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LHCb Run 2 trigger and upgrade reconstruction

Mark Whitehead on behalf of the LHCb collaboration

LHCb

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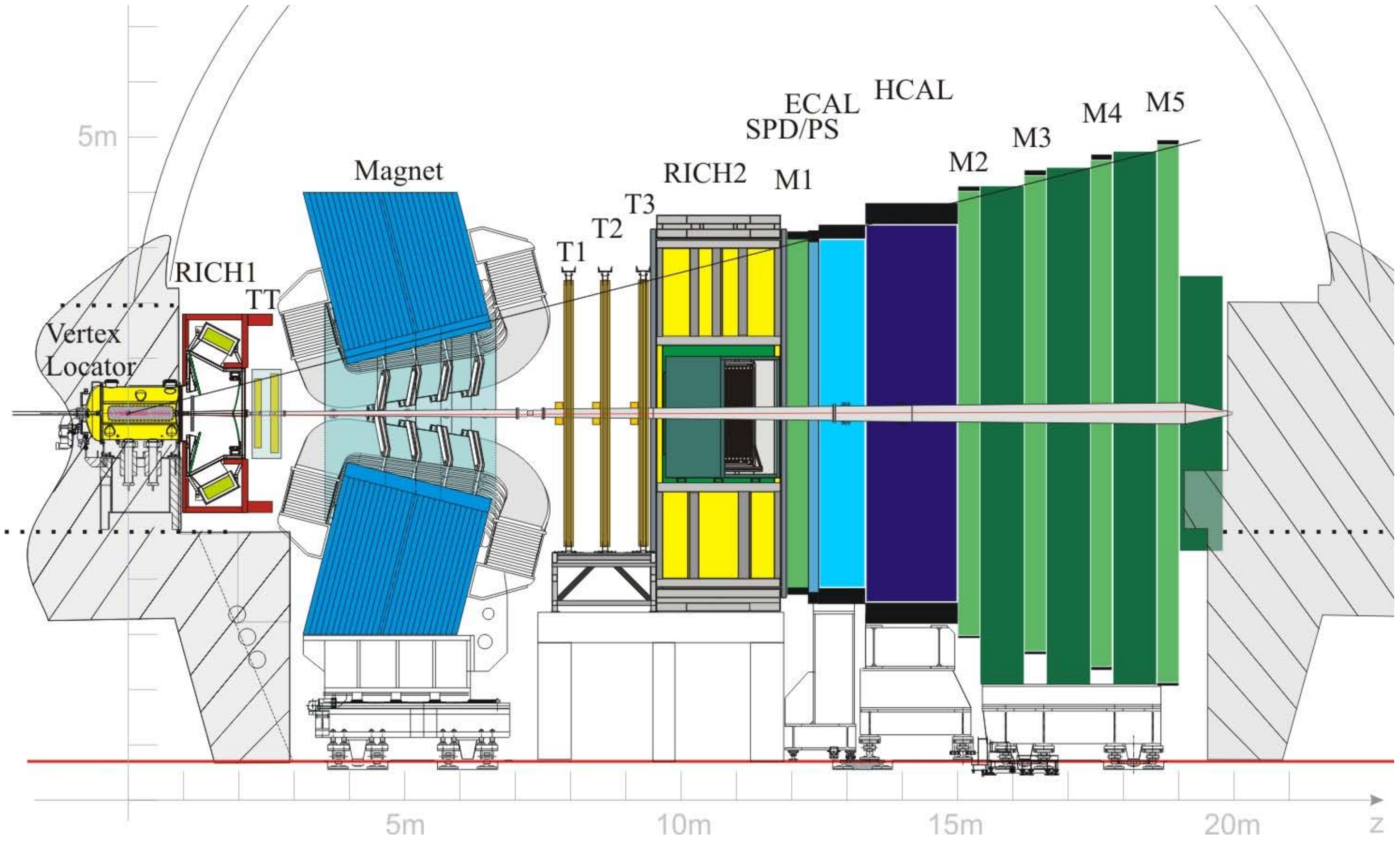
LHCb detector

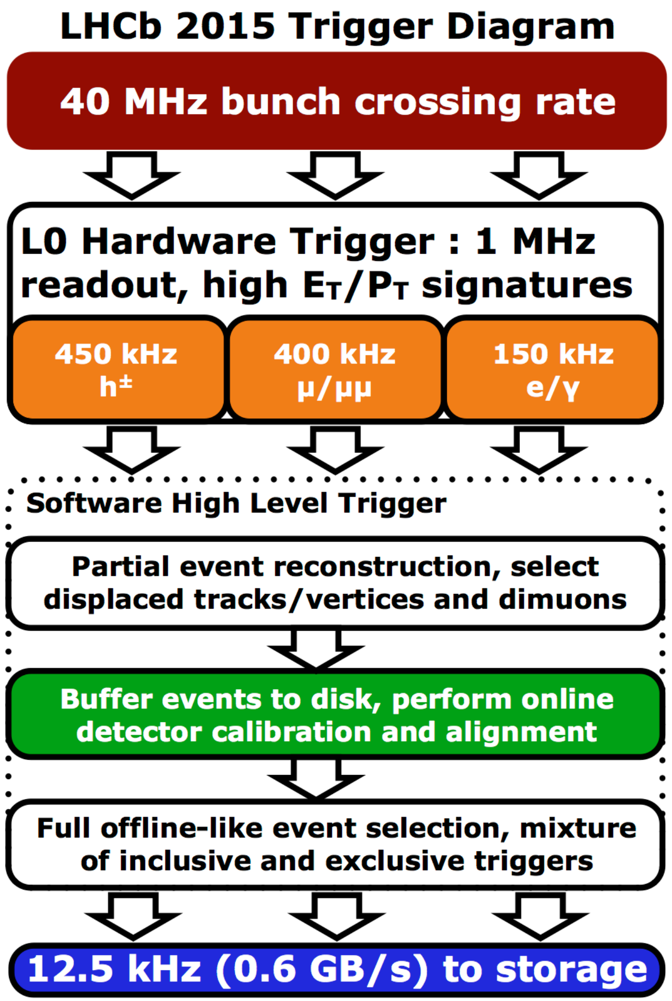
- Built to study beauty and charm decays at the LHC
  - Excellent PID performance
  - Excellent vertex resolution
  - Flexible and efficient trigger



- LHC Run II
  - 2015 - 2018
  - 13 TeV collisions
  - $\mathcal{L} \approx 4 \times 10^{32} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

