Rare B decay results from LHCb

- **Measurements**
- **Searches**
- **Selective**

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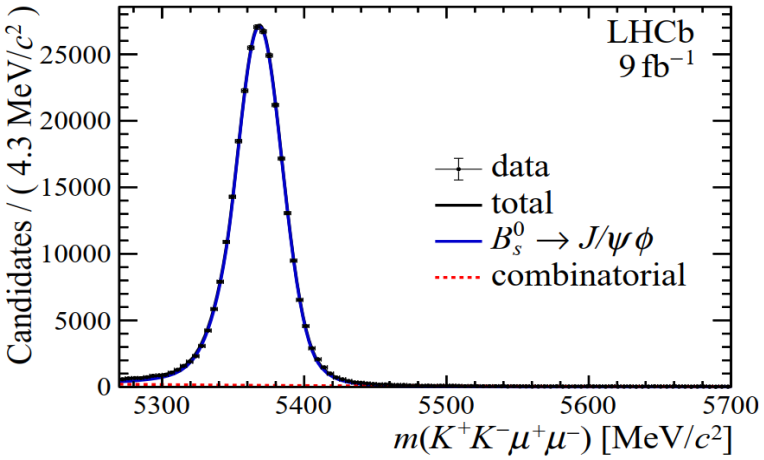
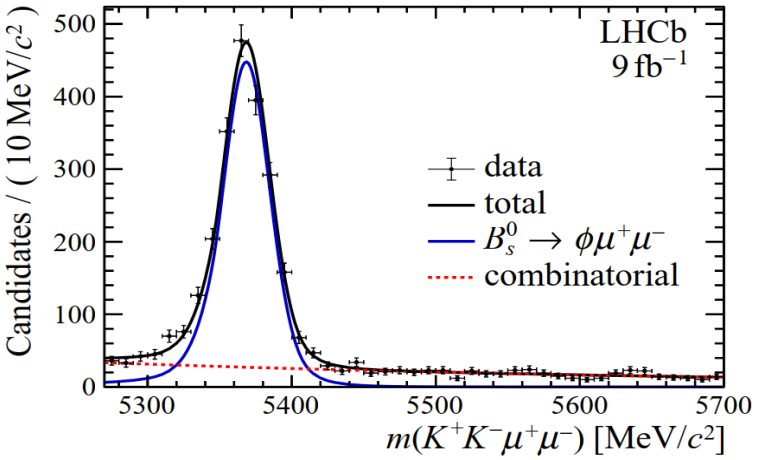
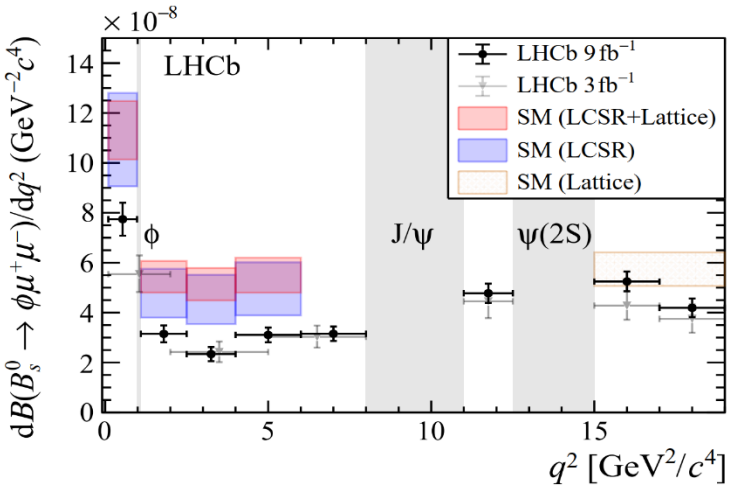
Measurements of $B_s^0 \to \phi\mu^+\mu^-$ and $B_s^0 \to f_2'(1525)\mu^+\mu^-$ decays

- $B_s^0 \to \phi\mu^+\mu^-$ BRs reported in intervals of $q2$, found 3.6σ below SM







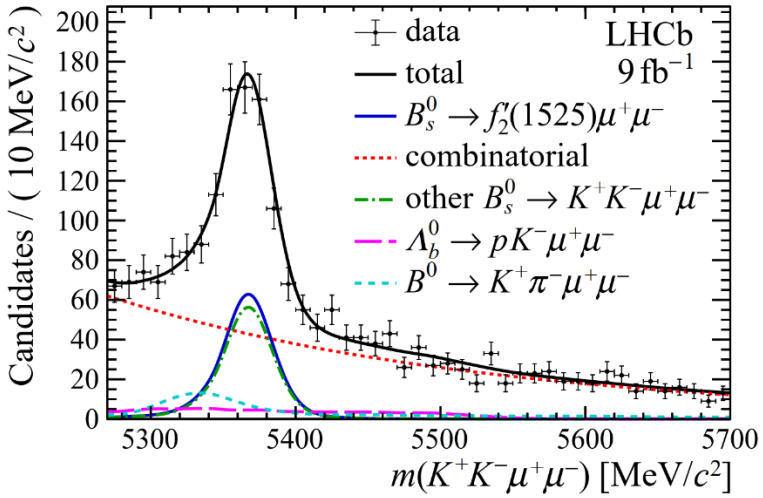
- Most precise measurement
- Differential BR, overlaid with SM predictions
- The results from the LHCb 3 fb^{-1} analysis are shown with gray markers

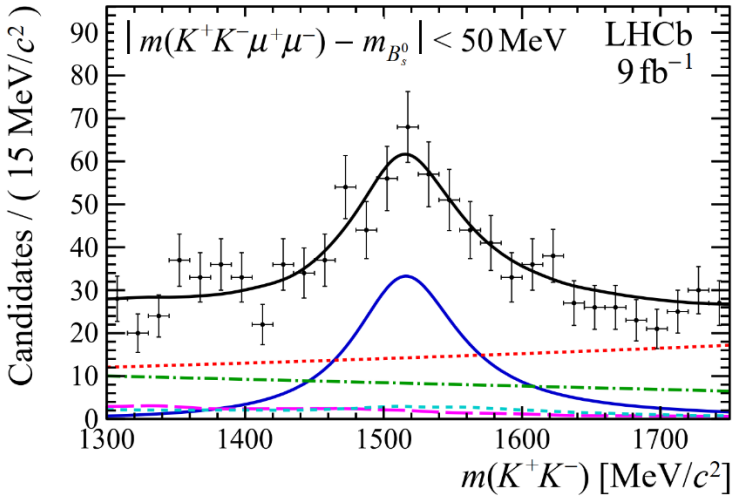
Phys. Rev. Lett. 127 (2021) 151801

Measurements of $B_s^0 \to \phi\mu^+\mu^-$ and $B_s^0 \to f_2'(1525)\mu^+\mu^-$ decays

- The first observation of the rare $B_s^0 \to f_2'(1525)\mu^+\mu^-$ decay is reported
- The first observation of a rare semileptonic decay involving a spin-2 meson in the final state:

  - provides complementary information to transitions involving pseudoscalar or vector mesons.





