Rare Decays at LHCb

Alexander Popov

Institute for High Energy Physics (Protvino, Russia)
on behalf of the LHCb collaboration

16th Lomonosov Conference on Elementary Particle Physics
Moscow State University
Moscow, 22 – 28 August 2013

Outline

- $B^0_{(s)} \to \mu^+\mu^-$ [arXiv:1307.5024]
- $D^0 \to \mu^+\mu^-$ [PL B725 (2013) 15-24] [arXiv:1305.5059]
- $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ [PRL 110 (2013) 211801] [arXiv:1303.1092]
- $B^0_{(s)} \to e^\pm\mu^\mp$ [arXiv:1307.4889]

Not presented:

- $B^0 \to p\bar{p}$ [arxiv:1308.0961] see Olafs' talk
- $B^+ \to K^+\mu^+\mu^-$ [JHEP 02 (2013) 105] [arxiv:1308.1340] [arxiv:1307.7595] see Olafs' talk
- $B^0 \to K^{*0}\mu^+\mu^-$ [arxiv:1304.6325] [arxiv:1308.1707] see Olafs' talk
- $B^+ \to \pi^+\mu^+\mu^-$ [arxiv:1210.2645]
- $K_s \to \mu^+\mu^-$ [arxiv:1209.4029]
- $D^+_{(s)} \to \pi^+\mu^+\mu^-$, $D^+_{(s)} \to \pi^-\mu^+\mu^+$ [arxiv:1304.6365]
- $\Lambda^0_b \to \Lambda\mu^+\mu^+$ [arxiv:1306.2577] see Olafs' talk
- $\tau^- \to \mu^-\mu^+\mu^-$, $\tau^- \to \bar{p}\mu^+\mu^-$, $\tau^- \to p\mu^-\mu^-$ [arxiv:1304.4518]
- ...

Why Rare Decays?

- It's a perfect framework for indirect searches of NP.
- RD are suppressed or forbidden in the SM (mostly occur via loop diagrams).
- The presence of NP could sensibly modify decay properties: branching fractions, angular distributions of the decay products, CP and isospin asymmetries.
- The results set constraints on the effective Hamiltonian describing the posible NP contributions.
- The LHCb is well adapted to perform RD searches: the high trigger efficiency, good particle identification system, excellent tracking system for precise determination of secondary vertexes, impact parameters and momenta.

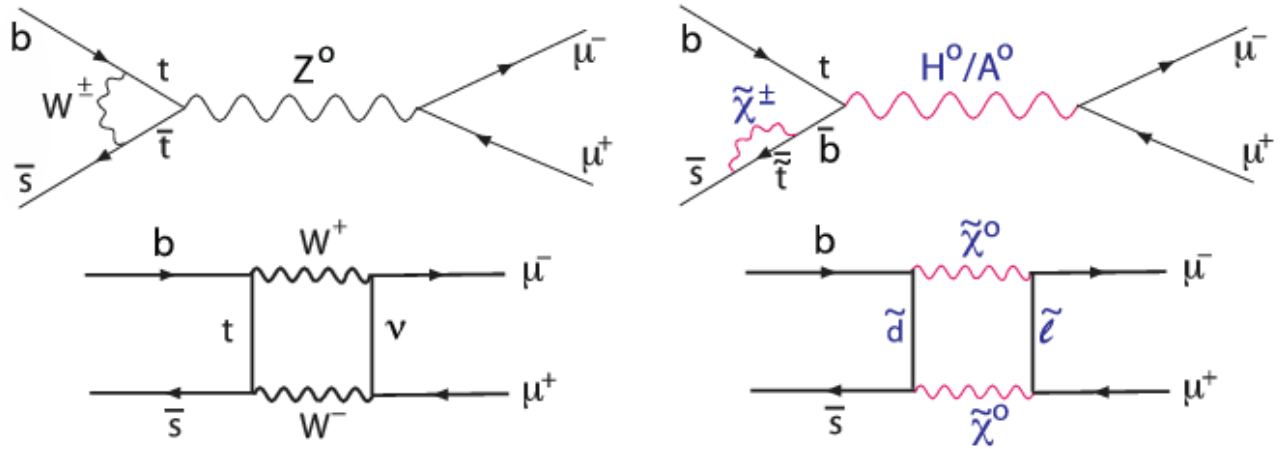
$B^0_{(s)} \to \mu^+\mu^-$

arXiv:1307.5024

$B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ are highly suppresed in the SM (FCNC and helicity suppresion):

$$\mathcal{B}(B^0_s \to \mu^+\mu^-)^{\rm SM} = (3.56 \pm 0.30) \times 10^{-9},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)^{\rm SM} = (1.07 \pm 0.10) \times 10^{-10}.$$

