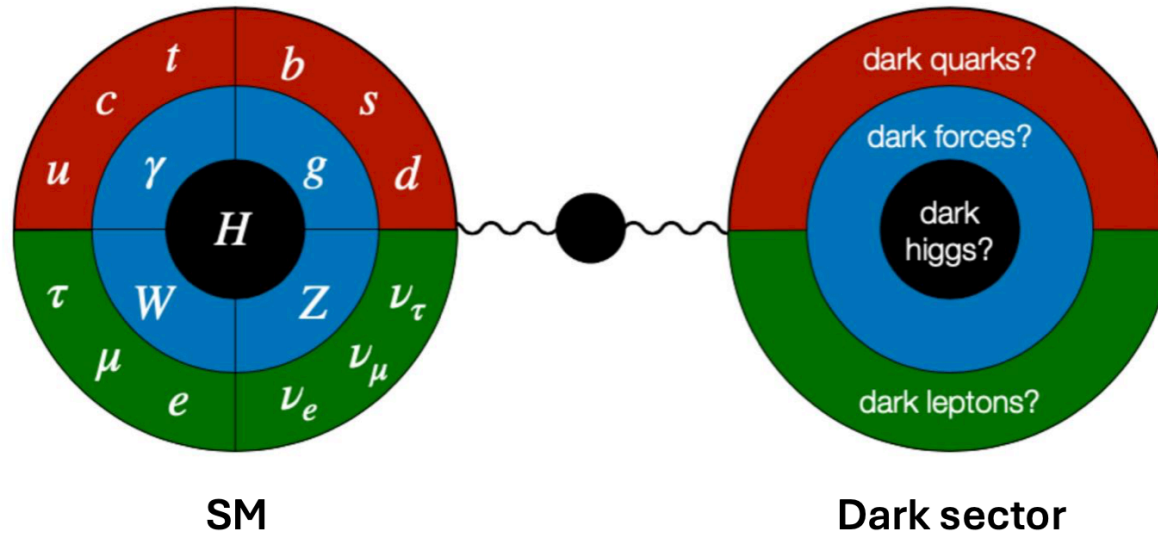


Dark sector searches at LHCb

Andrii Usachov
Nikhef, Amsterdam

French-Ukrainian workshop 2026
Orsay, October 12th, 2026

Portal framework



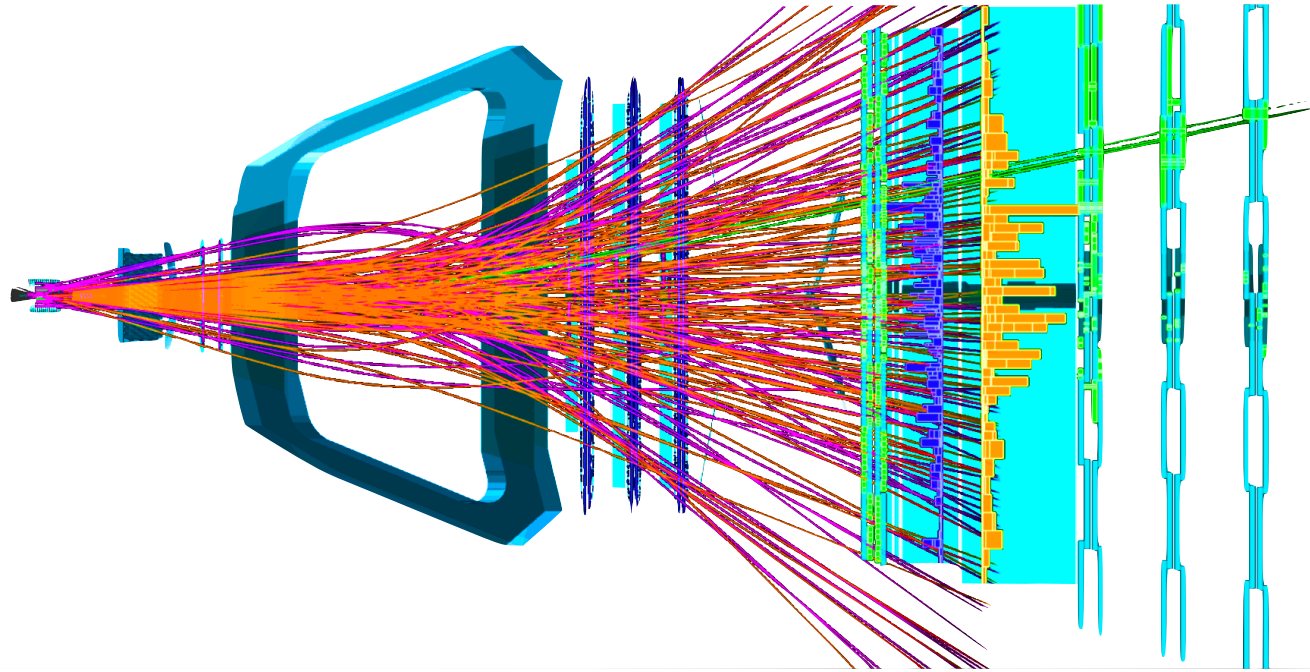
- Four portals to connect the Standard Model with the Dark Sector:

- Vector - Dark Photons
- Neutrino - Heavy Neutral Leptons (HNLs)
- Axion-like particles (ALPs)
- Dark Higgs boson

Portal		Coupling
Dark Photon	A'	$-\frac{\epsilon}{2\cos\theta_W}F'_{\mu\nu}B^{\mu\nu}$
Axion-like particles	a	$\frac{a}{f_a}F_{\mu\nu}\tilde{F}^{\mu\nu}, \frac{a}{f_a}G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}, \frac{\partial_\mu a}{f_a}\bar{\psi}\gamma^\mu\gamma^5\psi$
Dark Higgs	S	$(\mu S + \lambda_{HS}S^2)H^\dagger H$
Heavy Neutral Lepton	N	$y_N L H N$

- LHCb has performed searches for all portals with Run 1 and / or Run 2 data sets, with best sensitivity at low mass

Searches at LHCb so far

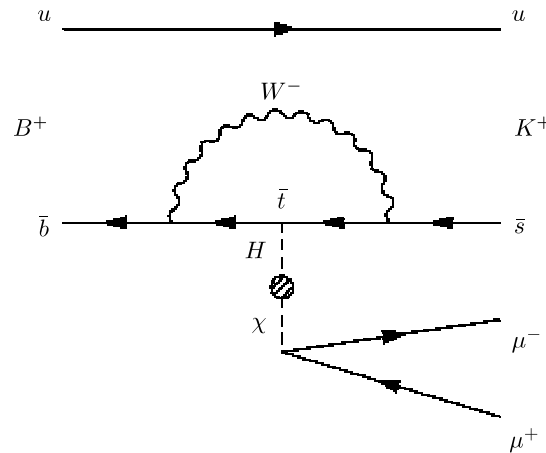


- Forward geometry - target low $O(\text{GeV})$ masses
- Mostly searches within the volume of Velo - best sensitivity for lifetimes of $O(\text{ps})$
- Knowledge of detector's material map is essential
- Larger lifetimes can be accessed for tracks escaping Velo
sensitivity for **lifetimes of $O(10 \text{ ns})$**

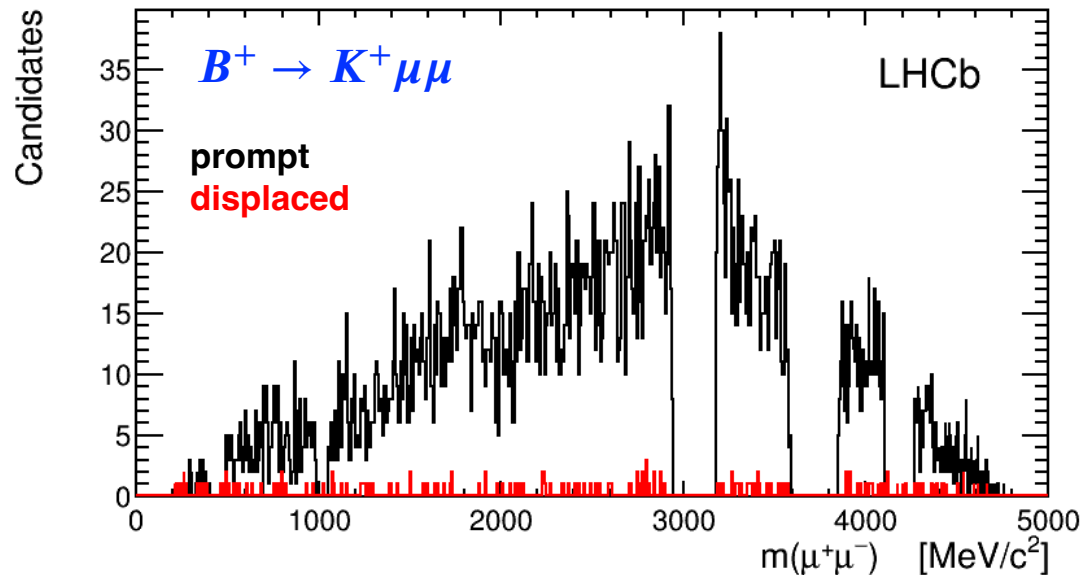
Light boson in $b \rightarrow s$ decays in Run 1