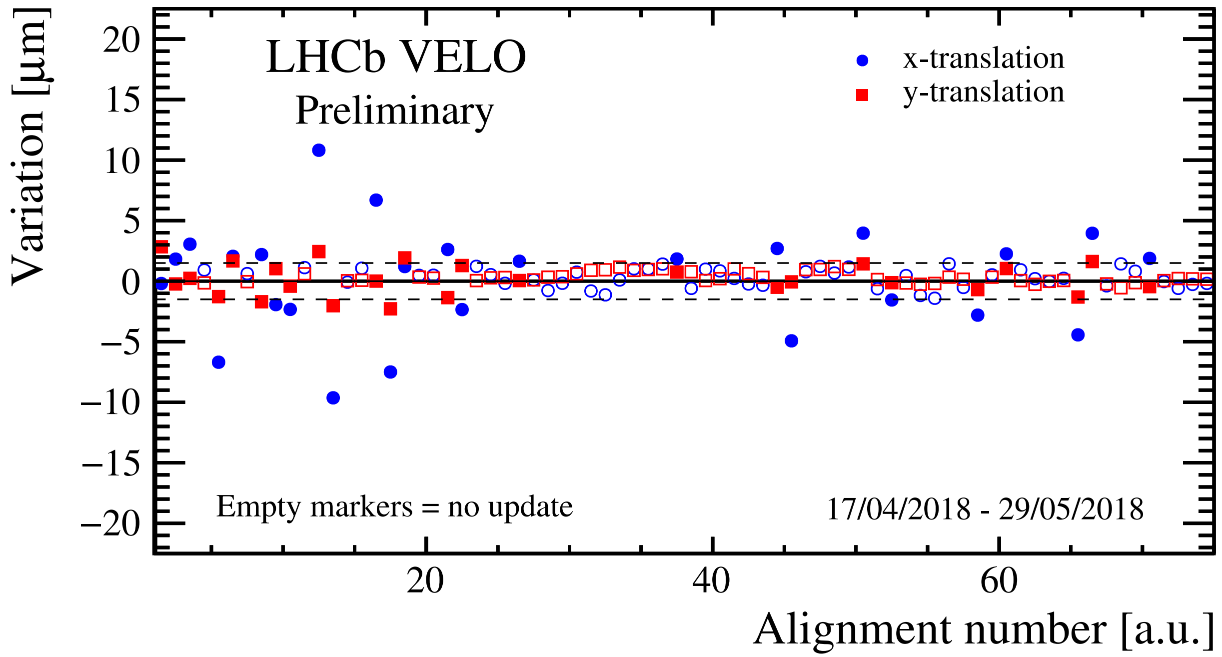
Run II trigger

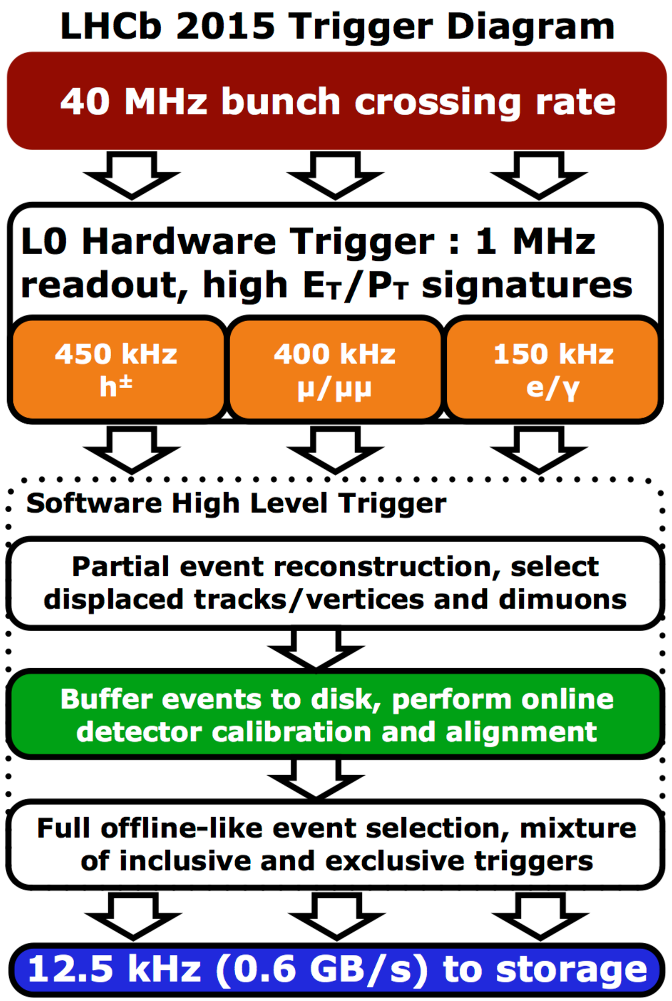
- Trigger strategy during Run II
  - Provide good performance for a very wide physics programme
  - Details on Run II tracking and reconstruction available in the poster session [Laurent Dufour, Renata Kopečná, Alex Pearce, Maarten van Veghel]
- Three stage trigger
  - L0 hardware trigger - reduces the rate from 40 MHz to 1 MHz using CALO and MUON information
  - Hlt1 - fast reconstruction performed, followed by one and two track MVA selections. Rate reduces from 1 MHz to about 100 kHz
  - Hlt2 - full event reconstruction, hundreds of trigger lines (both inclusive and exclusive) reducing the rate from 100 kHz to around 12.5 kHz



Run II trigger

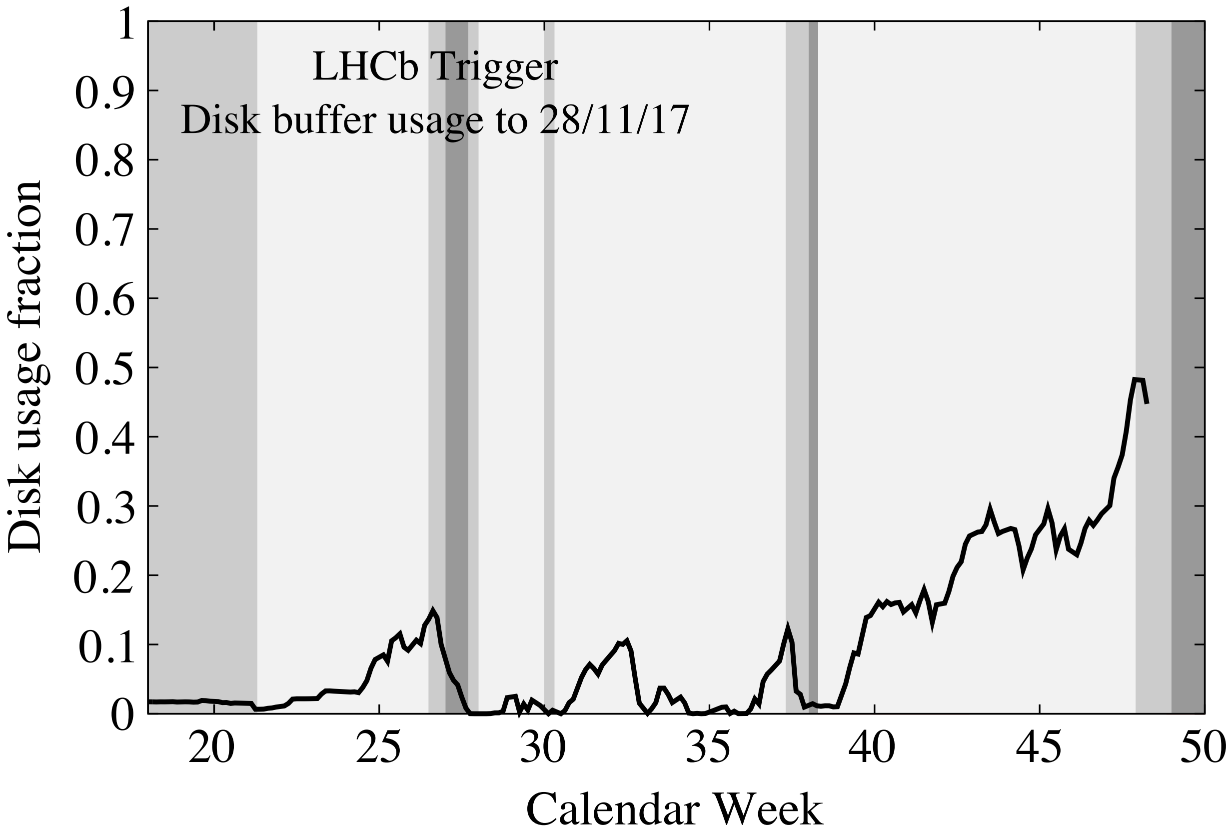
- Disk buffer between Hlt1 and Hlt2
  - Perform online detector calibration and alignment
    - Allows for physics analysis straight from the trigger
    - Turbo stream - see Alex Pearce's talk!





Disk buffer

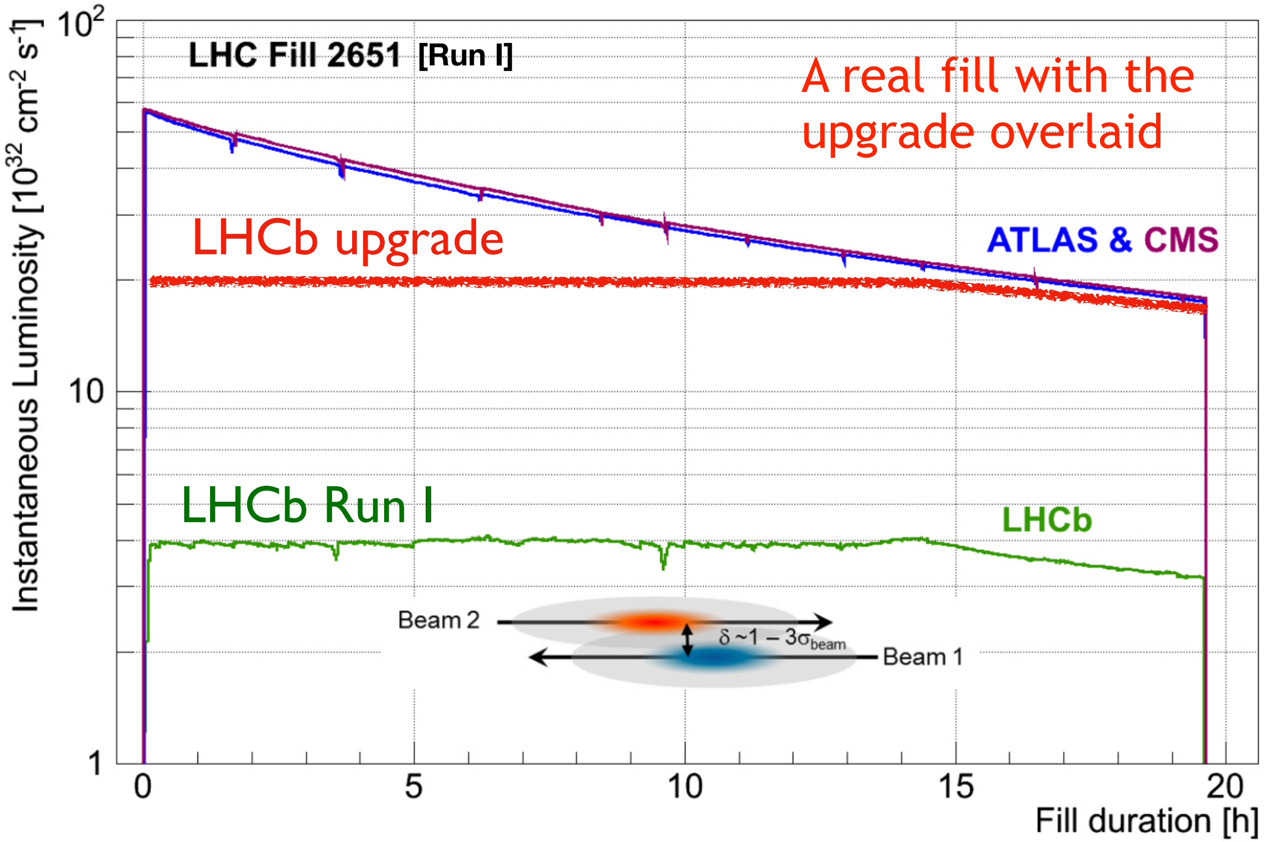
- Disk buffer between Hlt1 and Hlt2
  - 11 PB of storage, two weeks contingency when filled at 100 kHz by Hlt1. Effectively doubles available CPU resources
  - During fill - Hlt1@~100kHz, Hlt2 uses remaining CPU resources
  - Out of fill - Hlt2 runs at 100%
- Buffer constantly monitored
  - If the buffer is at risk of being filled due to exceptional LHC performance we can tighten Hlt1 to fill it more slowly.
  - In practice this has not yet been required



