# Impact of the high-level trigger for detecting long-lived particles at LHCb

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on behalf of the LHCb RTA project

# Outline

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  - Tracking system and track types
  - The High Level Trigger (HLT) in LHCb upgrade
  - LLPs at LHCb
- Physics case: Sensitivity studies of long-lived particles
  - LLPs in Standard Model
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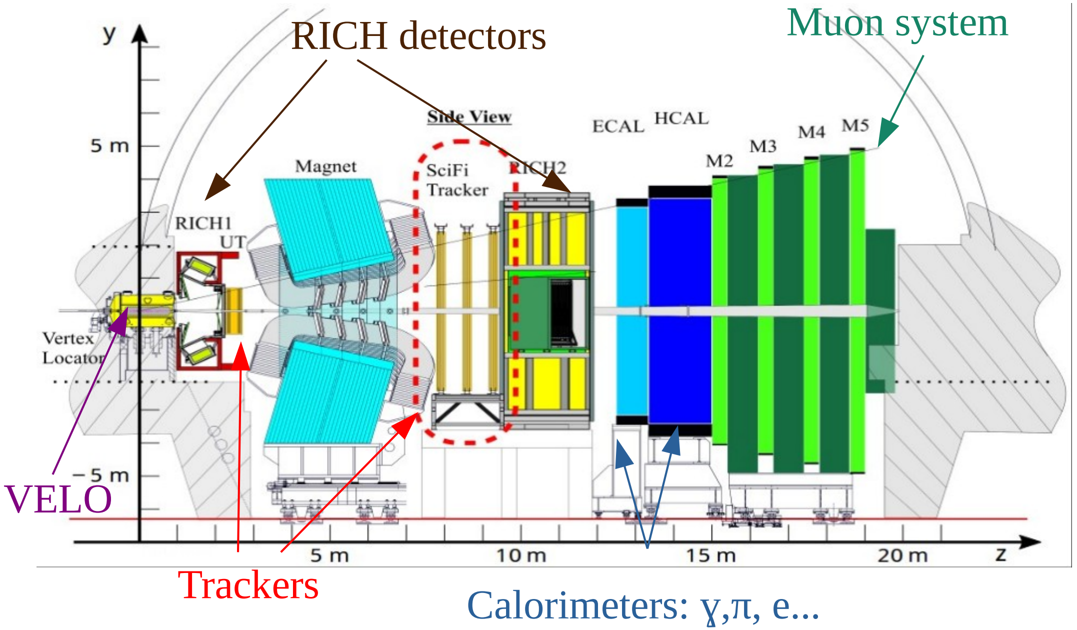
- 
- Summary

# LHCb detector in Run 3

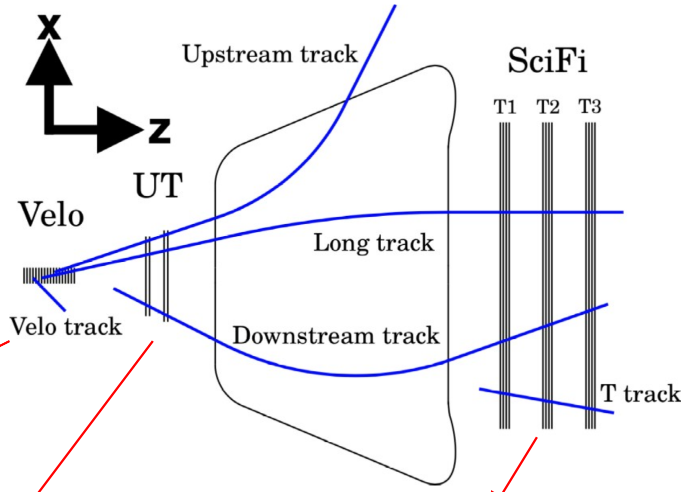
- Single-arm spectrometer in the forward direction
- Originally designed for specialised study of beauty and charm hadrons
- Excellent secondary vertex resolution
- Particle ID: calorimeters, muon systems and Ring Imaging Cherenkov (RICH) detectors
- Upgrade I (Run3):
  - Luminosity: $4\times10^{32}$ $cm^{-2}s^{-1}$ → $2\times10^{33}$ $cm^{-2}s^{-1}$
  - Purely software-based trigger @ 30MHz

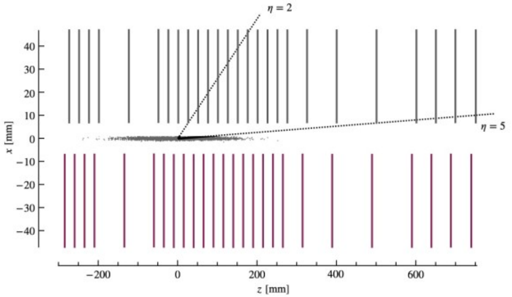
CERN-LHCC-2012-007, LHCb-TDR-12

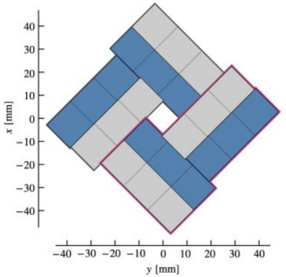


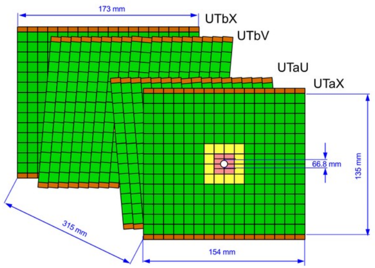
# Tracking system and track types

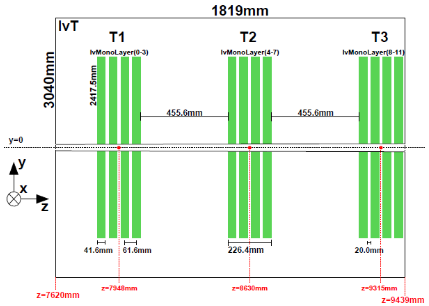
- Three tracking stations:
  - VELO: 26 modules of pixellated hybrid silicon detectors
  - UT: 4 planes of silicon strip trackers
  - SciFi: 12 planes of scintillating fibre trackers
- Main track types for physics analysis:
  - Long: signal in VELO and SciFi (minimum) + UT (full)
  - Downstream: signal in UT and SciFi
  - T: hits only in SciFi