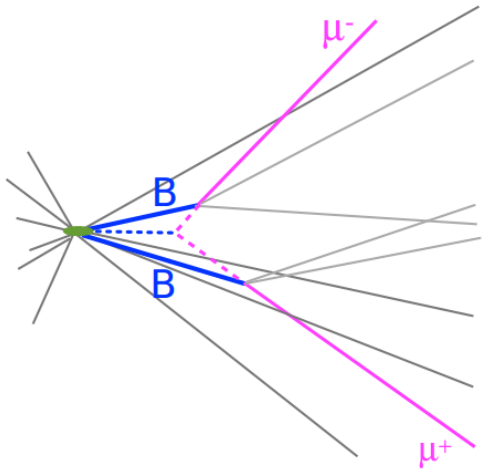
Sensitive for scalar and pseudo-scalar NP contribution.



$B^0_{(s)} \to \mu^+\mu^-$ Analisis strategy

arXiv:1307.5024

- Full dataset 3 fb^{-1}: 1 fb^{-1} @ 7 TeV (2011) and 2 fb^{-1} @ 8 TeV (2012)
- Signal and background discrimination with MVA (12 kinematic and geometrical variables: proper time, IP, min IP significance, p_T, ...)



- Normalization on $B^+ \to J/\psi\, K^+$ and $B^0 \to K^+\pi^-$
- Background estimations
  - Combinatorial from $m_{\mu\mu}$ sidebands
  - Double misidentified $B^0_{(s)} \to h^+h^-$
  - Detailed study on various exclusive backgrounds
- BF: likelihood fit to the invariant mass
- Upper limit: CL method

$B^0_{(s)} \to \mu^+\mu^-$ Results

arXiv:1307.5024

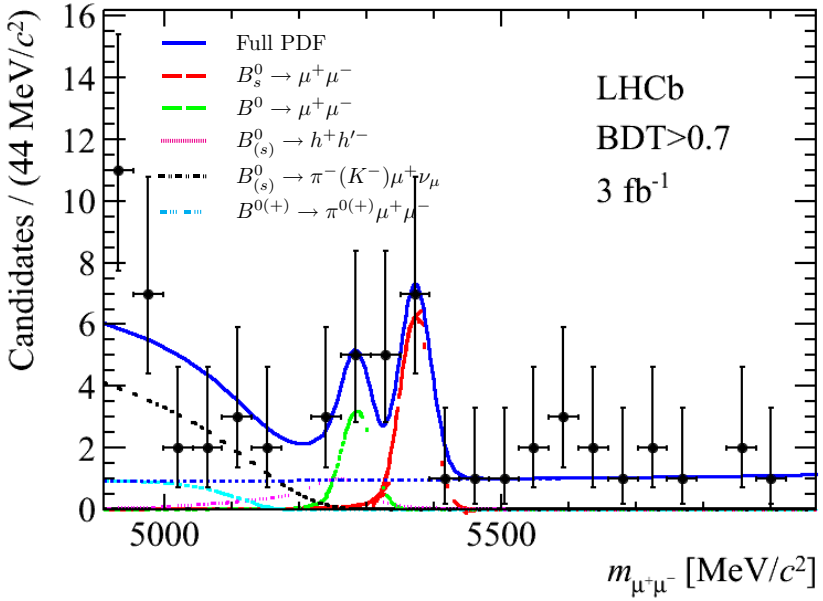
- BF measurements:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}\,\mathrm{st}\ ^{+0.3}_{-0.1}\mathrm{sy}) \times 10^{-9}$$

