

New results in the search for $B^0_{(s)} \rightarrow \mu^+ \mu^-$ from LHCb

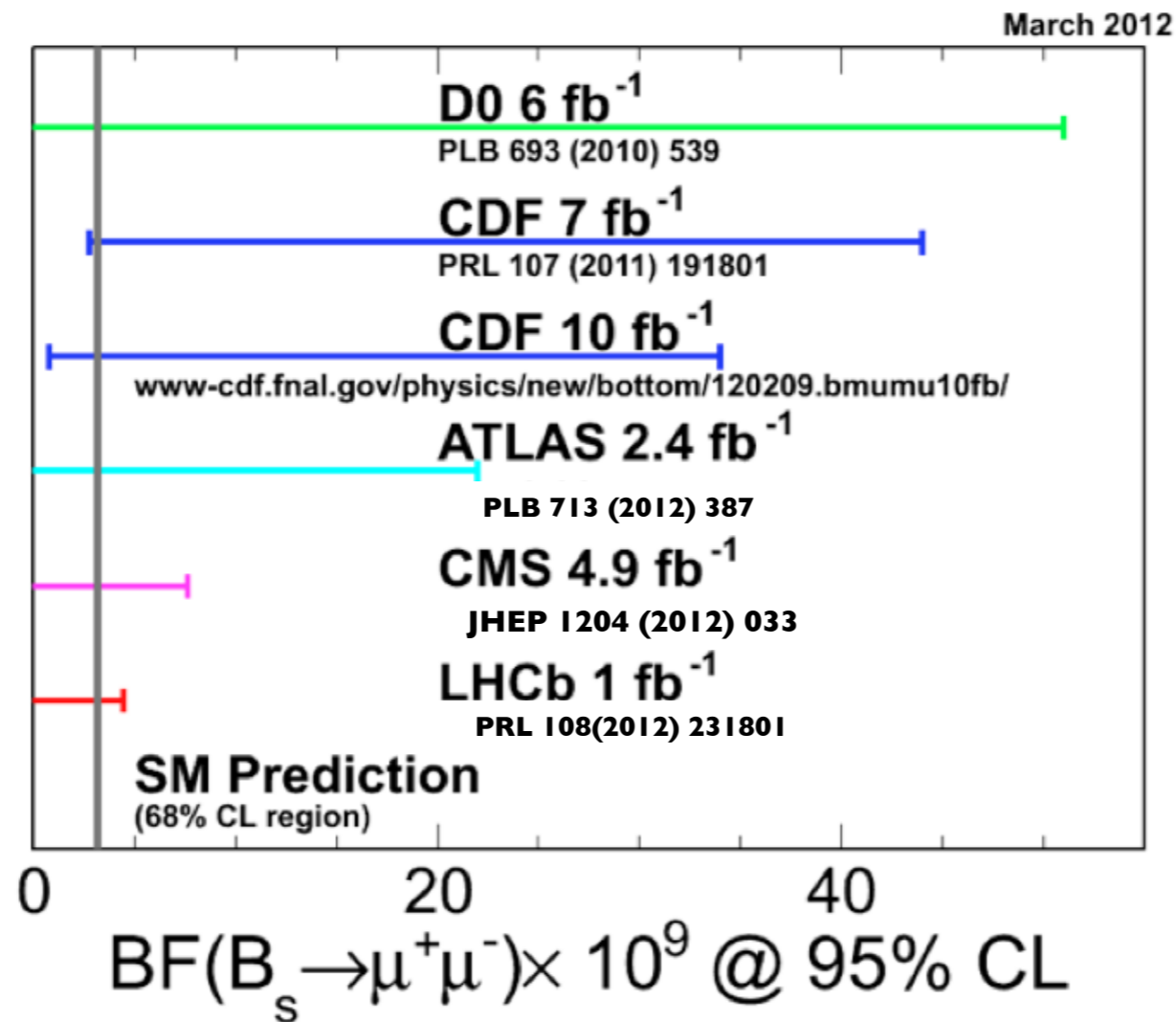
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on behalf of the LHCb Collaboration
CERN, 2012/11/13

Outline

- Introduction
- Signal characterization
- Normalization
- Background estimation
- Results

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



March 2012

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

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

LHCb-CONF-2012-017

CMS-PAS-BPH-12-009

ATLAS-CONF-2012-061

Roadmap for $B^0_{(s)} \rightarrow \mu^+ \mu^-$



- Look for significant NP enhancement of $\mathcal{B}(B^0_s \rightarrow \mu^+ \mu^-)$ gone
- Discovery of $B^0_s \rightarrow \mu^+ \mu^-$ decay next step
- Precision measurement of $\mathcal{B}(B^0_s \rightarrow \mu^+ \mu^-)$; look for significant enhancement of $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)$
- Discovery of $B^0 \rightarrow \mu^+ \mu^-$ decay
- Measure the ratio $\mathcal{B}(B^0_s \rightarrow \mu^+ \mu^-) / \mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)$: excellent test of MFV models

Standard Model prediction

FCNC process \rightarrow very small branching fraction:

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

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)_{t=0} = (1.07 \pm 0.10) \cdot 10^{-10}$$

Buras et al., arXiv:1208.0934

The authors used $f_{B_s} = (227 \pm 8)$ 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_s^0 system:

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

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

De Bruyn et al., PRL 109, 041801 (2012)

uses LHCb-CONF-2012-002

$B_s^0 \rightarrow \mu^+ \mu^-$ beyond SM



$$\text{BR}(B_s \rightarrow \mu^+ \mu^-) \propto |C_S - C'_S|^2 \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) + \left| (C_P - C'_P) + \frac{2m_\mu}{m_{B_s}^2} (C_{10} - C'_{10}) \right|^2$$

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 $b \rightarrow s \ell^+ \ell^-$

Start to be probed only now

Model independent view:

use all experimental info from $B \rightarrow X_s \ell^+ \ell^-$, $B \rightarrow X_s \gamma$, $B \rightarrow K^* \mu^+ \mu^-$, $B \rightarrow K \mu^+ \mu^-$, $B \rightarrow \mu^+ \mu^-$ 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

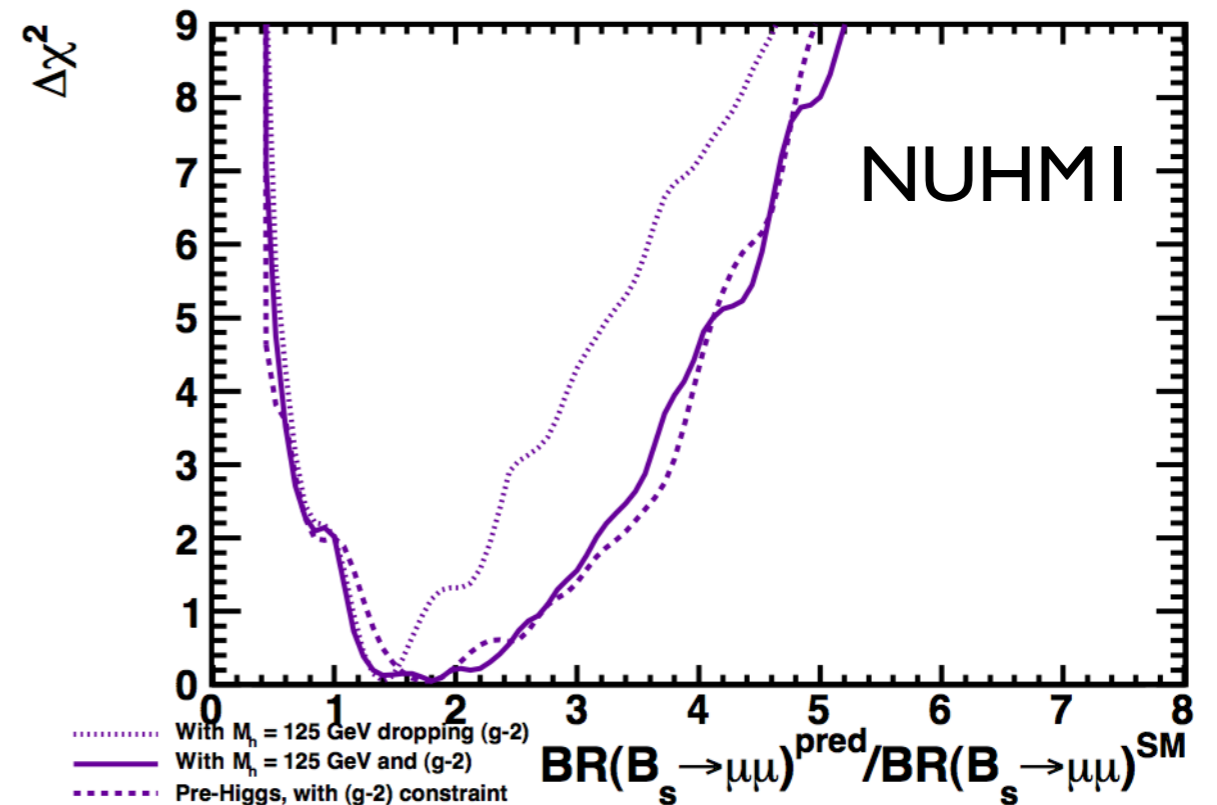
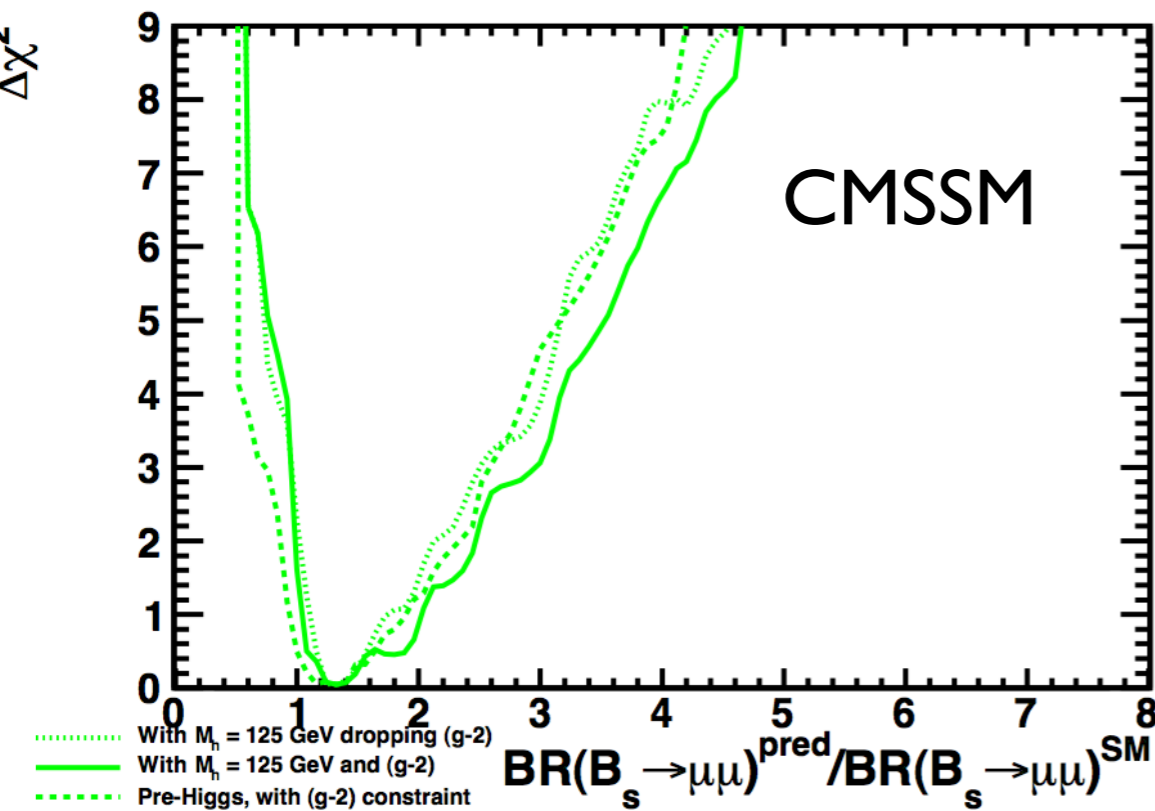
arXiv:1104.3342

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

$B_s^0 \rightarrow \mu^+ \mu^-$ beyond SM

Model dependent views

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



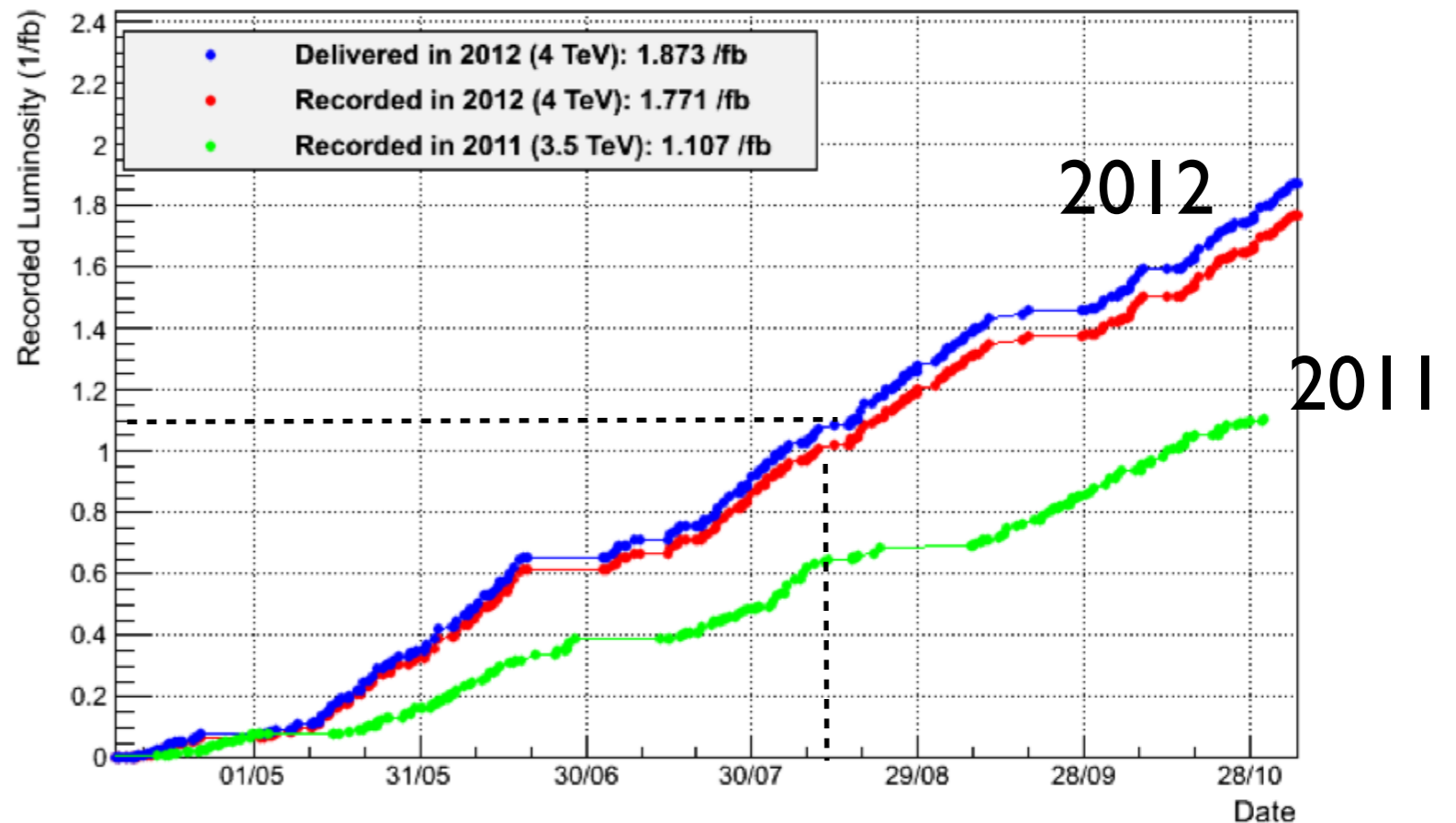
NP enhancements of $\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$ are constrained to be smaller or at the same level than the SM prediction. There still remains, however, room for a contribution from physics beyond the Standard Model.

Datasets

Today we'll present the update on $B^0_{(s)} \rightarrow \mu^+ \mu^-$ search with

1.0 fb⁻¹ at 7 TeV (2011) + **1.1 fb⁻¹ at 8 TeV (2012)**

LHCb Integrated Luminosity in 2011 and 2012

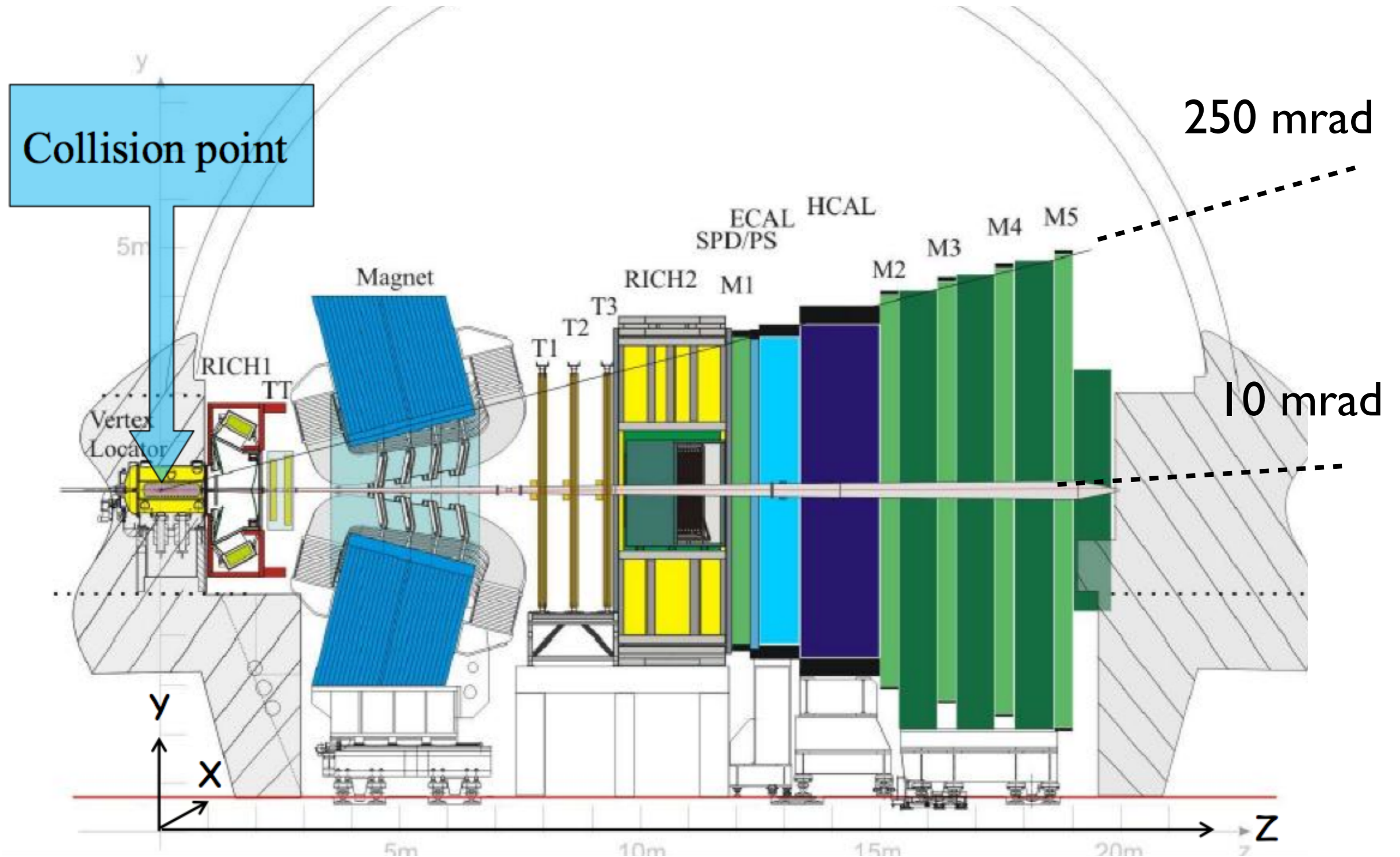


2012: another great year of data taking thanks to the performance of LHC!