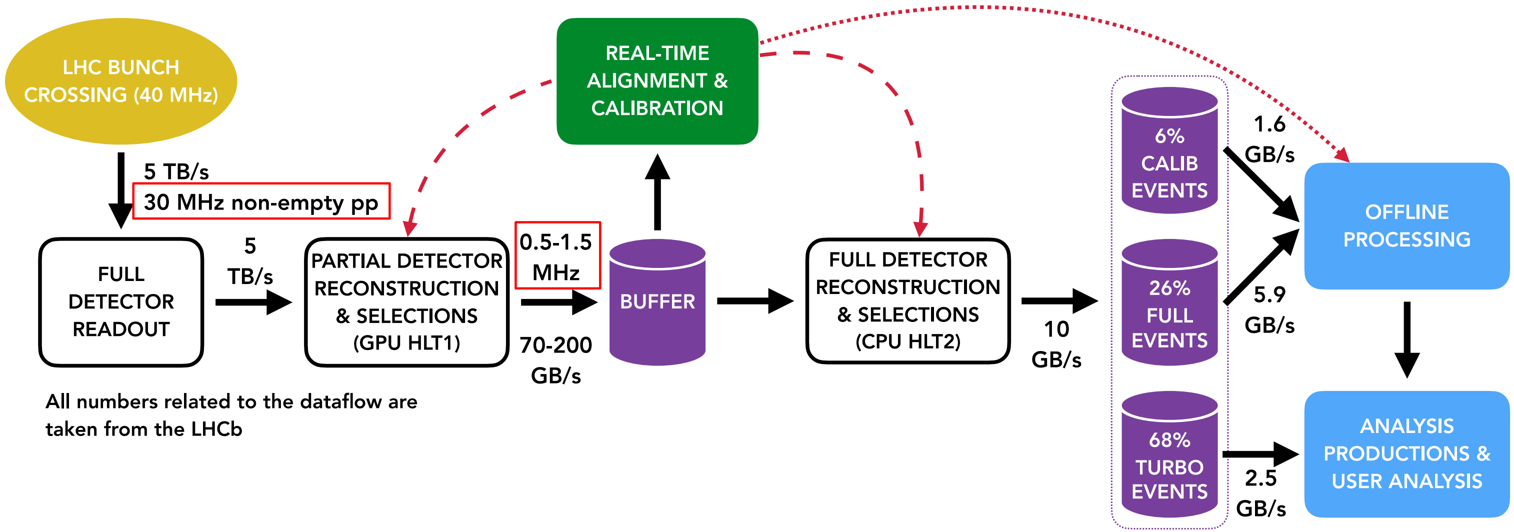




CERN-LHCC-2012-007, LHCb-TDR-12

# The High Level Trigger (HLT) in LHCb upgrade

Run HLT in 2 stages:

- HLT1: Partially reconstructs event and reduces bandwidth from 30MHz to 1MHz
- HLT2: Fully reconstructs event and reduces bandwidth from 70-200GB/s to 10GB/s



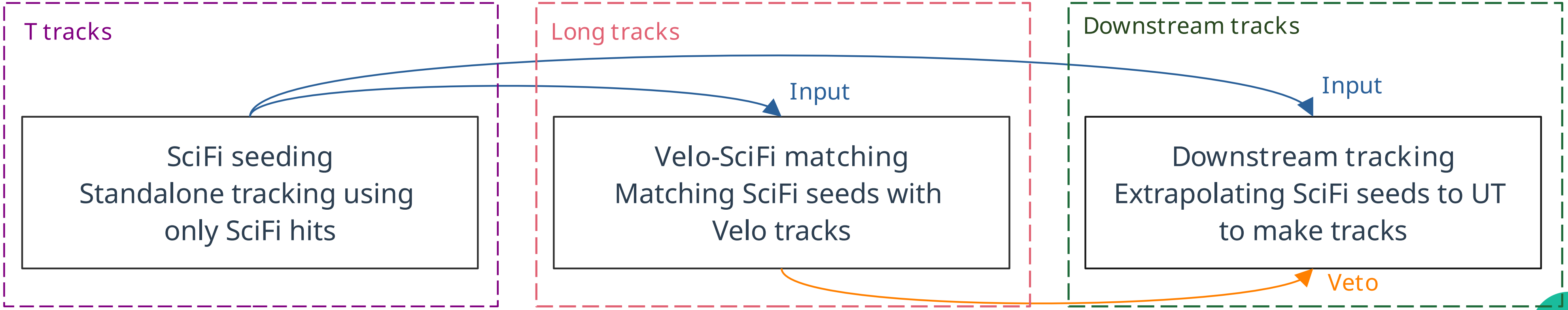

All numbers related to the dataflow are taken from the LHCb

Data rate (kB/s) = Event size (kB) * Event rate (Hz)

Event size:
- Turbo ~ 35 kB
- Full ~ 70 kB

# The High Level Trigger (HLT) in LHCb upgrade

- Long living particles (LLPs) are particles that travel significant distances before decaying into other particles:
  - Likely to decay after VELO ⇒ Downstream / T tracks
  - The current HLT1 only triggers long tracks ⇒ Less sensitive to LLPs searches
- We need to add dedicated LLP triggers to HLT1: Implementing the Hybrid seeding arxiv:2007.02591



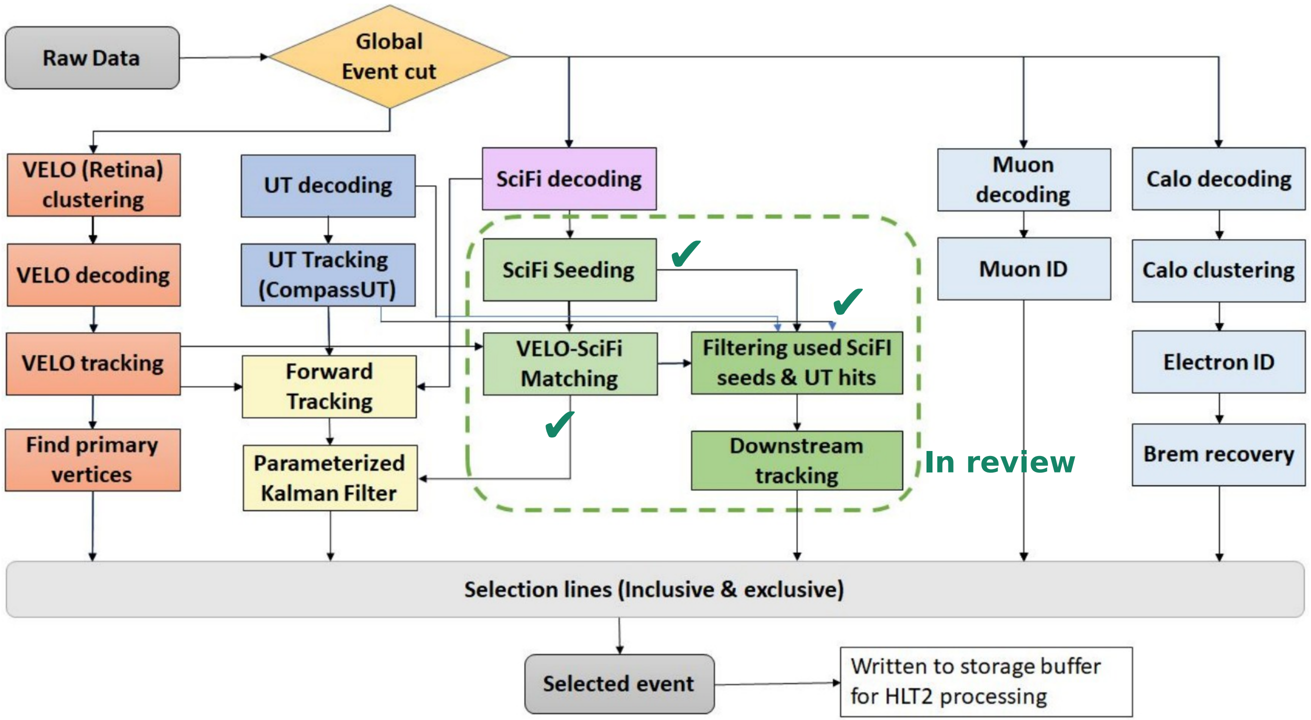
# The High Level Trigger (HLT) in LHCb upgrade