- Light boson can contribute to $b \rightarrow s\mu\mu$ penguin decays

PRL 115 (2015)161802



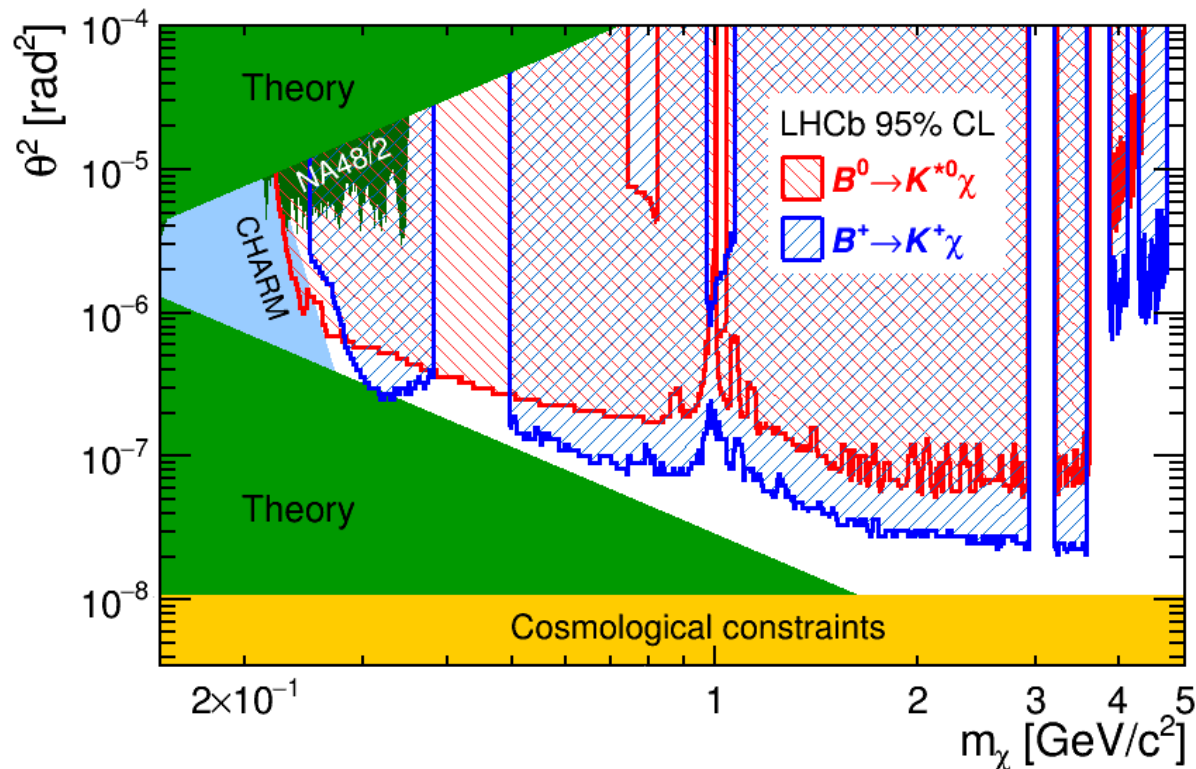
- LHCb has world's largest sample of $b \rightarrow s\mu\mu$ decays
- Study of di-muon spectrum



