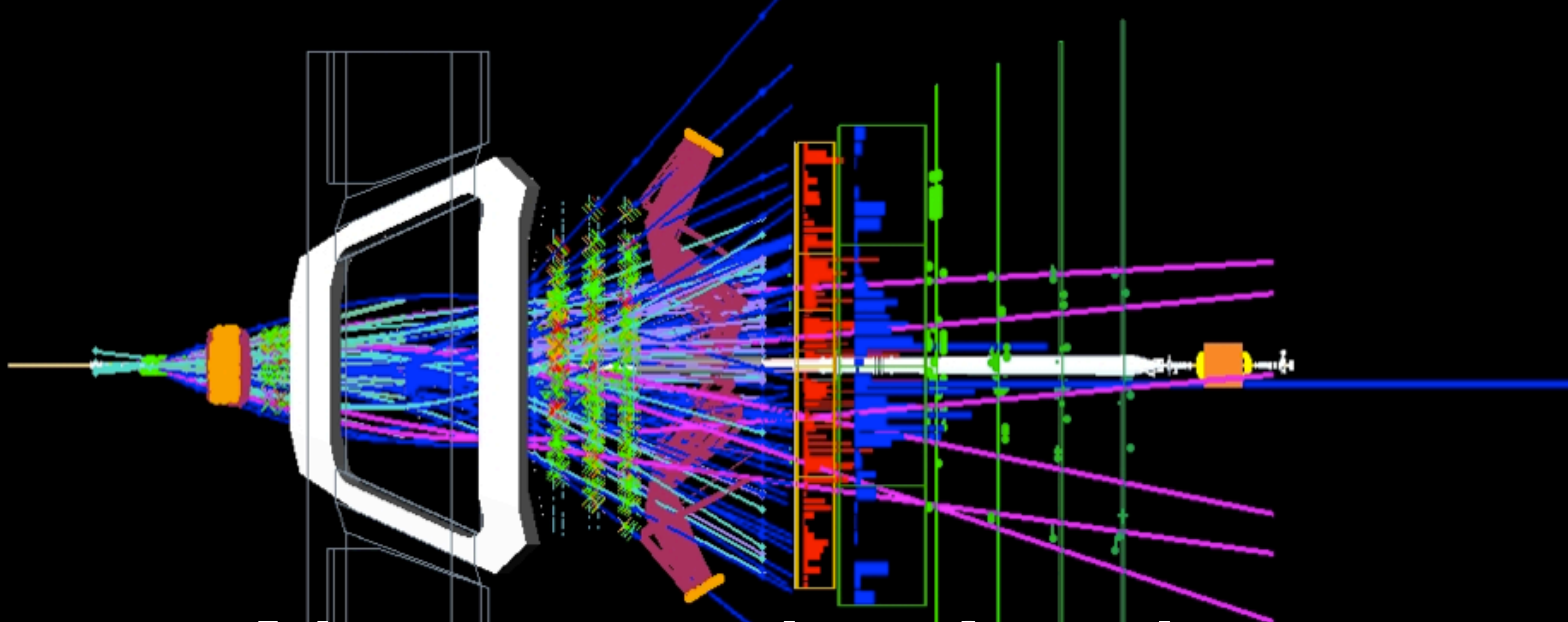


New results in the search for $B^0_{(s)}\rightarrow\mu^+\mu^-$

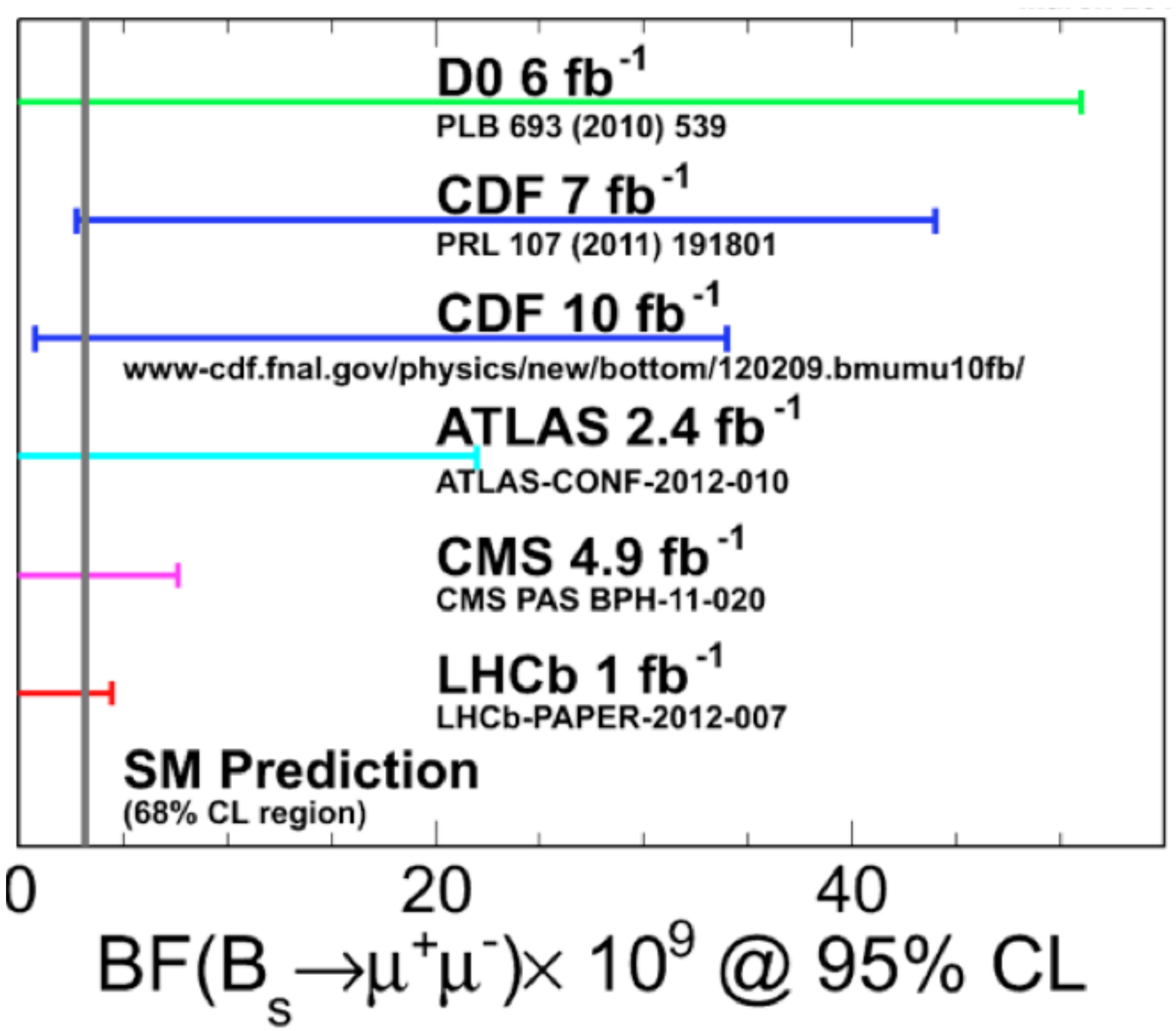
Flavio Archilli
LNF - INFN

Istituto Nazionale di Fisica Nucleare

... the Bsmumu group

Status of $B_s^0 \to \mu^+\mu^-$

March 2012



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

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

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

Standard Model prediction

FCNC process $\rightarrow$ 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 $f_{Bs} = (227 \pm 8)$ 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^0_s system:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)^{\langle t \rangle} = \frac{1}{1-y_s} \cdot \mathcal{B}(B_s^0 \to \mu^+\mu^-)^{t=0}$$
$$= (3.54 \pm 0.30) \cdot 10^{-9}$$

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

Beyond the SM

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

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

Start to be probed only now

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

Model independent view:

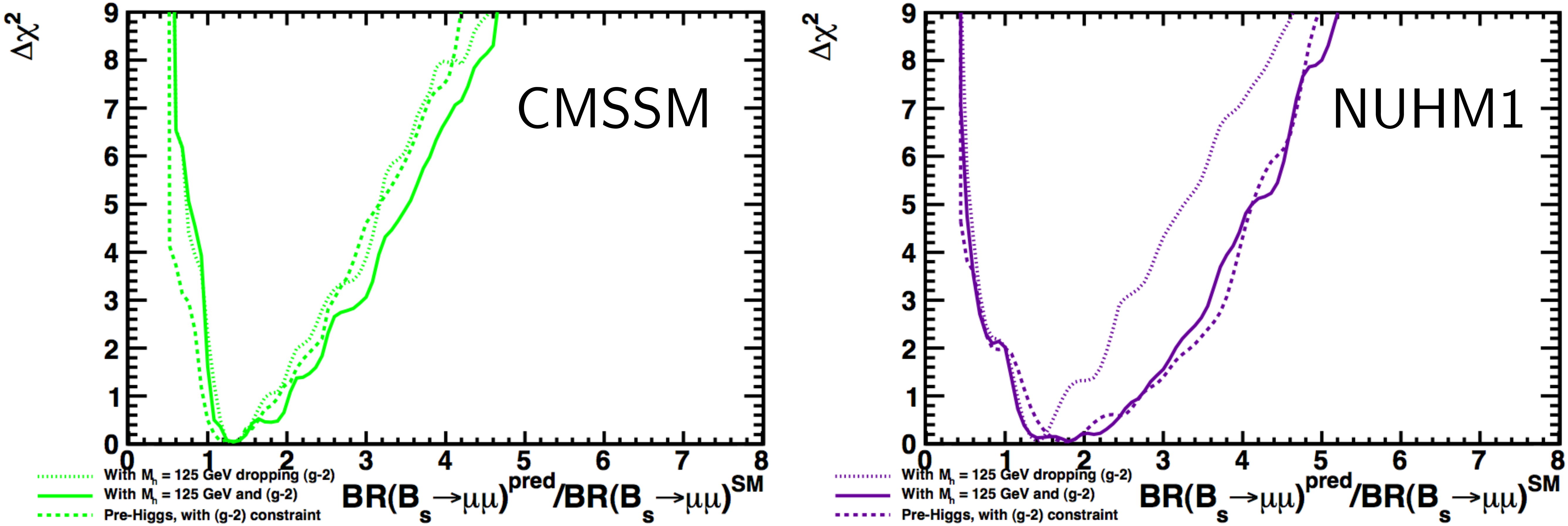
use all experimental info from $B \to X_s \ell^+\ell^-$, $B \to X_s\gamma$, $B \to K^*\mu^+\mu^-$, $B \to K\mu^+\mu^-$ and $B \to \mu^+\mu^-$ to set model-independent constraints on Wilson coefficients

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

Beyond the 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.