- In agreement with SM predictions:

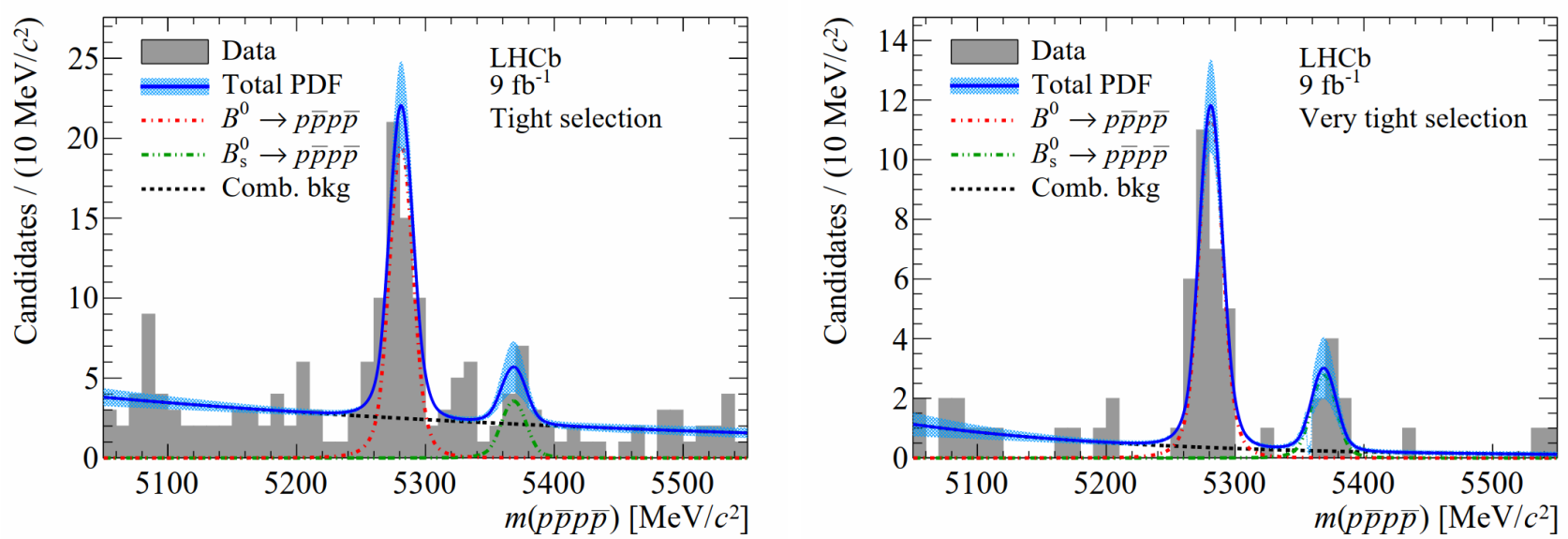
$$\frac{\mathcal{B}(B_s^0 \to f_2'\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = (1.55 \pm 0.19 \pm 0.06 \pm 0.06) \times 10^{-4} ,$$

$$\mathcal{B}(B_s^0 \to f_2'\mu^+\mu^-) = (1.57 \pm 0.19 \pm 0.06 \pm 0.06 \pm 0.08) \times 10^{-7} ,$$

Phys. Rev. Lett. 127 (2021) 151801

The rare hadronic decay $B^0_{(s)} \to p\bar{p}p\bar{p}$

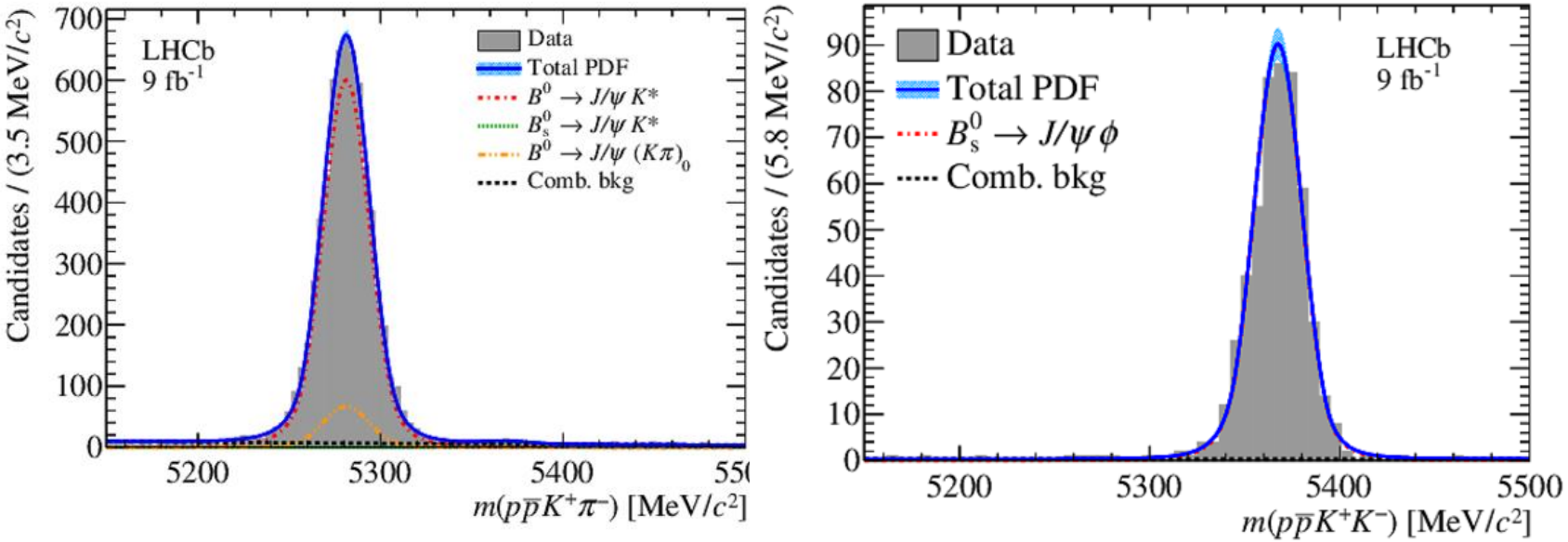
- No reliable theoretical prediction for $B^0_{(s)} \to p\bar{p}p\bar{p}$ decays for now, a first measurement of the corresponding BR would allow to better understand the underlying dynamics
- The BRs of multi-body baryonic decay modes may be significantly increased due to a threshold enhancement effect in the baryon-antibaryon invariant mass, while two-body baryonic decays (such as $B^0_{(s)} \to p\bar{p}$) are suppressed
- B^0 / B^0_s: significance of 9.3σ and 4.0σ