Light boson in $b \rightarrow s$ decays in Run 1

PRL 115 (2015)161802

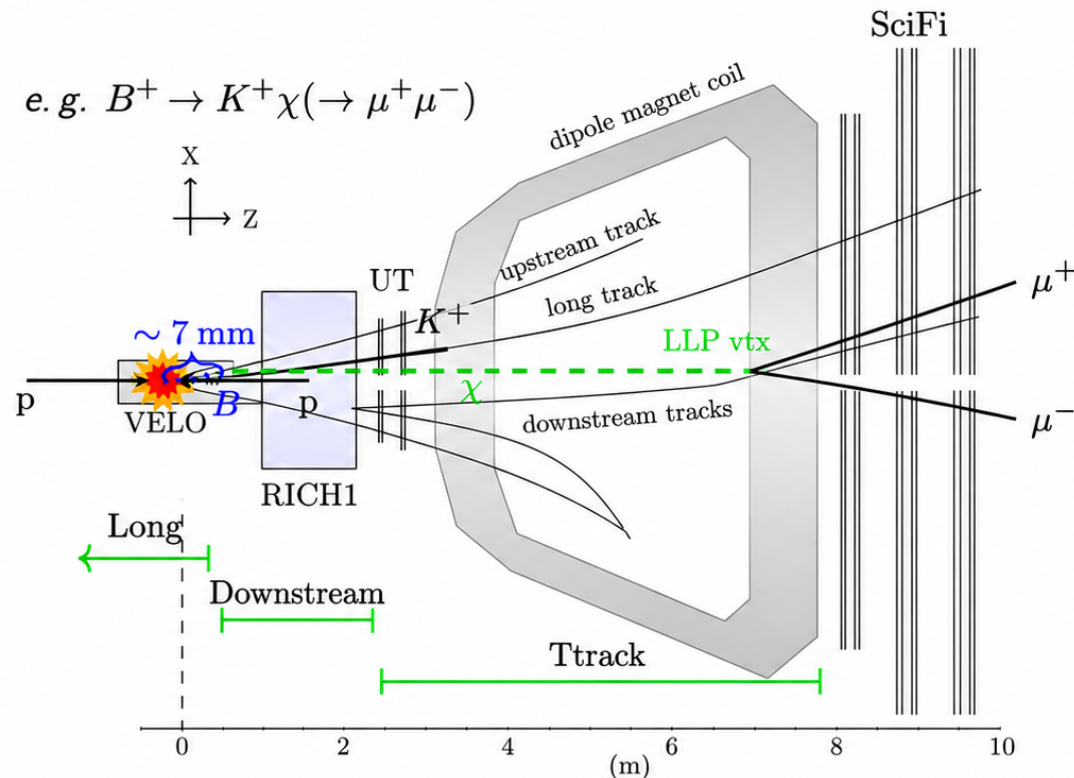
- Search for a narrow di-muon peak
- Displacement of muon pair is considered
- Upper limits on mixing with SM Higgs



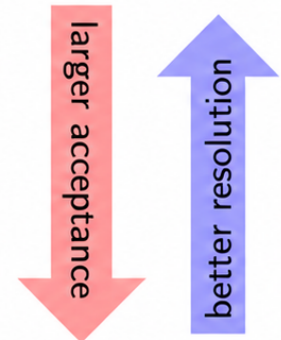
*Theory: inflaton model [PLB 736 \(2014\) 494](#)

- Searches target specific exclusive channels to deal with HF bkg
- Access to smaller couplings is limited by Velo volume / trigger

