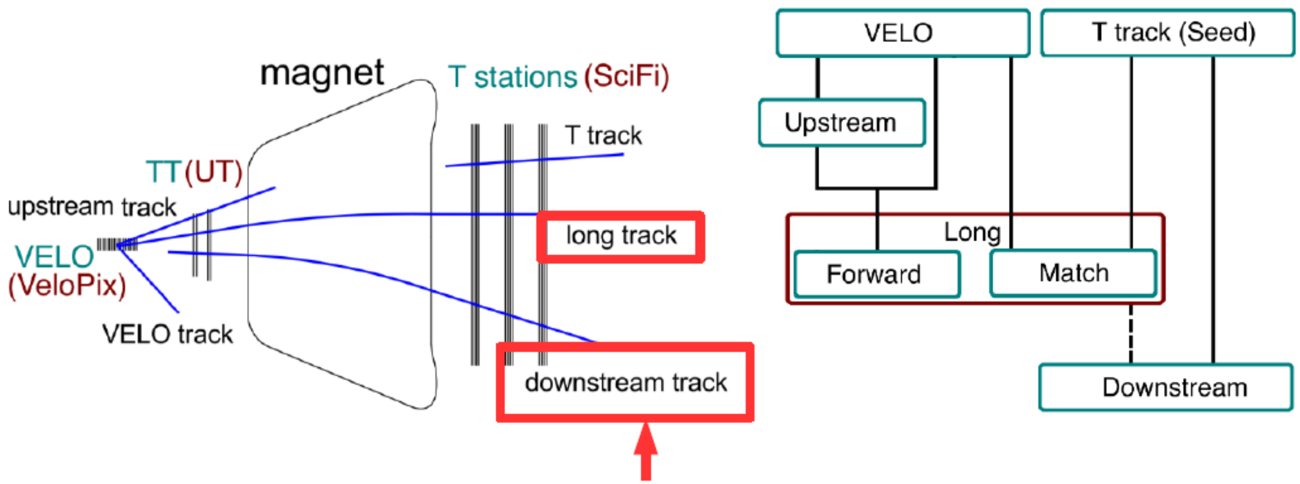
Plus a bunch of new exotica long living particles…

Prospects for Run3



The case for long living particles

Track reconstruction



Most long-lived particles decay products

Not triggered by HLT1 (fast tracking reconstruction with VELO hits)

Efficiencies below 30%

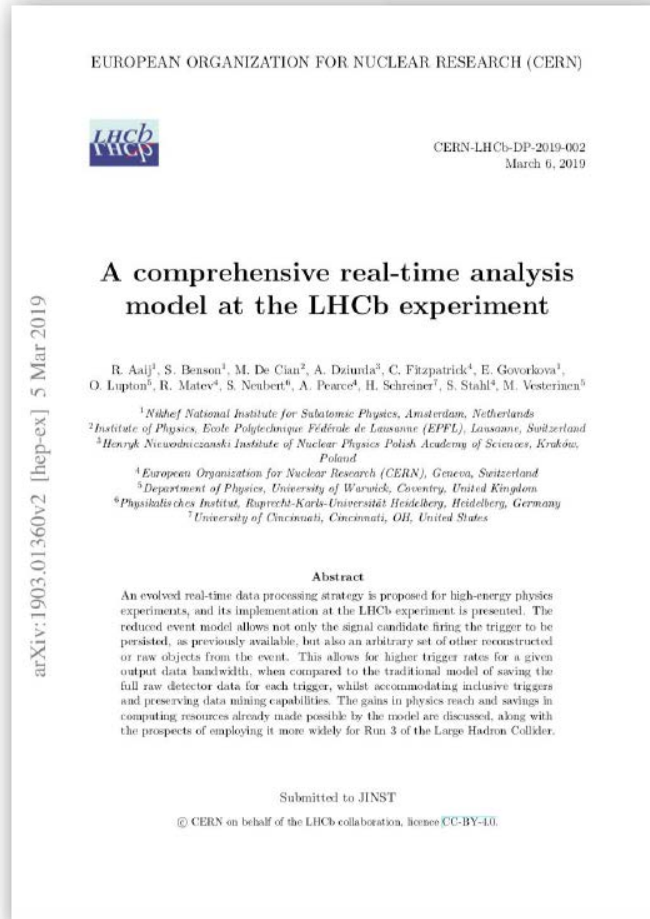
Could we trigger these events?

Conclusions

- New **Real Time Analysis** strategies are crucial to reduce the computing needs while keeping the LHCb physics program for Run3

- **Alignment and calibration** in quasi real time allows high quality and fast reconstruction at the trigger level

- Still **room to improve**, new ideas to be more inclusive to come !



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

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

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

A comprehensive real-time analysis model at the LHCb experiment

R. Aaij[1], S. Benson[1], M. De Cian[2], A. Dziurda[3], C. Fitzpatrick[4], E. Govorkova[1], O. Lupton[5], R. Matev[4], S. Neubert[6], A. Pearce[4], H. Schreiner[7], S. Stahl[4], M. Vesterinen[5]

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[7]*University of Cincinnati, Cincinnati, OH, United States*

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

JINST 14 (2019) P04006