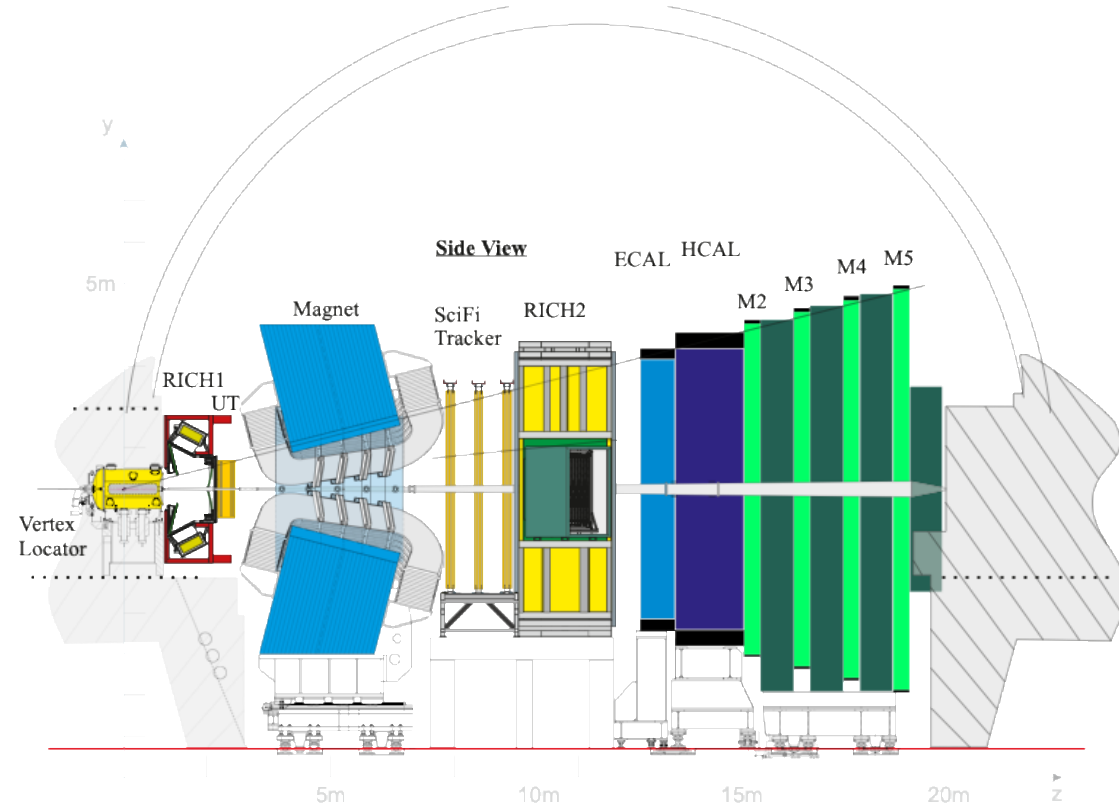


Recent results on dark sector searches and rare decays at LHCb

Spencer Collaviti, EPFL,
on behalf of the LHCb Collaboration
spencer.collaviti@epfl.ch

What I want you to take from this talk

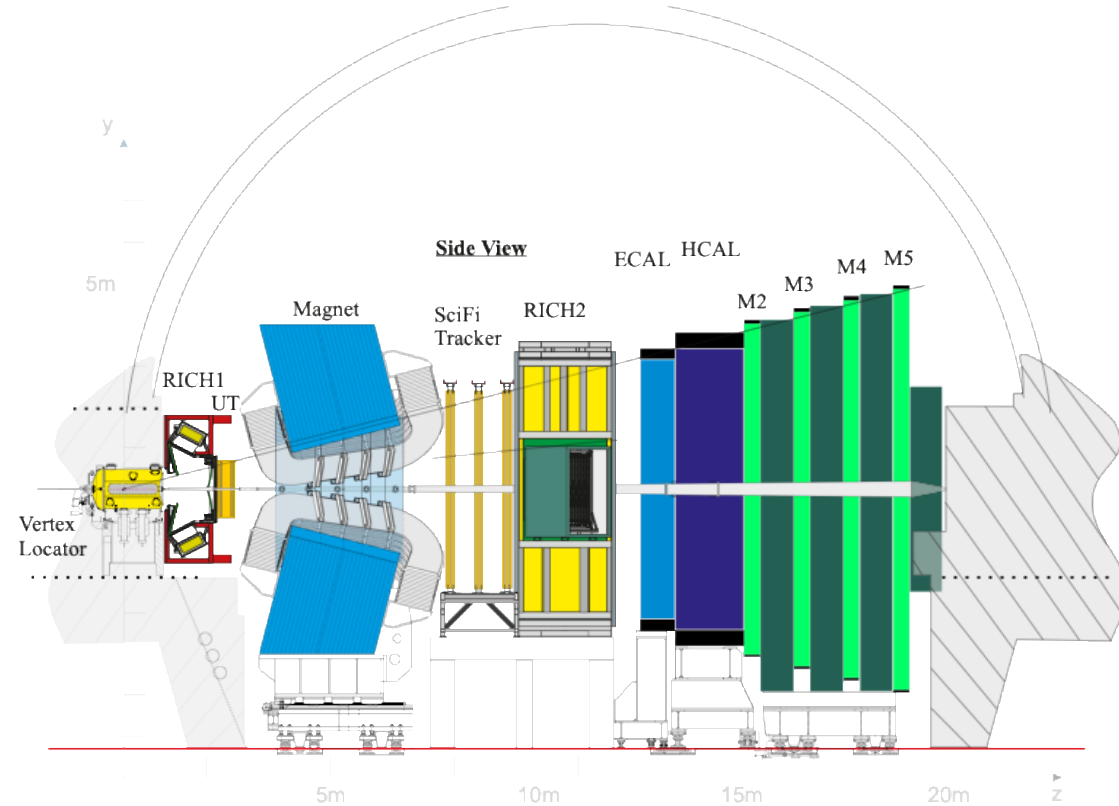
1. Familiarity with the Large Hadron Collider beauty (LHCb) experiment
2. Awareness of the results and ongoing work at LHCb



LHCb Collaboration,
[Journal of Instrumentation 19 2024](#)

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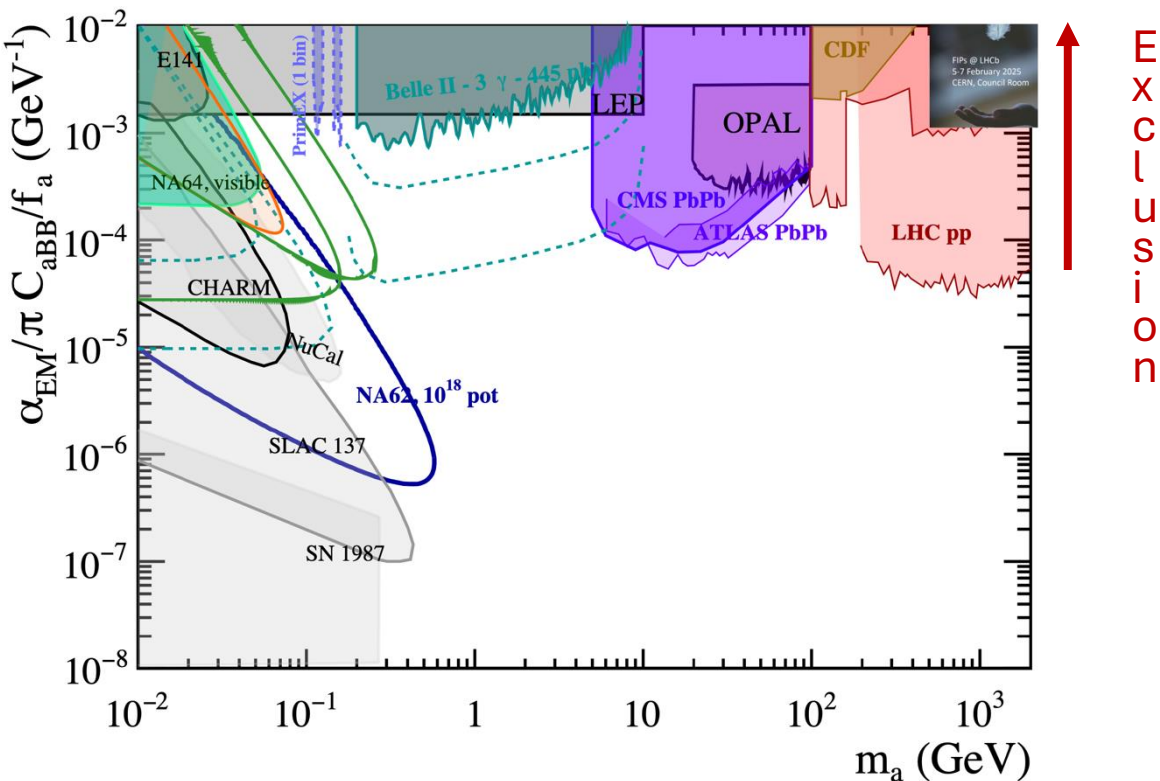
1. Familiarity with the Large Hadron Collider beauty (LHCb) experiment
2. Awareness of the results and ongoing work at LHCb
3. Desire to solve a shared problem in particle physics and cosmology



LHCb Collaboration,
[Journal of Instrumentation 19 2024](#)

The problem

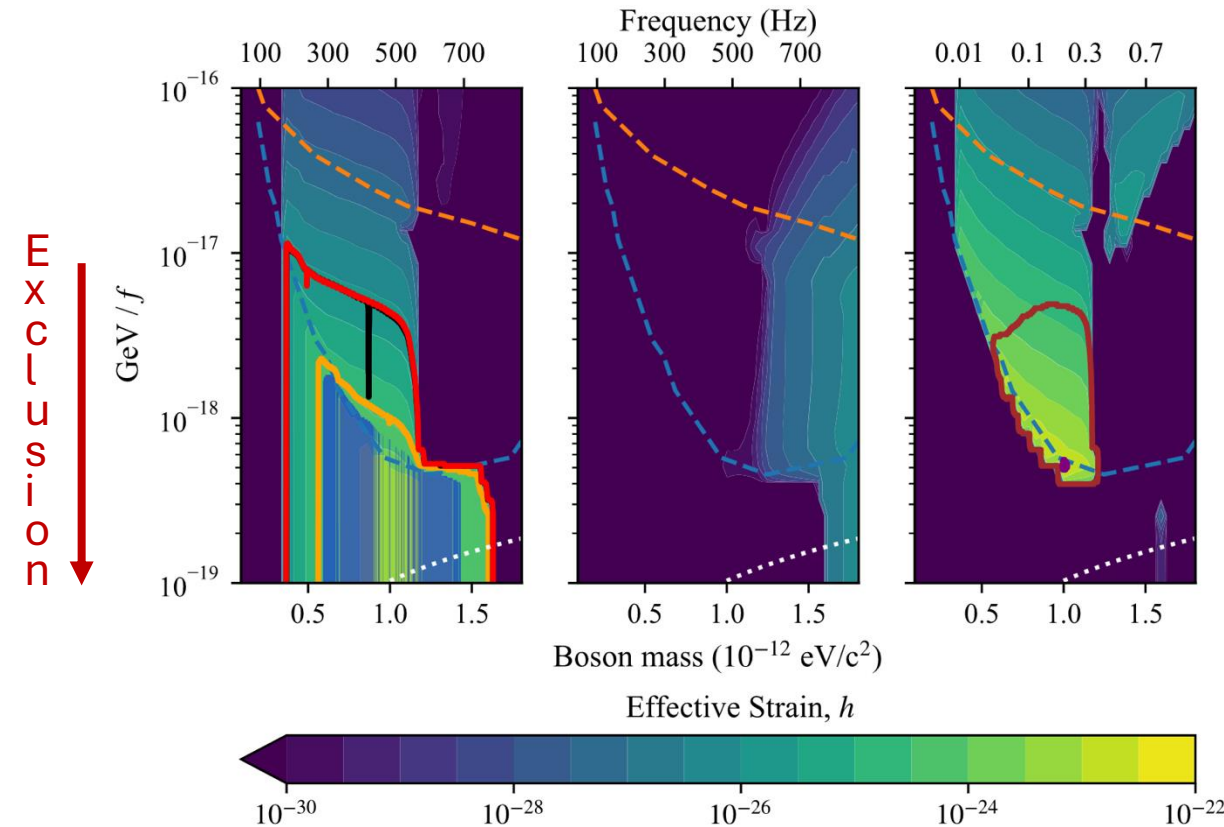
- Excluded region often only to a **lower** bound of coupling strength



Alimena et al. 2025, [arXiv:2510.05257v2](https://arxiv.org/abs/2510.05257v2)

The problem

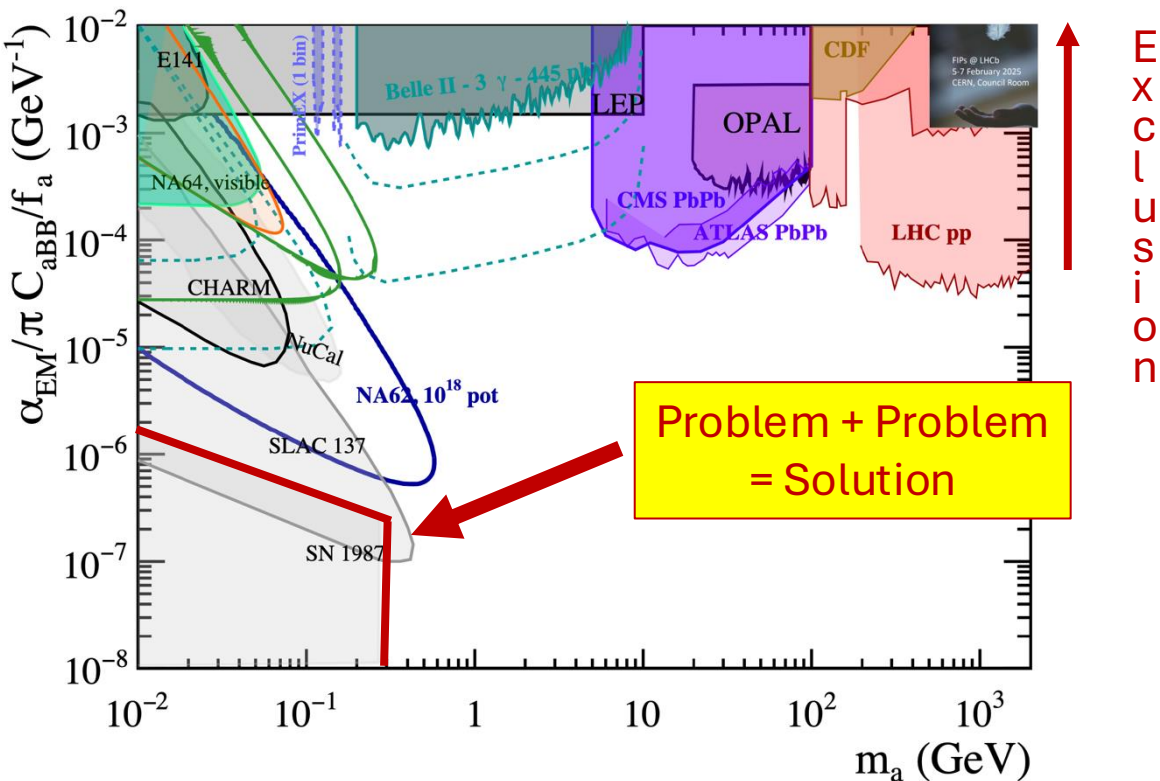
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Collaviti et al. 2024, [Classical and Quantum Gravity 42\(2\)](https://arxiv.org/abs/2405.12345)

The problem

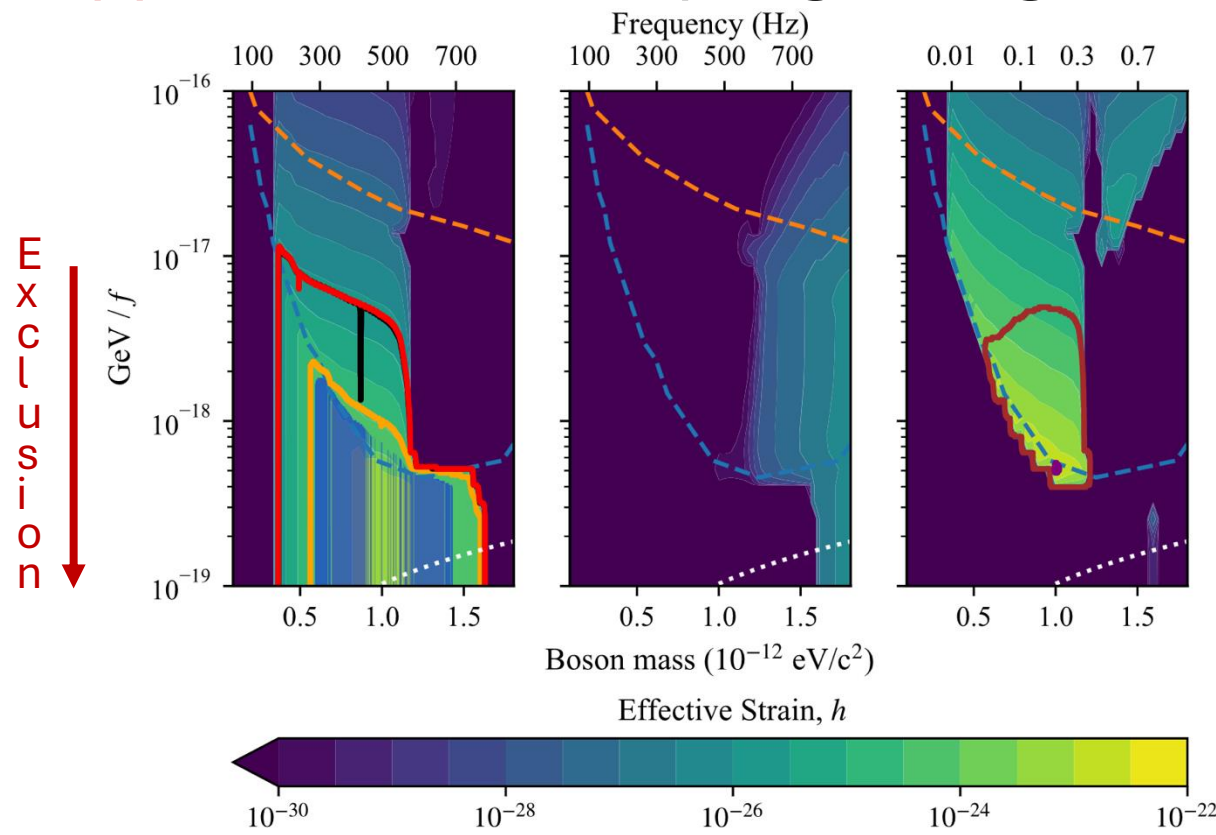
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Alimena et al. 2025, [arXiv:2510.05257v2](https://arxiv.org/abs/2510.05257v2)