Main goal:

- Add LLP reconstruction and selection to HLT1 in Run3

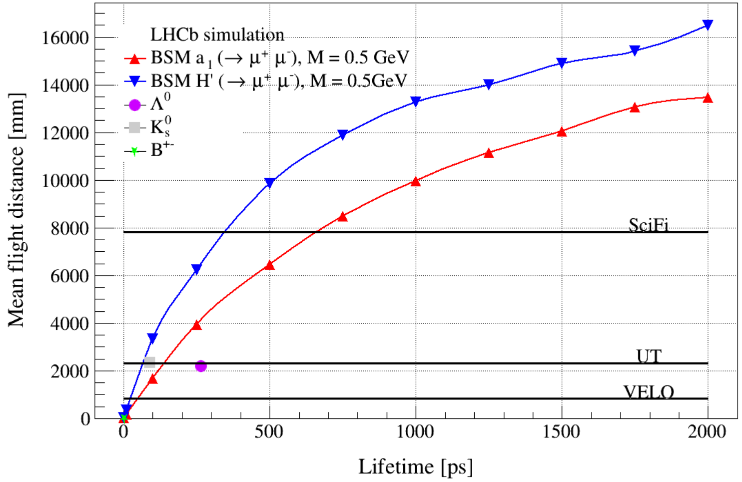
Progress in reconstruction

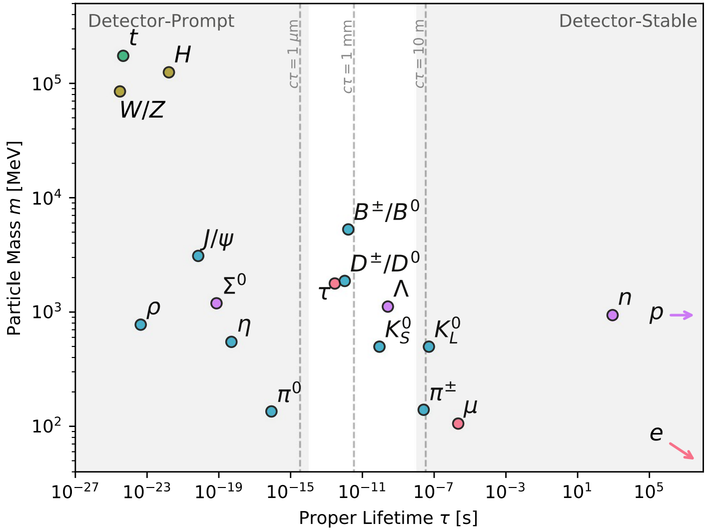
- SciFi seeding ✔ Done
- Velo-SciFi matching ✔ Done
- Downstream In review



# LLPs at LHCb

- LLPs present in SM and many BSM extensions
- Expected track types depend on LLP flight distance
- Downstream and T tracks are NOT yet considered in HLT1 decision before → target Run3




10.1016/j.ppnp.2019.02.006

Hunt for LLPs in LHCb with Downstream and T tracks

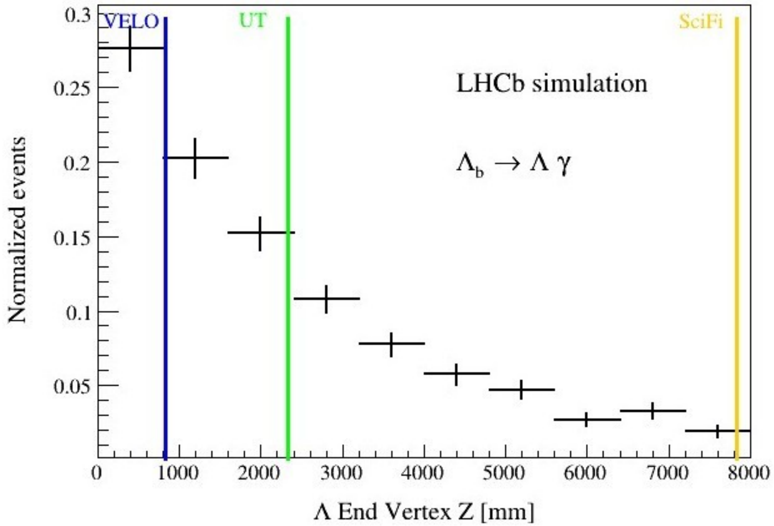
10.3389/fdata.2022.1008737

# LLPs in the Standard Model

- $\Lambda_b \to \Lambda^0 [\to p^+ \pi^-] \gamma$: photon polarization
  - Non-standard right-handed current

$$(\alpha_\gamma) = \frac{P(\gamma_L) - P(\gamma_R)}{P(\gamma_L) + P(\gamma_R)}$$

10.1140/epjc/s10052-019-7123-7

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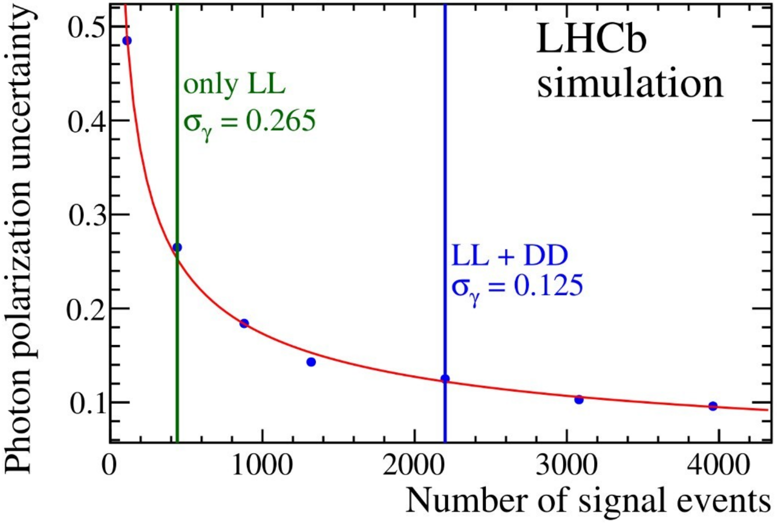
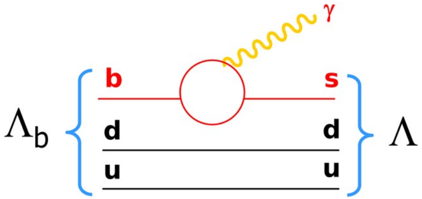
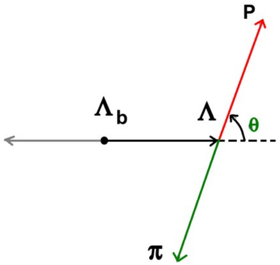
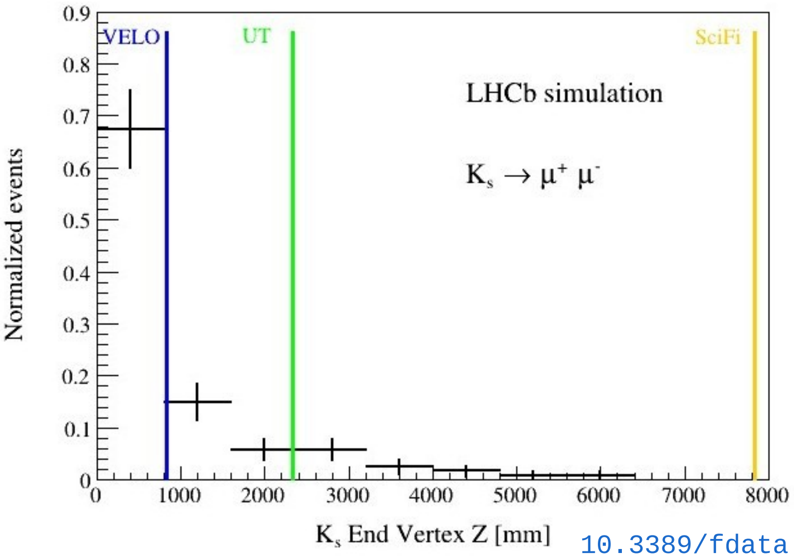


