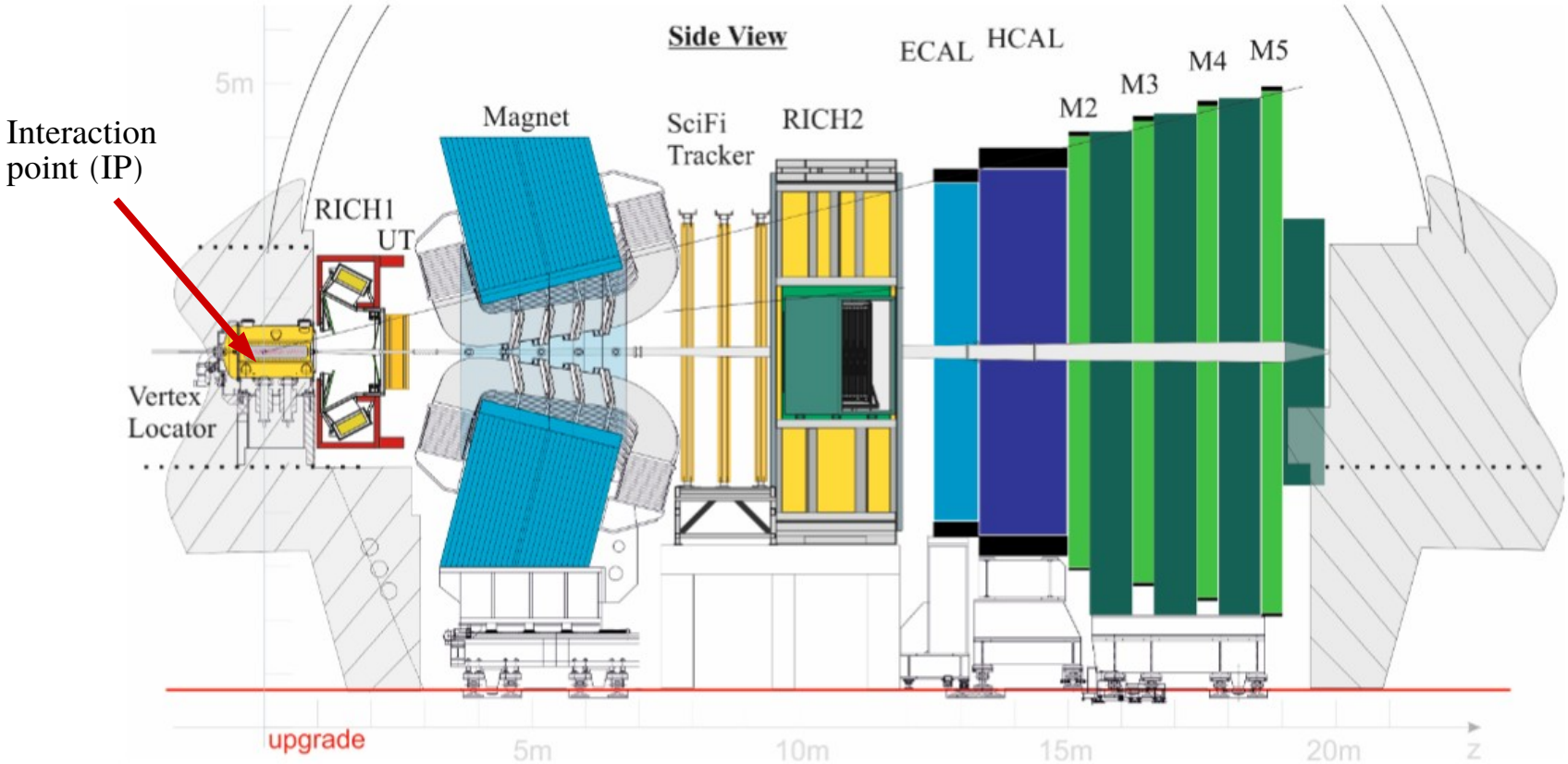
Reconstruction and physics opportunities of long-lived particles decaying downstream of the LHCb magnet

