Following the muon track of hierarchical sectors at LHCb

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[Based on PRD 100, 115015 (2019) and **arXiv:2206.01759**]

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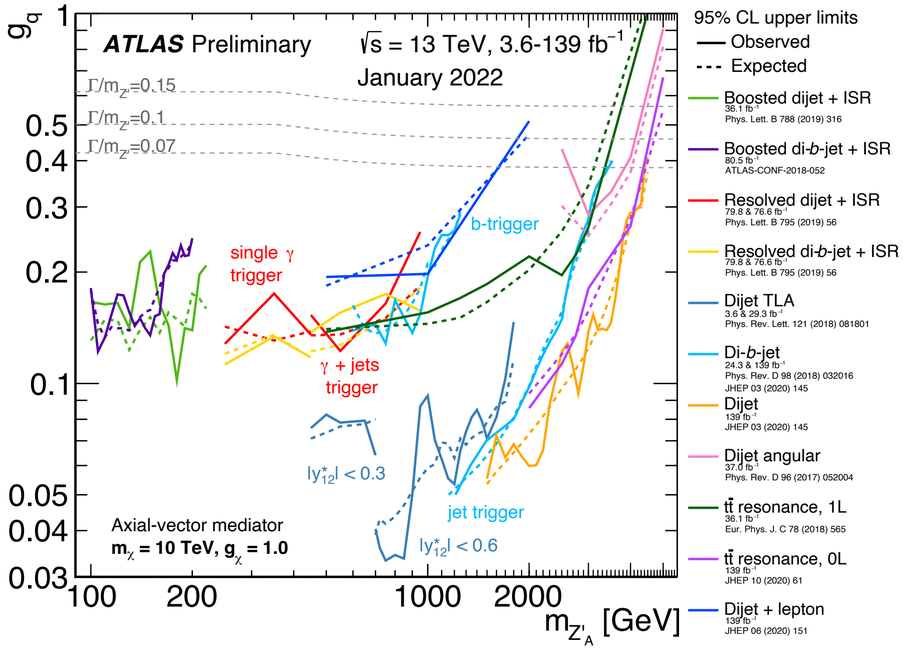
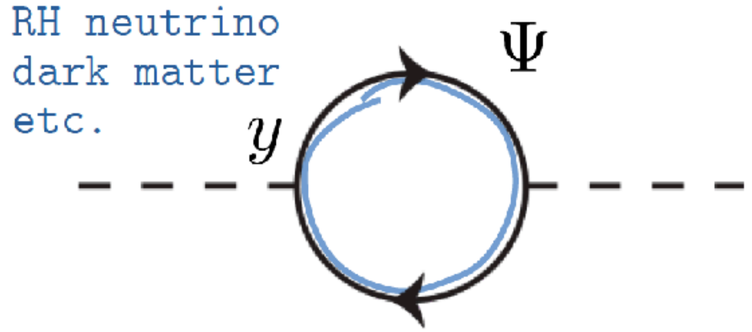
Where is New Physics?

- There are observations beyond the Standard Model: Dark Matter, neutrino oscillations, Matter-Antimatter asymmetry…
- But no observation at colliders
- New Physics should not be too heavy, but
  - Too heavy to be seen at colliders?
  - Too weakly coupled/exotic signatures to be seen experimentally?
  - Can be coupled in models with spontaneous symmetry breaking