# LLPs in the Standard Model

- $K_s^0 \rightarrow \mu^+ \mu^-$: not yet observed
  - Suppressed by SM
  - Sensitive to BSM: SUSY and Leptonquarks

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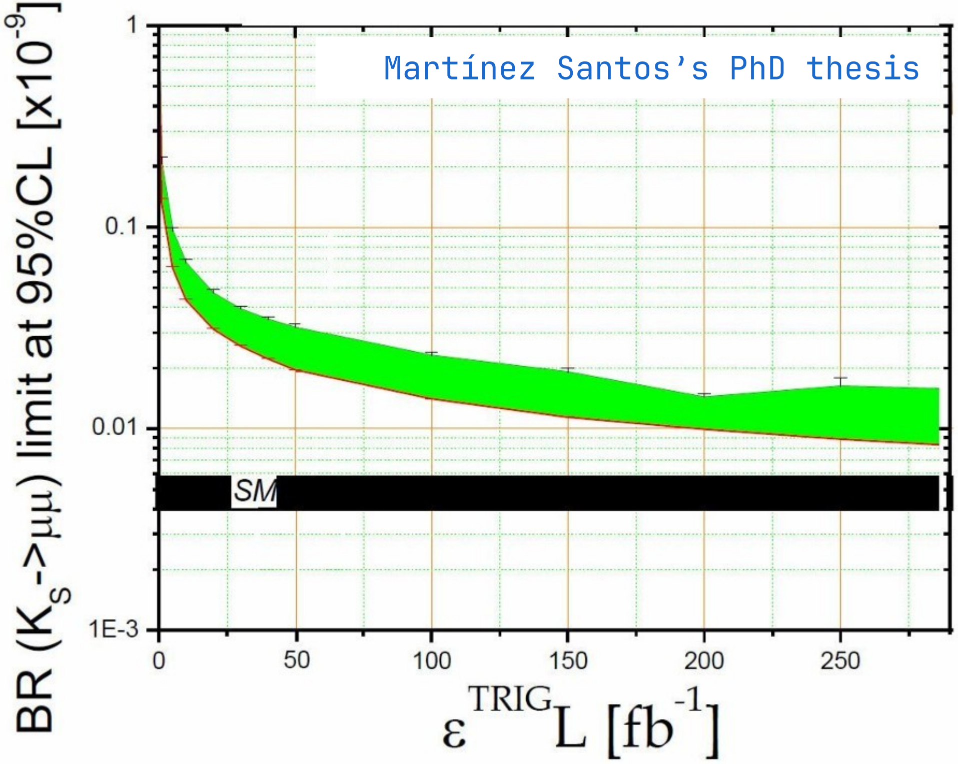
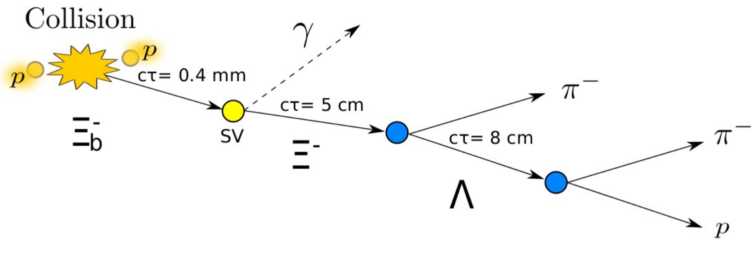


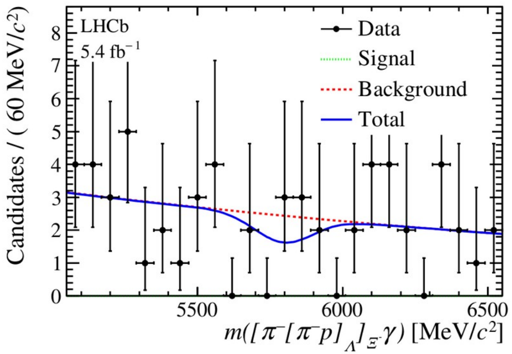
# LLPs in the Standard Model

- SM LLPs: $\Lambda^0$ and $K_s^0$

10.3389/fdata.2022.1008737

| | LL | DD | TT | HLT1 eff (TOS) |
|---|---|---|---|---|
| $\Lambda^0$ | 12% | 51% | 37% | **< 10%** |
| $K_s^0$ | 46% | 39% | 16% | **< 25%** |




No observed in Run2

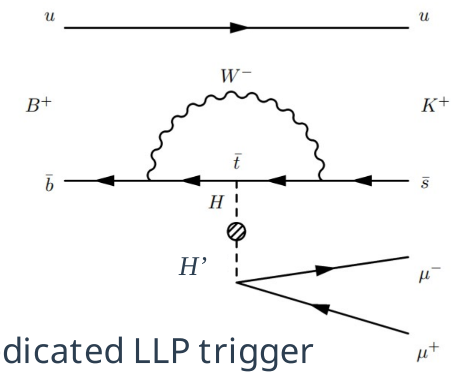
$Br(\Xi_b^- \rightarrow \Xi^-\gamma) < 1.3(0.6) \times 10^{-4}$

at 95%(90%) CL

(PHYS. REV. D105 (2022) L051104)