Why do we want to upgrade for Run III?

- We currently level our luminosity at $\mathcal{L} \approx 4 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Huge gains available if we can run at higher luminosities
- Why do we run at lower luminosity?
  - Design choices for our physics programme
  - Detector and trigger limitations

Run I + II target : 8 fb^{-1}
Run III + IV target: 50 fb^{-1}

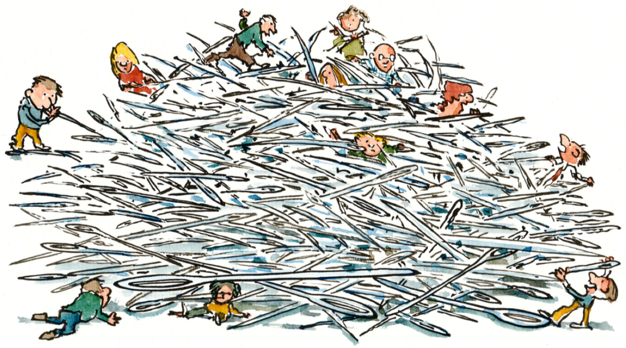


- Note that upgrading for Run 3 is before the HL-LHC era in Run 4 onwards

Upgrade challenge

- A change in paradigm for the trigger
  - 24% (2%) of bunch crossings contain a charm (beauty) hadron
  - Obviously we cannot save them all at a rate of 30MHz * 0.25 = 7.5MHz!
  - Must separate signal from backgrounds, but also signals from other signal decays
- Trigger must be flexible and efficient
  - No one size fits all solution
  - Need to cater for high rate charm and very rare B decays at the same time
  - Turbo paradigm is the way forward
  - We are limited by bandwidth, not the rate, so smaller event sizes let us save more signal events!

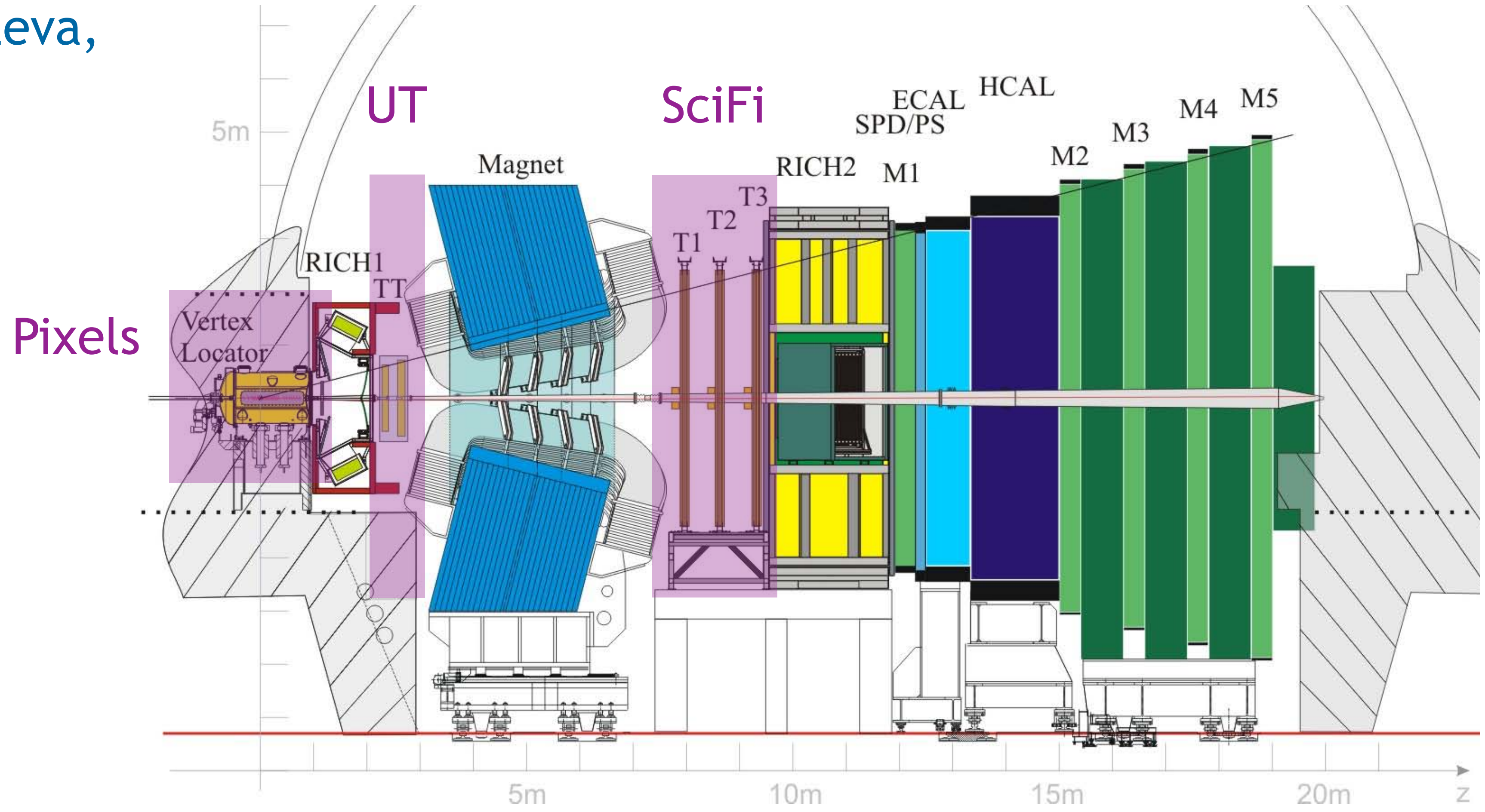
Triggers today



Triggers in the future

Upgrade detector

- Upgrade detector must deal with a factor of 5 more instantaneous luminosity
  - Talks from Giovanni Passaleva, Stefano De Capua and Michele Piero Blago
  - Replace the tracking
  - Aim to maintain Run II performance



- LHC Run III
  - 2021 onwards
  - 14 TeV collisions
  - $\mathcal{L} \approx 2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