Very long-lived particles in Run 3



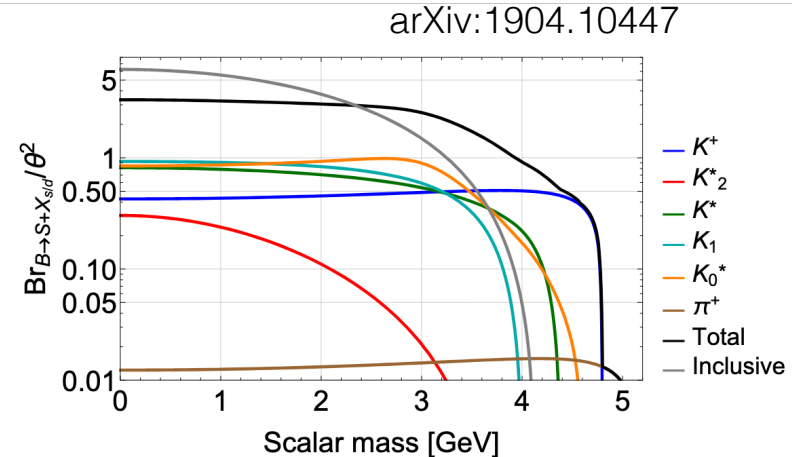
- Long tracks (Velo+[UT]+SciFi): $z_{\text{LLP vtx}} \lesssim 40$ cm
- Downstream tracks (UT+SciFi): $z_{\text{LLP vtx}} \lesssim 250$ cm
- Ttracks (SciFi only): $z_{\text{LLP vtx}} \lesssim 780$ cm
- In all cases control of backgrounds is crucial



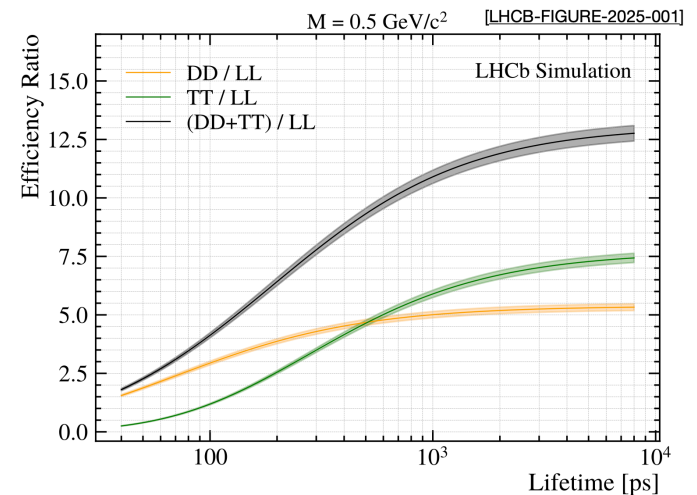
Access to very long-lived particles in Run 3 at the trigger level

Very long-lived particles : Dark Scalar

- Example: Dark Scalar in $b \rightarrow s$ transitions inclusive signature, following prediction
 - gain in both efficiency and production
 - very similar for axion-like particles

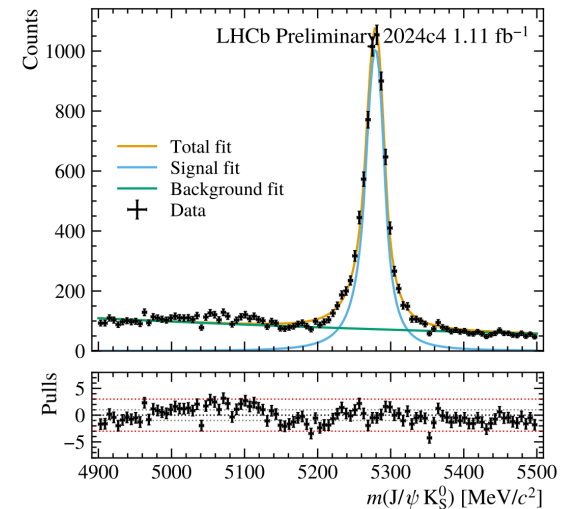
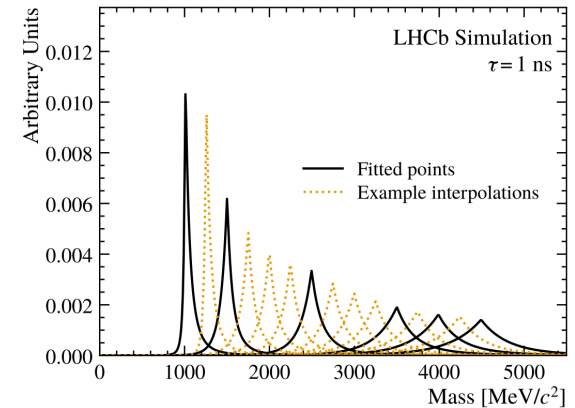