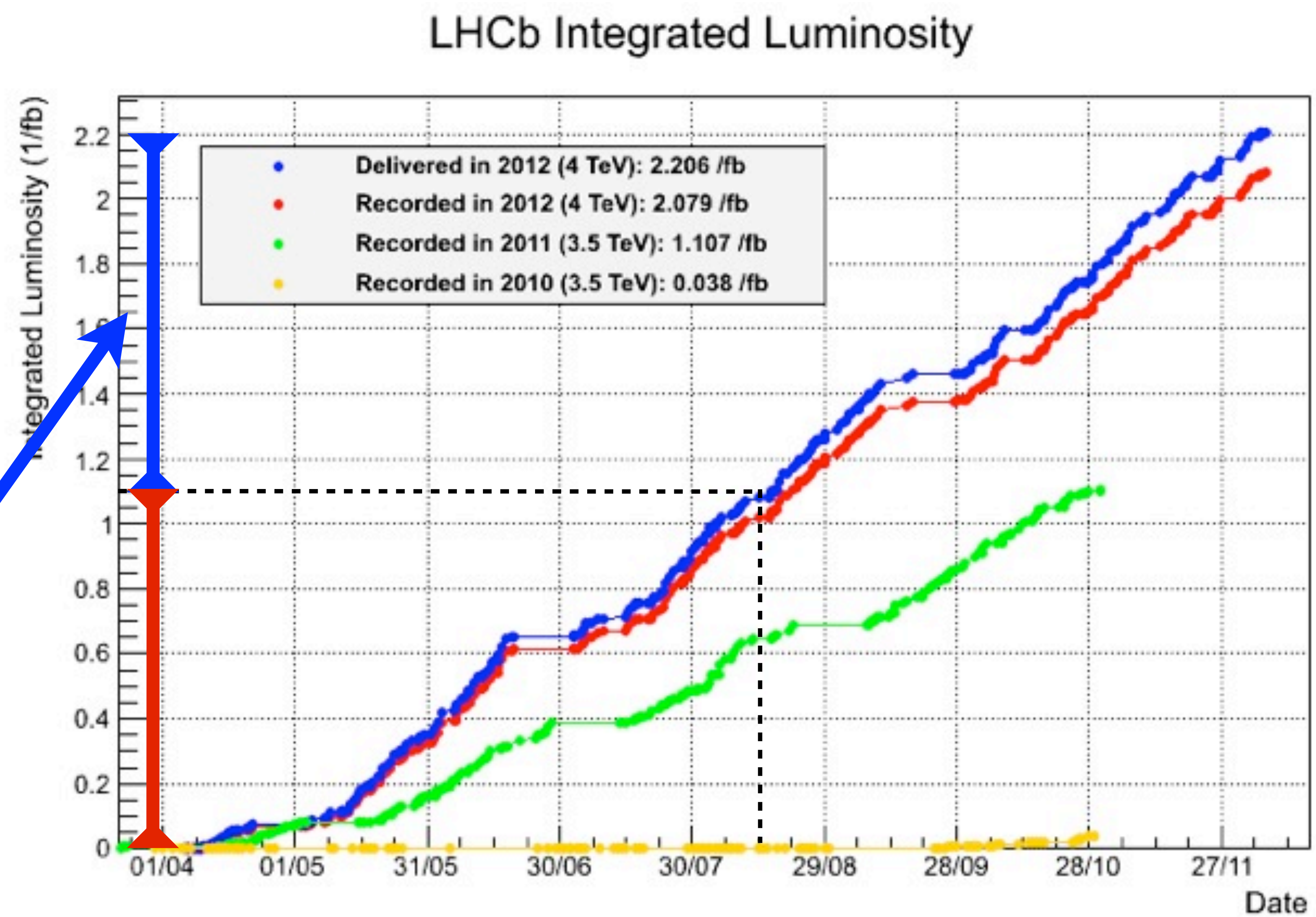
Datasets

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)**

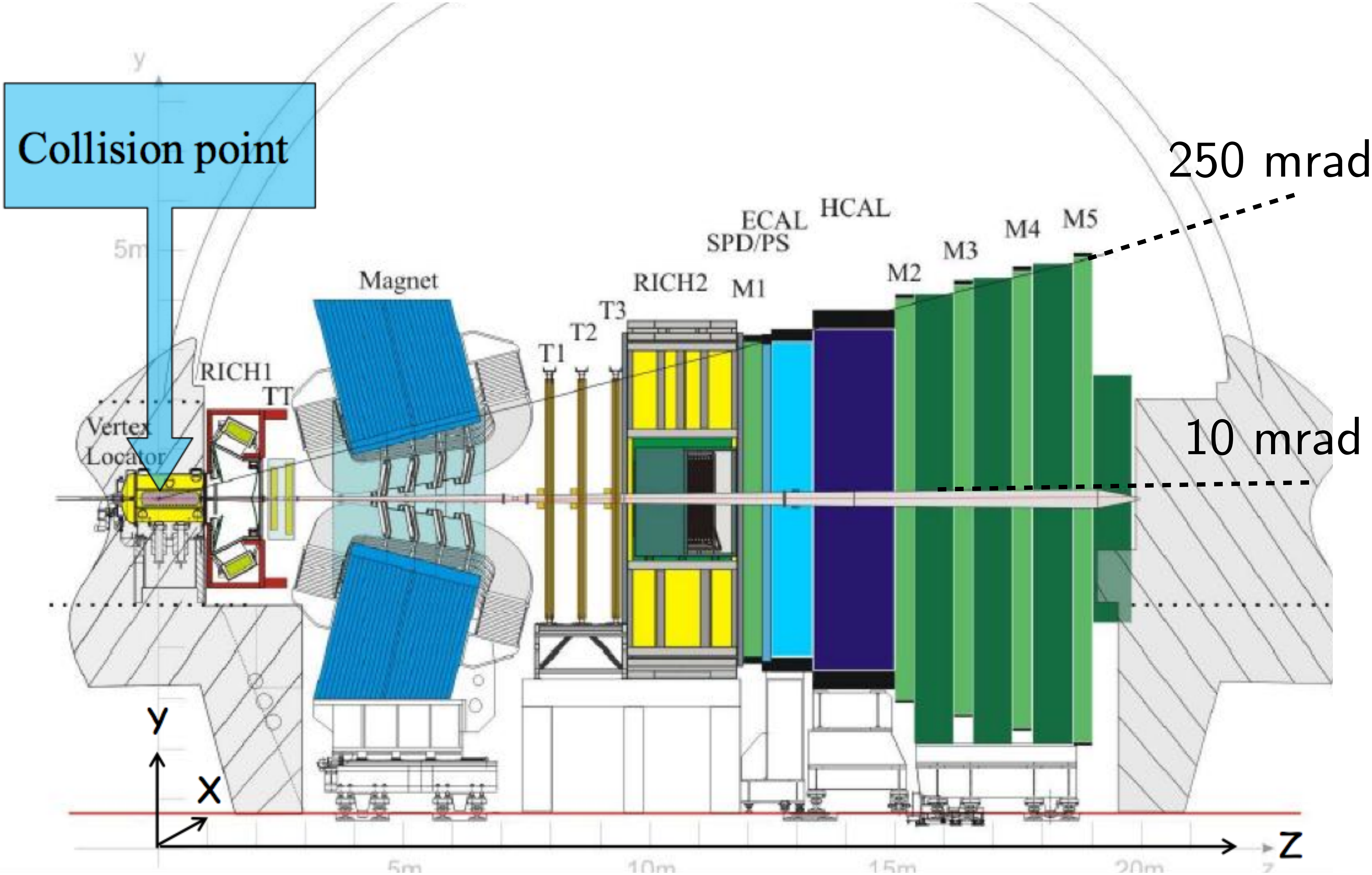
2012: another great year of data taking thanks to the performance of LHC!

additional 1.1 fb^{-1} to be analyzed



7 TeV data already published in PRL 108 (2012) 231801 **is reanalyzed** as part of the measurement presented here; <u>the result supersedes the previous publication</u>

LHCb detector



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

1) Managed to run the experiment at 4×10^{32} cm^{-2}s^{-1} with 1262 colliding bunches (twice the design luminosity with half number of bunches)

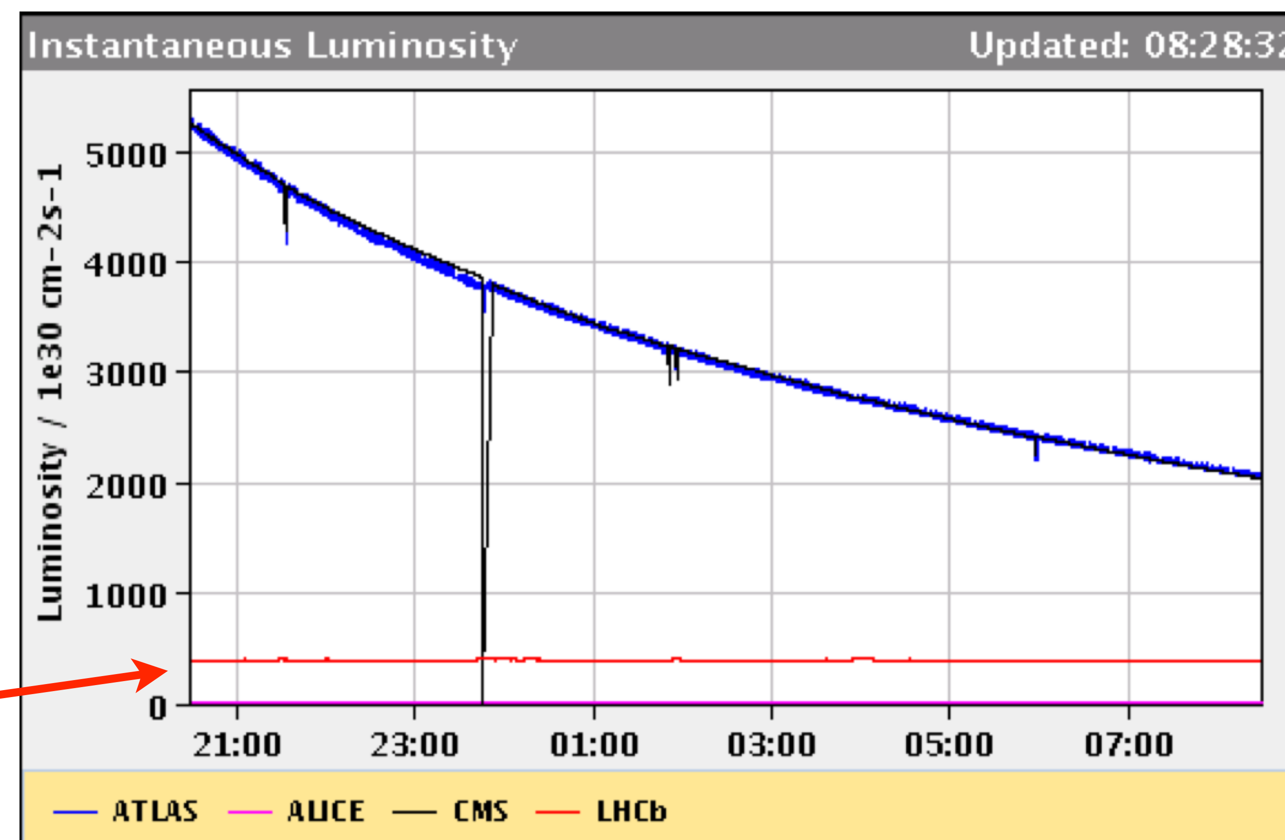
→ **4 times more collisions per crossing than design: $\langle\mu\rangle_{8TeV}\sim1.7$**

→ higher occupancy in the detector

→ challenging for the trigger

2) Large acceptance, efficient muon trigger

- **acceptance × reconstruction efficiency for signal is ~10%**
- L0: single μ $p_T>1.76$ GeV/c, di-μ $\sqrt{(p_{T1} * p_{T2})}>1.6$GeV/c
- HLT: IP and invariant mass cuts
- **overall trigger efficiency ~90%**



LHCb instantaneous luminosity: leveling @ work!

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

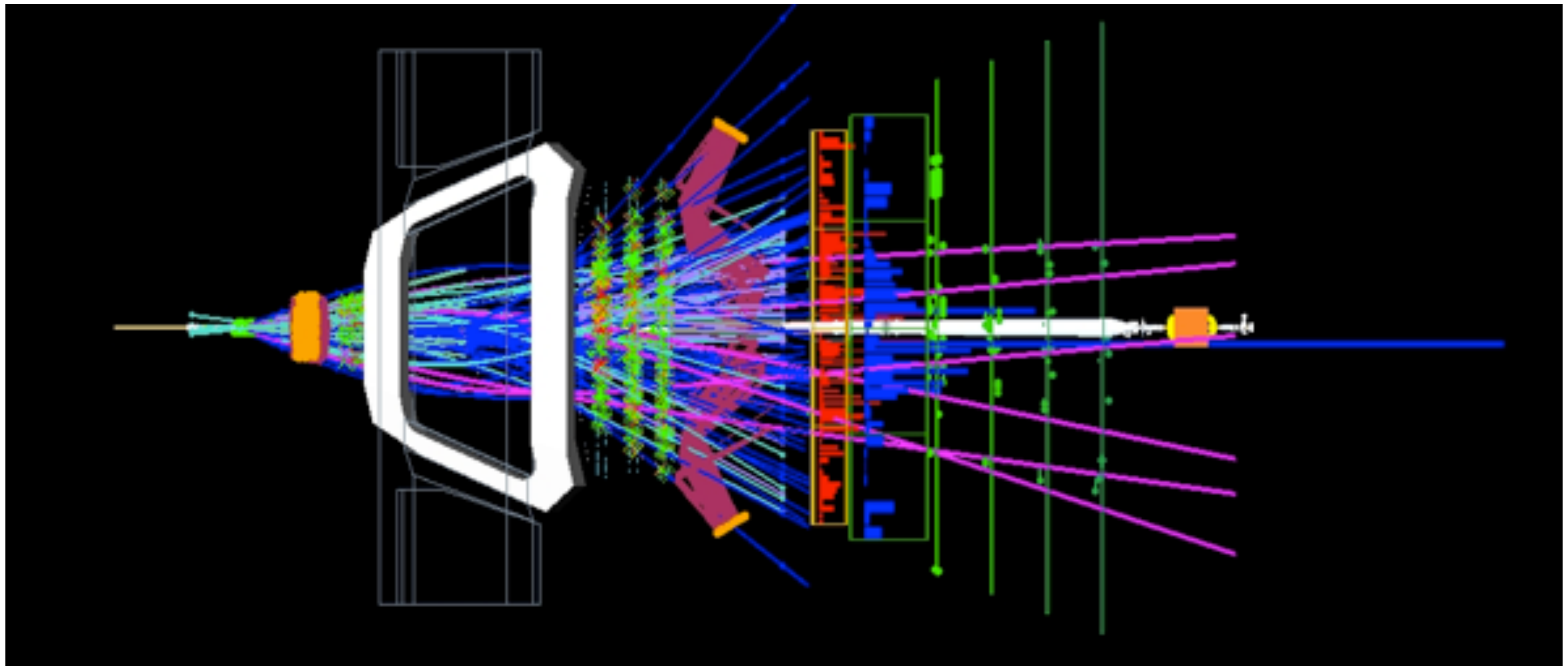
3) Background reduction:

- Very good momentum resolution : $\delta p/p \sim 0.4\% \to 0.6\%$ 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: $\varepsilon(\mu\to\mu)\sim 98\%$, $\varepsilon(\pi\to\mu)\sim 0.6\%$, $\varepsilon(K\to\mu)\sim 0.3\%$, $\varepsilon(p\to\mu)\sim 0.3\%$

4) Excellent vertex and IP resolution:

- to separate signals from background : $\sigma(IP)\sim 25$ μm @ $p_T=2$ GeV/c



~1.7 pp interactions per Xing

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

Analysis strategy

- 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/c^2; loose cut on MVA discriminant

- Signal/Background separation by invariant di-μ 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 ($h=\pi$, K) and for background with IM sidebands

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

Analysis strategy

- Background estimation

  Combinatorial $bb \to \mu\mu X$

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

  Detailed studies on various exclusive backgrounds

updated on 7 TeV
and 8 TeV

Results are provided in terms of:

- Limits and significance determination with CLs method

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

- Unbinned maximum likelihood fit for the branching fraction

  Use full mass range: [4900-6000] MeV/c^2

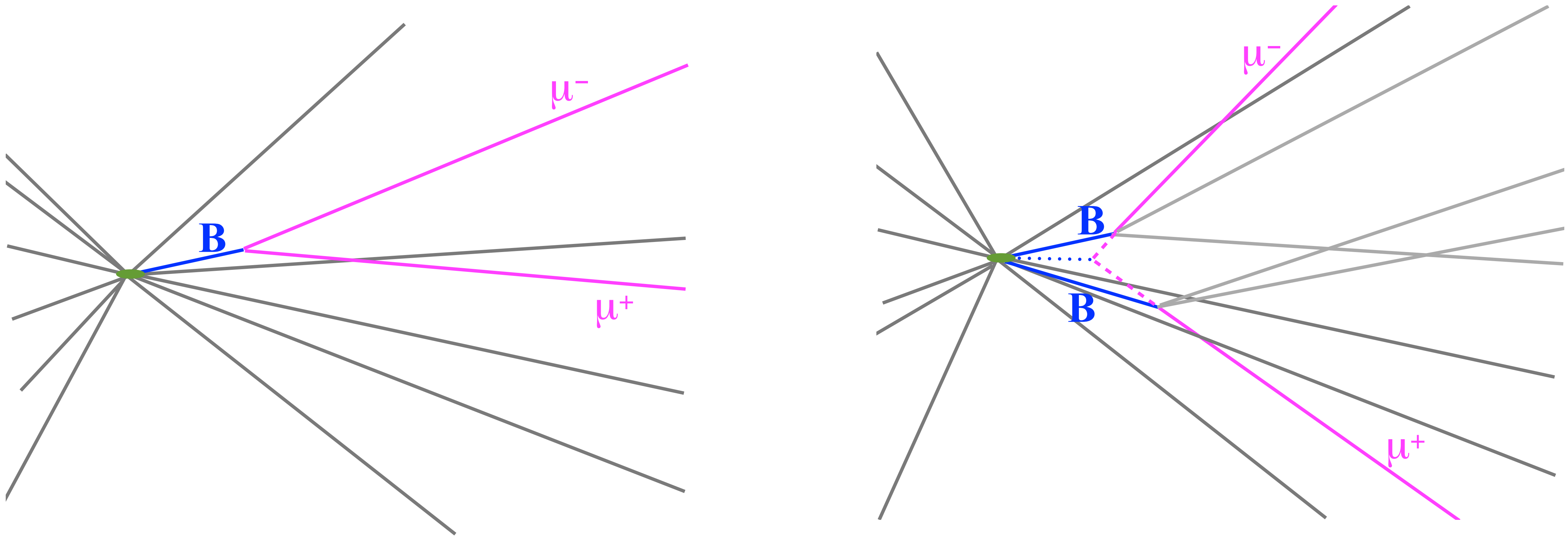
The results **have been updated for 7 TeV data**, after the improvements in the background determination