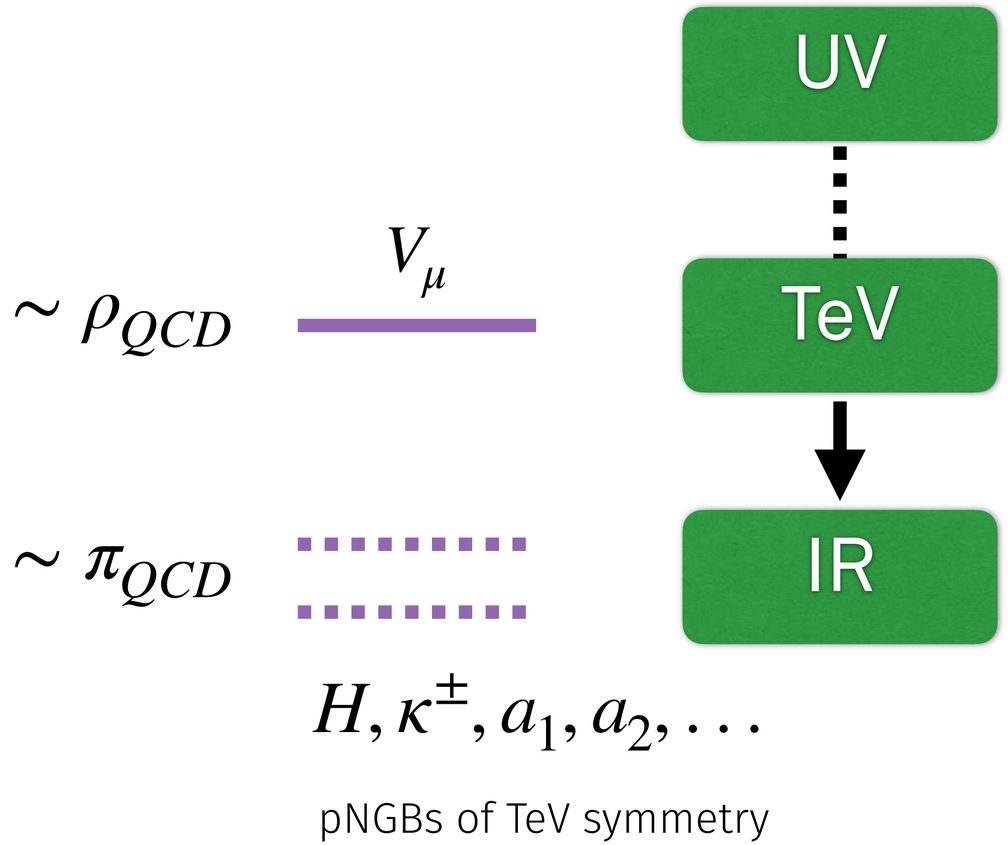




$$\delta m_h^2 \sim \frac{y^2}{(4\pi)^2} M_\Psi^2$$

Composite Higgs model

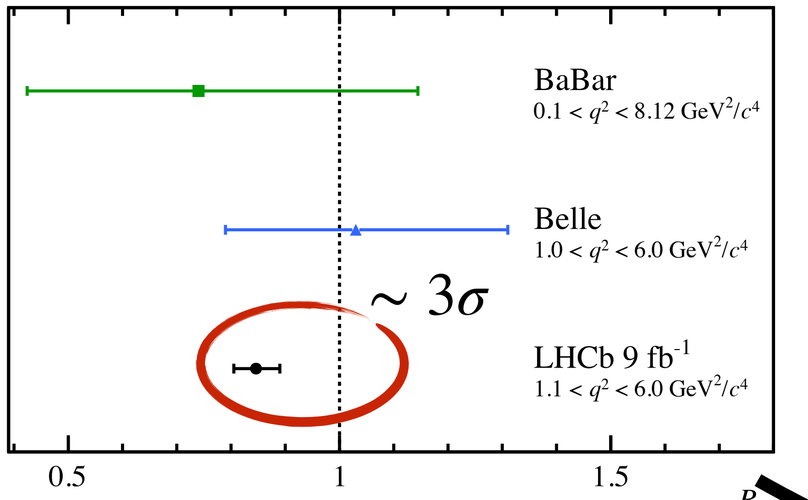
- The Higgs particle is one of several pseudo-Goldstones of a symmetry broken at the electroweak scale
- Additional pseudo-Goldstone particles can arise as singlets
- Heavy and light fields couple strongly
- In analogy to QCD, large range of lifetime in Goldstone particles expected



Anomalies in the muon sector

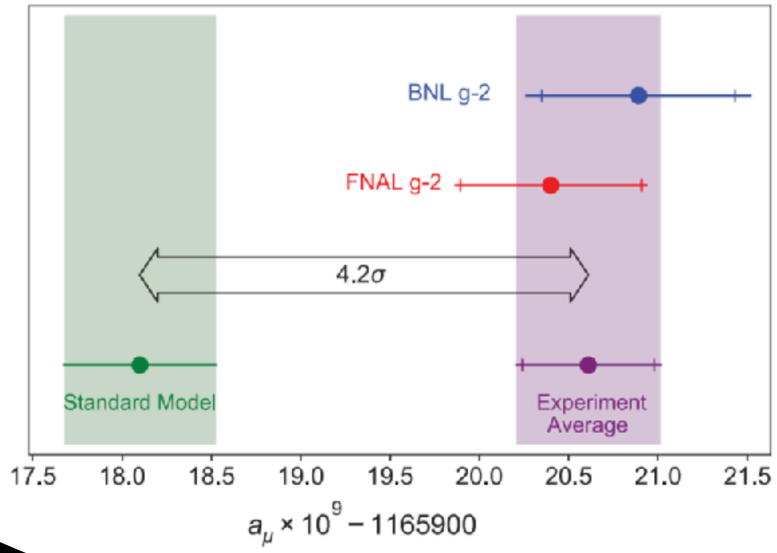
- Lepton-flavour violating V_μ explains anomalies seen in the muon sector

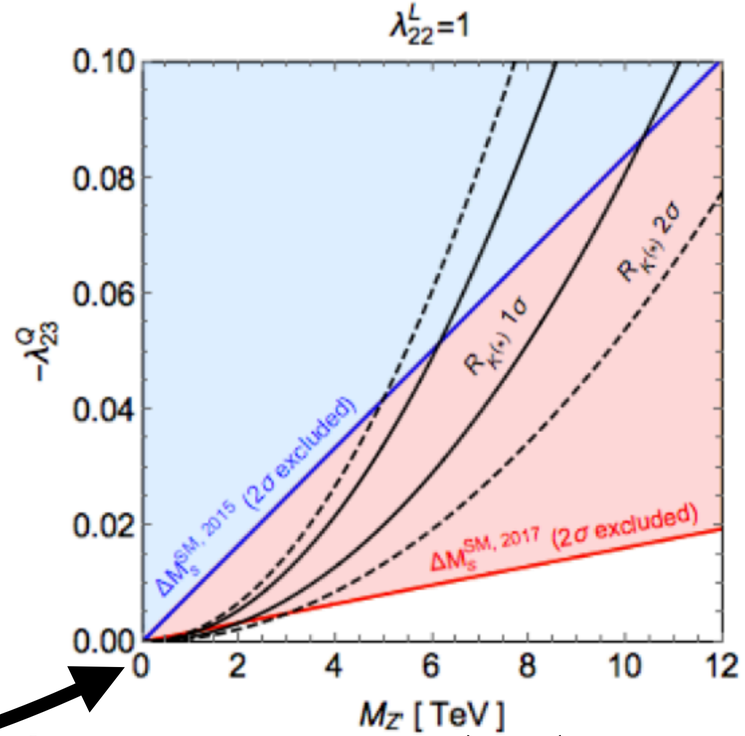
[Nature Physics 18, (2022) 277-282]



$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)}$$

[PRL 126, 141801 (2021)]





[Di Luzio et al., PRD 97 (2018) 9, 095035]