significance 4.0σ

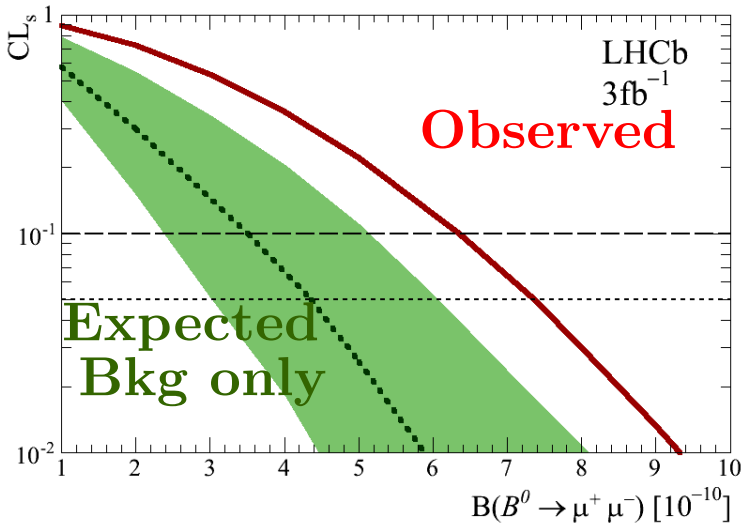
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.7^{+2.4}_{-2.1}\,\mathrm{st}\ ^{+0.6}_{-0.4}\mathrm{sy}) \times 10^{-10}$$

significance 2.0σ



- 95% CL upper limit

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 7.4 \times 10^{-10}$$



$B^0_{(s)} \to \mu^+\mu^-$ LHCb & CMS

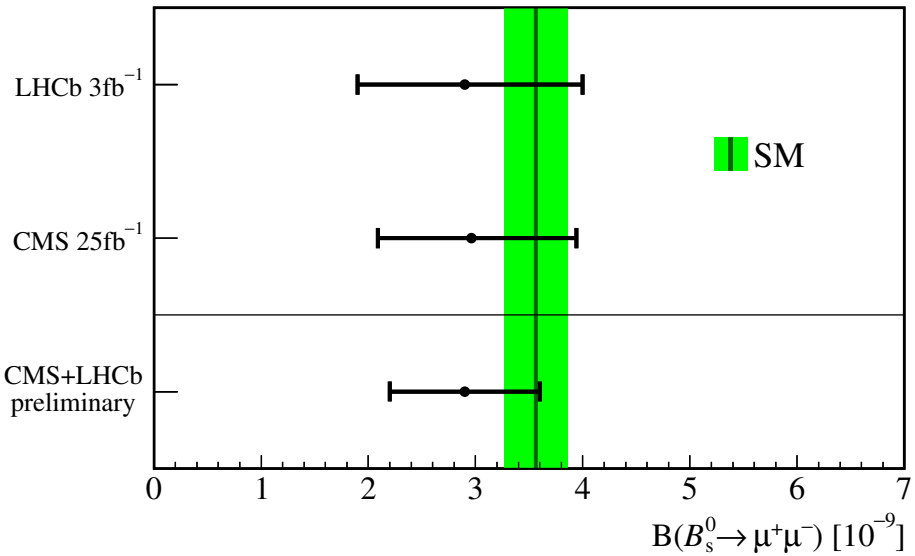
LHCb-CONF-2013-012
CMS-PAS-BPH-13-007

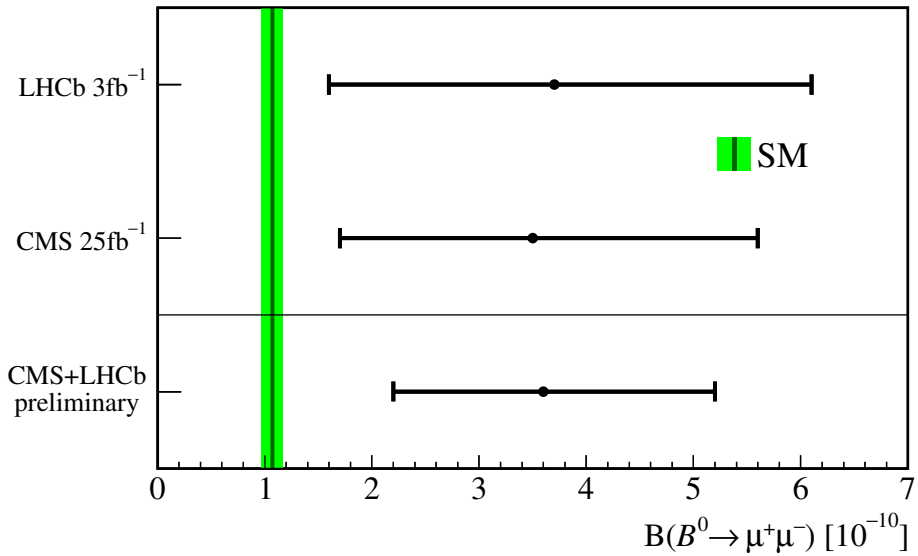
- CMS results ($25\ fb^{-1}$)

