# LHCb as lifetime frontier experiment: `Downstream` algorithm

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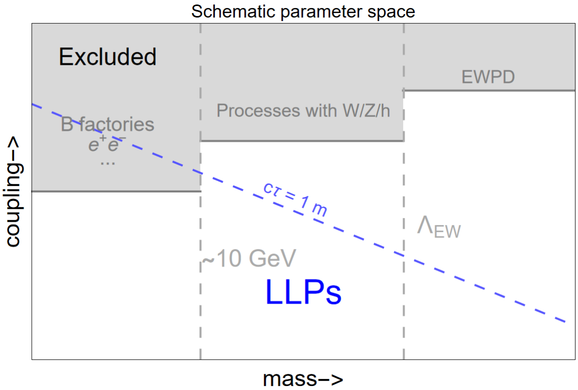
# Long-lived particles I

- Consider a new physics particle with mass $m$ and coupling $g$
- Below the EW scale, past experiments excluded large couplings

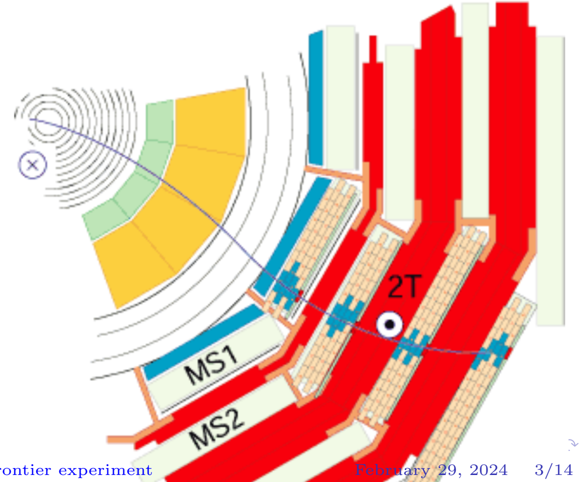



- Since $c\tau \propto g^{-2}$, the unexplored parameter space corresponds **Long-Lived Particles** (LLPs)

# Main LHC detectors as lifetime frontier? I

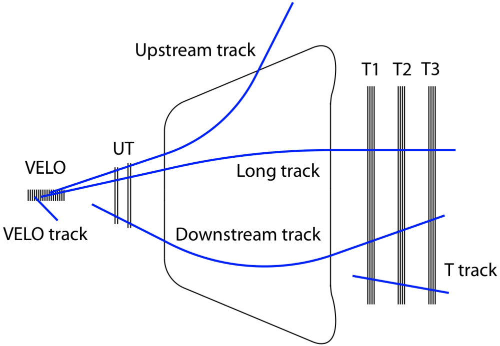
- LHC: high luminosity+ large energies ⇒ natural lifetime frontier experiment
- Past searches at the LHC are inefficient for LLPs:
  1. Triggering the events by their production vertex
  2. Limiting the decay volume by the inner trackers

- Search schemes that partially omit the problem:
  - Search with muon chambers at ATLAS, CMS, LHCb
  - Missing mass searches at LHCb
  - `Downstream` **algorithm**



# Downstream algorithm at LHCb I

- Tracks from prompt events (SM): hits in three trackers: VELO, TT, T1-3 (SciFi)
- Tracks from displaced events (decays of $\Lambda, K_s$, hypothetical new physics) leave hits only in far trackers – UT and/or T1-3 (SciFi)

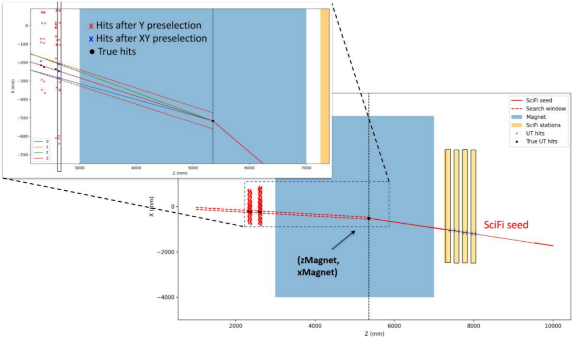



- Search for such events: develop an algorithm allowing to filter and write data with *downstream-* (SciFi+UT hits) or *T-tracks* (SciFi hits only) on-flight

# Downstream algorithm at LHCb II

Downstream algorithm: trigger decision requiring at least two downstream tracks on the common vertex (hits in SciFi+UT). To match between UT and SciFi hits:

- Take SciFi output and filter out the used seeds
- Extrapolate them to the UT through the magnetized region




To reduce the rate of fake tracks (improper SciFi-UT connections), a neural network is used; the rate of correctly reconstructed tracks is 70%

*V. Kholoimov, A. Oyanguren, V. Svintozelskyi, J. Zhuo, B. Jashal, to be published soon*

# Backgrounds

Background sources (and how to suppress them in general):

