First Evidence for the Rare Decay $B^0_s \to \mu^+\mu^-$

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The LHCb Collaboration
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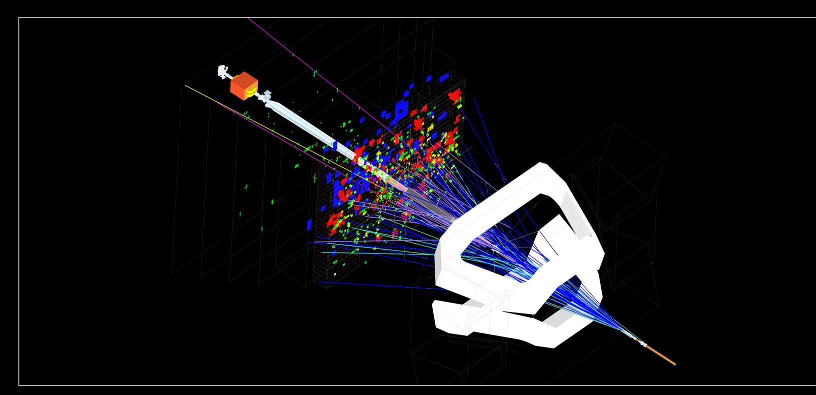
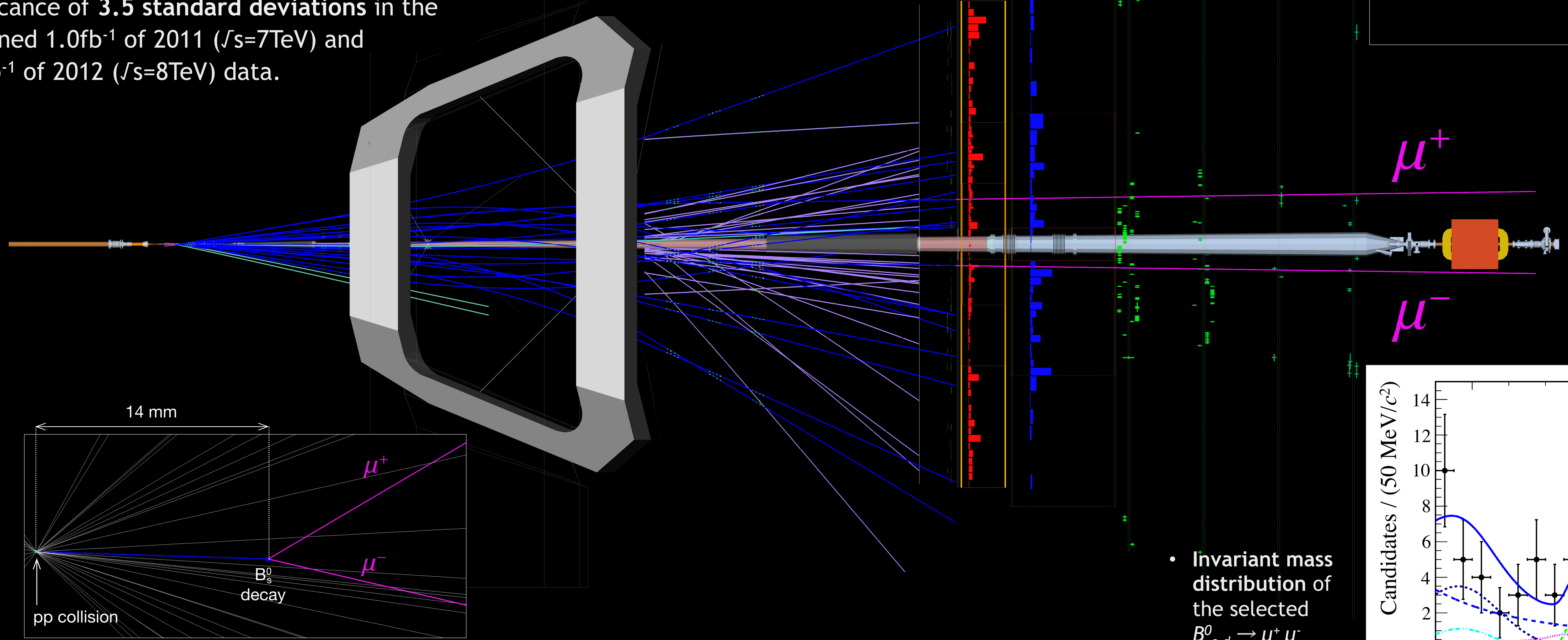
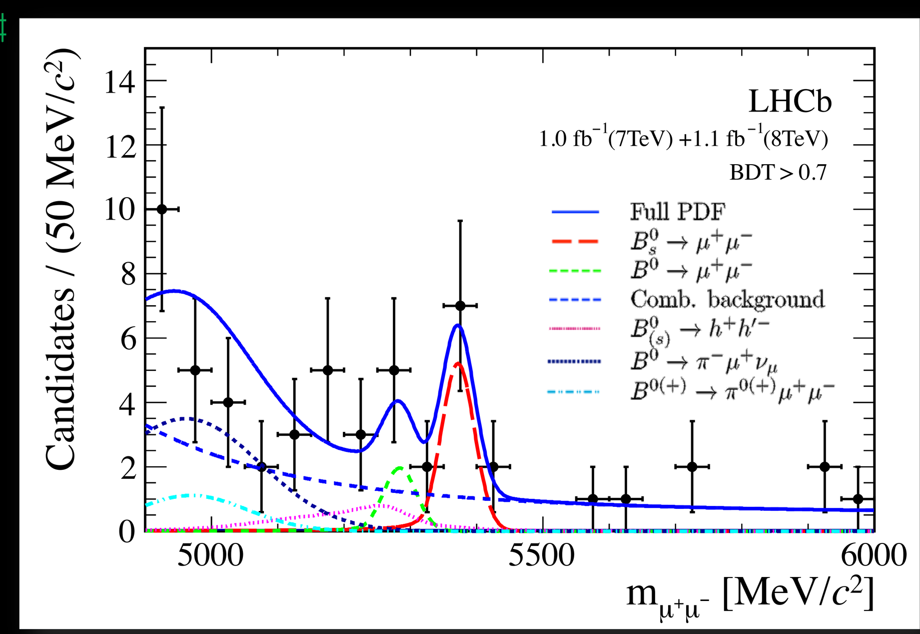
ONE OF THE RAREST DECAYS EVER SEEN