arXiv:2211.08847

The rare hadronic decay $B^0_{(s)} \to p\bar{p}p\bar{p}$

- The branching fractions are measured relative to the topologically similar normalisation decays: $B^0 \to J/\psi(\to p\bar{p})K^{*0}(\to K\pi)$ and $B^0_s \to J/\psi(\to p\bar{p})\phi(\to KK)$
- Results: BR($B^0 \to p\bar{p}p\bar{p}$)= $(2.2\pm0.4\pm0.1) \times 10^{-8}$ and BR($B^0_s \to p\bar{p}p\bar{p}$)= $(2.2\pm1.0\pm0.2) \times 10^{-8}$



arXiv:2211.08847

The baryon and lepton number violating decays $B_s^0 \to p\mu^-$ and $B^0 \to p\mu^-$

- Matter-antimatter asymmetry is a serious challenge to our understanding of nature. Proposed three necessary conditions to produce such a large matter-antimatter asymmetry, one of which is baryon number violation.
- Various violation processes have been searched for in τ , Λ, D, J/ψ, and B decays by the CLEO, CLAS, BESIII and BABAR experiments, but no evidence has been found so far.

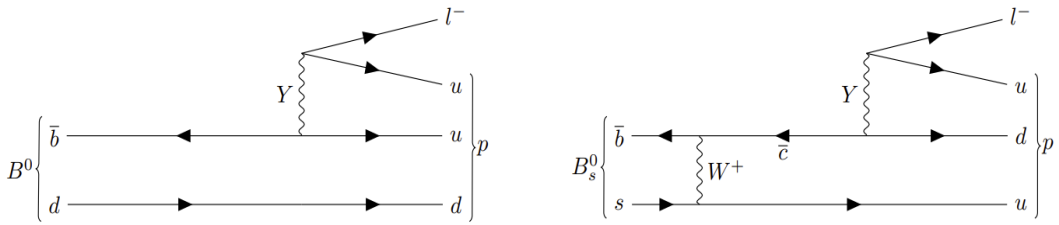
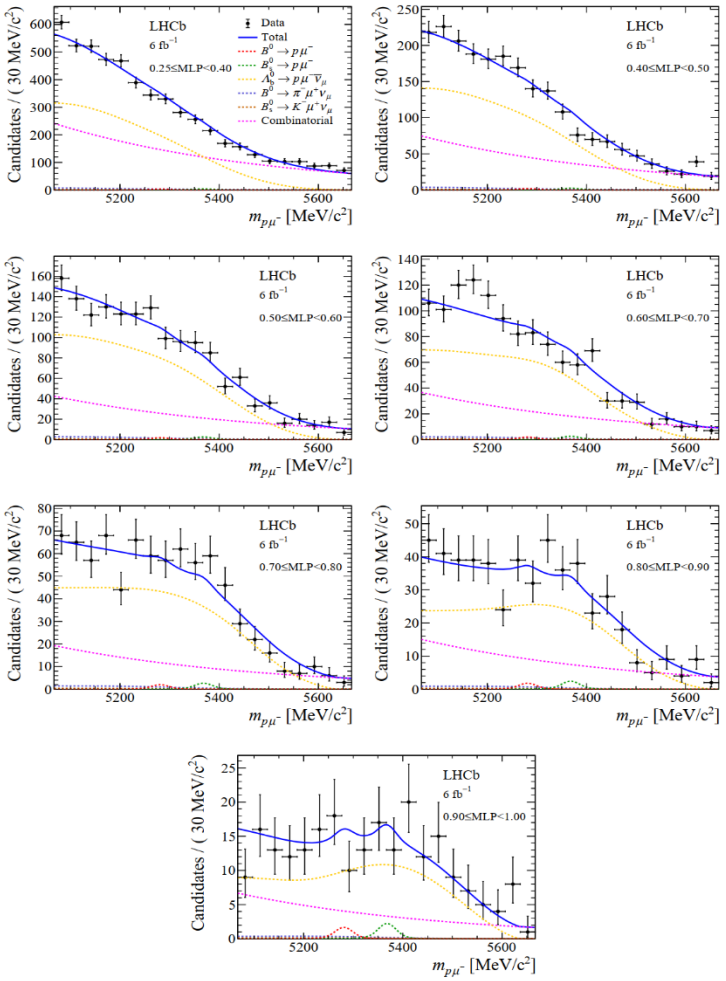
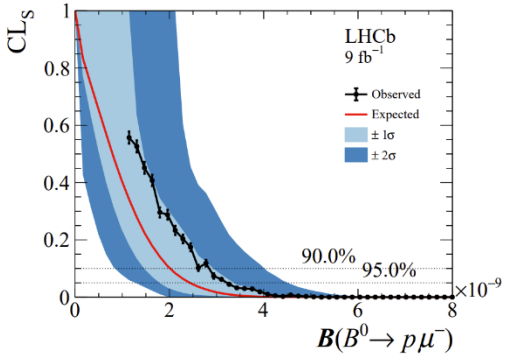


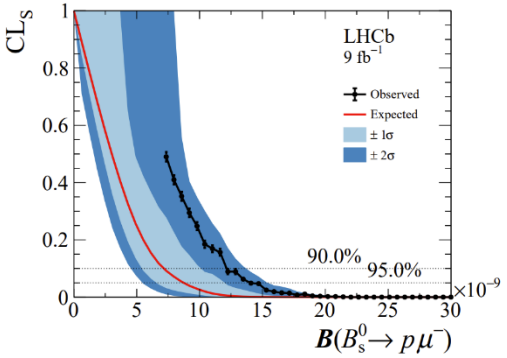
Figure 1: Hypothetical Feynman diagrams of $B^0_{(s)} \to p\ell^-$ mediated by a hypothetical Y boson.

The baryon and lepton number violating decays $B_s^0 \to p\mu^-$ and $B^0 \to p\mu^-$

- Mass distribution of signal candidates for Run 2 samples in regions of MLP.







