

Following the muon track of hierarchical sectors at LHCb

LLP12 Workshop

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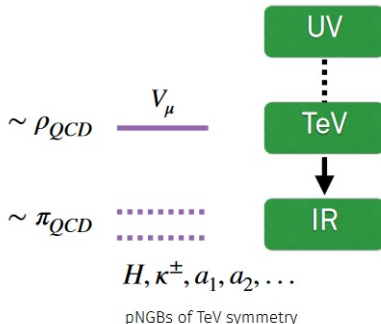
Where is New Physics?

- Departures from the Standard Model expected: DM, Matter-Antimatter Asymmetry, Neutrino Oscilations...
- No direct signal of NP observed to date
- Too heavy to be seen at colliders or too feebly interacting (extend SM with new degrees of freedom)
- Coupled in hierarchical models with spontaneously symmetry breaking



Composite Higgs Model

- The Higgs is one of several pNGB of a symmetry broken at the TeV scale
- Heavy and light fields arise naturally
- Composite vectors couple $\mathcal{O}(1)$ due to strong dynamics
- Analogy with QCD: large range of lifetimes in Goldstone particles expected



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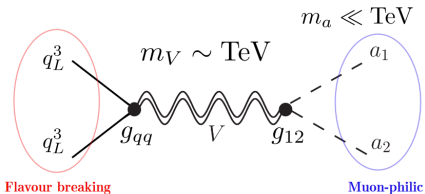
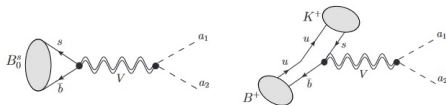


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Composite Higgs Model

- Light singlet scalars $a_{1,2}$ produced in very rare B meson decays
- Decays mediated by a heavy flavour-violating vector boson V at low energies



- If the structure similar to SM, coupling to 3rd generation quarks
- Low energy signatures: $a_1 \rightarrow \mu^+ \mu^-$ and $a_2 \rightarrow \mu^+ \mu^-$
- $m_2 > 2m_1$ regime: $a_2 \rightarrow a_1 a_1 \rightarrow 2\mu^+ 2\mu^-$



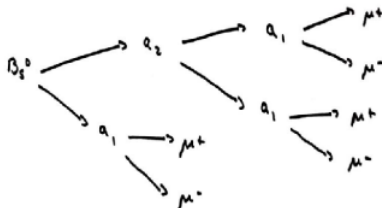
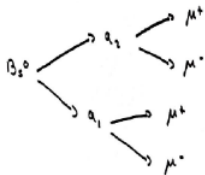
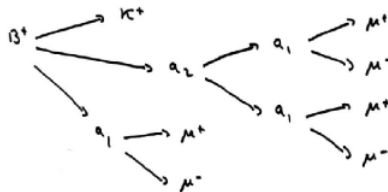
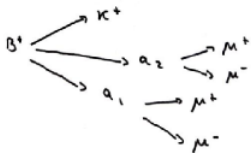
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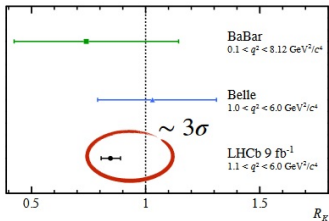


Decay Chains

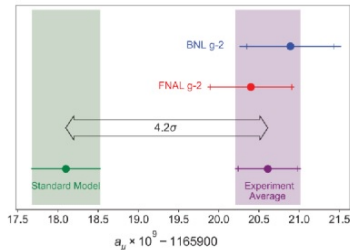


Anomalies in muon sector

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



(a) Nature Physics 18, (2022)
277-282



(b) PRL 126, 141801 (2021)



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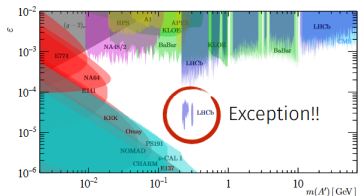