Signal characterization

Signal discrimination: BDT

signal: 2 muons from a single well reconstructed secondary vertex

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



Discrimination is achieved by a BDT with 9 input variables

B candidate:

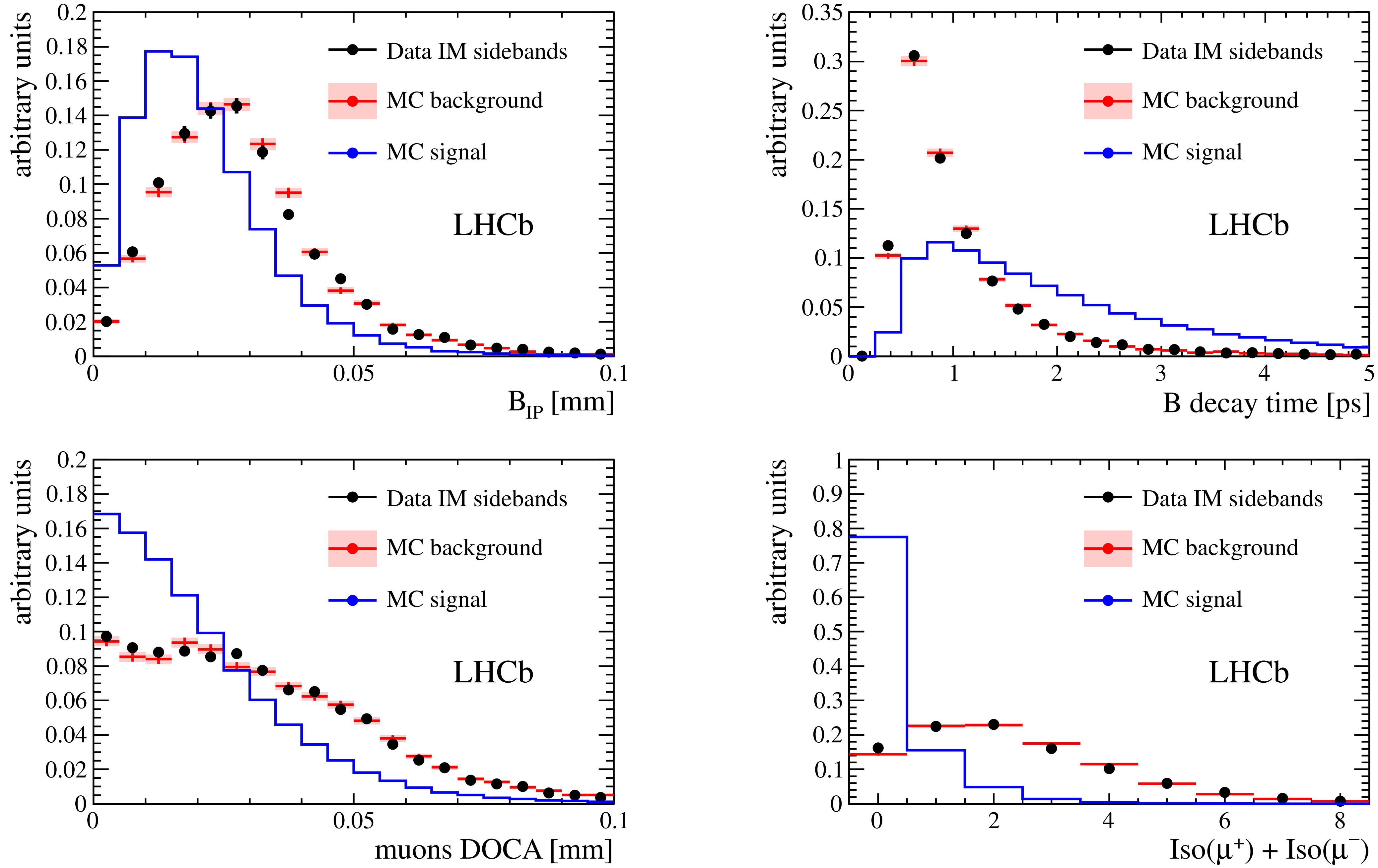
- proper time
- impact parameter
- transverse momentum
- B isolation

muons:

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

this choice of variables avoids correlation with invariant mass

BDT variables



7 TeV data

Optimization and training on MC $B^0_s \to \mu^+\mu^-$ signal and $bb \to \mu^+\mu^- X$ background

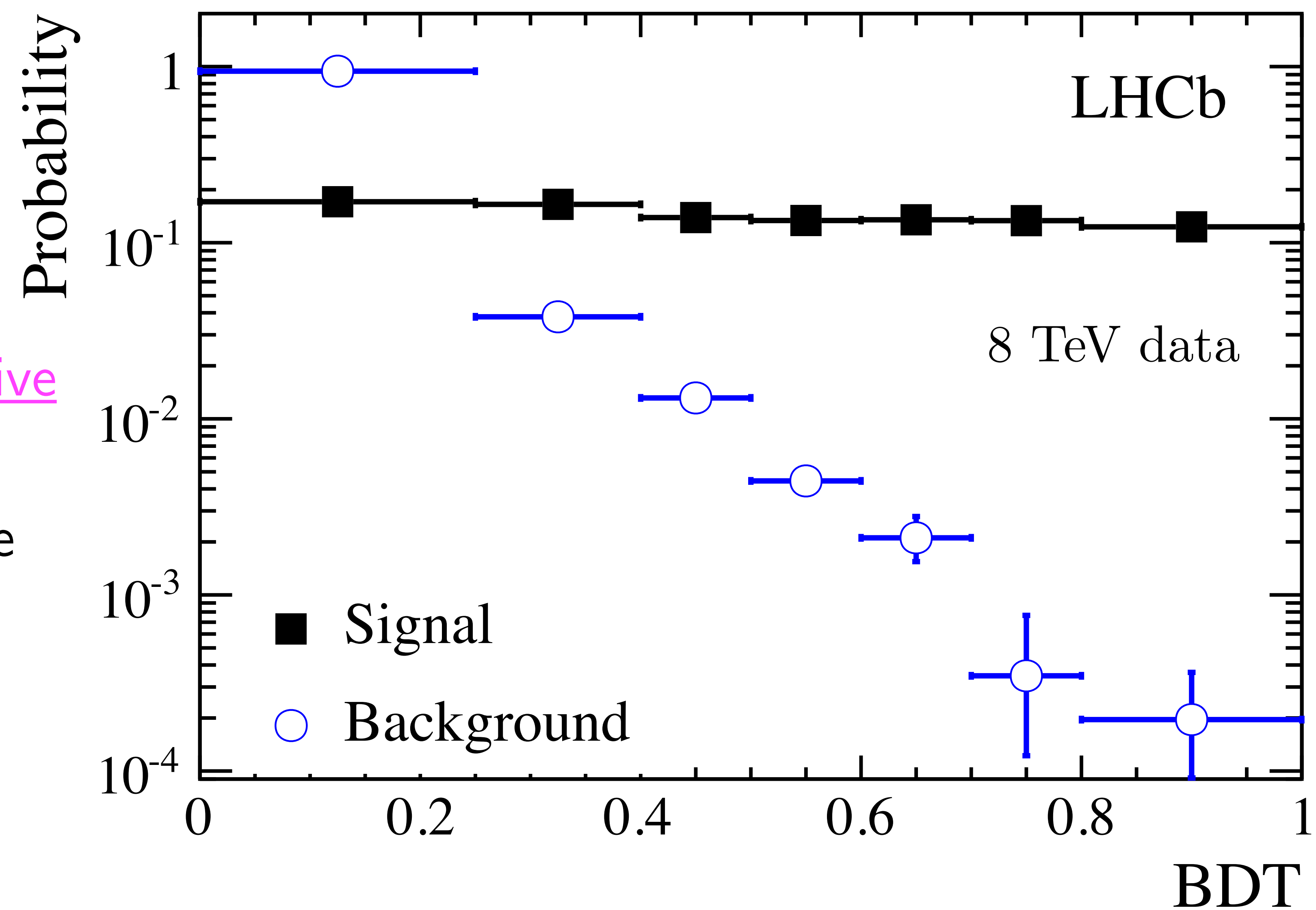
Same definition of BDT is used for 7 TeV and 8 TeV data, since most of the input variables are in very good agreement (checked on $B^\pm \to J/\psi K^\pm$)

BDT calibration

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

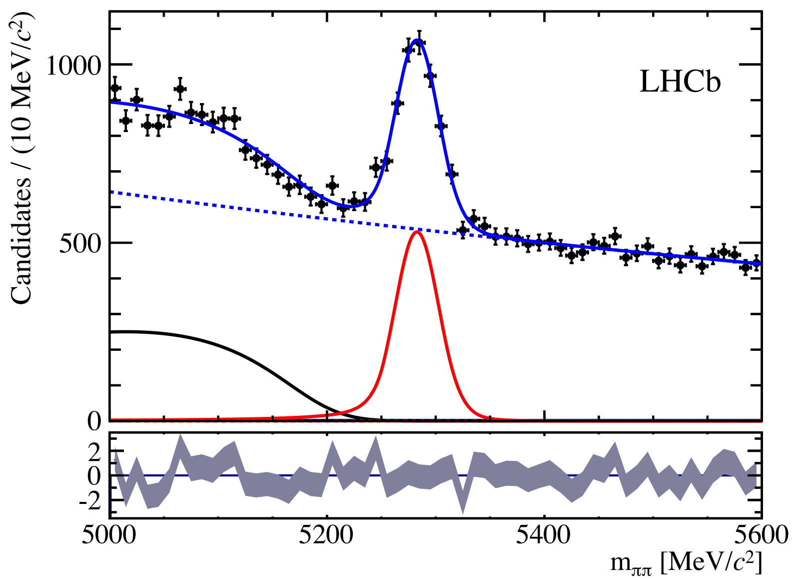
Signal BDT shape from exclusive $B^0_{(s)} \to h^+ h'^-$ ($h = K, \pi$) events, which have same topology as the signal