- Results from the CLs scan used to obtain the limit on BR($B^0 \to p\mu^-$) and BR($B_s^0 \to p\mu^-$)
- the first upper limits on these decays

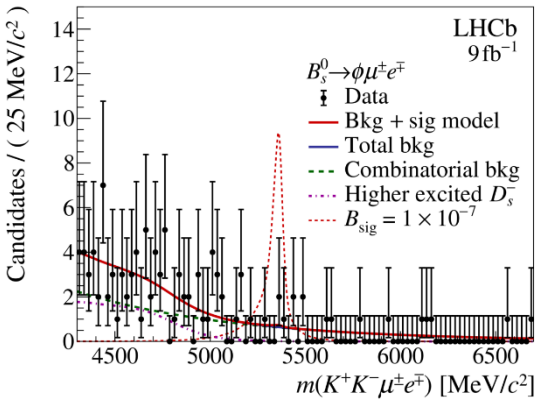
Channel	Expected	Observed
$B^0 \to p\mu^-$	$1.9\ (2.4) \times 10^{-9}$	$2.6\ (3.1) \times 10^{-9}$
$B_s^0 \to p\mu^-$	$7.0\ (8.6) \times 10^{-9}$	$12.1\ (14.0) \times 10^{-9}$

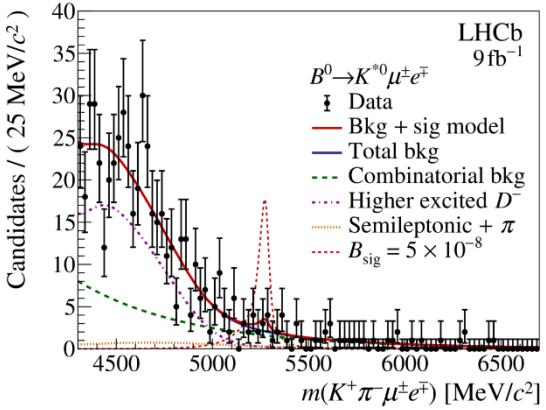
arXiv:2210.10412

LFV decays $B_s^0 \to \phi\mu^\pm e^\mp$, $B^0 \to K^{*0}\mu^\pm e^\mp$ and $B^0 \to K^{*0}\mu^\pm\tau^\mp$

- An observation of LFV decays involving charged leptons would constitute a clear and unambiguous sign of New Physics
  - Specific NP scenarios that can induce LFV b-hadron decays include models with scalar or vector leptoquarks and models with additional Z' bosons
- the flavour anomalies in rare $b \to sl^+l^-$ also make LFV important, as lepton flavour non-universality is closely connected with LFV

$$\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7 \times 10^{-9} (6.9 \times 10^{-9}),$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8 \times 10^{-9} (7.9 \times 10^{-9}),$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 10.1 \times 10^{-9} (11.7 \times 10^{-9}),$$
$$\mathcal{B}(B_s^0 \to \phi\mu^\pm e^\mp) < 16.0 \times 10^{-9} (19.8 \times 10^{-9})$$





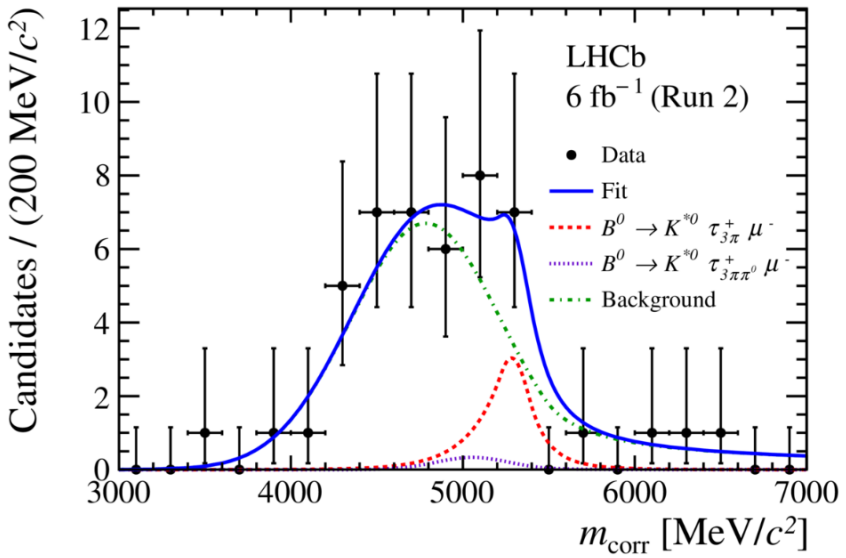
- The world's most stringent limits to date