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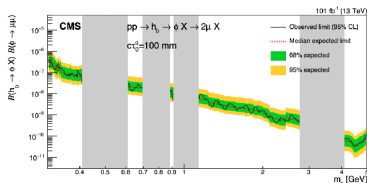


Existing Searches

- Promptly decaying particles: $B_s^0 \rightarrow a_1 a_1 \rightarrow 2\mu^+ 2\mu^-$ [arXiv:2111.11339v2]



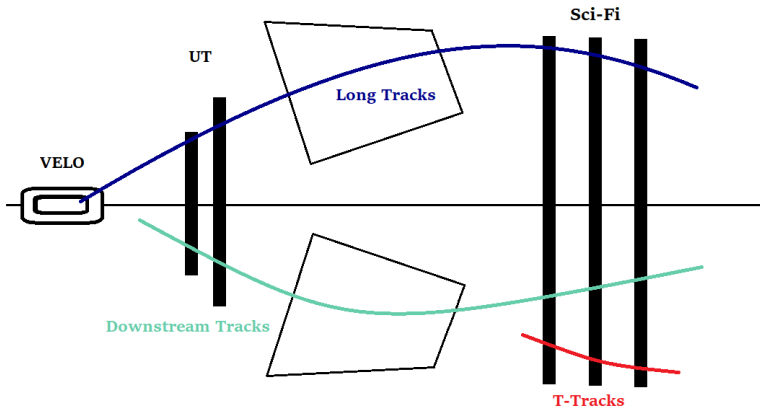
(a) Phys. Rev. Lett 124 (2020)
041801



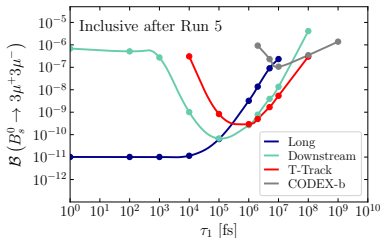
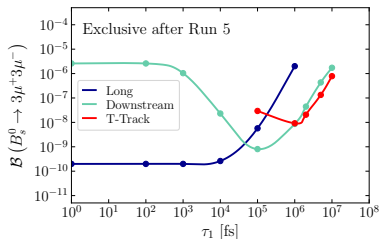
(b) JHEP 04 (2022) 06

- The long-lived scenario is not yet probed!!

Displaced searches at LHCb



Exclusive or Inclusive searches?



- Normalization to the $B_s^0 \rightarrow a(\mu^+\mu^-)a(\mu^+\mu^-)$ channel [JHEP 03 (2022) 109]
- Improvement in the reconstruction efficiency
- Gain over 1/2 orders of magnitude in sensitivity
- Can extend accessible lifetime reach by adding the proposed CODEX-b experiment



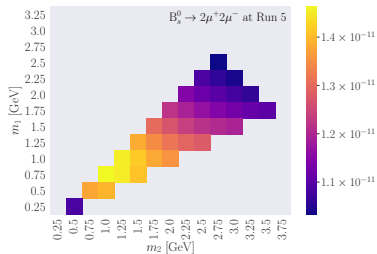
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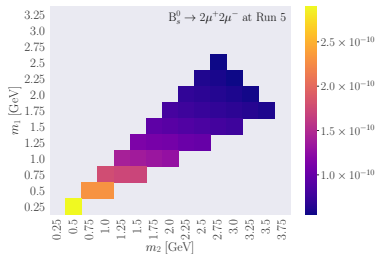
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Exclusive or Inclusive searches?