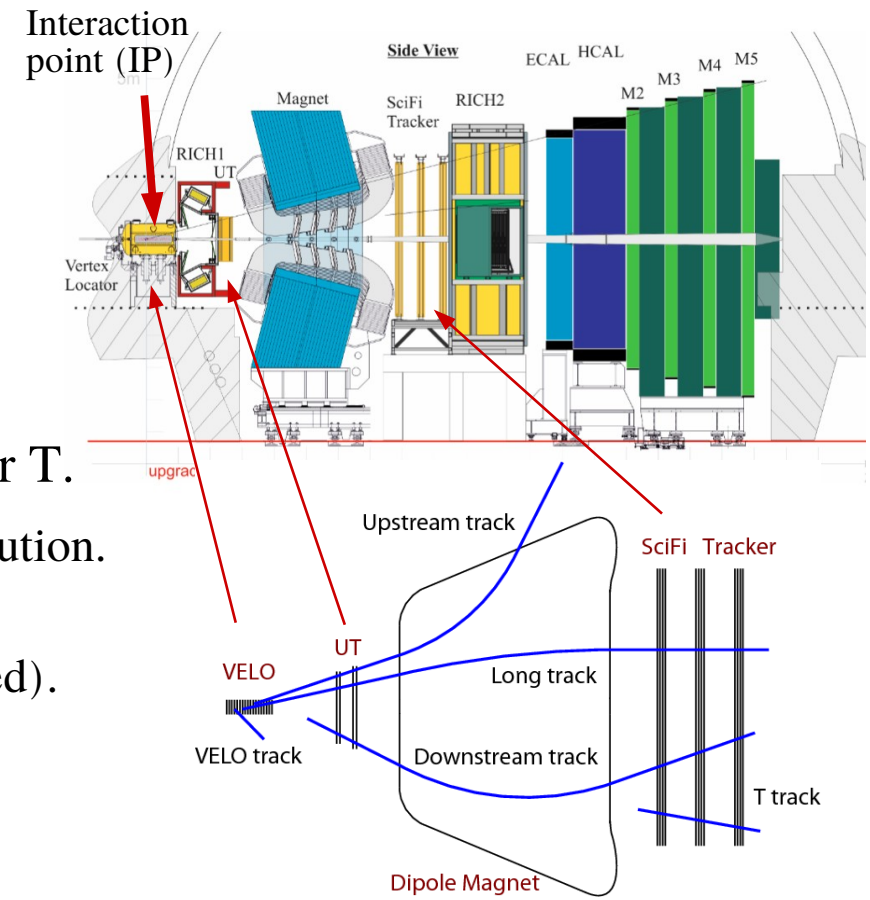
Louis Henry, on behalf of the RTA project
CERN, 31/05/2022

The LHCb detector in Run 3



LHCb: tracking strategy and current blind spots

- LHCb in Run 3 has 3 tracking systems:
  - VELO: close to IP, very efficient and fast;
  - UT: 4 layers of strips, help in momentum evaluation and ghost rejection;
  - SciFi: 12 layers of scintillating silicon fibres downstream of the magnet.
- Depending on subsystems, tracks are Long, Down or T.
  - T tracks only have info after the magnet → poor *p* resolution.
  - For reference, K_S mesons ($\tau \sim 10^{-10}$ s) from *B* decay as 33% Long-Long, 66% Down-Down (other topos ignored).
- Current (and Run 2) status is the following:
  - (HLT1 and HLT2 are the two levels of the trigger)



	Rough reach	HLT1	HLT2	Analysis	
Long	[0-1]m	Yes	Yes	Yes	
Down	[1-2.5]m	No	Yes	Yes	*Less available statistics*
T	[2.5-8]m	No	No	No	*Reduced lifetime reach*

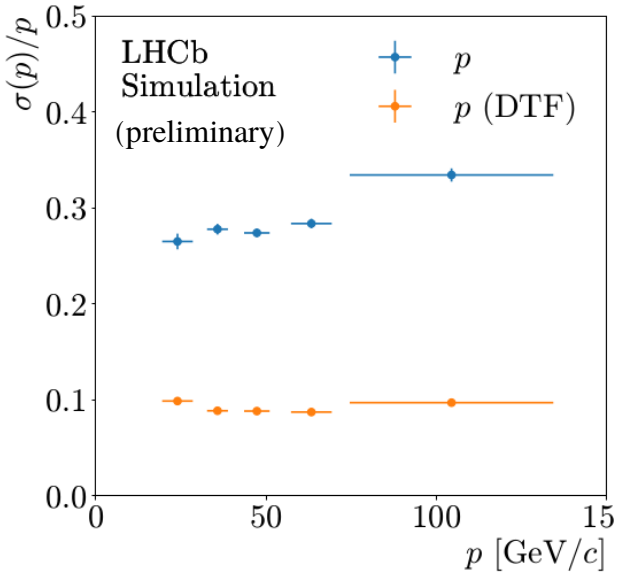
Adding T tracks to Analysis

	Rough reach	HLT1	HLT2	Analysis
Long	[0-1]m	Yes	Yes	Yes
Down	[1-2.5]m	No	Yes	Yes
T	[2.5-8]m	No	No	No