Background BDT shape is evaluated on the dimuon mass sidebands

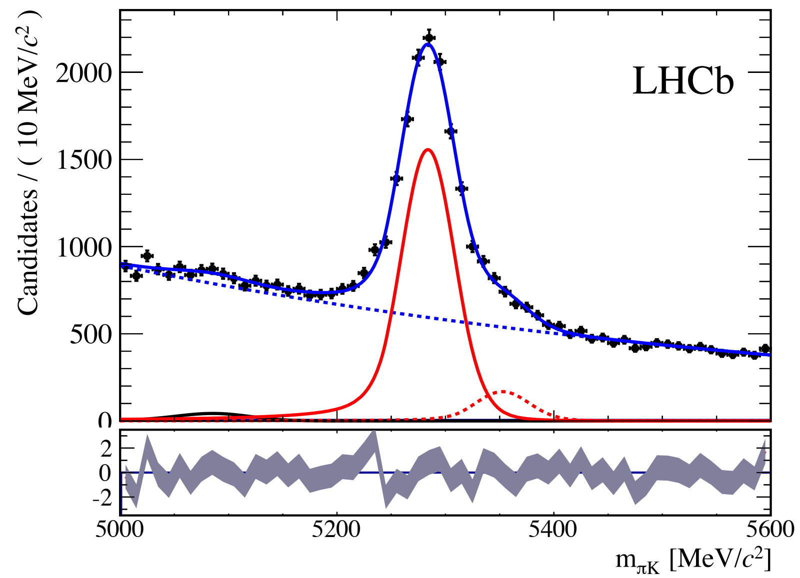


$B^0_{(s)}$ mass peak

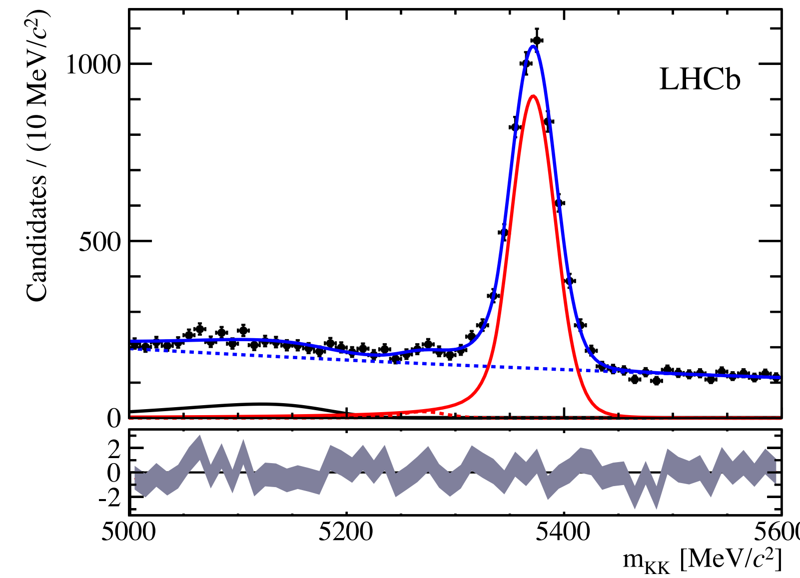
$B^0 \to \pi^+\pi^-$



$B^0 \to K\pi$



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



8 TeV data

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

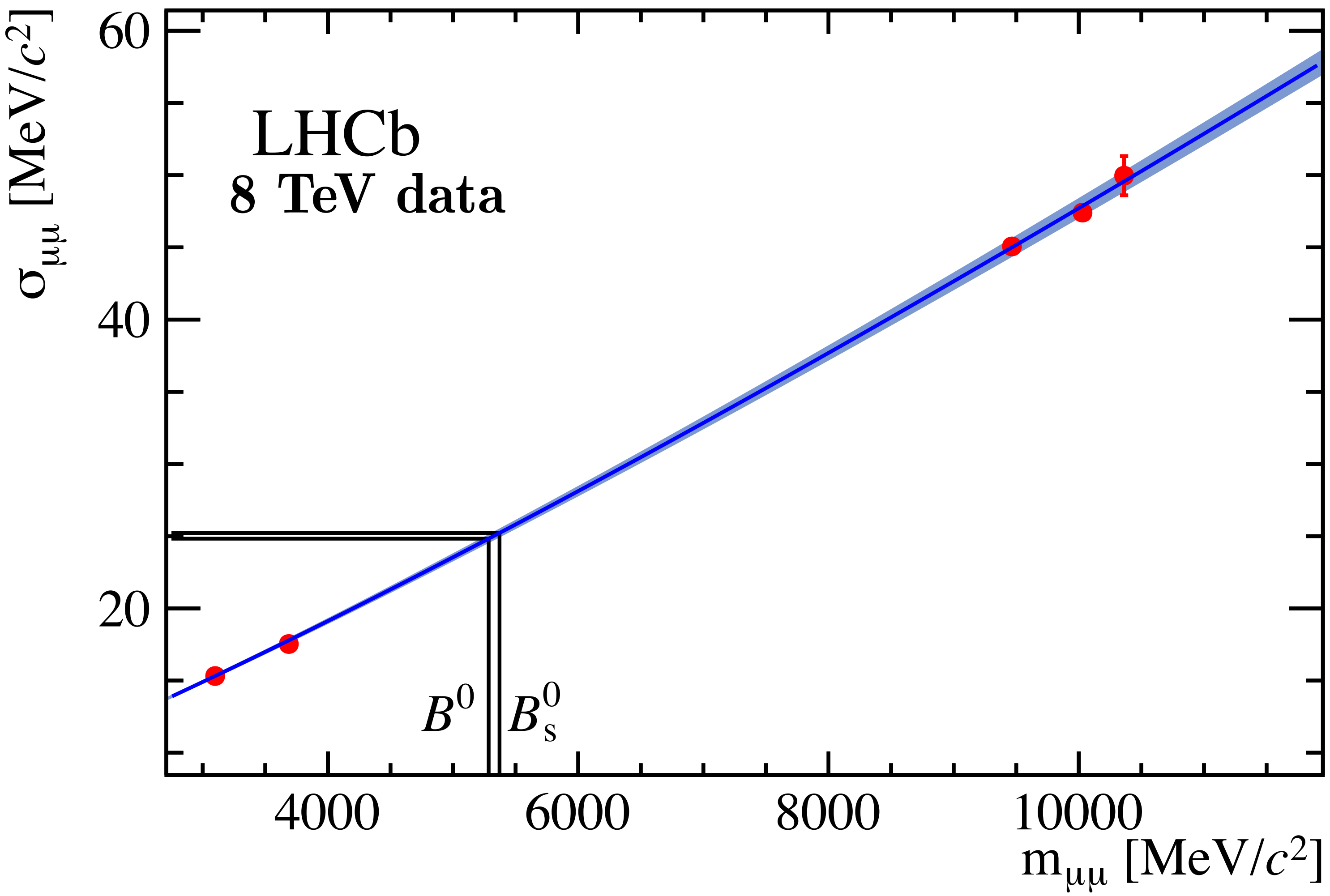
Peak position determinations for 7 TeV and 8 TeV data agree at better than 5×10^{-4}

mass resolution

Two independent methods:

1) Interpolation of dimuon resonances: J/ψ and $\psi(2S)$, $\Upsilon(1S)$,Υ (2S), Υ (3S)

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



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

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

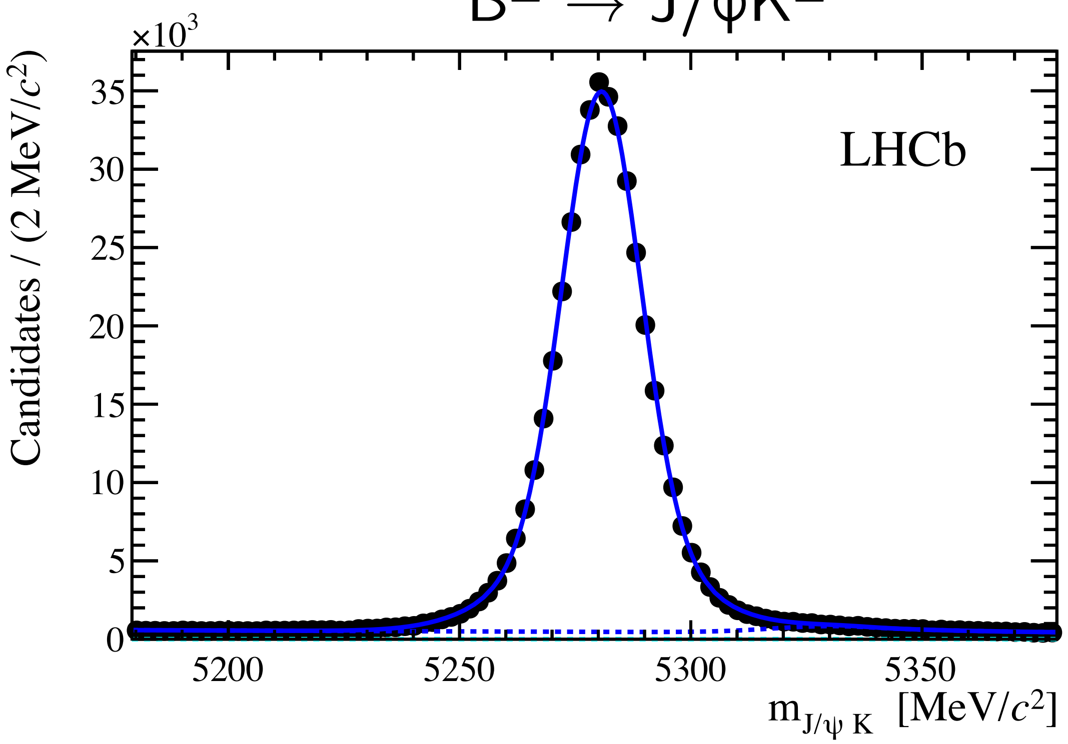
Evaluated from MC, cross-checked with data

Measured on data

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

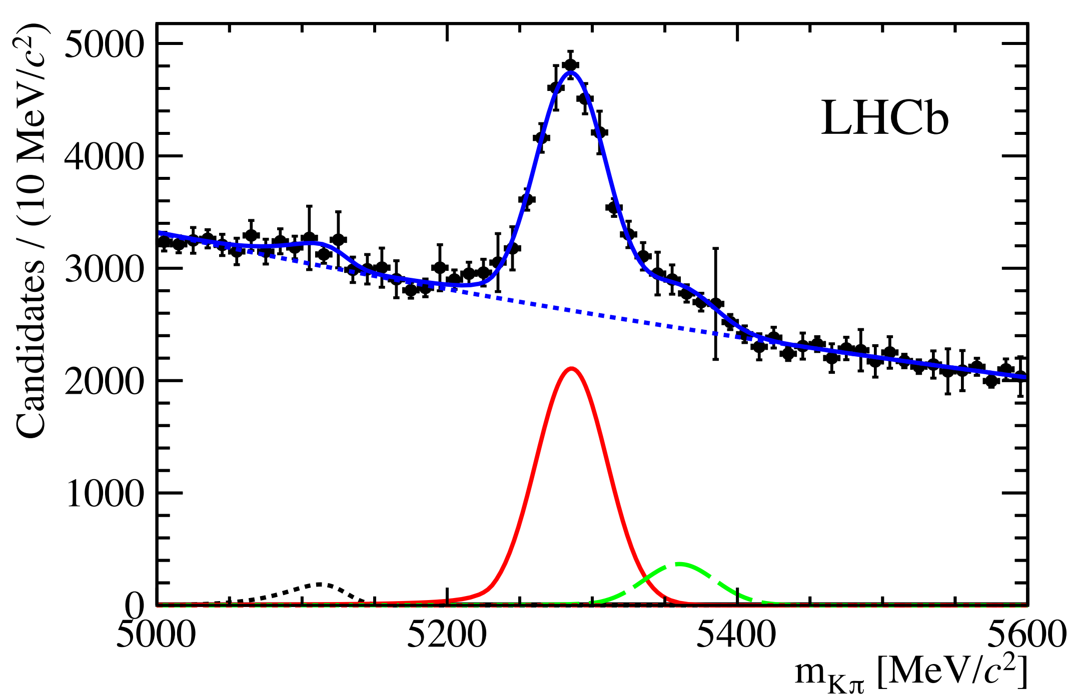
2 independent channels:

$B^\pm \to J/\psi K^\pm$



wrt signal: similar trigger, one more track

$B^0 \to K\pi$



wrt signal: different trigger, same topology

errors dominated by PID reweighting

Trigger independent of the signal is required

b fragmentation f_s/f_d

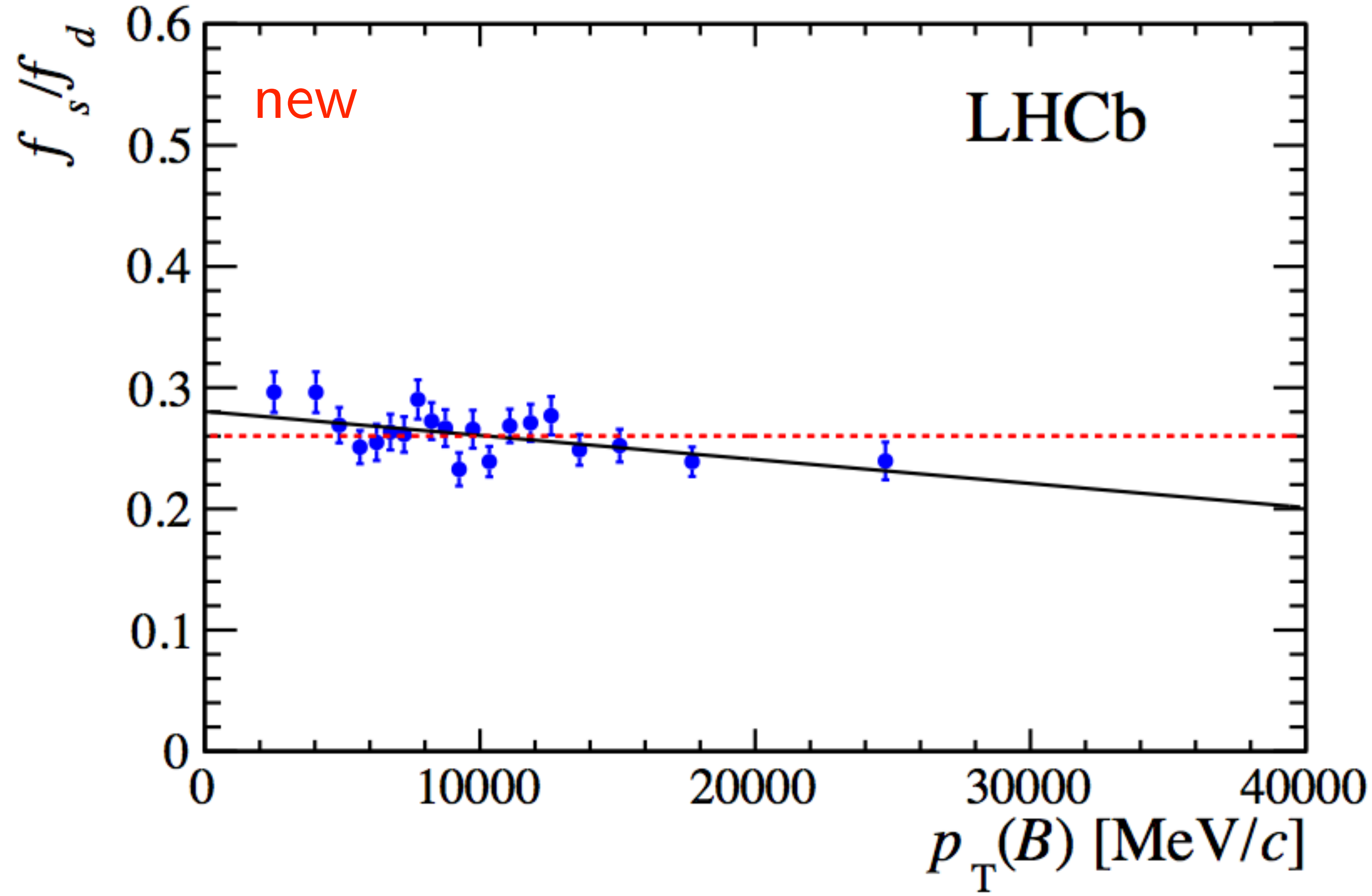
LHCb measured has 2 independent measurements (at 7 TeV):

- ratio of $B^0_s \to D_s\mu X$ 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

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



Found to be moderately dependent on p_T:

effect $\leq 1\sigma$ for the considered p_T range $\to$ **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

Single event sensitivity

	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon^{rec}_{norm}\epsilon^{sel\|rec}_{norm}}{\epsilon^{rec}_{sig}\epsilon^{sel\|rec}_{sig}}$	$\frac{\epsilon^{trg\|sel}_{norm}}{\epsilon^{trg\|sel}_{sig}}$	N_{norm}	$\alpha^{norm}_{B_d\to\mu^+\mu^-}$ $(\times 10^{-11})$	$\alpha^{norm}_{B_s\to\mu^+\mu^-}$ $(\times 10^{-10})$
$B^+\to J/\psi K^+$	6.01 ± 0.21	0.548 ± 0.018	0.932 ± 0.012	$424\,200\pm1500$	7.24 ± 0.39	2.83 ± 0.27
$B^0\to K^+\pi^-$	1.94 ± 0.06	0.908 ± 0.031	0.057 ± 0.002	$14\,600\pm1100$	6.93 ± 0.67	2.71 ± 0.34