LHCb observed evidence for a very rare decay of a neutral B_s meson into a pair of muons[1]. The probability that the background could produce such an excess or larger is mere 5.3x10^{-4}. This corresponds to signal significance of **3.5 standard deviations** in the combined 1.0fb^{-1} of 2011 (√s=7TeV) and 1.11fb^{-1} of 2012 (√s=8TeV) data.



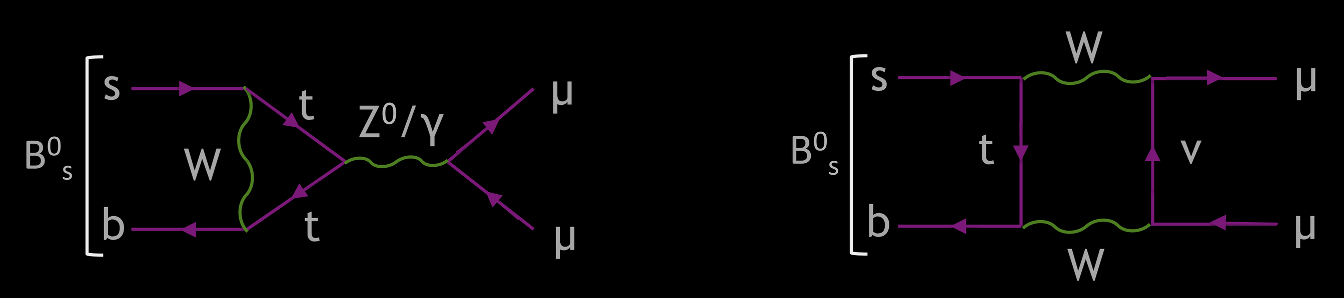




- **Invariant mass distribution** of the selected $B^0_{s,d} \to \mu^+\mu^-$ candidates in high BDT region

Why so rare?