- In terms of flight distance, T tracks are very interesting for LLPs.
- However, use only hits downstream of the magnet, and decay vertex in the magnet → not trivial to use.
  - Poor (20-30%) momentum resolution
  - Difficult vertexing
  - Larger ghost rate, lower efficiencies (algorithms tuned for particles coming from upstream)
- First step: proving that we can reconstruct signal from already available data.

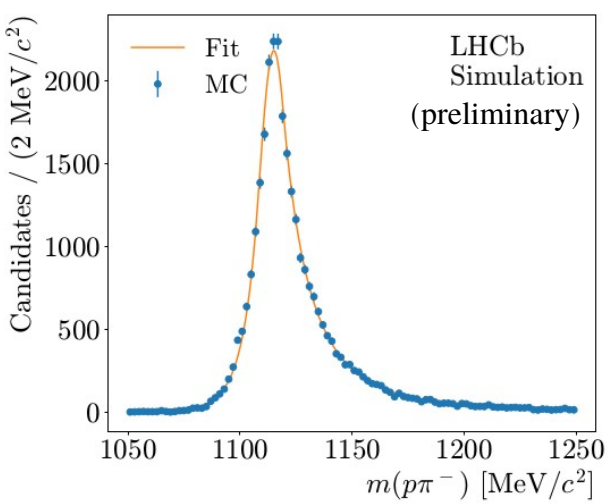
Adding T tracks to Analysis

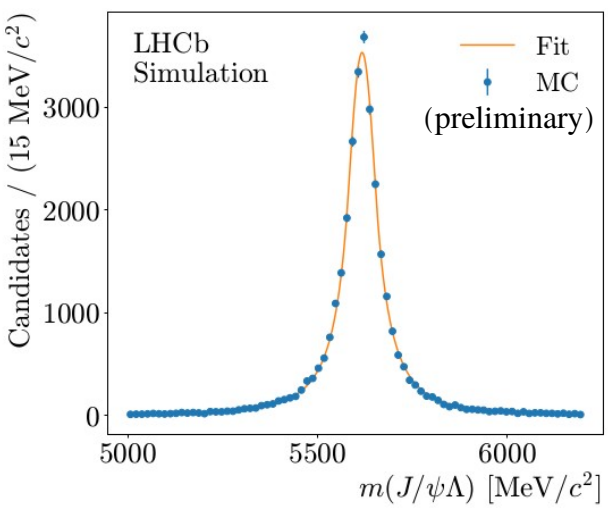
- Goal: reconstruct the $\Lambda_b \to J/\Psi\Lambda$ and $B \to J/\Psi\ K_S$ modes, with Λ and K_S reconstructed with T tracks.
  - Presence of a J/Ψ bypasses HLT1/HLT2 issues.



- Constraints allow to improve momentum resolution from ~30 % to 10 %.

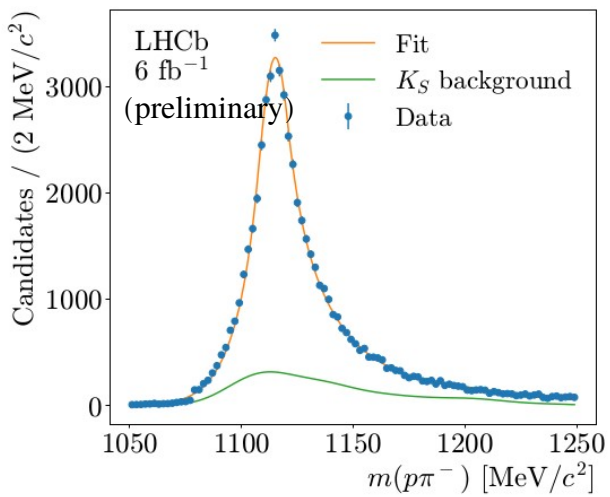
- $\sigma(\Lambda) = 6.9$ MeV/c^2 ; $\sigma(\Lambda_b) = 41$ MeV/c^2 .
  - Λ_b resolution from long-long decays: ~7 MeV/c^2.
    Λ baryons usually have a resolution around 2-3 MeV/c^2.