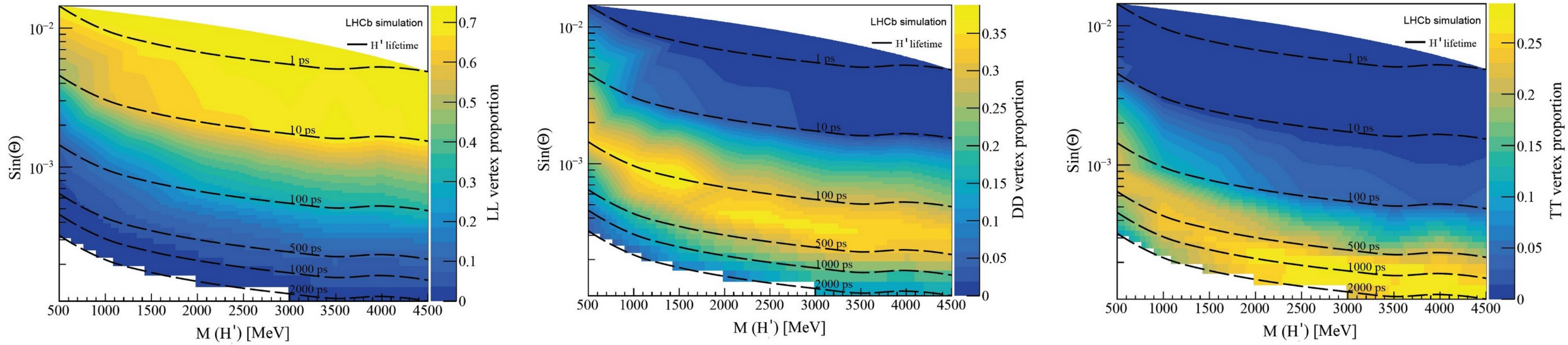
# LLPs in Beyond the Standard Model

- Higgs portal to Dark Matter: $B^+ \to K^+ H' [\to \mu^+\mu^-]$ arXiv:1612.07818
  - The new scalar particle, H', can mix with the SM Higgs boson (H)
  - Presence of displaced vertices
  - Sensitivity depend on H' lifetime, mass and track types.



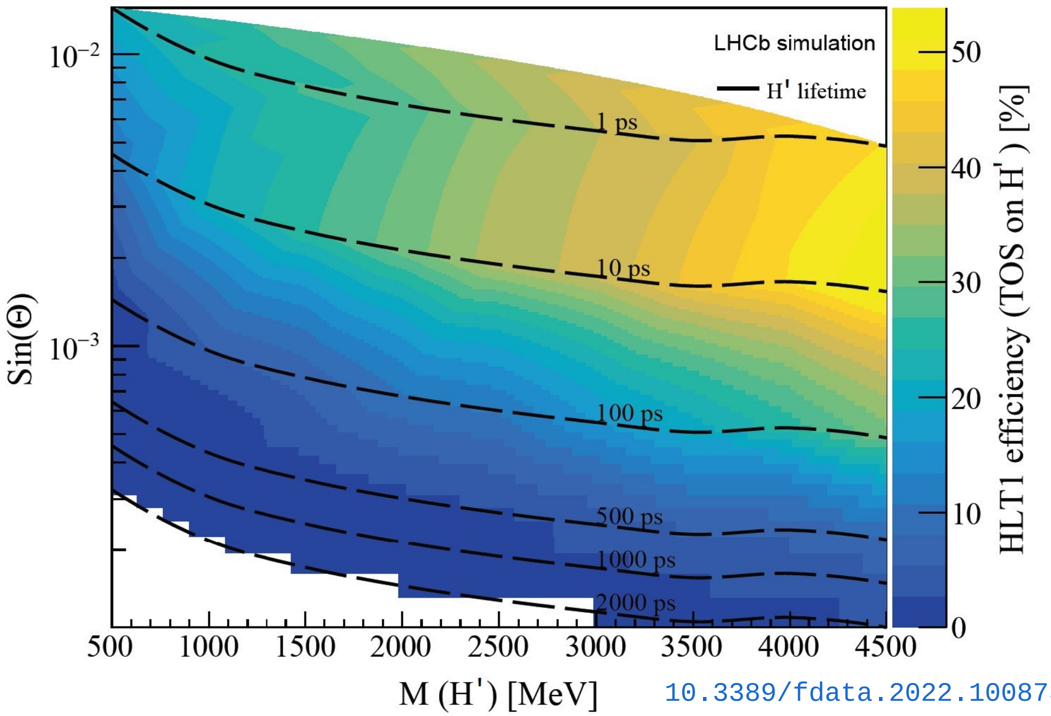

Note: If H' is long-lived, the two final decay particles can't be triggered by HLT1 → Need dedicated LLP trigger

10.3389/fdata.2022.1008737



# LLPs in Beyond the Standard Model

- Current HLT1 trigger efficiency (Trigger On Signal):
  - Only Long tracks are triggered by HLT1TrackMVA and HLT1TwoTrackMVA
  - Decent efficiency (30-50 %) for low lifetime
  - Poor efficiency (< 10 %) for τ > 100 ps
  - Loss in sensitivity for small H’ mass
- Expect significant improvement from dedicated LLP trigger in HLT1 (DD or TT):
  - Throughput challenge in HLT1: 30MHz
  - Output rate challenge in HLT1: 1MHz



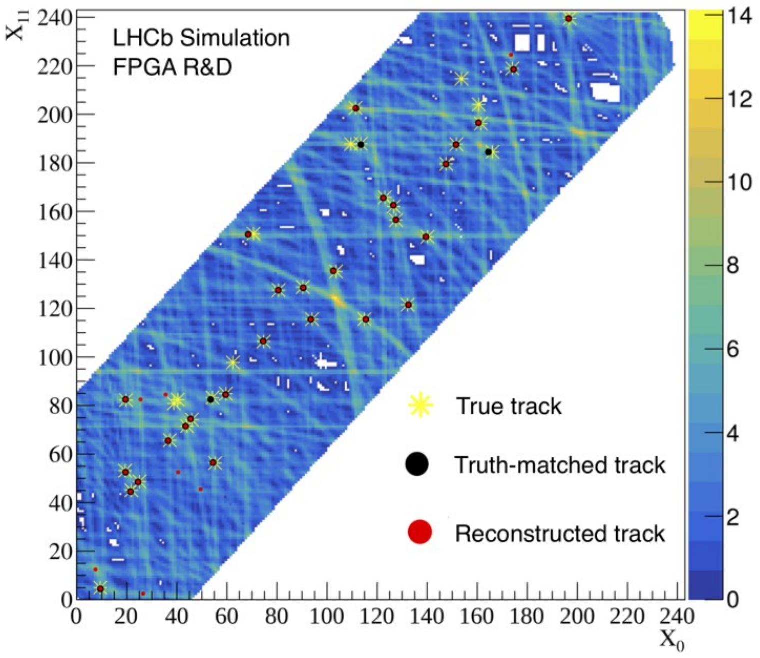

10.3389/fdata.2022.1008737

$B^+ \to K^+ H' [\to \mu^+\mu^-]$

# LHCb advanced R&D on LLP triggers

LHCb advanced R&D on LLP triggers

- Target Run 4 and beyond
- FPGA-based:
  - Utilize pattern recognition for tracking through the RETINA algorithm cf. Federico Lazzari's talk
  - Performing SciFi tracking right after readout
  - The resulting tracks are passed on to the GPU as raw data
  - Saving time for more complex tasks




