Searches for very rare decays to purely leptonic final states at LHCb

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Outline

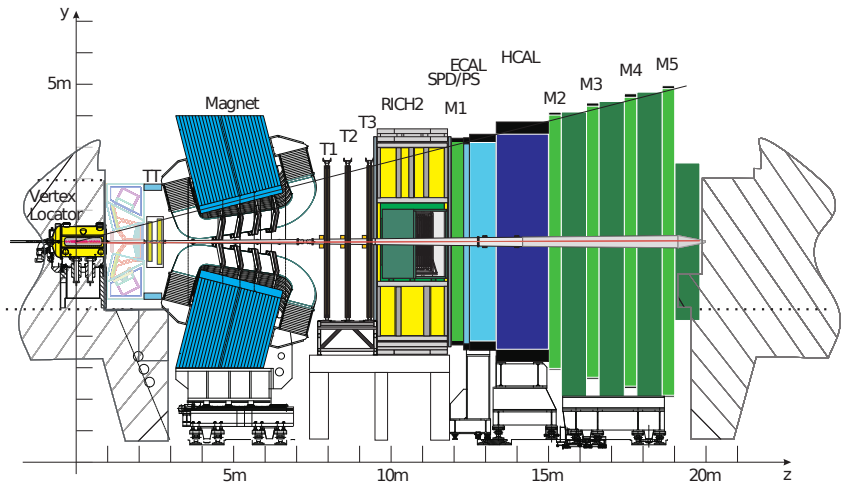
Introduction

Muons at LHCb:

- Trigger on very low transverse momentum muon (0.5 GeV)
- Momentum resolution ($0.4\% < \delta p/p < 0.6\%$)
- Muon Identification:
  $\epsilon(\mu) \simeq 97\%$
  $\epsilon(\pi \to \mu) = 1$ to 3%

Data set for the 3 analyses:

- $\sim 1\ \mathrm{fb}^{-1}$ collected in 2011
- Blind signal mass region



Outline

References: LHCb-CONF-2012-017
PRL 108 (2012) 231801, arXiv:1203.4493

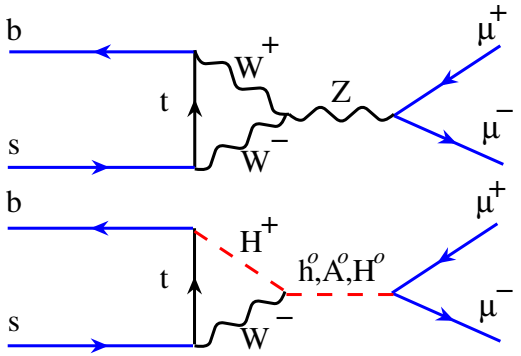
Motivation

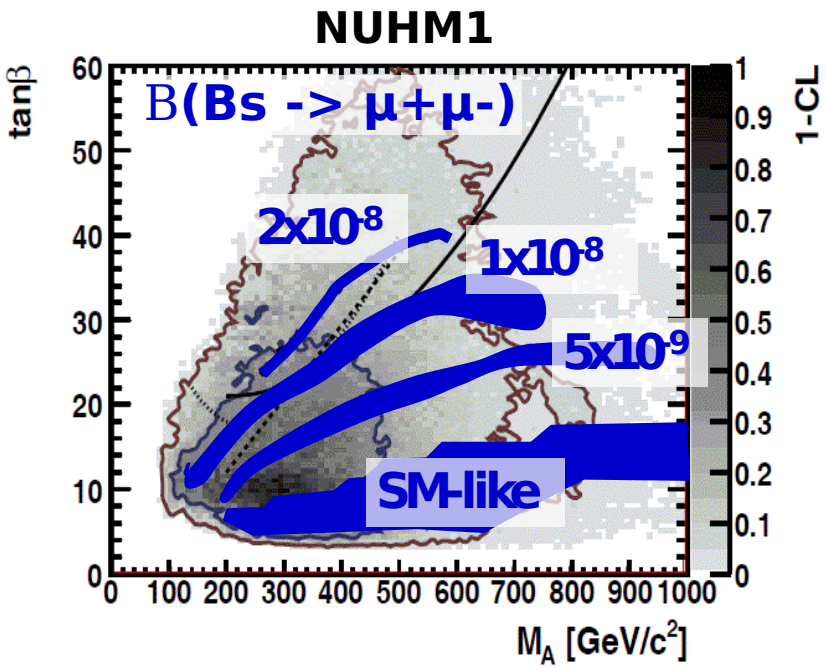
- Very suppressed in SM:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

Buras, JHEP 1010 (2010) 009,arXiv:1005.5310

- Could be enhanced in physics beyond SM





modified from arXiv:0907.5568

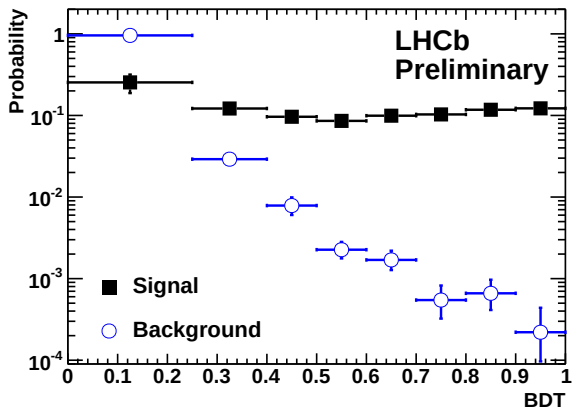
Selection and Multivariate Classifier

Event selection

- Loose selection
- Particle identification requirement to reduce peaking background from $B^0_{(s)} \to h^+(\mu^+)h'^-(\mu^-)$