The problem

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Collaviti et al. 2024, [Classical and Quantum Gravity 42\(2\)](https://arxiv.org/abs/2405.12345)

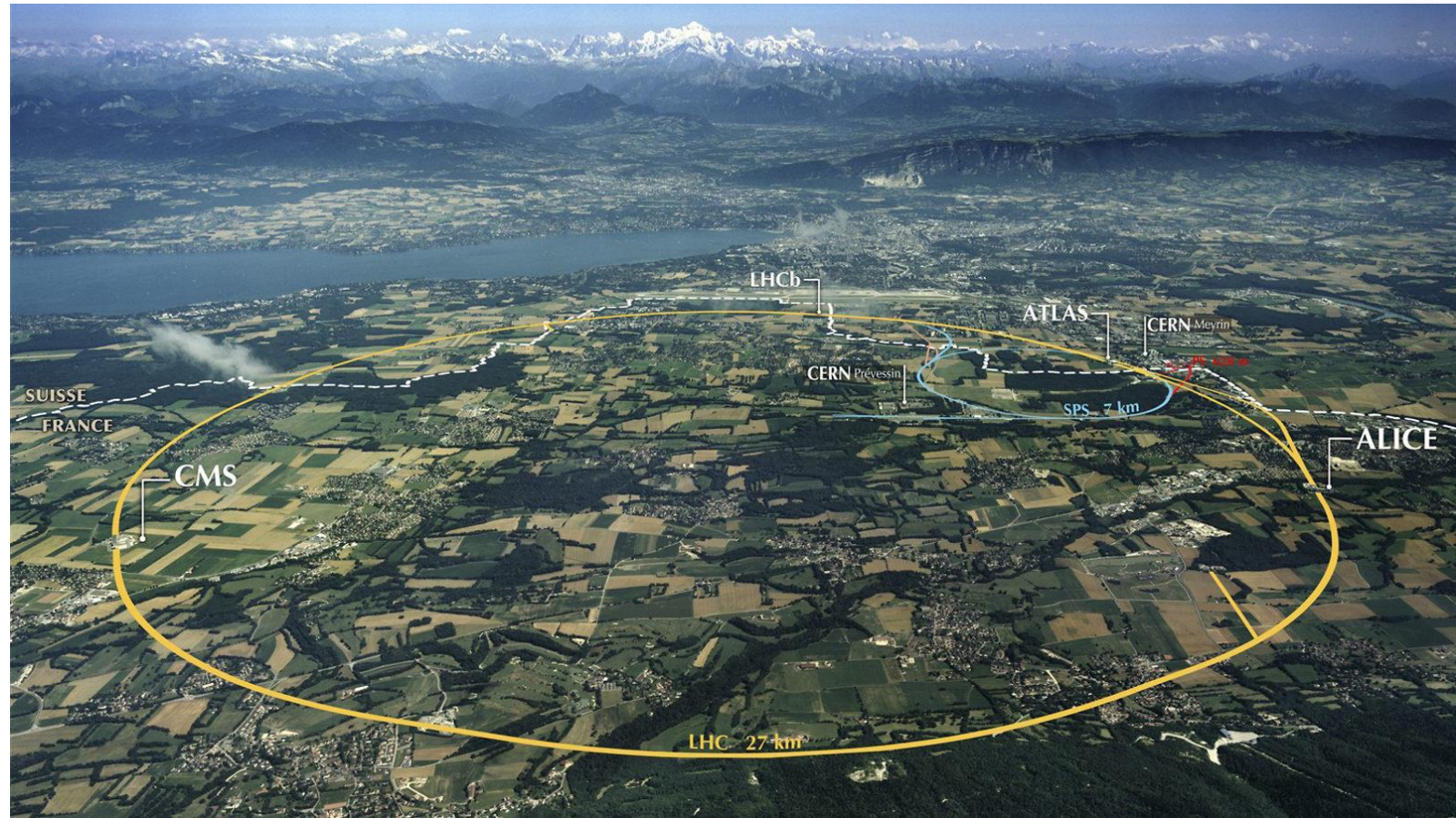
Presentation Outline

- The LHCb Experiment
- Dark sector portal framework
- Results
 - Direct dark sector searches
 - Indirect rare decay measurements

The Large Hadron Collider beauty Experiment

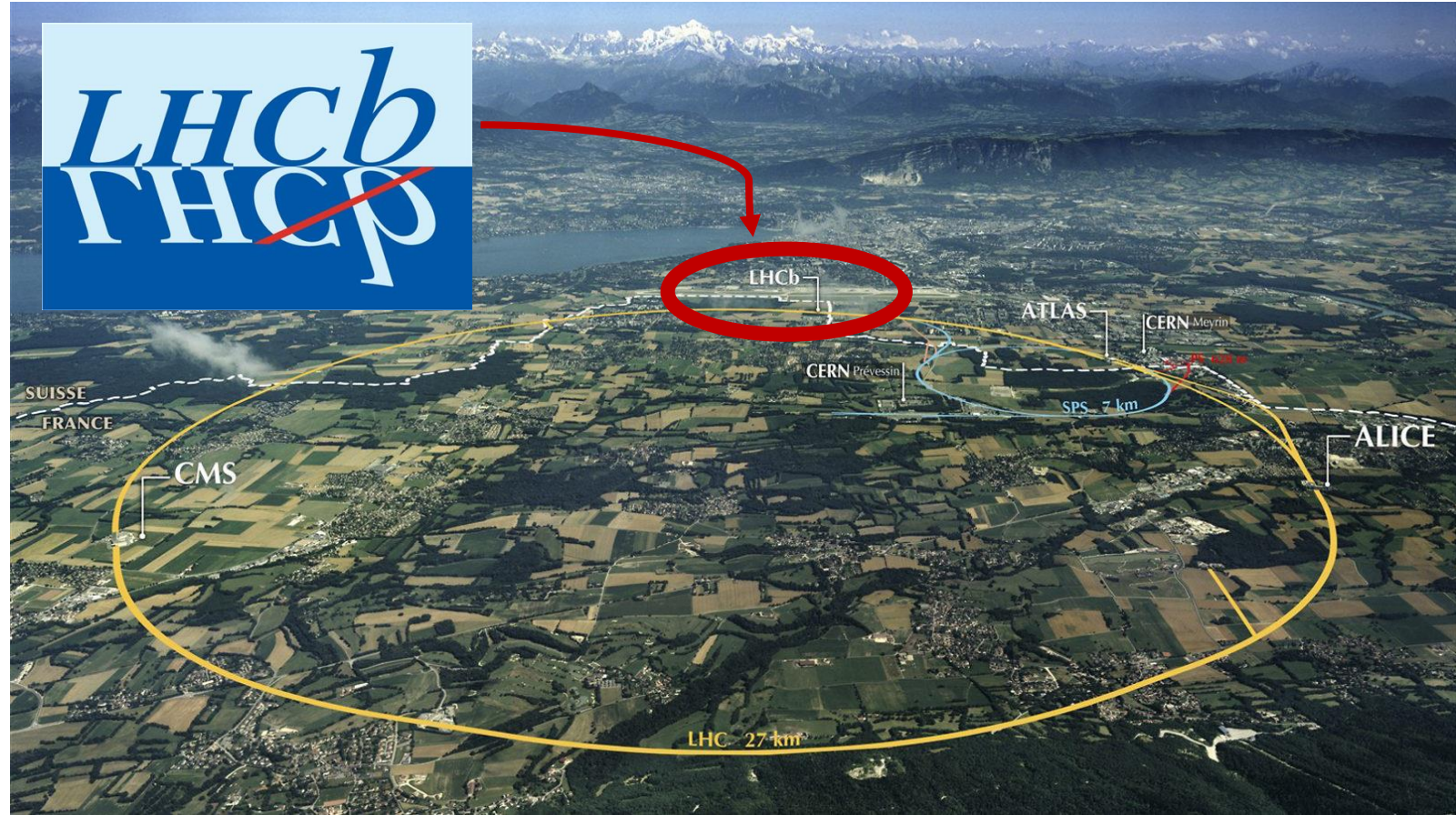
The Large Hadron Collider beauty Experiment

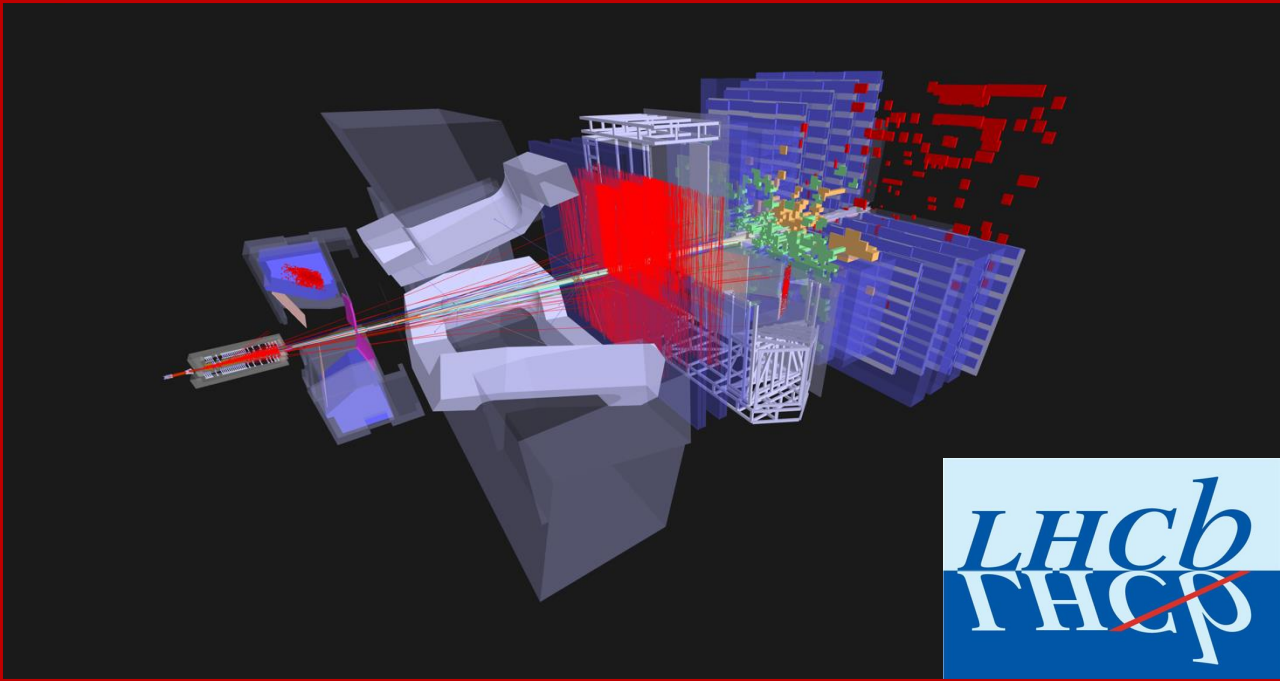
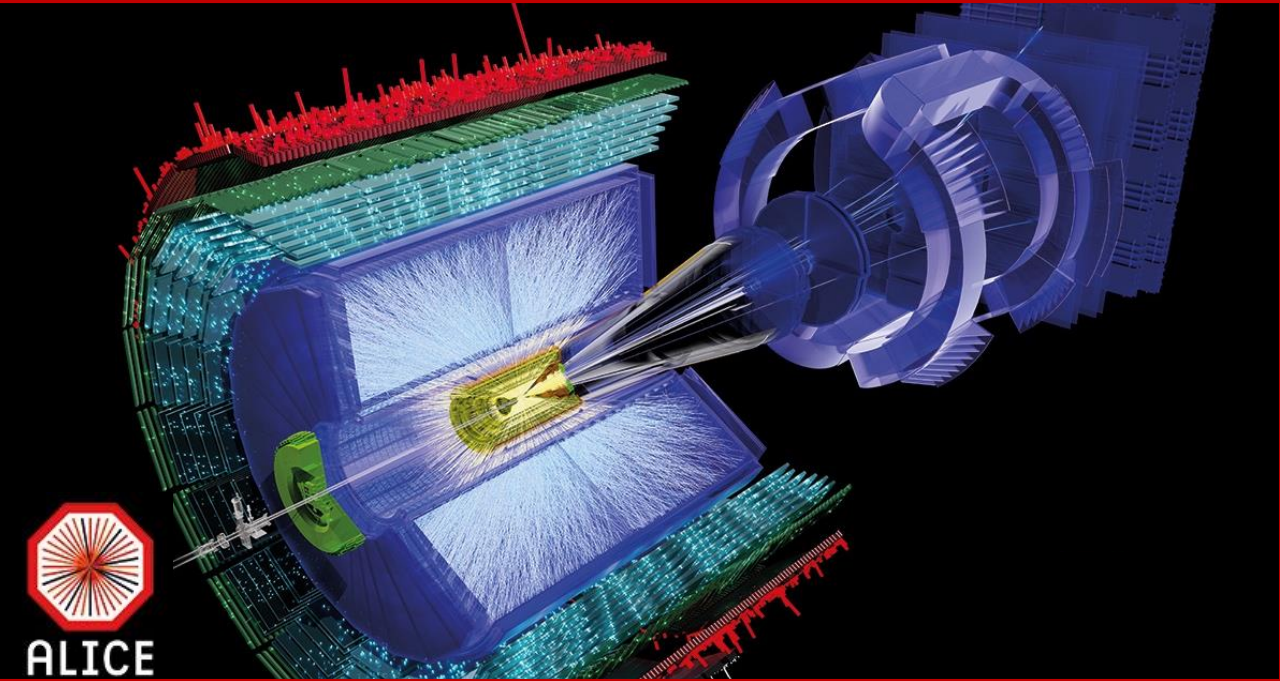
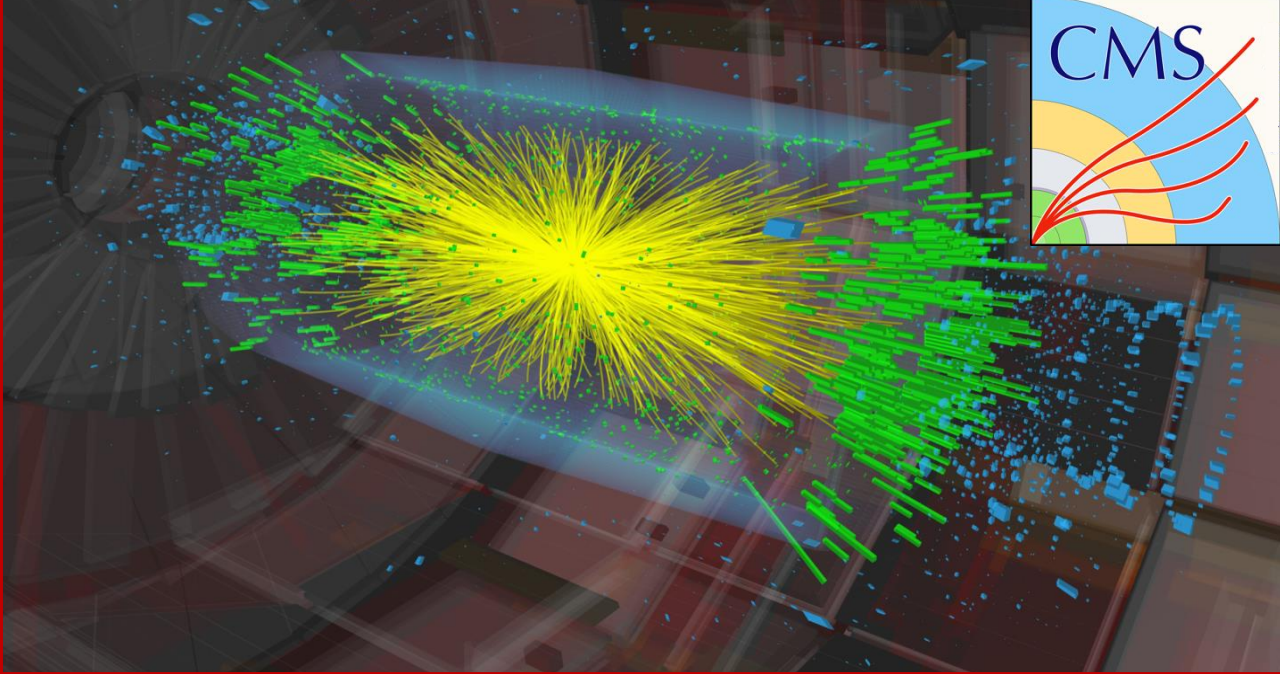
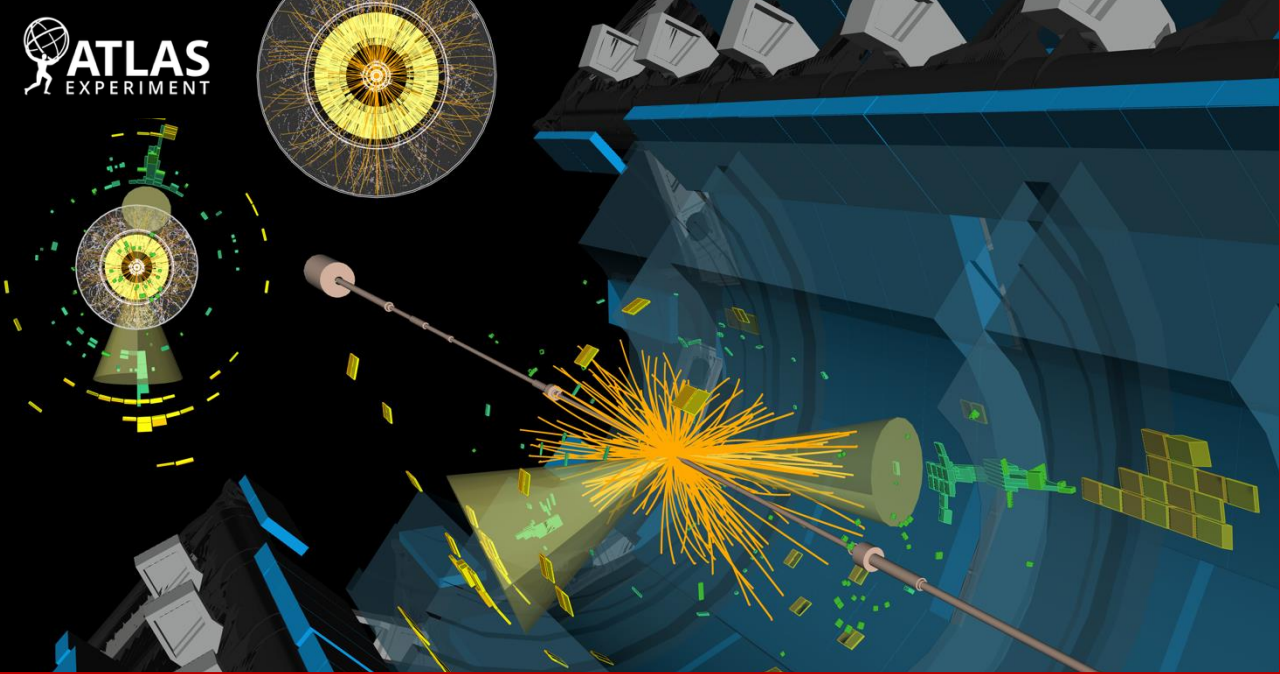
- One of four “grand” experiments on the Large Hadron Collider
- Specialises in:
 - b -hadrons
 - Charge-parity (CP) asymmetry