1525 (2020) 012101 (ACAT 2019)

# Summary

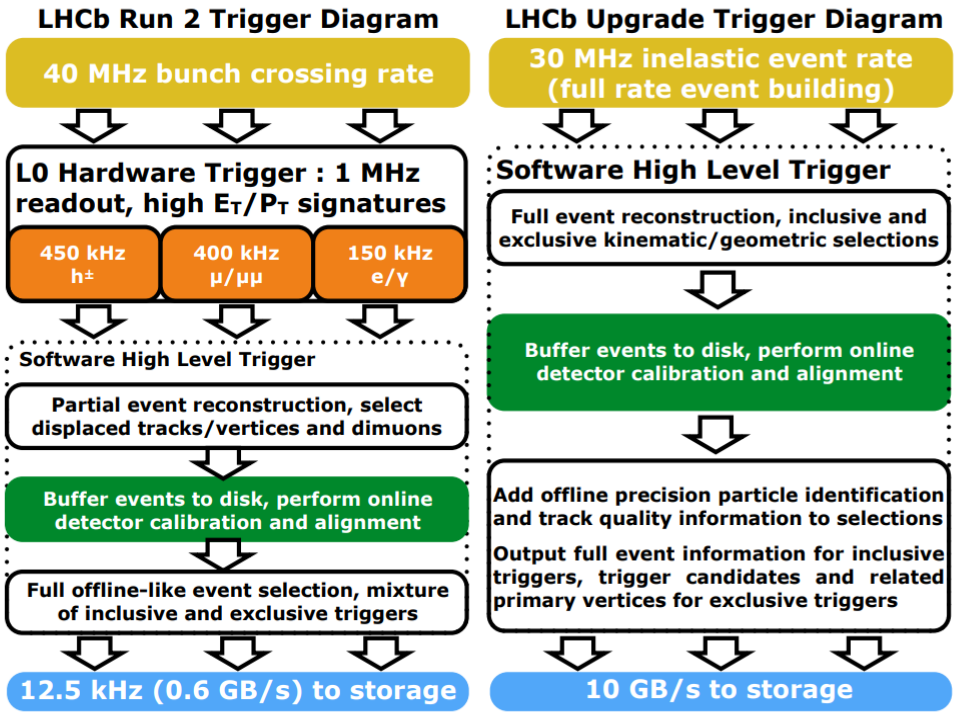
- Dedicated High-Level Trigger 1 (HLT1) for Downstream and T tracks substantially contributes to long-lived particle (LLP) research in both Standard Model (SM) and Beyond the Standard Model (BSM) scenarios:
  - SM: Increase the efficiency for $\Lambda^0$ and $K_s^0$ in $\Lambda_b \rightarrow \Lambda^0 \gamma$ and $K_s^0 \rightarrow \mu^+ \mu^-$.
  - BSM: Improve sensitivity for large H' lifetimes and small H' masses in $B^+ \rightarrow K^+ H'$ .


THANKS FOR LISTENING
ANY QUESTIONS?

# The High Level Trigger (HLT) in LHCb upgrade

- Run 1+2 trigger system consist of two parts:
  - L0: hardware trigger on either muon tag or transverse energy
  - HLT: software trigger on displaced vertices, high transverse momentum signatures
- In higher luminosity, L0 saturates fully hadronic and $e^+e^-/\gamma$ modes

→ Run a software only trigger at 30MHz



# The High Level Trigger (HLT) in LHCb upgrade

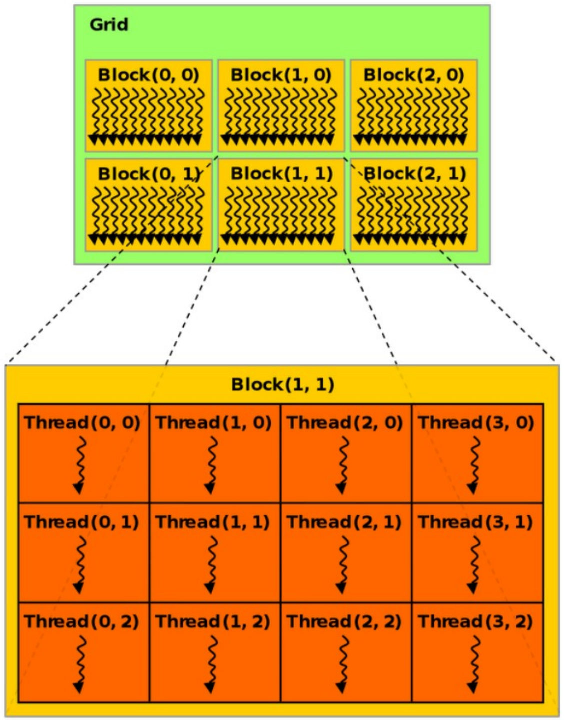
Challenge in HLT1: Process data in 30MHz and reduce the output rate to 1MHz

(178 GPUs in >168kHz each) or (356 GPUs in >84kHz each)

Solution: Accelerate with GPU (RTX A5000)

- One event per CUDA block
- Parallel threads for track/hit processing

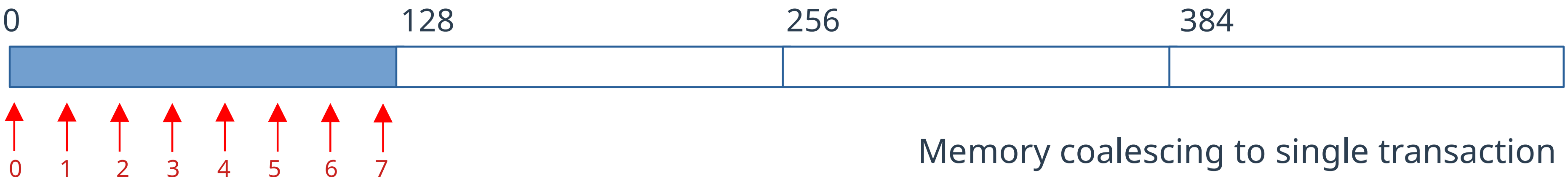
- Tricks:
  - Avoid dynamic allocation
  - Access global memory with coalescing
  - Use shared memory as user-managed data caches to store  frequently-accessed data



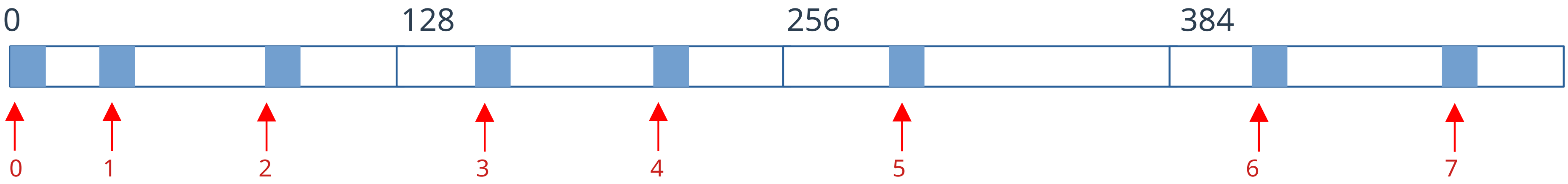
# Backup

## Memory coalescing

- Accessing global memory (DRAM) is slow ⇒ The device coalesces global memory loads and stores issued by threads of a warp into as few transactions as possible to minimize the bandwidth.
- Coalescing the global memory accessing making continues thread accessing continuous memory addresses can help achieve memory coalescing in CUDA by merging the memory accesses into a single transaction.