Events classification in a binned 2D plane:
Multivariate (MVA) $\times$ $m_{\mu\mu}$

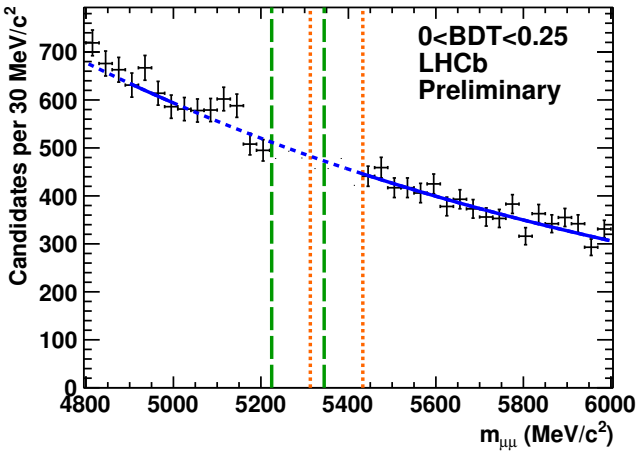
- MVA: Boosted Decision Tree (BDT)
  Inputs: 9 variables describing the topology of the candidates
- Trained on simulated data



- Calibrated on $B^0_{(s)} \to h^+h'^-$ for signal and peaking background
  on $m_{\mu\mu}$ side bands for combinatorial background

Invariant Mass

- Signal $m_{\mu\mu}$: Crystal Ball
  mean and resolution taken from data
- Combinatorial Background:
  exponential
  extrapolated from the side bands



- Peaking Background:
  -misidentification probability obtained on data in bins of p and p_T
  -applied to the spectra of a simulated $B^0_{(s)} \to h^+h'^-$ cocktail

Normalisation and Observed Data

Normalisation of the signal PDF obtained with a channel of known $\mathcal{B}$:

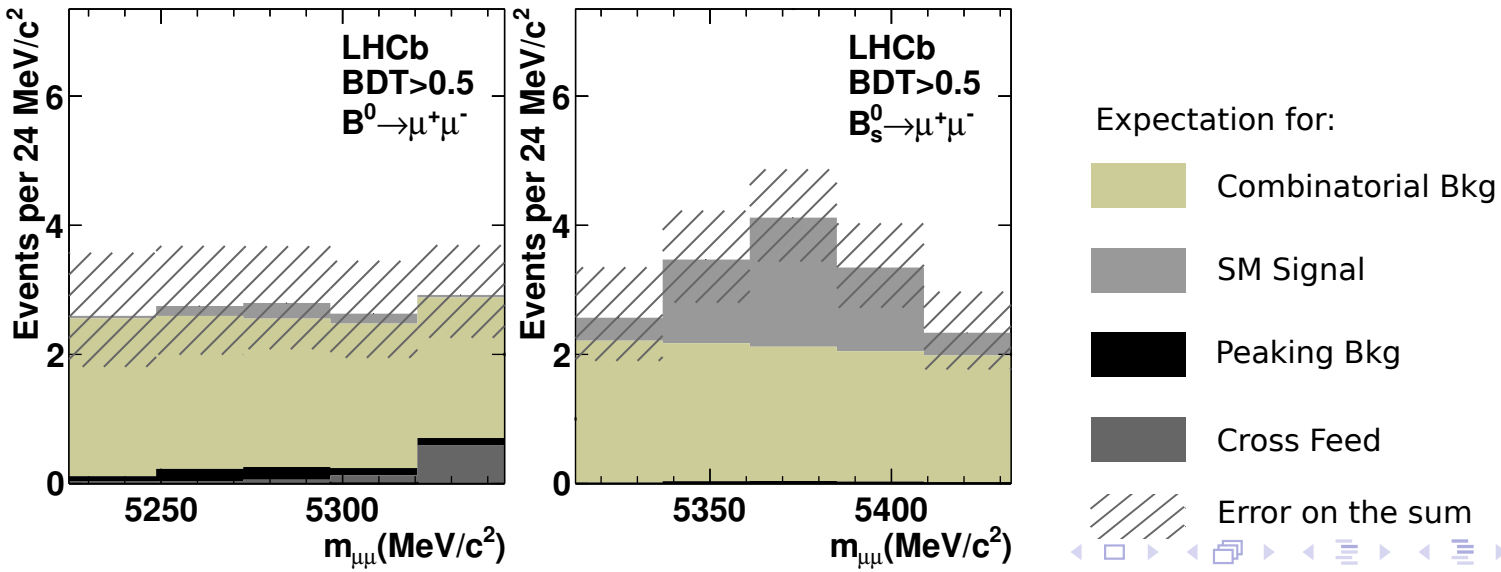
$B^0_s \to J/\psi\phi$ $B^0 \to K^+\pi^-$ $B^+ \to J/\psi K^+$

$$N_{B^0_{(s)}\to\mu^+\mu^-} = \frac{\epsilon_{sig}}{\epsilon_{norm}} \frac{f_{B_q}}{f_{norm}} \frac{N_{norm}}{\mathcal{B}_{norm}}$$

Efficiencies ($\epsilon_{sig}, \epsilon_{norm}$) obtained with a data driven method.

f_s/f_d measured at LHCb. PRD85 (2012) 032008, arXiv:1111.2357

All expectations for signal and background have been derived:



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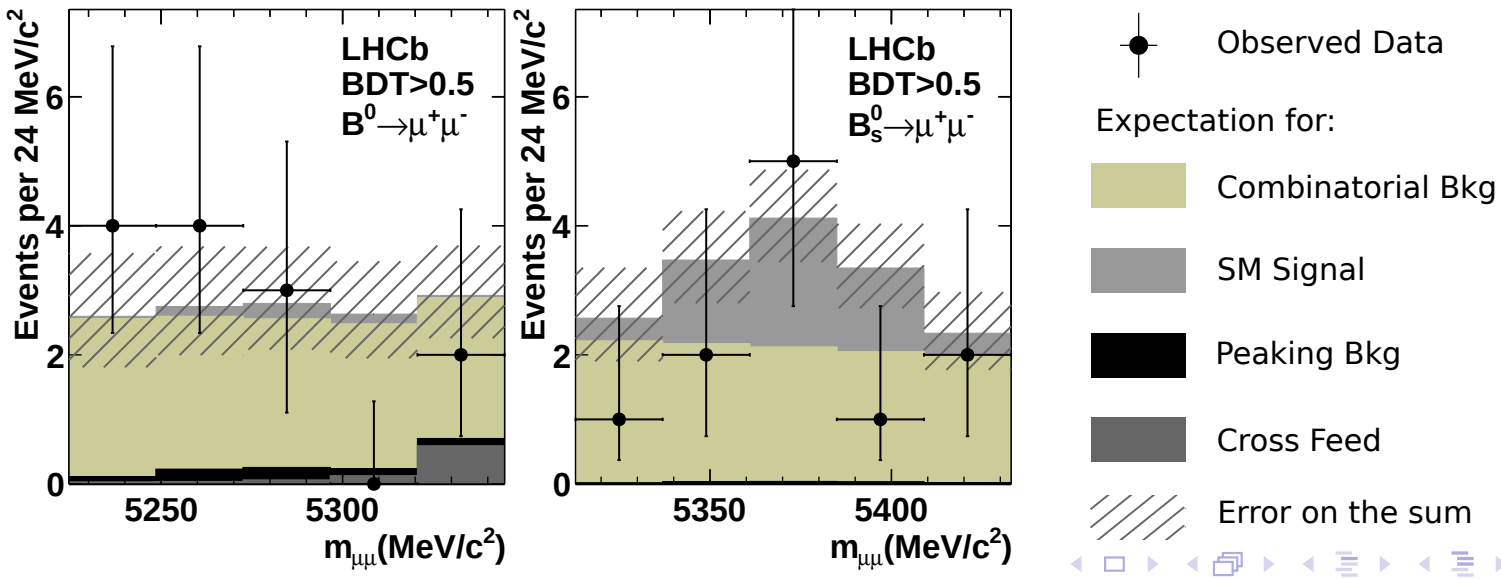
Unblind the data:

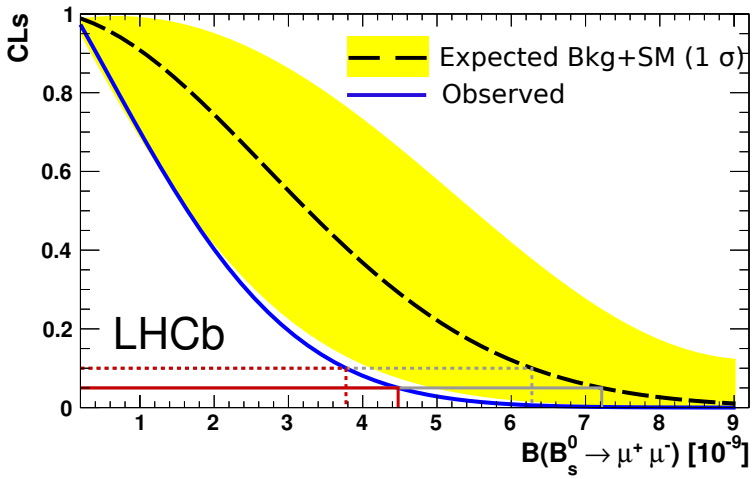


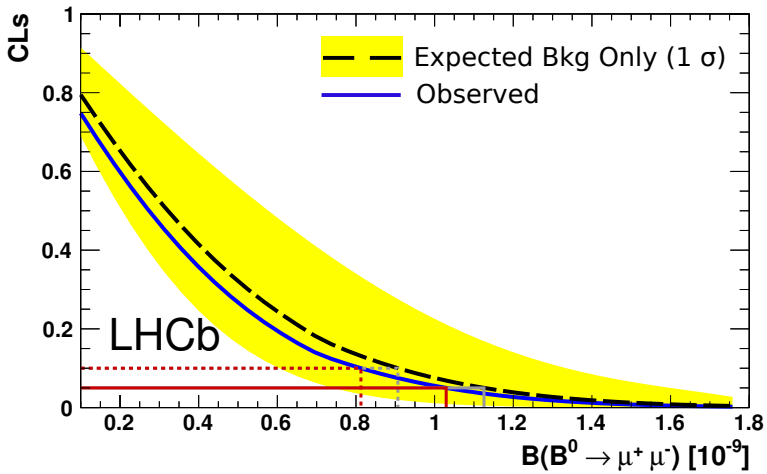
Results

Limits are extracted from data and expectations with the $\mathrm{CL_s}$ method:

$B^0_s \to \mu^+\mu^-$ upper limit (95% C.L.) **$B^0 \to \mu^+\mu^-$ upper limit (95% C.L.)**

Exp. SM+Bkg	7.2×10^{-9}	Exp. Bkg Only	1.1×10^{-9}
Obs.	4.5×10^{-9}	Obs.	1.0×10^{-9}

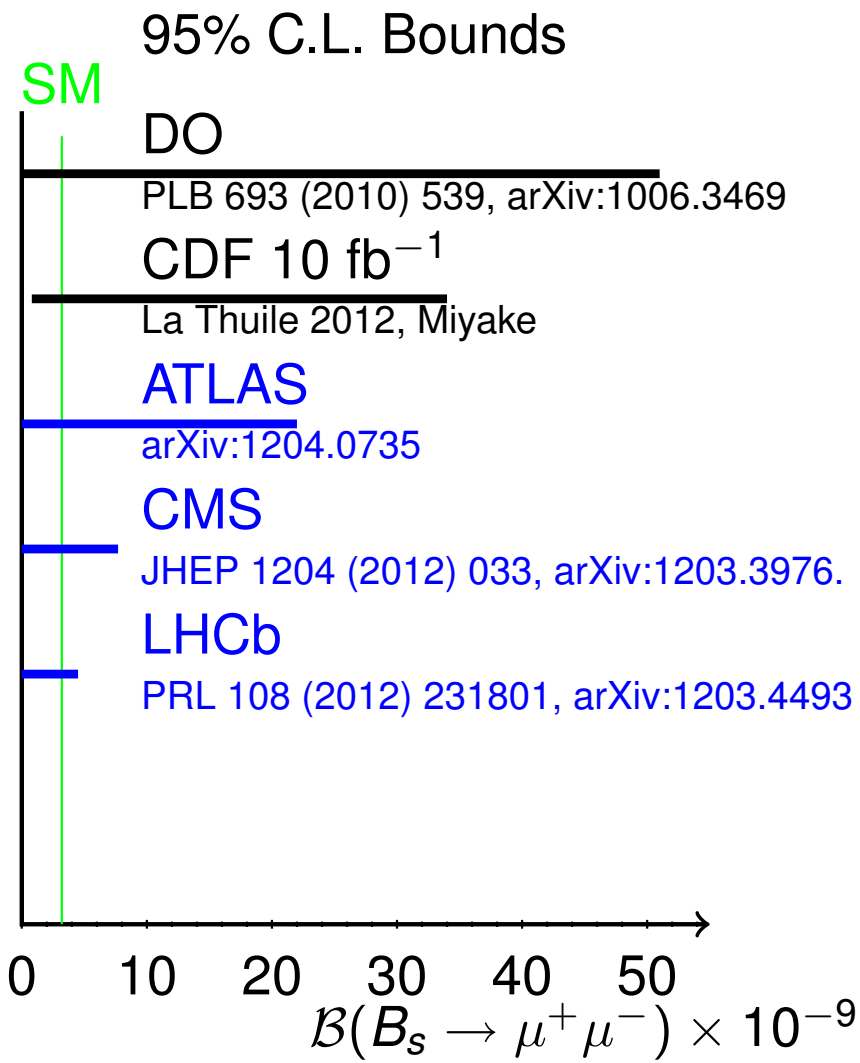




Is $B^0_s \to \mu^+\mu^-$ compatible with SM ?

- Data compatible with Bkg+SM within 1σ
- p-value (1-$\mathrm{CL_b}$) = 18%

New: Combination CMS–ATLAS–LHCb



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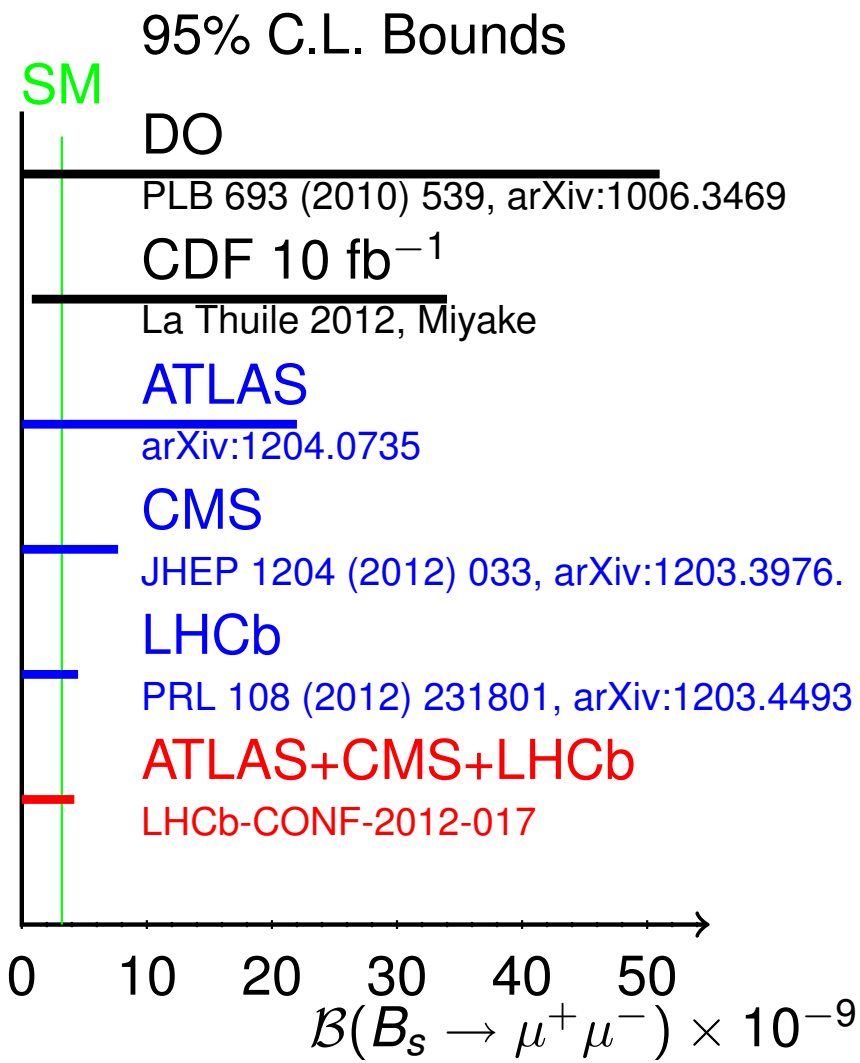