(a) Long tracks, 1ps, Run 5



(b) Downstream tracks, 10 ps

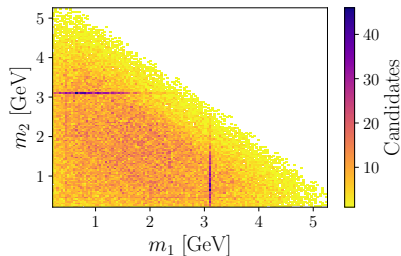


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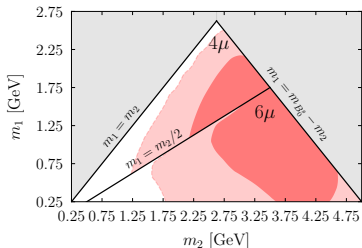
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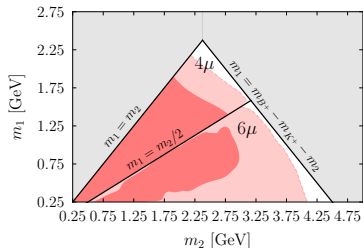


- Clean signal: low pollution from random muon combinations
- Intermediate SM prompt resonances: J/ψ , ϕ and $\psi(2S)$.
- Also events $q\bar{q} \rightarrow 4\mu$
- Veto needed for abundant $K_S^0 \rightarrow \pi^+\pi^-$
- Possibly veto combinations $B_s^0 \rightarrow J/\psi\phi$ and $B^0 \rightarrow J/\psi K_S^0$

Model Interpretation



(a) $B_s^0 \rightarrow a_1 a_2$



(b) $B^+ \rightarrow K^+ a_1 a_2$

Figure: Downstream tracks, $g_{12} = 1.5$, $\tau_1 = 100\text{ps}$



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Model Interpretation

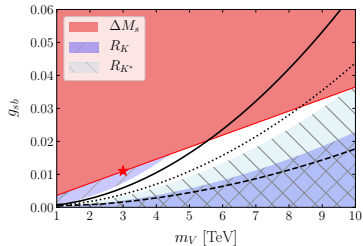
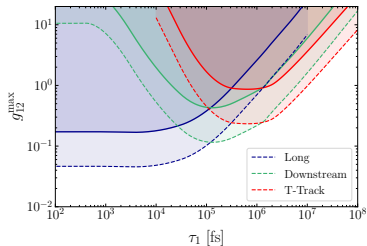


Figure: $(m_1, m_2) = (1.0, 2.5)$ GeV, $g_{12} = 1.5$, $\tau_1 = 1$ ns



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- 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
 - Experimentally very clean
 - Allows to explore and demonstrate new track reconstruction techniques

Back-Up

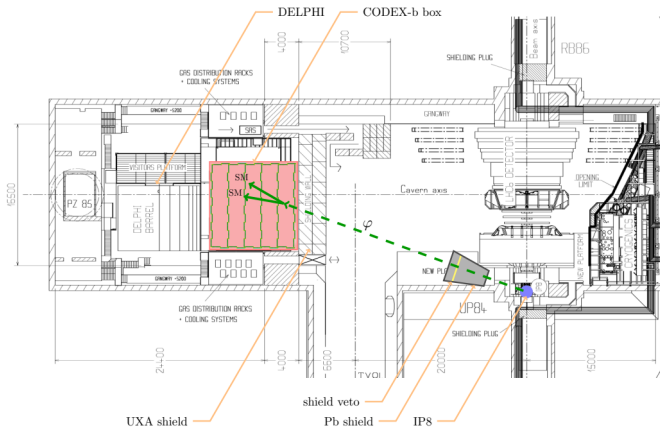


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Track Type	x [m]	y [m]	ρ [m]	z [m]	Penalty Tracking Factor
Long	—	—	[0, 0.03]	[0, 0.5]	0.98
Downstream	[-0.75, 0.75]	[-0.65, 0.65]	—	[0.6, 2.3]	0.89
T-Track	[-3.15, 3.15]	[-2.35, 2.35]	—	[2.3, 7.6]	0.70
CODEX-b	[26, 36]	[-7, 3]	—	[5, 15]	1.00

Table: Track geometrical requirements