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9} \qquad (4.3\sigma)$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.5^{+2.1}_{-1.4}) \times 10^{-10} \qquad (1.8\sigma)$$

- The **preliminary** combined results

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (2.9 \pm 0.07) \times 10^{-9} \qquad (> 5\sigma)$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.6^{+1.6}_{-1.4}) \times 10^{-10} \qquad (< 3\sigma)$$



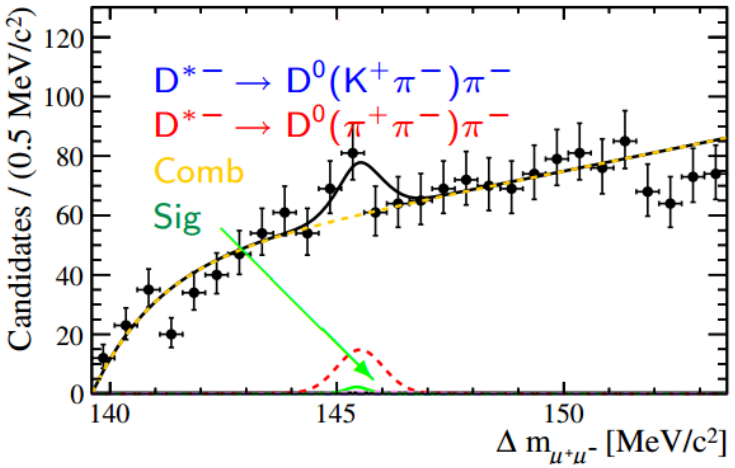


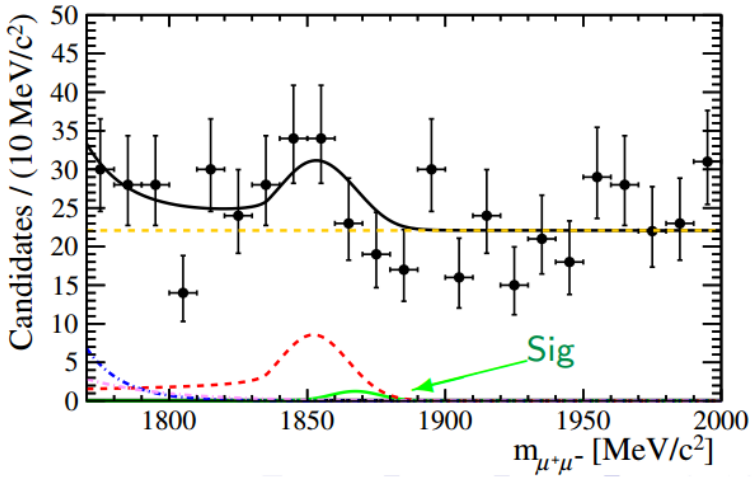
$D^0 \to \mu^+\mu^-$

Physics Letter B725 (2013) 15-24
arXiv:1305.5059

- FCNC and helicity suppressed in SM: $\mathcal{B}(D^0 \to \mu^+\mu^-) < 6 \times 10^{-11}$
- Complementary to B and K rare decays
- Search for $D^{*+} \to (D^0 \to \mu^+\mu^-)\pi^+$
  - Two fit variables: $m_{\mu\mu}$ and $\Delta m_{\mu\mu} = m_{\mu\mu\pi} - m_{\mu\mu}$
- Dataset 0.9 fb^{-1} @ 7 TeV
  - 80 pb^{-1} used to train MVA
- Normalise to $D^0 \to \pi^+\pi^-$
- Bkg: combinatorial + mis-ID $D^0 \to \pi^+\pi^-$
- 95% CL $\mathcal{B}$ upper limits (×20 improvement on previous best BELLE constraint arXiv:1003.2345):

