Search for hidden-sector bosons at LHCb

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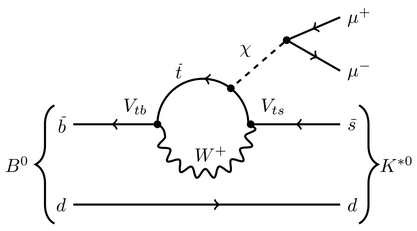
Motivation

- Many theoretical models predict the existence of new particles that couple to the SM by **mixing with the Higgs.**
- Inflaton, axion-like, dark matter mediator also predict the new boson to be **light** [1].

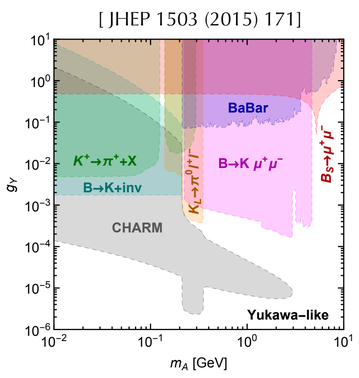
If kinematically allowed, **main production via B meson:**



$\Gamma(B^0 \to K^{*0}\chi) \propto (m_t^2 |V_{ts}^* V_{tb}|)^2 \propto m_t^4 \lambda^2$

Branching fraction into muons $\mathcal{B}(\chi \to \mu^+\mu^-)$:
- ✓ dominant till the hadronic threshold ($\chi \to 2h$, $\chi \to 3h$)
- ✓ always significant $\mathcal{O}(10^{-2})$ in the full mass range.

Current experimental limits: [2]



$g_Y = \sin\theta$, θ mixing angle with the Higgs

Main current constraints come from B factories and CHARM experiment (at low mass).

Signal properties

- Depending on the coupling SM/hidden sector we can identify two **lifetime** regimes:

Short lifetime

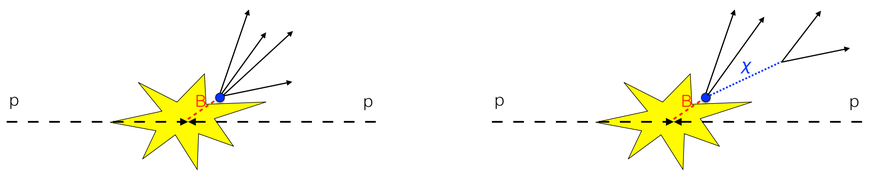
Pros:
- ✓ high reconstruction efficiency

Cons:
- ❖ prompt decay
  - large SM background contamination

Long lifetime

Pros:
- ✓ displaced vertex
  - ➤ very clear signature

Cons:
- ❖ signal events start to decay after the vertex detector
  - lower efficiency



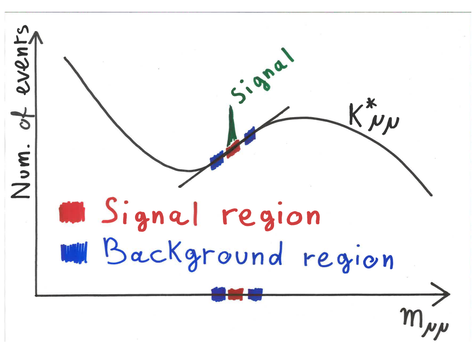
- **A di-muon displaced vertex is allowed, but not required.**

Selection & Strategy

- Multivariate selection: ***uBDT*** - *uniform Boosted Decision Tree* [3]
  - ✓ performance independent of mass and lifetime of χ
- Optimized maximizing Punzi figure-of-merit $P_{f.o.m.} = \frac{S}{\frac{5}{2} + \sqrt{B}}$
- Factorize lifetime into two components:
  - ✓ **prompt**, $\tau < 3\sigma_\tau$ (irreducible SM $B^0 \to K^{*0}\mu^+\mu^-$)
  - ✓ **displaced**, $\tau > 3\sigma_\tau$ (only combinatorial background)
    - lifetime resolution: $\sigma_\tau \sim 0.2$ ps

$$\mathcal{L} = \mathcal{L}^{prompt} \cdot \mathcal{L}^{displaced}$$

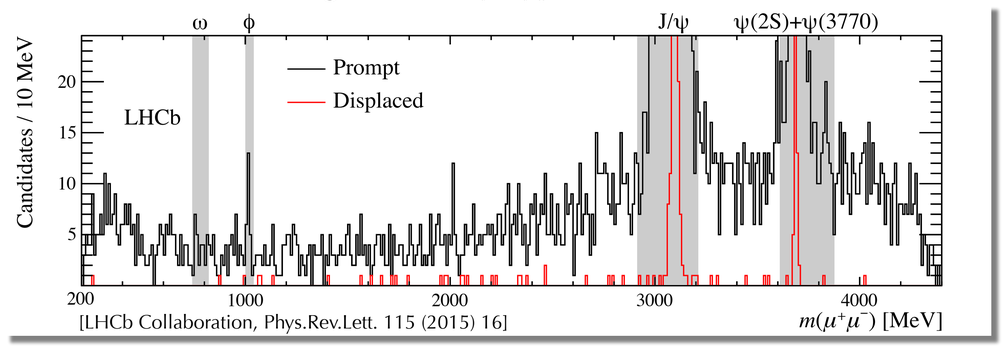
- **Looking for a di-muon excess:**
  - ✓ $\sigma_m = 2 \div 8$ MeV.
  - ✓ B^0 mass is constrained to its known value to improve to mass resolution.
  - ✓ scan the di-muon mass in step of $\frac{1}{2}\sigma_m$ [4].