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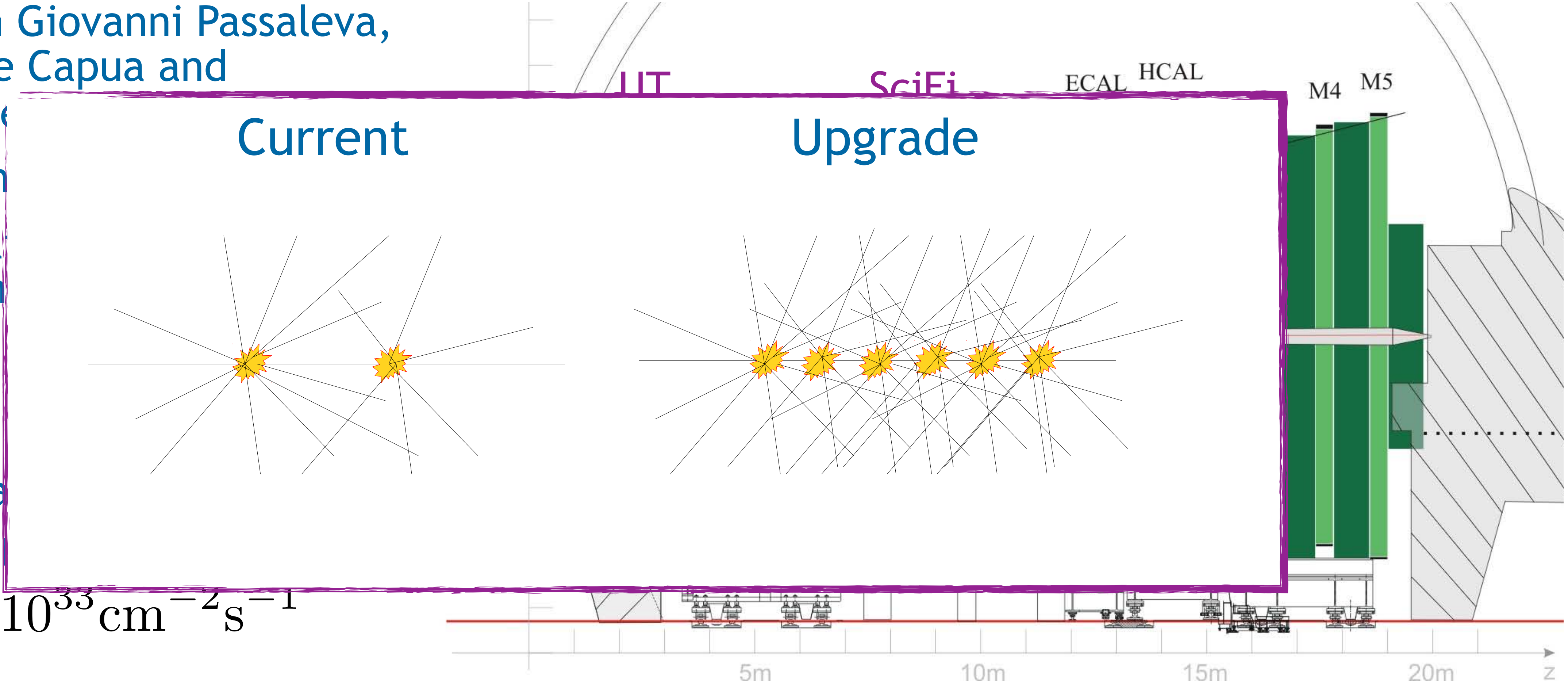

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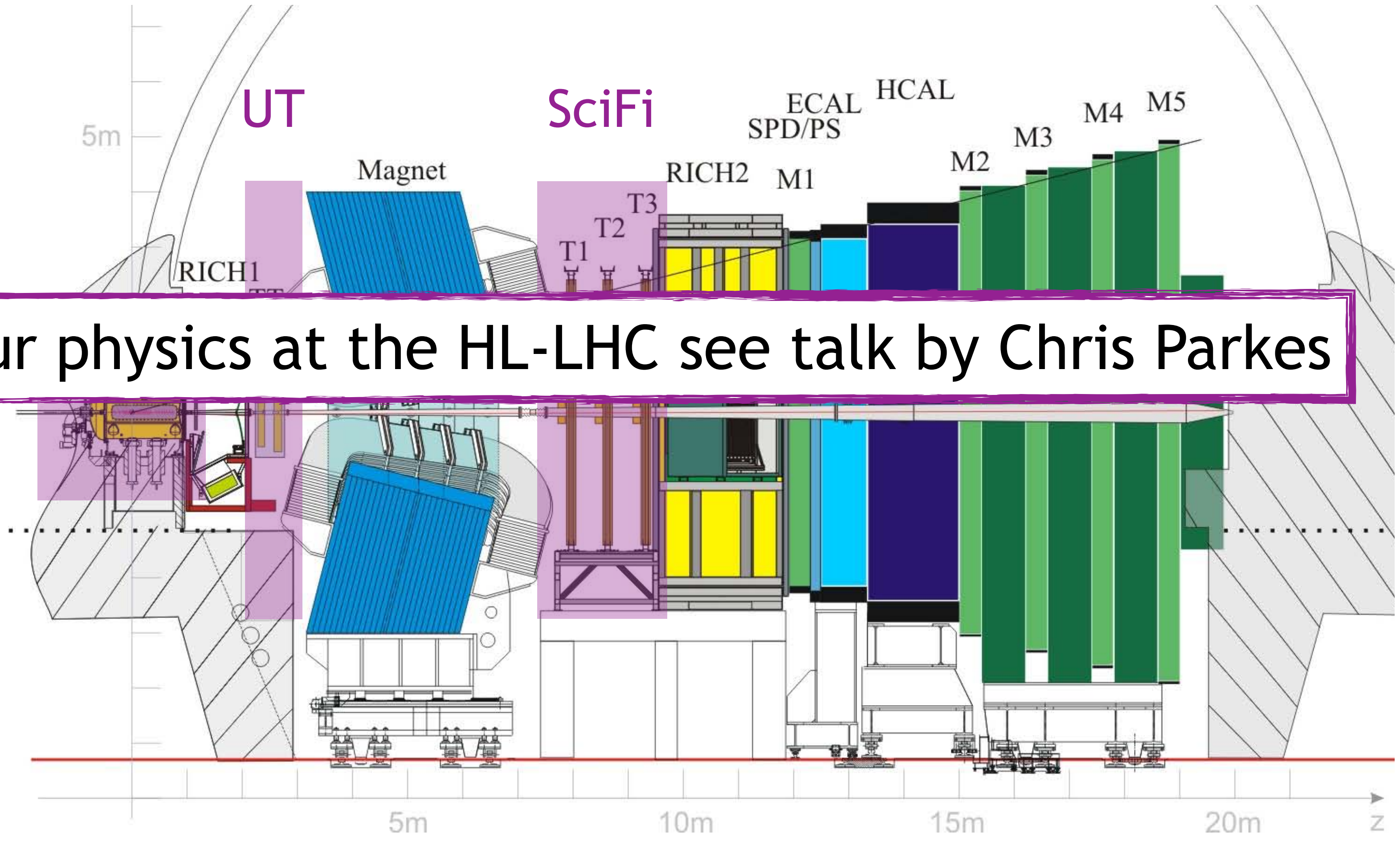
If you are interested in flavour physics at the HL-LHC see talk by Chris Parkes