- Focusing on **di-muon signature** reconstructed as T tracks,
 - decays few meters away from the collision
- Sensitivity for **lifetimes of 1-10 ns**



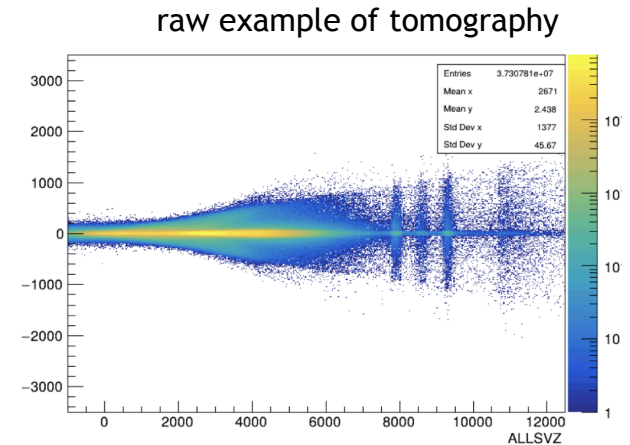
Very long-lived particles : Dark Scalar

- However, the momentum resolution is limited by $O(10\text{-}20\%)$ - broad invariant mass peaks
- Data / MC differences controlled by abundant $B \rightarrow J/\psi K_s$ where K_s is reconstructed with T-tracks



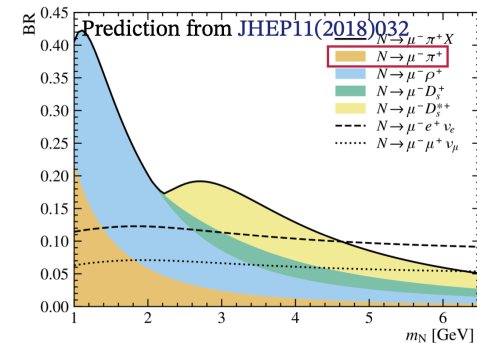
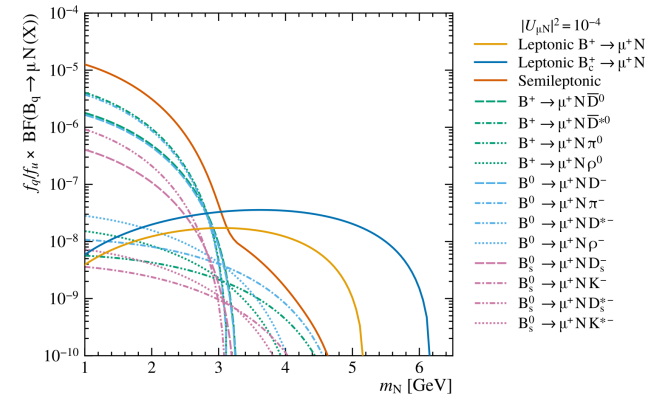
Very long-lived particles : Dark Scalar

- Important backgrounds
 - material interactions can be heavily suppressed geometrically
 - Ks, KL and Lambda - makes very low mass region below ~ 1 GeV difficult / deprioritised
 - prompt remnants
 - combinatorial / decays in flight -> MVA classifier with ABCD blinding, see ABCDiscoTEC by CMS
<https://arxiv.org/abs/2506.08826>