Memory coalescing to single transaction

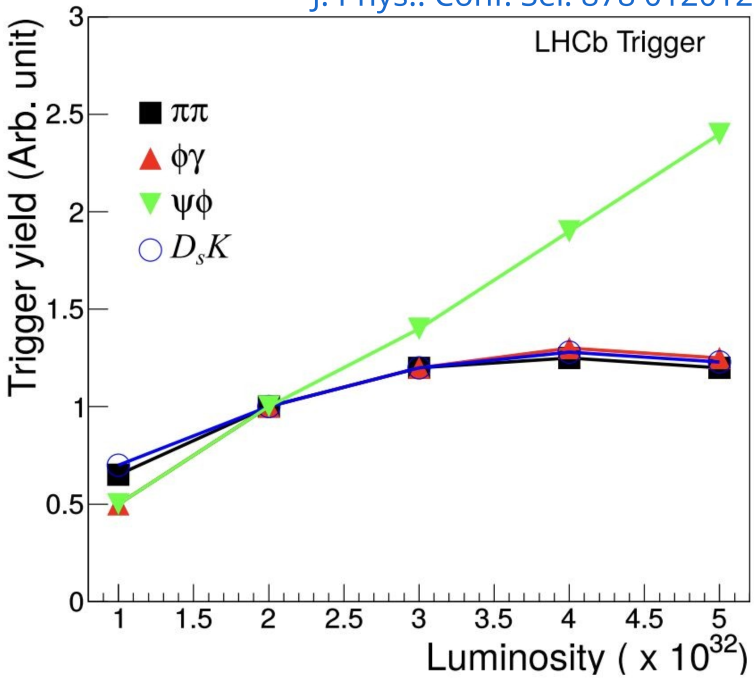



Memory coalescing to 4 transaction

# Backup

## L0 Saturation

J. Phys.: Conf. Ser. 878 012012

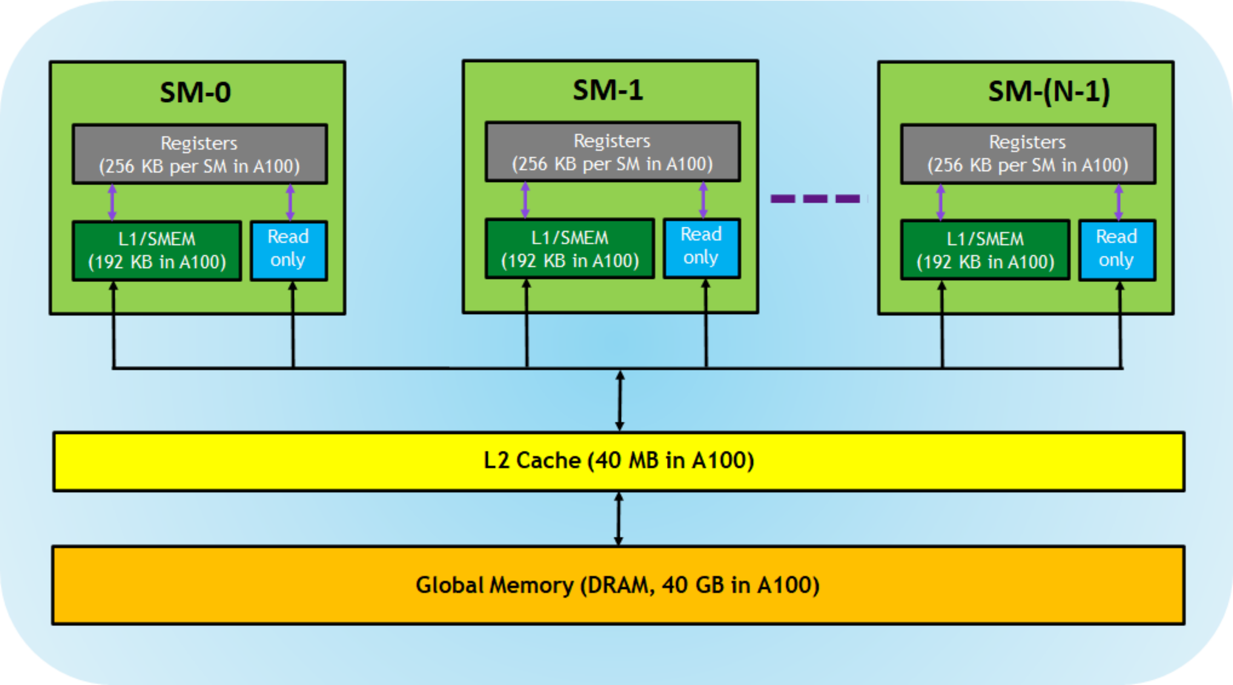



- L0 limit the rate to 1 MHz
- The hadronic and $e^+e^-/\gamma$ modes are fully saturated:

  ⇒ randomly reject signal events

# Backup

## Shared memory

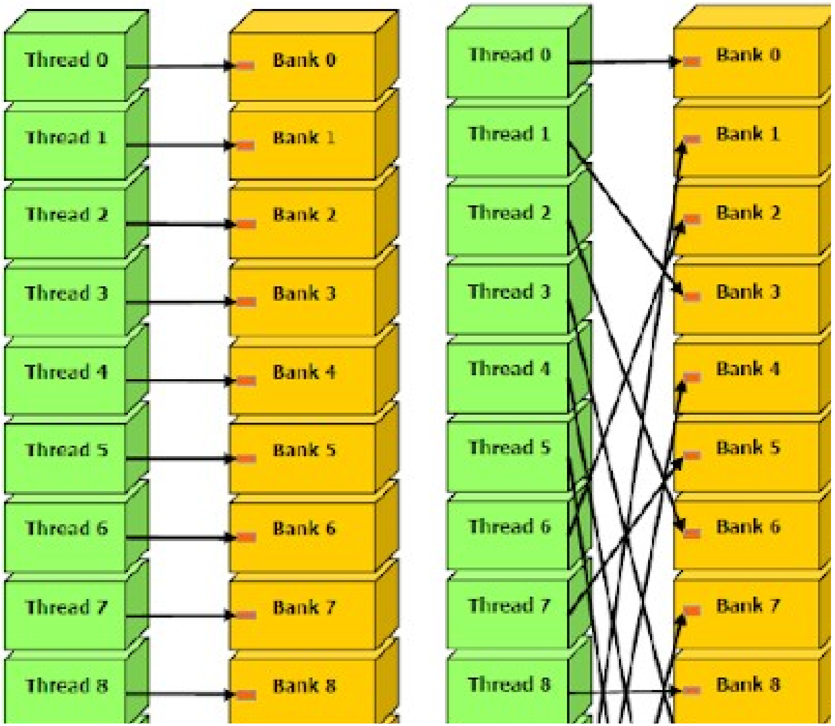



- Scratch-pad memory on each SM
- Compared to DRAM
  - 20-40x lower latency
  - ~15x higher bandwidth
- Shared with L1 cache, 128 KB/SM in A5000 (CUDA 8.6)
- Should avoid the bank conflict in shared memory