The 2 channels give consistent results, we take the average

$$\alpha_{B^0_s\to\mu^+\mu^-} = (2.80\pm0.25)\times10^{-10}$$
$$\alpha_{B^0\to\mu^+\mu^-} = (7.16\pm0.34)\times10^{-11}$$

8 TeV data

[the quoted values for α refer to $m(B^0_{(s)})\pm60\ MeV/c^2$ 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}) ~13 $B^0_s\to\mu^+\mu^-$ and ~1.5 $B^0\to\mu^+\mu^-$ **in signal region ($m(B^0_{(s)})\pm60\ MeV/c^2$)**

Background estimation

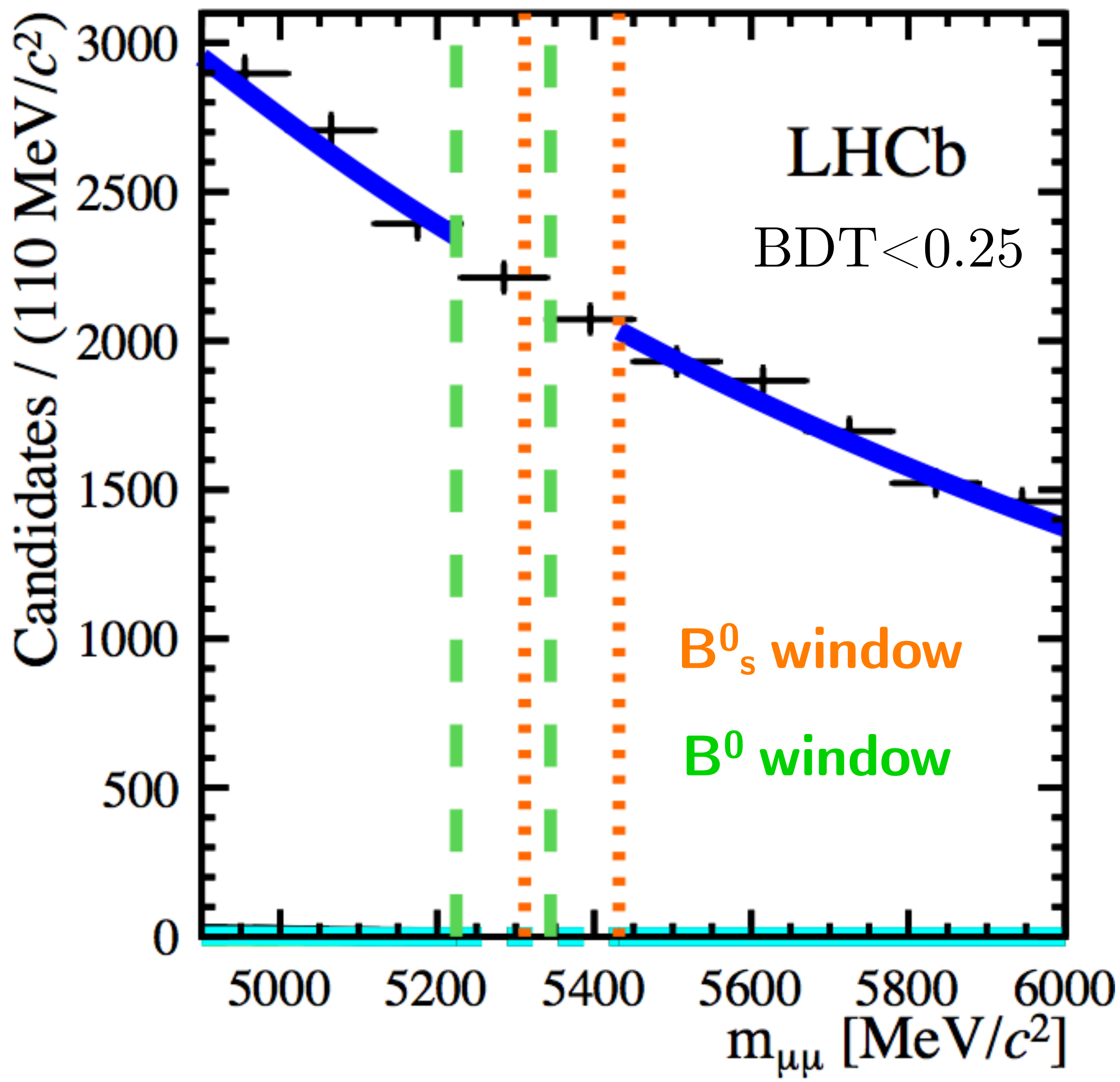
Background sources

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 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] 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:

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

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

$\Lambda^0_b \to p \mu^- \nu_\mu$

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

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

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

(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

2) mass shape different from exponential $\to$ 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

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

1. $K \to \mu$, $\pi \to \mu$ probabilities as a function of momentum and transverse momentum **are determined on data** from $D^{*+} \to D^0 \pi^+$, with $D^0 \to K^- \pi^+$
2. These probabilities **are then folded with the MC spectra** for the $B^0_{(s)} \to h^+ h'^-$ decays to get the average double misID efficiency, $\varepsilon_{\text{double-misID}}$
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:

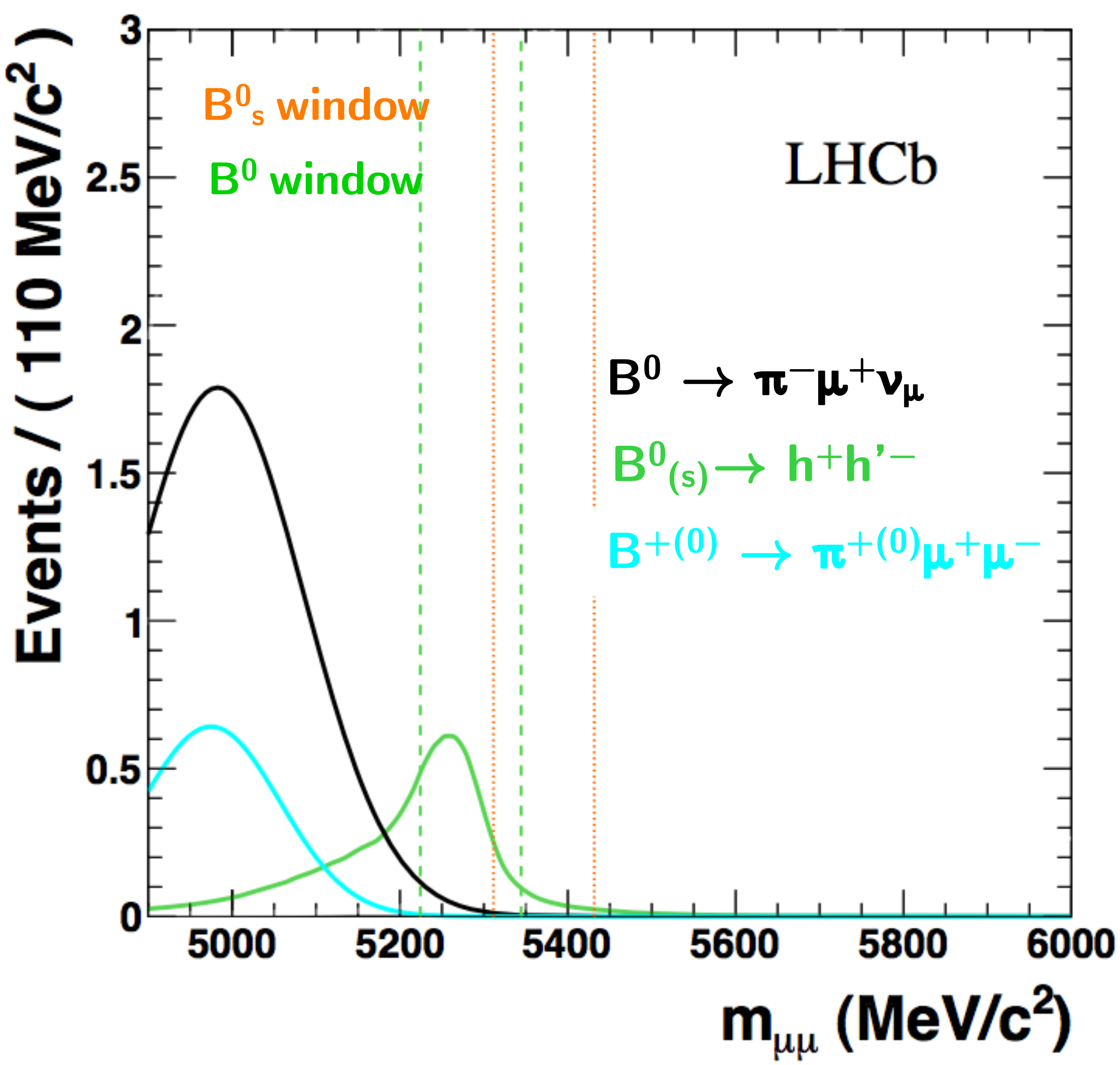
N_{Bhh} → $\varepsilon_{\text{double-misID}}$ after muon chamber matching 0.94×10^{-4} → $\varepsilon_{\text{double-misID}}$ after global PID likelihood 0.18×10^{-4}

- $\times 0.09$ → Events in B^0_s mass window $0.76^{+0.26}_{-0.18}$
- $\times 0.48$ → Events in B^0_d mass window $4.1^{+1.7}_{-0.8}$

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 $B^{\pm} \to J/\psi K^{\pm}$



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**

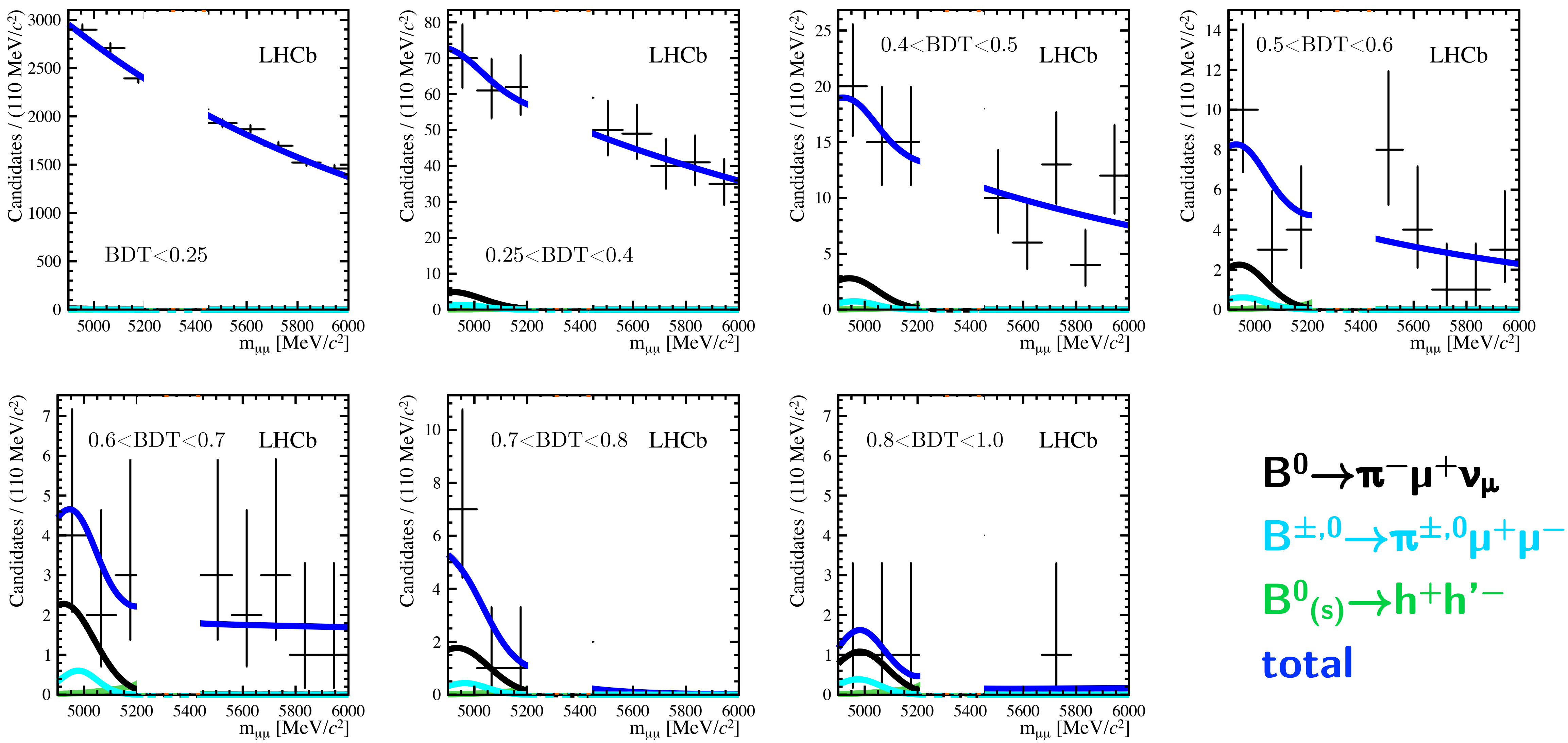
these decays are included in the mass sideband fits (constrained to their expected yields)

systematic studies to evaluate the effect of the subdominant channels

Background description (8TeV)