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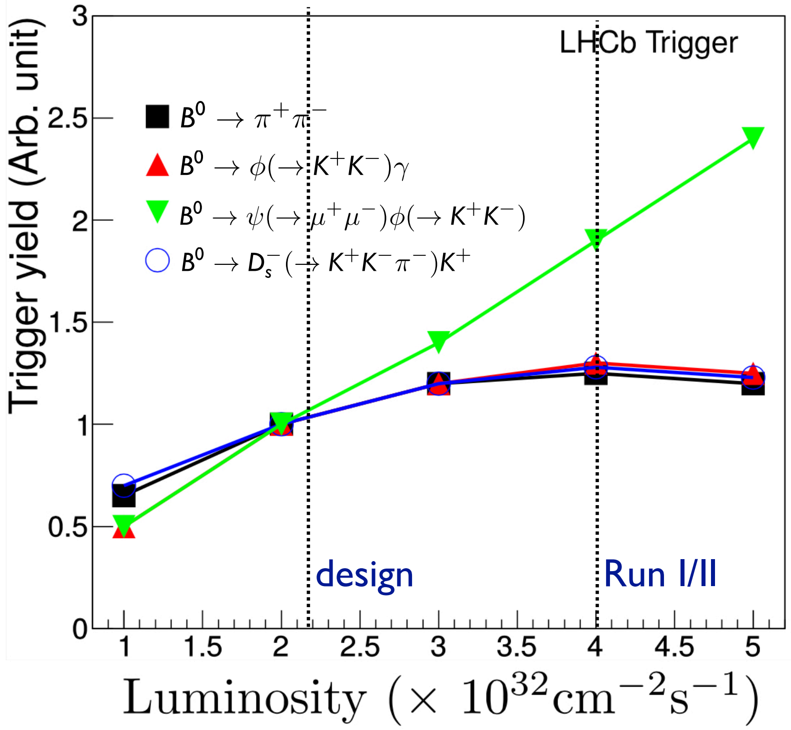
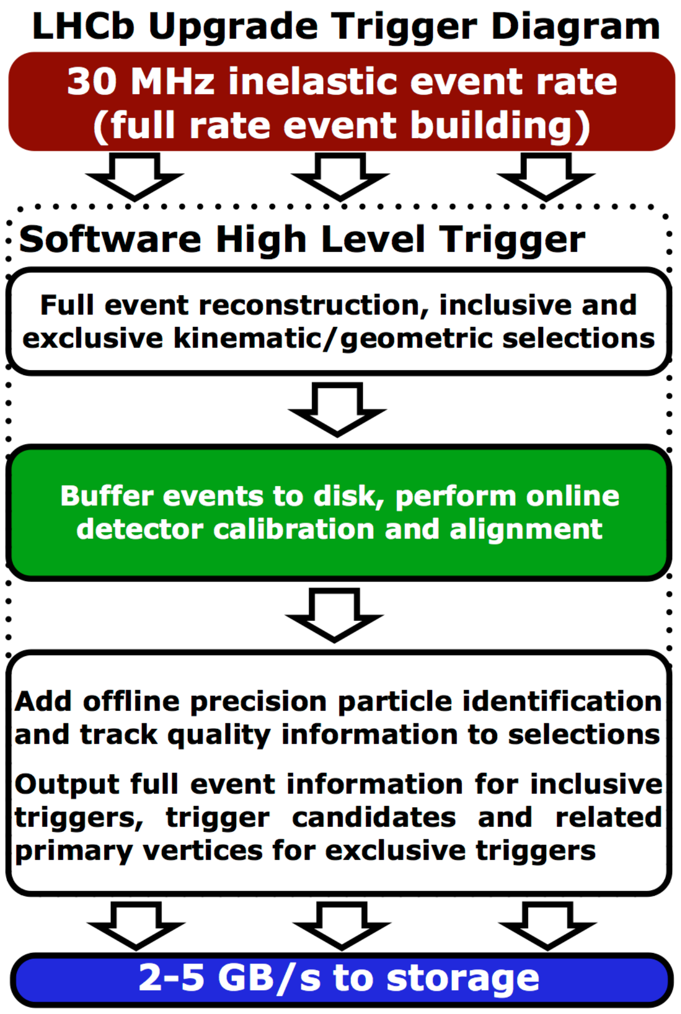
Upgrade

- Change trigger strategy - remove the readout limitation
  - Remove the hardware trigger
    - Readout is inefficient, expect a factor of two improvement for hadronic modes



- Move to a full software trigger
- Read out the full detector at 40 MHz
- Replace the entire tracking system



Upgrade

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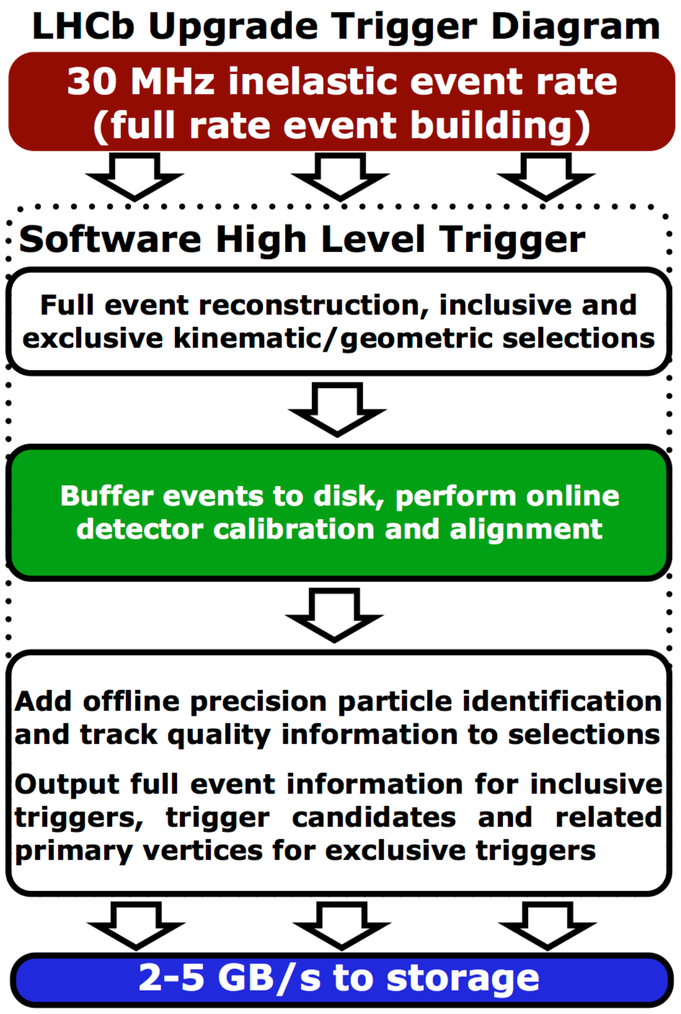
Partial event reconstruction

- Data preparation for tracking
- Track reconstruction
- Efficient event selection to reduce the rate to between 500 - 1000 kHz

Re use the Run II strategy

Full event reconstruction

- Best tracking performance, add PID information
- Offline quality selections
- Physics analysis on output of the trigger



Upgrade tracking and reconstruction

- Take advantage of the Run II trigger strategy
  - Perform a fast reconstruction stage in Hlt1 for selections and alignment and calibration
  - The second, best, stage performs the rest of the reconstruction in Hlt2

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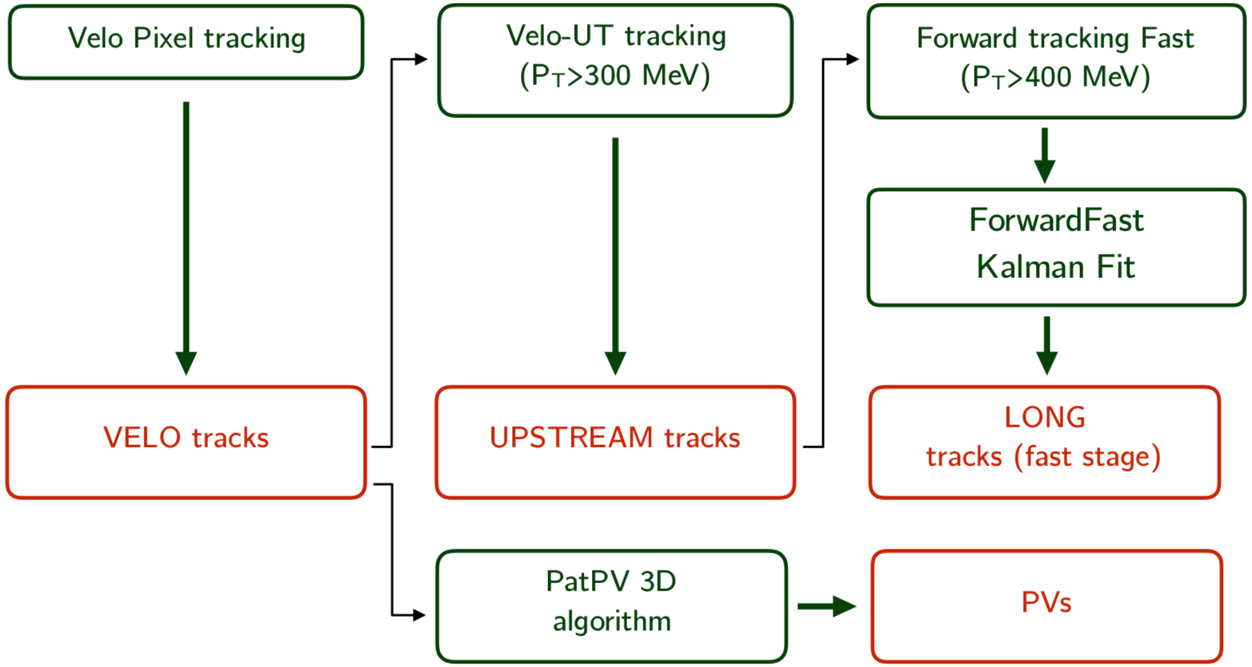
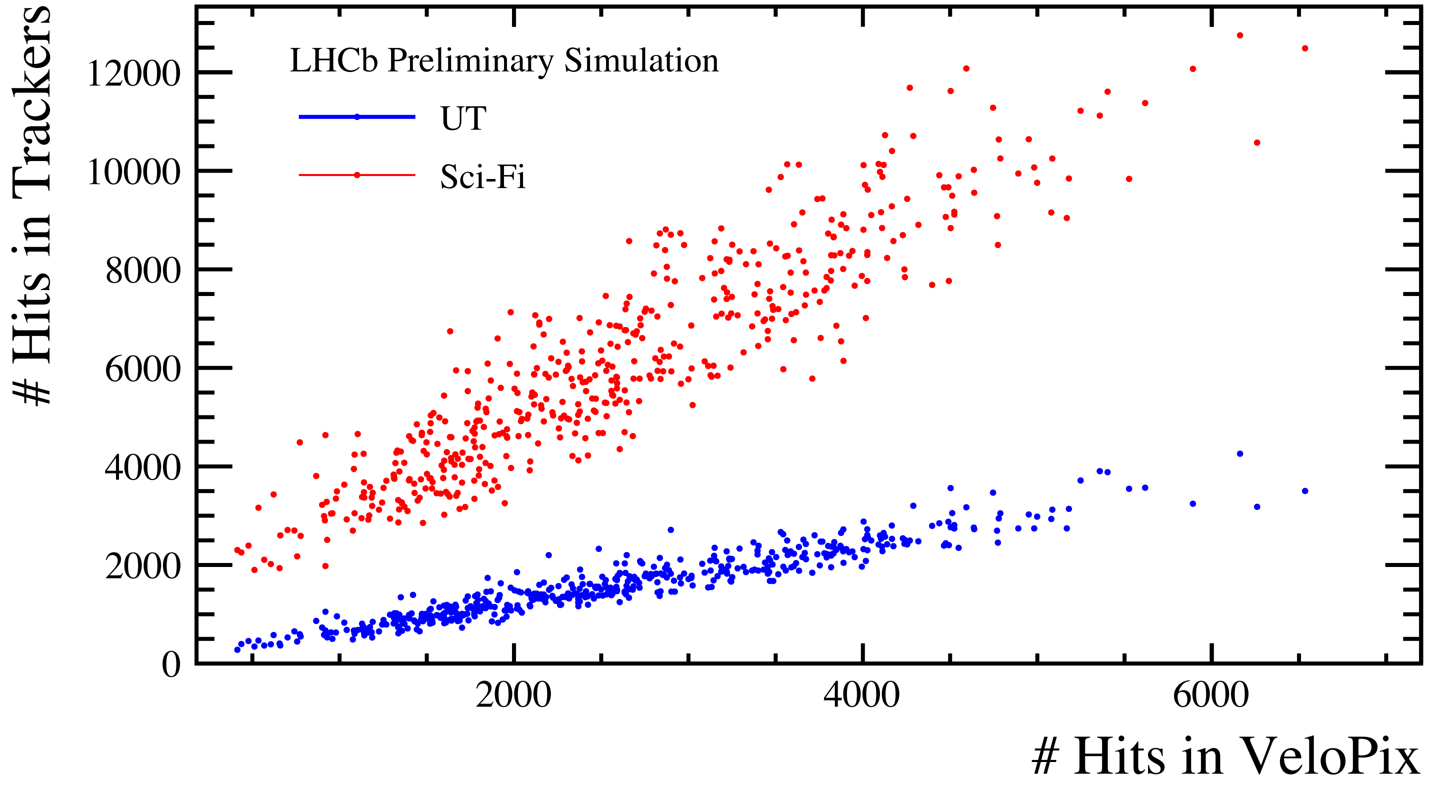