7 TeV data already published in PRL 108 (2012) 231801:

it has been reanalyzed as part of the measurement presented here; the result supersedes the previous publication

LHCb detector



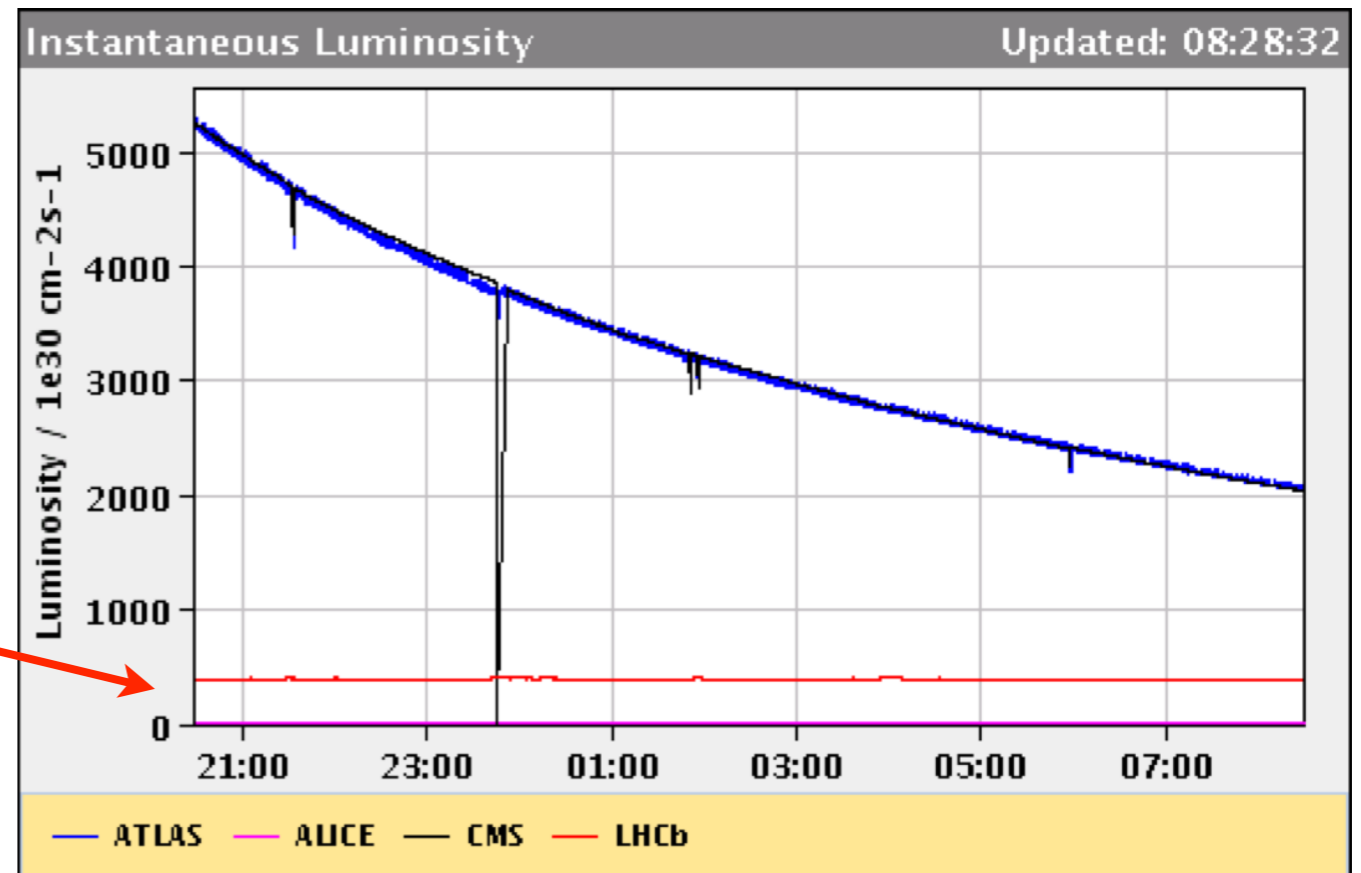
$B^0_s \rightarrow \mu^+ \mu^-$ at LHCb

1) Run the experiment at $4 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ with 1262 colliding bunches

- twice the design luminosity with half number of bunches
 - 4 times more collisions per crossing than design: $\langle \mu \rangle_{8\text{TeV}} \sim 1.7$
 - higher occupancy in the detector
 - challenging for the trigger

2) Large acceptance, efficient muon trigger

- acceptance \times reconstruction efficiency for signal is $\sim 10\%$
- L0: single muon $p_T > 1.76 \text{ GeV}/c$, dimuon $\sqrt{p_{T1} \cdot p_{T2}} > 1.6 \text{ GeV}/c$
- HLT: IP and invariant mass cuts
- overall trigger efficiency $\sim 90\%$



LHCb instantaneous
luminosity

luminosity leveling at work!

$B_s^0 \rightarrow \mu^+ \mu^-$ at LHCb

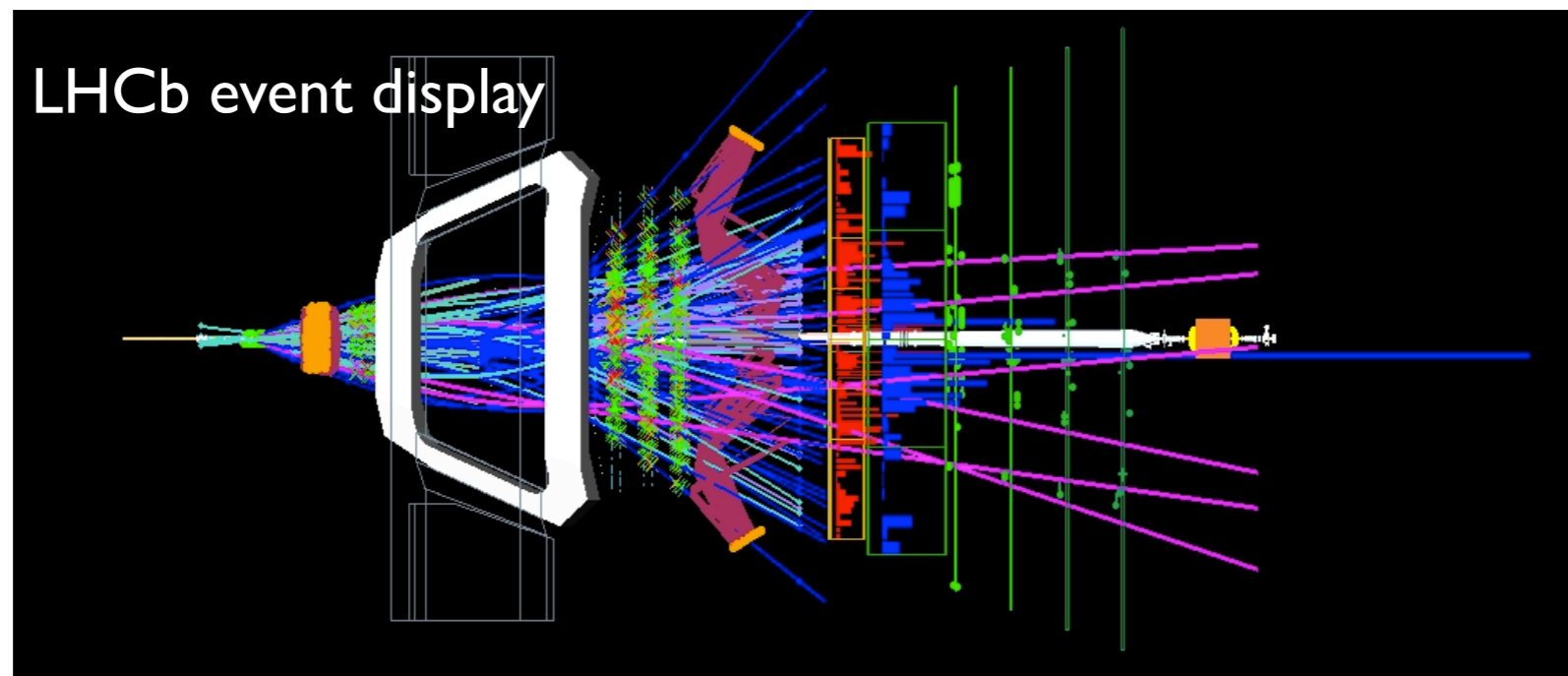
3) Background reduction:

- Very good momentum resolution : $\delta p/p \sim 0.4\% \rightarrow 0.6\%$ for $p=(5-100)$ GeV/c
- Muon identification: matching between tracks reconstructed in the spectrometer and hits in the muon stations + moderate requirements on global PID likelihood (RICH+CALO+MUON);

for this analysis: $\epsilon(\mu \rightarrow \mu) \sim 98\%$, $\epsilon(\pi \rightarrow \mu) \sim 0.6\%$, $\epsilon(K \rightarrow \mu) \sim 0.3\%$, $\epsilon(p \rightarrow \mu) \sim 0.3\%$,

4) Excellent vertex and IP resolution:

- to separate signals from background : $\sigma(\text{IP}) \sim 25 \mu\text{m}$ @ $p_T=2$ GeV/c



~ 1.7 pp
interactions
per Xing

11 + 14 SM events expected in $1.0 \text{ fb}^{-1} + 1.1 \text{ fb}^{-1}$

Analysis strategy



Well established since the analysis of 7 TeV data; a few significant improvements have been introduced in the analysis of 8 TeV data; signal region on 8 TeV data kept blind until analysis completion

- Selection

Pairs of opposite charged muons, making a vertex displaced with respect to the primary vertex and $m_{\mu\mu}$ in the range [4900-6000] MeV/c²; loose cut on MVA discriminant

- Signal/Background separation by invariant dimuon mass and a MVA classifier (BDT) including kinematic and topological information

BDT training on MC signal and background samples

BDT calibration for signal with exclusive $B^0_{(s)} \rightarrow h^+h'^-$ channels (h= π , K)

updated
on 8 TeV

- Normalization with $B^\pm \rightarrow J/\psi K^\pm$ and $B^0 \rightarrow K^+\pi^-$

$B^0_s \rightarrow J/\psi\varphi$ was dropped as third normalization channel for 8 TeV data, but use $B^0_s \rightarrow J/\psi\varphi/B^\pm \rightarrow J/\psi K^\pm$ to check \sqrt{s} dependence of f_s/f_d

updated
on 8 TeV

Analysis strategy



- Background estimation

updated on 7 TeV and 8 TeV

Combinatorial $b\bar{b} \rightarrow \mu\mu X$

Double mis-identified $B^0_{(s)} \rightarrow h^+h'^-$

Detailed studies on various exclusive backgrounds

Results

- Limits and significance determination with CLs method

Signal window: $m(B^0_{(s)}) \pm 60 \text{ MeV}/c^2$

- Unbinned maximum likelihood fit for the branching fraction

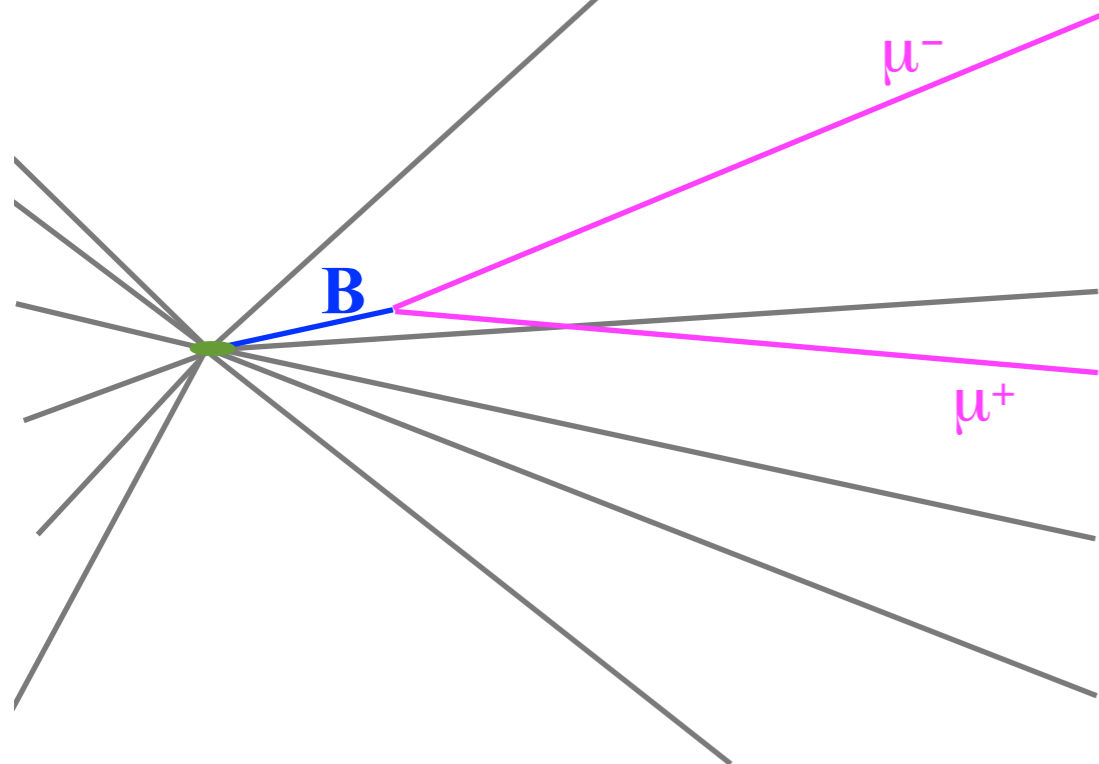
Use full mass range: $[4900-6000] \text{ MeV}/c^2$

The results have been updated for 7 TeV data, after the improvements in the background determination

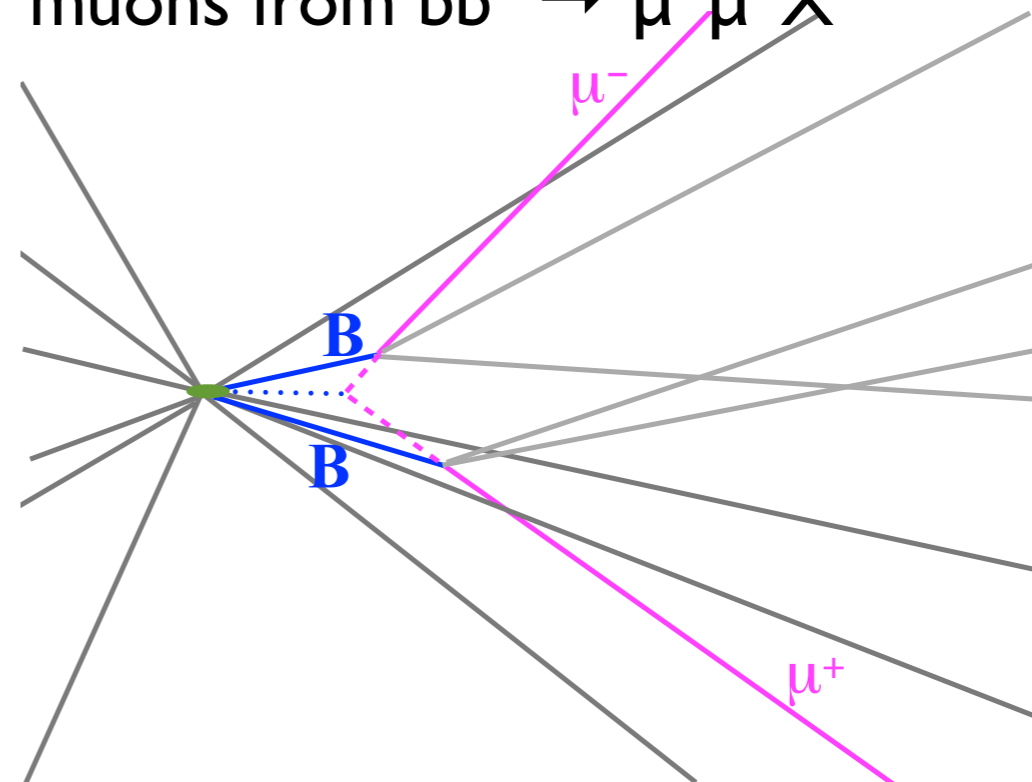
Signal characterization

Signal discrimination: BDT

signal: 2 muons from a single well reconstructed secondary vertex



dominant background: two real muons from $b\bar{b} \rightarrow \mu^+\mu^-X$



Discrimination is achieved by a BDT with 9 input variables

B candidate:

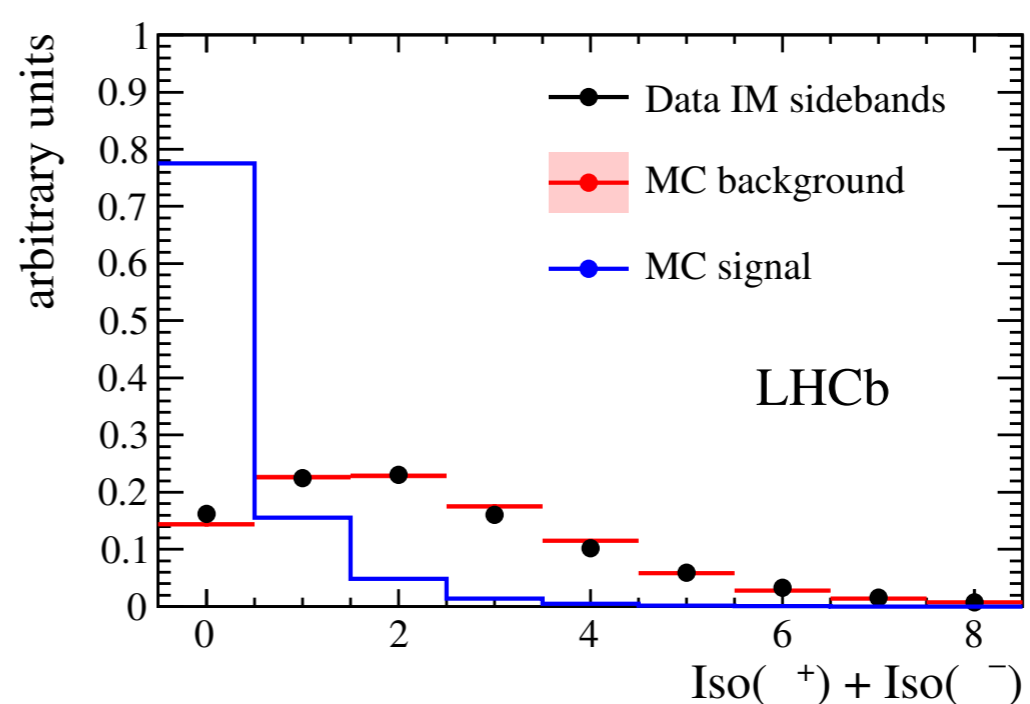
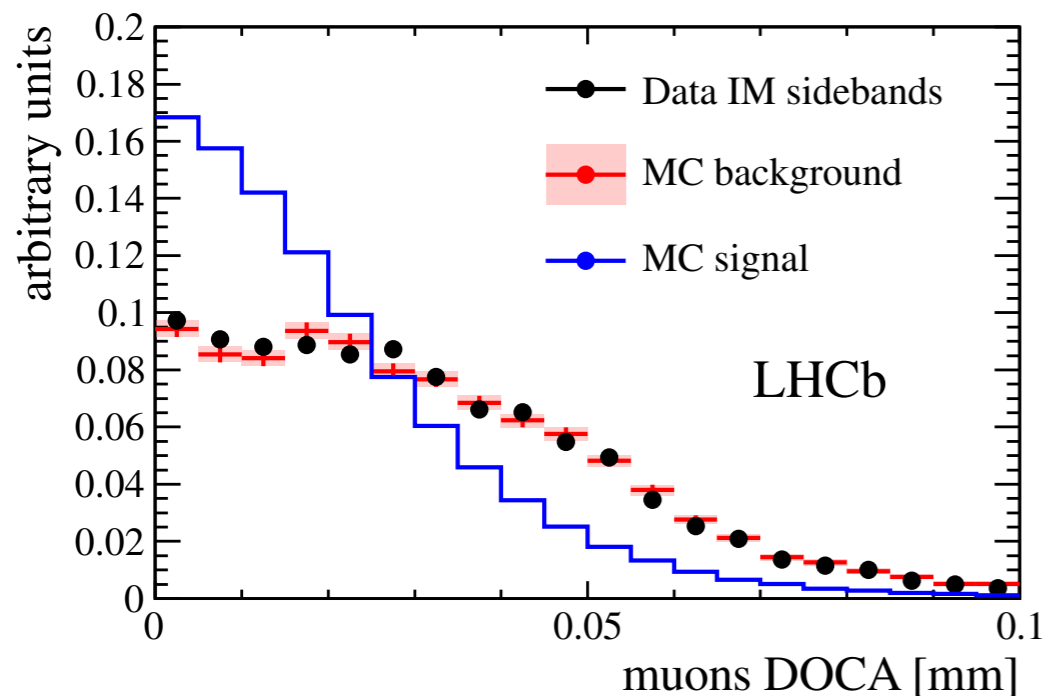
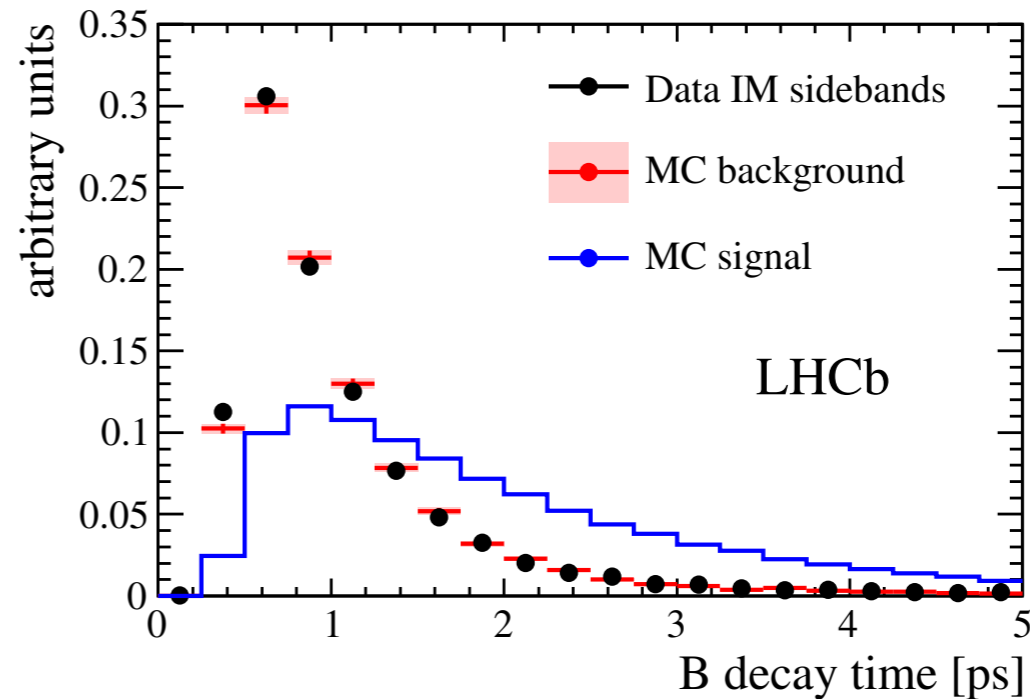
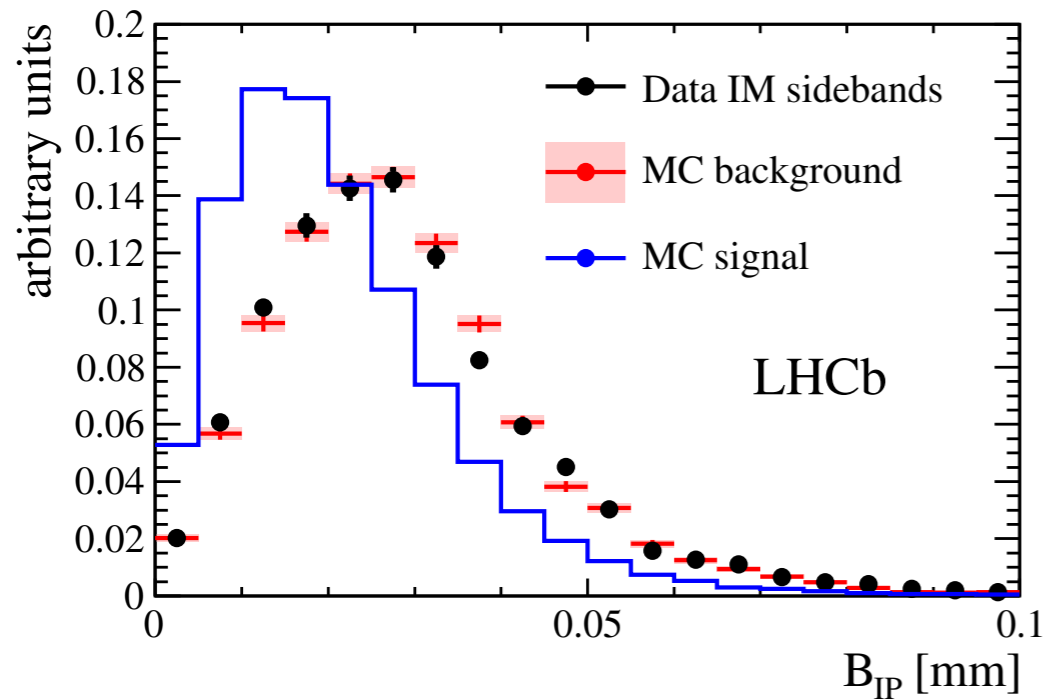
- proper time
- impact parameter
- transverse momentum
- B isolation

muons:

- min p_T
- min IP significance
- distance of closest approach
- muon isolation,
- $\cos P$

this choice of variables avoids correlation with invariant mass

Signal discrimination: BDT



7 TeV
data

Optimization and training on MC $B^0_s \rightarrow \mu^+\mu^-$ signal and $b\bar{b} \rightarrow \mu^+\mu^-X$ background
 Same definition of BDT is used for 7 TeV and 8 TeV data, since most of the input variables are in very good agreement (checked on $B^\pm \rightarrow J/\psi K^\pm$)

Signal discrimination: BDT



BDT output defined to be flat for signal, and peaked at zero for background

Signal BDT shape from $B^0_{(s)} \rightarrow h^+h'^-$ events, which have same topology as the signal (use sample triggered independent of the signal, to avoid bias)

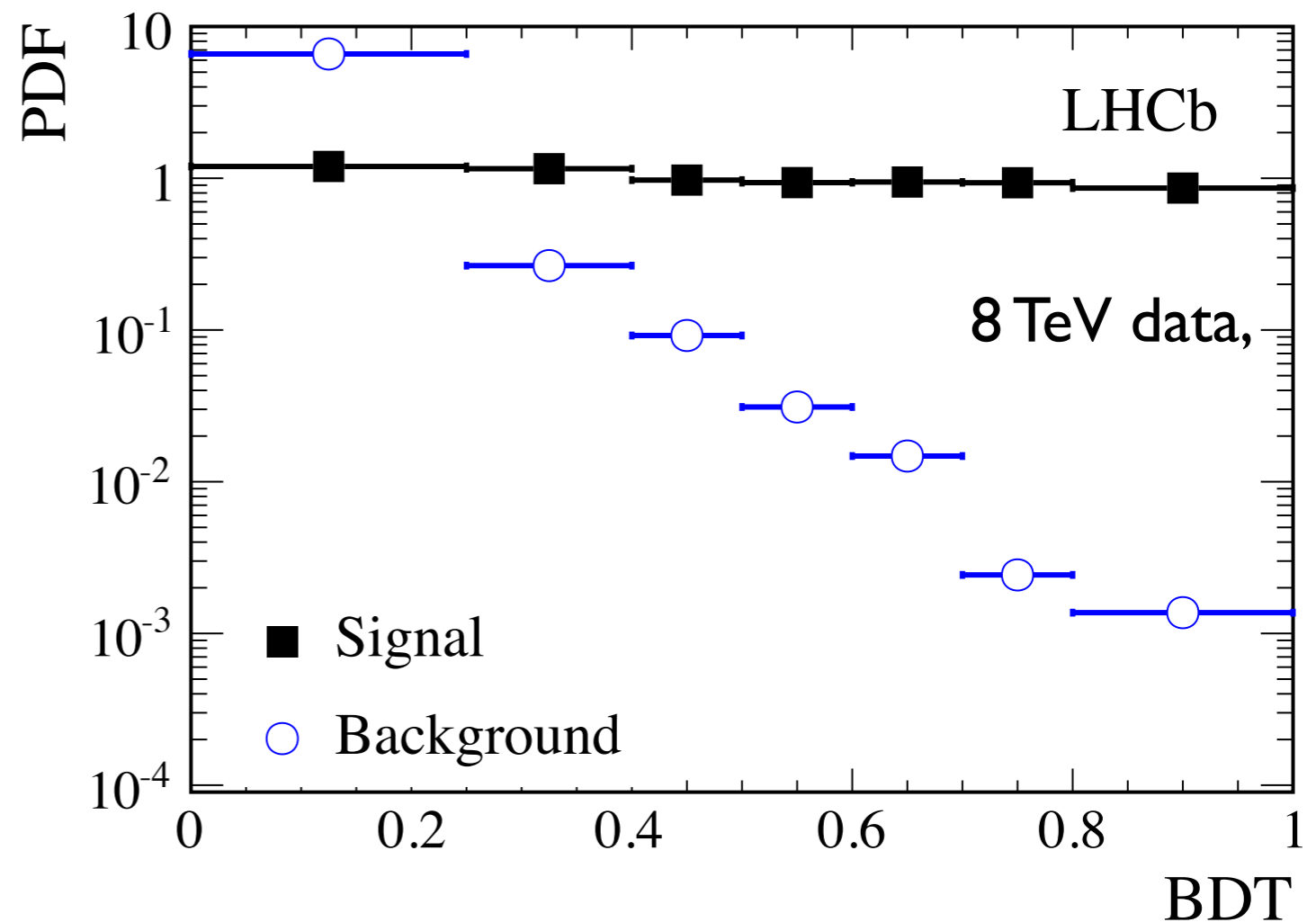
Background BDT shape is evaluated on the dimuon mass sidebands

Analysis is performed in BDT bins

- BDT binning optimized on **7 TeV data \rightarrow 8 bins**

- For 8 TeV data we merged the two most sensitive bins ($BDT > 0.8$), since we had no events on the mass sidebands:

8 TeV data \rightarrow 7 bins

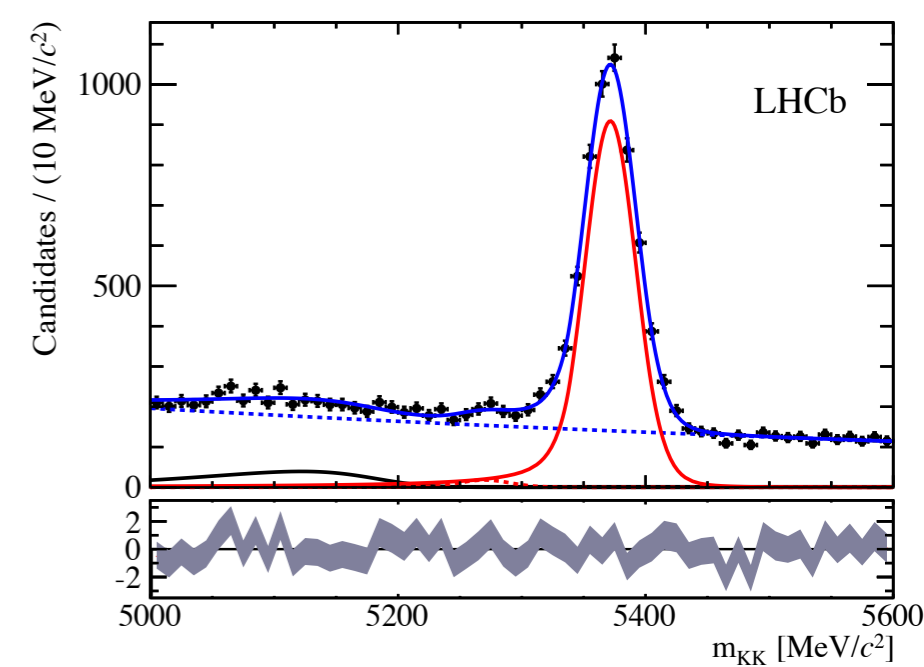
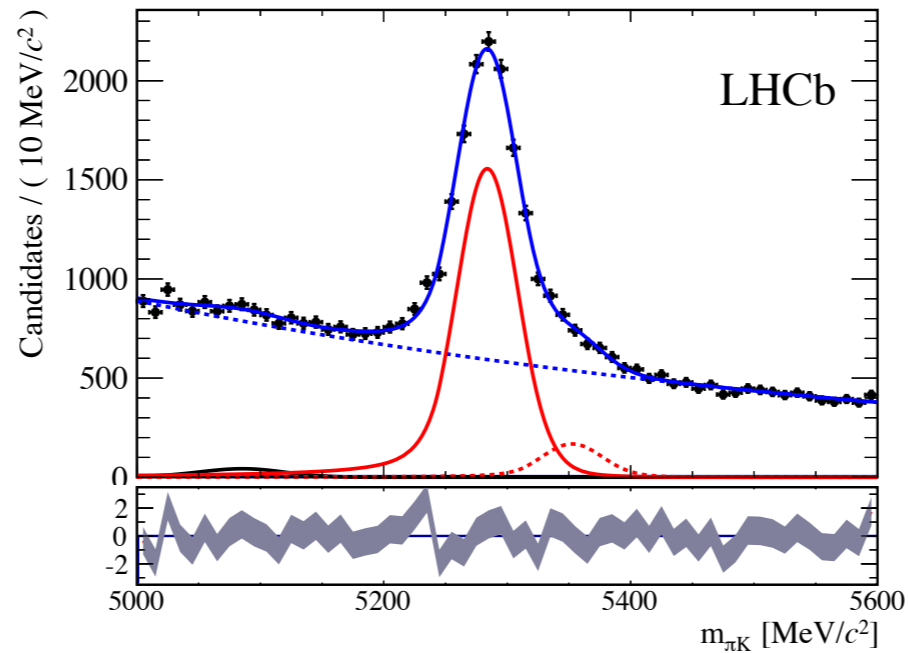
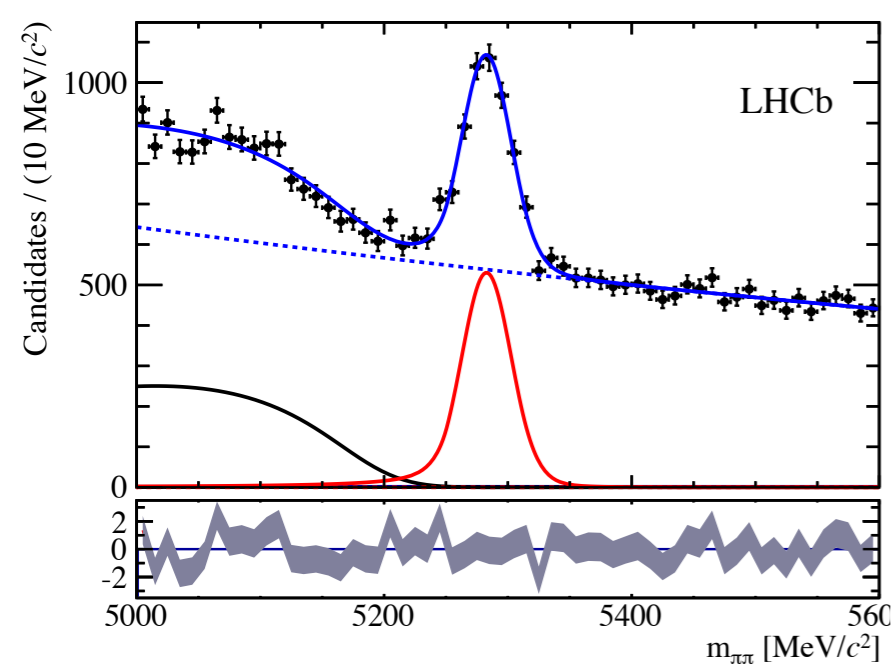