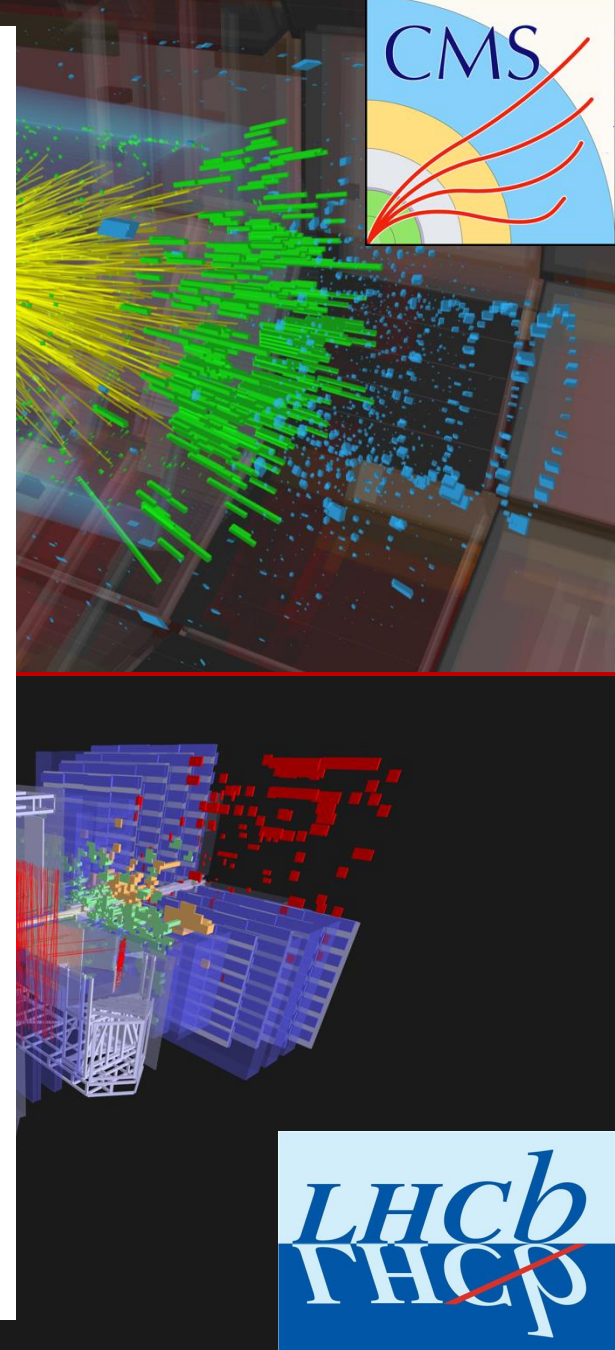
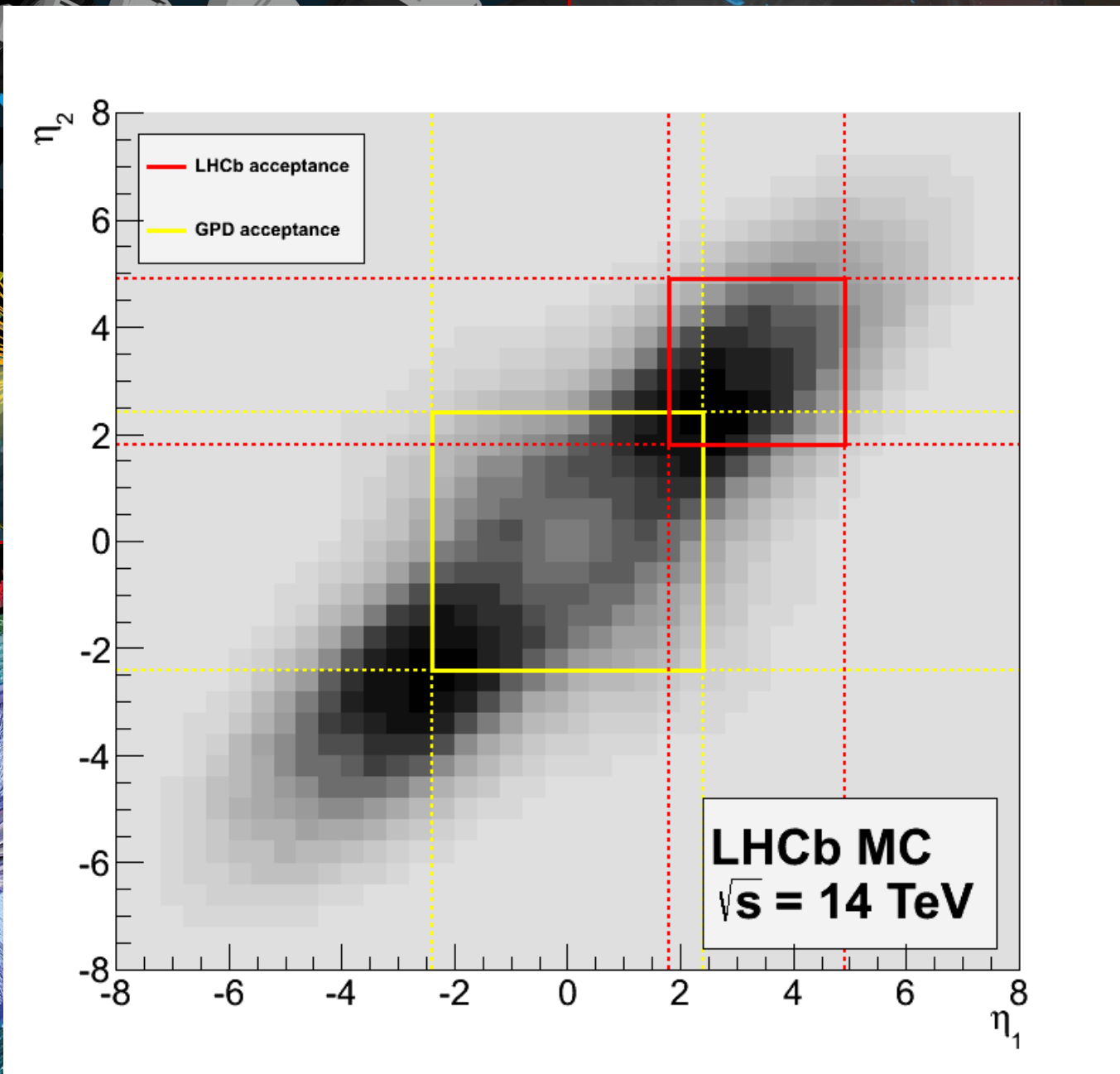
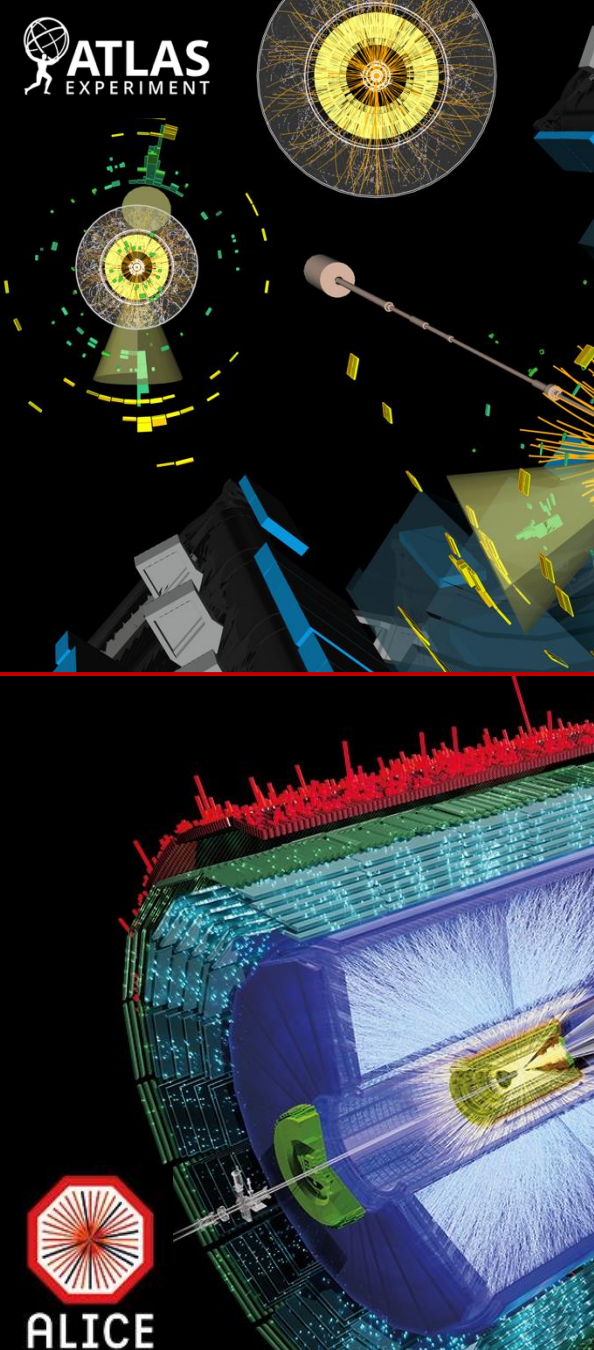


The Large Hadron Collider beauty Experiment

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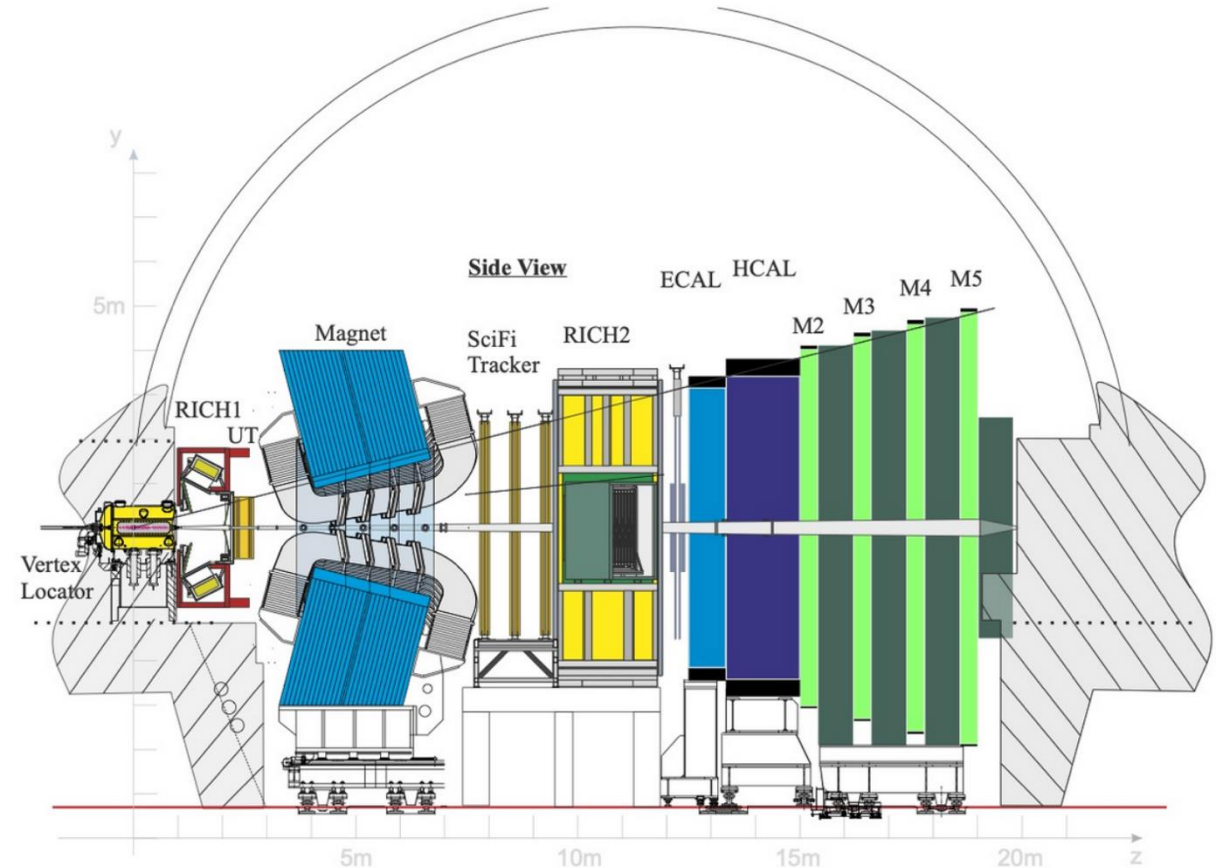






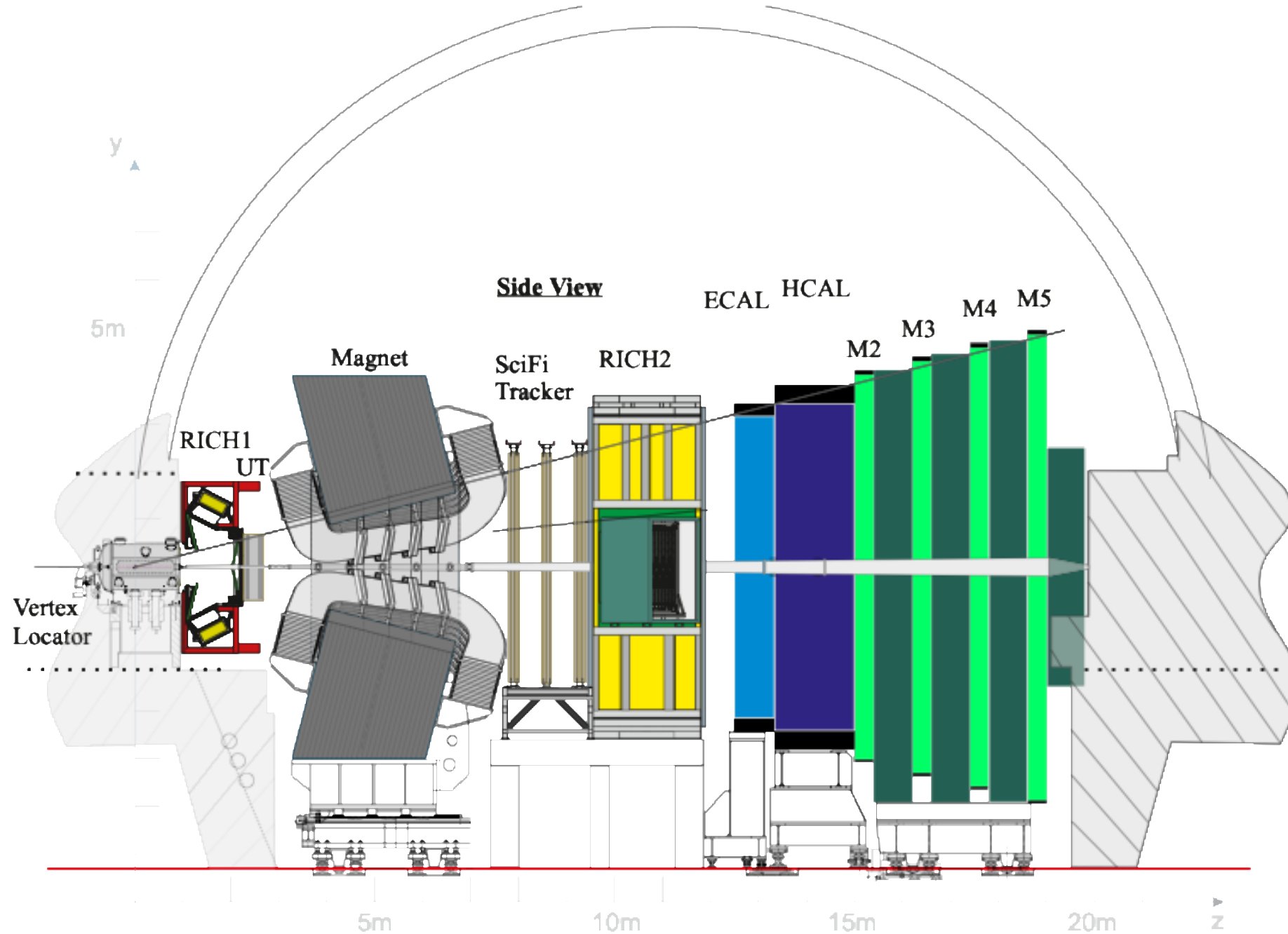
The LHCb Design

- LHCb is a forward-tracking detector at the Large Hadron Collider
 - Angular acceptance optimised for b and c physics



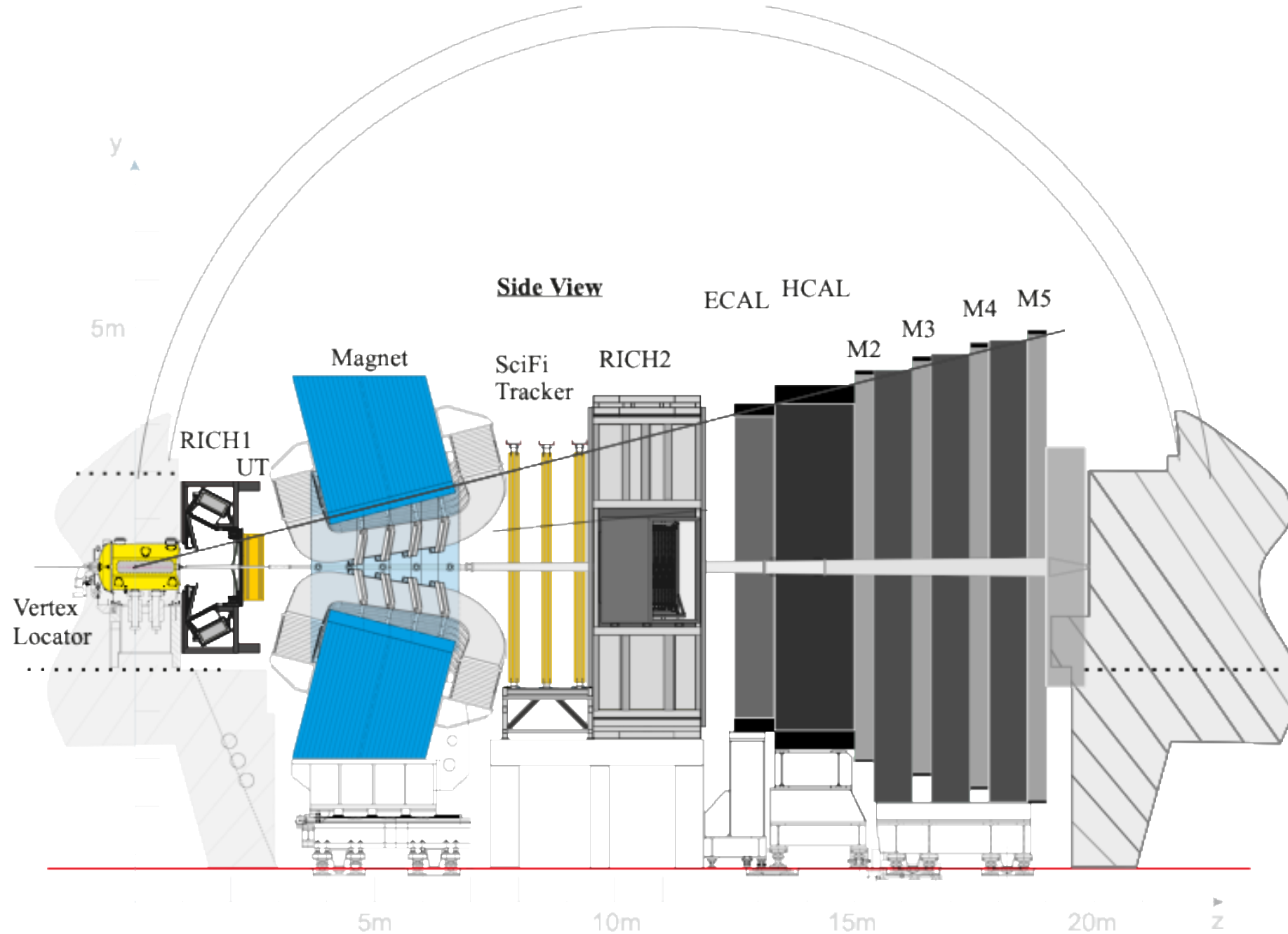
LHCb Collaboration,
[Journal of Instrumentation 19 2024](#)