Figure 1: A schematic view of the fast tracking stage.

Data preparation

- Must also prepare data for the algorithms
  - This uses a significant amount CPU resources and makes up half of the current timing budget
  - Decoding of the raw data
  - Performing clustering for the VELO
    - SciFi and UT have clusters in the raw data
- A global optimisation
  - Fast algorithms are critical but so is preparing the data for them as efficiently as possible



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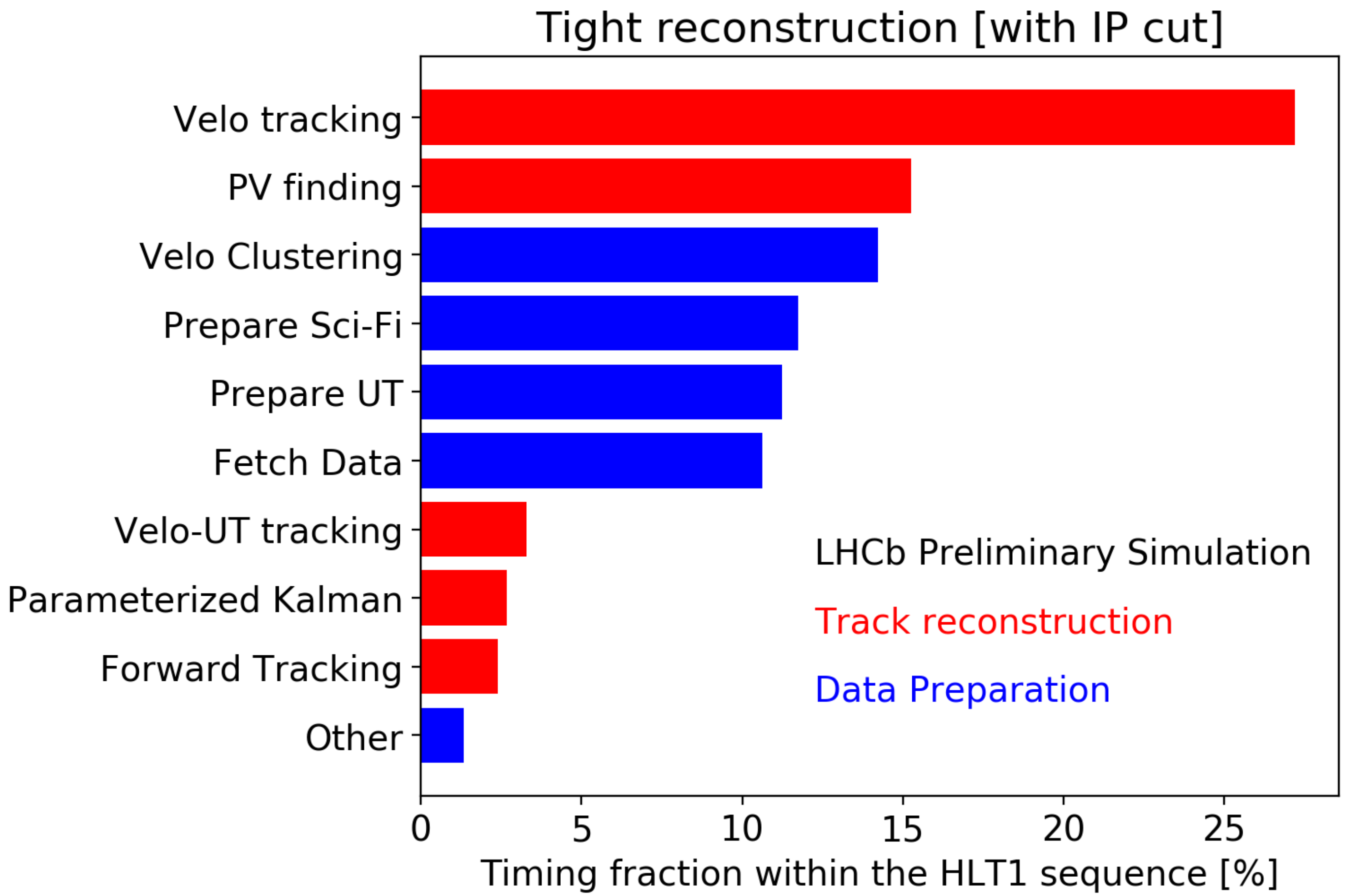
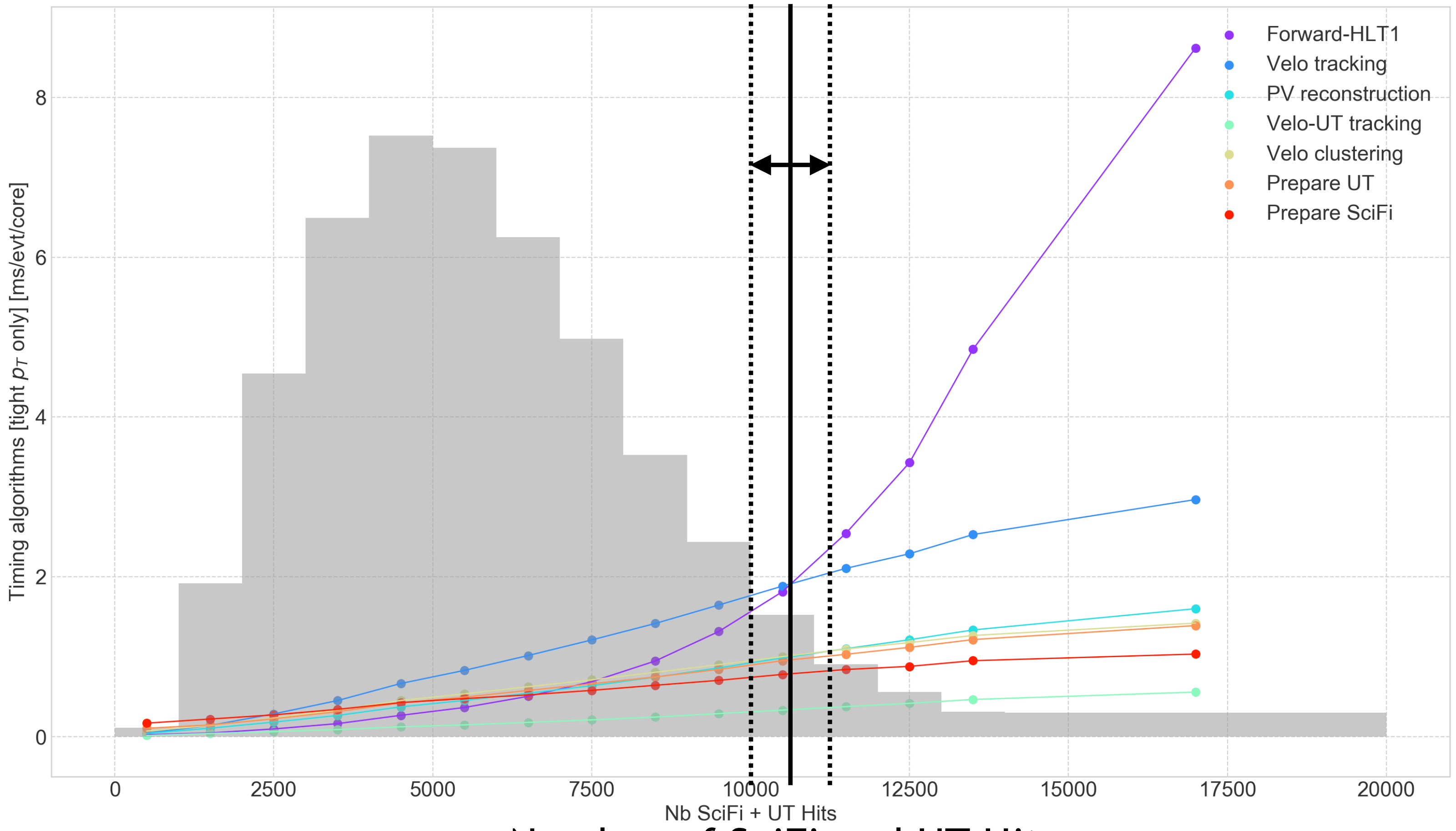