$B^0_{(s)}$ mass peak positions

$B^0 \rightarrow \pi^+ \pi^-$

$B^0 \rightarrow K \pi$

$B^0_s \rightarrow K^+ K^-$



8 TeV data

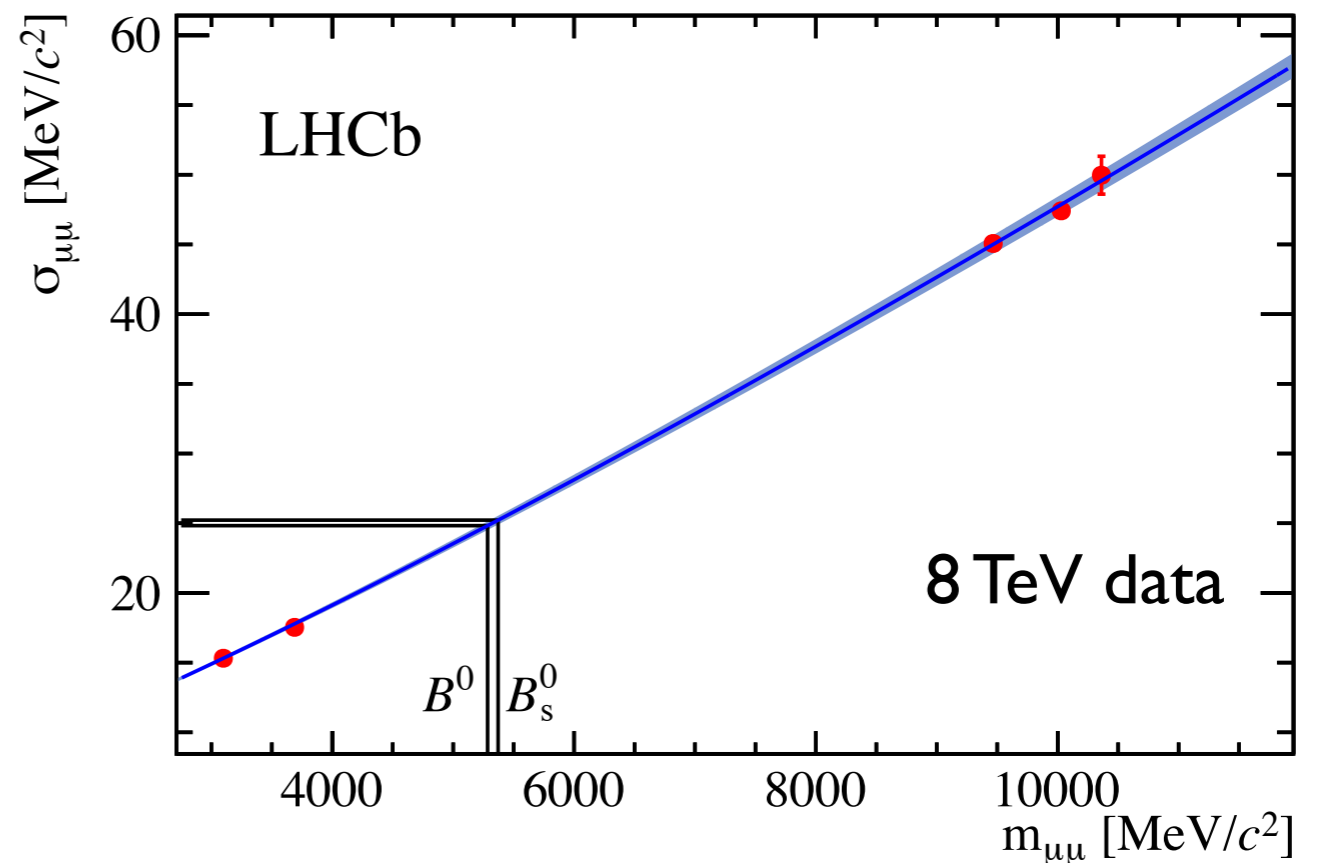
m_{B^0}	$(5284.36 \pm 0.26_{\text{stat}} \pm 0.13_{\text{syst}}) \text{ MeV}/c^2$
$m_{B^0_s}$	$(5371.55 \pm 0.41_{\text{stat}} \pm 0.16_{\text{syst}}) \text{ MeV}/c^2$

Peak position determinations for 7 TeV and 8 TeV data agree at better than 5×10^{-4}

Mass resolution

Two independent methods

- 1) Interpolation of dimuon resonances:
 J/ψ and $\psi(2S)$,
 $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$
- 2) From $B^0_{(s)} \rightarrow h^+ h'^-$



Results are in agreement:

$$\sigma_{B^0} = (24.63 \pm 0.13_{\text{stat}} \pm 0.36_{\text{syst}}) \text{ MeV}/c^2$$

$$\sigma_{B^0_s} = (25.04 \pm 0.18_{\text{stat}} \pm 0.36_{\text{syst}}) \text{ MeV}/c^2$$

8 TeV data:

~1% difference observed between 7 TeV and 8 TeV data

For the signal mass pdf we use a Crystal Ball function: transition point of the radiative tail from simulated events smeared to reproduce the measured resolution

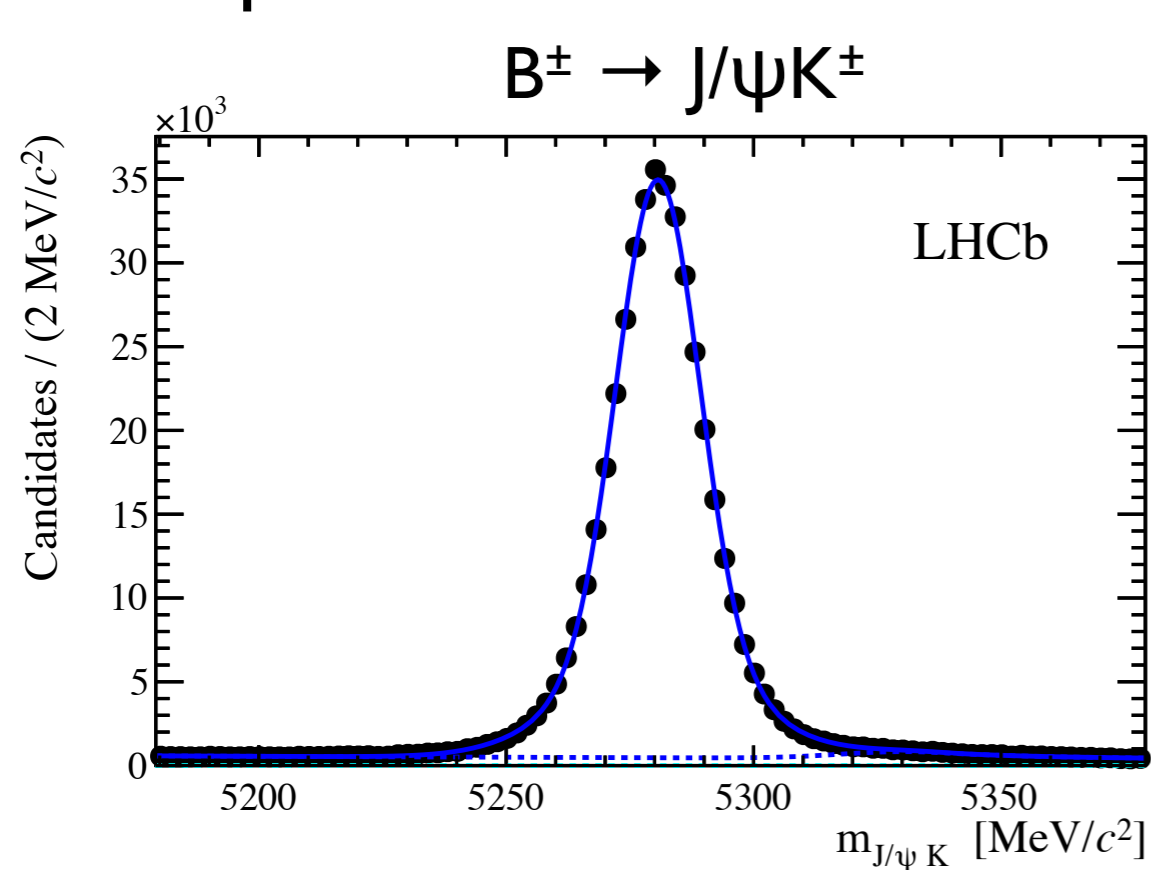
Normalization

Normalization strategy

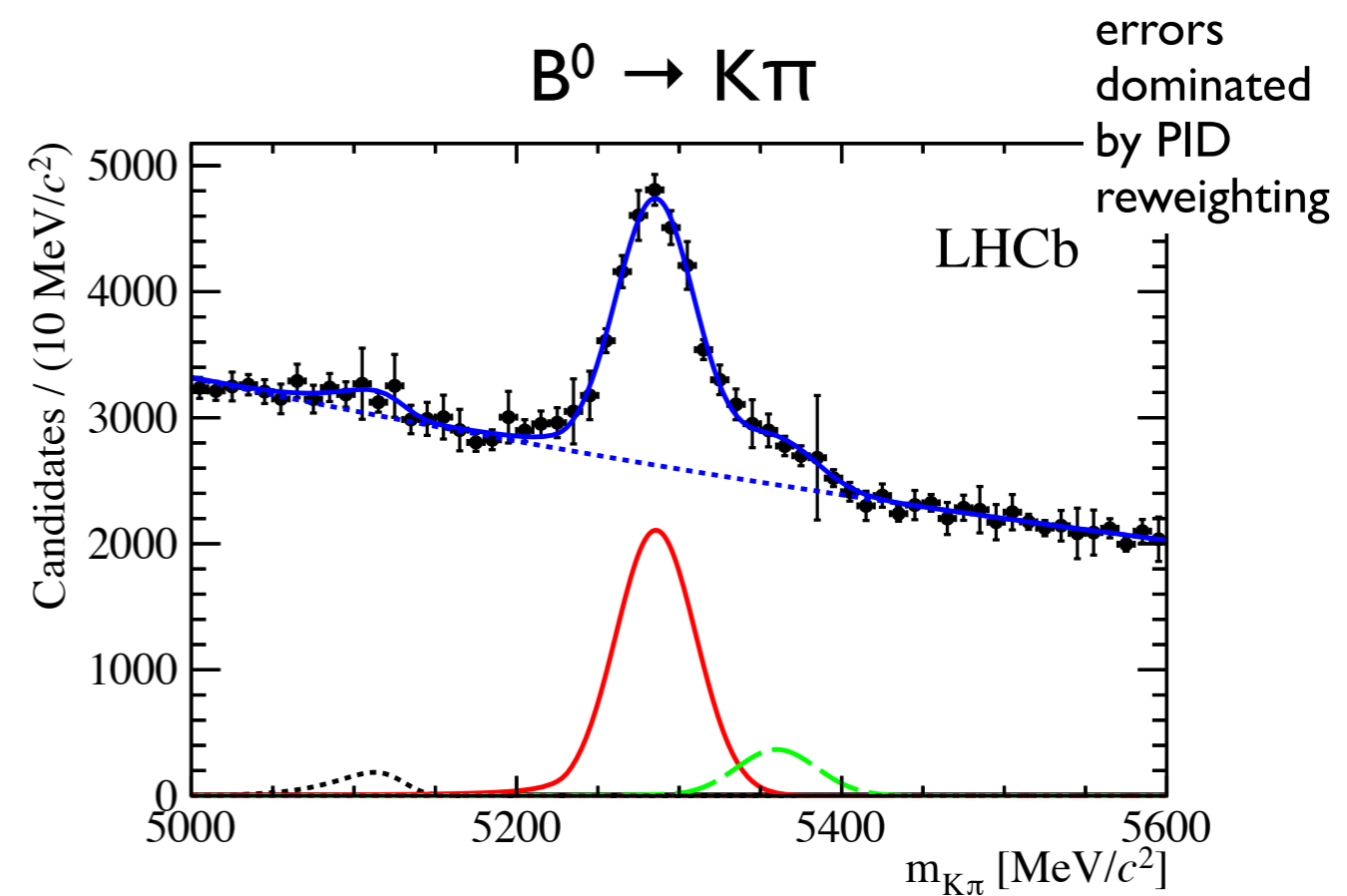
$$BR = BR_{cal} \times \frac{\epsilon_{cal}^{REC} \epsilon_{cal}^{SEL|REC} \epsilon_{cal}^{TRIG|SEL}}{\epsilon_{sig}^{REC} \epsilon_{sig}^{SEL|REC} \epsilon_{sig}^{TRIG|SEL}} \times \frac{f_{cal}}{f_{B_q^0}} \times \frac{N_{B_q^0 \rightarrow \mu^+ \mu^-}}{N_{cal}} = \alpha_{cal} \times N_{B_q^0 \rightarrow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

Evaluated from MC, cross-checked with data Measured on data Ratio of probabilities for a b quark to hadronize to a given meson

2 independent channels:



wrt signal: similar trigger, one more track



wrt signal: different trigger, same topology

a trigger independent of the signal is required

b fragmentation f_s/f_d

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

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

new

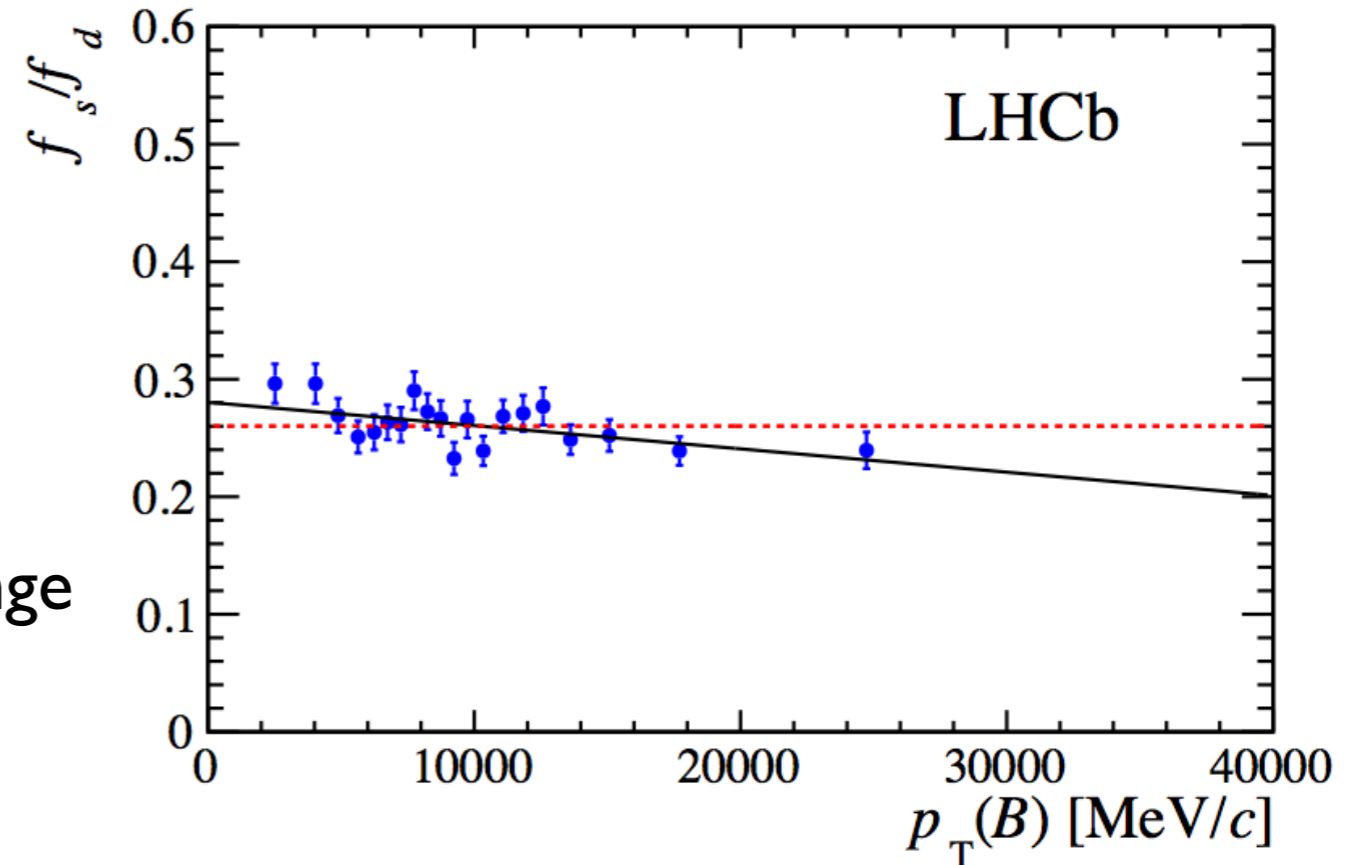
updated at HCP

Combined result at 7 TeV

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

Found to be moderately dependent on p_T :

- effect $\leq 1\sigma$ for the considered p_T range
 \rightarrow dependence is ignored



For 8 TeV data, check the \sqrt{s} dependence of f_s/f_d by looking at $B_s^0 \rightarrow J/\psi \varphi / B^\pm \rightarrow J/\psi K^\pm$ ratio \Rightarrow stable within 1.5σ

Normalization: results



	\mathcal{B} ($\times 10^{-5}$)	$\frac{\epsilon_{\text{norm}}^{\text{rec}} \epsilon_{\text{norm}}^{\text{sel rec}}}{\epsilon_{\text{sig}}^{\text{rec}} \epsilon_{\text{sig}}^{\text{sel rec}}}$	$\frac{\epsilon_{\text{norm}}^{\text{trg sel}}}{\epsilon_{\text{sig}}^{\text{trg sel}}}$	N_{norm}	$\alpha_{B_d \rightarrow \mu^+ \mu^-}^{\text{norm}}$ ($\times 10^{-11}$)	$\alpha_{B_s \rightarrow \mu^+ \mu^-}^{\text{norm}}$ ($\times 10^{-10}$)
$B^+ \rightarrow J/\psi K^+$	6.01 ± 0.21	0.548 ± 0.018	0.932 ± 0.012	$424\,200 \pm 1500$	7.24 ± 0.39	2.83 ± 0.27
$B^0 \rightarrow K^+ \pi^-$	1.94 ± 0.06	0.908 ± 0.031	0.057 ± 0.002	$14\,600 \pm 1100$	6.93 ± 0.67	2.71 ± 0.34