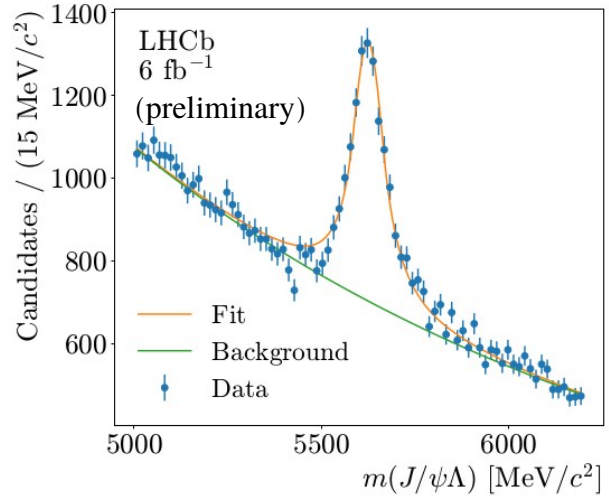




Adding T tracks to Analysis

- Fit to data finds tens of thousands of Λ baryons and ~6,000 Λ_b baryons.





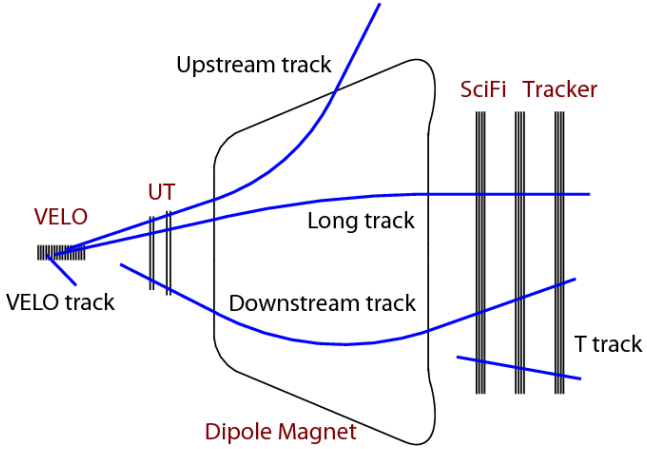
- Width of the distributions compatible with that found on MC.
- Still some possible improvements → could we use PID, improve vertexing?
- Study of the B mode finds ~18,000 signal events.

We are indeed able to use T tracks to reconstruct heavy-flavour hadron decays.

Adding Down and T tracks to HLT1

	Rough reach	HLT1	HLT2	Analysis
Long	[0-1]m	Yes	Yes	Yes
Down	[1-2.5]m	No	Yes	Yes
T	[2.5-8]m	No	No	No

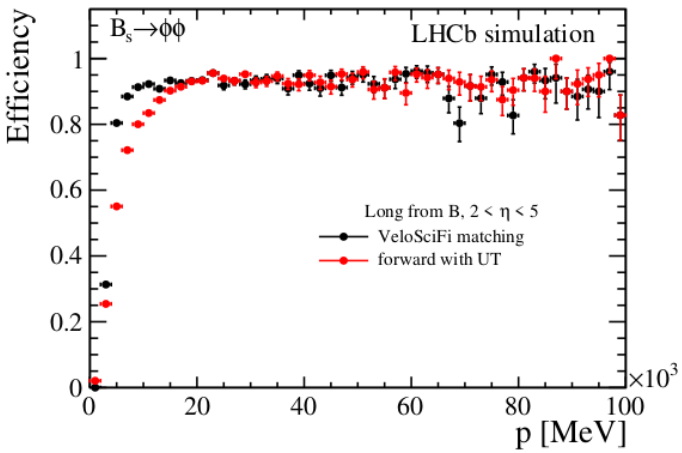
- Statistical price depends on the mode, but in general even SM decays with a K_S or a Λ suffer a lot.
- Current nominal reconstruction in HLT1 only relies on Long tracks, reconstructed by adding UT or SciFi hits to Velo segments.
  - No usable by-product.
- In HLT2, long tracks also reconstructed through matching of Velo segments and SciFi segments
  - SciFi segments are T tracks!
  - Also used for downstream track reconstruction.