LHCb-TDR-017

Effect of detector occupancy

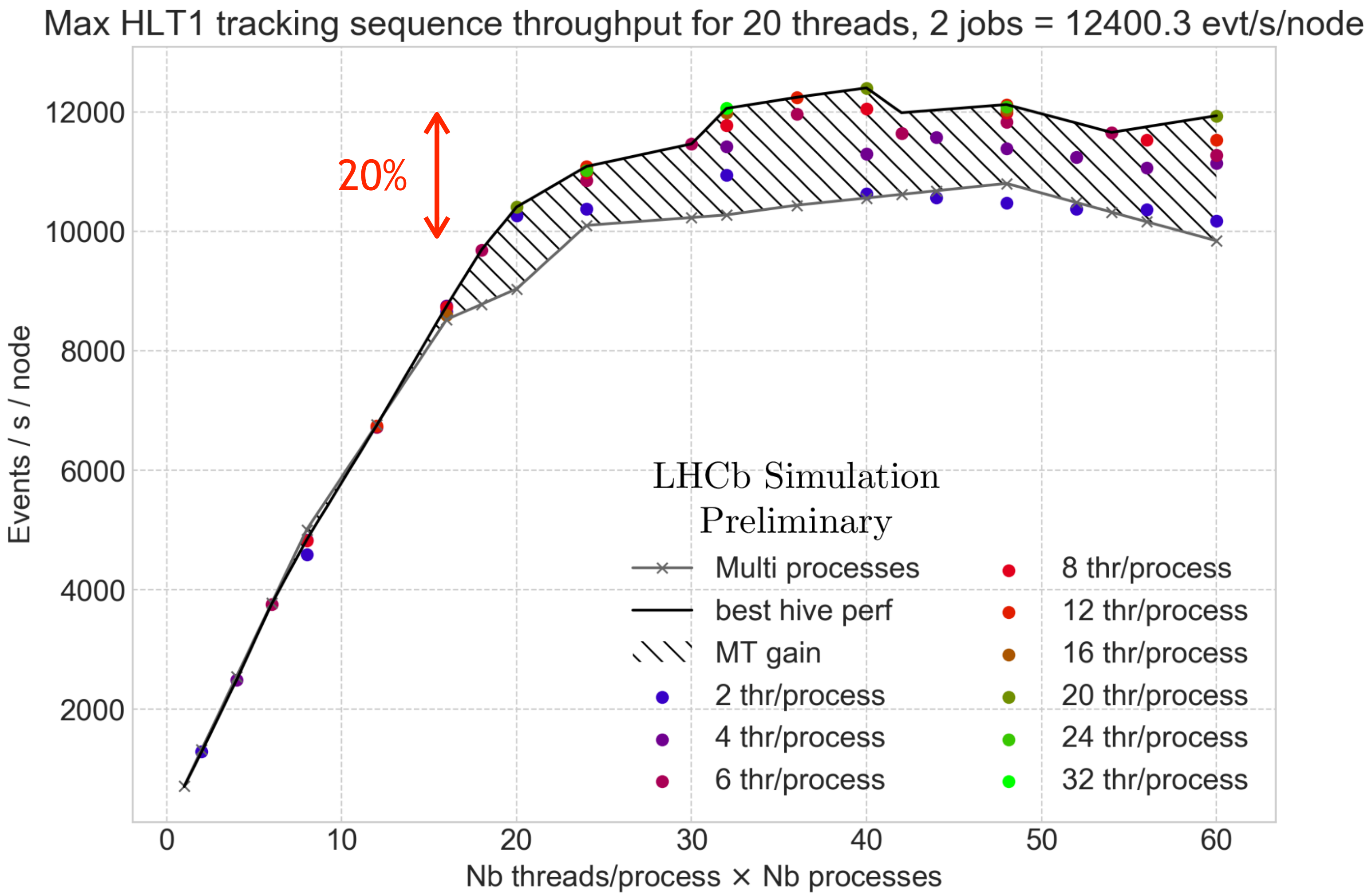
- High occupancy events take longer to process
  - Typically not representative of signal topologies anyway
  - Most algorithms scale linearly
- Reject events that take a long time to process
  - More efficient to reject them and use the time to process more signal decays



Number of SciFi and UT Hits

Throughput for Hlt1 tracking sequence

- Framework
  - Move from Run II framework to multi-threading framework
    - how much can be gained?
- Throughput studies
  - 20% improvement with multi-threading from the framework alone!
  - Tested on 20 physical cores with 40 hyper-threaded cores