arXiv:2207.04005

LFV decays $B^0 \to K^{*0}\mu^{\pm}\tau^{\mp}$

- Not ever investigated by any prior experiment

corrected mass

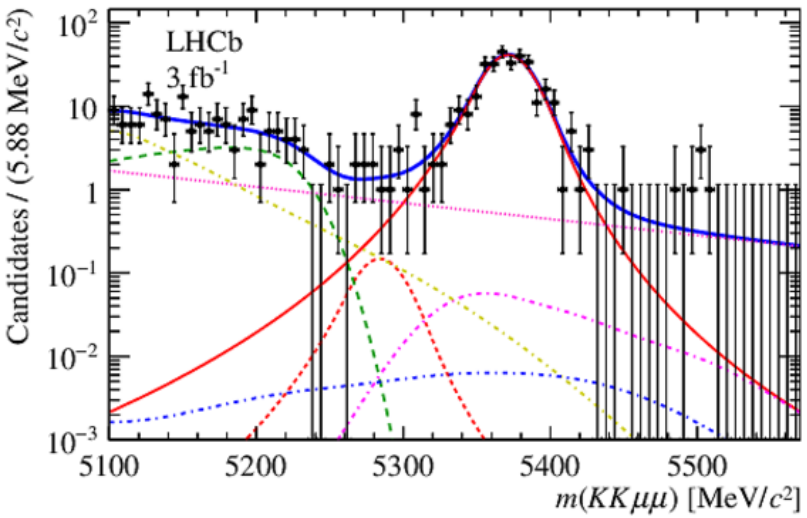


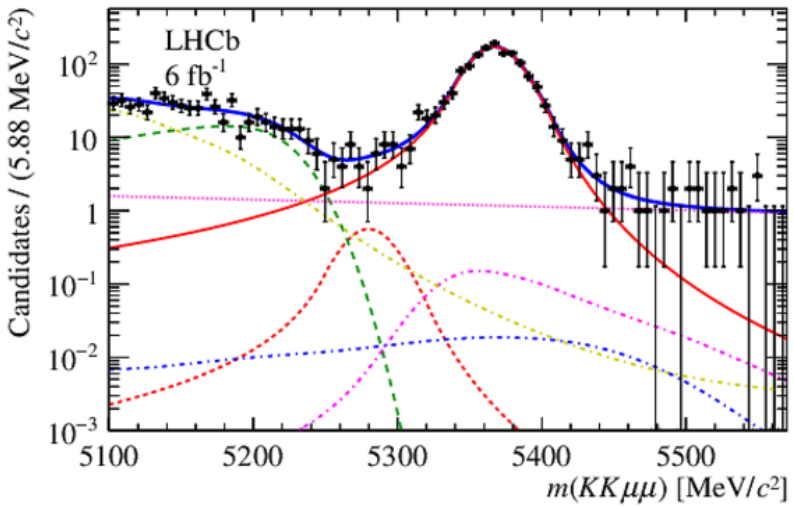
$\mathrm{BR}(B^0 \to K^{*0}\mu^-\tau^+) < 1.0(1.2) \times 10^{-5}$, $\mathrm{BR}(B^0 \to K^{*0}\mu^+\tau^-) < 8.2(9.8) \times 10^{-6}$

- The world's most stringent limits to date

arXiv:2209.09846

Search for the $B^0 \to \varphi\mu^+\mu^-$





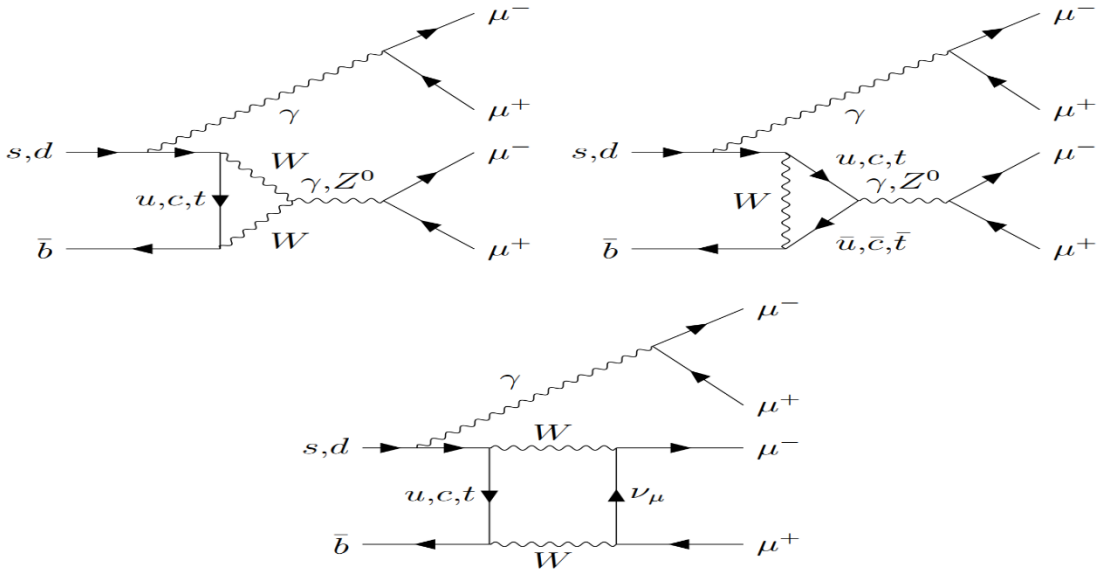
- No statistically significant excess of the decay $B^0 \to \varphi\mu^+\mu^-$
- An upper limit on its BR excluding the φ and charmonium regions in the dimuon spectrum, relative to that of the decay $B_s^0 \to \varphi\mu^+\mu^-$ is determined to be 4.4×10^{-3} at a 90% CL.
- Using the LHCb measurement of $B(B_s^0 \to \varphi\mu^+\mu^-)$, an upper limit on $B(B^0 \to \varphi\mu^+\mu^-)$ in the full q^2 range is set to be 3.2×10^{-9} at a 90% CL, which is compatible with the SM prediction.

JHEP 05 (2022) 67

Search for the rare decays $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to \mu^+\mu^-\mu^+\mu^-$

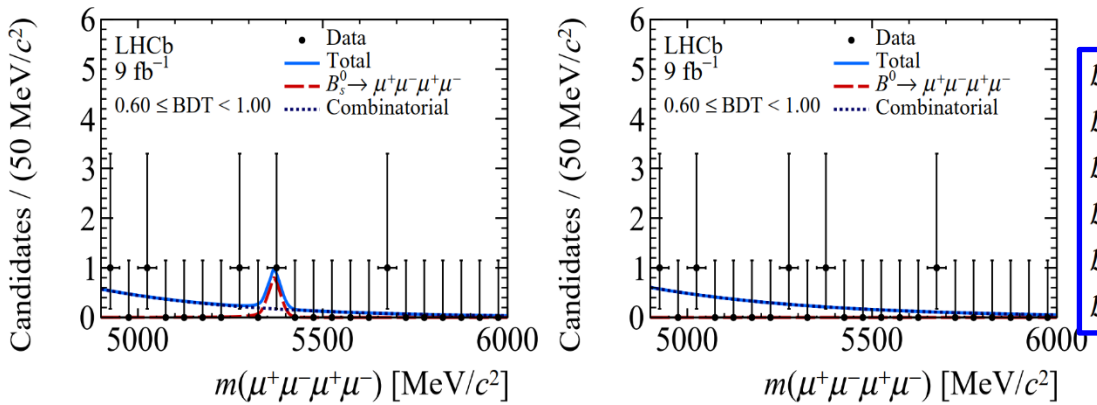
- Highly suppressed in SM: BR $(B^0 \to 4\mu) \sim 10^{-12}$, BR$(B_s^0 \to 4\mu) \sim 10^{-10}$
- For example, decays via scalar and pseudoscalar Sgoldstino particles into a pair of dimuons in the MSSM may lead to significant enhancements of the BRs
- Furthermore, the decays into a pair of dimuons mediated by BSM light narrow scalars, $B_{(s)}^0 \to a(\mu^+\mu^-)a(\mu^+\mu^-)$, naturally occur in the extensions of SM

  - In particular, such models can account for the long-standing tension of the anomalous magnetic dipole moment of the muon, as well as the widely discussed anomalies in transitions