The LHCb Design



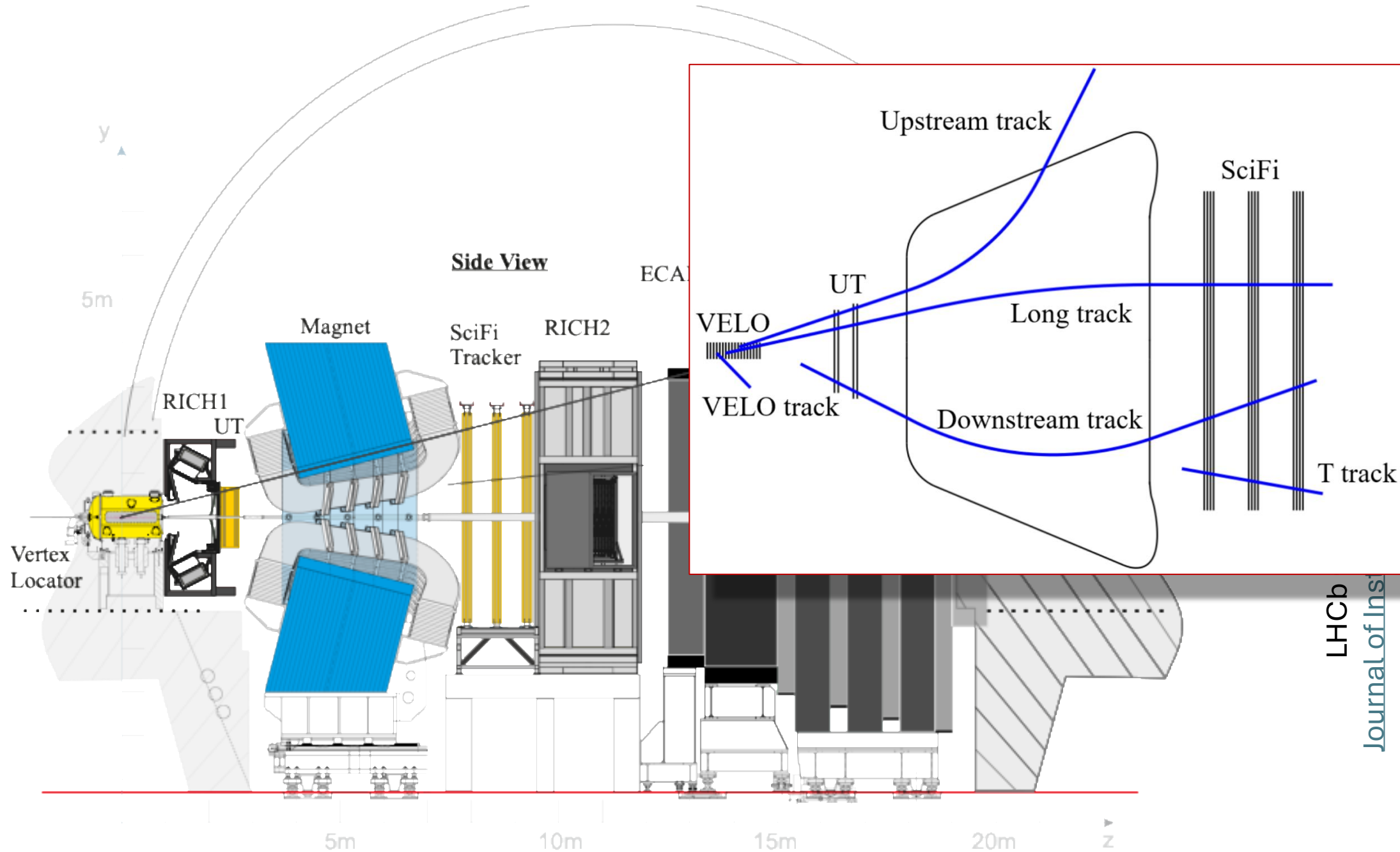
LHCb Collaboration,
[Journal of Instrumentation 19 2024](#)

The LHCb Design



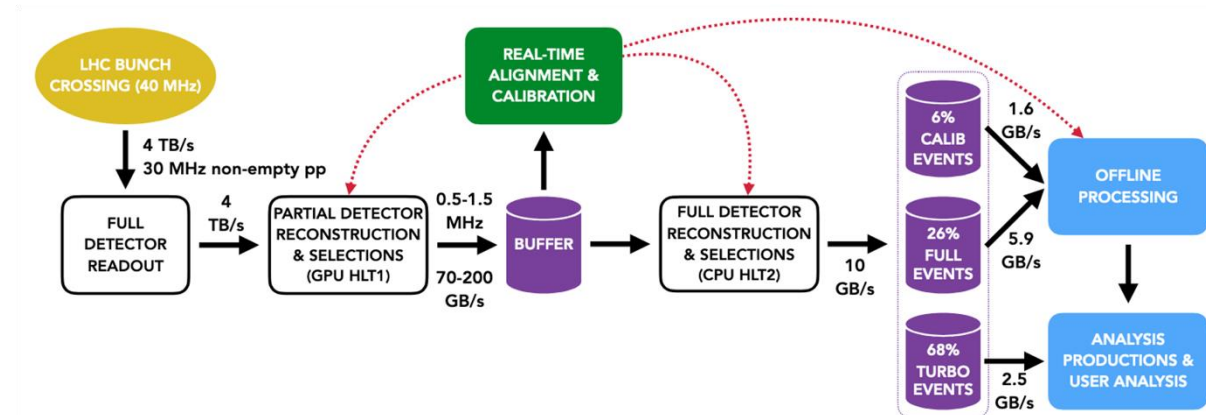
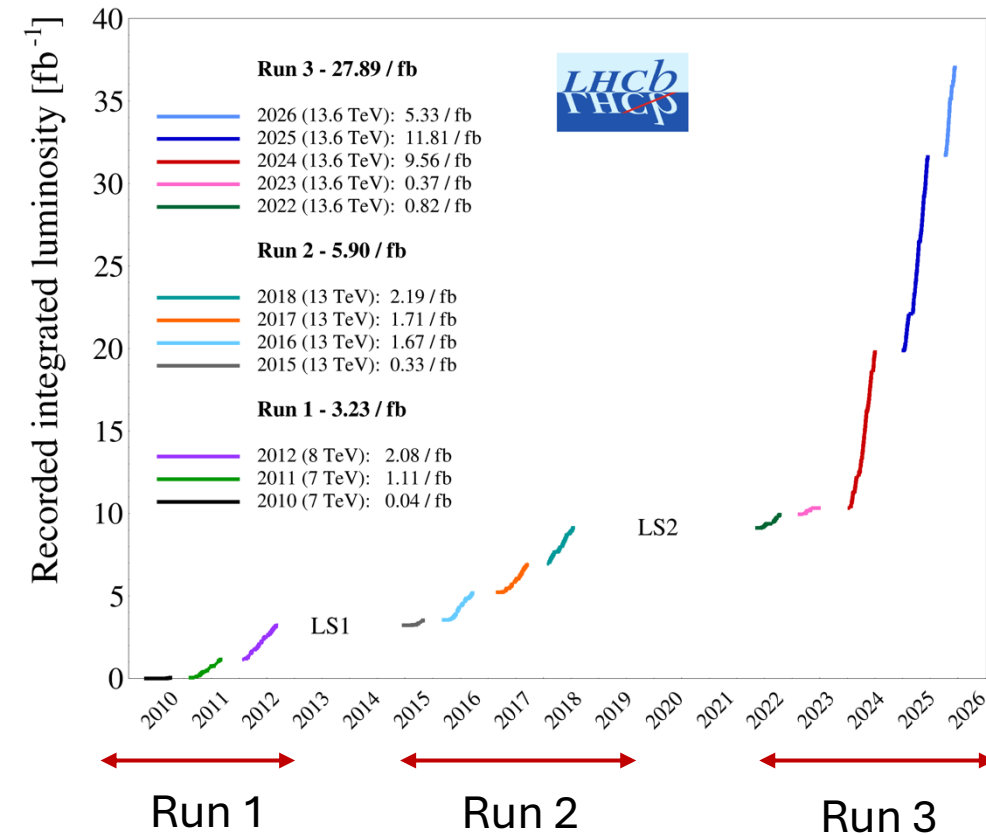
LHCb Collaboration,
[Journal of Instrumentation 19 2024](#)

The LHCb Design



LHCb Upgrade I

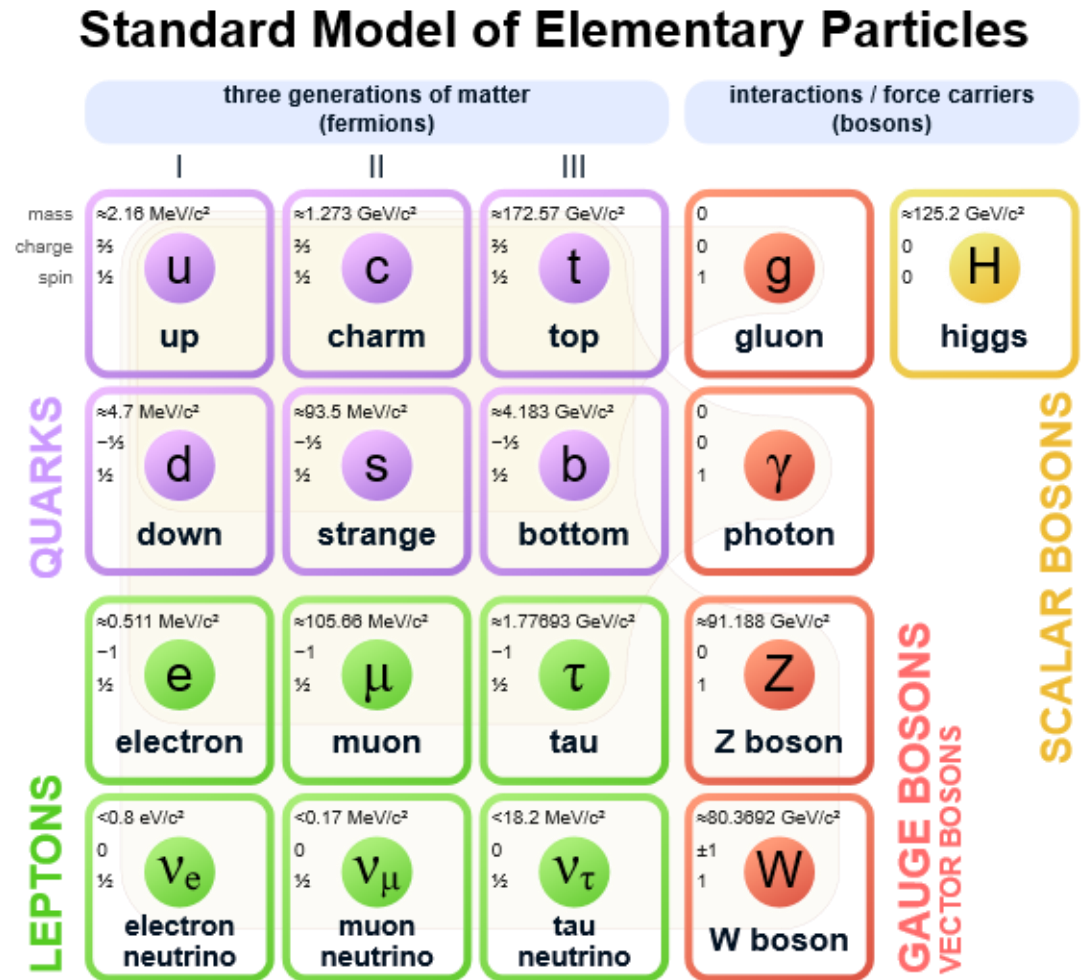
- Between Run 2 and Run 3, LHCb underwent an upgrade
 - Able to collect data 5-times faster
 - Fully software-based trigger
- Exciting prospects for new and near-future results



Dark Sector Portal Framework

The Standard Model (SM)

- The SM Lagrangian contains all renormalizable operators of the known fields
- However, it is necessarily incomplete:
 - SM neutrino mass
 - Baryogenesis
 - Dark matter
 - Inflation
- Many Beyond Standard Model (BSM) extensions to address these faults



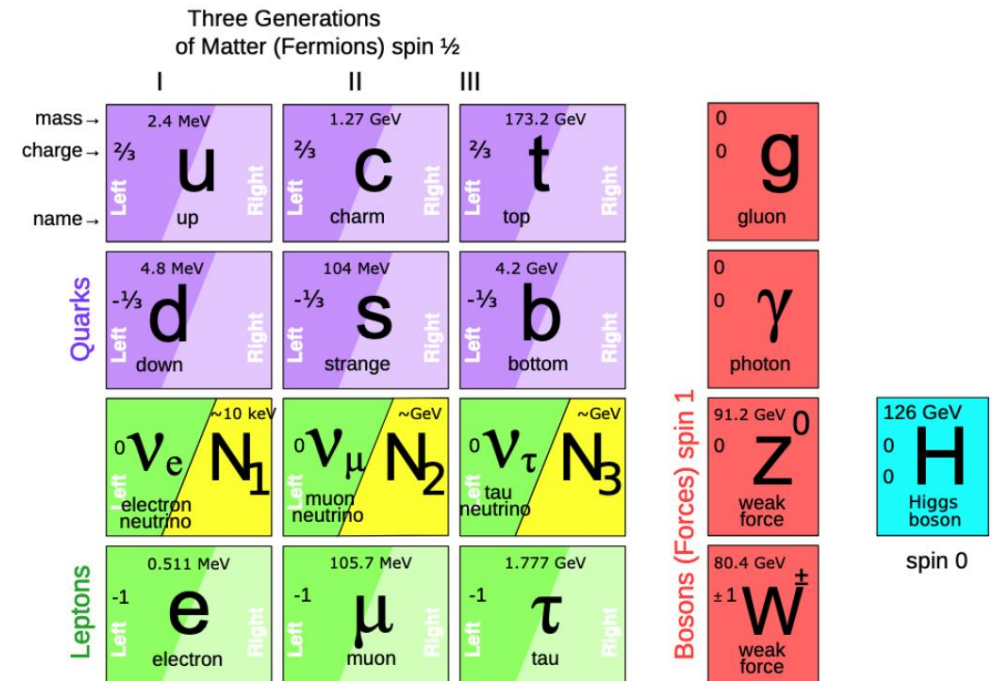
The 4 Dark Sector (Portal) Mediators

- Dark sector portal models are a particularly simple category of extensions:
 - ❑ Introduce a new, sterile field (the “mediator”)
 - ❑ Consider renormalizable (ALP: lowest dimensional) couplings to the SM
 - ❑ Model is done

	Lorentz transformation	Typical name	Typical Lagrangian notation
1.	Scalar	Dark Higgs boson	$(\mu S + \lambda_{HS} S^2) H^\dagger H$
2.	Spinor	Heavy neutral lepton	$y_N L_i H N$
3.	Vector	Dark photon	$-\frac{\epsilon}{2 \cos \theta_W} F'_{\mu\nu} B^{\mu\nu}$
4.	Pseudoscalar	Axion-like particle	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}, \frac{a}{f_a} G_{i,\mu\nu} \tilde{G}_i^{\mu\nu}, \frac{\partial_\mu a}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$

Benefits of Dark Sector Portal Models

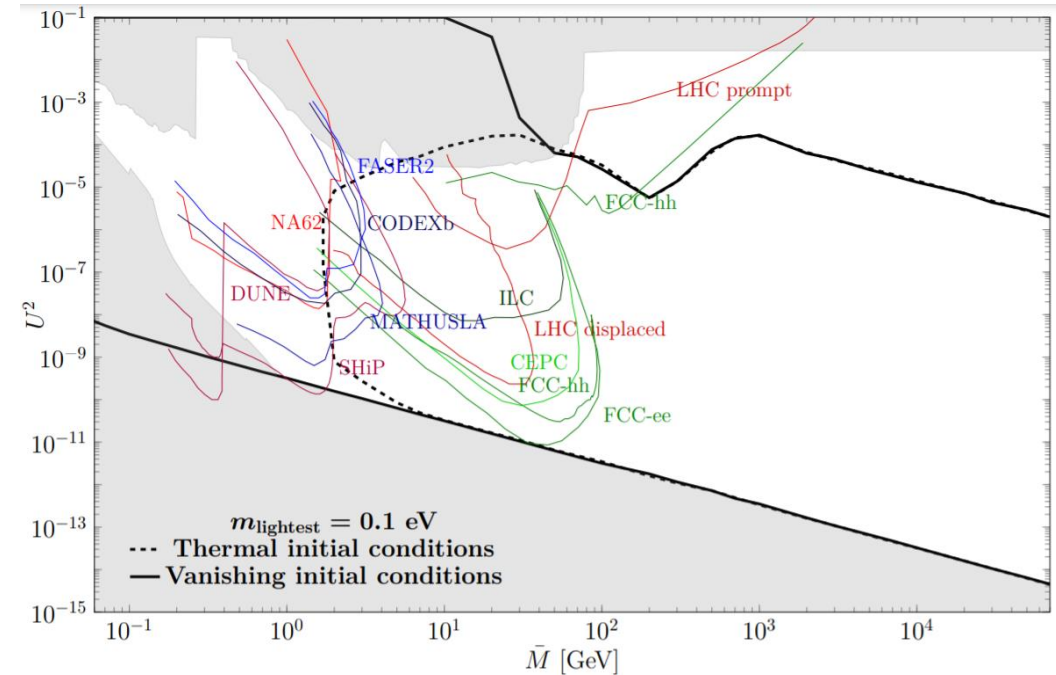
- Common benchmark of experimental sensitivity
- Dark sector mediators appear in more complex BSM models:
 - Phenomenologically approximate simple mediators (e.g. neutrino Minimal Standard Model, ν MSM)
 - Constraints can be reinterpreted (e.g. Hidden Valley models)