LHCb-CONF-2012-017

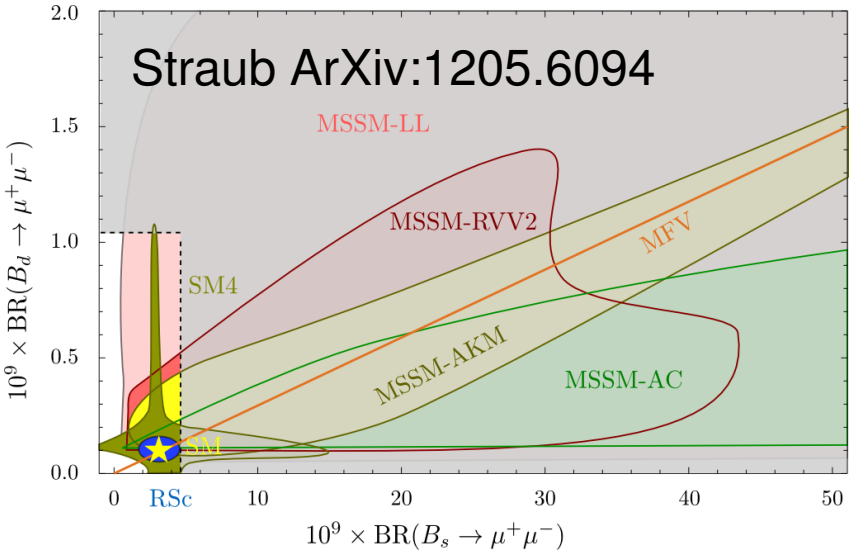
Preliminary upper limits (95%C.L.):

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) < 4.2 \times 10^{-9}$$

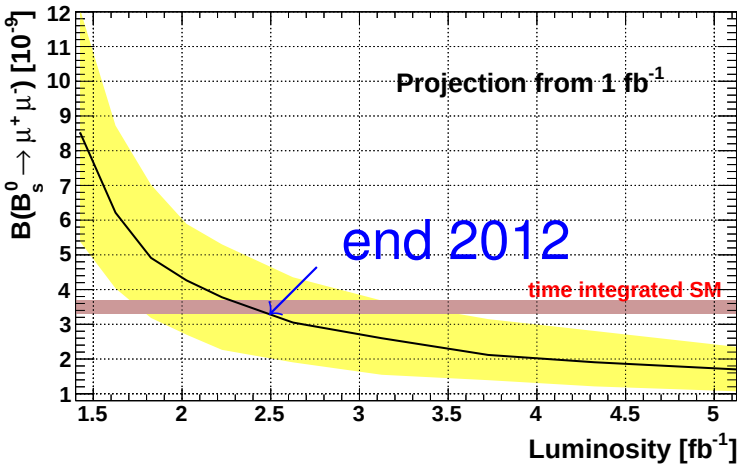
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 8.1 \times 10^{-10}$$

Implication and Prospects

LHCb results put stringent constraints on physics beyond the SM:



Prospect for a 3σ observation at LHCb:



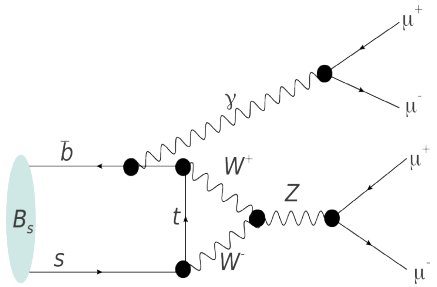
Outline

Reference: LHCb-CONF-2012-010

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

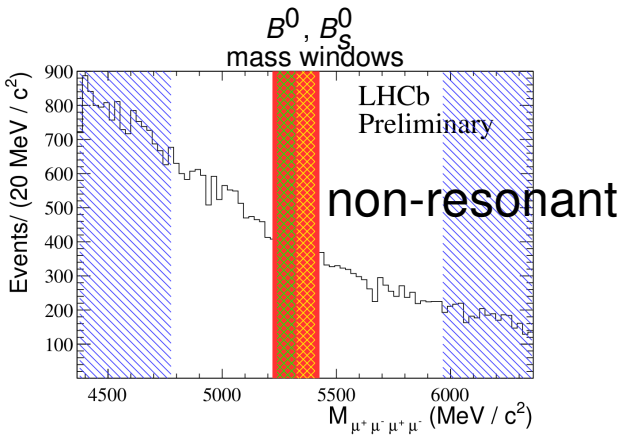
Motivations

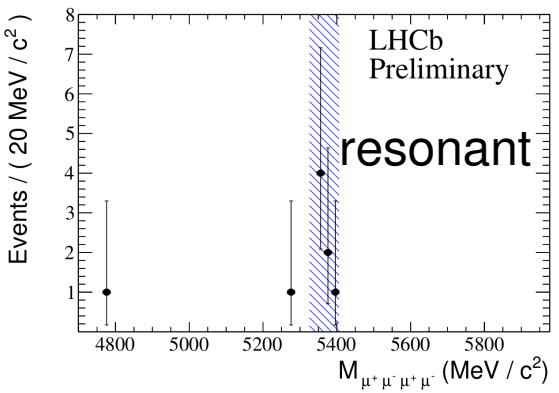
- Resonant SM mode $B^0_s \to J/\psi\phi$:
  $\mathcal{B}(B^0_s \to J/\psi\phi \to \mu\mu\mu\mu) = (2.3 \pm 0.8) \times 10^{-8}$
- Non-resonant SM mode $\mathcal{B}(B^0_{(s)} \to \mu\mu\mu\mu) < 10^{-10}$
- Could be enhanced by physics beyond SM.
  c.f. HyperCP anomaly PRL. 94 (2005) 021801



Strategy: a cut and count analysis

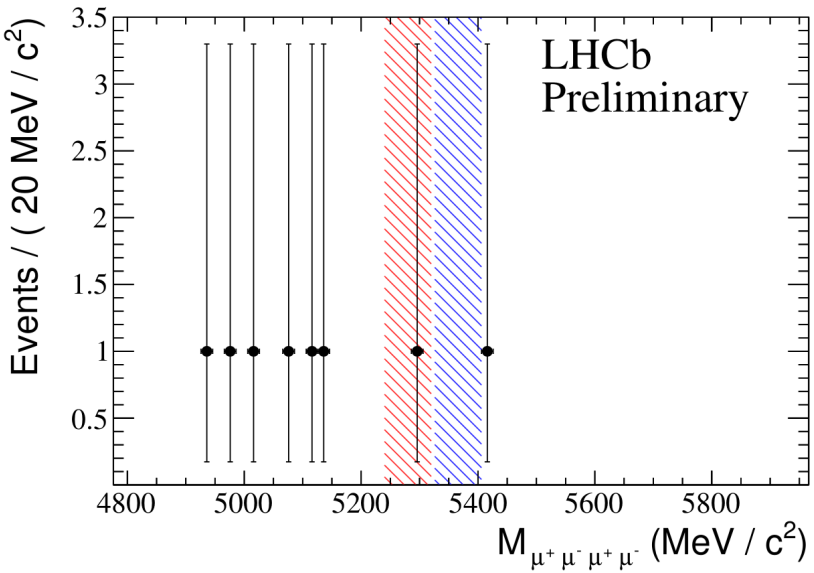
- Selection based on:
  - Quality and displacement of secondary vertex
  - Good particle identification
  - Flag of the resonant candidates
    $B^0_s \to J/\psi\phi \to \mu\mu\mu\mu$:
    used them to optimise the selection
- Normalisation to $B^0 \to J/\psi(\mu^+\mu^-)\bar{K}^{0*}(K^+\pi^-)$





Results

- Event distribution in the non-resonant mass window compatible with background expectation



- Preliminary upper limits (95%C.L.) extracted with the $\mathrm{CL_s}$ method:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 1.3 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 5.4 \times 10^{-9}$$

- First limits on these processes.

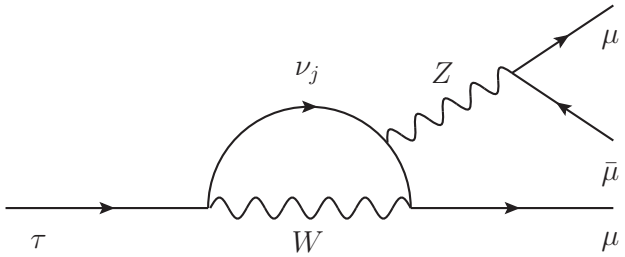
Outline

Reference: LHCb-CONF-2012-015

Motivation and Strategy

Motivation

- Lepton Flavour Violation
- $\tau^- \to \mu^+\mu^-\mu^-$ is very suppressed in SM
- Could be enhanced by physics beyond SM



Strategy very similar to $B^0_s \to \mu^+\mu^-$

- Loose selection

Motivation and Strategy

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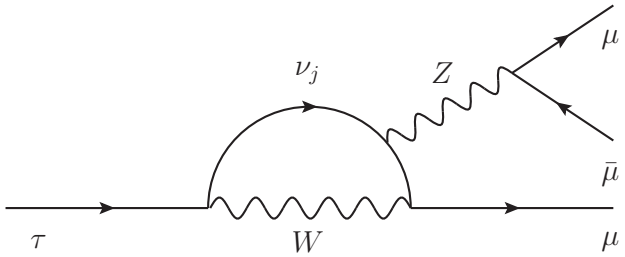

Strategy very similar to $B^0_s \to \mu^+\mu^-$

- Loose selection
- Event classification in a **3D space**:
  - Invariant mass $m_{\mu\mu\mu}$