# Backup

## Bank conflict

- Shared memory are divided into equally-sized banks
- Different banks can be accessed simultaneously
- Multiple threads access the same bank causes Bank conflict



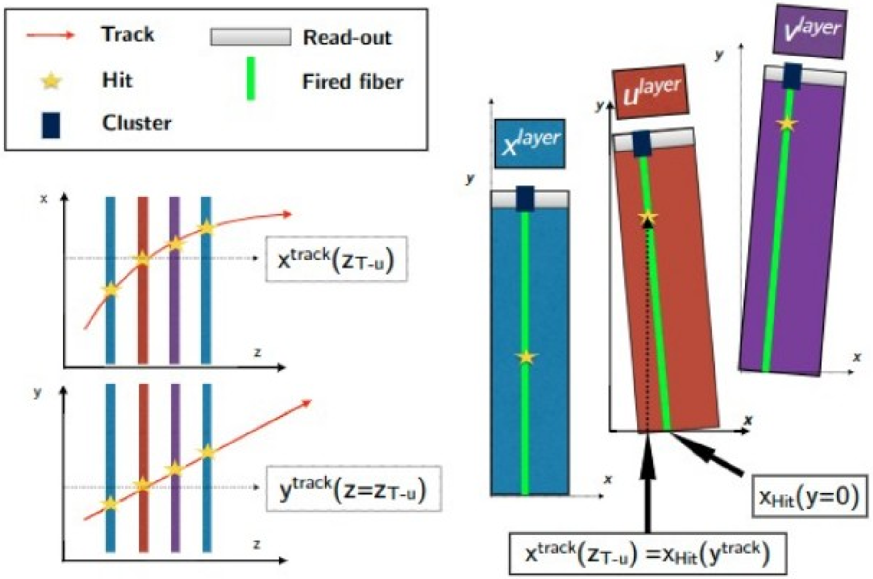
# Backup

## Standalone SciFi seeding in HLT1

- 12 layers: 6 $x^{layer}$ + 3 $u^{layer}$ +3 $v^{layer}$
- 2.7 meters fibers: poor information in Y axis
- Tracking in two steps:

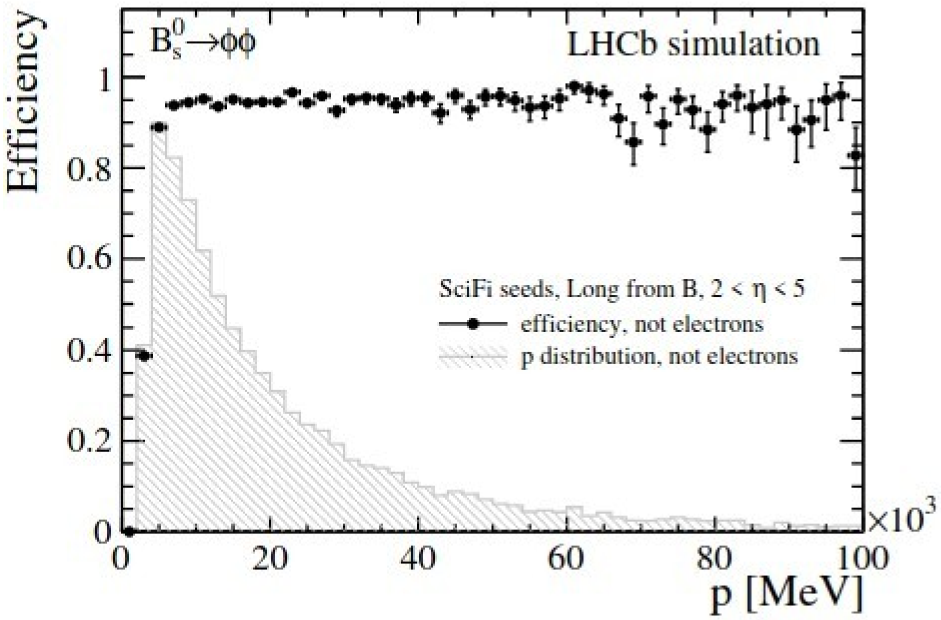
SciFi hits → Seeding XZ → Confirm Tracks

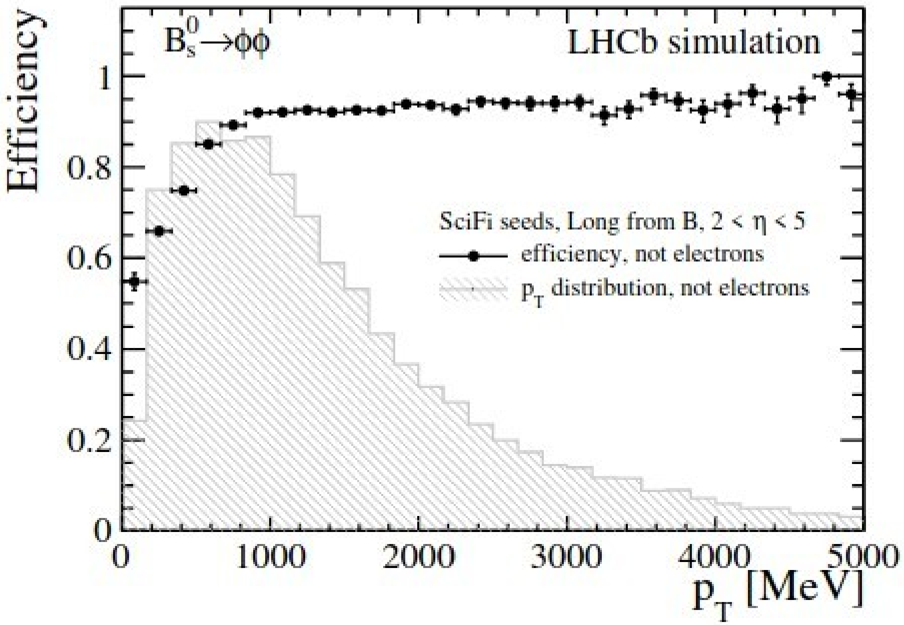
| SciFi hits | Seeding XZ | Confirm Tracks |
|---|---|---|
| input | Seeding with hits in X layers | Add UV hits and fit tracks for Y information |



# Backup

## Standalone SciFi seeding in HLT1



# Backup

## Velo-SciFi matching

- Reconstruct the long tracks by matching Velo tracks with SciFi seeds
- The performance meets the baseline requirements for HLT1 long track reconstruction.