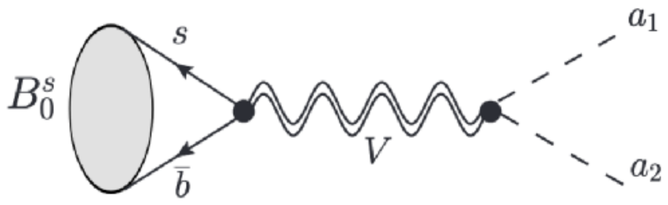
Embedding of the Composite model

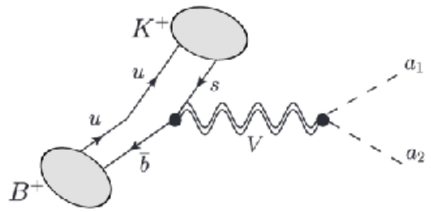
- Extend the SM with a flavour violating heavy vector boson V and 2 singlets $a_{1,2}$ with $m_2 > m_1$

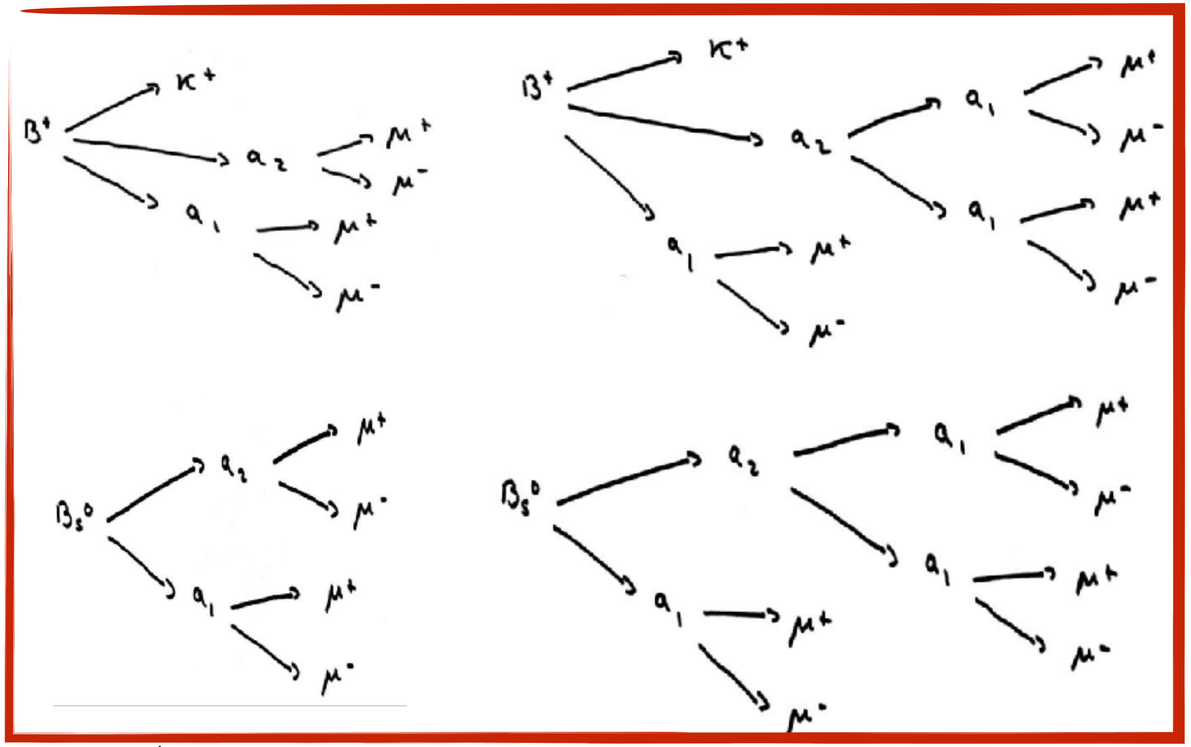
$$L_{\text{eff}} \supset \left[g_{qa}(\overline{b_L}\gamma^\mu s_L)(a_1 \overleftrightarrow{\partial_\mu} a_2) + \mathrm{i} g_1 y^\ell a_1 \bar{\ell}\gamma_5 \ell + g_2 y^\ell a_2 \bar{\ell}\ell + \text{h.c.} \right] - \frac{m_1^2}{2} a_1^2 - \frac{m_2^2}{2} a_2^2 - m_{12} a_2 a_1^2$$

$$g_{qa} = \frac{g_{sb} g_{12}}{m_V^2}$$

- If more than one scalar, $B_s^0 \to 4\mu$ suppressed



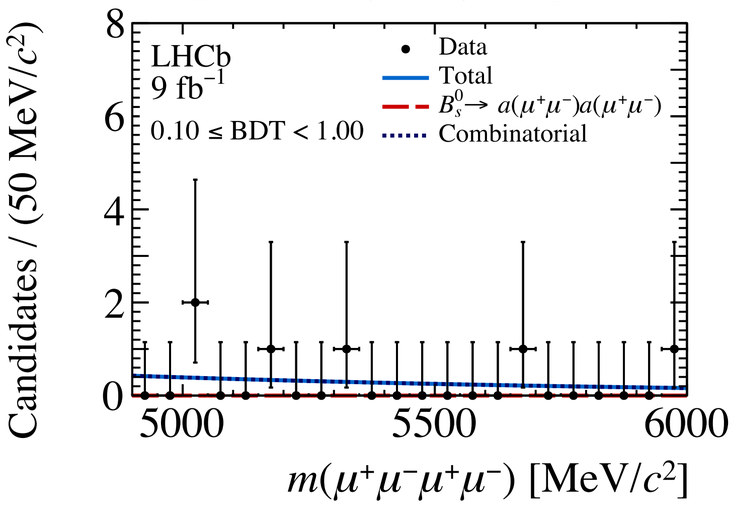




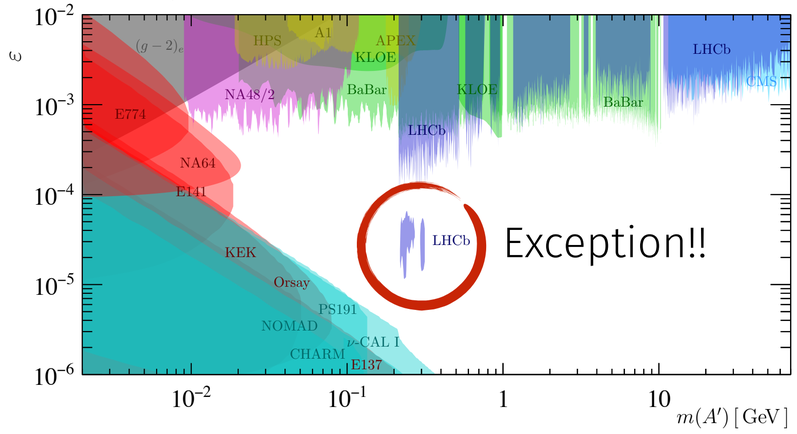
Existing searches - the lifetime problem

