Dipartimento di Scienze di Base e Applicate per l'Ingegneria

Sapienza Università di Roma

Rencontres de Moriond EW 2013

Latest results on $B_{(s)}^0 \to \mu\mu$ and other very rare decays

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on behalf of the LHCb collaboration

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A rare beauty!

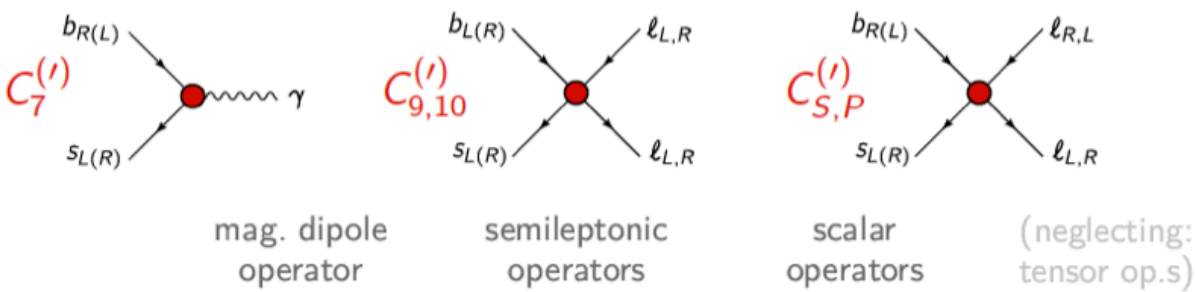
- LHCb pursues a physics program aiming to a precise validation of SM predictions and **indirect NP searches** in the heavy flavor sector, which is fully complementary to direct NP searches done with GP experiments
- A key role is played by B decays occurring trough ΔB = ΔS = 1 transitions, which are highly suppressed in SM (FCNC) and are thus sensitive probes of NP

Two distinct theoretical approaches can be followed:

model-independent

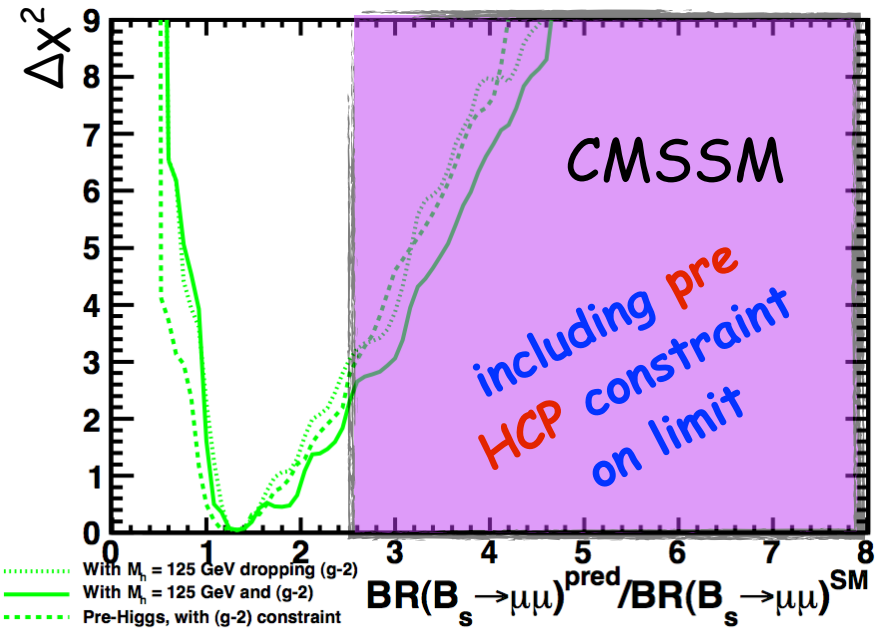
$$\mathscr{H}_{\text{eff}}^{\Delta F=1} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum (C_i \mathcal{O}_i + C_i' \mathcal{O}_i')$$

Wilson coefficient — Dimension-6 operator



use rare decays to set constraints on Wilson coefficients

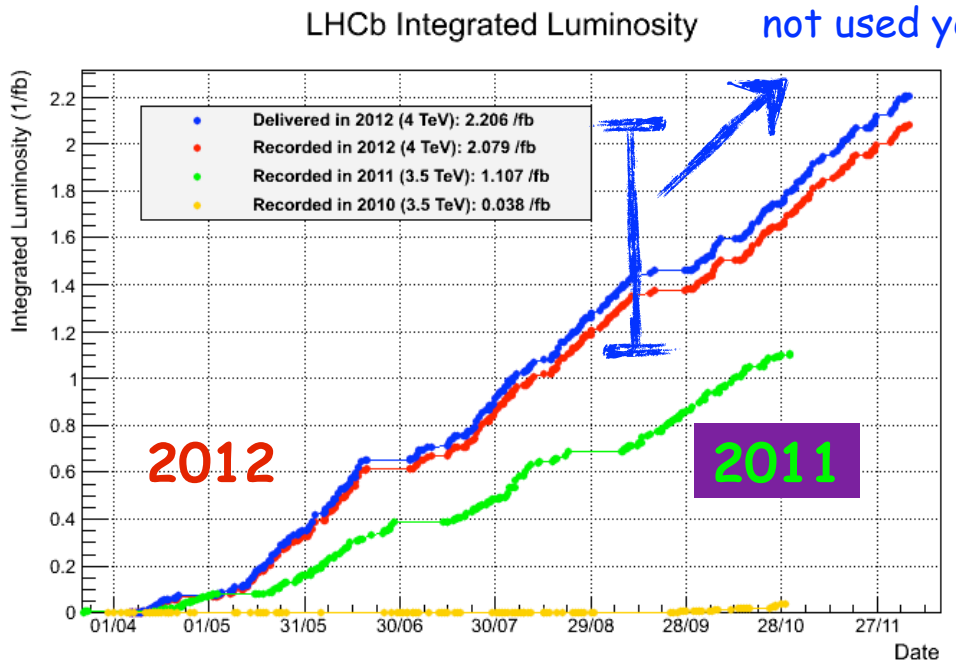
model-dependent



LHCb: a golden mine for rare B decays

- Rare decays:
  - Radiative decays: ($K^{*0}\gamma$, $\phi\gamma$) [Nucl. Phys., Sect. B 867 (2013), pp. 1-18]
  - $B \to Xll$ decays: $B \to K^{(*)}\mu\mu$, $B \to \phi\mu\mu$ [Phys. Rev. Lett. 110, 031801 (2013), JHEP 02 (2013) 105]; $B \to \pi\mu\mu$ [JHEP 12 (2012) 125]
  - Ongoing analyses: $D^0 \to \mu\mu$, $\tau \to 3\mu$, $B_{(s)}^0 \to e\mu$
- In this presentation:
  - $B \to 4\mu$ and $K_s \to \mu\mu$: **latest** results on 1 fb^{-1} 2011 dataset
  - $B_{(s)}^0 \to \mu\mu$. LHC combination (Jun '12): $BR(B^0_s \to \mu^+\mu^-) < 4.2\times10^{-9}$ @ 95% CL. Today I present here the **latest** result on 2.1 fb^{-1} 2011/12 dataset (published in Jan '13)

1 fb^{-1} collected but not used yet



1 fb^{-1} at 7 TeV (2011) **2 fb^{-1} at 8 TeV (2012): only ~50% (1.1 fb^{-1}) used for published results so far**