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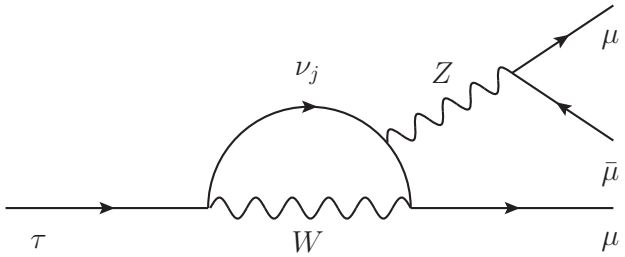
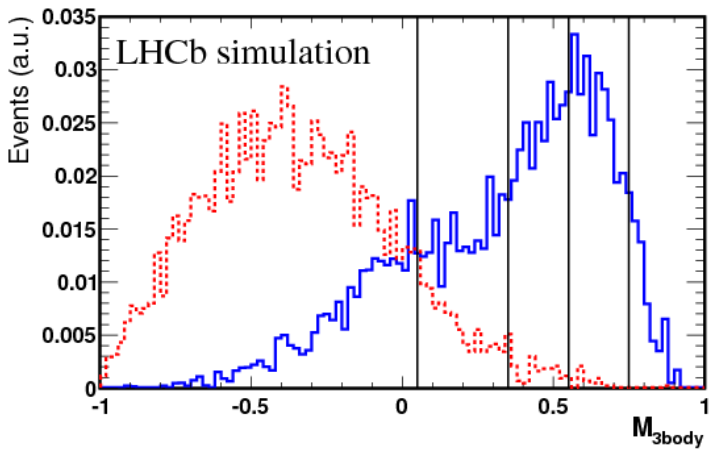


Strategy very similar to $B^0_s \to \mu^+\mu^-$

- Loose selection
- Event classification in a **3D space**:
  - Invariant mass $m_{\mu\mu\mu}$
  - Topological MVA

Bkg. Sig.



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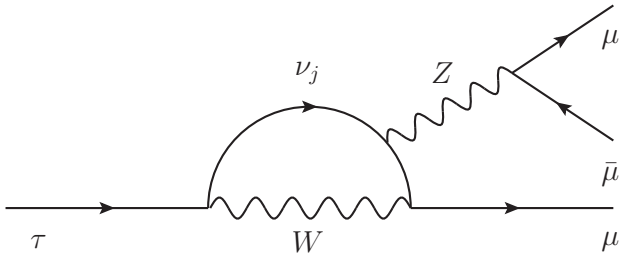
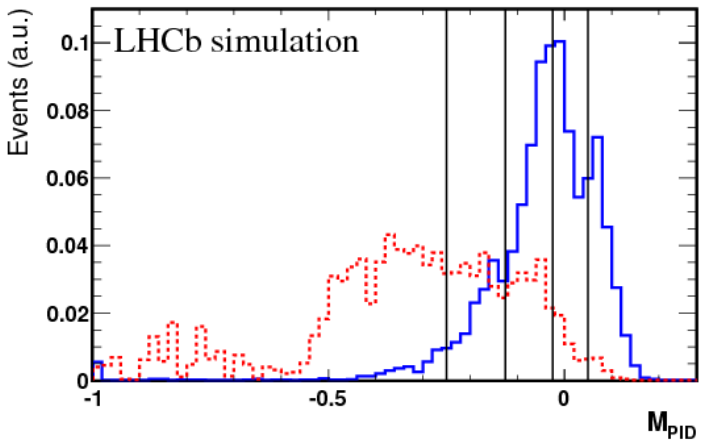


Strategy very similar to $B^0_s \to \mu^+\mu^-$

- Loose selection
- Event classification in a **3D space**:
  - Invariant mass $m_{\mu\mu\mu}$
  - Topological MVA
  - Particle identification MVA

Bkg. Sig.



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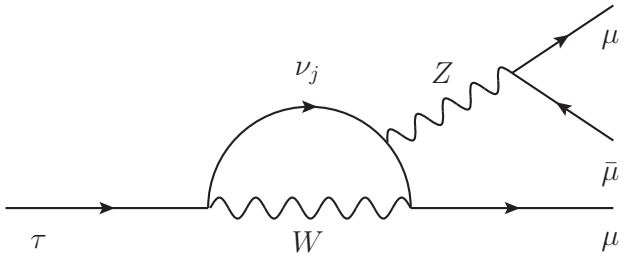
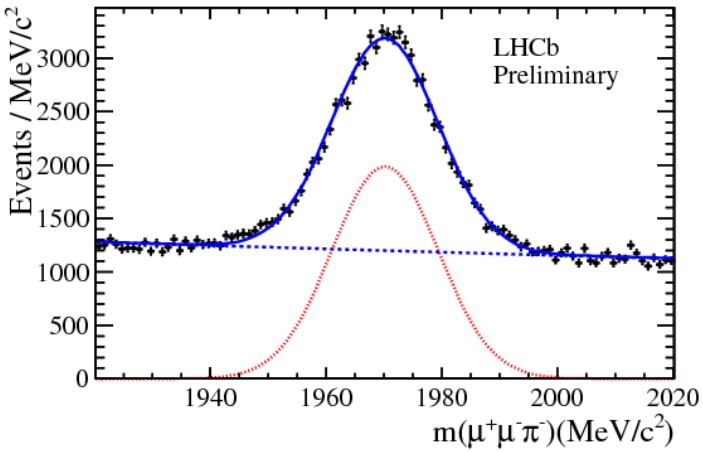


Strategy very similar to $B^0_s \to \mu^+\mu^-$

- Loose selection
- Event classification in a **3D space**:
  - Invariant mass $m_{\mu\mu\mu}$
  - Topological MVA
  - Particle identification MVA
- Normalisation to $D_s^- \to \phi(\mu^+\mu^-)\pi^-$