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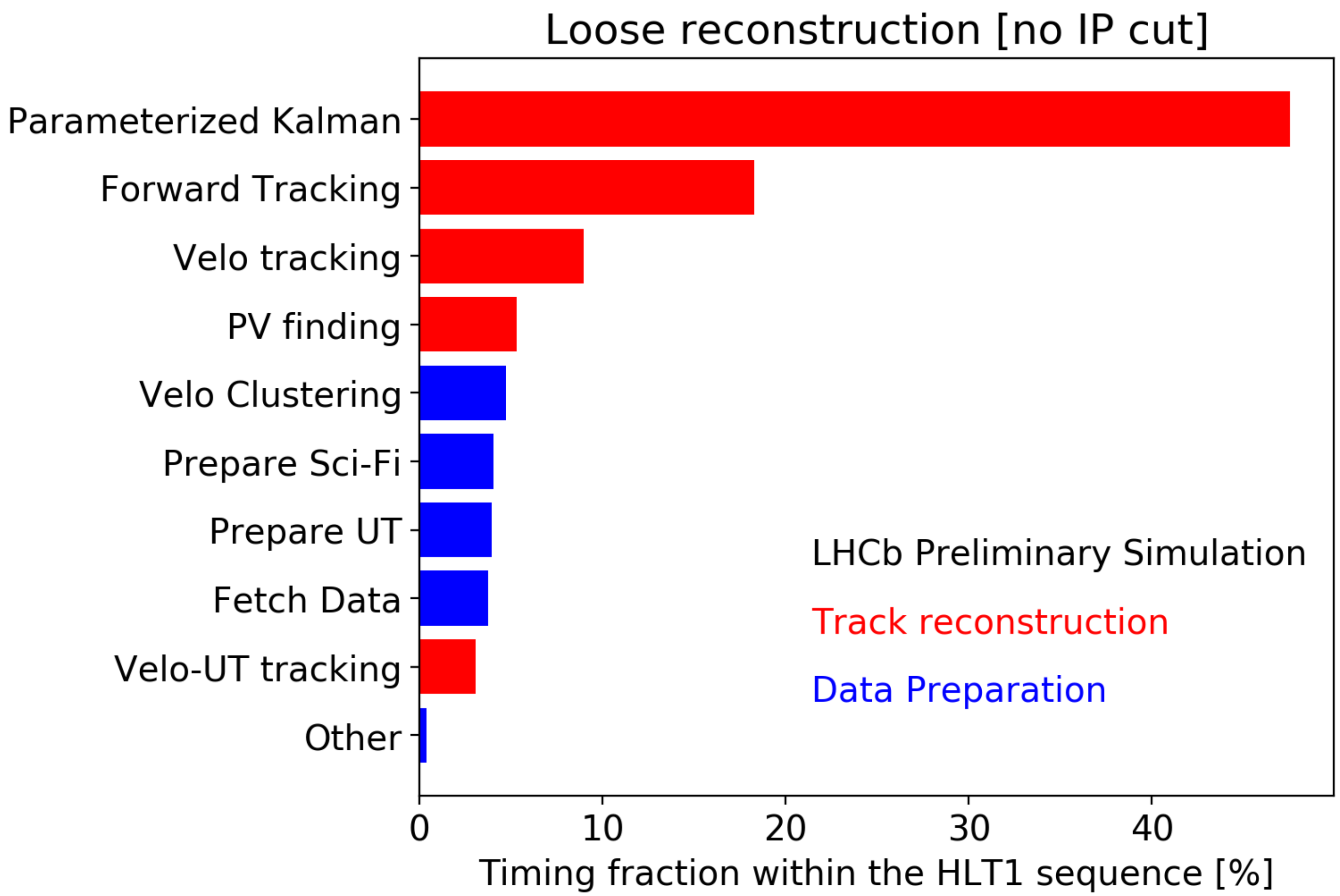
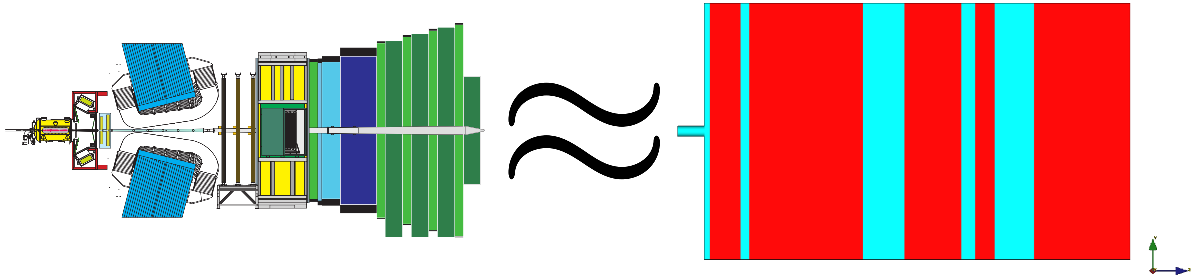
Kalman filter

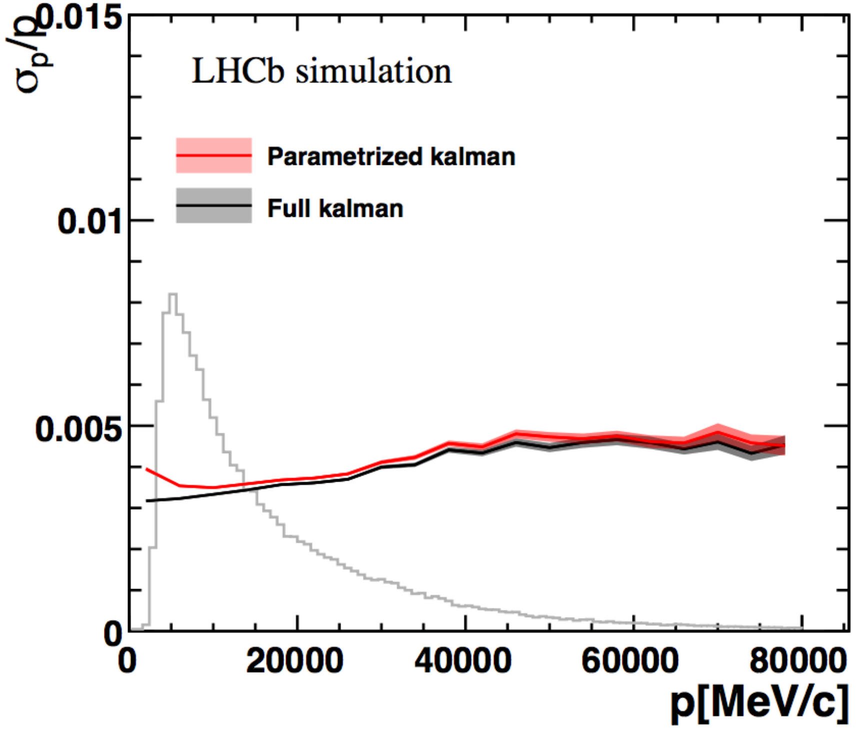
- Track fit (Kalman filter) uses a significant part of the Hlt1 budget



Kalman filter

- Track fit (Kalman filter) uses a significant part of the Hlt1 budget
  - Run I - Material look-up and B field propagation
  - Run II - Material map replaced with a simplified model





- Going further for the upgrade…
  - Parameterised Kalman - replaces material and B-field with analytic functions
  - Much faster and already has excellent performance

Optimisation

- Study efficiencies using signal MC samples

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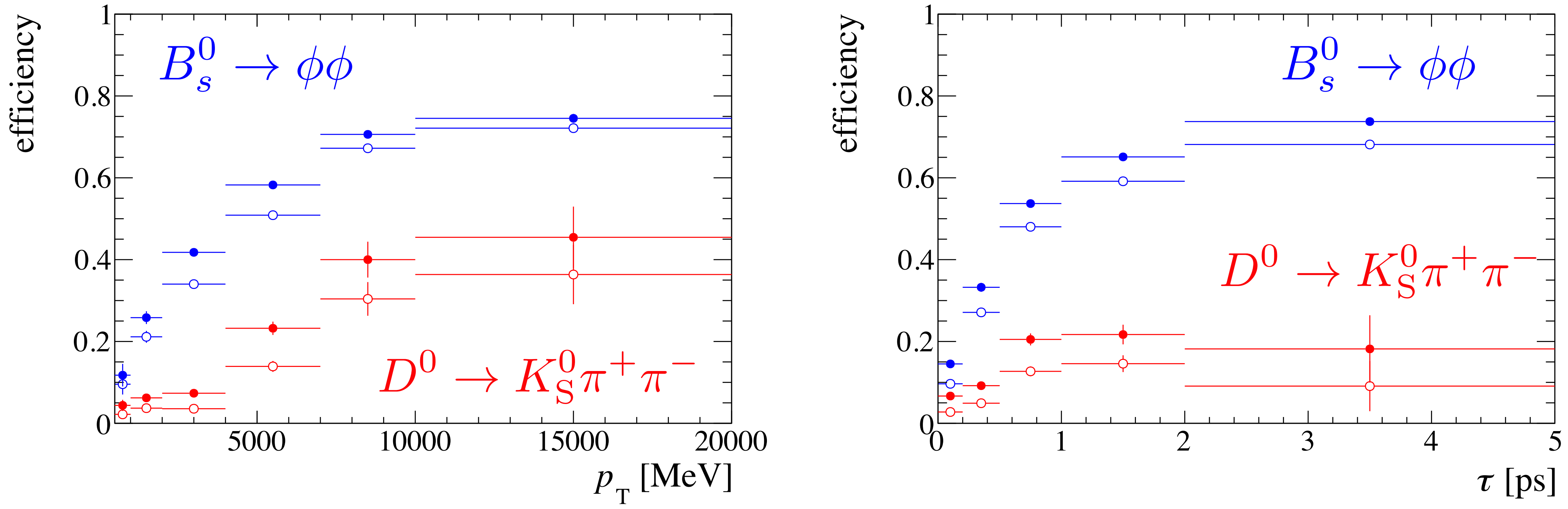
  - Already better than Run II (removal of the hardware trigger)
  - Study efficiencies as a function of pT and track displacement



Summary

- The Run II trigger strategy leads us to the upgrade trigger
  - No hardware trigger - software part to run at 30 MHz
  - This is a real challenge and great progress is being made

- Displaced-track reconstruction sequence in place
  - Throughput is now equally limited by data preparation and reconstruction algorithms
  - Detailed profiling being performed to highlight areas for further improvements

- Already more efficient for beauty and charm decays than in Run II
  - Gained a factor of two in throughput performance in the last year
  - Excellent progress from the work of many people in specific areas