New physics (NP) is easiest to spot where according to the Standard Model (SM) an event is not likely to happen. In SM, $B^0_{s,d} \to \mu^+\mu^-$ decays are so rare because (i) only decays through loop diagrams are allowed (flavor-changing neutral-current), and (ii) strong helicity suppression. The main SM diagrams contributing to $BR(B^0_s \to \mu^+\mu^-)$ are



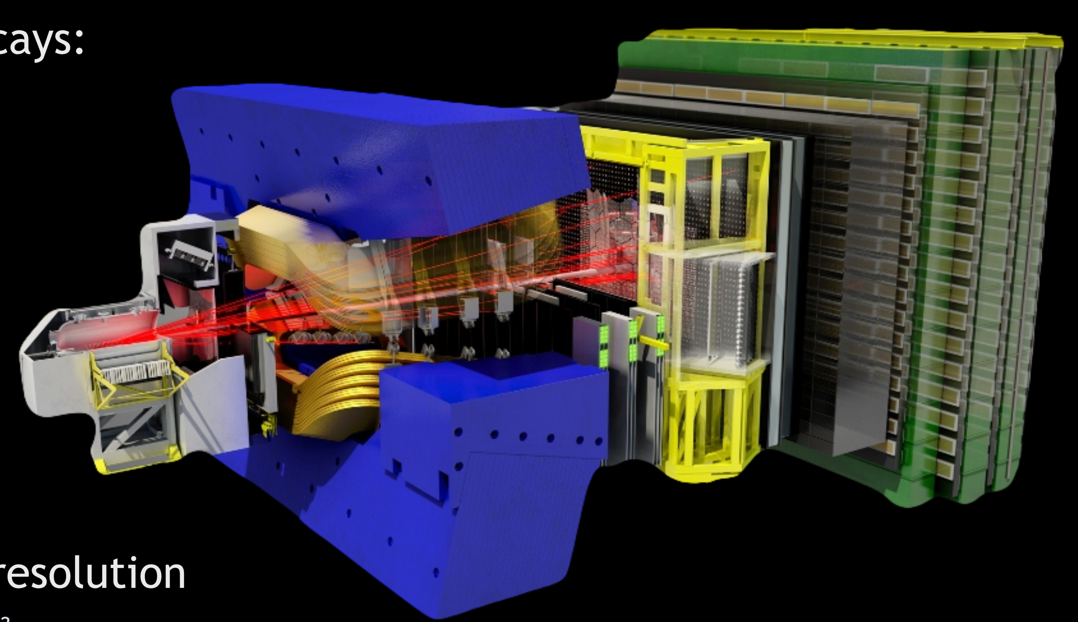
LHCb measures a flavor-averaged and time-integrated branching ratio. For the same quantity, precise SM predictions read[2]:

$$BR(B_s \to \mu^+\mu^-)^{\langle t \rangle \langle CP \rangle} = (3.54 \pm 0.30) \times 10^{-9}$$
$$BR(B_d \to \mu^+\mu^-)^{\langle t \rangle \langle CP \rangle} = (1.07 \pm 0.10) \times 10^{-10}$$

Why LHCb?

The LHCb detector is well suited for measuring $B^0_{s,d} \to \mu^+\mu^-$ decays:

The LHCb detector is a single-arm forward (2<η<5) spectrometer.



- Abundant bb_{bar} pairs
  σ(pp → bb_{bar}X) ~ 300 μb at 7 TeV [2]
- Outstanding muon ID performance
  ε(μ→μ) ~ 97 % (p>10 GeV/c), ε(h→μ) < 1% (p>10 GeV/c).
- Excellent mass and impact parameter resolution
  σ($B_{s,d}$→ μ μ) = ~25 MeV/c^2 σ(IP) ~25 μm (pT = 2 GeV/c^2)
- Efficient trigger on *low-p_T* muons