- Most searches target promptly decaying particles

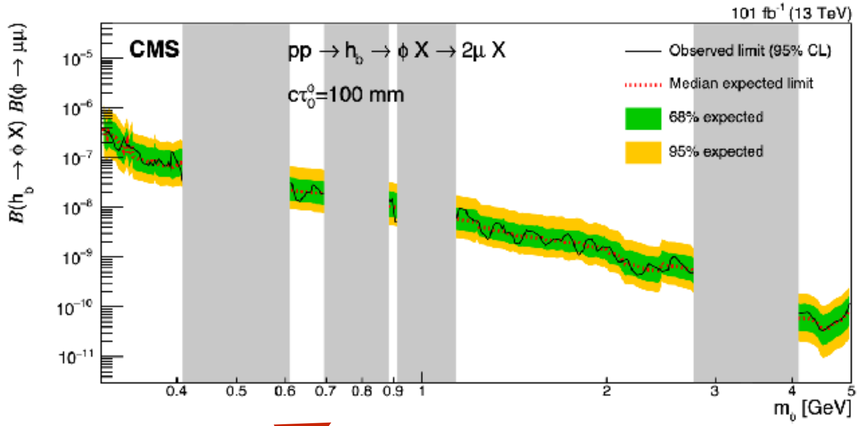
[JHEP 03 (2022) 109]



[Phys. Rev. Lett. 124 (2020) 041801]



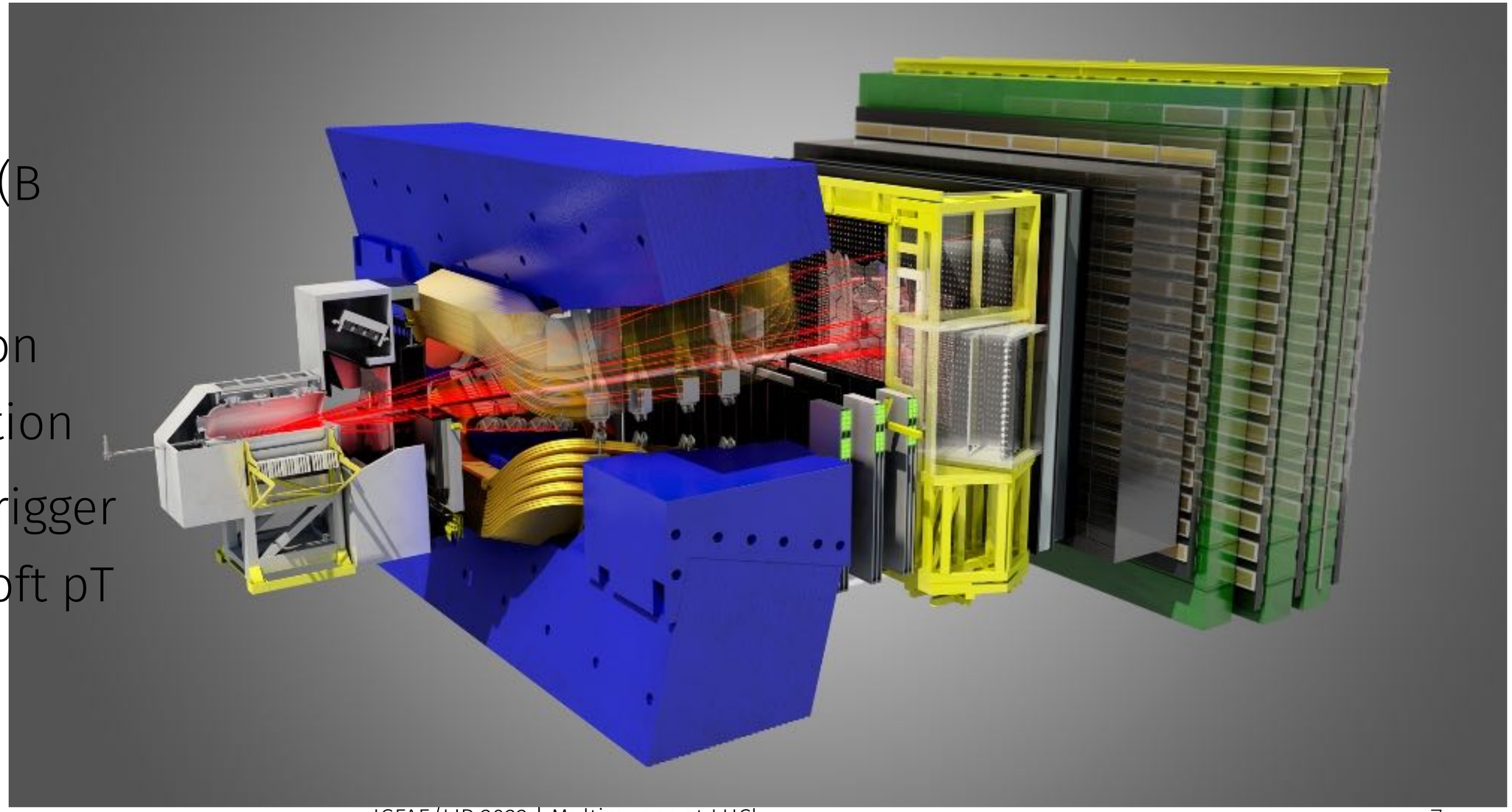
[JHEP 04 (2022) 062]