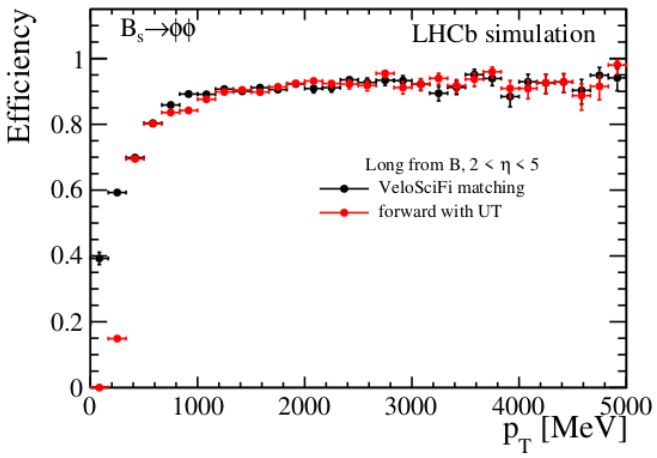


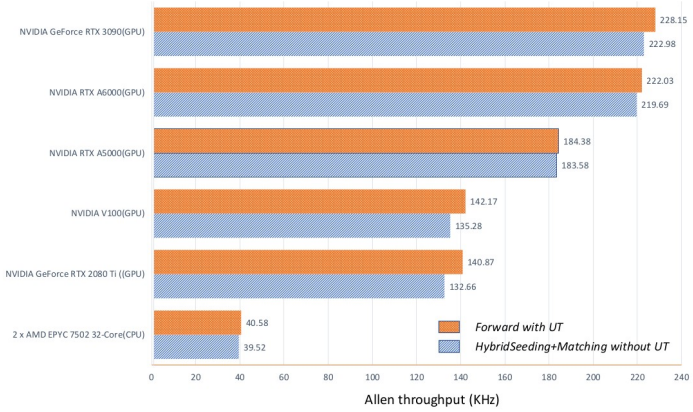
- Adding Down and T tracks to HLT1 rely on possibility to reconstruct SciFi segments fast enough.

Adding Down and T tracks to HLT1

- T track reconstruction relies on the Hybrid Seeding algorithm in HLT2
  - Paper: Computer Physics Communications, 2020, 107713, ISSN 0010-4655
  - Connecting the Dots 2020 talk.
- We ported the algorithm to GPU last year → speed and efficiency compatible with HLT1 operations!
  - Poster at Pisa meeting on advanced detectors and talk at Connecting the dots.
- Then ported the matching algorithm to create Long tracks: competitive with the baseline algorithm (Forward with UT).







Ported T track reconstruction to HLT1, work ongoing on the downstream reconstruction and on the design of trigger lines.

Overview of past and current work

	Rough reach	HLT1	HLT2	Analysis
Long	[0-1]m	Yes	Yes	Yes
Down	[1-2.5]m	No	Yes	Yes
T	[2.5-8]m	No	No	No

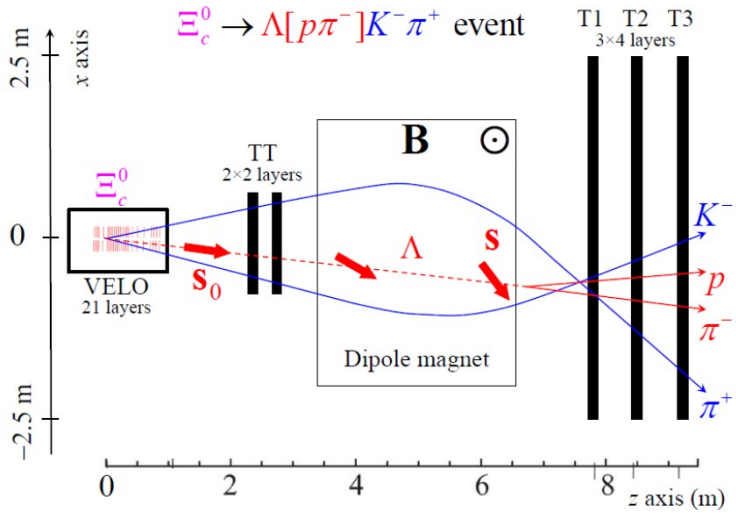
Reconstruction now possible, need to commission it and write trigger lines

Trigger lines being written, no showstopper.

Showed it was possible in Run 2!

Physics case: EDM and MDM of the Λ baryon

- LHCb is a source of Λ baryons produced in charm, beauty, charmonium decays → polarised.
  - These baryon then precess inside the B field.
  - Possibility to measure Λ baryon EDM/(g-2) at LHCb.
  - Proposal detailed in [Eur. Phys. J. C 77, 181 (2017)]



- Possible to improve sensitivity to Λ EDM (flavour-diagonal CP violation) by two orders of magnitude (1.3 10^{18} e.cm) with Run 3.