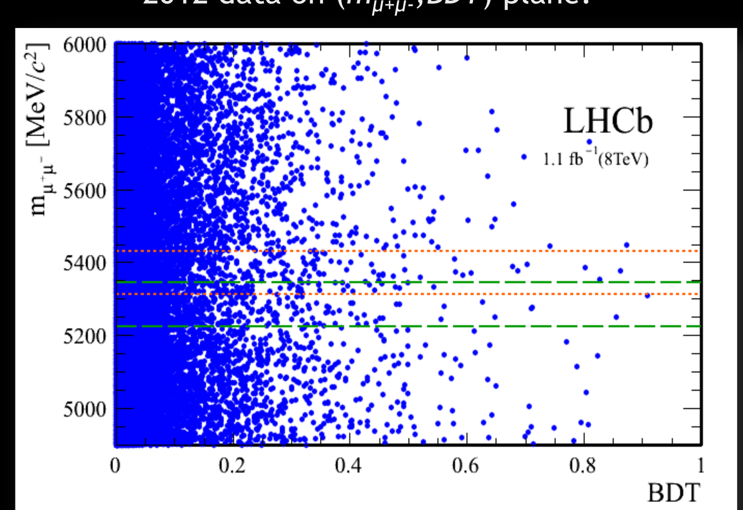
How do we separate the signal candidates?

After a loose pre-selection, we classify the events in two independent variables:

- Di-muon invariant mass ($m_{\mu+\mu-}$)
- Boosted Decision Tree output (*BDT*)

We divide the *BDT* range into 8 bins. In each bin, we compare the number of observed events to the number of expected signal and background events.

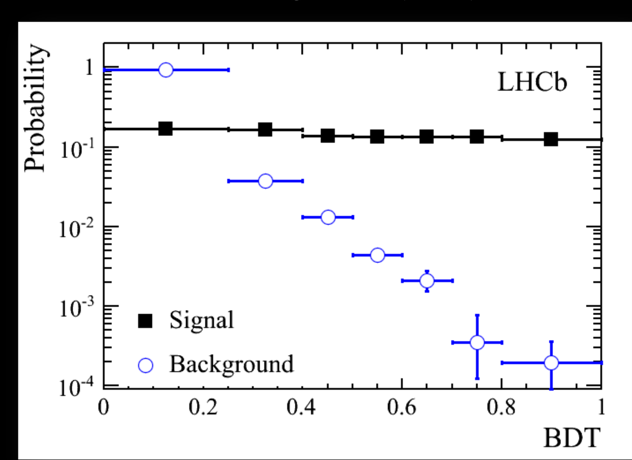
2012 data on ($m_{\mu+\mu-}$,*BDT*) plane.



Boosted Decision Tree (*BDT*)

- *BDT* combines the separation power of 9 carefully chosen topological and kinematic variables.
- We train the *BDT* with simulated $B^0_{s,d} \to \mu^+\mu^-$ events for the signal and $bb_{bar} \to \mu^+\mu^-X$ for the background.
- We use $B_s^0 \to K^+\pi^-$ data to describe the signal distribution in *BDT*.

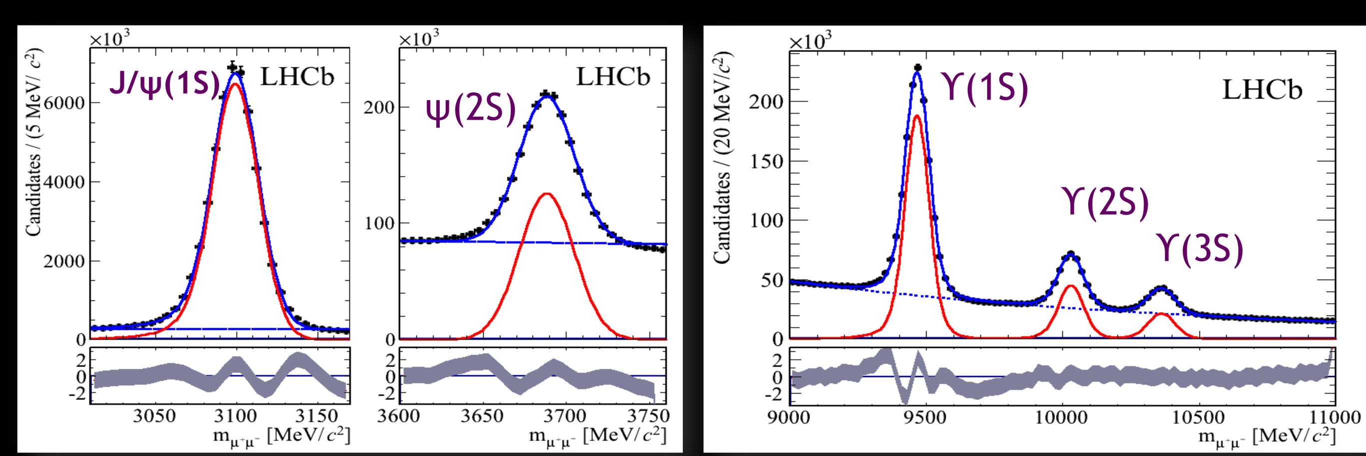
BDT distribution for signal (black) and combinatorial background (blue).