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 6.2 \times 10^{-9}$$

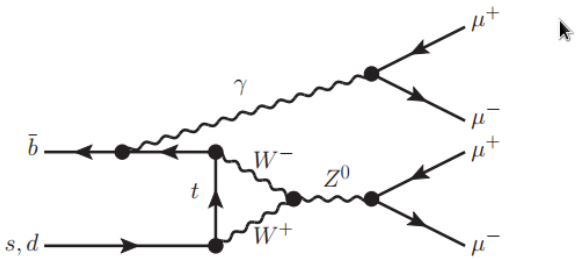


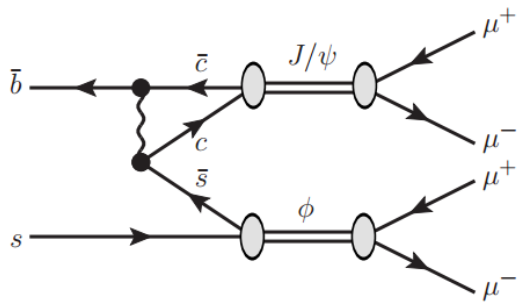


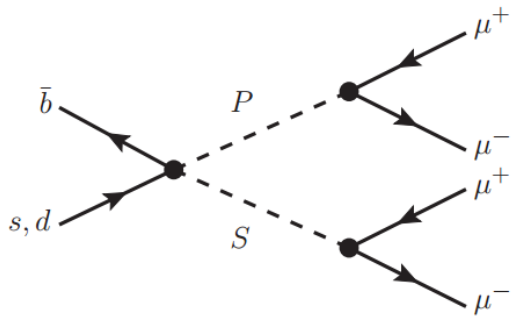
$B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$

Physical Review Letter 110 (2013) 211801
arXiv:1303.1092

- Strongly suppressed in the SM, two contributions:
  - Resonant $B^0_{(s)} \to J/\psi(\to \mu\mu)\phi(\to \mu\mu)$, with $\mathcal{B} = (2.4 \pm 0.9) \times 10^{-8}$, excluded in the analysis
  - Non-resonant $B^0_{(s)} \to \mu\mu\gamma(\to \mu\mu)$, with $\mathcal{B} < 10^{-10}$ [PRD 70 (2004) 114028]
- In NP models, scalar and pseudoscalar particles enhance the $\mathcal{B}$ via $B \to PS$