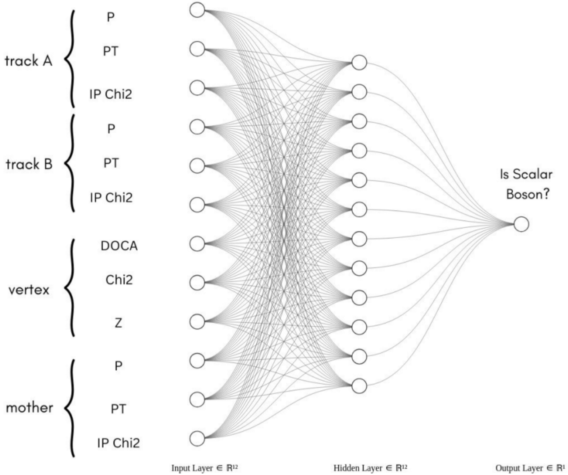
- Long-lived resonances $K_S^0, \Lambda$: vetoing by kinematics (domain in $m_{\text{inv}}$, ratio between the momenta of daughters)
- Material interaction – beam pipe, boundaries of the effective decay volume: suppressed by using control data samples and vetoing specific regions of the detector. May be reduced down to a negligible level [1803.07466]
- Combinatorial background: vetoed by kinematics ($\chi^2$, DOCA), hits only in UT+SciFi, IP/number of coinciding tracks, neural network and PID

**To be studied later this year on real data**

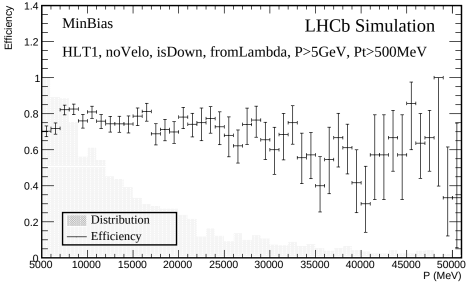
# Signal selection/background reduction I

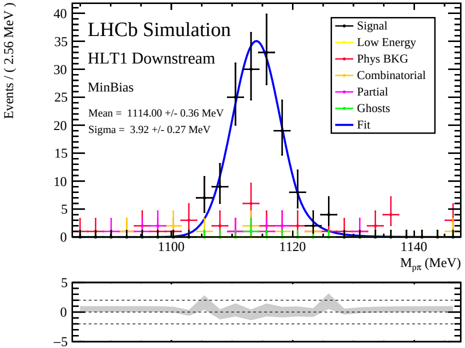
Signal selection for post-processing: based on a neural network.

- For LLPs decaying into two particles:
  - Takes track and vertex quality + IP as an input
  - Trained with simulated signal events and background MinBias
  - Excellent background rejection and tracking efficiencies
- For many-body decays: different input - number of tracks (in preparation)



# Signal selection/background reduction II



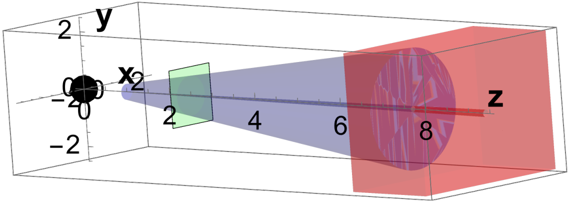




The downstream algorithm has been studied in details for $\Lambda/K_S^0$ decays

*LHCb-FIGURE-2023-028*

# Implementation of setup in SensCalc I

– Sensitivity studies must be as transparent as possible and reproducible
– The LHCb setup for `Downstream algorithm` has been implemented in SensCalc

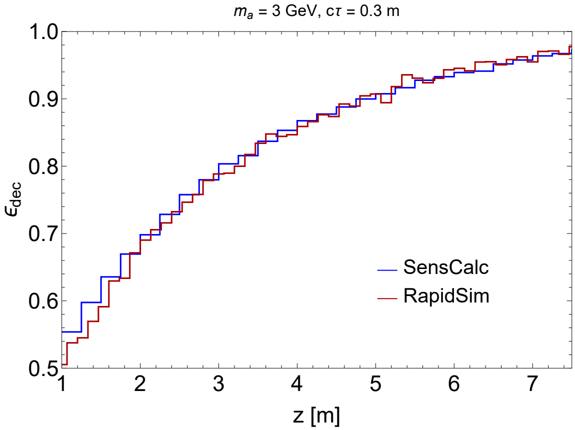



– **SensCalc: public and unified sensitivity calculator:**
- A variety of experiments at FermilabBD, SPS, LHC, FCC-hh, etc. is implemented
- Validated across several simulation frameworks and light-weight MC codes
- HNLs, ALPs coupled to photons, fermions, gluons, dark scalars, dark photons, $B-L$ mediators are implemented
- Supports many production channels, 2-,3-,4-body decays, flexible selection criteria
- Exists in private: inelastic LDM, HNL dipole portal

# Implementation of setup in SensCalc II

Event selection and efficiency assumptions:

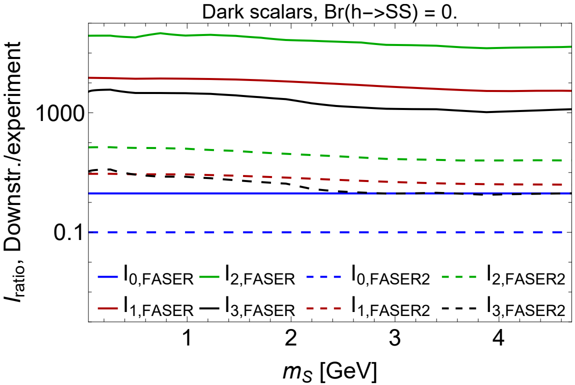
- Decay vertex within $z_{\text{VELO}} < z < z_{\text{UT}}$ and $2 < \eta < 5$;
- At least two charged tracks with energies $E > 5$ GeV within the last SciFi layer;
- $\epsilon_{\text{reco}} \approx 0.4$




- Predictions of `SensCalc` agree with full LHCb simulation framework and `RapidSim`

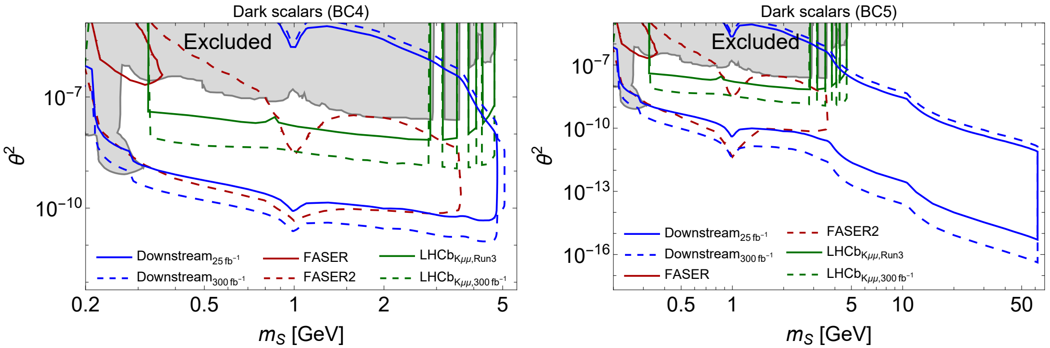
# Signal yield: qualitative comparison with FASER/FASER2

- Two Downstream setups: $\mathcal{L} = 25\ \text{fb}^{-1}$ (for comparison with FASER) and $300\ \text{fb}^{-1}$ (with FASER2)
- Comparison is made for the regime $c\tau\langle\gamma\rangle \gg 500$ m
- $I_0$ – total number of produced LLPs, $I_1$ – the amount of those intersecting the decay volume, $I_2$ – the amount decayed inside, $I_3$ – the amount passed decay products acceptance



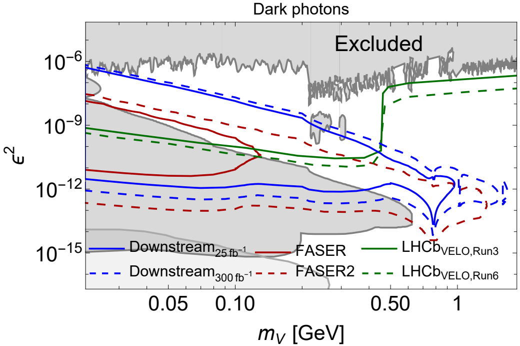

**In the regime of large lifetimes, the potential of the Downstream algorithm is comparable with FASER2**

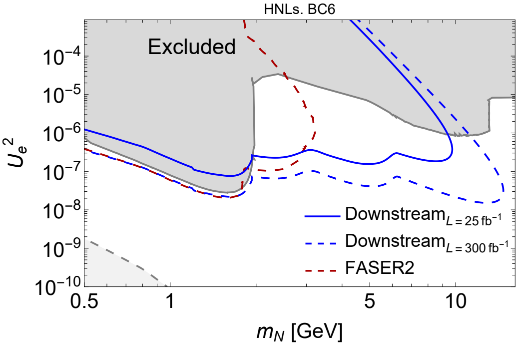
# Sensitivities I




Dask scalars: qualitative agreement with estimates above. BC5: access to the whole mass range $m_S < m_h/2$

# Sensitivities II




– Dark photons: most DPs fly in the far-forward direction, while LHCb covers $\eta < 5$. However, there is good sensitivity at the upper bound due to the small distance to the decay volume.

– HNLs: conclusions similar to dark scalars + access to the HNLs produced by decays of $W$

# Conclusions I

- With the development of new triggers, LHC may become a powerful lifetime frontier experiment
- The `Downstream` algorithm at LHCb provides opportunities to search for new physics already this year
- Its potential may be comparable with the potential of FASER2
- Room for future improvements: upgrade of the detector, adding the possibility to pass the trigger using T-tracks only

# Backup slides