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

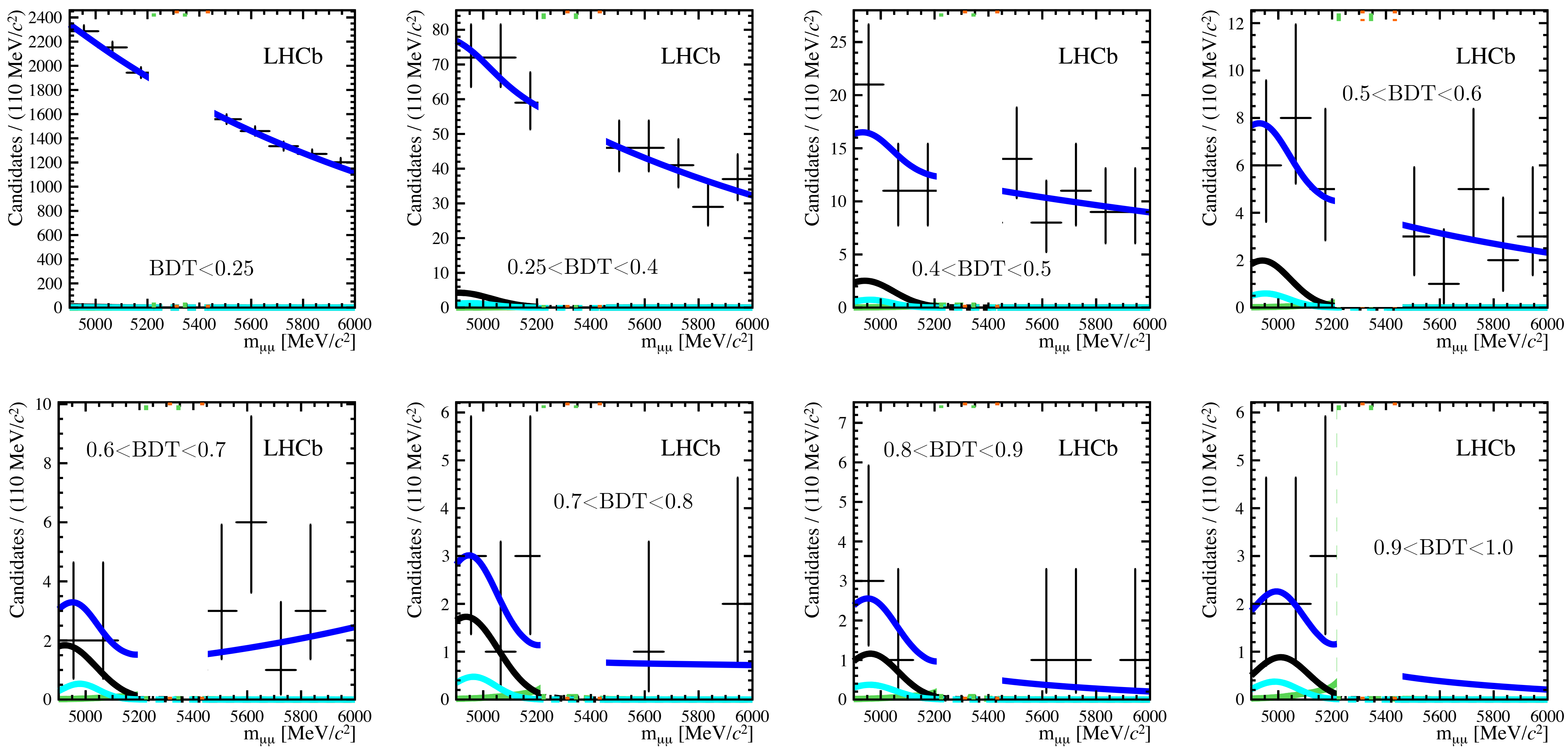
Fit components: combinatorial (exponential)+ $B^0 \to \pi^- \mu^+ \nu_\mu$ + $B^{+(0)} \to \pi^{+(0)} \mu^+ \mu^-$ + $B^0_{(s)} \to h^+ h'^-$



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 (7TeV)

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



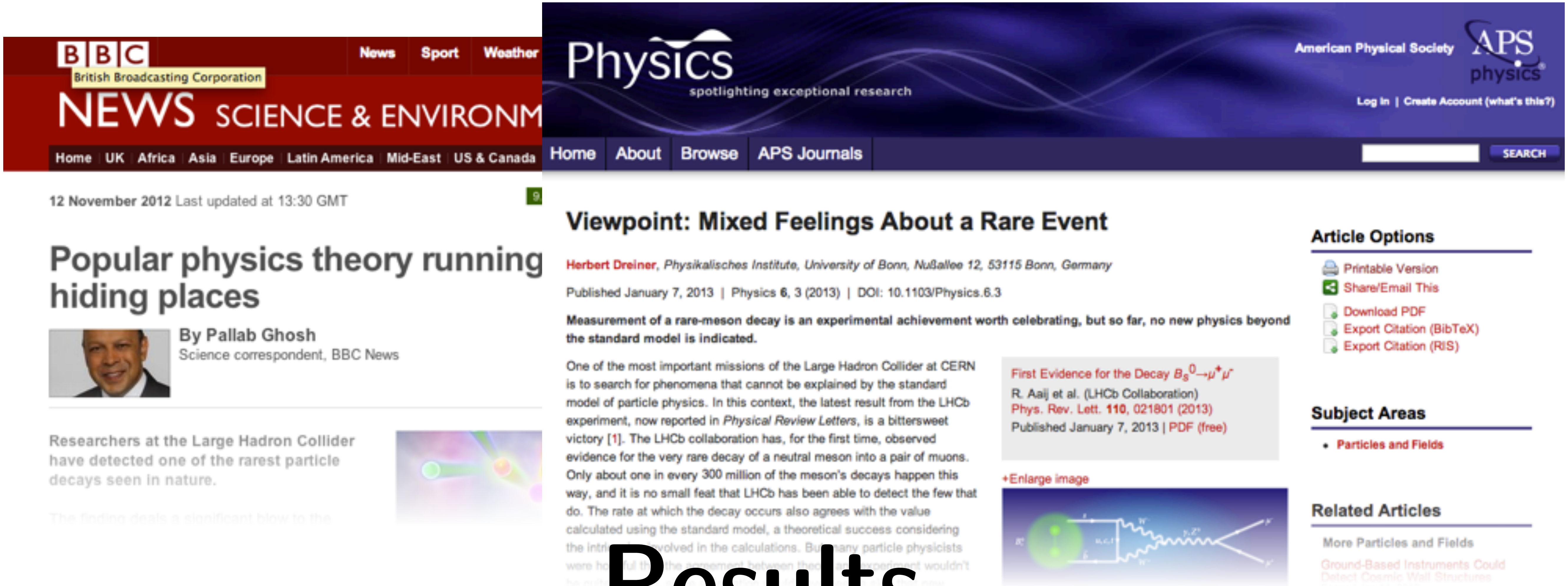
Combinatorial background yield reduced in the high sensitive bins;
impact on the published results has been evaluated

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

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

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

total



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12 November 2012 Last updated at 13:30 GMT

Popular physics theory running hiding places

By Pallab Ghosh
Science correspondent, BBC News

Researchers at the Large Hadron Collider have detected one of the rarest particle decays seen in nature.

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Viewpoint: Mixed Feelings About a Rare Event

Herbert Dreiner, Physikalisches Institute, University of Bonn, Nußallee 12, 53115 Bonn, Germany

Published January 7, 2013 | Physics 6, 3 (2013) | DOI: 10.1103/Physics.6.3

Measurement of a rare-meson decay is an experimental achievement worth celebrating, but so far, no new physics beyond the standard model is indicated.

One of the most important missions of the Large Hadron Collider at CERN is to search for phenomena that cannot be explained by the standard model of particle physics. In this context, the latest result from the LHCb experiment, now reported in *Physical Review Letters*, is a bittersweet victory [1]. The LHCb collaboration has, for the first time, observed evidence for the very rare decay of a neutral meson into a pair of muons. Only about one in every 300 million of the meson's decays happen this way, and it is no small feat that LHCb has been able to detect the few that do. The rate at which the decay occurs also agrees with the value calculated using the standard model, a theoretical success considering the intri... involved in the calculations. But many particle physicists were ho... the agreement between theory and experiment wouldn't

First Evidence for the Decay $B_s^0 \to \mu^+\mu^-$
R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. 110, 021801 (2013)
Published January 7, 2013 | PDF (free)

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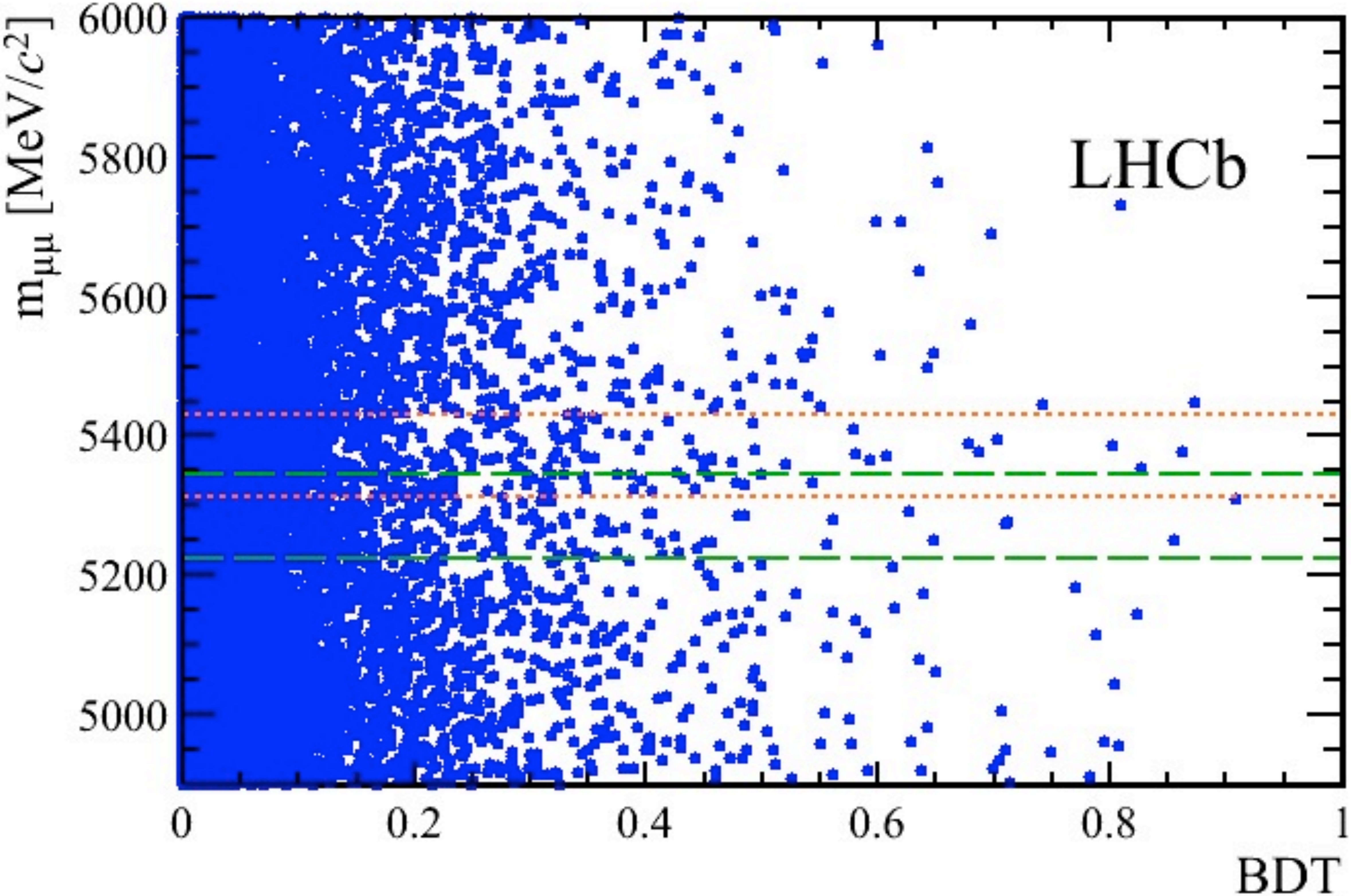
Results

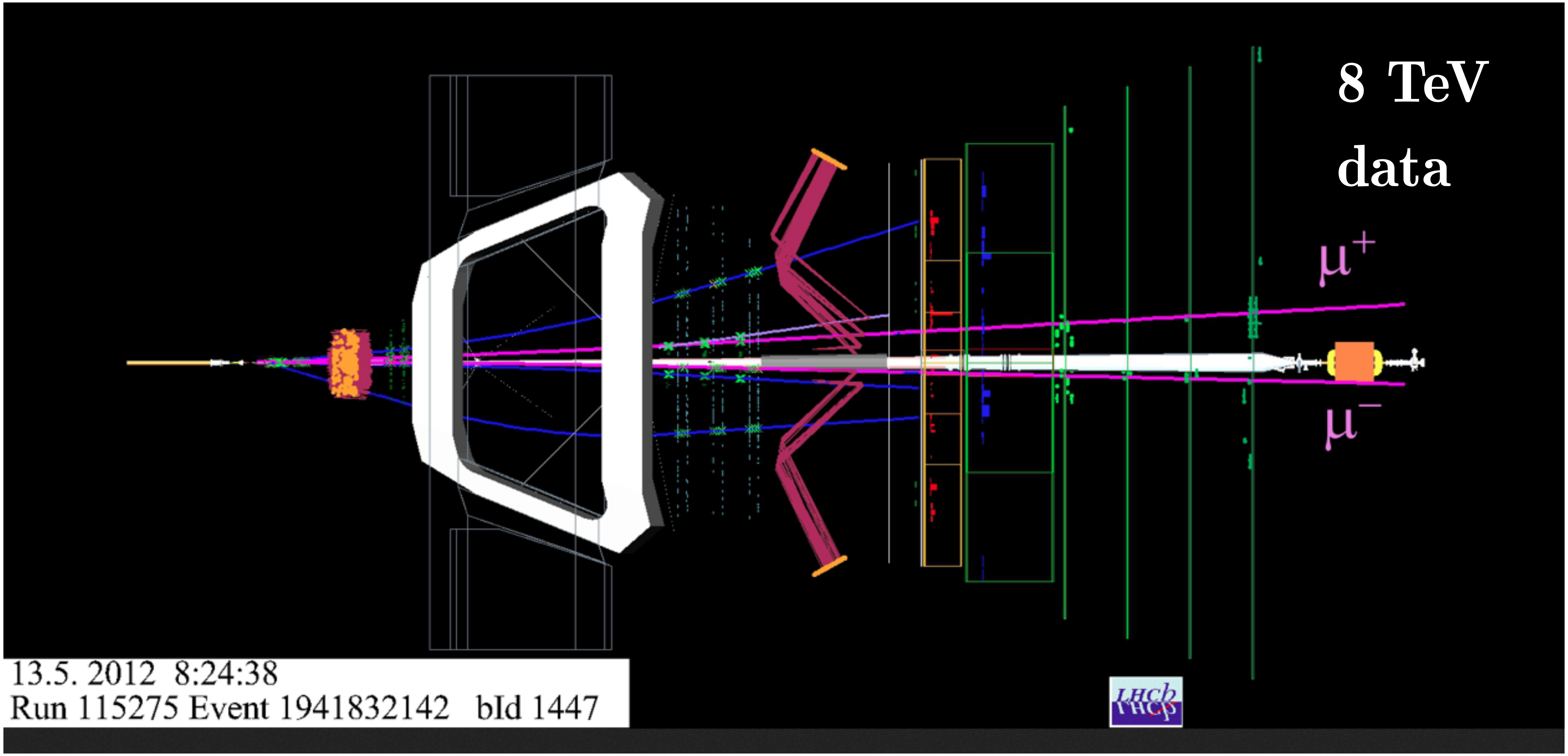
arXiv:1211.2674

6/12/12 accepted for publication as a Letter in Physical Review Letters.