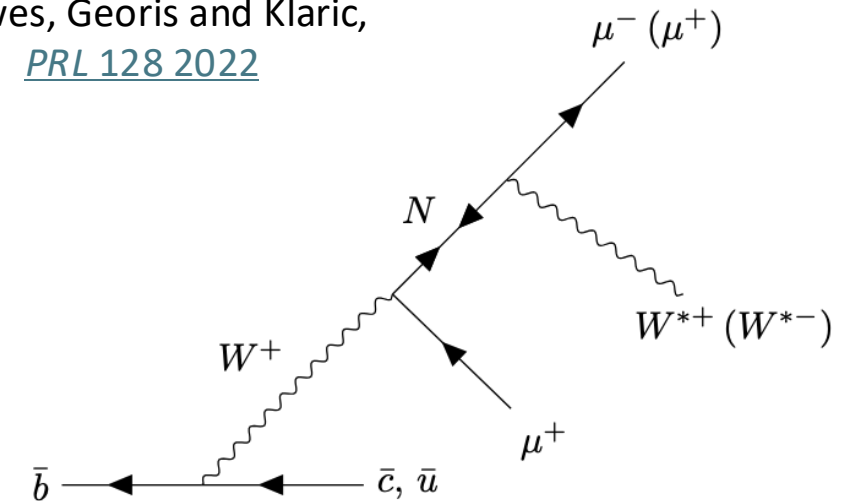
Bonivento *et al.*,
[arXiv:1310.1762](https://arxiv.org/abs/1310.1762) 2013

Mass Regimes of Searches

- Mediators can be produced from several sources giving rise to several different search regimes:
 - Kaon ($< 0.3 \text{ GeV}/c^2$)
 - D meson ($< 2 \text{ GeV}/c^2$)
 - B meson ($1.6 - 6 \text{ GeV}/c^2$)
 - W and Z boson ($4 - 91 \text{ GeV}/c^2$)
 - W and Z mediated ($> 91 \text{ GeV}/c^2$)



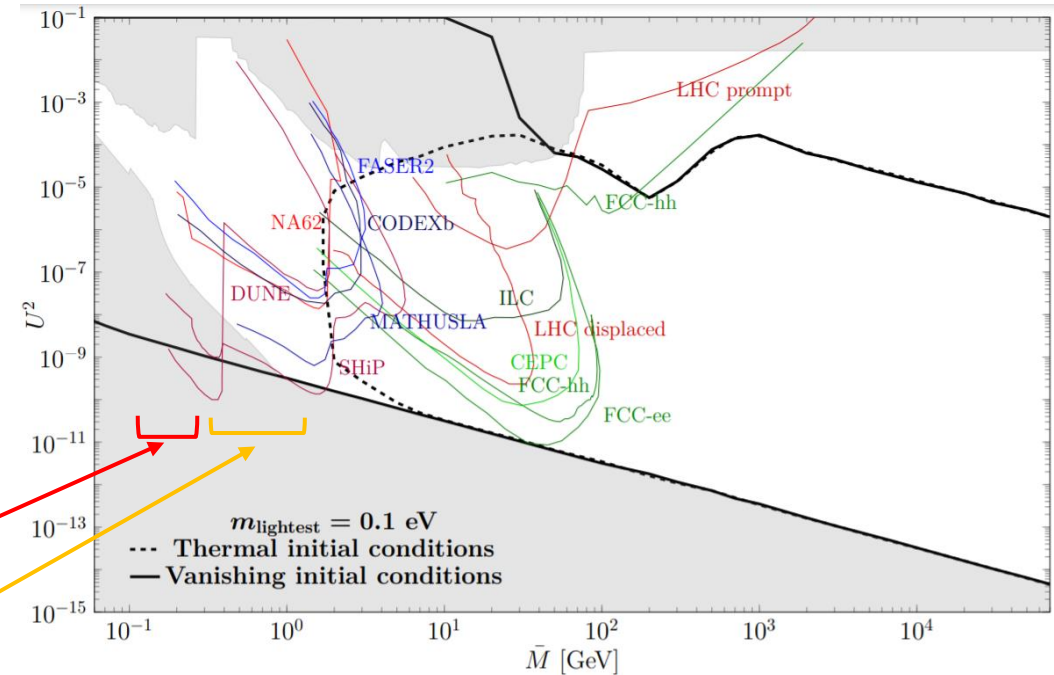
Drewes, Georis and Klaric,
[PRL 128 2022](#)



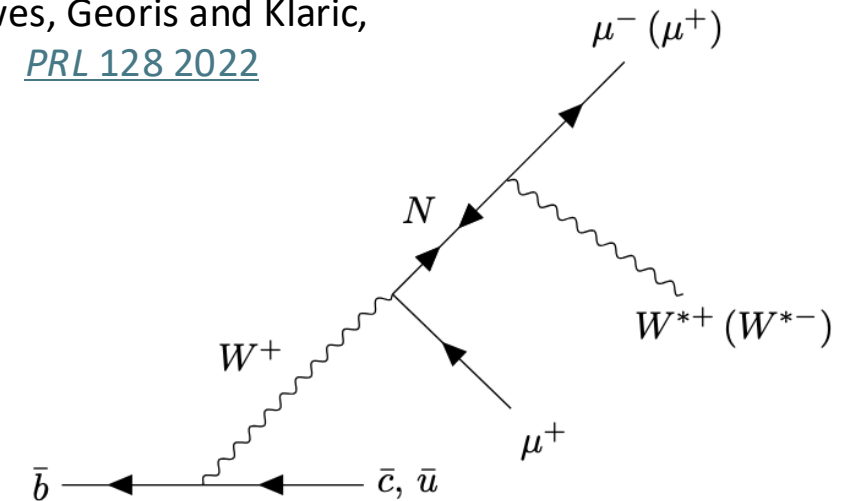
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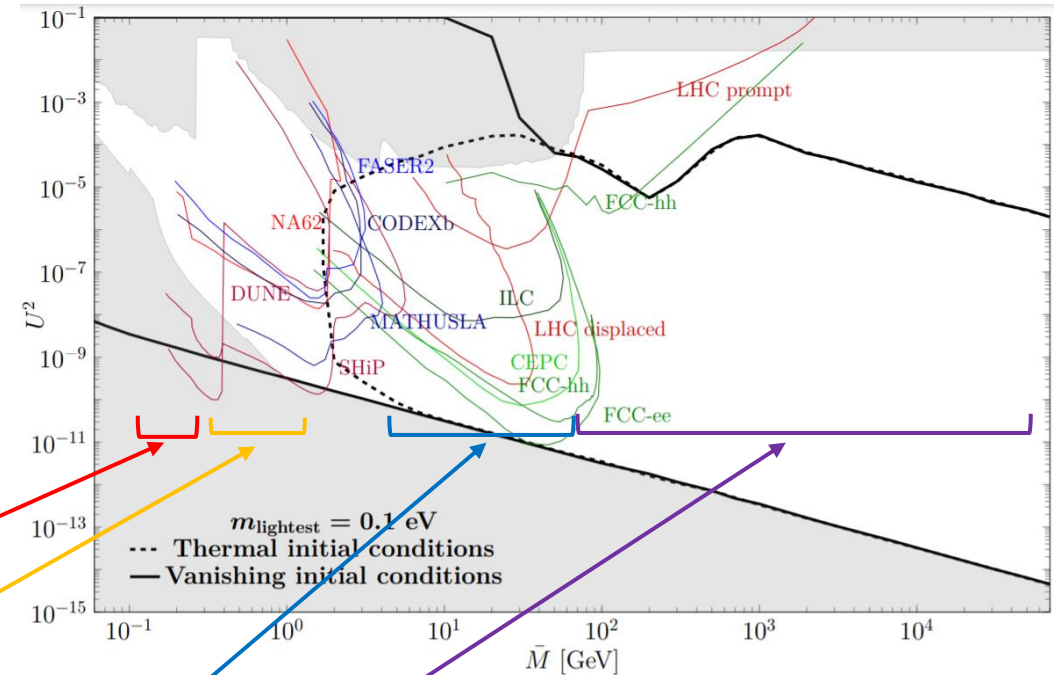
Drewes, Georis and Klaric,
[PRL 128 2022](#)



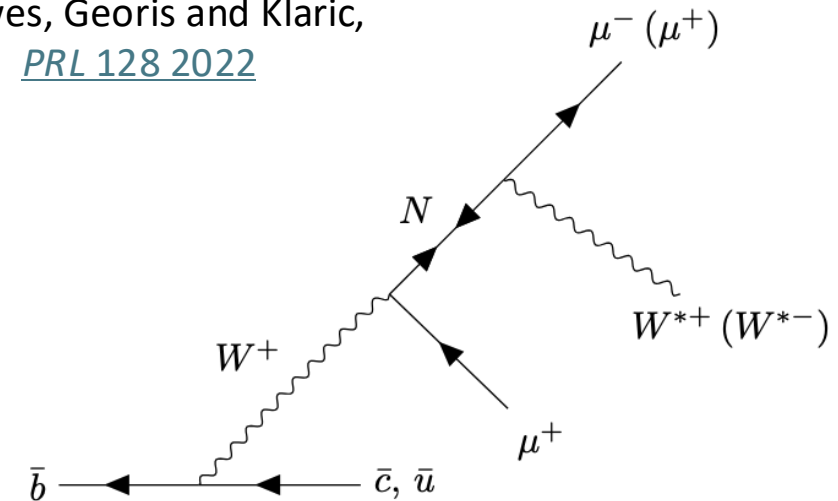
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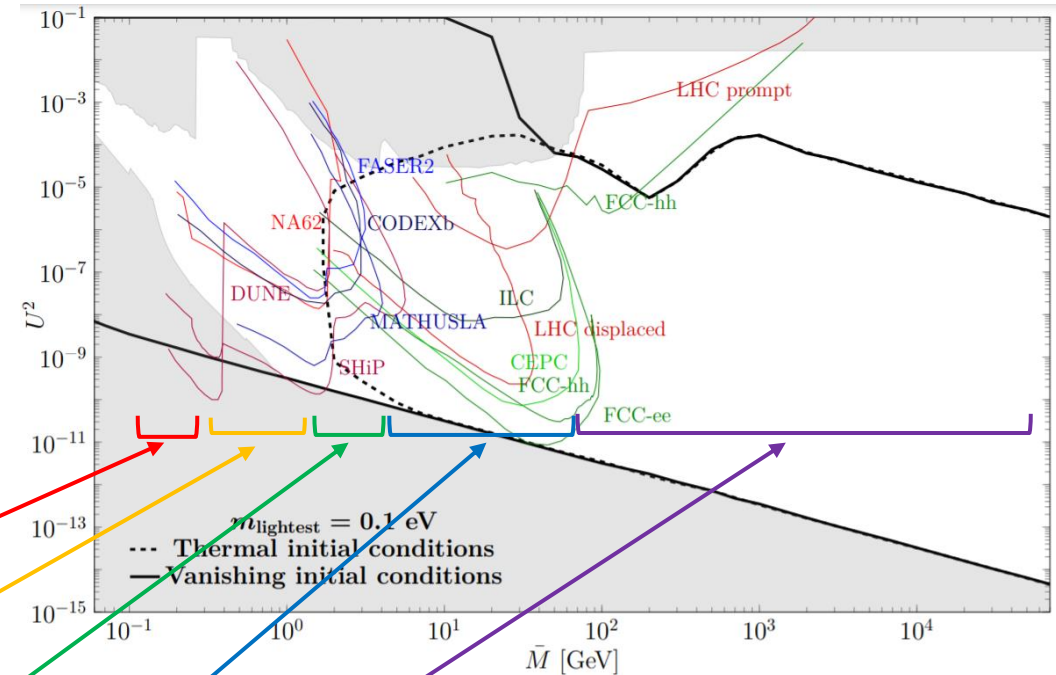
Drewes, Georis and Klaric,
[PRL 128 2022](#)



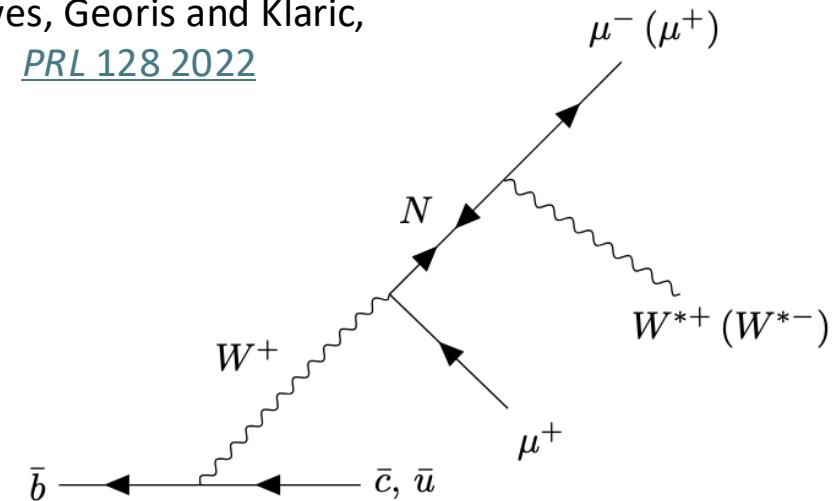
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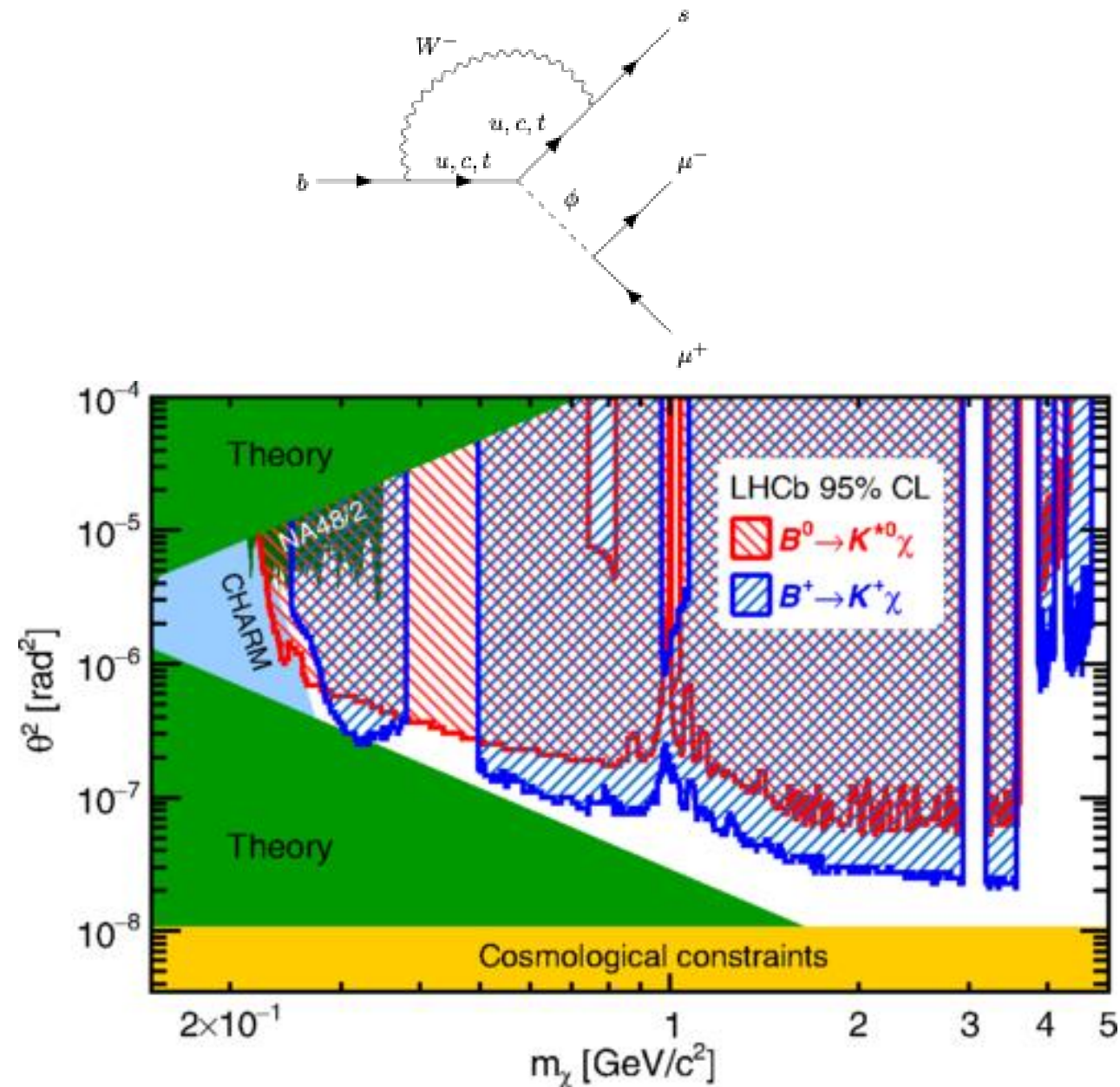
Drewes, Georis and Klaric,
[PRL 128 2022](#)