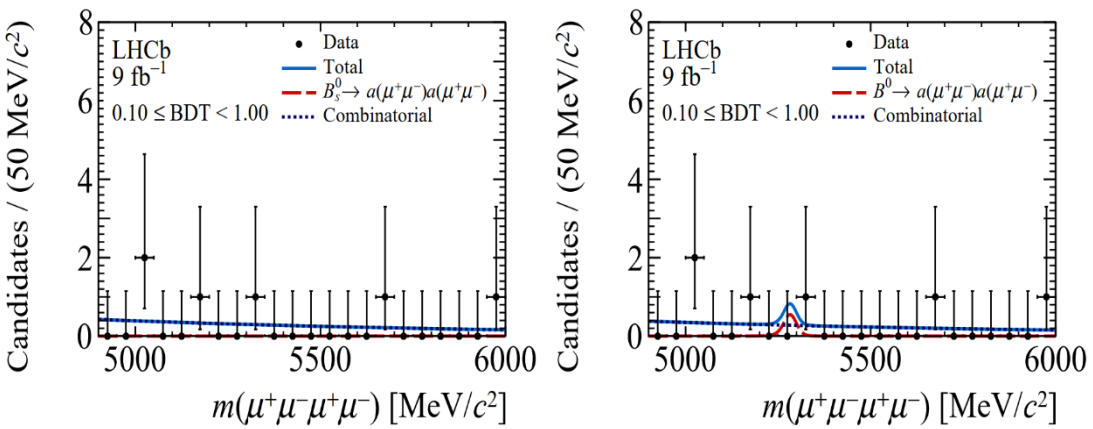


Search for the rare decays $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to \mu^+\mu^-\mu^+\mu^-$

- No evidence for the six signal decay modes, with the most significant excesses found in the $B^0_{(s)} \to J/\psi(\mu^+\mu^-)\mu^+\mu^-$ searches, amounting to 2σ



$\mathcal{B}\left(B_s^0 \to \mu^+\mu^-\mu^+\mu^-\right)$	$< 8.6 \times 10^{-10}$,
$\mathcal{B}\left(B^0 \to \mu^+\mu^-\mu^+\mu^-\right)$	$< 1.8 \times 10^{-10}$,
$\mathcal{B}\left(B_s^0 \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right)$	$< 5.8 \times 10^{-10}$,
$\mathcal{B}\left(B^0 \to a\left(\mu^+\mu^-\right) a\left(\mu^+\mu^-\right)\right)$	$< 2.3 \times 10^{-10}$,
$\mathcal{B}\left(B_s^0 \to J/\psi\left(\mu^+\mu^-\right)\mu^+\mu^-\right)$	$< 2.6 \times 10^{-9}$,
$\mathcal{B}\left(B^0 \to J/\psi\left(\mu^+\mu^-\right)\mu^+\mu^-\right)$	$< 1.0 \times 10^{-9}$.



- The most stringent limits on each of the six decays

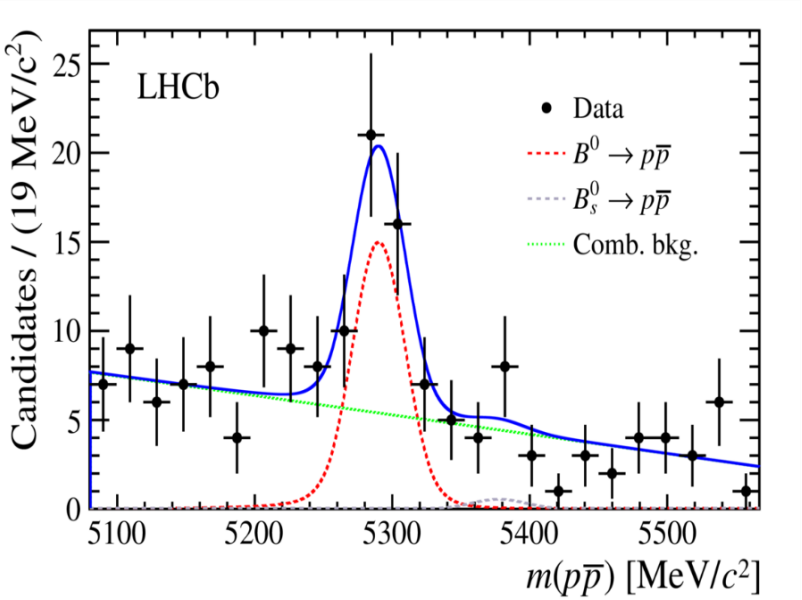
JHEP 03 (2022) 109

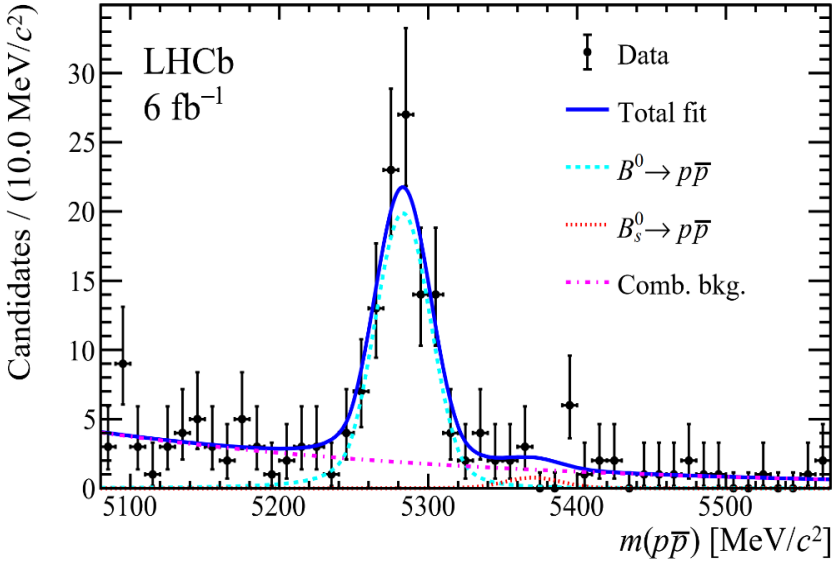
Search for the rare hadronic decay $B_s^0 \to p\bar{p}$

- To date only three charmless two-body baryonic decays have been observed, namely the $B^+ \to p\,\bar{\Lambda}(1520)$, $B^+ \to p\,\bar{\Lambda}$ and $B^0 \to p\bar{p}$ modes.

- Run-I result:

  BR($B^0 \to p\bar{p}$)= (1.25±0.27±0.18) $\times 10^{-8}$





arXiv:2206.06673

Search for the rare hadronic decay $B_s^0 \to p\bar{p}$

- No statistically significant excess of the decay is observed.