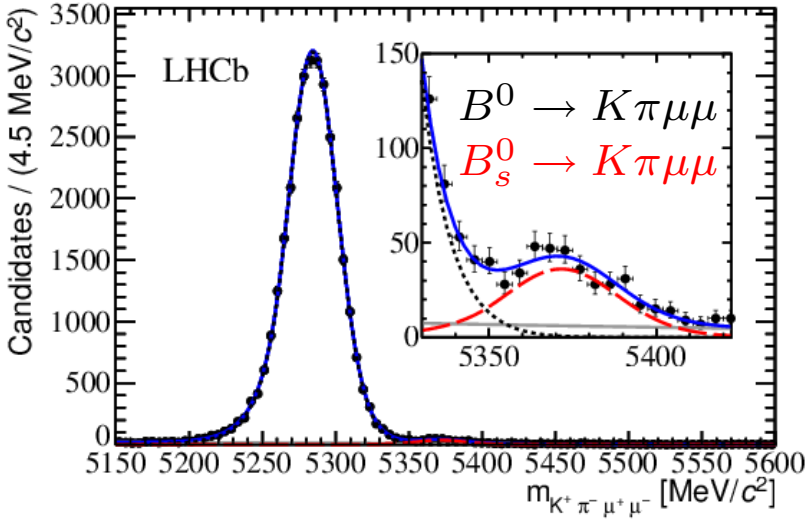


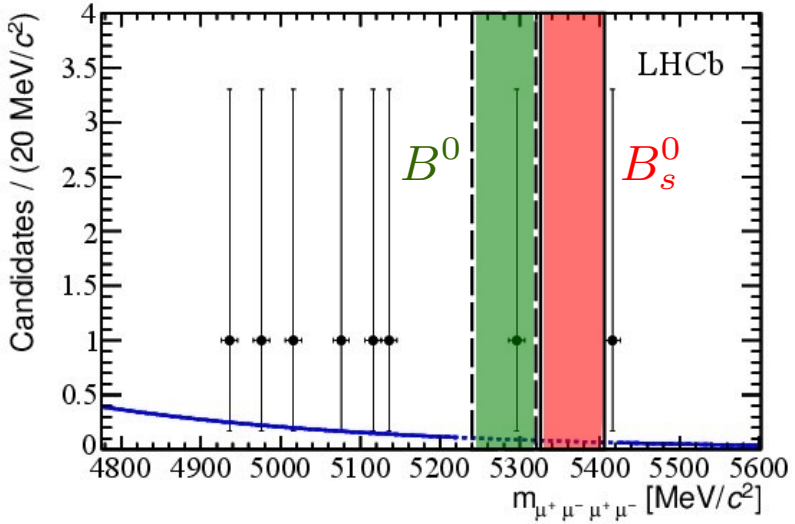
$B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ Results

Physical Review Letter 110 (2013) 211801
arXiv:1303.1092

- Analysis on $1 fb^{-1}$ @ 7 TeV of 2011 data.
- Resonant $B^0_{(s)} \to J/\psi\phi$ removed in the signal selection and used as a control channel to develop the selection criteria
- Only combinatorial background considered
- Normalization channel:
  $B^0 \to J/\psi(\to \mu\mu)K^{*0}(\to K^+\pi^-)$
- Upper limits at 95% CL:

$$\mathcal{B}(B^0_s \to 4\mu) < 1.6 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to 4\mu) < 6.6 \times 10^{-9}$$





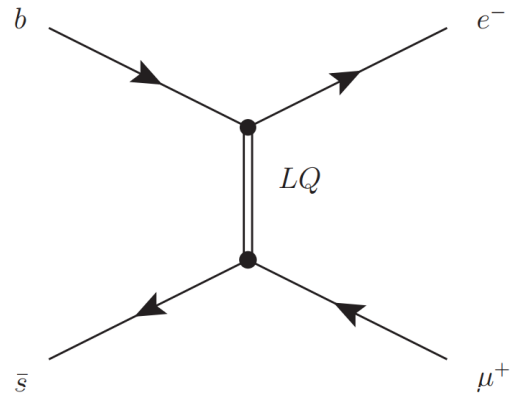
$B^0_{(s)} \to e^{\pm}\mu^{\mp}$

arXiv:1307.4889

Lepton Flavour Violation is forbidden in the SM.

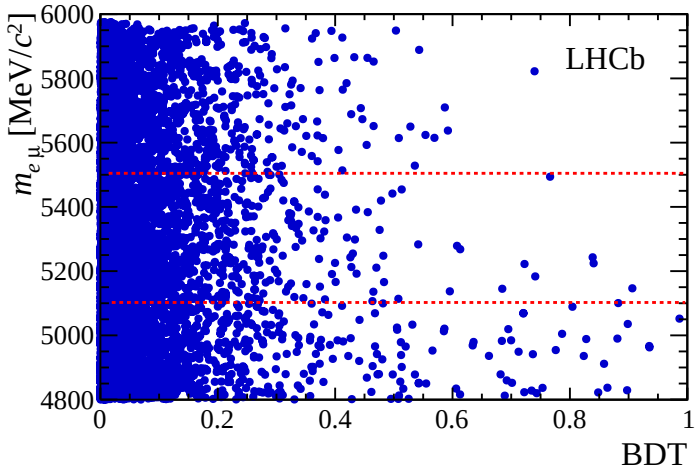
These decays are allowed in some scenarios beyond the SM that include models with

- heavy singlet Dirac neutrinos,
- SUSY models,
- Pati-Salam model with **leptoquarks**.



Analysis strategy:

- analysis of $1 fb^{-1}$ @ 7 TeV 2011 data,
- analysis similar $B^0_s \to \mu^+\mu^-$,
- events studied in $m_{e\mu} \times$ BDT plane,
- normalisation on $B^0 \to K\pi$
- CLs method for upper limits.