Results: Direct dark sector searches

1. Dark Higgs: Results

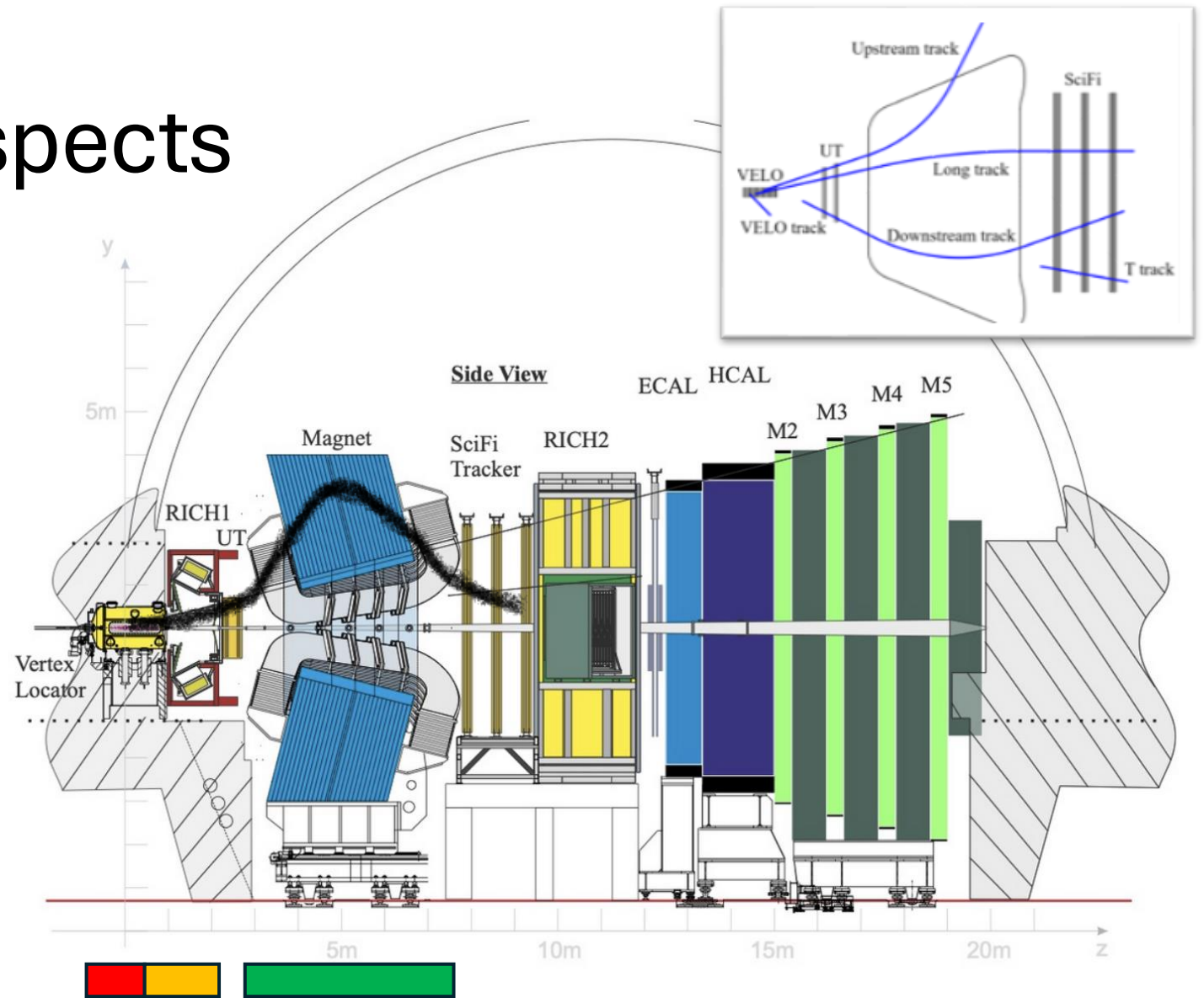
- **Analysis strategy:** Fully reconstruct i) B-meson, ii) non-displaced dark Higgs
- **Target modes:**
 - $B^0 \rightarrow K^{*0}(\chi \rightarrow \mu^+ \mu^-)$ [1]
 - $B^+ \rightarrow K^+(\chi \rightarrow \mu^+ \mu^-)$ [2]
- **Data:** Run 1
- **Interpretation:** Scalar inflaton
- But: Not fully excluded; e.g. Hidden Valley models



LHCb Collaboration 2017, [Phys. Rev. D 95](#)

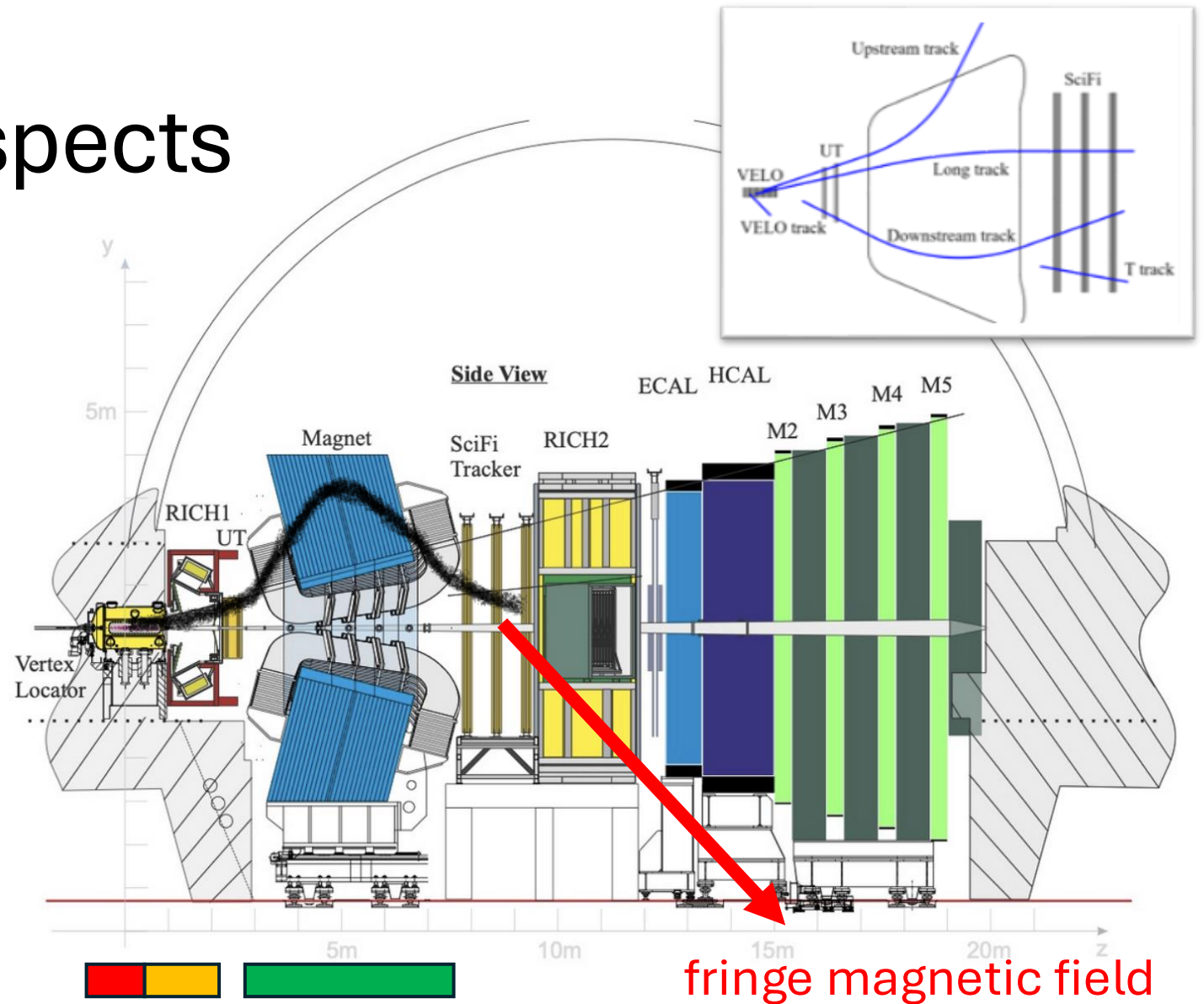
1. Dark Higgs: Prospects

- Run 1 and 2 analyses used **long tracks** $z < 0.5 \text{ m}$, but also:
- **Downstream tracks** $0.5 \text{ m} < z < 2.0 \text{ m}$, and
- **T tracks** $2.5 \text{ m} < z < 8.0 \text{ m}$
- Idea is to use T tracks to search for mediators



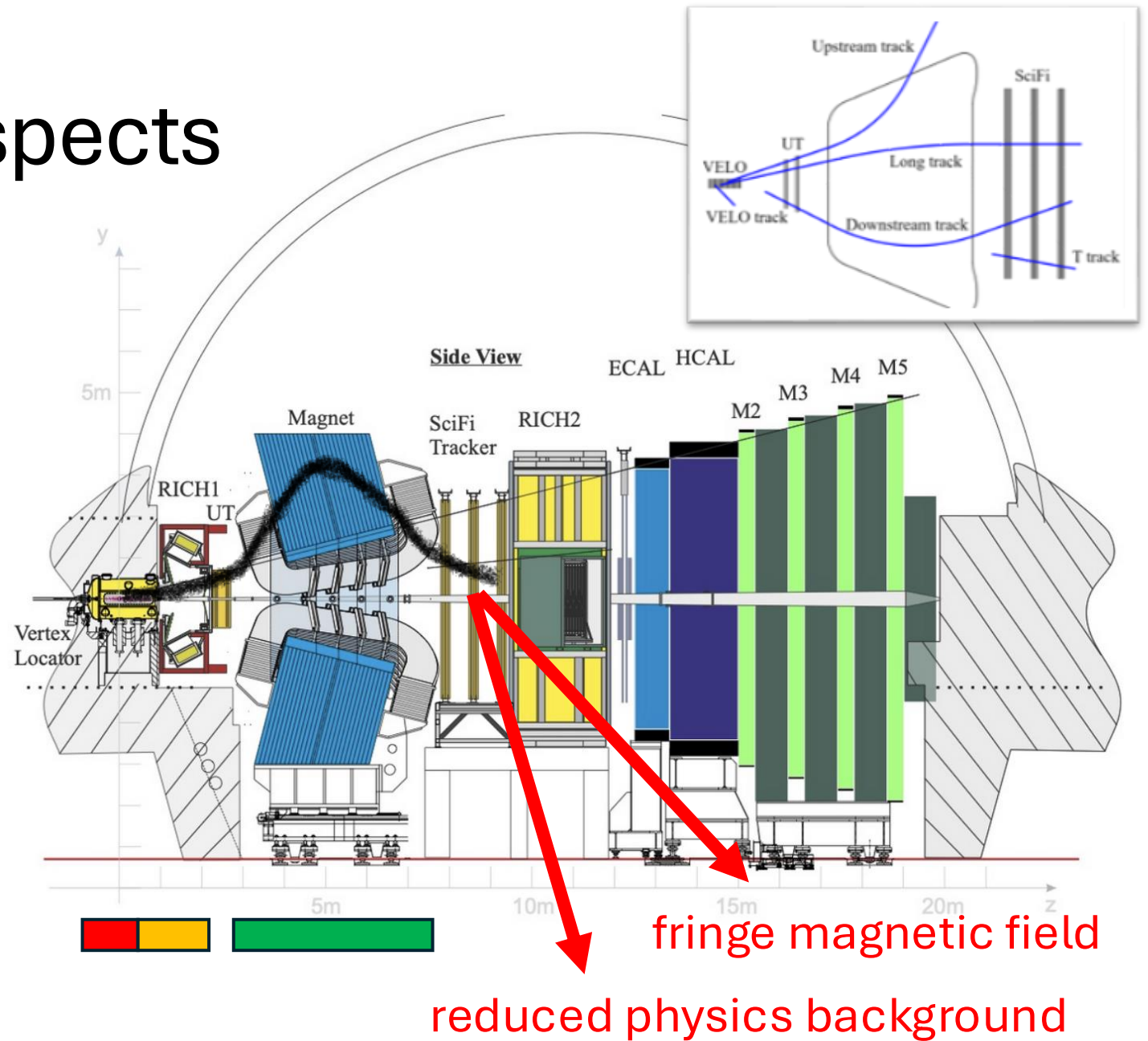
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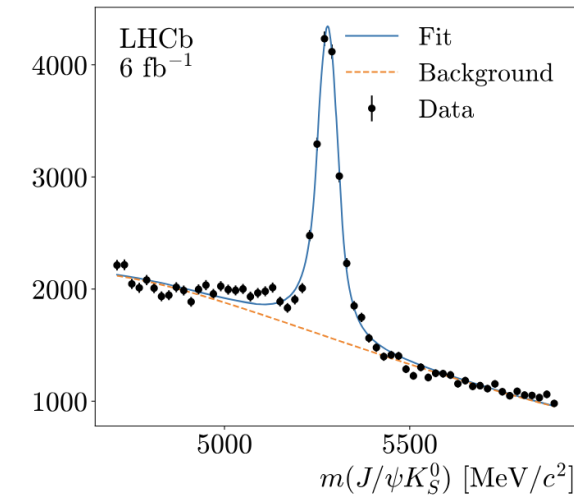
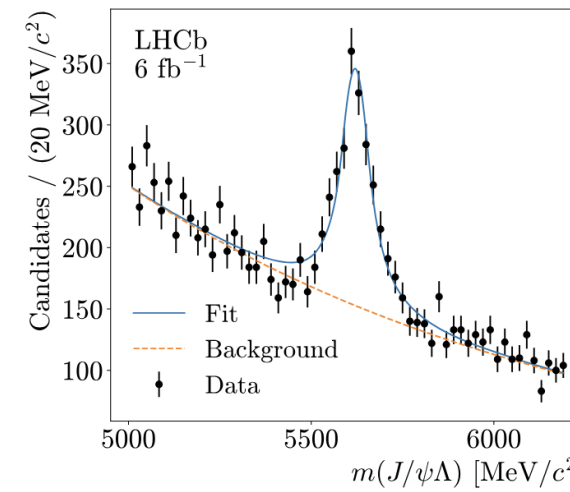
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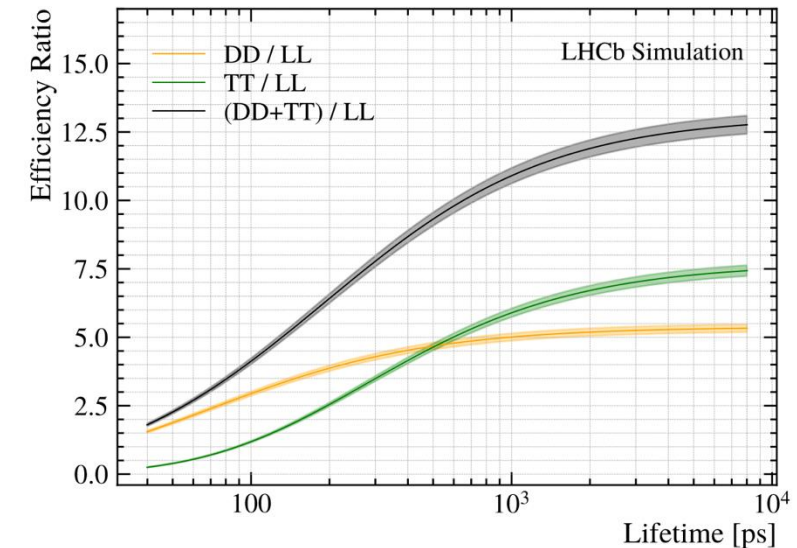


1. Dark Higgs: Prospects

- The usage of T tracks at LHCb is a new concept
- Proof-of-concept in Run 2 data for SM decays:
 - $\Lambda_b^0 \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)(\Lambda^0 \rightarrow p^+ \pi^-)$
 - $B^0 \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)(K_S^0 \rightarrow \pi^+ \pi^-)$
- Never used in:
 - An analysis
 - In BSM searches
 - Without long tracks



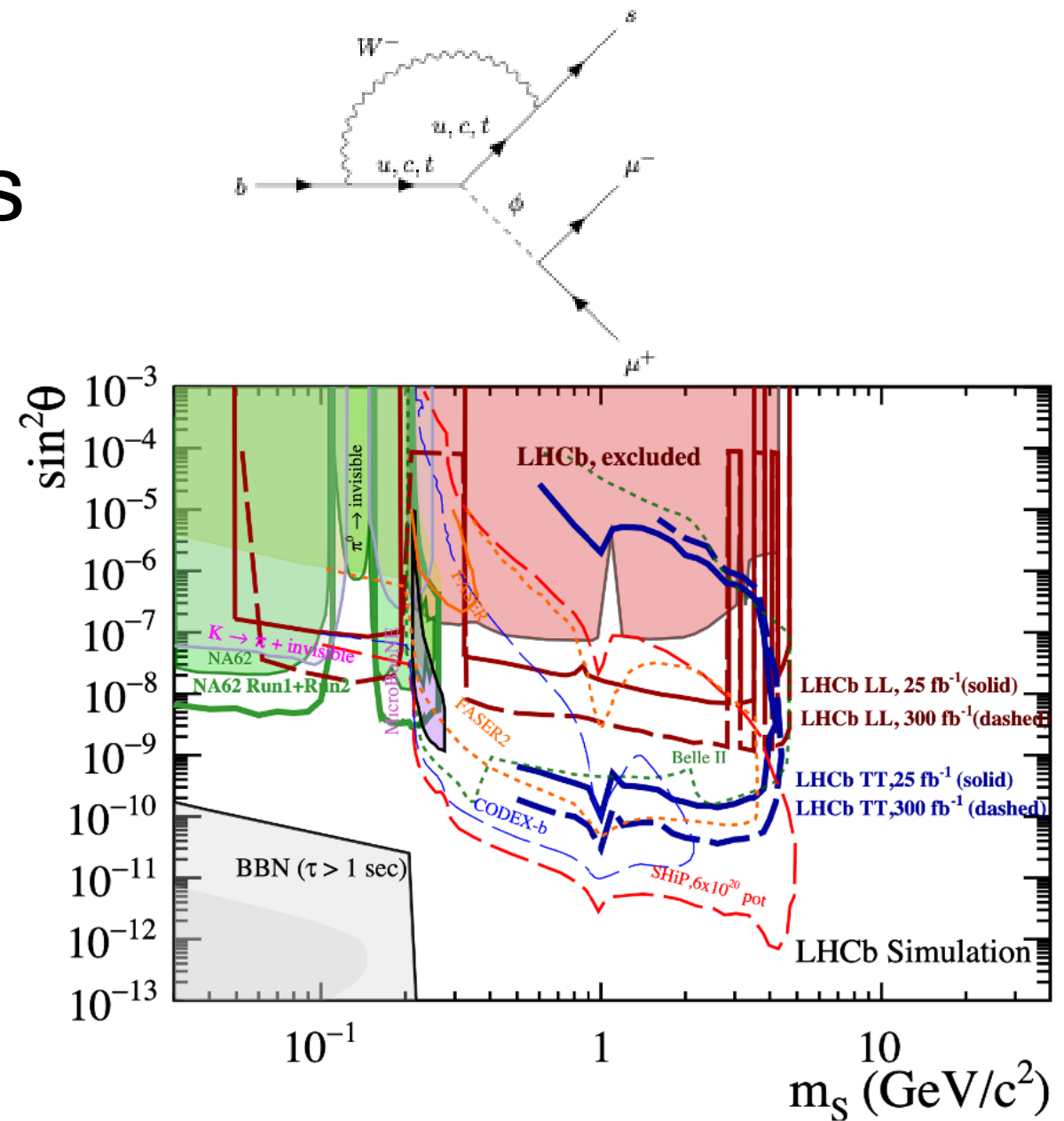
LHCb Collaboration,
[European Physics Journal C 85\(7\) 2025](#)



LHCb Collaboration,
[LHCb-FIGURE-2025-001](#)