The 90% (95%) upper limit on the $B_s^0 \to p\bar{p}$ decay branching fraction is set at

$$\mathcal{B}(B_s^0 \to p\bar{p}) < 4.4\ (5.1) \times 10^{-9} \text{ at } 90\%\ (95\%)\ \text{CL.}$$

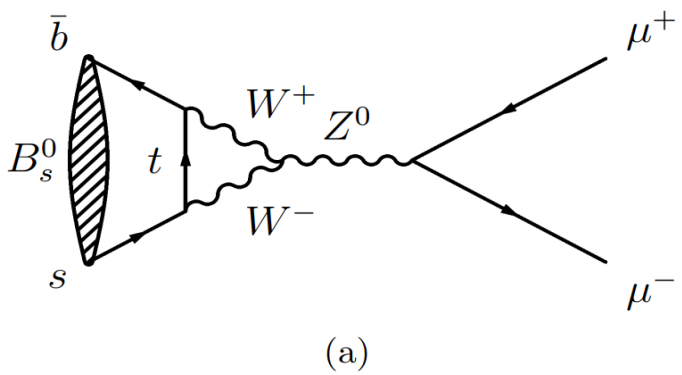
- Using the measured quantities and the equation below, the branching fraction of the ($B^0 \to p\bar{p}$) decay is measured more precisely to be:

$$\mathcal{B}(B^0_{(s)} \to p\bar{p}) = \frac{N(B^0_{(s)} \to p\bar{p})}{N(B^0 \to K^+\pi^-)} \times \frac{\varepsilon_{B^0 \to K^+\pi^-}}{\varepsilon_{B^0_{(s)} \to p\bar{p}}} \times \mathcal{B}(B^0 \to K^+\pi^-) \times \frac{f_d}{f_{d(s)}}, \qquad (1)$$

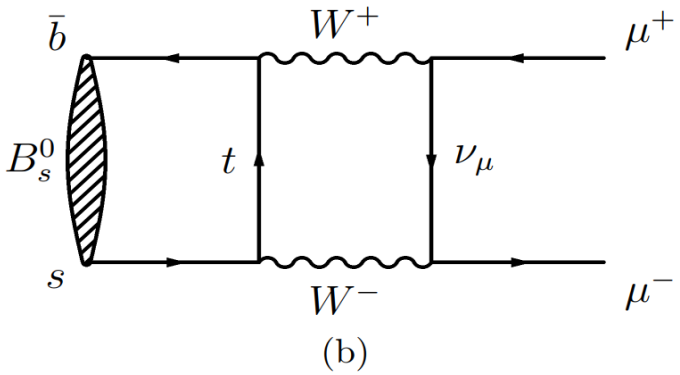
$$\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04) \times 10^{-8},$$

arXiv:2206.06673

Measurement of $B_s^0 \to \mu^+\mu^-$ and search for $B^0 \to \mu^+\mu^-$, $B_s^0 \to \mu^+\mu^-\gamma$

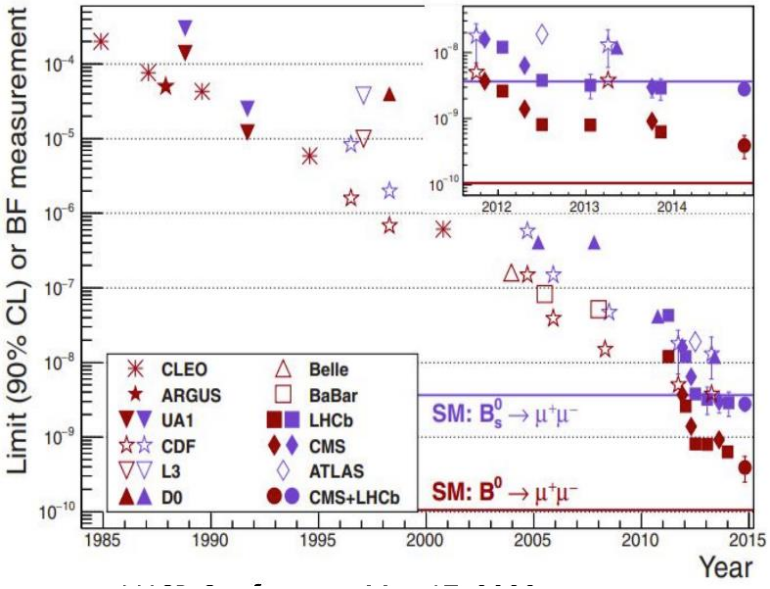


(a)



(b)

- Highly suppressed in SM, (i)Cabibbo suppressed, (ii)Helicity suppressed
- Extremely rare in SM ($B_s^0 \to \mu^+\mu^-$ ~(3.66±0.14) $\times 10^{-9}$, $B^0 \to \mu^+\mu^-$ ~(1.03±0.05) $\times$ 10^{-9}).
- powerful probes for detecting deviations from the SM due to new physics contributions mediated, for instance, by heavy Z' gauge bosons, leptoquarks or non-SM Higgs bosons