Signal distribution in mass

We obtain the **$B^0_{s,d}$ mass central values** from *the* $B^0_{s,d} \to h^+h^-$ data (where *h* is a kaon or pion). The **mass resolutions** are determined by combining the results from the mass central value fits with the power-law interpolation between $\mu^+\mu^-$ resonances:

- B^0_s and B^0_d mass peaks are separated by more than three times the mass resolution (Δm ~87MeV/c²).



Normalization

The observed $B^0_{s,d} \to \mu^+\mu^-$ yields are translated into *absolute branching ratios* by normalizing to well known $B^+_u \to J/\psi\, K^+$ and $B^0_d \to K^+\pi^-$ branching ratios.

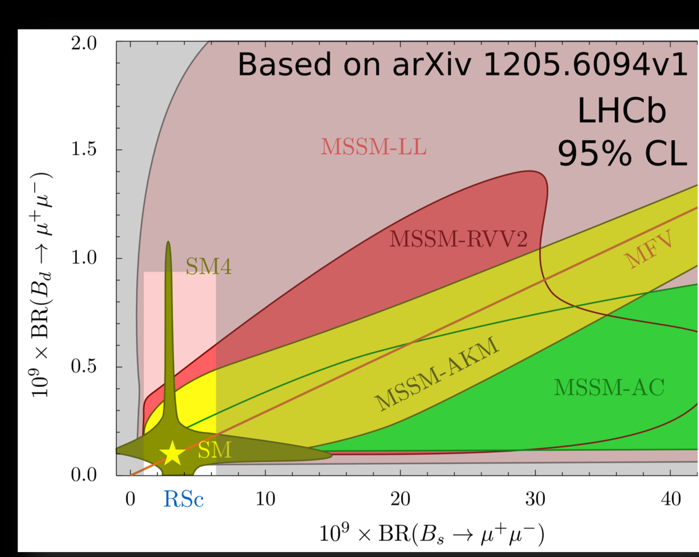
- Single event sensitivity:
  ~2.5x10^{-10} for $B^0_s \to \mu^+\mu^-$
  ~6.5x10^{-11} for $B^0_d \to \mu^+\mu^-$

$$BR(B^0_{s,d} \to \mu^+\mu^-) = \frac{N_{B^0_{s,d}\to\mu^+\mu^-}\, \varepsilon^{norm} f^{norm}}{N_{norm}\, \varepsilon_{sig} f_{sig}} \times BR^{norm}$$

Impact on new physics

Contributions from NP models to the $BR(B^0_s \to \mu^+\mu^-)$ and $BR(B^0_d \to \mu^+\mu^-)$ are strongly limited by the LHCb results[1]:

$$BR(B^0_s \to \mu^+\mu^-) = [3.2^{+1.4}_{-1.2}(stat)^{+0.5}_{-0.3}(syst)] \times 10^{-9}$$
$$BR(B^0_d \to \mu^+\mu^-) < 9.4 \times 10^{-10}\ @95\%CL$$



- Constraints on new physics models [4]
  Shaded area is excluded by LHCb @ 95% CL.

References

[1] The LHCb Collaboration, Phys. Rev. Lett. 110, 021801 (2013)
[2] A.J. Buras *et al*, Eur. Phys. J. C **72, 2172 (2012)**
[3] The LHCb Collaboration, Phys. Lett. B 694 (2010) 209
[4] D. M. Straub, arXiv:1205.6094v1 (2012)