Very long-lived particles : HNLs

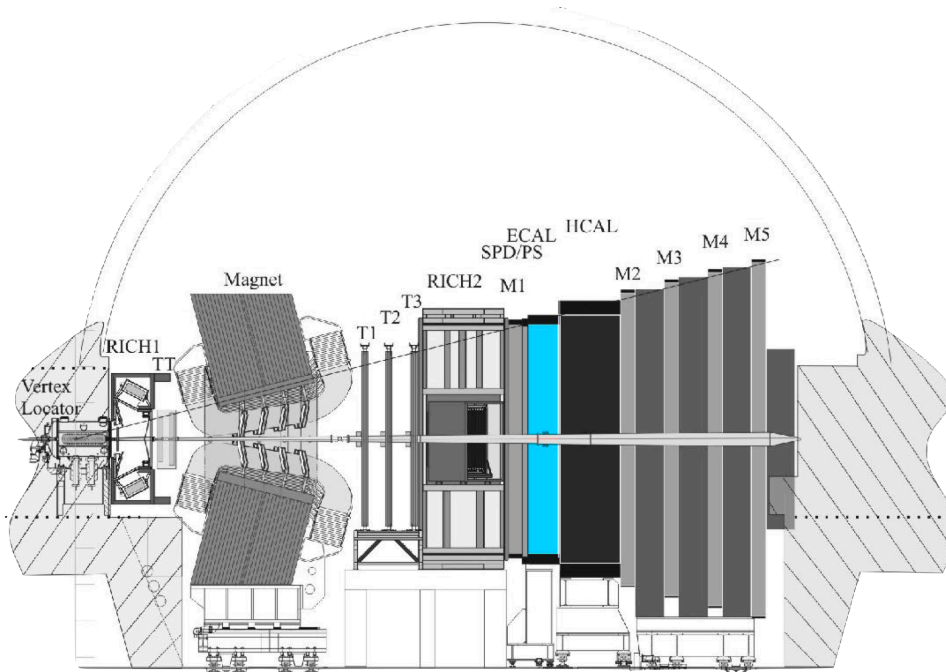
- Similar approach can be applied to heavy neutral leptons coming from b-decays
- But seen as partially reconstructed $\mu\mu\nu$ decays
- Would complement recent LHCb search with long tracks [JHEP 03 \(2026\) 178](#)



Search for ALPs decaying to photon pairs

[arxiv.2507.14390](https://arxiv.org/abs/2507.14390)

- Target: ALPs produced in gluon fusion and decaying to a photon pair



Photon reconstruction

- Reconstructed from energy deposits in ECAL
- No secondary vertex information – photons are assumed to come from the PV
- No significant energy smearing for lifetimes up to 20 ps
- Nominal resolution: $\frac{\sigma_E}{E} \sim 3\%$
- **Dedicated low mass di-photon trigger in 2018**

Search for ALPs decaying to photon pairs

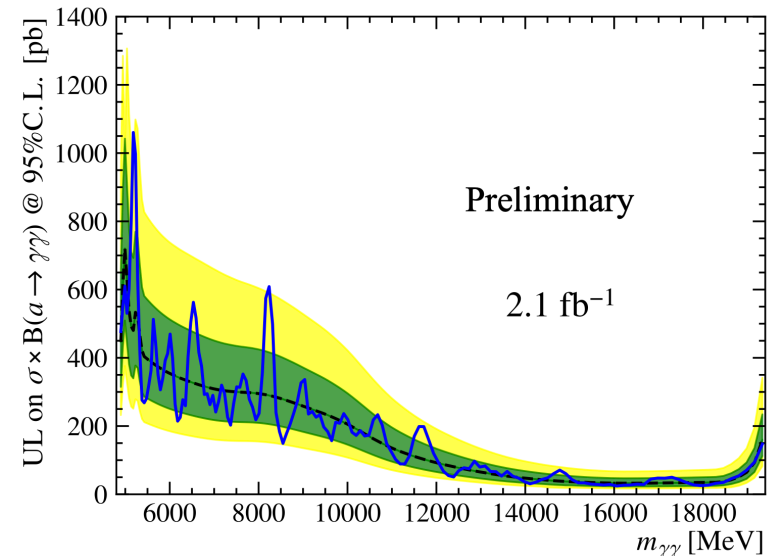
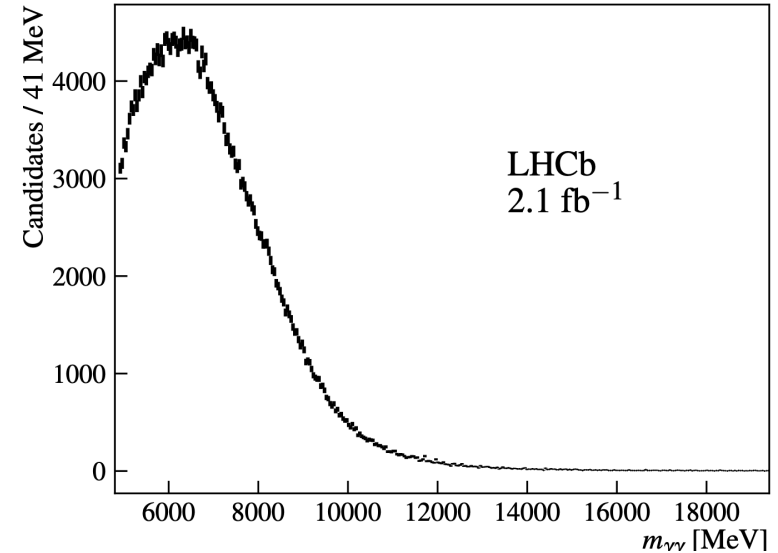
arxiv.2507.14390