- Or require strong transverse momentum requirements

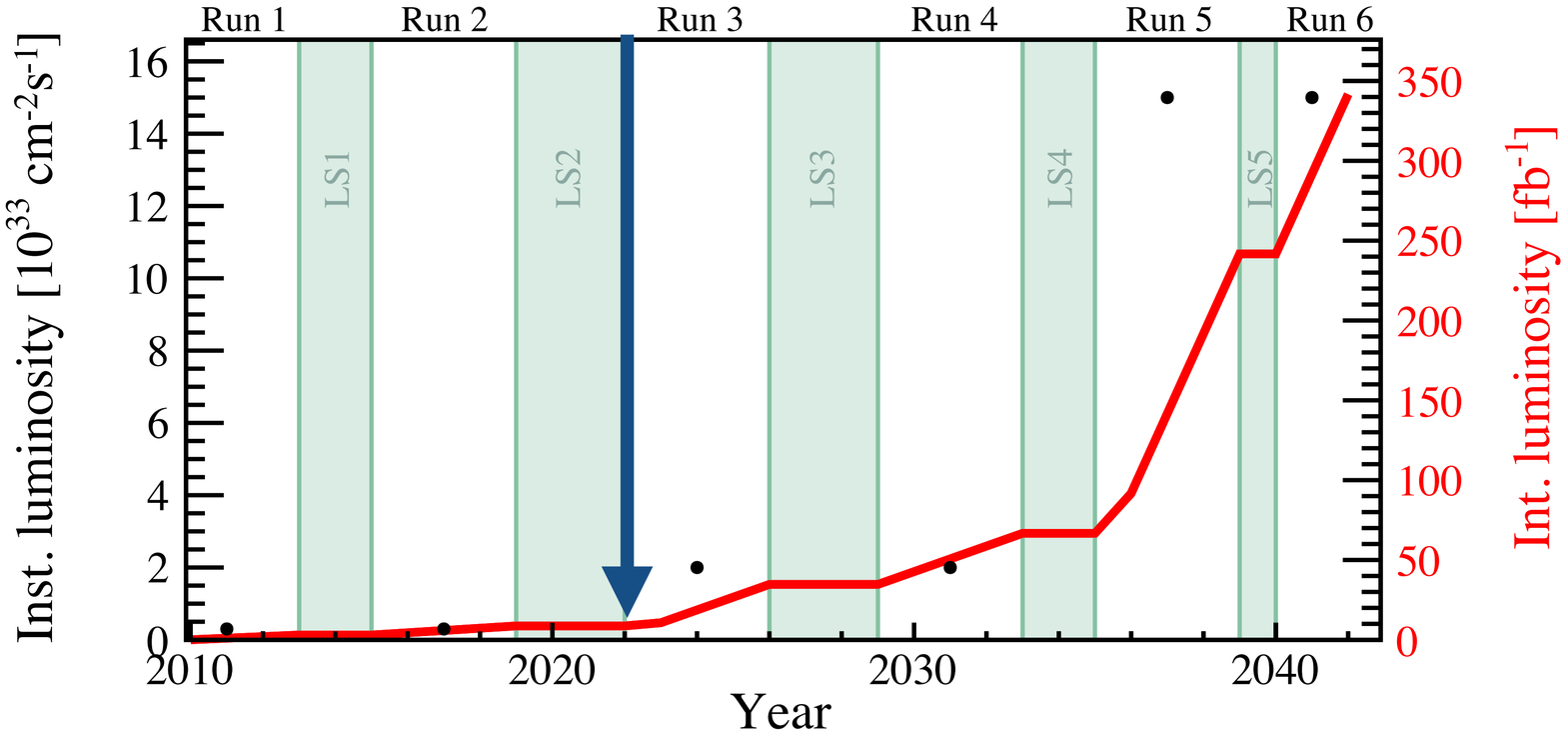
The LHCb experiment

- Excellent vertexing (B vertex)
- Good muon identification
- Efficient trigger also for soft pT particles