The 2 channels give consistent results, we take the average

$$\alpha_{B_s^0 \rightarrow \mu^+ \mu^-} = (2.80 \pm 0.25) \times 10^{-10}$$

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

8 TeV data

[the quoted values for α refer to $m(B_{0(s)}) \pm 60 \text{ MeV}/c^2$ mass range; they have to be multiplied by ~ 0.9 in the full mass range]

Assuming SM rates, after selection we expect in 8 TeV data (1.1 fb^{-1})

$\sim 13 B_s^0 \rightarrow \mu^+ \mu^-$ and $\sim 1.5 B^0 \rightarrow \mu^+ \mu^-$ in signal region ($m(B_{0(s)}) \pm 60 \text{ MeV}/c^2$)

Background estimation

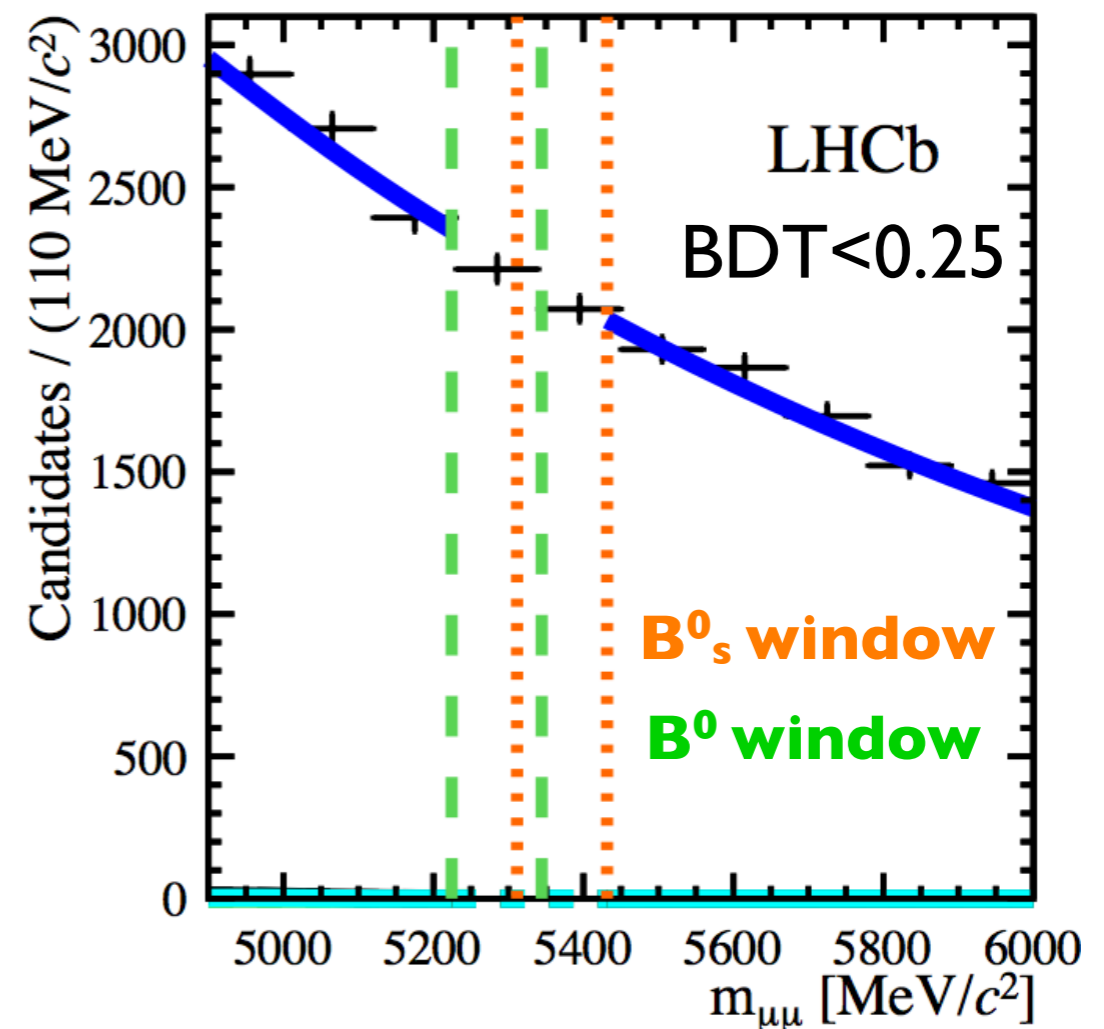
Background sources

The main background source in the $B^0_s \rightarrow \mu^+\mu^-$ signal window, $m(B^0_s) \pm 60 \text{ MeV}/c^2$, is combinatorial from $b\bar{b} \rightarrow \mu^+\mu^-X$

For CLs 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 assumed

For BDT values < 0.5 this is by far the dominant bkg source in the mass range $[4900-6000] \text{ MeV}/c^2$



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:

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

$$B^0_s \rightarrow K^- \mu^+ \nu_\mu$$

$$\Lambda_b^0 \rightarrow p \mu^- \nu_\mu$$

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

$$B^{+(0)} \rightarrow \pi^{+(0)} \mu^+ \mu^-$$

$$B^+_c \rightarrow J/\psi (\mu^+ \mu^-) \mu^+ \nu_\mu$$

(other channels like $B \rightarrow (D \rightarrow \mu X) \mu X$, $B \rightarrow \tau \tau X$ being negligible in [4900-6000] MeV/c² ...)

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/c²

only $B^0_{(s)} \rightarrow h^+ h'^-$ has to be accounted for (mainly for B^0); same as in published analysis of 7 TeV data,

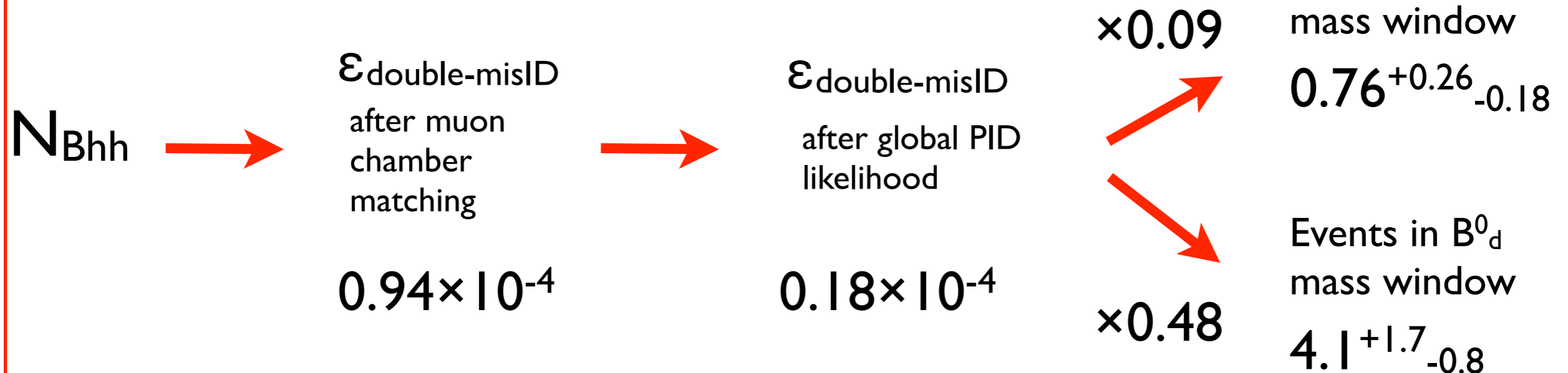
2) mass shape different from exponential \rightarrow bias in the combinatorial background interpolation from mass sidebands

in published analysis, all backgrounds were approximated by an exponential shape, but we reduced the mass range for the interpolation to minimize the bias

$B^0_{(s)} \rightarrow h^+ h'^-$ double misID

1. $K \rightarrow \mu, \pi \rightarrow \mu$ probabilities as a function of momentum and transverse momentum are determined on data from $D^{*+} \rightarrow D^0 \pi^+$, with $D^0 \rightarrow K^- \pi^+$
2. These probabilities are then folded with the MC spectra for the $B^0_{(s)} \rightarrow h^+ h'^-$ decays to get the average double misID efficiency, $\epsilon_{\text{double-misID}}$
3. The mass acceptance for the decay to fall into the signal window is then evaluated by using smeared MC

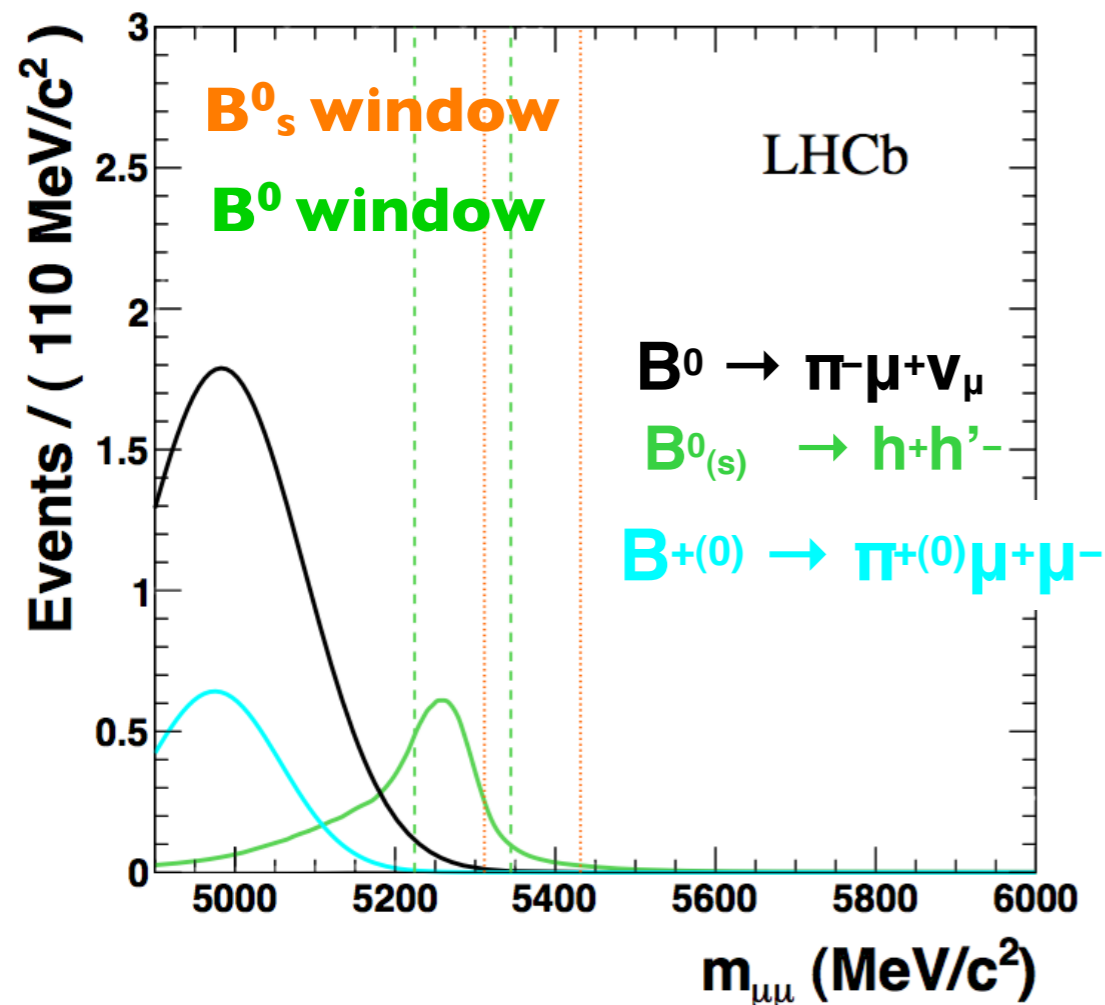
4. For 8 TeV data, full BDT range, we get:



Exclusive background sources

In the present version of the analysis, we improved the combinatorial background interpolation, by including the relevant exclusive backgrounds 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 $B^\pm \rightarrow J/\psi K^\pm$



dominant channels:

Yields for [4900-6000] MeV/c², and BDT>0.8

B⁰ → π⁻μ⁺ν_μ	4.04 ± 0.28
B⁺⁽⁰⁾ → π⁺⁽⁰⁾μ⁺μ⁻	1.32 ± 0.39
B⁰_(s) → h+h'⁻	1.37 ± 0.11

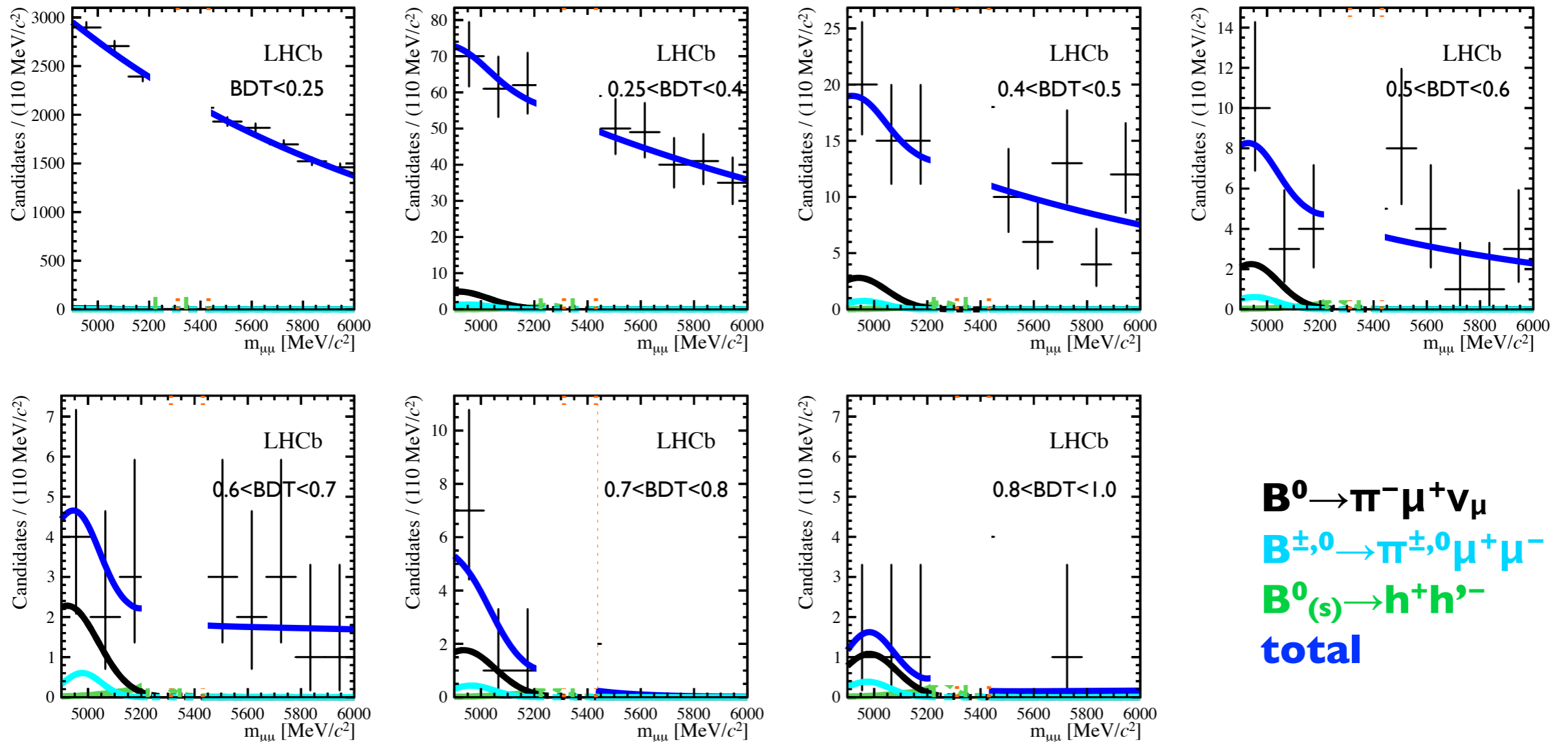
these decays are included in the mass sideband fits (constrained to their expected yields)

systematic studies to evaluate the effect of the subdominant channels

Background description: 8 TeV

Mass sideband fit is shown: 7 BDT bins considered (two most sensitive bins merged)

Fit components: combinatorial (exponential) + $B^0 \rightarrow \pi^- \mu^+ \nu_\mu$ + $B^{+ (0)} \rightarrow \pi^{+ (0)} \mu^+ \mu^-$ + $B^0_{(s)} \rightarrow h^+ h'^-$

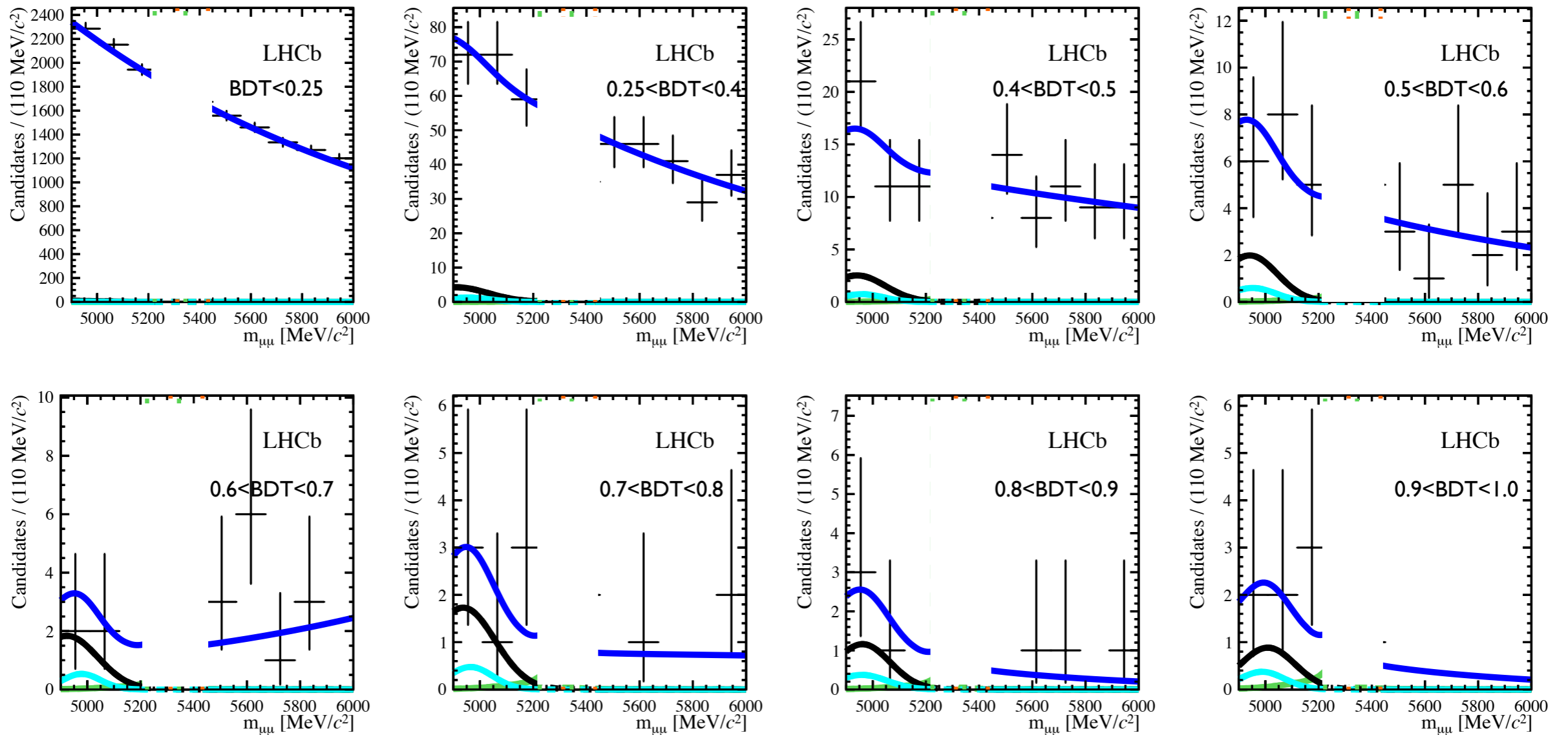


The combinatorial bkg in the signal region is extrapolated from the sideband fit result (accounting for poissonian fluctuations of the number of events in the sideband)