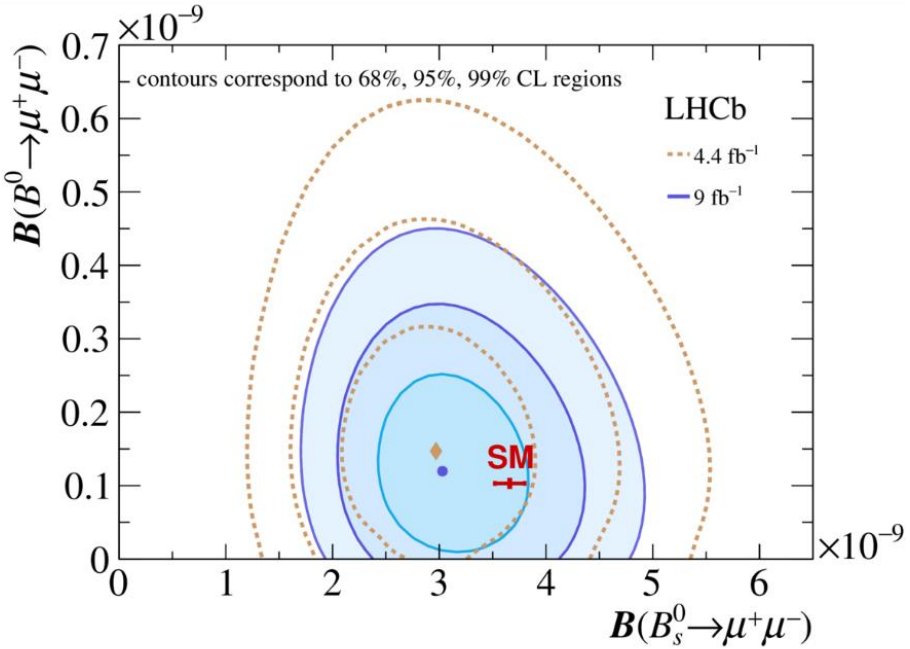


Phys. Rev. Lett. 128, (2022) 041801

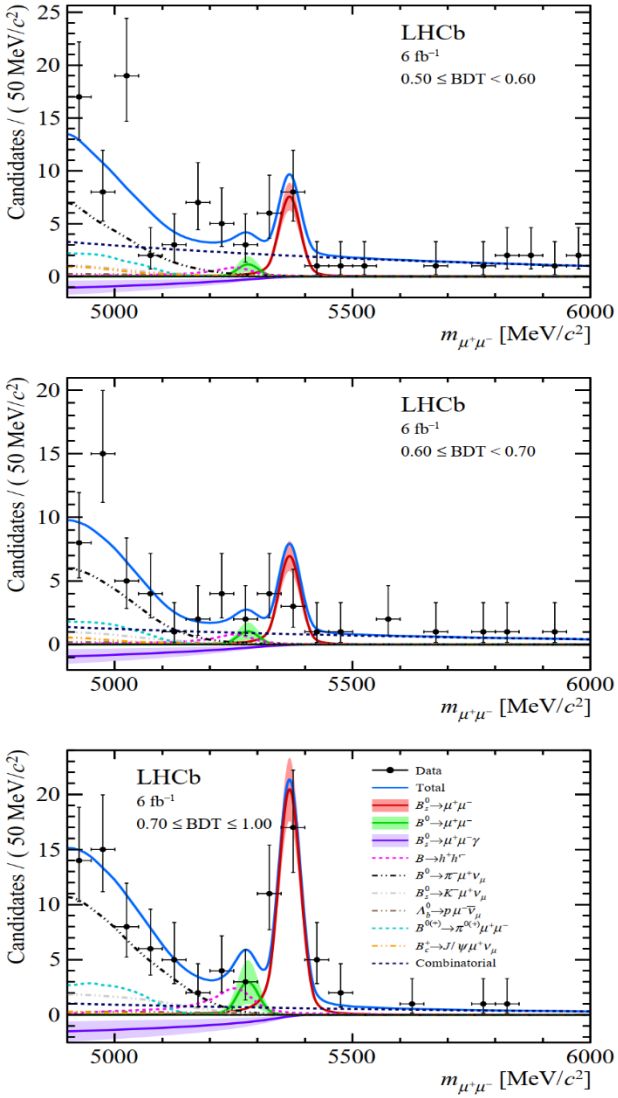
Phys. Rev. D105 (2022) 012010

LHCb Run 1 + Run 2, $B_s^0 \to \mu^+\mu^-$

- Branching ratios, consistent with SM:



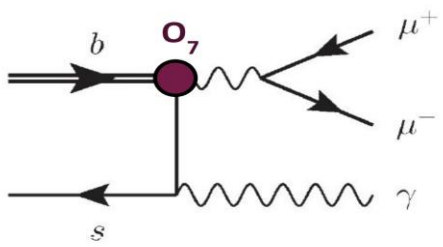
- Systematic uncertainties of $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ are dominated by the uncertainty on *fs/fd* (3%) and the knowledge of the background from specific processes (9%), respectively.

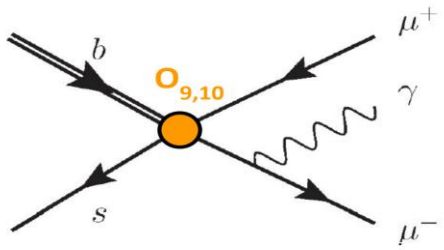


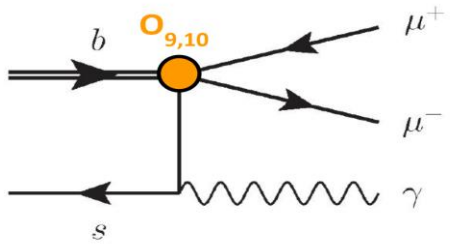
Phys. Rev. Lett. 128, (2022) 041801 Phys. Rev. D105 (2022) 012010

Search for $B_s^0 \to \mu^+\mu^-\gamma$

- Compared to the $B_s^0 \to \mu^+\mu^-$ amplitude, the additional suppression arising from the photon is compensated by no longer helicity suppressed, increasing the total predicted BR
- The $B_s^0 \to \mu^+\mu^-\gamma$ process is a powerful probe of SM, being sensitive to C7 , C9 and C10, While $B_s^0 \to \mu^+\mu^-$ is only sensitive to C10



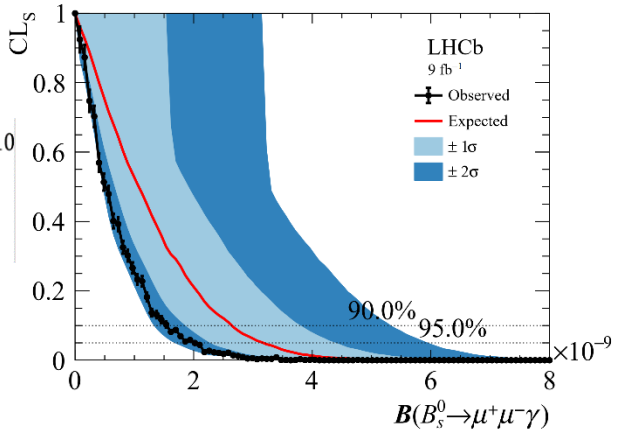




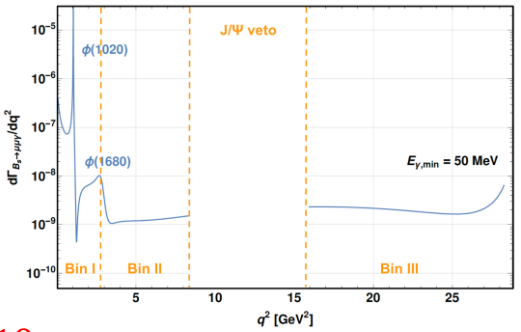
- Indirect search:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-\gamma) < (8.90 \pm 0.98) \times 10^{-10}$$

$$q^2 \in [15.84, 28.27]\, GeV^2/c^4$$



- Direct search (coming very soon):
  - Direct photon search first time
  - Probe low q^2 regions for the first time



Phys. Rev. Lett. 128, (2022) 041801 Phys. Rev. D105 (2022) 012010

Summary

• LHCb provides ideal environment for searching for rare decays (and new physics) in B decays

• No evidence for some, although the world's best upper limits on the BFs are set

• More results are on the way; looking forward to new data (Run3 and beyond) in the years to come!

谢谢大家！