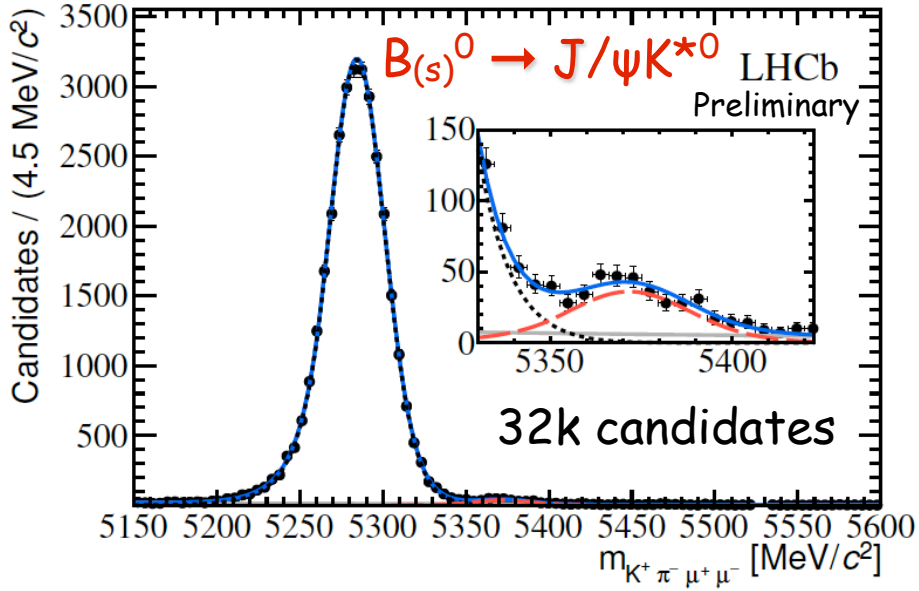
$B_{(s)}^0 \to 4\mu$

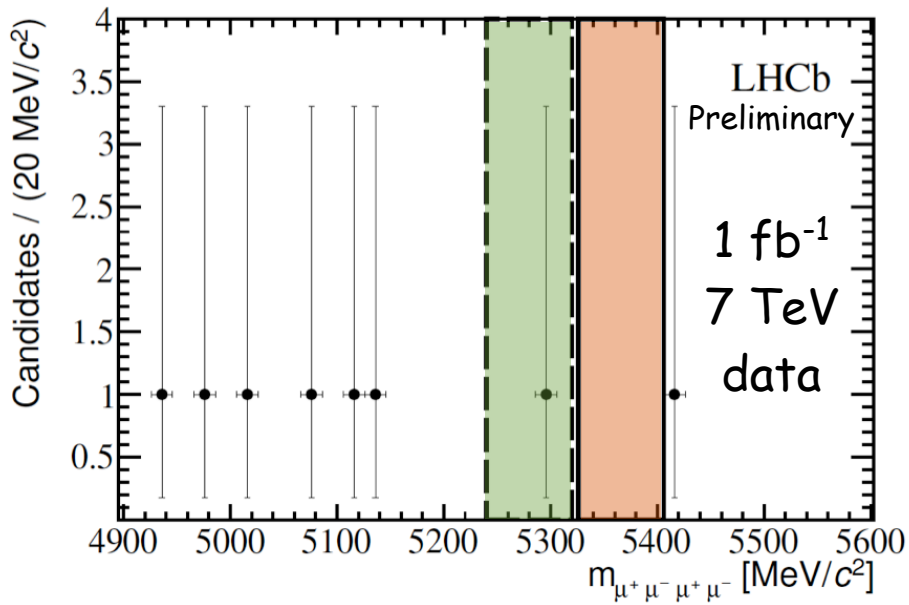
LHCb-PAPER-2012-049

- $B \to 4\mu$ decays in SM:
  - Non resonant $BR(B_{(s)}^0 \to \mu^+\mu^-\ \gamma^*(\mu^+\mu^-)) < 10^{-10}$ [D. Melikhov and N. Nikitin, Phys. Rev. D 70 (2004) 114028]
  - $B_s^0 \to J/\psi\varphi$ (control) channel = $2.3 \pm 0.9\ 10^{-8}$ [Phys. Rev. D86 (2012) 010001]
- In MSSM: sensitive to new scalar (S) and pseudoscalar (P) sGoldstino particles
- Normalization on $B^0 \to J/\psi(\to\mu\mu)K^{*0}(\to K\pi)$
- Result: observed 1 event in B^0 window, 0 in B_s^0. Consistent with expected bkg.
- [preliminary] Limits at 95(90)% C.L.:
  - $BR\ (B_s^0 \to 4\mu) < 1.6\ (1.2) \cdot 10^{-8}$
  - $BR\ (B^0 \to 4\mu) < 6.6\ (5.3) \cdot 10^{-9}$

Paper in preparation

First experimental limit to date





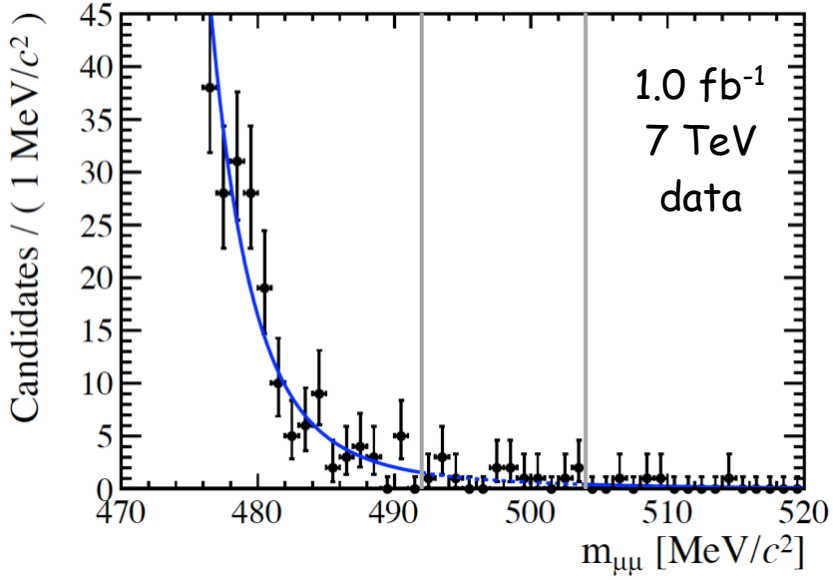
$K_S \to \mu\mu$

[JHEP 01 (2013) 090]

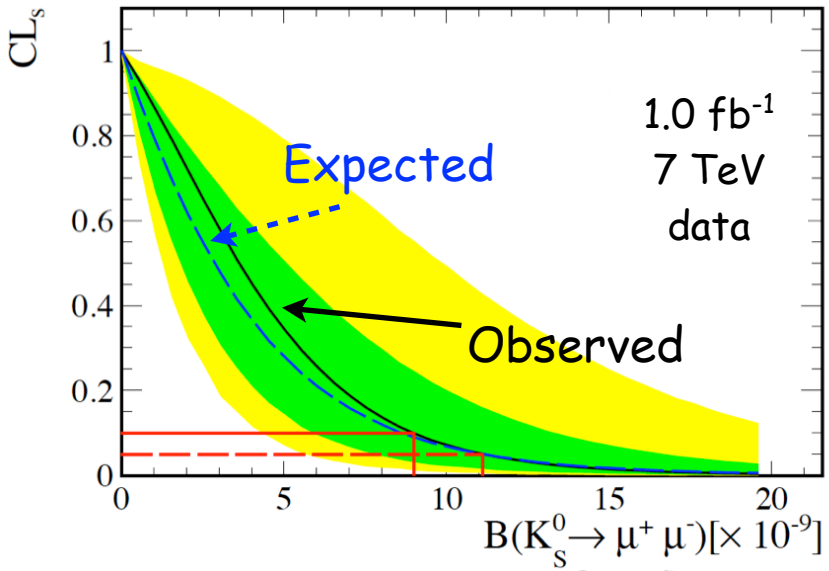
- The SM prediction for $BR(K_S \to \mu^+\mu^-)$ is $5.1 \pm 1.5\ 10^{-12}$ [NuPh B366(1991) 189; JHEP 0401 (2004) 009]. Best exp. limit ('73) < $3.2\ 10^{-7}$ @ 90% CL [PL B44 (1973) 217]
  - Comparison with $K_L \to \mu^+\mu^-$ can reveal effects due to new light scalars and bounds at 10^{-11} level constrain CP violating phase from $s \to d\bar{l}l$ (E.g.: $K \to \pi\nu\bar{\nu}$)

Limit is computed using the CL_s (modified frequentist) approach [J. Phys. G28 (2002) 2693]

combinatorial (exp) + $K_S \to \pi\pi$ misidentified bkg from mass sidebands



Normalization channel: $K_S \to \pi\pi$



Results: BR $(K_S^0 \to \mu^+\mu^-) < 11(9) \cdot 10^{-9}$ at 95(90)% C.L.

$B_{(s)}^0 \to \mu\mu$ in the Standard Model

FCNC process → very small branching fraction:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)^{t=0} = (3.23 \pm 0.27) \cdot 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)^{t=0} = (1.07 \pm 0.10) \cdot 10^{-10}$$

Buras et al., arXiv:1208.0934

The authors used f_{Bs} = (227±8) MeV, averaging from recent lattice inputs

Mc Neile et al., PRD 85 (2012) 031503 Na et al., arXiv:1202.4914 Bazavov et al., arXiv:1112.3051

To compare with experiment need a time integrated branching fraction, taking into account the finite width of the B^0_s system:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)^{\langle t \rangle} = \frac{1}{1-y_s} \cdot \mathcal{B}(B_s^0 \to \mu^+\mu^-)^{t=0}$$

$y_s = \Delta\Gamma_s/2\Gamma_s$

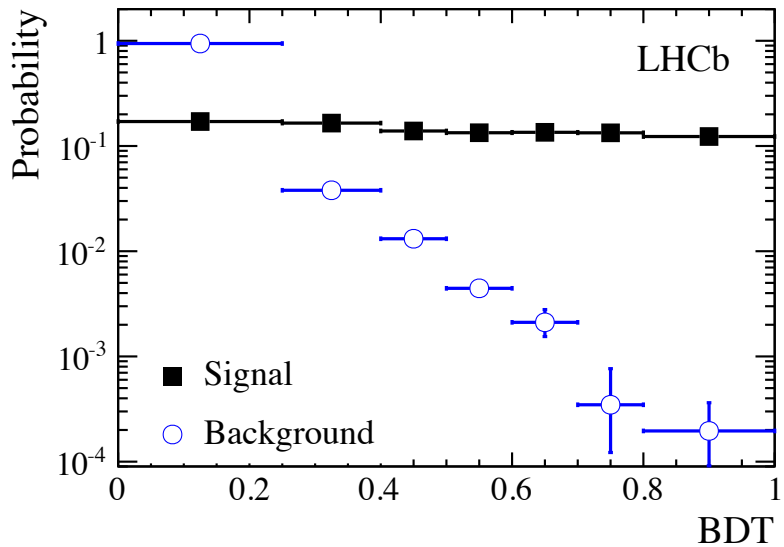
$$= \boxed{(3.54 \pm 0.30) \cdot 10^{-9}}$$

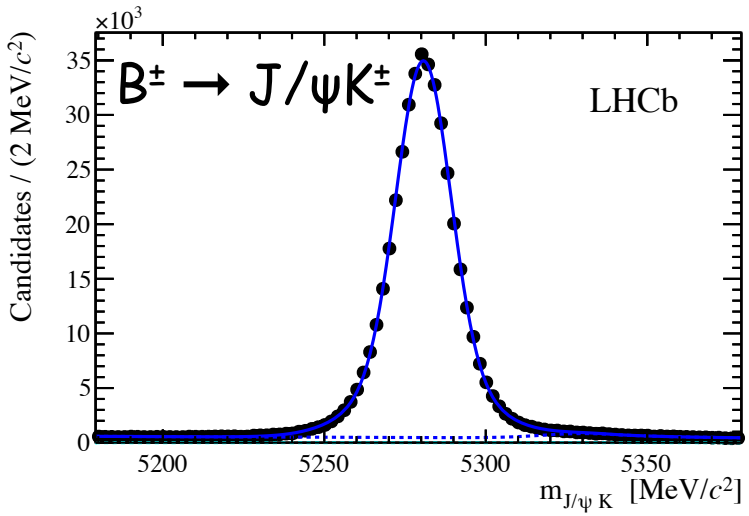
De Bruyn et al., PRL 109, 041801 (2012)
uses LHCb-CONF-2012-002

$B_{(s)}^0 \to \mu\mu$ analysis

Performed on full 2011 [@ 7 TeV] data (reanalyzed, with improved bkg evaluation), and **1.1 fb^{-1} of 2012** [@ 8 TeV] **sample (~50% of available statistics)**: 8 TeV data signal region kept blind until analysis completion