Background description: 7 TeV



The same fit has been repeated also for 7 TeV data, 8 BDT bins, since in the published result no exclusive bkg were considered in the sidebands

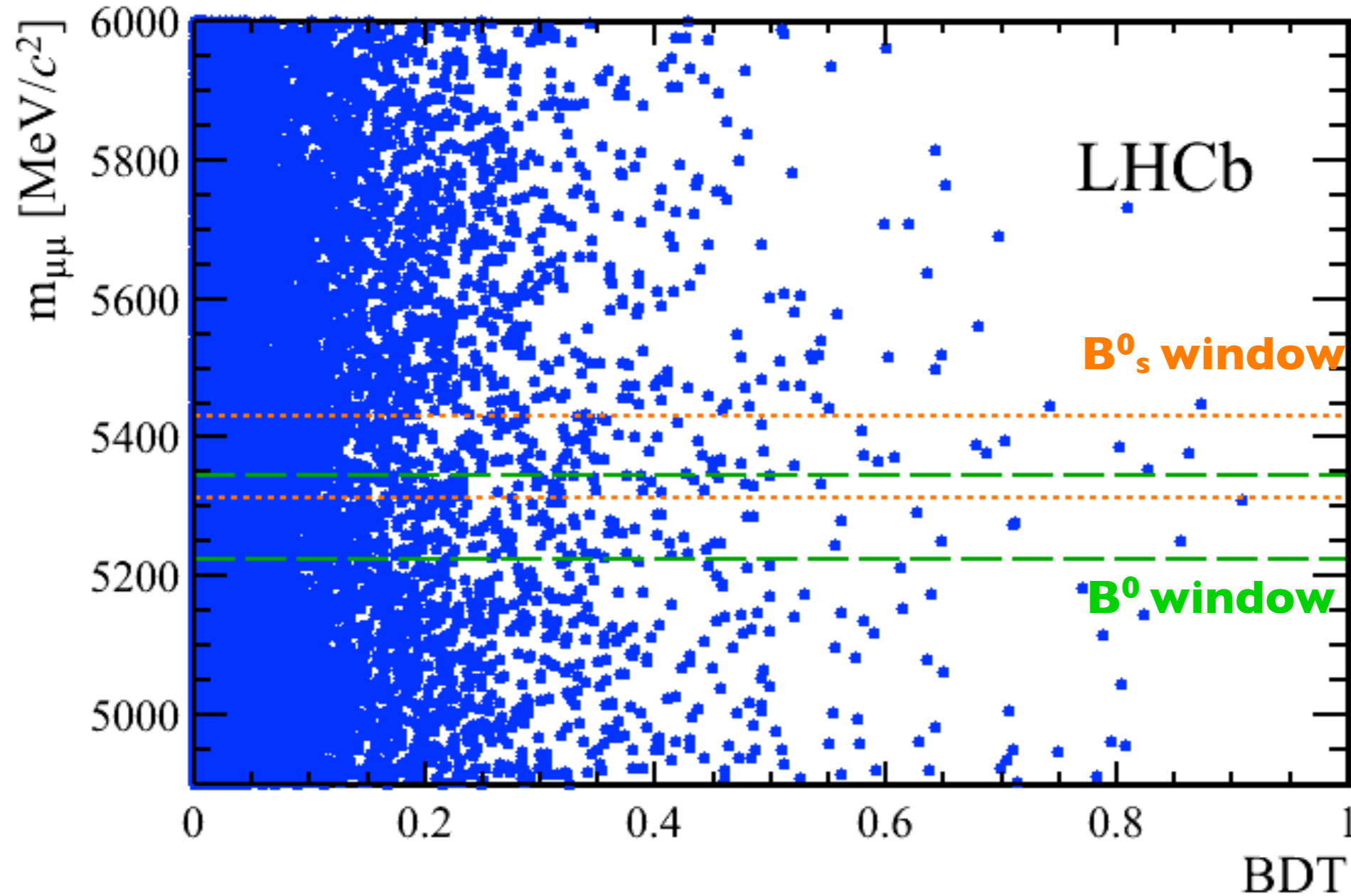


Combinatorial background yield reduced in the high sensitive bins; impact on the published results has been evaluated

$B^0 \rightarrow \pi^- \mu^+ \nu_\mu$
 $B^{\pm,0} \rightarrow \pi^{\pm,0} \mu^+ \mu^-$
 $B^0_{(s)} \rightarrow h^+ h'^-$
total

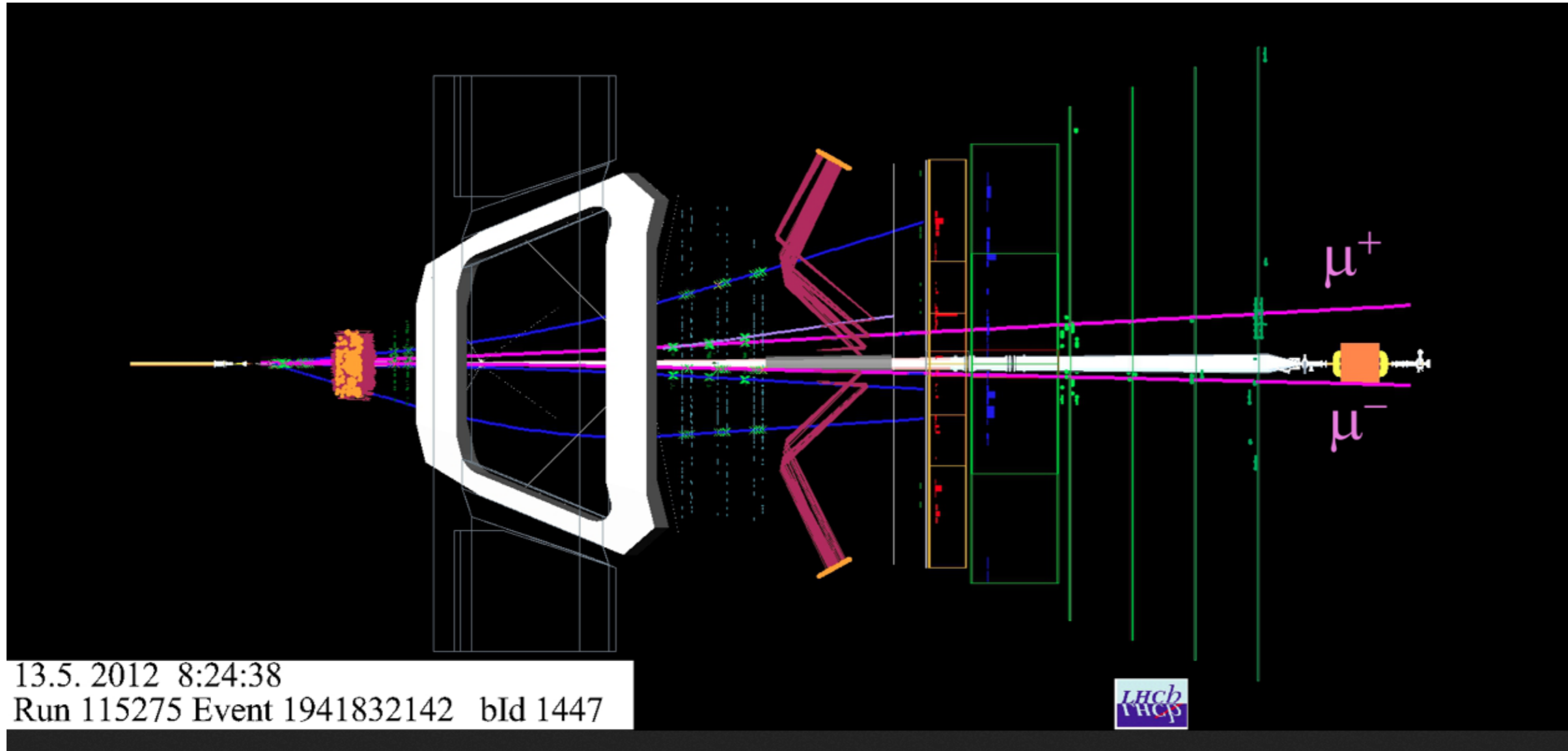
Results

Unblinded 8 TeV data



$B_s^0 \rightarrow \mu^+ \mu^-$ candidate

8 TeV data



B candidate:

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

$$p_T = 4077.4 \text{ MeV}/c \quad t = 2.84 \text{ ps}$$

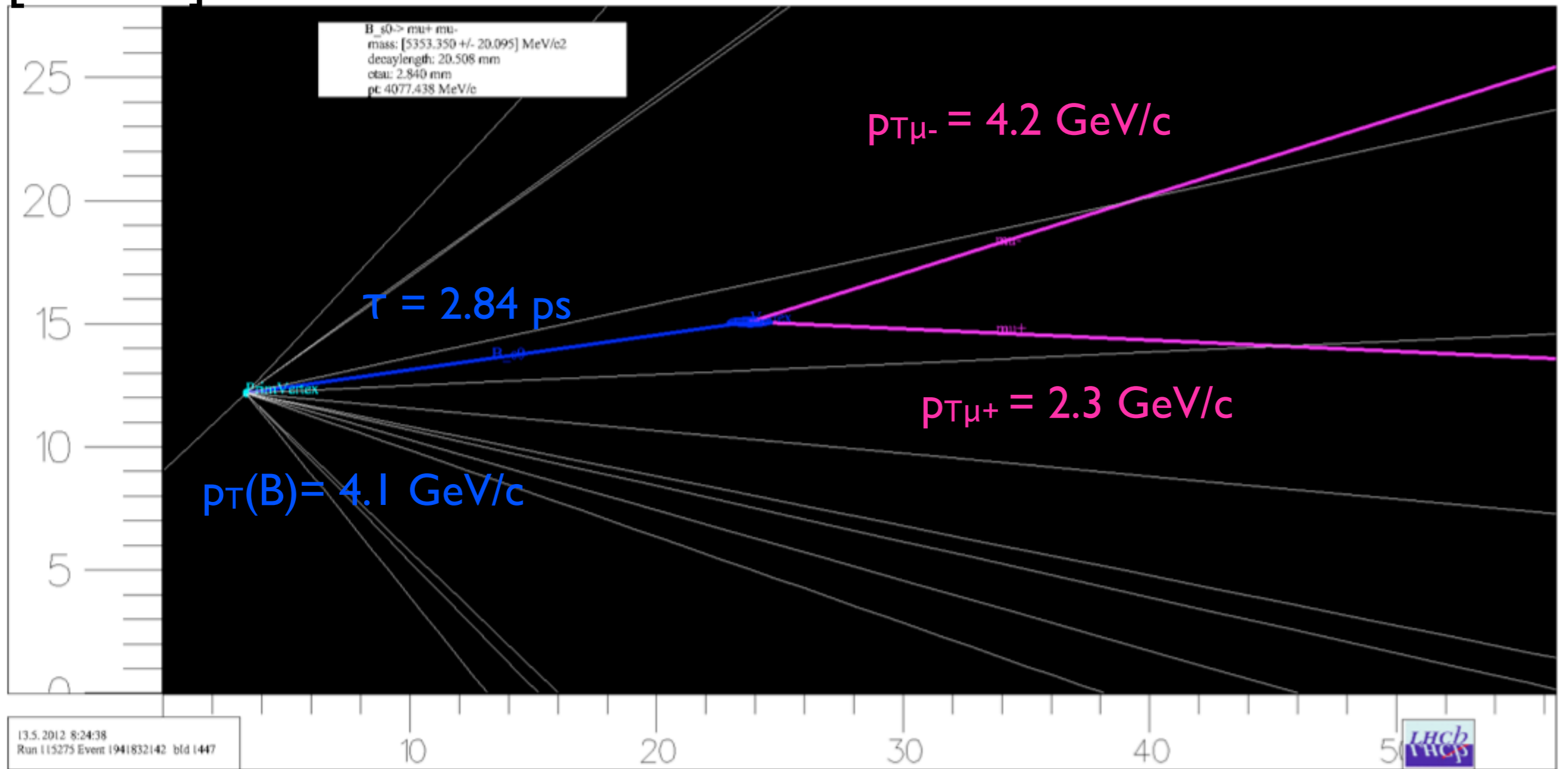
muons:

$$p_{T\mu^+} = 2329.5 \text{ MeV}/c \quad p_{T\mu^-} = 4179.4 \text{ MeV}/c$$

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

8 TeV data

[0.2 mm]



[mm]

$B^0 \rightarrow \mu^+ \mu^-$: upper limit

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

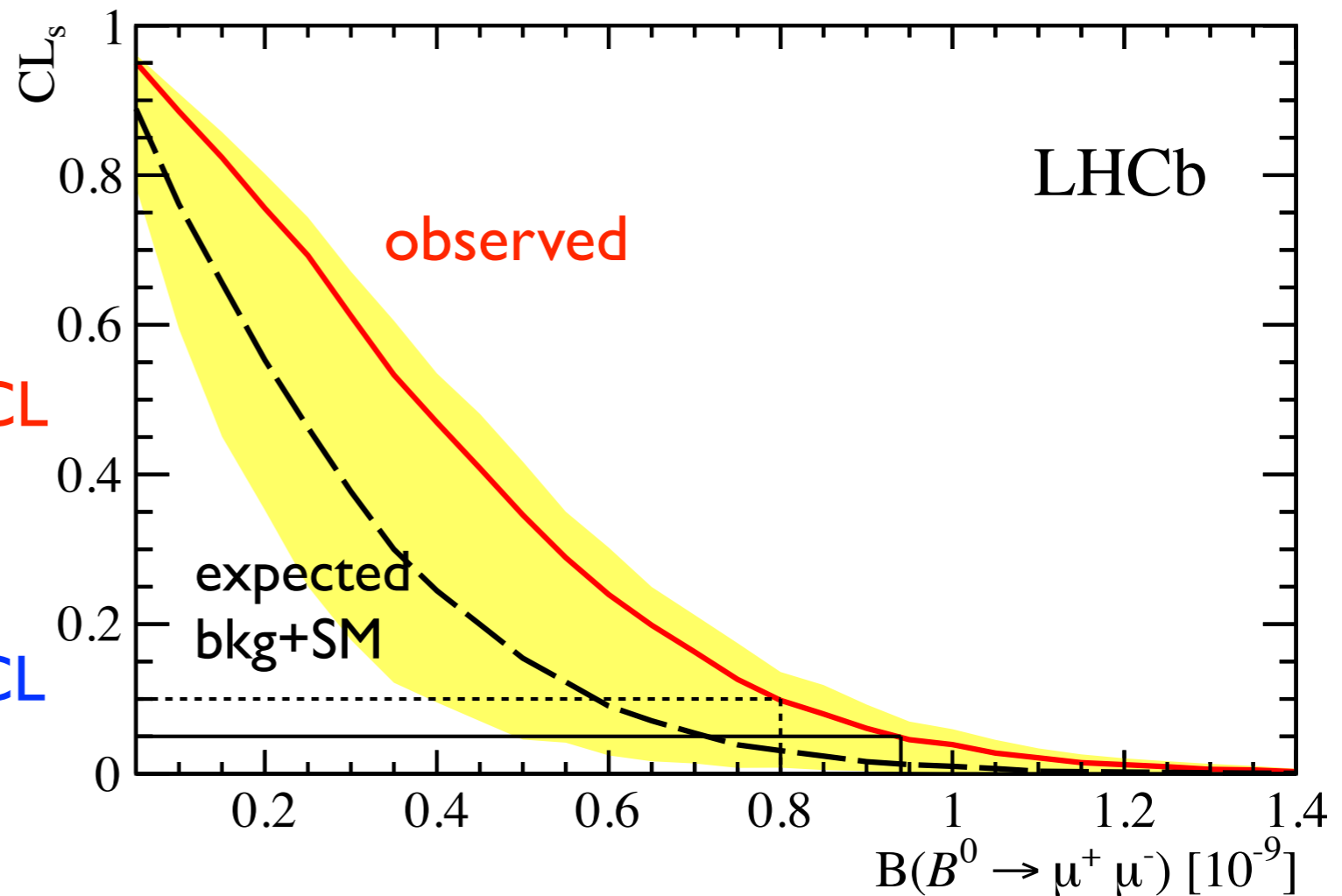
7 TeV (1 fb⁻¹) + 8 TeV (1.1 fb⁻¹):

observed upper limit:

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 9.4 \times 10^{-10} \text{ at 95\% CL}$$

expected limit:

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 7.1 \times 10^{-10} \text{ at 95\% CL}$$