The coming LHCb data taking periods

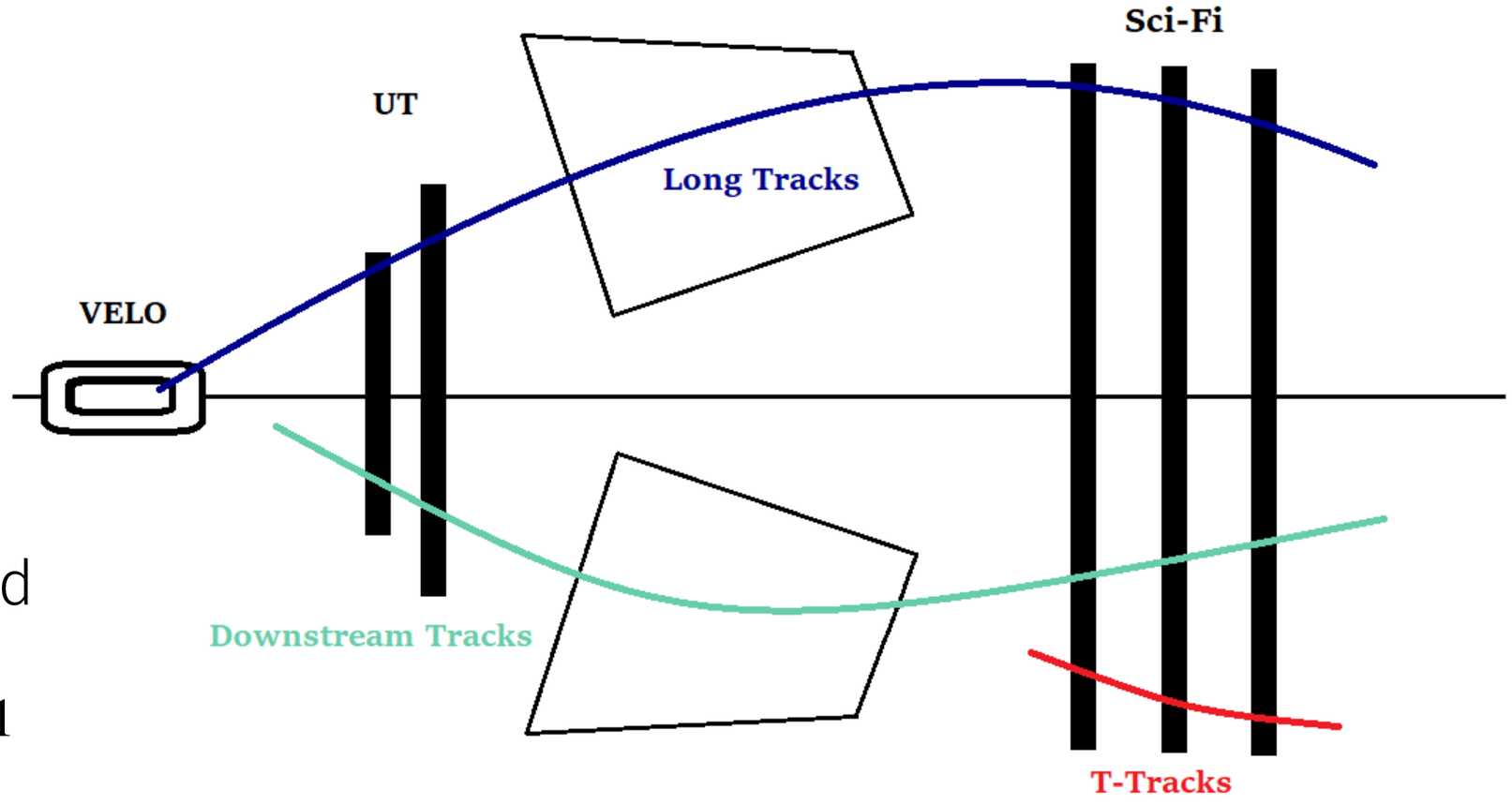
- Full software trigger from Run 3 on (allows flexible low momentum selection)
- Possibility to trigger on incomplete tracks → can exploit high lifetimes!



Search at LHCb

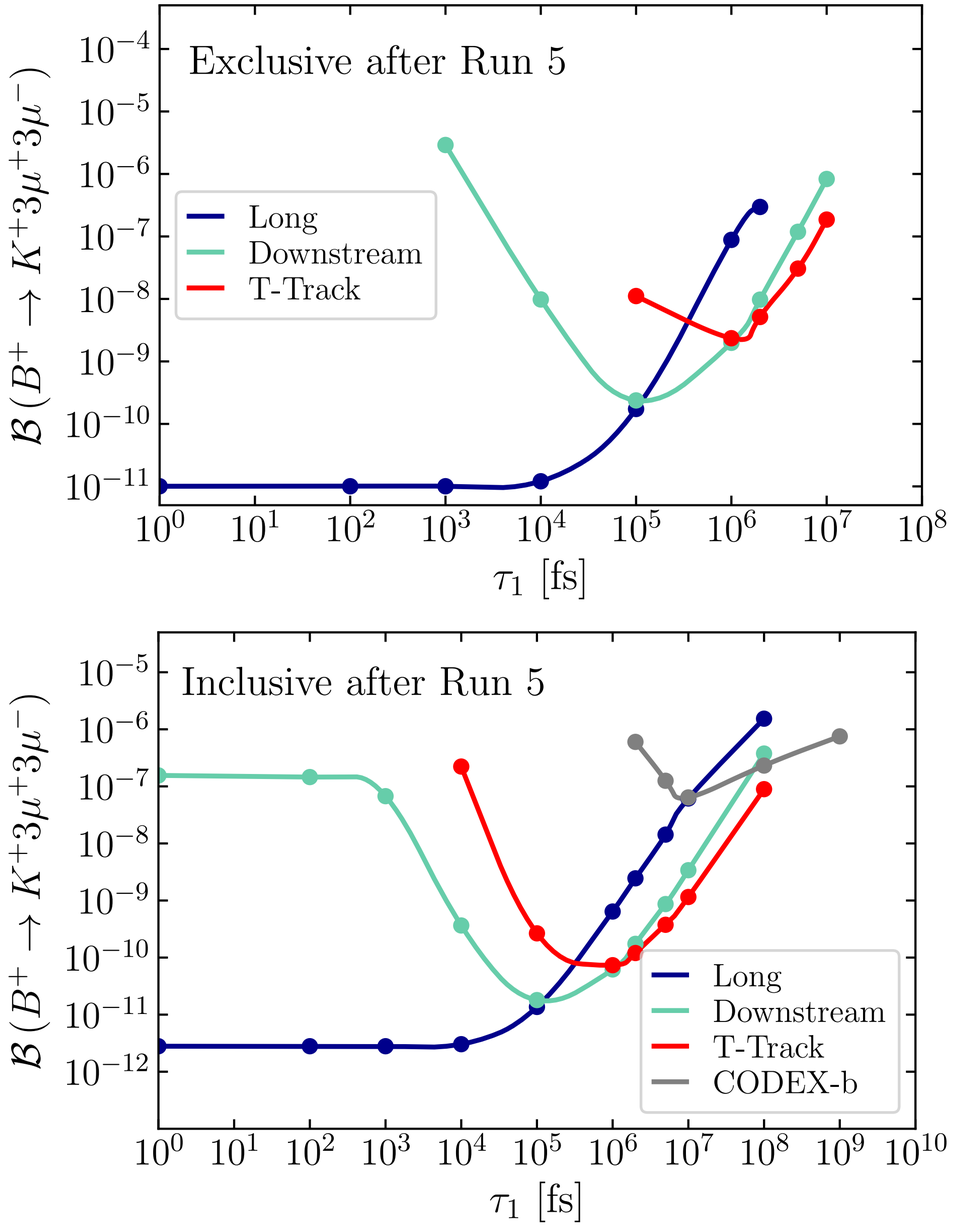
- Require detector geometry
- Muon pT >250 MeV
- Muon p > 2.5 GeV (muon ID)
- Normalise to published search for $B^0_{(s)} \to a_1 a_1$