- Signal/Background separation by invariant di-μ mass (IM) and a multivariate (MVA) classifier (Boosted Decision Trees, BDT)
  - BDT training on MC signal and bkg
  - BDT calibration on data: for signal used exclusive $B^0_{(s)} \to h^+h'^-$ channels ($h=\pi$, K)
- Normalization with $B^\pm \to J/\psi K^\pm$ & $B^0 \to K^+\pi^-$
  - $B^0_s \to J/\psi\varphi$ was dropped for 2012 data as third normalization channel, but used to check $\sqrt{s}$ dependence of f_s/f_d
- Analysis performed in 7(8) bins of BDT and 9 bins of IM for the analysis of 8(7) TeV data





Normalization

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}}\,\epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}}\,\epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_q^0}} \times \frac{N_{B_q^0\to\mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha_{\mathrm{cal}} \times N_{B_q^0\to\mu^+\mu^-}$$

Evaluated from MC, cross-checked with data

Measured on data

Ratio of probabilities for a b quark to hadronize to a given meson

Combined result at 7 TeV

$$f_s/f_d = 0.256 \pm 0.020$$

[PRD85 (2012) 032008; LHCB-PAPER-2012-037 submitted to JHEP]

checked on 2012 data: no significant change → used same value for 2011 and 2012

$B^{\pm} \to J/\psi K^{\pm}$ and $B^0 \to K^+\pi^-$ channels give consistent results, and are averaged

$$\alpha_{B_s^0\to\mu^+\mu^-} = (2.80 \pm 0.25) \times 10^{-10}$$
$$\alpha_{B^0\to\mu^+\mu^-} = (7.16 \pm 0.34) \times 10^{-11}$$

8 TeV data

Assuming SM rates, after selection we expect in 7 TeV + 8 TeV data (1.0 + 1.1 fb^{-1}) ~11+13 $B^0_s \to \mu^+\mu^-$ and ~1.3+1.5 $B^0 \to \mu^+\mu^-$ **in signal region ($m(B^0_{(s)})\pm 60$ MeV/c^2)**

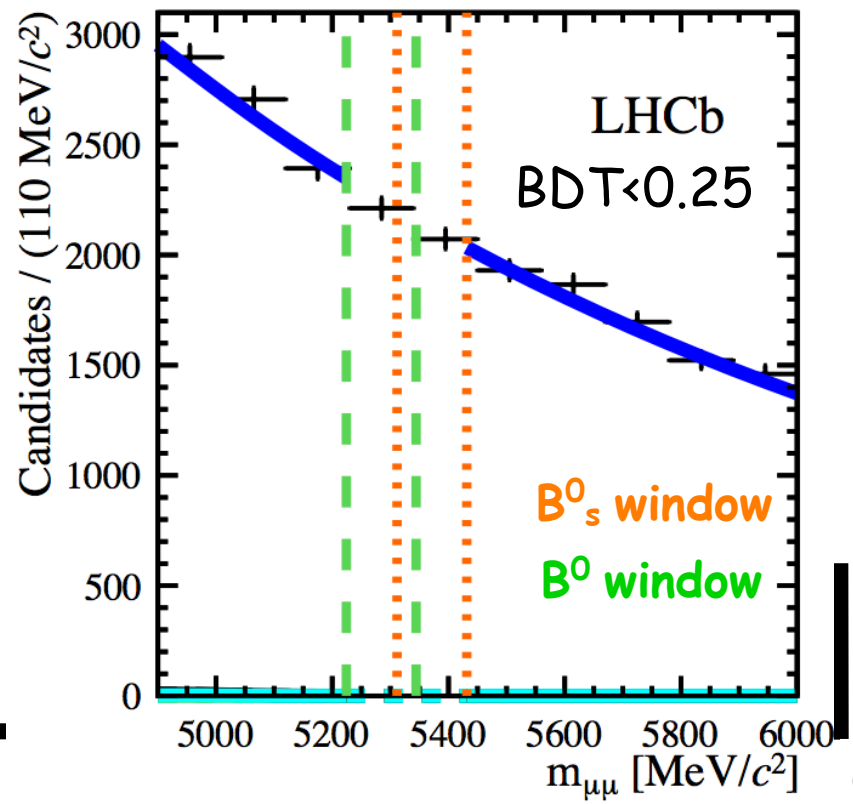
Combinatorial background

The main background source in the $B^0_s \to \mu^+\mu^-$ signal window, $m(B^0_s) \pm 60$ MeV/c^2, **is combinatorial from $bb \to \mu^+\mu^- X$**

For the CL_s computation, the expected background yield in the signal region is evaluated from a **fit to the mass sidebands**, for each BDT bin separately

An exponential shape is used to model the combinatorial bkg

For BDT values <0.5 this is **by far the dominant bkg source**



Exclusive background sources

Various exclusive decays have been studied which are able to fake a signal by misID of either one or two hadrons or by two muons coming from the same vertex:

$B^0 \to \pi^-\mu^+\nu_\mu$ $\quad B^0_s \to K^-\mu^+\nu_\mu$ $\quad B^{+(0)} \to \pi^{+(0)}\mu^+\mu^-$

$\Lambda^0_b \to p\mu^-\nu_\mu$ $\quad B^0_{(s)} \to h^+h'^-$ $\quad B^+_c \to J/\psi(\mu^+\mu^-)\mu^+\nu_\mu$

(other channels like $B \to (D \to \mu X)\mu X$, $B \to \tau\tau X$ being negligible in [4900-6000] MeV/c^2 ...)

These background sources can affect the result in two ways:

1) non negligible contribution in the signal mass window, $m(B^0_{(s)})\pm 60$ MeV/c^2
   only $B^0_{(s)} \to h^+h'^-$ has to be accounted for (mainly for B^0): take $K\to\mu$ **and $\pi\to\mu$ from data, fold with MC spectra.** In the full BDT range, for 8 TeV data we get:

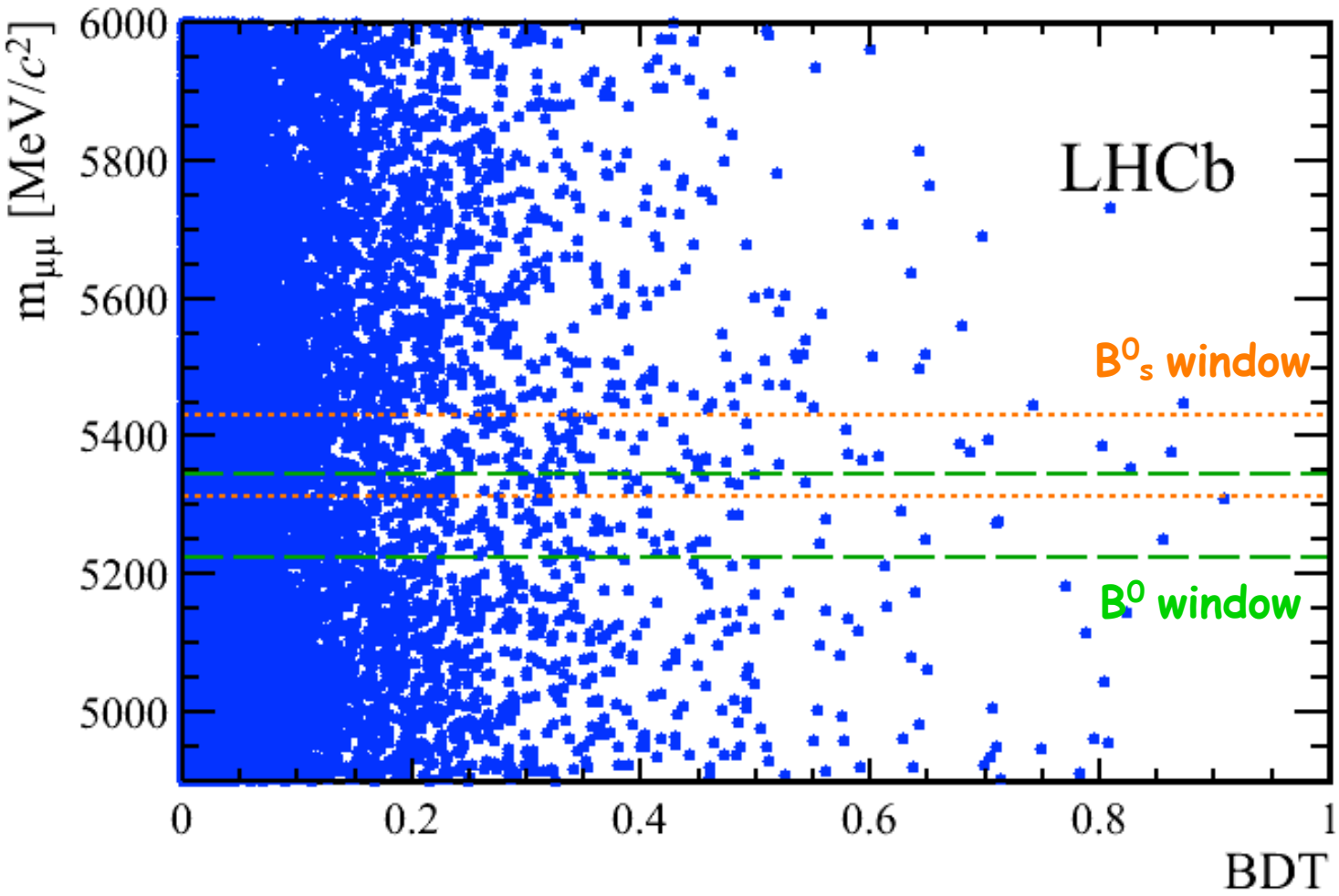
   Events in B^0_s mass window $0.76^{+0.26}_{-0.18}$ $\quad$ Events in B^0_d mass window $4.1^{+1.7}_{-0.8}$

2) mass shape different from exponential → bias in the combinatorial background interpolation from mass sidebands

Three dominant components have been added: $B^0 \to \pi^-\mu^+\nu_\mu$ $B^{+(0)} \to \pi^{+(0)}\mu^+\mu^-$ $B^0_{(s)} \to h^+h'^-$