$B^0_{(s)} \to e^\pm \mu^\mp$ Results

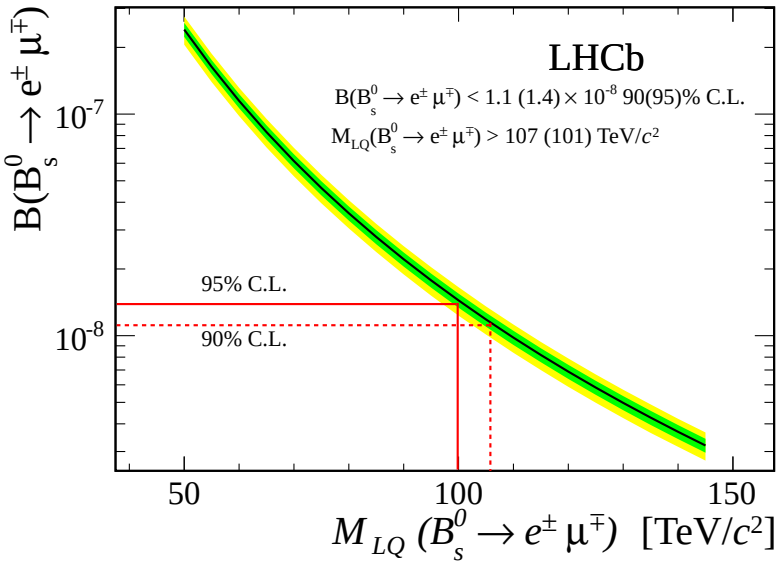
arXiv:1307.4889

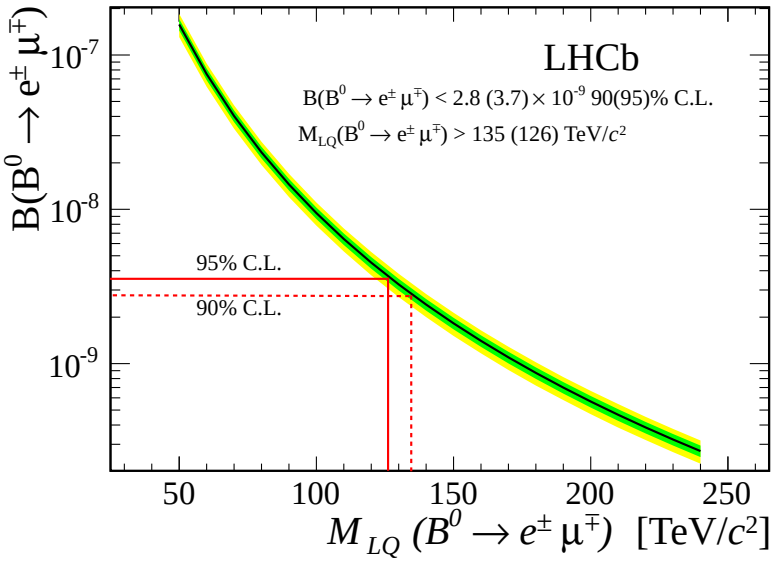
- 95% CL $\mathcal{B}$ upper limits:

		LHCb	CDF [Phys.Rev.Lett. 102(2009) 201901]
$\mathcal{B}(B^0_s \to e^+\mu^-)$	$<$	14×10^{-9}	206×10^{-9}
$\mathcal{B}(B^0 \to e^+\mu^-)$	$<$	3.7×10^{-9}	79×10^{-9}

- Leptoquark mass (see formula Phys. Rev. D 50 (1994) 6843):

		LHCb	CDF [Phys.Rev.Lett. 102(2009) 201901]
$m_{LQ}(B^0_s \to e^+\mu^-)$	$>$	$101\ TeV$	$44.9\ TeV$
$m_{LQ}(B^0 \to e^+\mu^-)$	$>$	$126\ TeV$	$53.6\ TeV$





Conclusion

LHCb is an excellent experiment for rare decay analyses.

We have:

- First evidence (4.0σ) of $B_s^0 \to \mu^+\mu^-$:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}\,\text{st}\ ^{+0.3}_{-0.1}\text{sy}) \times 10^{-9}$$

- World best upper limits:

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 7.4 \times 10^{-10}$$
$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 6.2 \times 10^{-9}$$
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-\mu^+\mu^-) < 1.6 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 6.6 \times 10^{-9}$$
$$\mathcal{B}(B_s^0 \to e^+\mu^-) < 1.4 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to e^+\mu^-) < 3.7 \times 10^{-9}$$

- A lot of other!

THANK FOR ATTENTION

Backup