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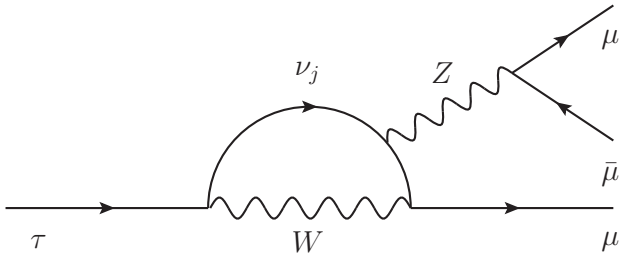
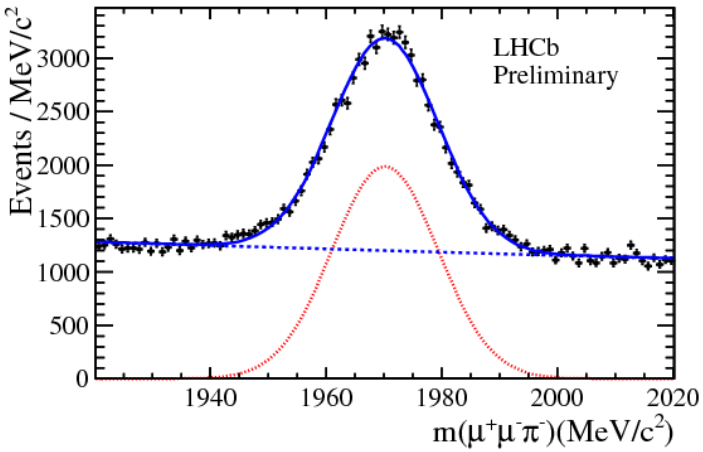


Strategy very similar to $B^0_s \to \mu^+\mu^-$

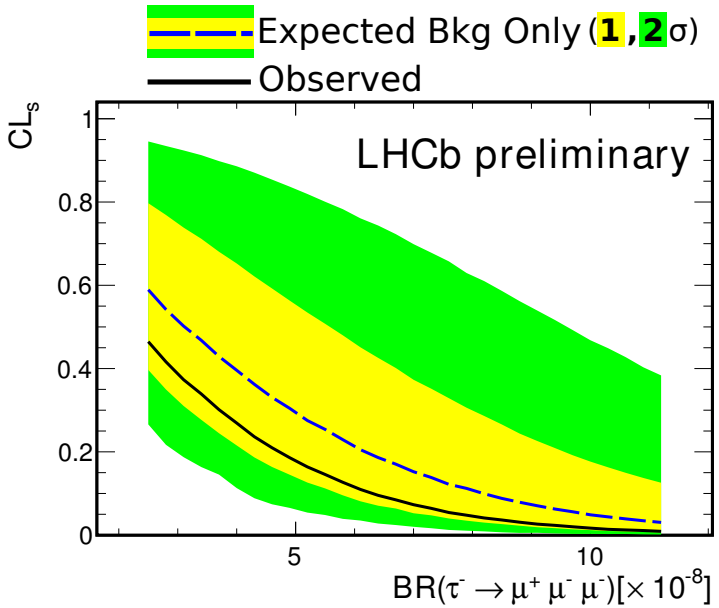
- Loose selection
- Event classification in a **3D space**:
  - Invariant mass $m_{\mu\mu\mu}$
  - Topological MVA
  - Particle identification MVA
- Normalisation to $D_s^- \to \phi(\mu^+\mu^-)\pi^-$
- Limits extracted with the $\mathrm{CL_s}$ method



Results

- Preliminary upper limits 95 (90)% C.L. extracted using the $\mathrm{CL_s}$ method

$$\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) < 7.8\ (6.3) \times 10^{-8}$$

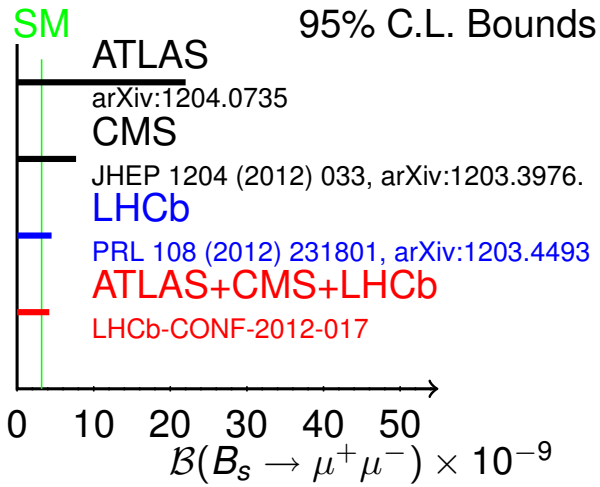


- Results comparable with Belle PLB 687 (2010) 139, arXiv:1001.3221
  $\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) < 2.1 \times 10^{-8}$ at 90% C.L.

Summary

- LHC (LHCb) searches for $B^0_{(s)} \to \mu^+\mu^-$:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) < 4.2\ (4.5) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 8.1\ (10) \times 10^{-10}$$



- Very first limits (preliminary) on the $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ processes:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 1.3 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 5.4 \times 10^{-9}$$

- First limits at hadron collider (preliminary) on $\tau^- \to \mu^+\mu^-\mu^-$:

$$\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) < 7.8 \times 10^{-8}$$

- All analyses performed with 1 fb^{-1}, outlook for 2012: another 1.5 fb^{-1}!