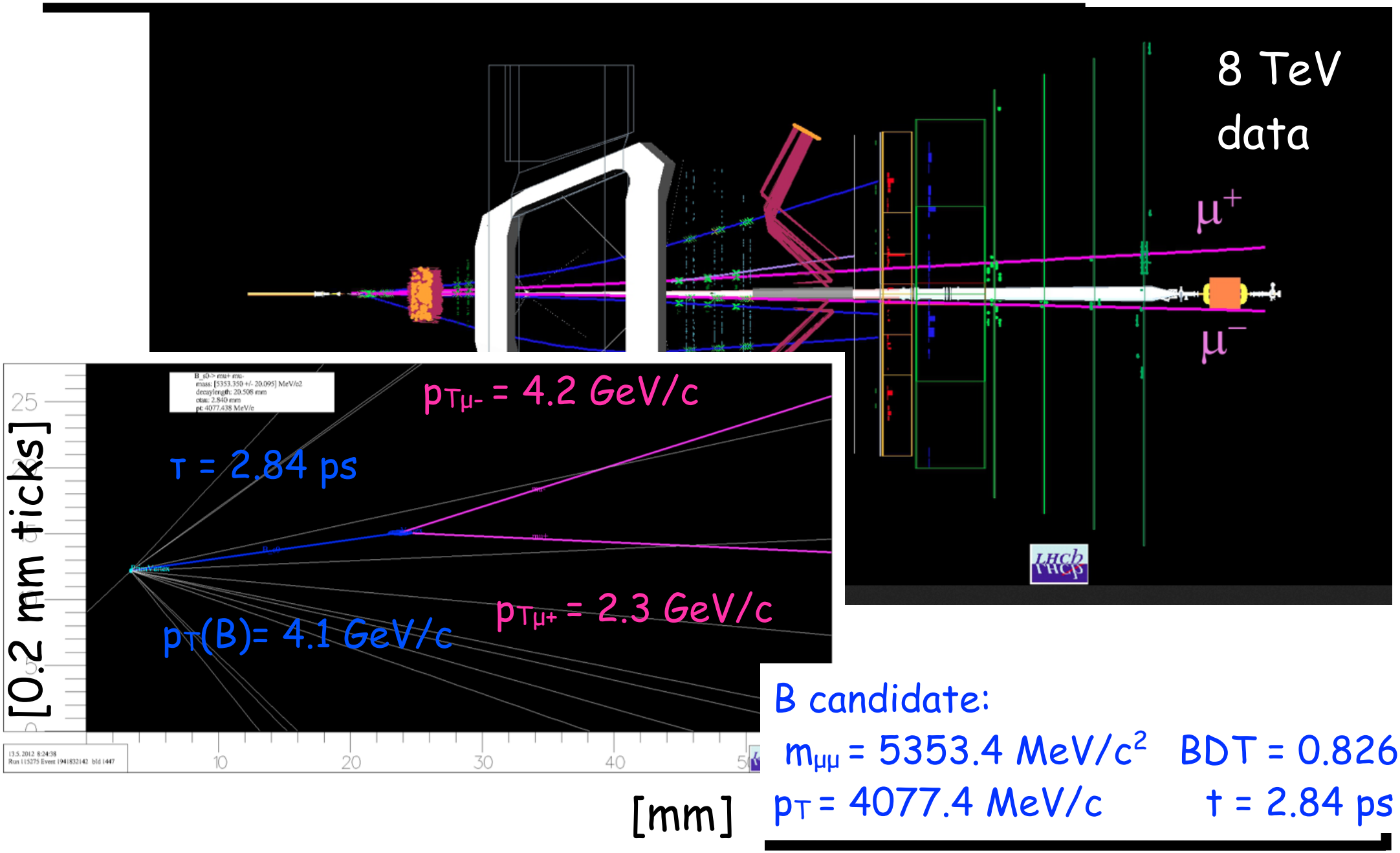
Unblinded 8 TeV data

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. **110**, 021801 (2013)



$B^0_s \to \mu^+\mu^-$ candidate

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. **110**, 021801 (2013)



B candidate:

$m_{\mu\mu}$ = 5353.4 MeV/c^2 BDT = 0.826

p_T = 4077.4 MeV/c τ = 2.84 ps

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

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. **110**, 021801 (2013)

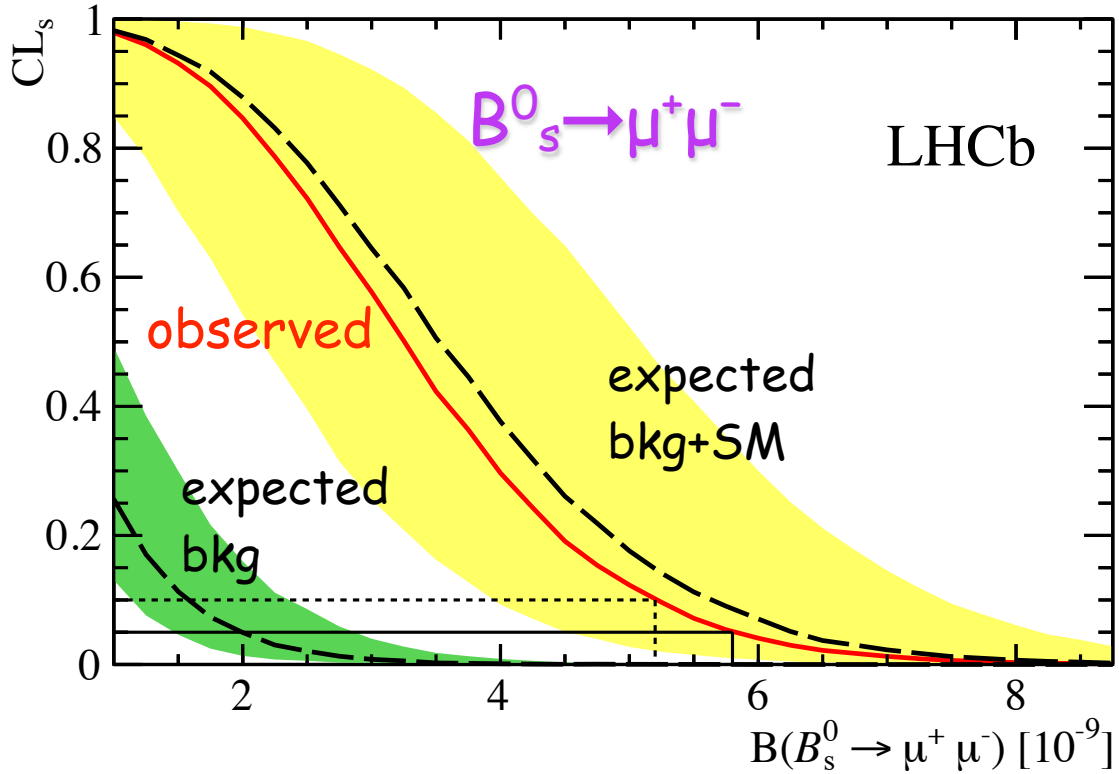
Use CLs method to evaluate compatibility with background only (CL_b) and signal + background hypotheses (CL_{s+b}); **the 95% CL upper limit is defined at $CL_s = CL_{s+b}/CL_b = 0.05$**

$B^0 \to \mu^+\mu^-$:

obs BR limit < 9.4×10^{-10} @ 95% CL

exp BR limit < 7.1×10^{-10} @ 95% CL

Compatibility with bkg only hypothesis: p-value = $1-CL_b$ = 0.11



$B^0_s \to \mu^+\mu^-$:

bkg only p-value= 5.3×10^{-4}

(3.5 σ excess)

double-sided limit: $1.1 \times 10^{-9} < B(B^0_s \to \mu^+\mu^-) < 6.4 \times 10^{-9}$ at 95% CL

where the lower and upper limits are evaluated at CL_{s+b} = 0.975 and CL_{s+b} = 0.025, respectively

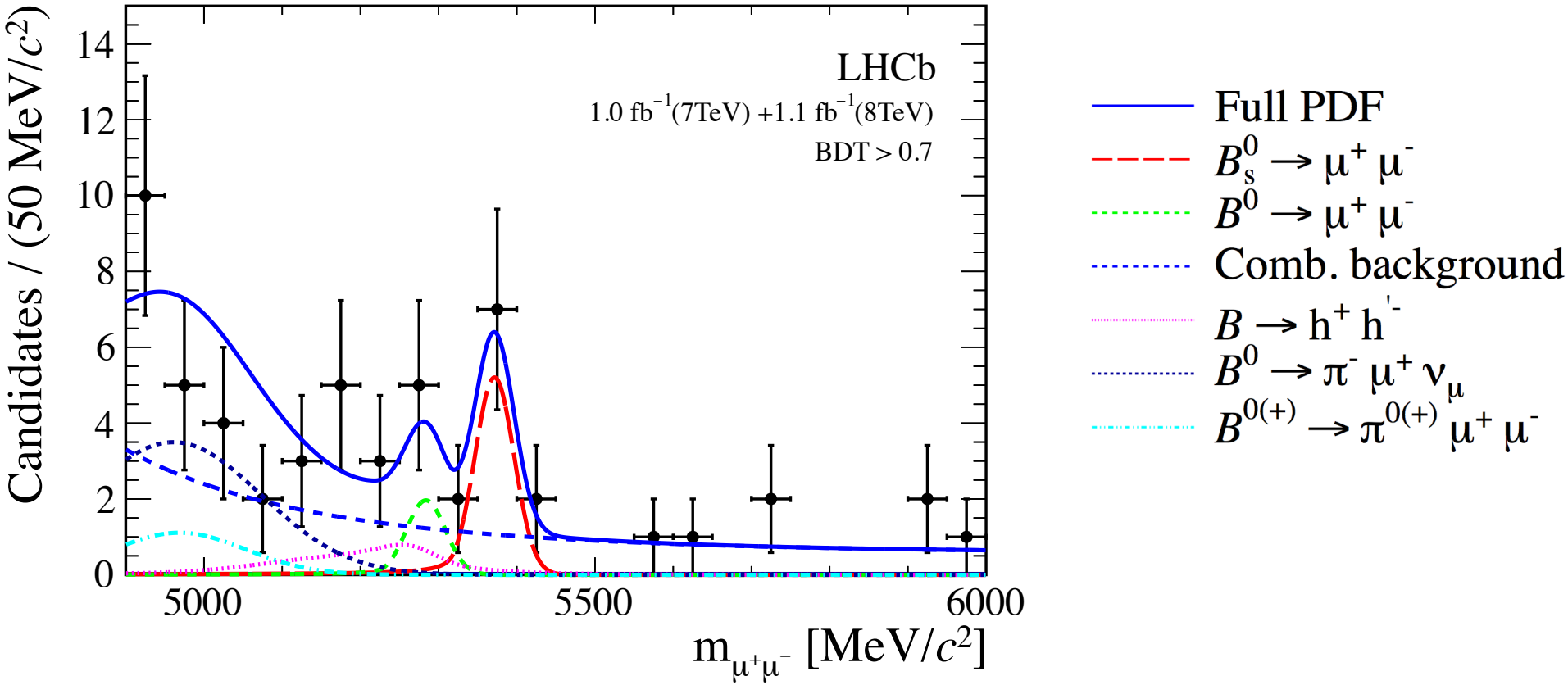
$B^0_s \to \mu^+\mu^-$: BR fit

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. **110**, 021801 (2013)