- Precision on the g factor of order 10^{-4} with same sample → CPT test.

- Work ongoing to estimate resolutions.

- HLT2 trigger lines being written.

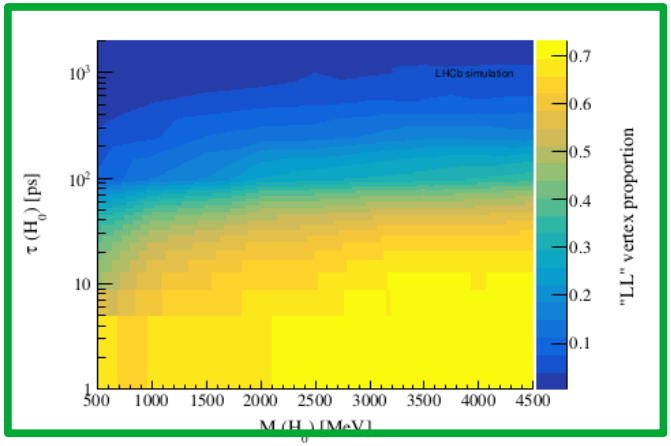
Physics case: search for LLPs

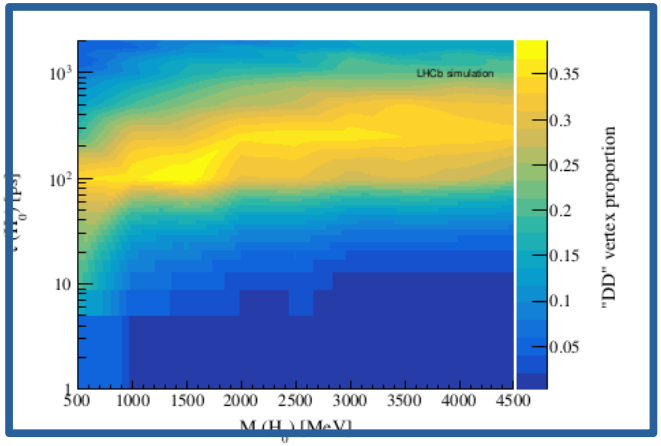
- From 2203.07048 (talk by Mike Williams at LLP XI):

Reference [9] showed that ultimately the reach of LHCb is limited by the size of its vertex detector (VELO); *i.e.*, that the sensitivity is not limited by the signal rate or backgrounds, but instead by the lifetime acceptance. This results in a minimal gain in sensitivity

- Below: reconstructibility of the muon daughters of a hidden Higgs in a B→H(→μμ)K decay [2003.01788] as a function of the h mass and lifetime

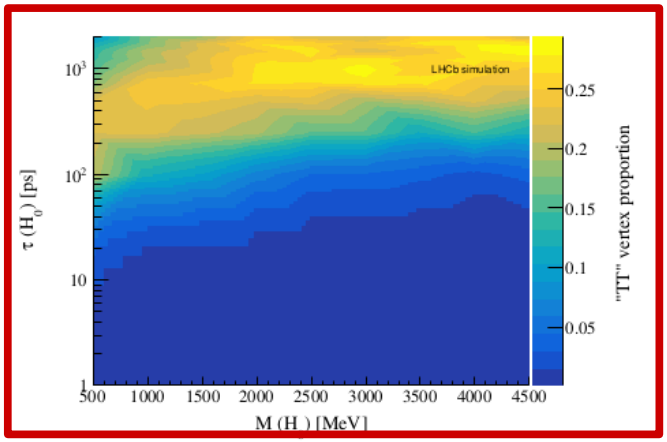
Current LHCb trigger+ analysis





Available for analysis

Not available at all



A systematic programme including Down and T tracks would probe large regions of the parameter space

Conclusion

- Flexibility of the full software trigger of LHCb from Run3 and beyond allows to look for new opportunities.

- Work is ongoing to include Downstream (z_{PV} ~ [1-2.5]m) tracks in the first level of the trigger.
  - Would increase available statistics for both SM modes and searches for LLPs.

- Article being written to showcase the possibility to use T tracks (z_{PV} ~ [2.5-8]m) in analysis.
  - Probes a completely new region of the parameter space.
  - Coupled with work to write dedicated HLT2 lines, and even perhaps HLT1 lines → increased statistics!
  - Talk by Izaac Sanderswood at Connecting the Dots 2022.

- Articles being written to evaluate the increased reach of LLP searches in LHCb using these tracks.