1. Dark Higgs: Prospects

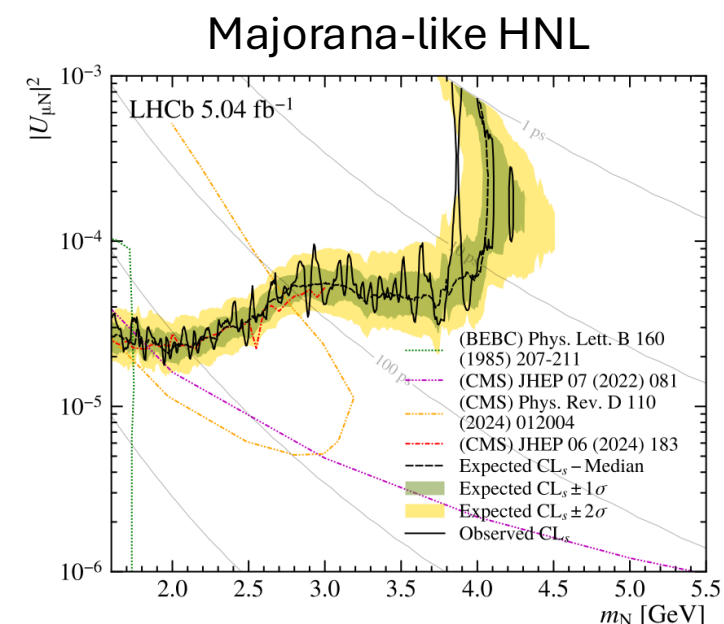
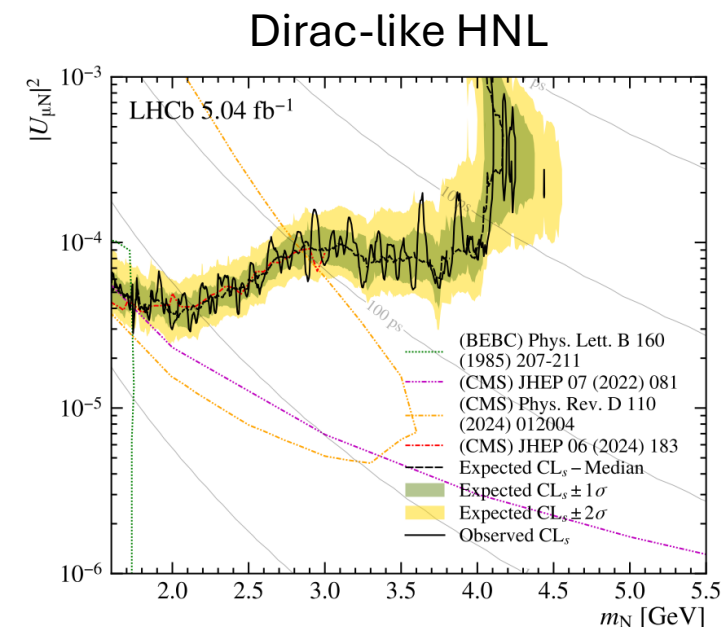
- **Analysis strategy:** Fully reconstruct T-track dark Higgs
- **Target modes:** $B_{u,d} \rightarrow K^* \chi$
- **Data:** Run 3 (and onwards)
- **Interpretation:** Scalar portal



Alimena et al. 2025, [arXiv:2510.05257v2](https://arxiv.org/abs/2510.05257v2)

2. Heavy Neutral Leptons: Results

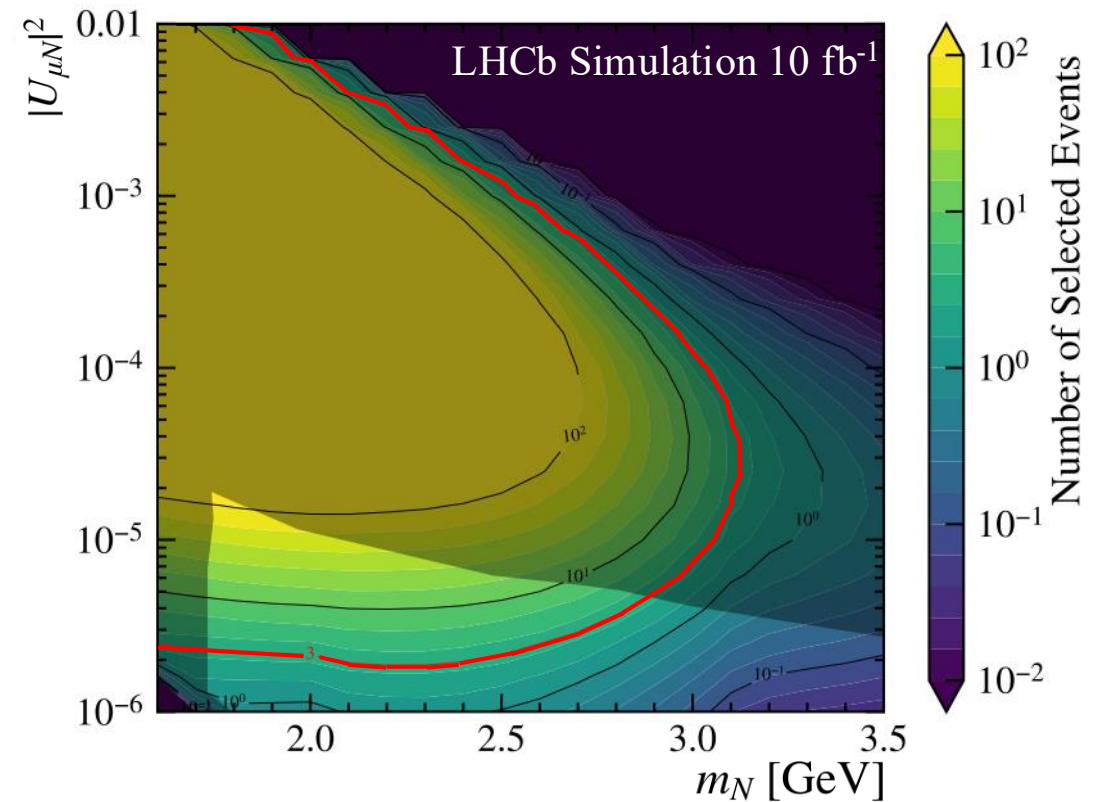
- **Analysis strategy:** Partially reconstruct long (and downstream) HNLs
- **Target modes:**
 - $B_{u,d,s,c} \rightarrow \mu^- (N \rightarrow \mu^+ \pi^-) [X]$
- **Data:** Run 2
- **Interpretation:** Fermionic portal / non-degenerate ν MSM
- **Order of magnitude** increase in sensitivity over past LHCb results
→ Competitive region for first time



LHCb Collaboration,
JHEP 178 2026

2. Heavy Neutral Leptons: Prospects

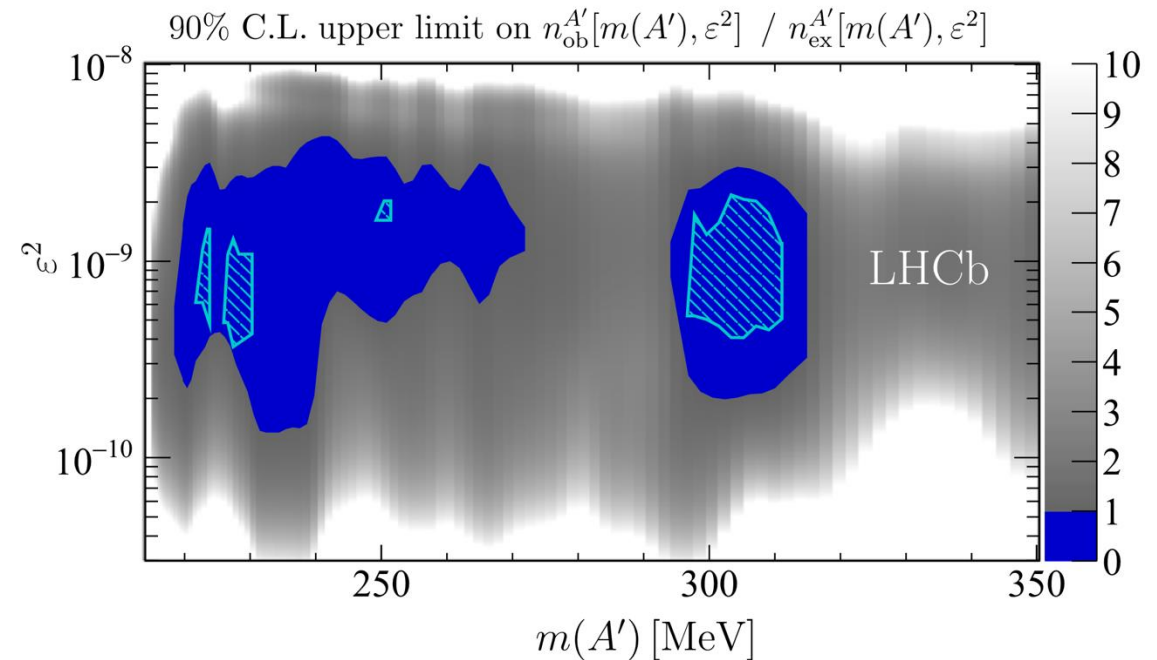
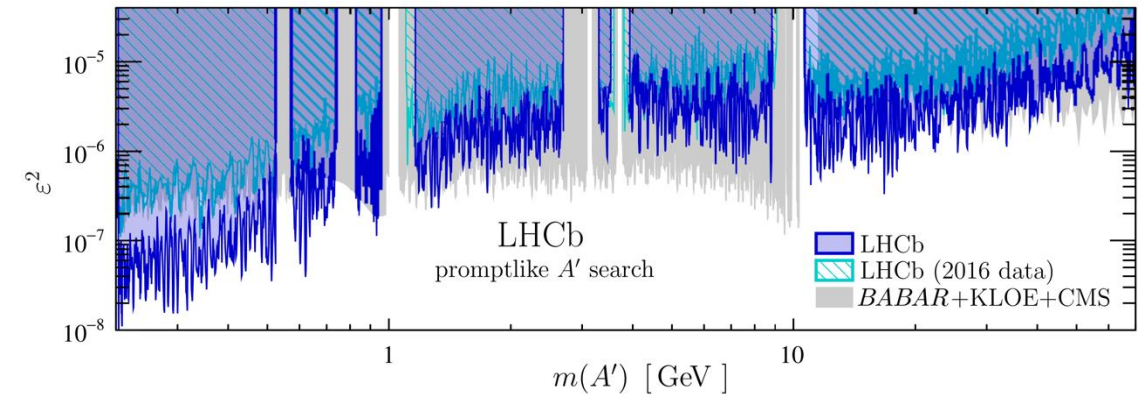
- **Analysis strategy:** Full or partially reconstruct T-track HNLs
- **Target modes:**
 - $B_{u,d,s,c} \rightarrow \mu^- N[X]$
 - $N \rightarrow \mu^+ \pi^-$, $N \rightarrow \mu^+ \mu^- \bar{\nu}_\mu$,
 $N \rightarrow \mu^+ \mu^- \bar{\nu}_e$
- **Data:** Run 3
- **Interpretation:** Fermionic portal / non-degenerate ν MSM



Alimena *et al.* 2025,
[arXiv:2510.05257v2](https://arxiv.org/abs/2510.05257v2)

3. Dark Photons: Results

- **Analysis strategy:** Fully reconstruct long track dark photons directly produced in pp collisions
- **Target modes:**
 - $A' \rightarrow \mu^+ \mu^-$
- **Data:** Run 2
- **Interpretation:** Vector portal

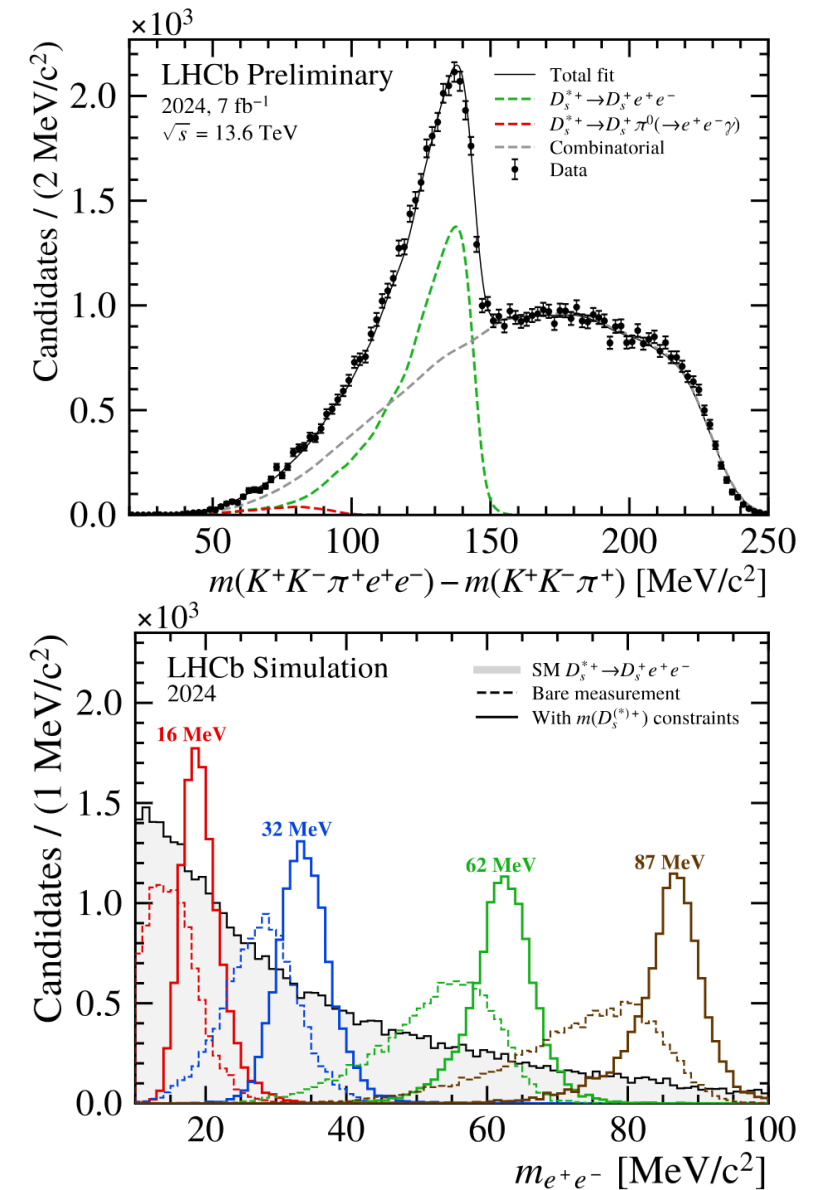


LHCb Collaboration 2020, [PRL 124](#)

[See also: LHCb Collaboration 2020, [JHEP 156 \(2020\)](#)]

3. Dark Photons: Prospects

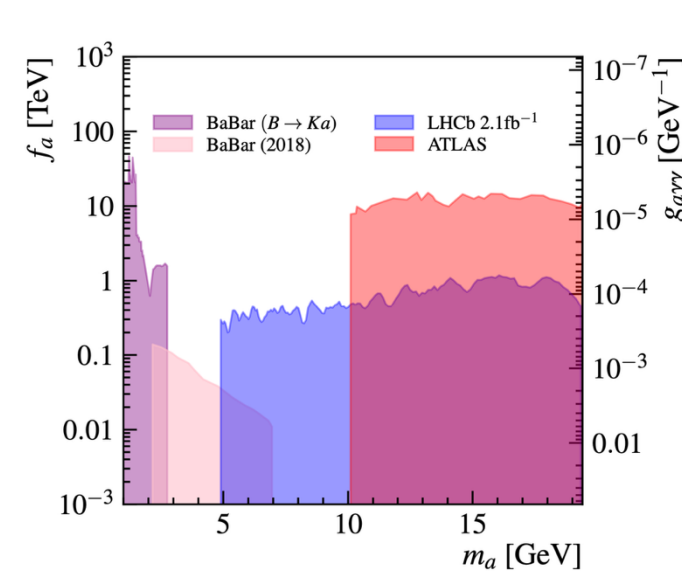
- **Analysis strategy:** Fully reconstruct long track dark photons directly and indirectly produced in pp collisions
- **Target modes:**
 - $pp \rightarrow A', D_s^{*+} \rightarrow D_s^+ A'$
 - $A' \rightarrow \mu^+ \mu^-, A' \rightarrow e^+ e^- (*)$
- **Data:** Run 3
- **Interpretation:** Vector portal



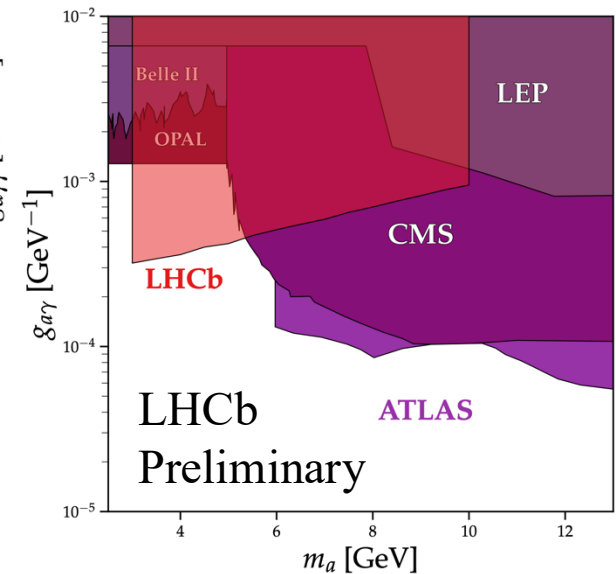
LHCb Collaboration,
LHCb-FIGURE-2025-022

4. Axion-like particles: Results

- **Analysis strategy:** Reconstruct prompt ALP to diphoton
- **Target modes:**
 - $pp \rightarrow a \rightarrow \gamma\gamma$
 - $PbPb \rightarrow \gamma\gamma \rightarrow a \rightarrow \gamma\gamma$
- **Data:** Run 2
- **Interpretation:** Universally-coupling ALP (pp), photophillic ALP (PbPb)