- **Unbinned maximum likelihood fit** to the mass spectra
  - 7 TeV and 8 TeV data are treated simultaneously
  - mass range [4900-6000] MeV/c^2
- Free parameters:
  - $BR(B^0_s \to \mu^+\mu^-)$, $BR(B^0 \to \mu^+\mu^-)$ and combinatorial background
  - The relative **signal yield** in each BDT bin is **constrained to the expectation from $B^0_{(s)} \to h^+h'^-$ calibration**,
  - The yields and pdf's for all of the relevant exclusive backgrounds are constrained to their expectations
- Additional systematic studies on background composition/ parameterization:
  - add the $B^0_s \to K^-\mu^+\nu_\mu$ component to the exclusive background
  - change the combinatorial pdf from single to double exponential, to account for possible residual contributions from Λ^0_b and B^+_c decays

Combined dataset result

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. **110**, 021801 (2013)



syst from nuisance parameters and background models:

$BR = (3.2^{+1.4}_{-1.2}\,(stat)\ ^{+0.5}_{-0.3}\,(syst))\times10^{-9}$ **fully dominated by stat error**

$BR(B^0_s \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2})\times10^{-9}$

SM expectation
$(3.54\pm0.30)\times10^{-9}$

Summary & outlook

LHCb is contributing to the rare decays exp. knowledge with a lot of NEW high precision/sensitivity results..

for $BR(B^0_s \to 4\mu)$ and $BR(B^0 \to 4\mu)$ the FIRST limits 1.6×10^{-8} & 0.63×10^{-8} @ 95% CL have been obtained!

The limit on the BR $(K_S^0 \to \mu^+\mu^-)$ has been improved a factor 30 w.r.t previous best limit: BR $(K_S^0 \to \mu^+\mu^-) < 11(9) \cdot 10^{-9}$ at 95(90)% C.L.

In nov '12 the first evidence of $B^0_s \to \mu^+\mu^-$ decay [3.5 σ] was found ending a 25 years exp. campaign!

The max likelihood fit result is $BR(B^0_s \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2})\times10^{-9}$ in agreement with SM expectation

LHCb also set the most stringent limit on $B^0 \to \mu^+\mu^-$ decay:
$BR(B^0 \to \mu^+\mu^-) < 9.4\times10^{-10}$ at 95% CL

We are getting ready for another analysis round on the final full 2011+2012 (~3 fb^{-1}) dataset!

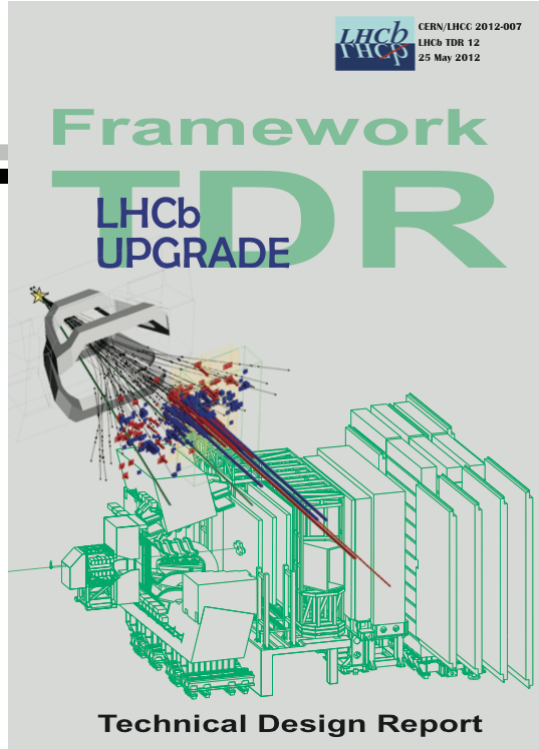
Spares

Glimpse on the future

2012: LHCb Upgrade Framework TDR
http://cdsweb.cern.ch/record/1443882/files/LHCB-TDR-012.pdf

year	2011	2012	2015-2017	upgrade
$\sqrt{s}$	7	8	13	14
L_{int}	1	1.5(*)	4	50

(*) we actually collected 2!



The integrated statistics used in the uncertainty extrapolation for 2018 and the upgrade (2028) are respectively L_{int} = 7 fb^{-1} and L_{int} = 50 fb^{-1}

Observable	Current precision	LHCb 2018	Upgrade (50 fb^{-1})	Theory uncertainty
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$

Extrapolation from 2011 Published analysis (1.5 10^{-9} precision) where the stat. uncertainty is scaled as $\sqrt{N}$.

Datasets

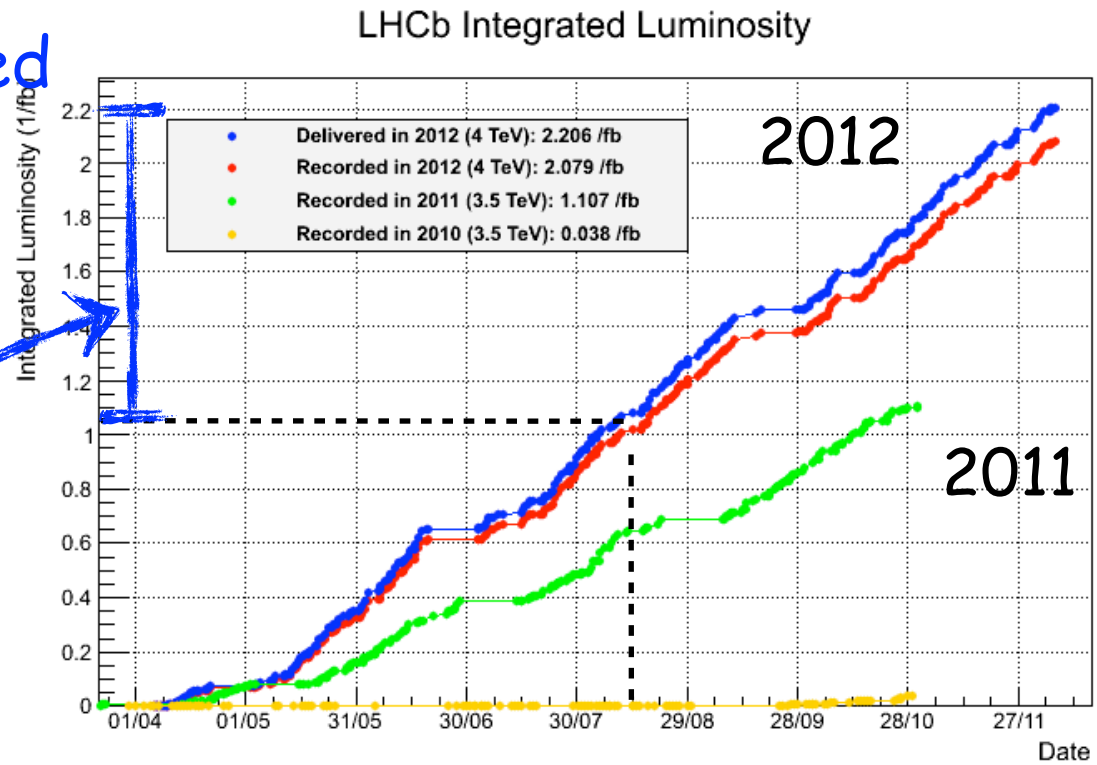
The updated $B^0_{(s)} \to \mu^+\mu^-$ search uses the following datasets:

1.0 fb^{-1} at 7 TeV (2011) + 1.1 fb^{-1} at 8 TeV (2012)

11+14 SM events expected

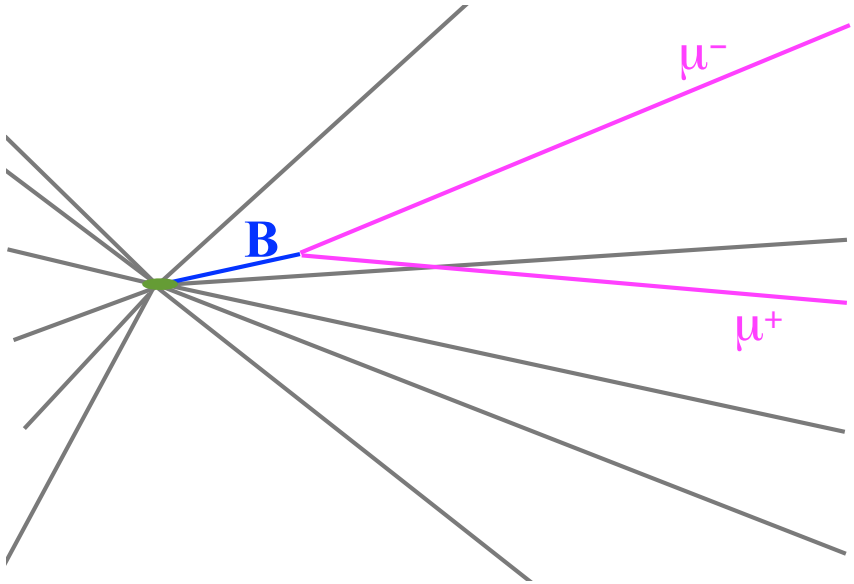
2012: another great year of data taking thanks to the performance of LHC!