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

$B_s^0 \rightarrow \mu^+ \mu^-$: sensitivity

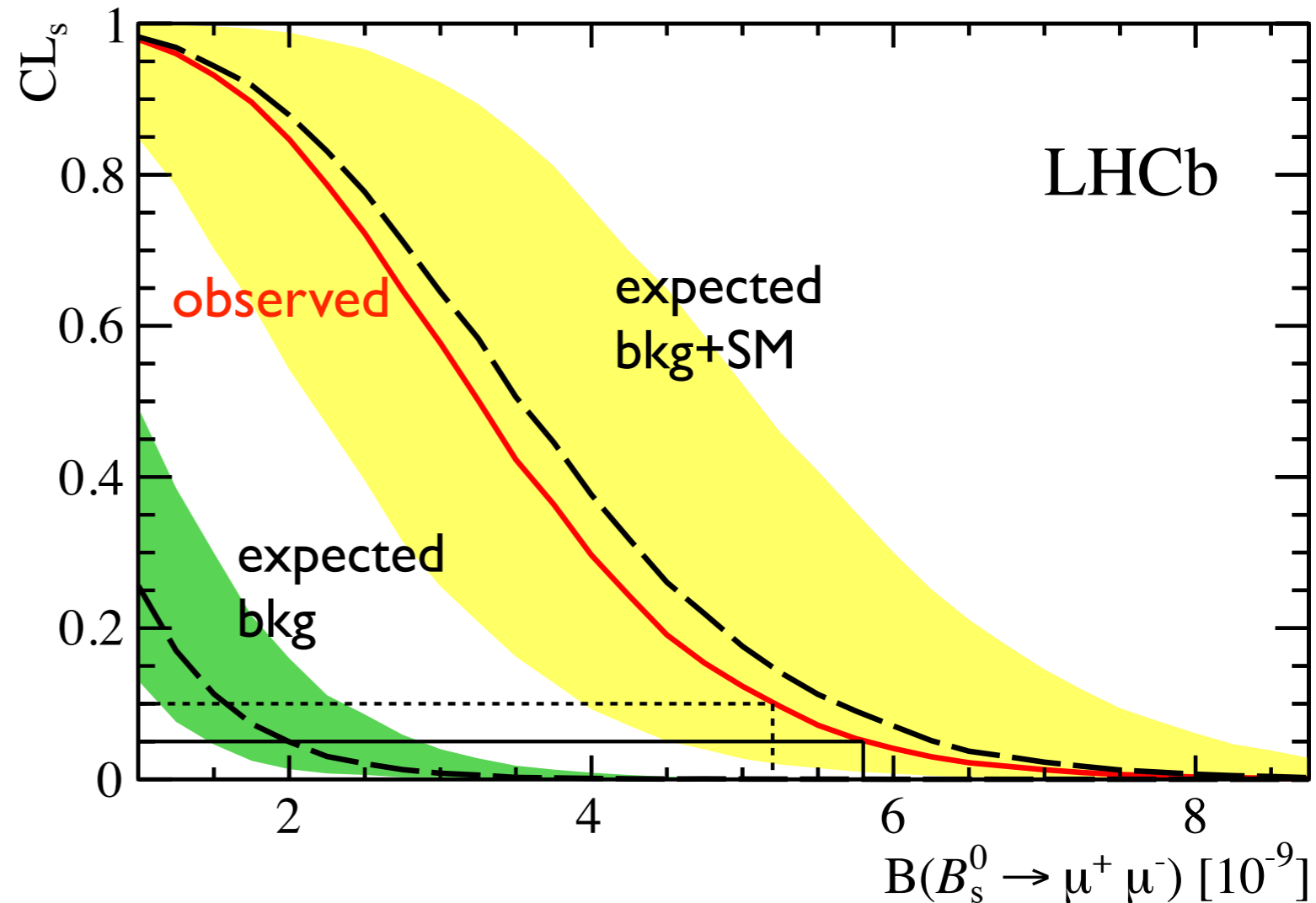
7 TeV (1 fb⁻¹) + 8 TeV (1.1 fb⁻¹)

bkg only p-value: 5.3×10^{-4}
(3.5 σ excess)

double-sided limit:

$$1.1 \times 10^{-9} < \mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 6.4 \times 10^{-9} \text{ at 95\% CL}$$

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



$B^0_s \rightarrow \mu^+ \mu^-$: branching fraction fit

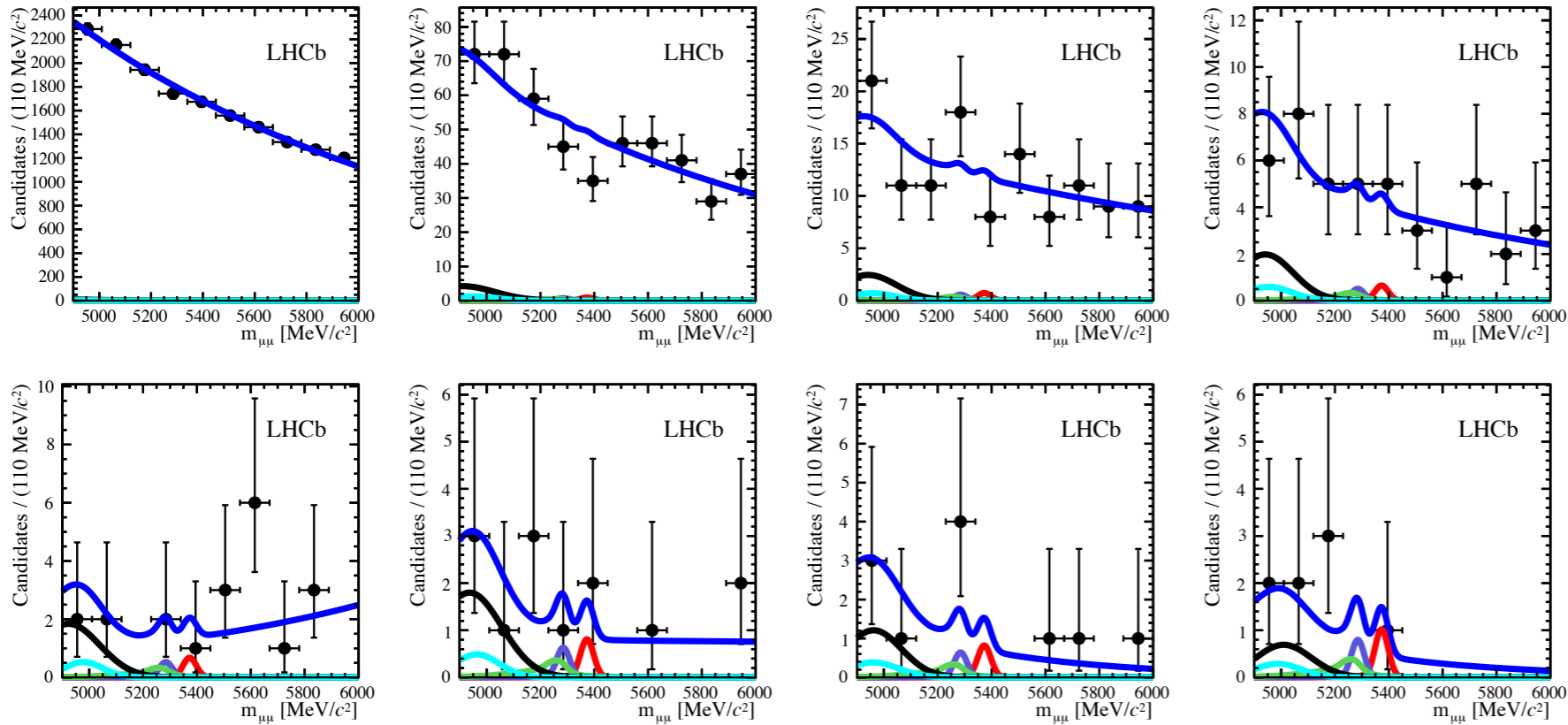


- Unbinned maximum likelihood fit to the mass spectra
 - 8 BDT bins of 7 TeV and 7 BDT bins of 8 TeV data are treated simultaneously
 - mass range [4900-6000] MeV/c²
- Free parameters: $\mathcal{B}(B^0_s \rightarrow \mu^+ \mu^-)$, $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)$ and combinatorial background
- The signal yield in each BDT bin is constrained to the expectation from $B^0_{(s)} \rightarrow h^+ h'^-$ 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 $B^0_s \rightarrow K^- \mu^+ \nu_\mu$ 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

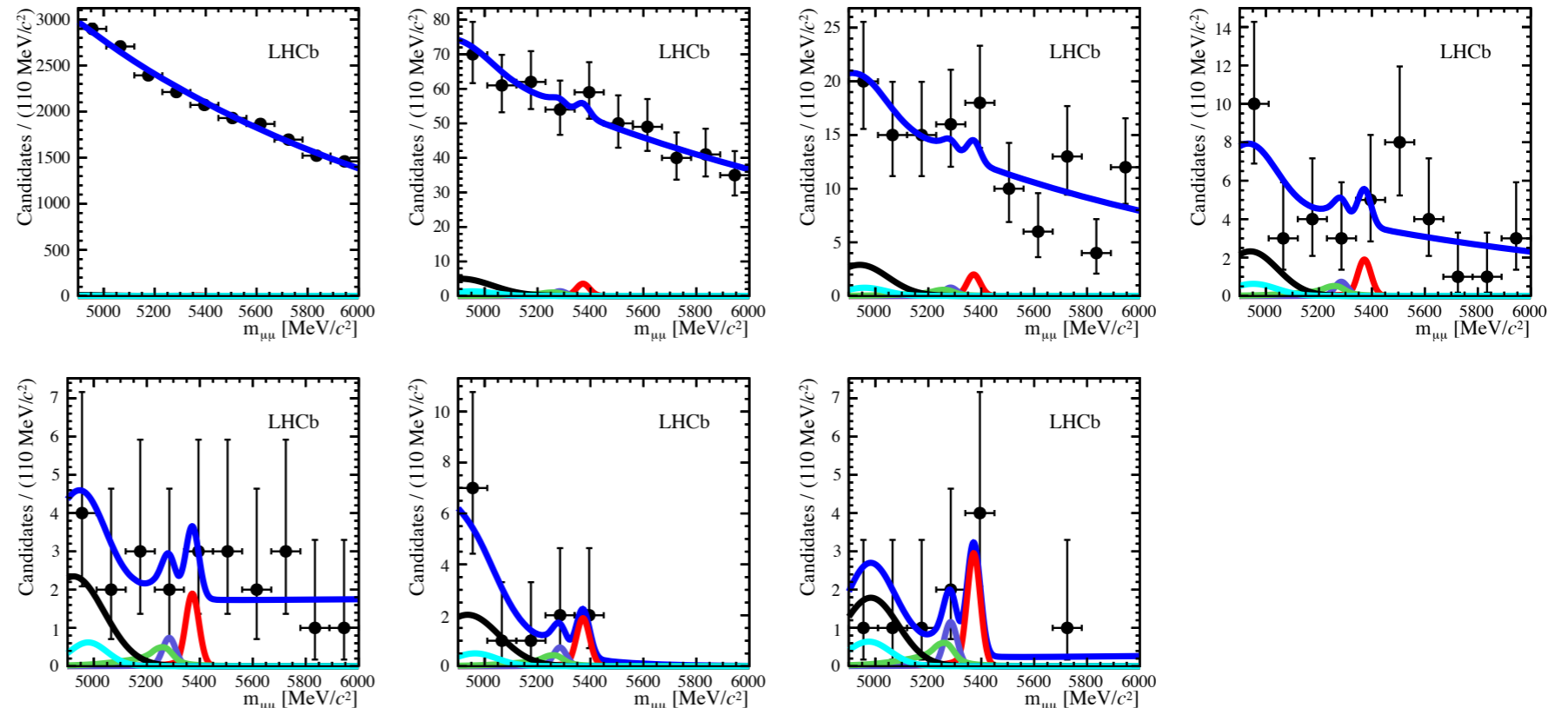
Fit slices

7 TeV data, 1.0 fb⁻¹
8 BDT bins

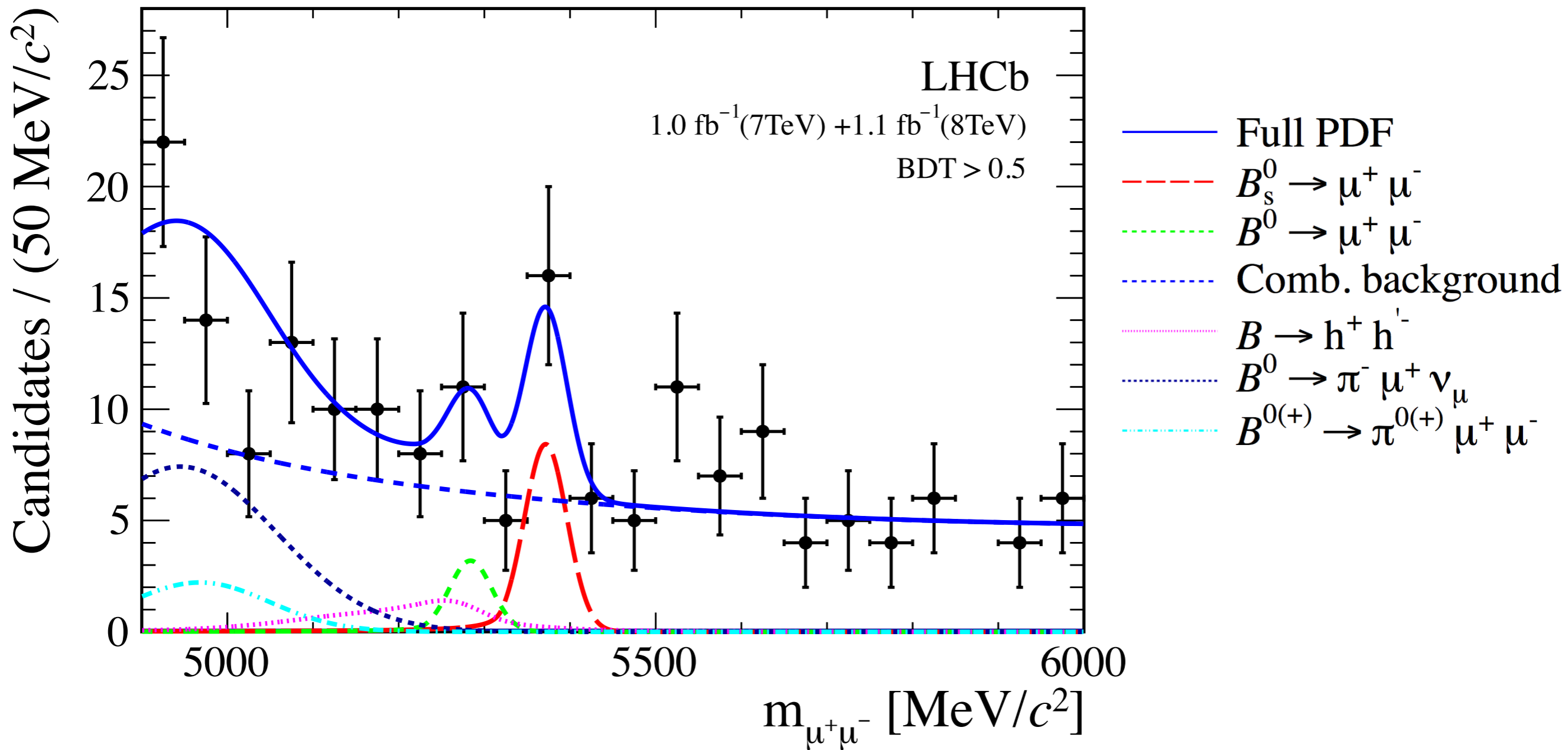
$B_s^0 \rightarrow \mu^+ \mu^-$
 $B^0 \rightarrow \mu^+ \mu^-$
 $B_{(s)}^0 \rightarrow h^+ h'^-$
 $B^0 \rightarrow \pi^- \mu^+ \nu_\mu$
 $B^{\pm,0} \rightarrow \pi^{\pm,0} \mu^+ \mu^-$
total