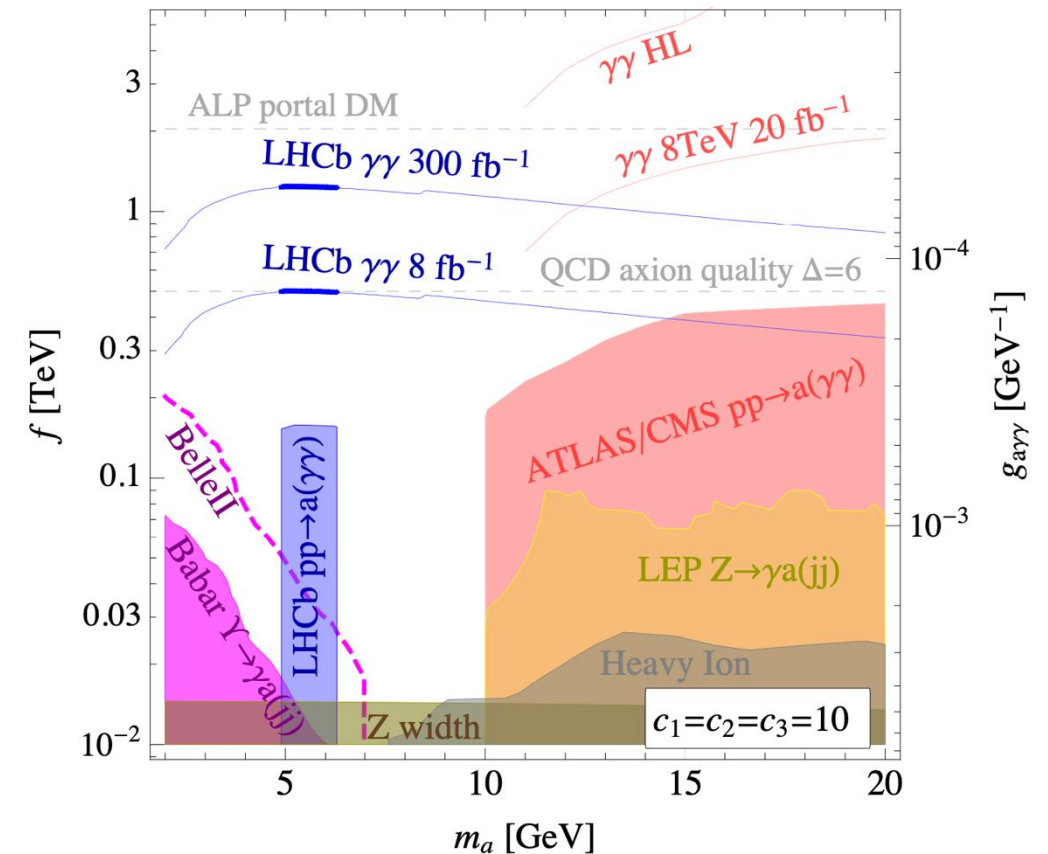
pp : LHCb Collaboration 2025,
[arXiv:2507.14390](https://arxiv.org/abs/2507.14390)



$PbPb$: LHCb-PAPER-2026-029
(Preliminary)

4. Axion-like particles: Prospects

- **Analysis strategy:** Reconstruct prompt ALP to diphoton
- **Target modes:**
 - $pp \rightarrow a \rightarrow \gamma\gamma$
- **Data:** Run 2, onwards
- **Interpretation:** Universally-coupling ALP



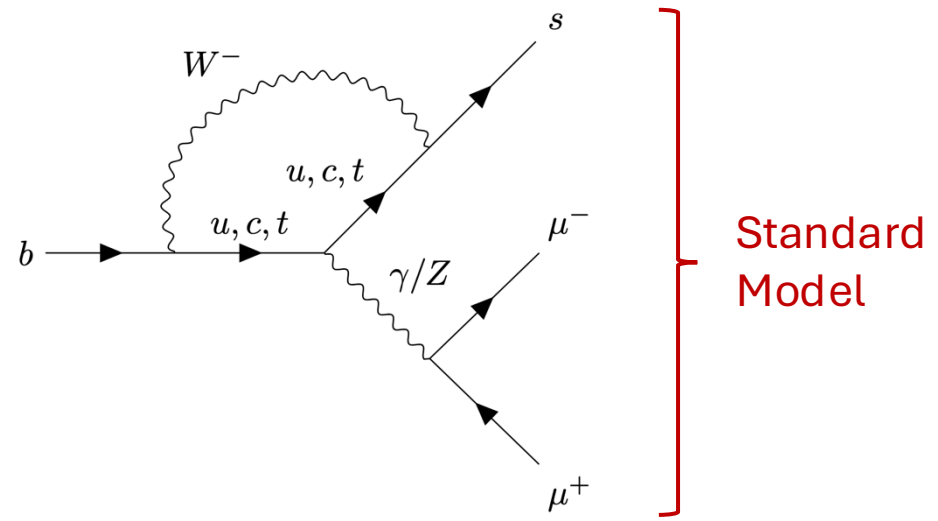
Cid Vidal et al. 2019, [JHEP 113 \(2019\)](#)

And what if we don't
see anything?

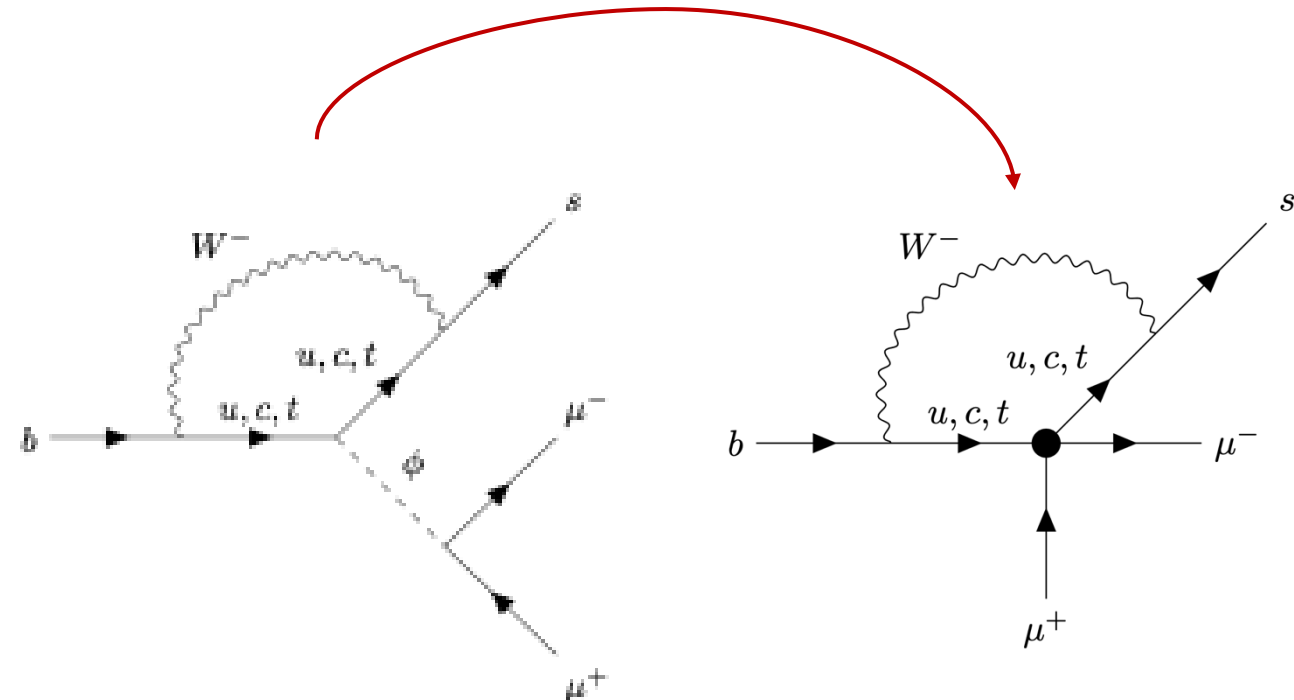
Results: Indirect rare decay searches

The Idea

- Search for rare (but observed) SM decays, e.g.:
 - $b \rightarrow sl^+l^-$
- High-mass dark sector mediators can appear as effective higher-dimension operators
- Can study:
 - Lepton Flavour Universality
 - Angular observables
 - Branching ratio measurements

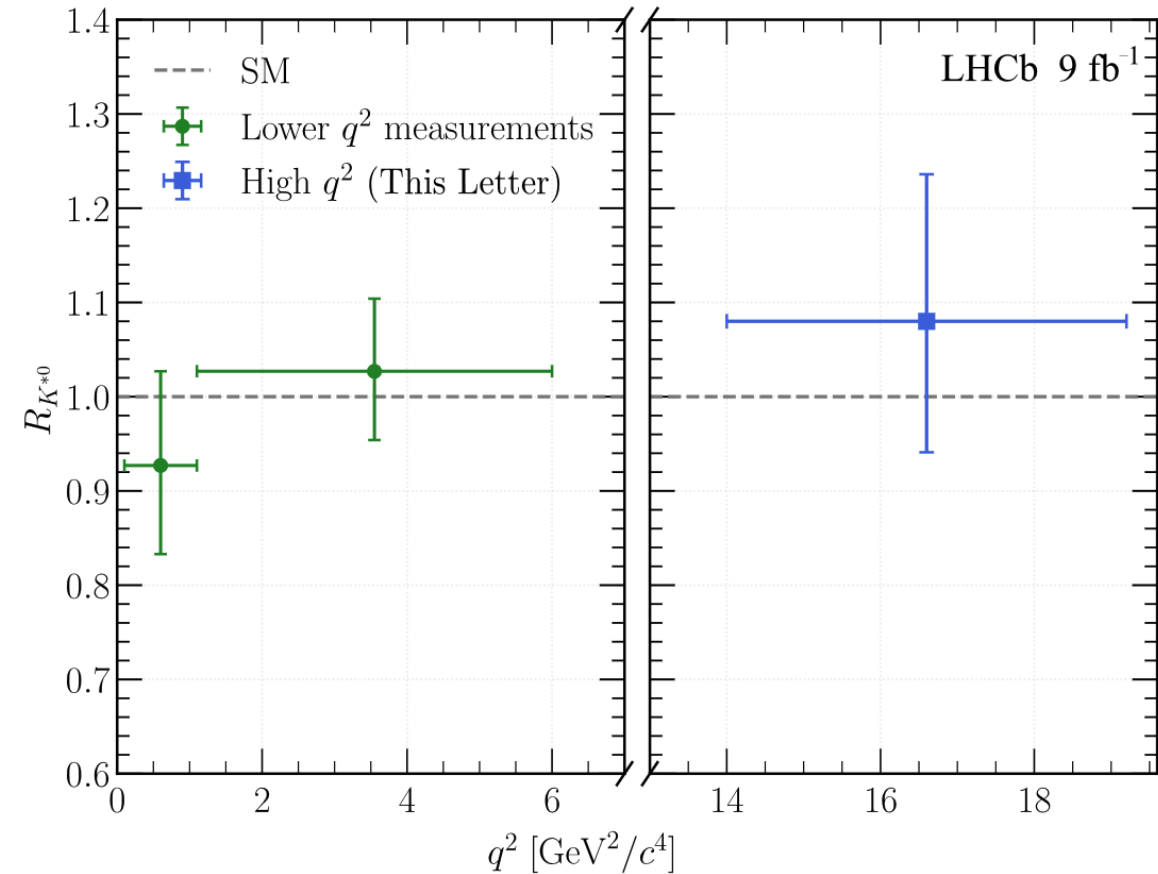


Heavy BSM: Approximates higher dimension operator



Lepton-Flavour Universality

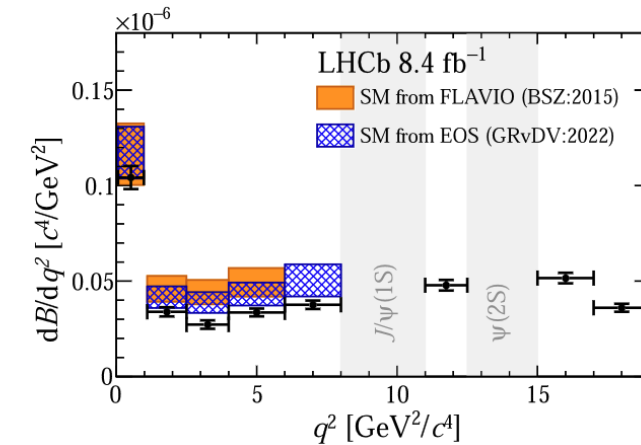
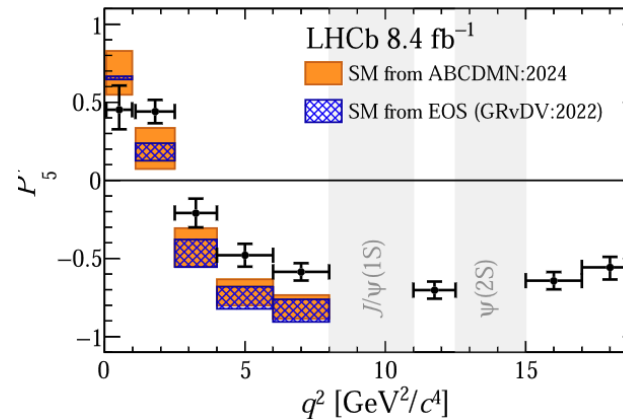
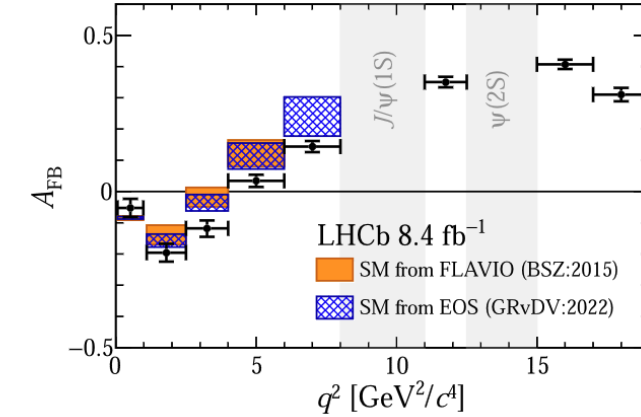
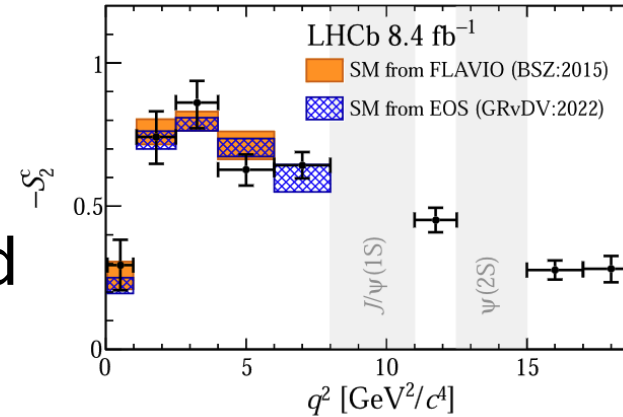
- **Analysis strategy:** Study ratio of muonic and electronic coupling in $b \rightarrow sl^+l^-$ normalised by resonant J/ψ
- **Target modes:**
 - $B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-)\mu^+\mu^-$
 - $B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-)e^+e^-$
- **Data:** Run 1 + Run 2
- **Result:** No tension with SM prediction; approximately flavour universal BSM contributions (if any)



LHCb Collaboration 2026, [PRL 137](#)

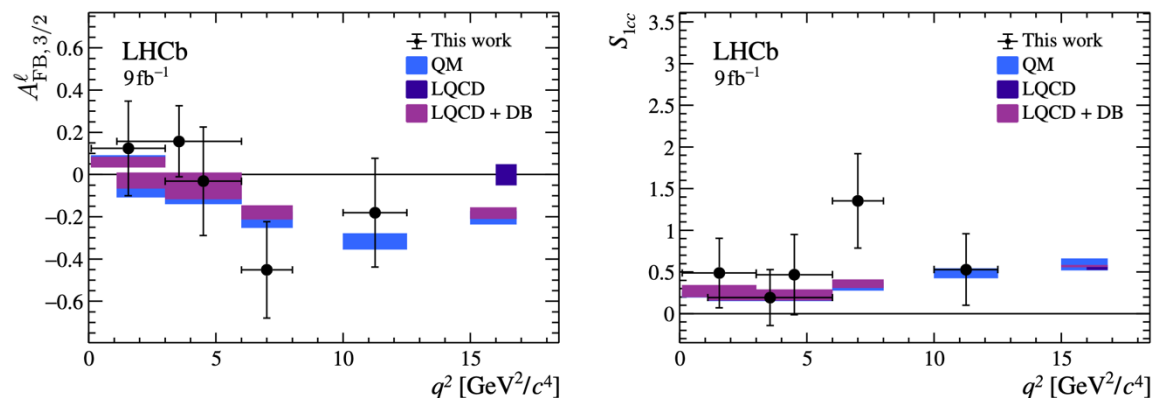
Angular Observables

- **Analysis strategy:** Study CP-asymmetries and CP-averaged angular observables
- **Target modes:**
 - $B^0 \rightarrow K^{*0}(\rightarrow K^+\pi^-)\mu^+\mu^-$
- **Data:** Run 1 + Run 2
- **Result:** Further tensions with respect to SM prediction; potential for BSM contributions



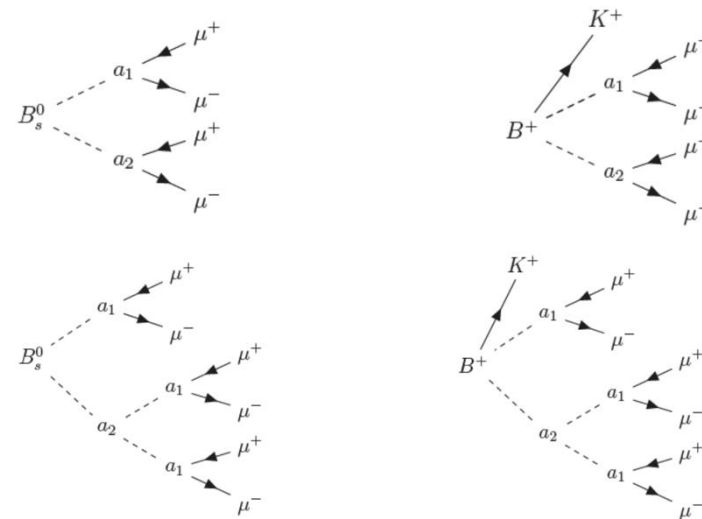
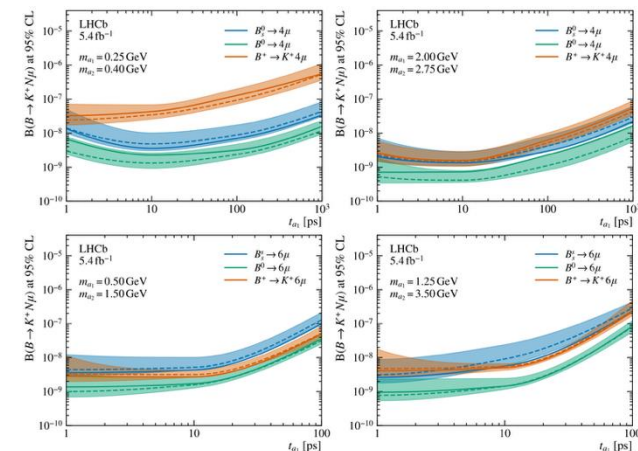
LHCb Collaboration 2026, [PRL 137](#)

Honorary Mentions



Angular analysis in $\Lambda_b \rightarrow \Lambda(1520)\mu^+\mu^-$

LHCb Collaboration (2026),
[LHCb-PAPER-2026-037](#)



Search for B meson decays to multimueon final states

LHCb Collaboration (2026),
[arXiv:2608.17855](#)

Conclusion

Take-aways

1. The LHCb experiment is an LHC experiment specialising in b -hadrons and their decay products
2. We have a rich physics program covering direct and indirect dark sector searches
3. There is a high degree of complementarity between collider particle physics and astrophysics; We are stronger together