LHCb already collected an **additional 1 fb^{-1}** wrt dataset used for this update

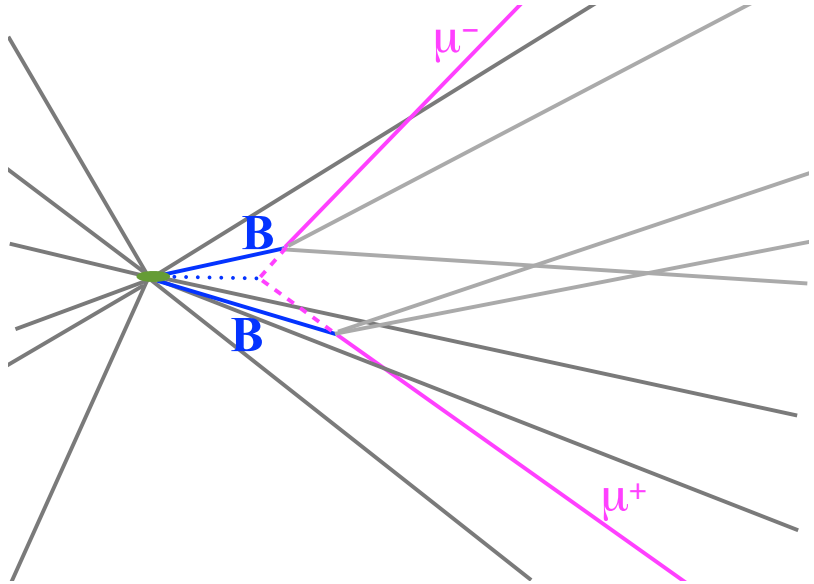


Signal discrimination: BDT

signal: 2 muons from a single well reconstructed secondary vertex



dominant background: two real muons from bb → $\mu^+\mu^-X$



Discrimination is achieved by a BDT with 9 input variables

B candidate:

- proper time
- impact parameter
- transverse momentum
- B isolation

muons:

- min p_T
- min IP significance
- distance of closest approach
- muon isolation,
- cosP

this choice of variables avoids correlation with invariant mass

b fragmentation: f_s/f_d

LHCb measured has 2 independent measurements (at 7 TeV):

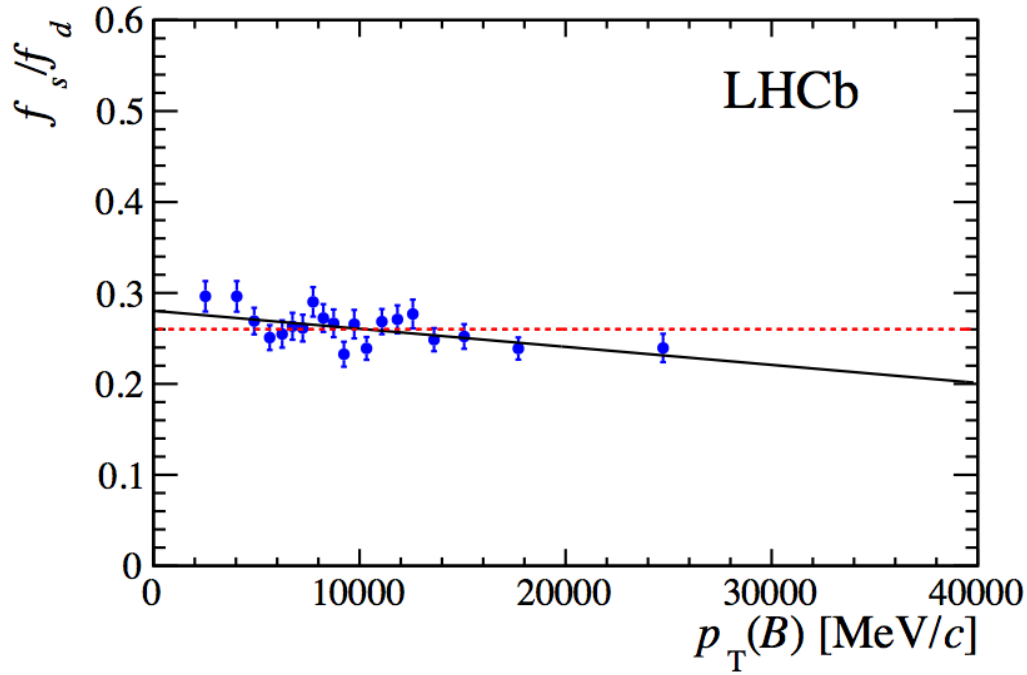
- ratio of $B^0_s \to D_s\mu X$ to $B \to D^+\mu X$ [PRD85 (2012) 032008]
- ratio of $B^0_s \to D^-_s\pi^+$ to $B^0 \to D^-K^+$ and $B^0 \to D^-\pi^+$ [LHCb-PAPER-2012-037 in preparation]

updated at HCP

Combined result at 7 TeV

$$f_s/f_d = 0.256 \pm 0.020$$

new



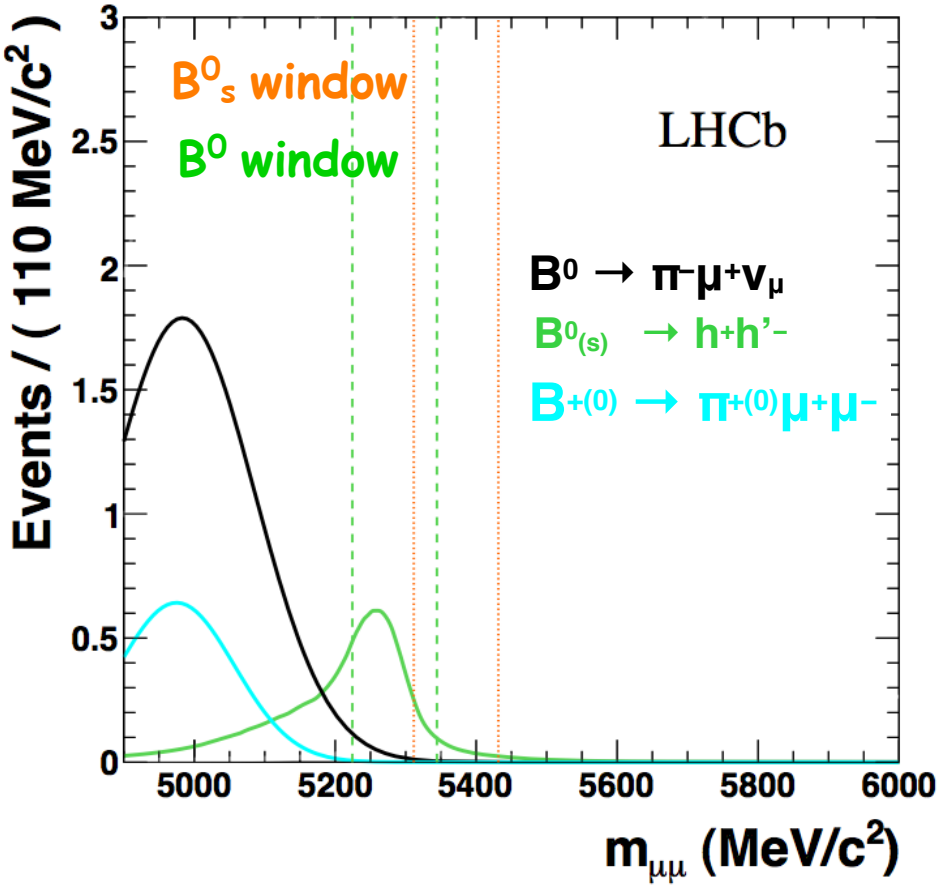
Found to be moderately dependent on p_T:
effect ≤1σ for the considered p_T range → **dependence is ignored**

For 8 TeV data, we checked the $\sqrt{s}$ dependence of f_s/f_d by looking at $B^0_s \to J/\psi\varphi$ / $B^\pm \to J/\psi K^\pm$ ratio and found it stable within 1.5 σ

Exclusive background sources

All **the relevant exclusive backgrounds** were included as separate component in the fit

- Invariant mass and BDT distributions from high statistics MC samples, weighted by misID probabilities measured on data
- Expected yields evaluated by normalizing to $B^{\pm} \to J/\psi K^{\pm}$



dominant channels:

Yields for [4900-6000] MeV/c^2, and BDT>0.8

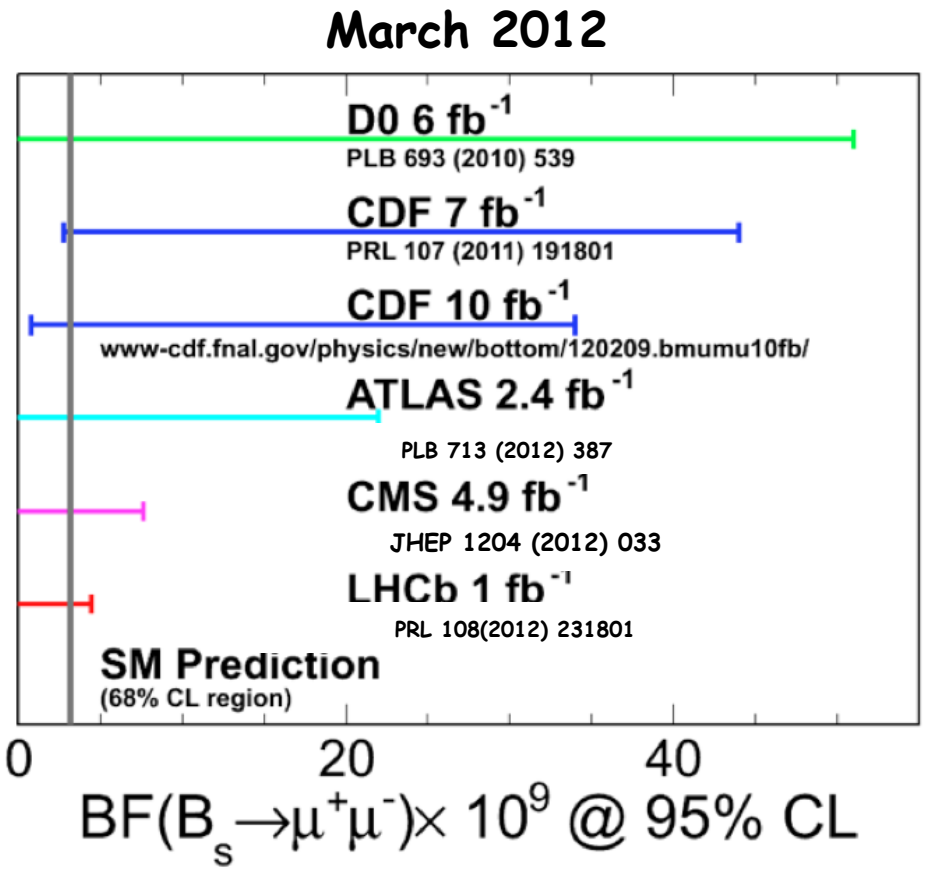
$B^0 \to \pi^-\mu^+\nu_\mu$	**4.04 ± 0.28**
$B^{+(0)} \to \pi^{+(0)}\mu^+\mu^-$	**1.32 ± 0.39**
$B^0_{(s)} \to h^+h'^-$	**1.37 ± 0.11**

these decays are included in the mass sideband fits (constrained to their expected yields)

systematic studies to evaluate the effect of the subdominant channels

Status of $B^0_s \to \mu^+\mu^-$ search

LHCb and CMS getting very close to get sensitivity for observing a SM rate...



LHC combination (June 2012): $BR(B^0_s \to \mu^+\mu^-) < 4.2 \times 10^{-9}$ at 95% CL

LHCb-CONF-2012-017 CMS-PAS-BPH-12-009 ATLAS-CONF-2012-061

$B^0_s \to \mu^+\mu^-$ beyond SM

$$\mathrm{BR}(B_s \to \mu^+\mu^-) \propto \left|C_S - C_S'\right|^2 \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) + \left|(C_P - C_P') + \frac{2m_\mu}{m_{B_s}^2}(C_{10} - C_{10}')\right|^2$$

Scalar Wilson coefficients C_S , C_P:

Virtually unconstrained by other proc.

Possibility of large effects ruled out at LHCb

Vector-Axial Wilson coefficients C_{10}:

Only C_{10} non-zero in the SM, constr. by $b \to s l^+ l^-$

Start to be probed only now

Model independent view:

use all experimental info from $B \to X_s l^+ l^-$, $B \to X_s \gamma$, $B \to K^* \mu^+\mu^-$, $B \to K \mu^+\mu^-$ and $B \to \mu^+\mu^-$ to set model-independent constraints on Wilson coefficients

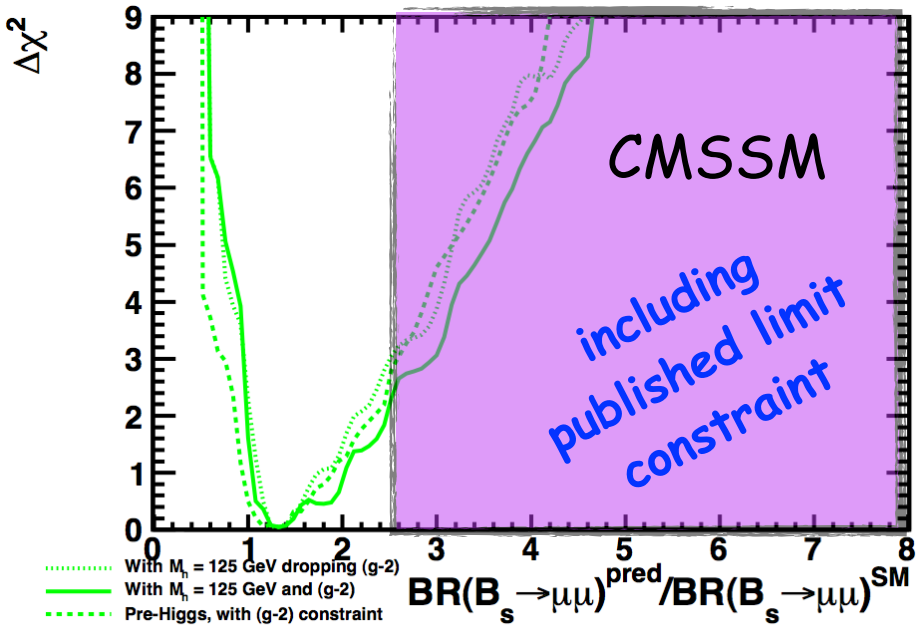
Altmannshofer, Paradisi, Straub	arXiv:1111.1257
Bobeth, Hiller, van Dyk, Wacker	arXiv:1111.2558
Descotes-Genon, Ghosh, Matias, Ramon	arXiv:1104.3342

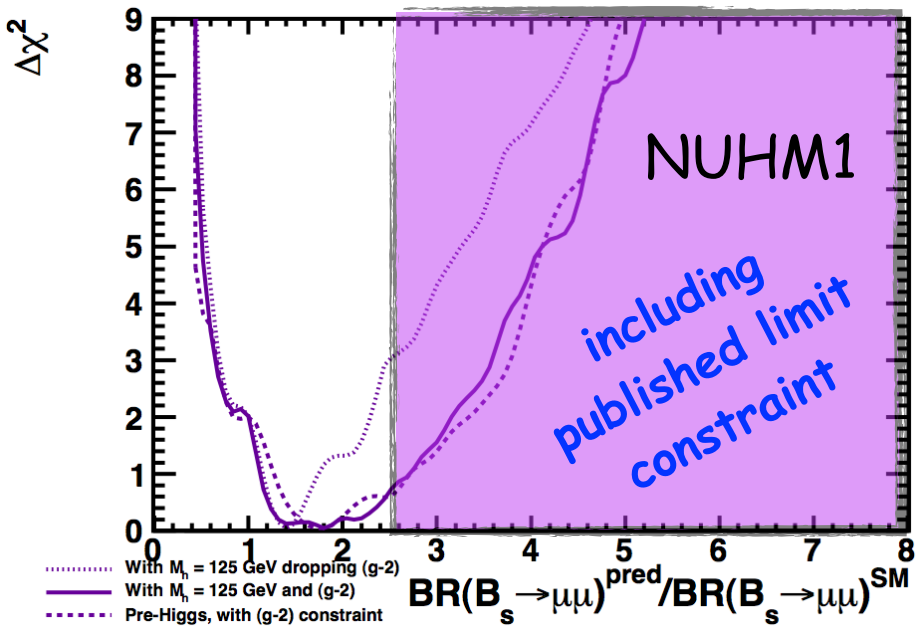
In the most general case, **every value of $B(B_s \to \mu^+\mu^-)$ below present limit** is possible without conflicting with the other observables

$B^0_s \to \mu^+\mu^-$ beyond SM

Model dependent views

CMSSM and NUHM1 predictions on $BR(B^0_s \to \mu^+\mu^-)_{NP}/BR(B^0_s \to \mu^+\mu^-)_{SM}$ including last constraints on Higgs (Buchmueller et al., arXiv:1112.3564v2, May 2012)





NP enhancements of $BR(B_s \to \mu^+\mu^-)$ are constrained to be smaller or at the same level than the SM prediction. There still remains, however, room for a contribution from physics beyond the Standard Model.

$B^0_s \to \mu^+\mu^-$: 7 TeV vs 8 TeV

7 TeV (1 fb^{-1}):

$BR(B^0_s \to \mu^+\mu^-) = (1.4^{+1.7}_{-1.3}) \times 10^{-9}$

p-value: 0.11

8 TeV (1.1 fb^{-1}):

$BR(B^0_s \to \mu^+\mu^-) = (5.1^{+2.4}_{-1.9}) \times 10^{-9}$

p-value: 9×10^{-4}

results from 7 TeV and 8 TeV are compatible at ~1.5σ

7 TeV alphas

$$\alpha_{B^0_s \to \mu^+\mu^-} = (3.19 \pm 0.28) \times 10^{-10}$$
$$\alpha_{B^0 \to \mu^+\mu^-} = (8.38 \pm 0.39) \times 10^{-11}$$

Exclusive backgrounds

Measurements:

$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-) = (2.3 \pm 0.6(\text{stat.}) \pm 0.1(\text{syst.})) \cdot 10^{-8}$ LHCb collab., arXiv:1210.2645

$f_c \cdot \mathcal{B}(B_c^+ \to J/\psi l^+\nu X) = 5.2^{+2.4}_{-2.1} \cdot 10^{-5}$ CDF collab., PRL 81 (1998) 2432

$B^0 \to \pi\mu\nu_\mu$ and $B^0(s) \to h^+h'^-$ Particle Data Group

Theoretical estimates:

$$\frac{\mathcal{B}(B^0 \to \pi^0\mu^+\mu^-)}{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)} = 0.47^{+0.22}_{-0.18}$$

W.-F. Wang and Z.-J. Xiao, arXiv:1207.0265

$B(B^0_s \to K^-\mu^+\nu_\mu) = (1.27 \pm 0.49) \times 10^{-4}$ W.-F. Wang and Z.-J. Xiao, arXiv:1207.0265

$\mathcal{B}(\Lambda_b^0 \to p\mu^-\nu) = (1.59 \pm 0.84) \cdot 10^{-4}$

Updated result from Wang [~4 10^{-4} will be used in next round]

A. Datta, arXiv:hep-ph/9504429

I. Bigi et al., JHEP 1109 (2011) 012

Limits and sensitivity

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

UL are quoted at 95%CL

	Expected UL (bkg)	Expected UL (SM+bkg)	Observed UL	Observed 1-CLb
7 TeV	9.4×10^{-10} *	10.5×10^{-10} *	13.0×10^{-10} *	0.19 *
8 TeV	9.6×10^{-10}	10.5×10^{-10}	12.5×10^{-10}	0.16
7TeV + 8TeV	6.0×10^{-10}	7.1×10^{-10}	**9.4×10^{-10}**	**0.11**