8 TeV data: open the box!



you really look like a $B^0_s \to \mu^+\mu^-$



B candidate:

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

BDT $= 0.826$

$p_T = 4077.4$ MeV/c

$t = 2.84$ ps

muons:

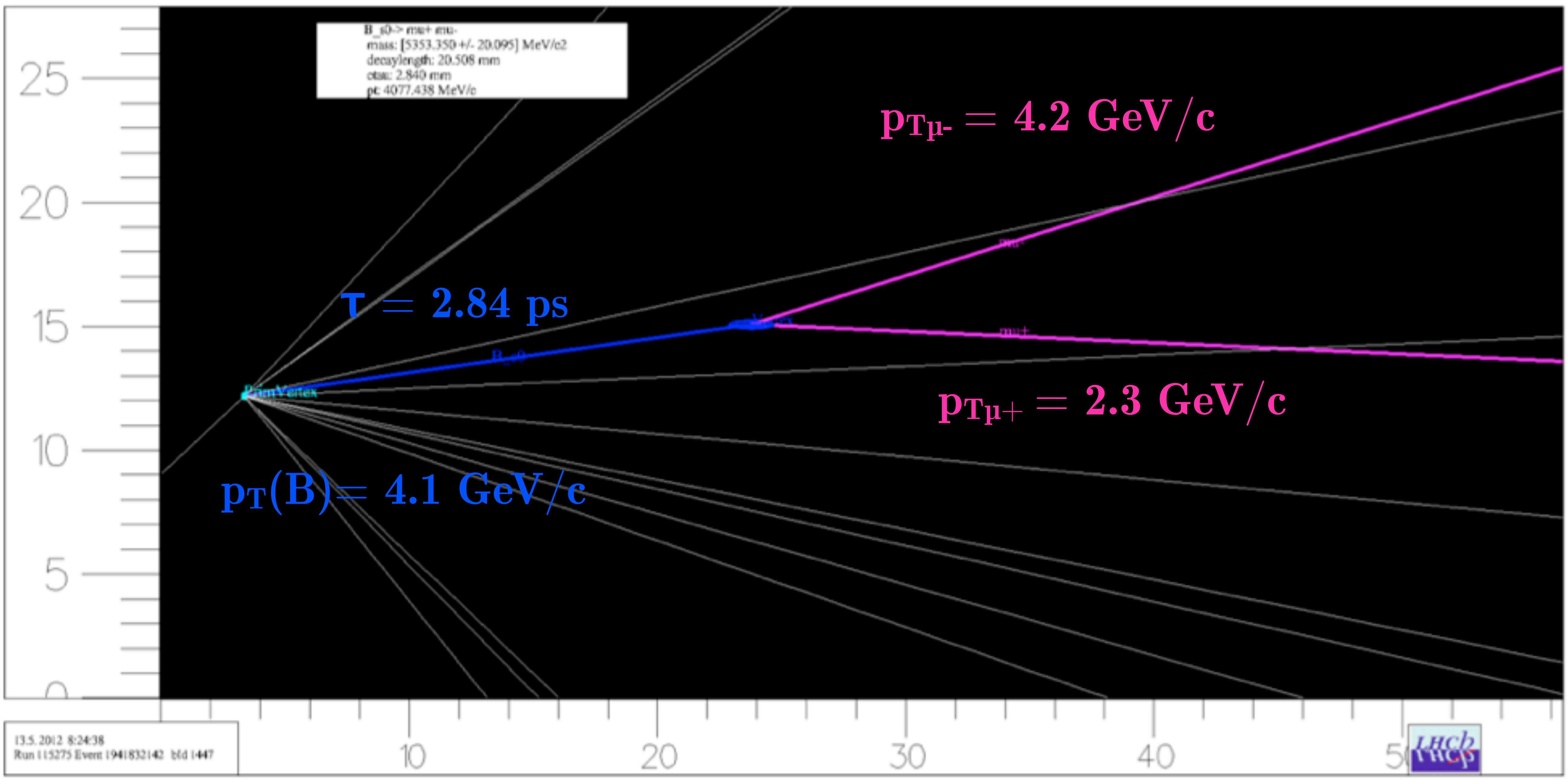
$p_{T\mu+} = 2329.5$ MeV/c

$p_{T\mu-} = 4179.4$ MeV/c

you really look like a $B^0_s \to \mu^+\mu^-$

[0.2 mm ticks]

8 TeV data



[mm]

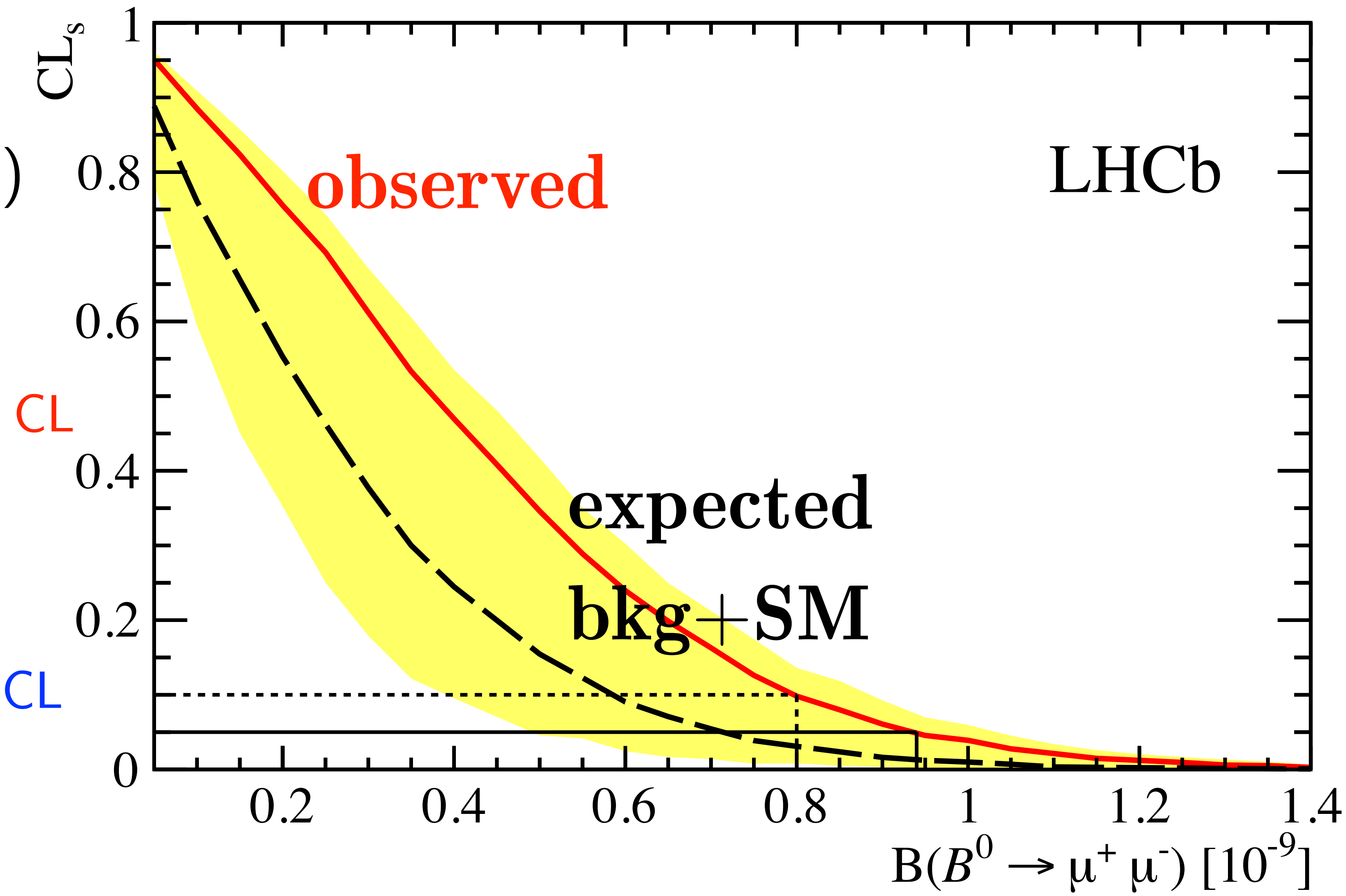
$B^0 \to \mu^+\mu^-$: upper limit

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 $CL_s = CL_{s+b}/CL_b = 0.05$**

7 TeV (1 fb^{-1}) + 8 TeV (1.1 fb^{-1})

observed upper limit:
$BR(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}$ at 95% CL