[JHEP 03 (2022) 109]



Exclusive vs. Inclusive searches

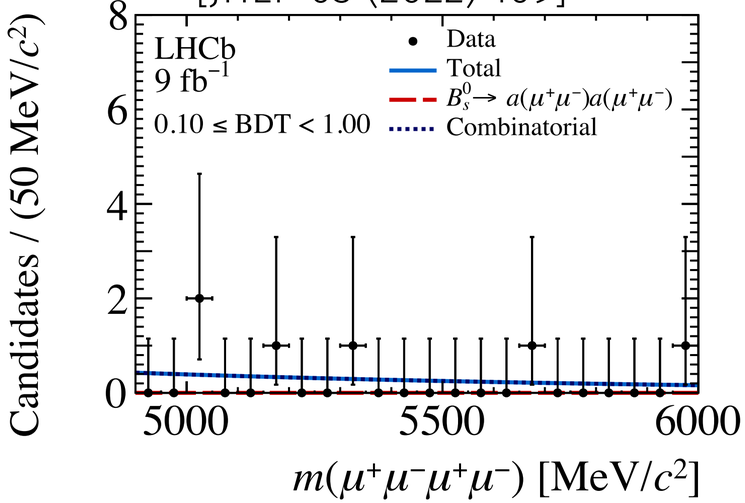
- Efficiency varies less than a factor 2 over all possible (m1,m2) configurations
- Sensitivities $< 10^{-9}$ up to 10 ps, $< 10^{-7}$ up to ~1ns already with Run 3 (~2025)
- Simplify the search only 4 muons in the detector
  - Not model specific
  - Gain 1-2 orders of magnitude in sensitivity
  - Can extend accessible lifetime reach by adding proposed CODEX-b experiment (strong IGFAE involvement)

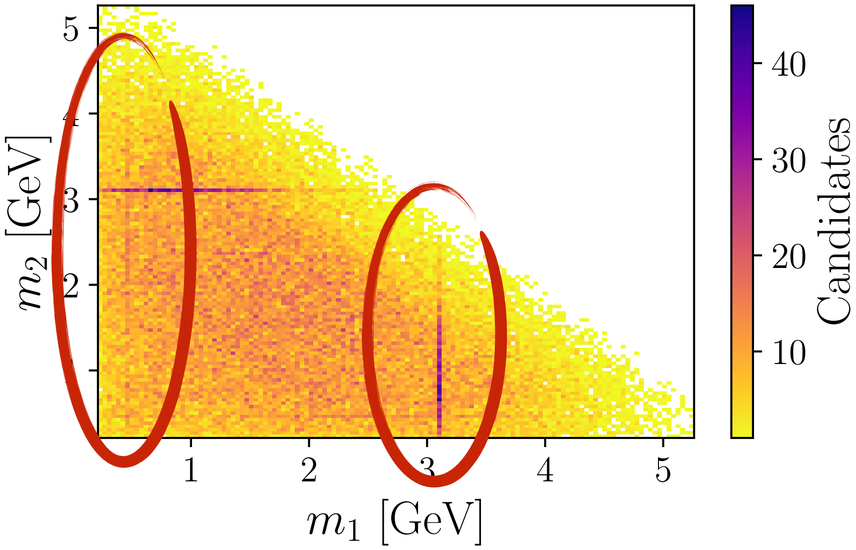


Possible backgrounds

- Extremely clean: low pollution from random muon combinations
- Known SM resonances:
  - $q\bar{q} \to \mu^+\mu^- : J/\psi, \psi(2S), \phi(1020)$ can be vetoed and are prompt resonances
  - Similarly $q\bar{q} \to 4\mu$
  - $K_S^0 \to \pi^+\pi^-$ abundant -> veto
  - Combinations of the above: $B_s^0 \to J/\psi\phi, B^0 \to J/\psi K_S^0$ can explicitly be vetoed, others extremely rare
  - Material interaction: efficient data-driven tool to veto vertices near detector material

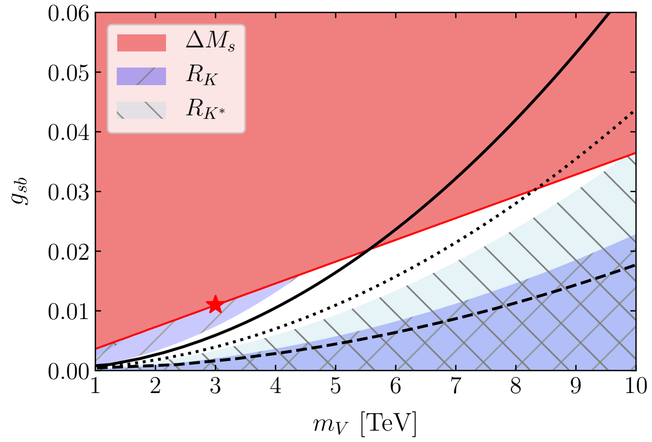
[JHEP 03 (2022) 109]