*published results:
UL = 10.3×10^{-10}
1-CLb = 0.60

$B^0_s \to \mu^+\mu^-$

7 TeV
1-CLb = 0.11
UL = 5.1×10^{-9} at 95% CL

to be compared with published:
1-CLb = 0.18
UL = 4.5×10^{-9} at 95% CL

Observed and expected events

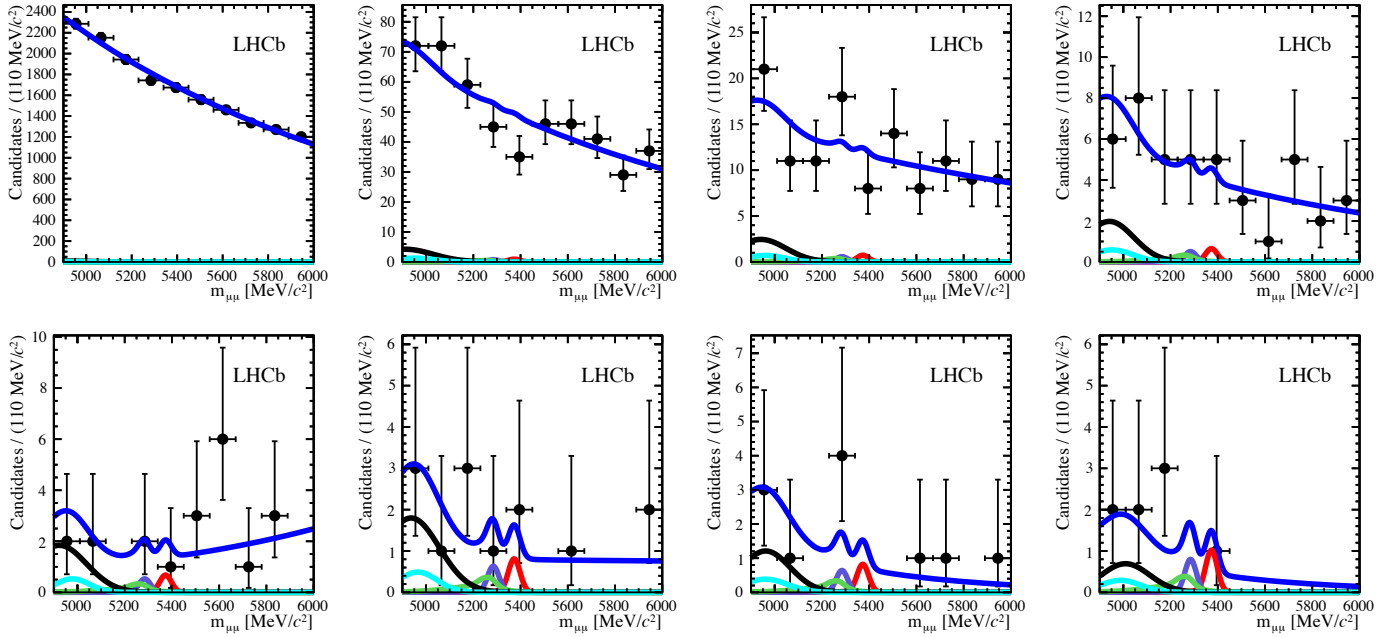
Mode	BDT bin	0.0 – 0.25	0.25 – 0.4	0.4 – 0.5	0.5 – 0.6	0.6 – 0.7	0.7 – 0.8	0.8 – 0.9	0.9 – 1.0
$B_s^0 \to \mu^+\mu^-$	Exp. comb. bkg	1880^{+33}_{-33}	$55.5^{+3.0}_{-2.9}$	$12.1^{+1.4}_{-1.3}$	$4.16^{+0.88}_{-0.79}$	$1.81^{+0.62}_{-0.51}$	$0.77^{+0.52}_{-0.38}$	$0.47^{+0.48}_{-0.36}$	$0.24^{+0.44}_{-0.20}$
(2011)	Exp. peak. bkg	$0.13^{+0.07}_{-0.05}$	$0.07^{+0.02}_{-0.02}$	$0.05^{+0.02}_{-0.02}$	$0.05^{+0.02}_{-0.01}$	$0.05^{+0.02}_{-0.01}$	$0.05^{+0.02}_{-0.01}$	$0.05^{+0.02}_{-0.01}$	$0.05^{+0.02}_{-0.01}$
	Exp. signal	$2.70^{+0.81}_{-0.80}$	$1.30^{+0.27}_{-0.23}$	$1.03^{+0.20}_{-0.17}$	$0.92^{+0.15}_{-0.13}$	$1.06^{+0.17}_{-0.15}$	$1.10^{+0.17}_{-0.15}$	$1.26^{+0.20}_{-0.17}$	$1.31^{+0.28}_{-0.25}$
	Observed	1818	39	12	6	1	2	1	1
$B^0 \to \mu^+\mu^-$	Exp. comb. bkg	1995^{+34}_{-34}	$59.2^{+3.3}_{-3.2}$	$12.6^{+1.6}_{-1.5}$	$4.44^{+0.99}_{-0.86}$	$1.67^{+0.66}_{-0.54}$	$0.75^{+0.58}_{-0.40}$	$0.44^{+0.57}_{-0.38}$	$0.22^{+0.48}_{-0.20}$
(2011)	Exp. peak. bkg	$0.78^{+0.38}_{-0.29}$	$0.40^{+0.14}_{-0.10}$	$0.31^{+0.11}_{-0.08}$	$0.28^{+0.09}_{-0.07}$	$0.31^{+0.10}_{-0.08}$	$0.30^{+0.10}_{-0.07}$	$0.31^{+0.10}_{-0.08}$	$0.30^{+0.11}_{-0.08}$
	Exp. cross-feed	$0.43^{+0.13}_{-0.13}$	$0.21^{+0.04}_{-0.04}$	$0.16^{+0.03}_{-0.03}$	$0.15^{+0.03}_{-0.02}$	$0.17^{+0.03}_{-0.03}$	$0.17^{+0.03}_{-0.02}$	$0.20^{+0.03}_{-0.03}$	$0.21^{+0.05}_{-0.04}$
	Exp. signal	$0.33^{+0.10}_{-0.10}$	$0.16^{+0.03}_{-0.03}$	$0.13^{+0.02}_{-0.02}$	$0.11^{+0.02}_{-0.02}$	$0.13^{+0.02}_{-0.02}$	$0.13^{+0.02}_{-0.02}$	$0.15^{+0.02}_{-0.02}$	$0.16^{+0.03}_{-0.03}$
	Observed	1904	50	20	5	2	1	4	1

7 TeV data

Mode	BDT bin	0.0 – 0.25	0.25 – 0.4	0.4 – 0.5	0.5 – 0.6	0.6 – 0.7	0.7 – 0.8	0.8–1.0
$B_s^0 \to \mu^+\mu^-$	Exp. comb. bkg	2345^{+40}_{-40}	$56.7^{+3.0}_{-2.9}$	$13.1^{+1.5}_{-1.4}$	$4.42^{+0.91}_{-0.81}$	$2.10^{+0.67}_{-0.56}$	$0.35^{+0.42}_{-0.22}$	$0.39^{+0.33}_{-0.21}$
(2012)	Exp. peak. bkg	$0.250^{+0.08}_{-0.07}$	$0.15^{+0.05}_{-0.04}$	$0.08^{+0.03}_{-0.02}$	$0.08^{+0.02}_{-0.02}$	$0.07^{+0.02}_{-0.02}$	$0.06^{+0.02}_{-0.02}$	$0.10^{+0.03}_{-0.03}$
	Exp. signal	$3.69^{+0.59}_{-0.52}$	$2.14^{+0.37}_{-0.33}$	$1.20^{+0.21}_{-0.18}$	$1.16^{+0.18}_{-0.16}$	$1.17^{+0.18}_{-0.16}$	$1.15^{+0.19}_{-0.17}$	$2.13^{+0.33}_{-0.29}$
	Observed	2274	65	19	5	3	1	3
$B^0 \to \mu^+\mu^-$	Exp. comb. bkg	2491^{+42}_{-42}	$59.5^{+3.3}_{-3.2}$	$13.9^{+1.6}_{-1.5}$	$4.74^{+1.00}_{-0.89}$	$2.10^{+0.74}_{-0.61}$	$0.55^{+0.50}_{-0.31}$	$0.29^{+0.34}_{-0.19}$
(2012)	Exp. peak. bkg	$1.49^{+0.50}_{-0.36}$	$0.86^{+0.29}_{-0.22}$	$0.48^{+0.16}_{-0.12}$	$0.44^{+0.15}_{-0.11}$	$0.42^{+0.14}_{-0.10}$	$0.37^{+0.13}_{-0.09}$	$0.62^{+0.21}_{-0.15}$
	Exp. cross-feed	$0.63^{+0.10}_{-0.09}$	$0.36^{+0.07}_{-0.06}$	$0.20^{+0.04}_{-0.03}$	$0.20^{+0.03}_{-0.03}$	$0.20^{+0.03}_{-0.03}$	$0.20^{+0.03}_{-0.03}$	$0.36^{+0.06}_{-0.05}$
	Exp. signal	$0.44^{+0.06}_{-0.06}$	$0.26^{+0.04}_{-0.04}$	$0.14^{+0.02}_{-0.02}$	$0.14^{+0.02}_{-0.02}$	$0.14^{+0.02}_{-0.02}$	$0.14^{+0.02}_{-0.02}$	$0.26^{+0.04}_{-0.03}$
	Observed	2433	59	19	3	2	2	2

8 TeV data

Fit results for all BDT bins



7 TeV data, 1.0 fb^{-1}

8 BDT bins

$B^0_s \to \mu^+\mu^-$

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

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

$B^0 \to \pi^-\mu^+\nu_\mu$

$B^{\pm,0} \to \pi^{\pm,0}\mu^+\mu^-$

total

8 TeV data, 1.1 fb^{-1}

7 BDT bins