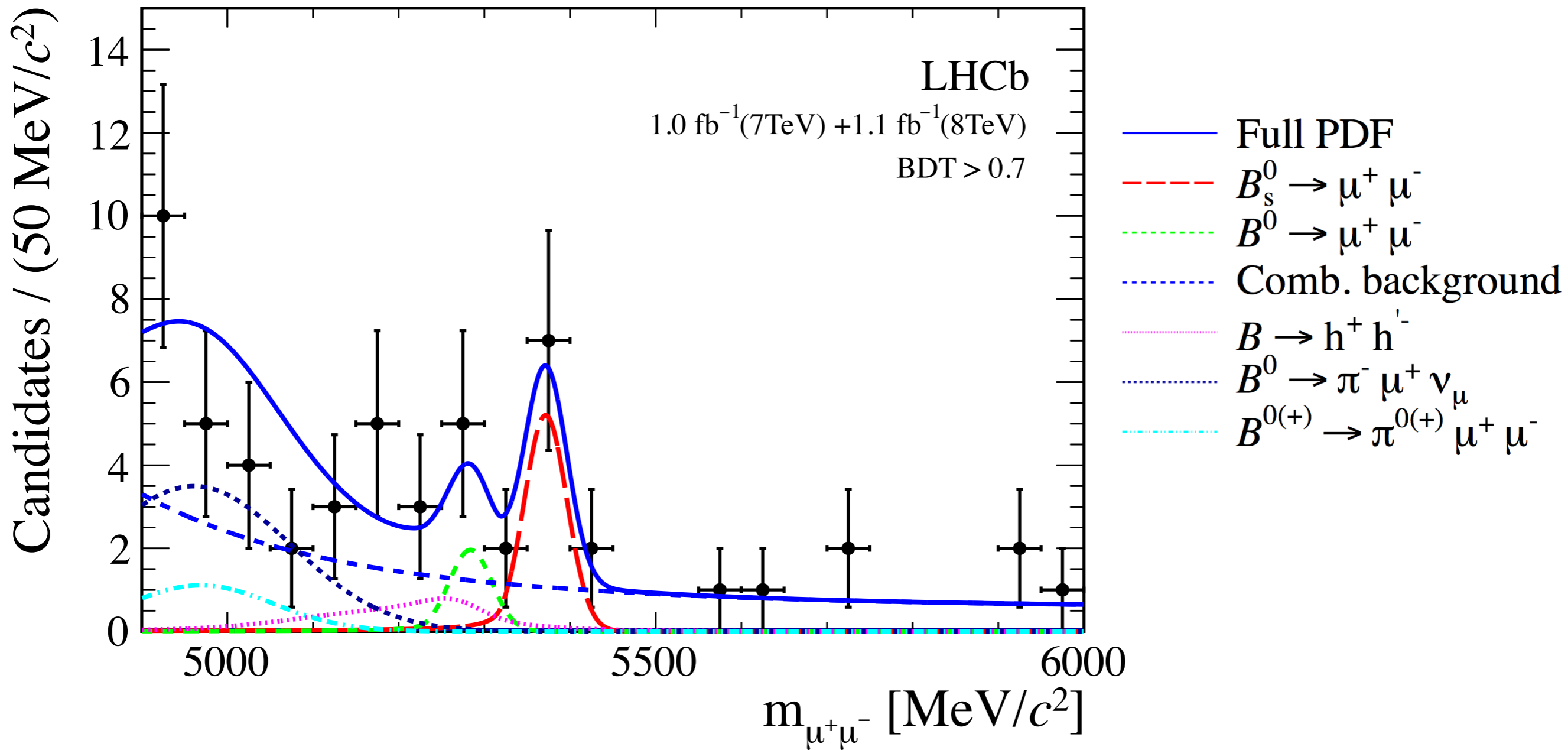
8 TeV data, 1.1 fb⁻¹
7 BDT bins



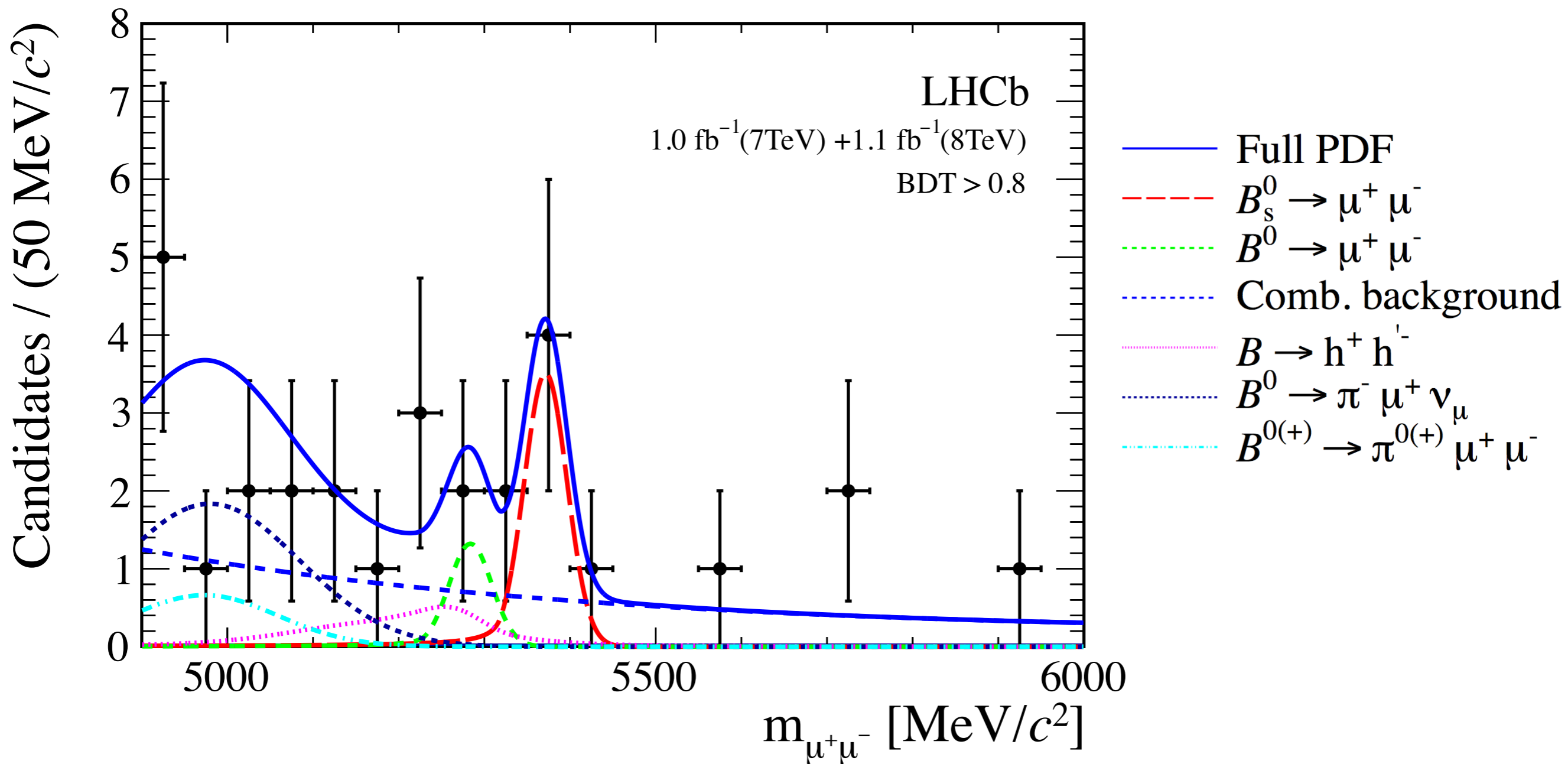
Combined dataset: BDT > 0.5



Combined dataset: BDT > 0.7



Combined dataset: BDT > 0.8



Combined dataset: $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$

7 TeV (1 fb⁻¹) + 8 TeV (1.1 fb⁻¹):

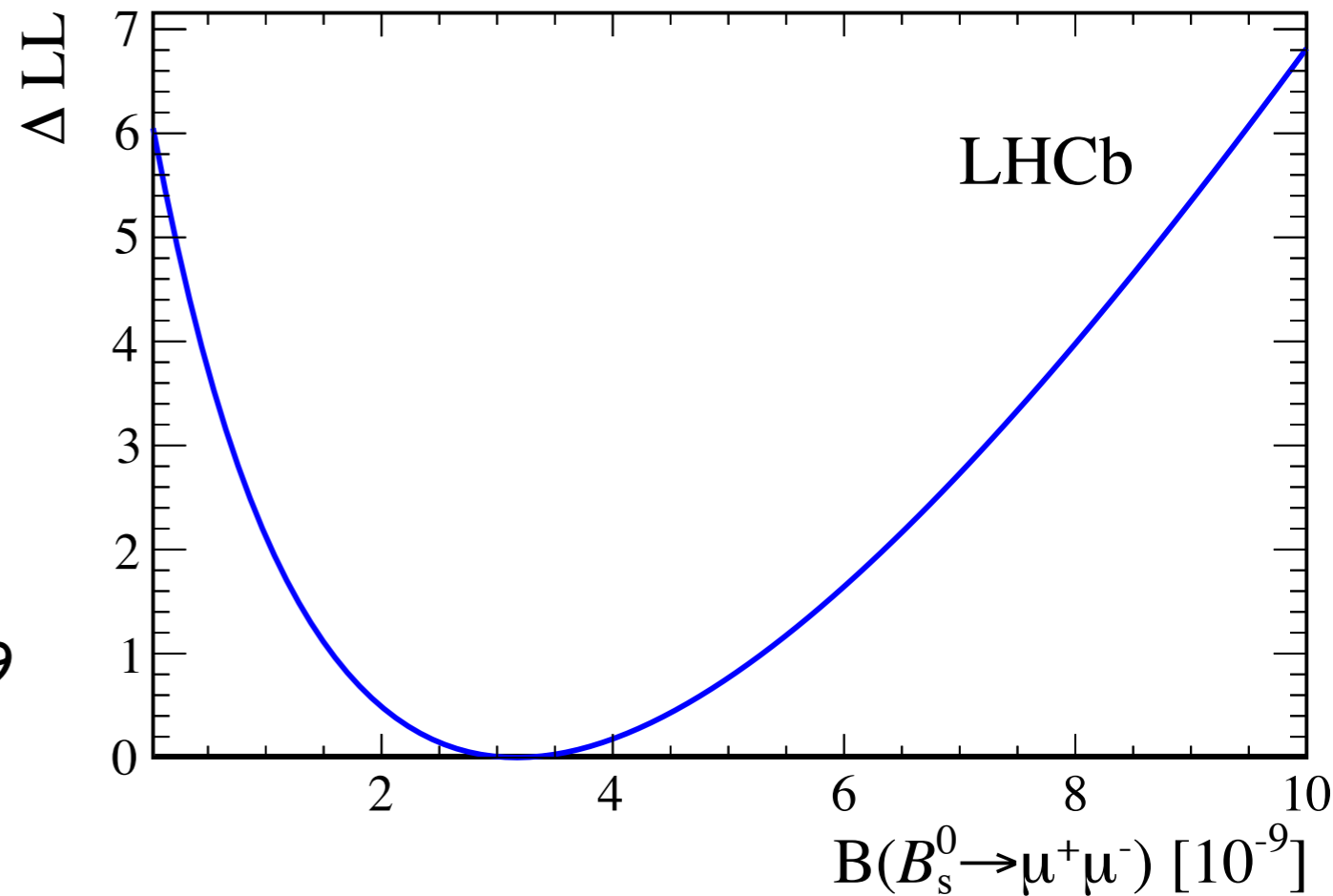
$$\hat{\mathcal{B}}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

SM expectation: $(3.54 \pm 0.30) \times 10^{-9}$

syst from nuisance parameters
and background models:

$$(3.2^{+1.4}_{-1.2} \text{ (stat)} \text{ } ^{+0.5}_{-0.3} \text{ (syst)}) \times 10^{-9}$$

fully dominated by stat error



profile likelihood with nuisance
parameters floated within their errors

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

7 TeV (1 fb⁻¹):

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

p-value: 0.11

8 TeV (1.1 fb⁻¹):

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

p-value: 9×10^{-4}

results from 7 TeV and 8 TeV are compatible at $\sim 1.5\sigma$

Conclusions

We presented today an updated search for $B^0_{(s)} \rightarrow \mu^+\mu^-$ combining 7 TeV (1.0 fb⁻¹) and 8 TeV (1.1 fb⁻¹) data

We see an excess of $B^0_s \rightarrow \mu^+\mu^-$ signal above background expectation with a p-value of 5.3×10^{-4} , corresponding to 3.5σ

this is the first evidence of $B^0_s \rightarrow \mu^+\mu^-$ decay!

A maximum likelihood fit to data yields

$$\mathcal{B}(B^0_s \rightarrow \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

in agreement with SM expectation

On the same dataset, we set the most stringent limit on $B^0 \rightarrow \mu^+\mu^-$ decay:

$$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) < 9.4 \times 10^{-10} \text{ at 95\% CL}$$

We warmly thank our colleagues in the CERN accelerator departments for the excellent performance of the LHC!!

25 years ago...

DEUTSCHES ELEKTRONEN - SYNCHROTRON **DESY**

DESY 87-111
September 1987



B MESON DECAYS INTO CHARMONIUM STATES

ABSTRACT. Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have studied the colour-suppressed decays $B \rightarrow J/\psi X$ and $B \rightarrow \psi' X$. We find the inclusive branching ratios for these two channels to be $(1.07 \pm 0.16 \pm 0.19)\%$ and $(0.46 \pm 0.17 \pm 0.11)\%$ respectively. From a sample of reconstructed exclusive events the masses of the B^0 and B^+ mesons are determined to be $(5279.5 \pm 1.6 \pm 3.0) \text{ MeV}/c^2$ and $(5278.5 \pm 1.8 \pm 3.0) \text{ MeV}/c^2$ respectively. Branching ratios are determined from five events of the type $B^0 \rightarrow J/\psi K^{*0}$ and three of $B^+ \rightarrow J/\psi K^+$. In the same data sample a search for $B^0 \rightarrow e^+e^-$, $\mu^+\mu^-$ and $\mu^\pm e^\mp$ leads to upper limits for such decays.

or even before:

CLEO, Phys. Rev. D 30 (1984) 11

$$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) < 2 \times 10^{-4} \text{ at } 90\% \text{CL}$$

Table 2 Upper limits for exclusive dilepton decays.

decay channel	upper limit with 90% CL
$B^0 \rightarrow e^+e^-$	$8.5 \cdot 10^{-5}$
$B^0 \rightarrow \mu^+\mu^-$	$5.0 \cdot 10^{-5}$
$B^0 \rightarrow e^\pm \mu^\mp$	$5.0 \cdot 10^{-5}$

...this morning...



CERN-PH-EP-2012-335
 LHCb-PAPER-2012-043
 November 12, 2012

First evidence for the decay $B_s^0 \rightarrow \mu^+ \mu^-$

A search for the rare decays $B_s^0 \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow \mu^+ \mu^-$ is performed using data collected in 2011 and 2012 with the LHCb experiment at the Large Hadron Collider. The data samples comprise 1.1 fb^{-1} of proton-proton collisions at $\sqrt{s} = 8 \text{ TeV}$ and 1.0 fb^{-1} at $\sqrt{s} = 7 \text{ TeV}$. We observe an excess of $B_s^0 \rightarrow \mu^+ \mu^-$ candidates with respect to the background expectation. The probability that the background could produce such an excess or larger is 5.3×10^{-4} corresponding to a signal significance of 3.5 standard deviations. A maximum-likelihood fit gives a branching fraction of $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.2_{-1.2}^{+1.5}) \times 10^{-9}$, where the statistical uncertainty is 95 % of the total uncertainty. This result is in agreement with the Standard Model expectation. The observed number of $B^0 \rightarrow \mu^+ \mu^-$ candidates is consistent with the background expectation, giving an upper limit of $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 9.4 \times 10^{-10}$ at 95 % confidence level.

Submitted to Physical Review Letters

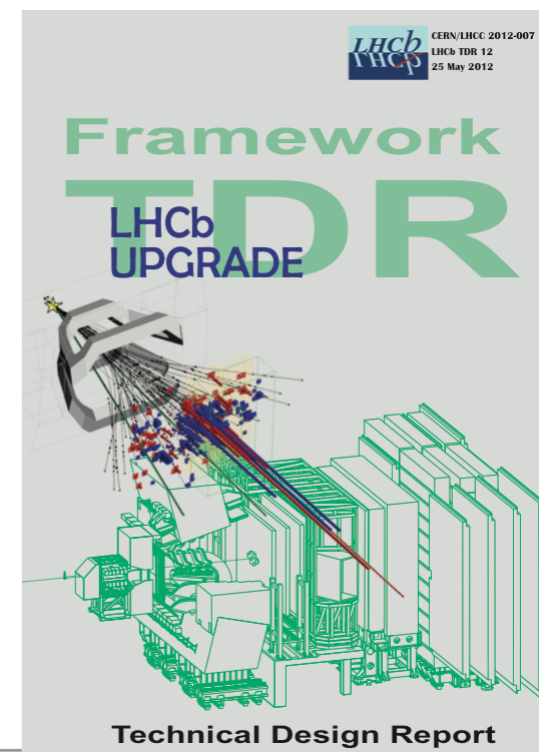
arXiv:1211.2674

...tomorrow!

2012: LHCb Upgrade Framework TDR

<http://cdsweb.cern.ch/record/1443882/files/LHCB-TDR-012.pdf>

- 2018: expect $L_{\text{int}} = 5 \text{ fb}^{-1}$
- 2028: expect $L_{\text{int}} = 50 \text{ fb}^{-1}$



Type	Observable	Current precision	LHCb 2018	Upgrade (50 fb ⁻¹)	Theory uncertainty
B_s^0 mixing	$2\beta_s (B_s^0 \rightarrow J/\psi \phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s (B_s^0 \rightarrow J/\psi f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\text{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta_s^{\text{eff}}(B^0 \rightarrow \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\text{eff}}(B_s^0 \rightarrow \phi\gamma)/\tau_{B_s^0}$	–	5%	1%	0.2%
Electroweak penguin	$S_3(B^0 \rightarrow K^{*0}\mu^+\mu^-; 1 < q^2 < 6 \text{ GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0 A_{\text{FB}}(B^0 \rightarrow K^{*0}\mu^+\mu^-)$	25% [14]	6%	2%	7%
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6 \text{ GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \rightarrow \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \rightarrow K^+\mu^+\mu^-)$	25% [16]	8%	2.5%	$\sim 10\%$
Higgs penguin	$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)/\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$	–	$\sim 100\%$	$\sim 35\%$	$\sim 5\%$
Unitarity triangle angles	$\gamma (B \rightarrow D^{(*)}K^{(*)})$	$\sim 10\text{--}12^\circ$ [19, 20]	4°	0.9°	negligible
	$\gamma (B_s^0 \rightarrow D_s K)$	–	11°	2.0°	negligible
	$\beta (B^0 \rightarrow J/\psi K_S^0)$	0.8° [18]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Spares

Exclusive backgrounds



Measurements:

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

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

$$B^0 \rightarrow \pi \mu \nu_\mu \quad \text{and} \quad B^0(s) \rightarrow h^+ h^- \quad \text{Particle Data Group}$$

Theoretical estimates:

$$\frac{\mathcal{B}(B^0 \rightarrow \pi^0 \mu^+ \mu^-)}{\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-)} = 0.47_{-0.18}^{+0.22} \quad \text{W.-F. Wang and Z.-J. Xiao,, arXiv:1207.0265}$$

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

$$\mathcal{B}(\Lambda_b^0 \rightarrow p \mu^- \nu) = (1.59 \pm 0.84) \cdot 10^{-4} \quad \text{A. Datta, arXiv:hep-ph/9504429}$$

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

Limits and sensitivity



UL are quoted at 95%CL

	Expected UL (bkg)	Expected UL (SM+bkg)	Observed UL	Observed I-CLb
7 TeV	$9.4 \times 10^{-10} *$	10.5×10^{-10}	$13.0 \times 10^{-10} *$	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}
 I-CLb = 0.60



7 TeV

I-CLb = 0.11

UL = 5.1×10^{-9} at 95% CL

to be compared with published:

I-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
$B_s^0 \rightarrow \mu^+ \mu^-$ (2011)	Exp. comb. bkg	1880^{+33}_{-33}	$55.5^{+3.0}_{-2.9}$	$12.1^{+1.4}_{-1.3}$	$4.16^{+0.88}_{-0.79}$	$1.81^{+0.62}_{-0.51}$	$0.77^{+0.52}_{-0.38}$	$0.47^{+0.48}_{-0.36}$	$0.24^{+0.44}_{-0.20}$
	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
$B^0 \rightarrow \mu^+ \mu^-$ (2011)	Exp. comb. bkg	1995^{+34}_{-34}	$59.2^{+3.3}_{-3.2}$	$12.6^{+1.6}_{-1.5}$	$4.44^{+0.99}_{-0.86}$	$1.67^{+0.66}_{-0.54}$	$0.75^{+0.58}_{-0.40}$	$0.44^{+0.57}_{-0.38}$	$0.22^{+0.48}_{-0.20}$
	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
$B_s^0 \rightarrow \mu^+ \mu^-$ (2012)	Exp. comb. bkg	2345^{+40}_{-40}	$56.7^{+3.0}_{-2.9}$	$13.1^{+1.5}_{-1.4}$	$4.42^{+0.91}_{-0.81}$	$2.10^{+0.67}_{-0.56}$	$0.35^{+0.42}_{-0.22}$	$0.39^{+0.33}_{-0.21}$	
	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	
$B^0 \rightarrow \mu^+ \mu^-$ (2012)	Exp. comb. bkg	2491^{+42}_{-42}	$59.5^{+3.3}_{-3.2}$	$13.9^{+1.6}_{-1.5}$	$4.74^{+1.00}_{-0.89}$	$2.10^{+0.74}_{-0.61}$	$0.55^{+0.50}_{-0.31}$	$0.29^{+0.34}_{-0.19}$	
	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	

7 TeV
data

8 TeV
data