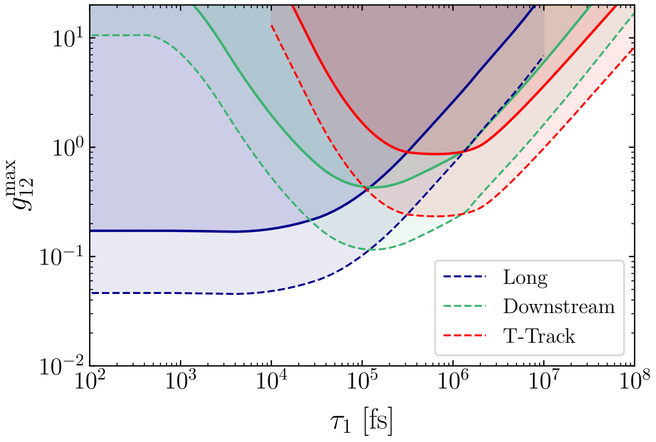




Exclusion potential

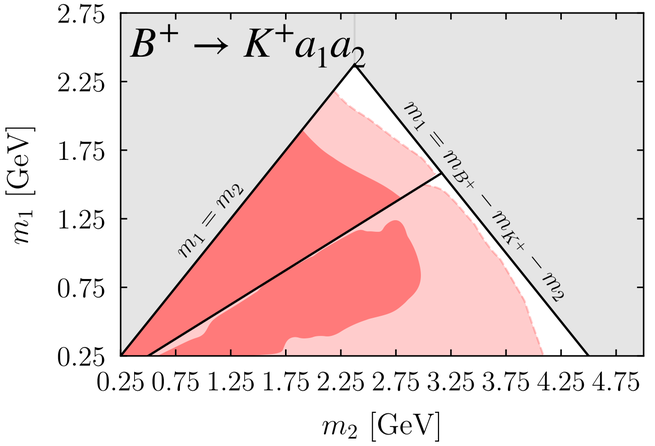
- With the full LHCb data can probe almost the full allowed (m1,m2) configuration space even at 100 ps
- Sensitive to the proposed model in the scenarios favoured by the muon anomalies
- Stringent constraints on the couplings between the Vector and the scalars

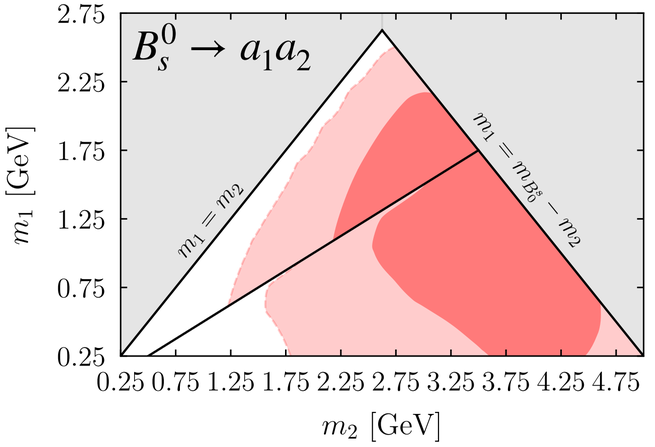




Using downstream tracks at

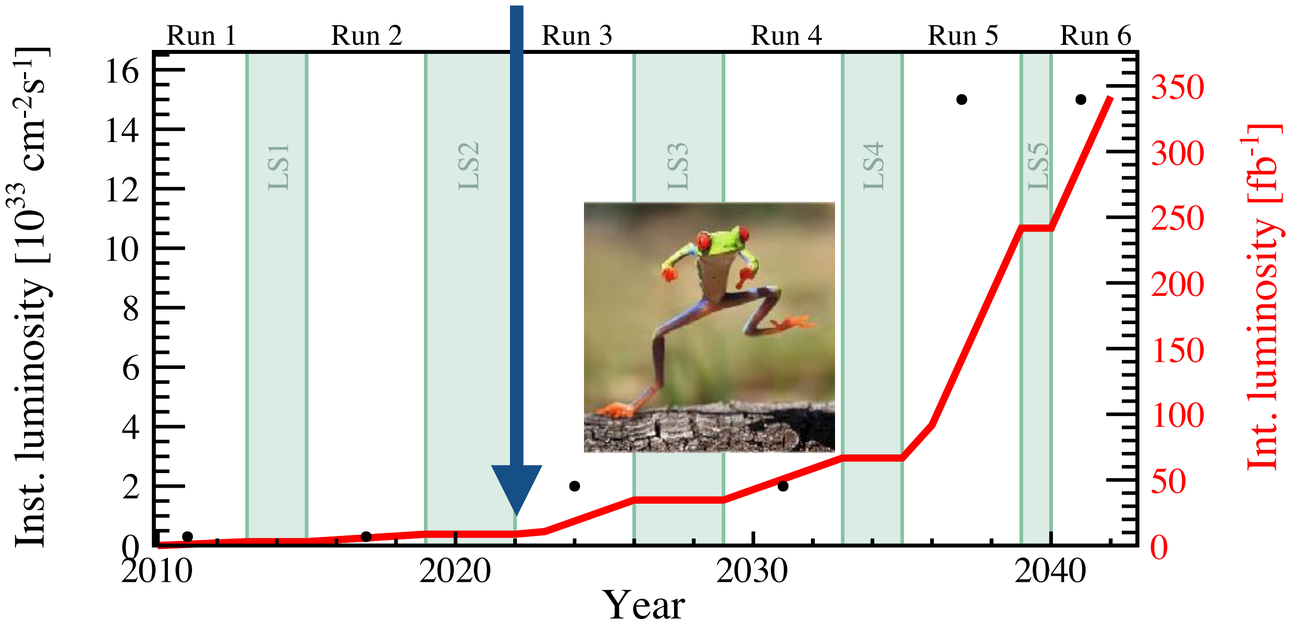
$\tau_1 = 100\,\text{ps}$





Summary

- New Physics might manifest in exotic signatures
- Next-to-minimal scenarios can result in suppression of the usually tested minimal scenarios
- The search for B decays into multiple muons at LHCb
  - Is a powerful tool to constrain composite Higgs models
  - Is experimentally very clean
  - Allows to explore and demonstrate new track reconstruction techniques



We're living in exciting times!