Backgrounds

- No substantial peaking backgrounds are in the considered inv. mass window
- Contributions from b - and c -hadrons found to be negligible compared to the background level
- Combinatorial photons mostly coming from π^0 and η decays

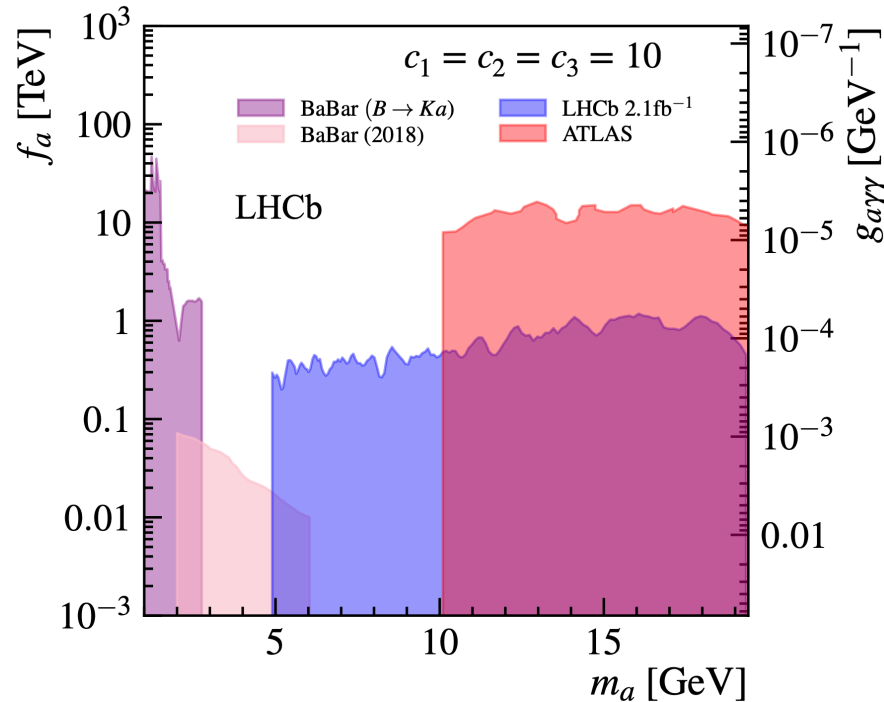
Bump hunt

- Upper limits using CLs method to the [4.9 GeV, 14.9 GeV] range
- **The first LHCb search using only neutrals in the final state**



Search for ALPs decaying to photon pairs

arxiv.2507.14390



- **Strongest limits by LHCb for ALPs decaying to $\gamma\gamma$ between 4.9 and 10 GeV** with $c_1 = c_2 = c_3 = 10$
- Stronger limits by ATLAS above 10 GeV
- Also, limits for the SM decays @ 95% CL

$$BR(B_s^0 \rightarrow \gamma\gamma) < 2.68 \times 10^{-5}$$

$$BR(B^0 \rightarrow \gamma\gamma) < 0.8 \times 10^{-5}$$

$$\sigma(pp \rightarrow \eta_b X) \times BR(\eta_b \rightarrow \gamma\gamma) < 765 \text{ pb (84 pb)}_{\text{fiducial}}$$

first direct limit on ground-state bottomonium production in pp collisions

Summary

Upgraded LHCb has several new opportunities and extended reach in direct dark sector searches with

- tracking for very long-lived particles decaying beyond Velo - access to longer lifetimes / smaller couplings
- generally soft triggers additionally improve efficiency
- recent results also show first fully neutral search
 - interesting interplay with bottomonium physics