  - ✓ di-muon sidebands used to extract the expected number of background events assuming local linearity.

Result

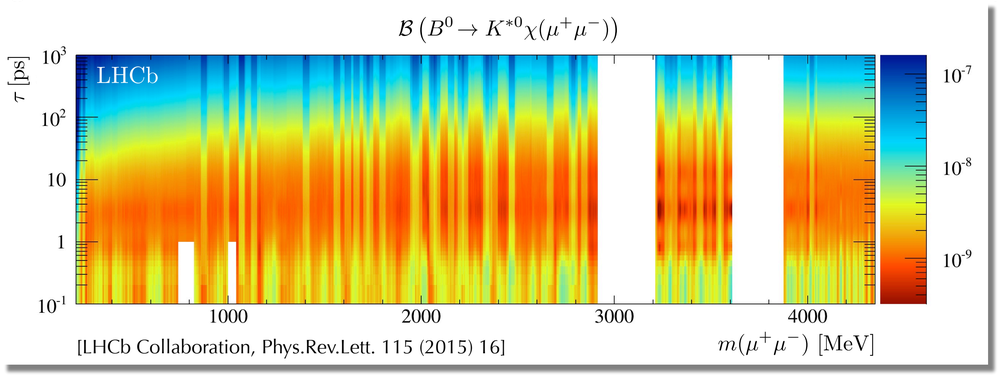
- Look Elsewhere Effect taken into account.
- Largest deviation at m = 253 MeV, local p-value = 0.02.
- **No deviation from the background-only hypothesis is observed** [5].



Grey regions are vetoed in the analysis.

Exclusion limit

- 95% CL upper limit on the branching fraction $\mathcal{B}(B^0 \to K^{*0}\chi(\to \mu^+\mu^-))$ [5]
  - ✓ function of mass and lifetime
  - ✓ assumed spin 0
  - ✓ long lifetimes have weaker limit due to the loss of reconstruction efficiency



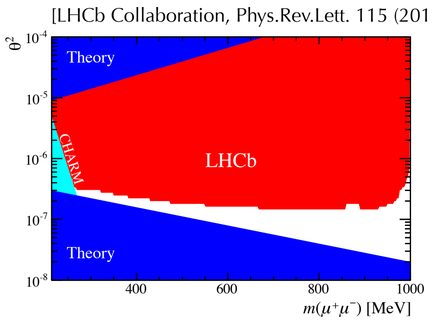
- Model-independent limit: can be interpreted in your favorite BSM theory.

Benchmark models

- Two model-dependent exclusion limits:

Inflaton [6]
- ✓ $0.1 < m_\chi < 1$ MeV
- ✓ $\tau_\chi \sim 10^{-5} \div 10^{-12}$ s

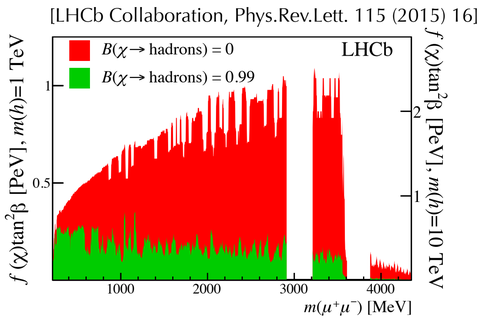
[LHCb Collaboration, Phys.Rev.Lett. 115 (2015) 16]



Cosmological and CHARM experiment excluded regions are also shown.

Axion-portal [7]
- ✓ larger allowed mass range
- ✓ short lifetime

[LHCb Collaboration, Phys.Rev.Lett. 115 (2015) 16]



Excluded region by the analysis for two extreme branching fractions of the axion-like particle.

Complementary searches

- A second very similar search is ongoing at the LHCb experiment:

$$B^+ \to K^+\chi(\to \mu^+\mu^-)$$

Differences:
- ✓ Only 3 tracks in the final state
  - less precise B decay vertex reconstruction.
- ✓ More sensitive to (pseudo)scalar particle
  - angular momentum conservation:
    - ‣ $J^P(K^{*0}) = 1^-,\ J^P(K^+) = 0^-$
  - effect significant only at high mass.

References

[1] F. Bezrukov and D. Gorbunov, JHEP 1005, 010 (2010)
[2] M. Dolan, F. Kahlhoefer, C. McCabe and K. Schmidt-Hoberg, JHEP 1503 (2015) 171
[3] J. Stevens and M. Williams, JINST 8, P12013 (2013)
[4] M. Williams, JINST 10, no. 06, P06002 (2015)
[5] LHCb Collaboration (Aaij, Roel et al.) Phys.Rev.Lett. 115 (2015) 16
[6] F. Bezrukov and D. Gorbunov, Phys. Lett. B 736, 494 (2014)
[7] M. Freytsis, Z. Ligeti and J. Thaler, Phys. Rev. D 81, 034001 (2010)

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