expected limit:
$BR(B^0 \to \mu^+\mu^-) < 7.1 \times 10^{-10}$ at 95% CL

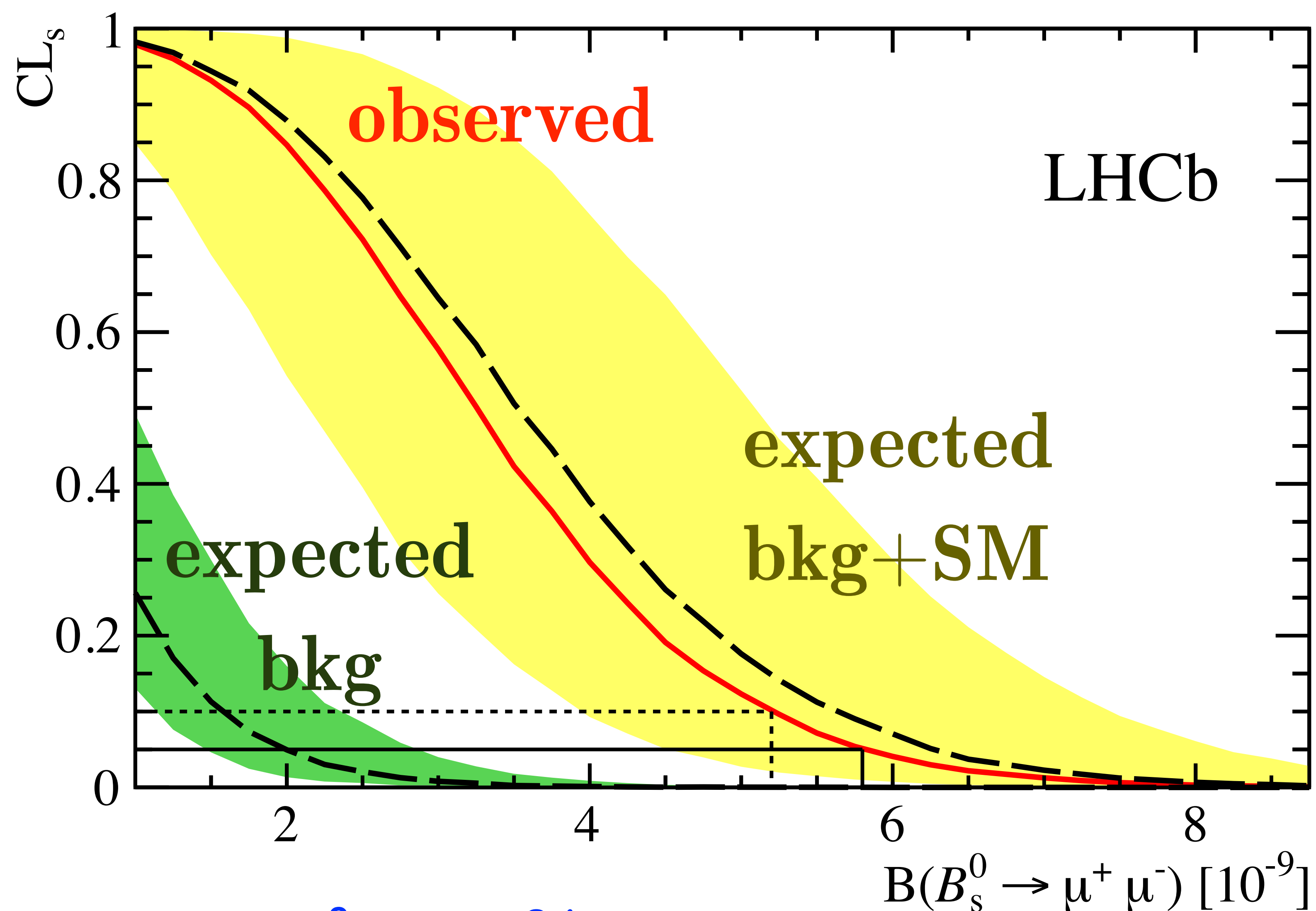


Compatibility with bkg only hypothesis: p-value = 1-CL_b = 0.11

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

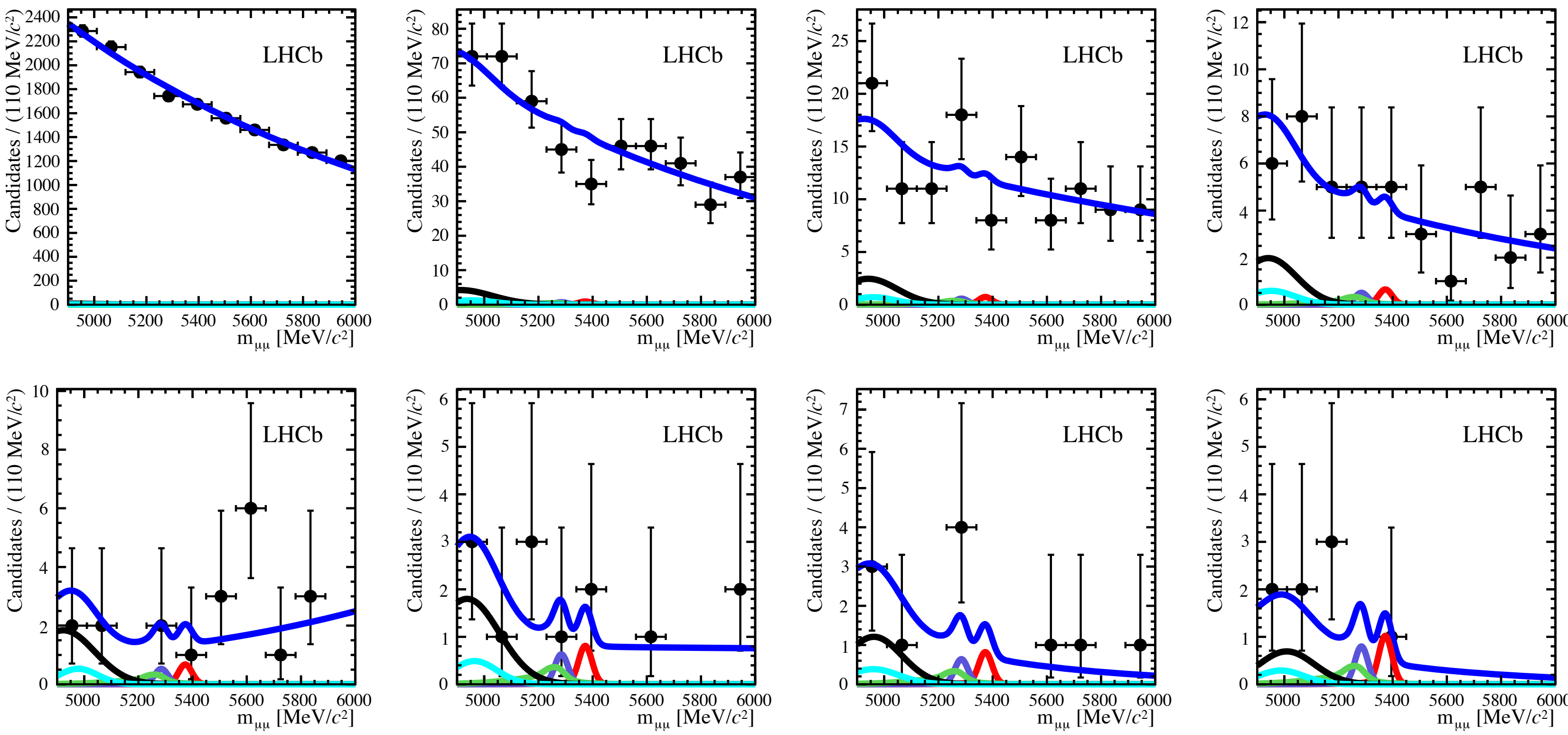
$1.1\times 10^{-9} < B(B^0_s \to \mu^+\mu^-) < 6.4\times10^{-9}$ at 95% CL

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

$B^0_s \to \mu^+\mu^-$: 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/c^2
- Free parameters:
  - BR($B^0_s \to \mu^+\mu^-$), BR($B^0 \to \mu^+\mu^-$) and combinatorial background
  - The **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

Fit results for all BDT bins



7 TeV data, 1.0 fb^{-1}

8 BDT bins

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

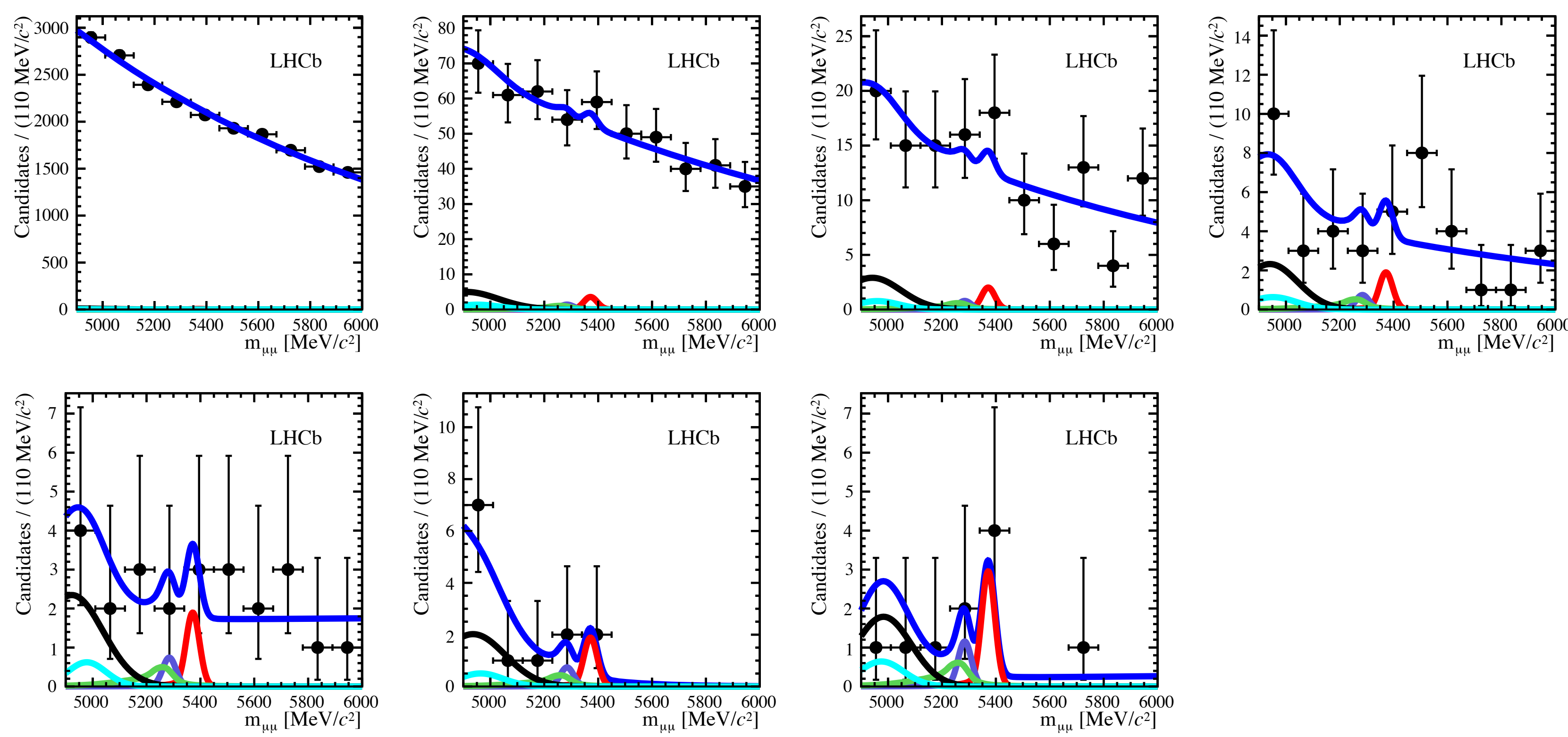
$B^0 \to \mu^+\mu^-$

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

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

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

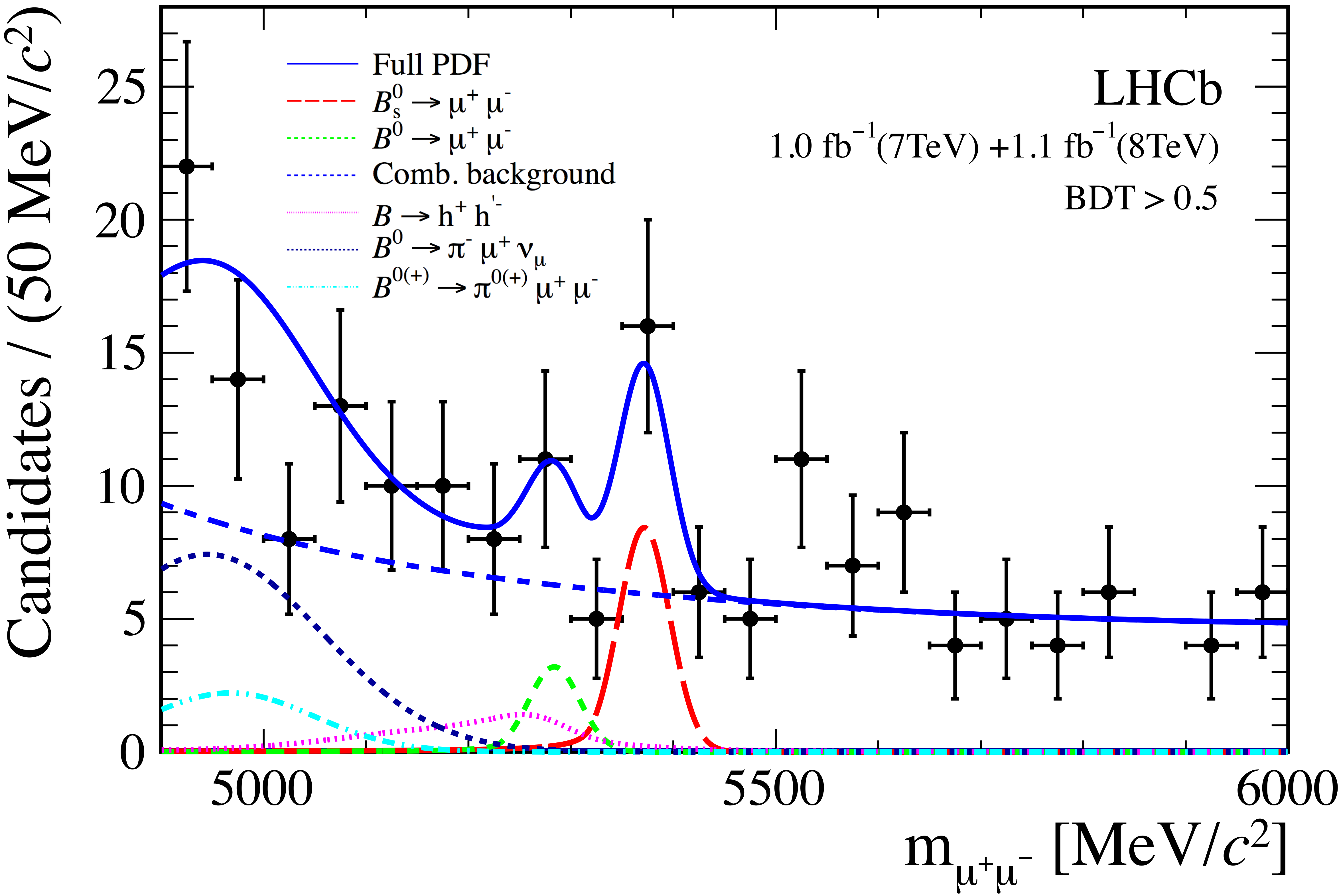
total



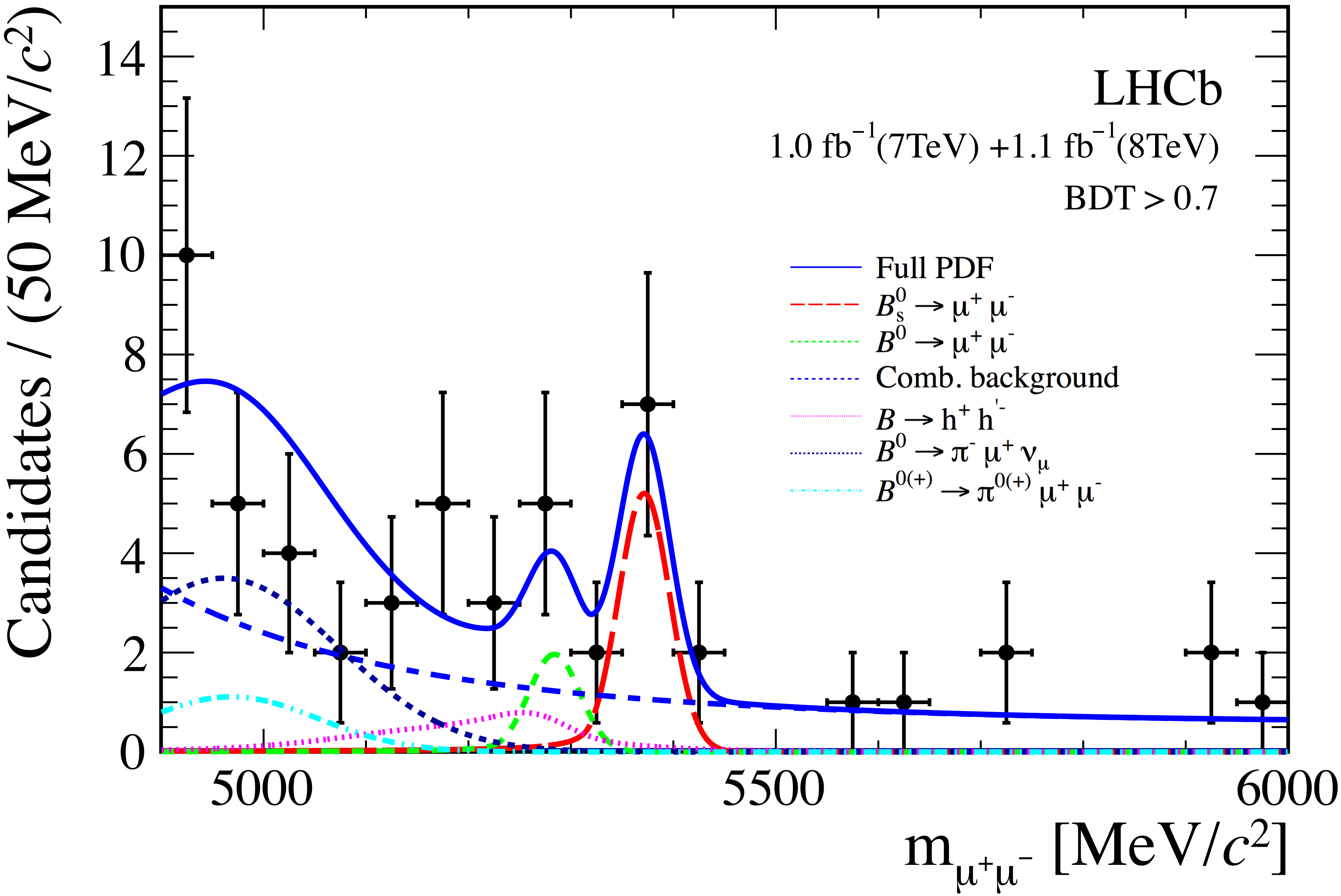
8 TeV data, 1.1 fb^{-1}

7 BDT bins

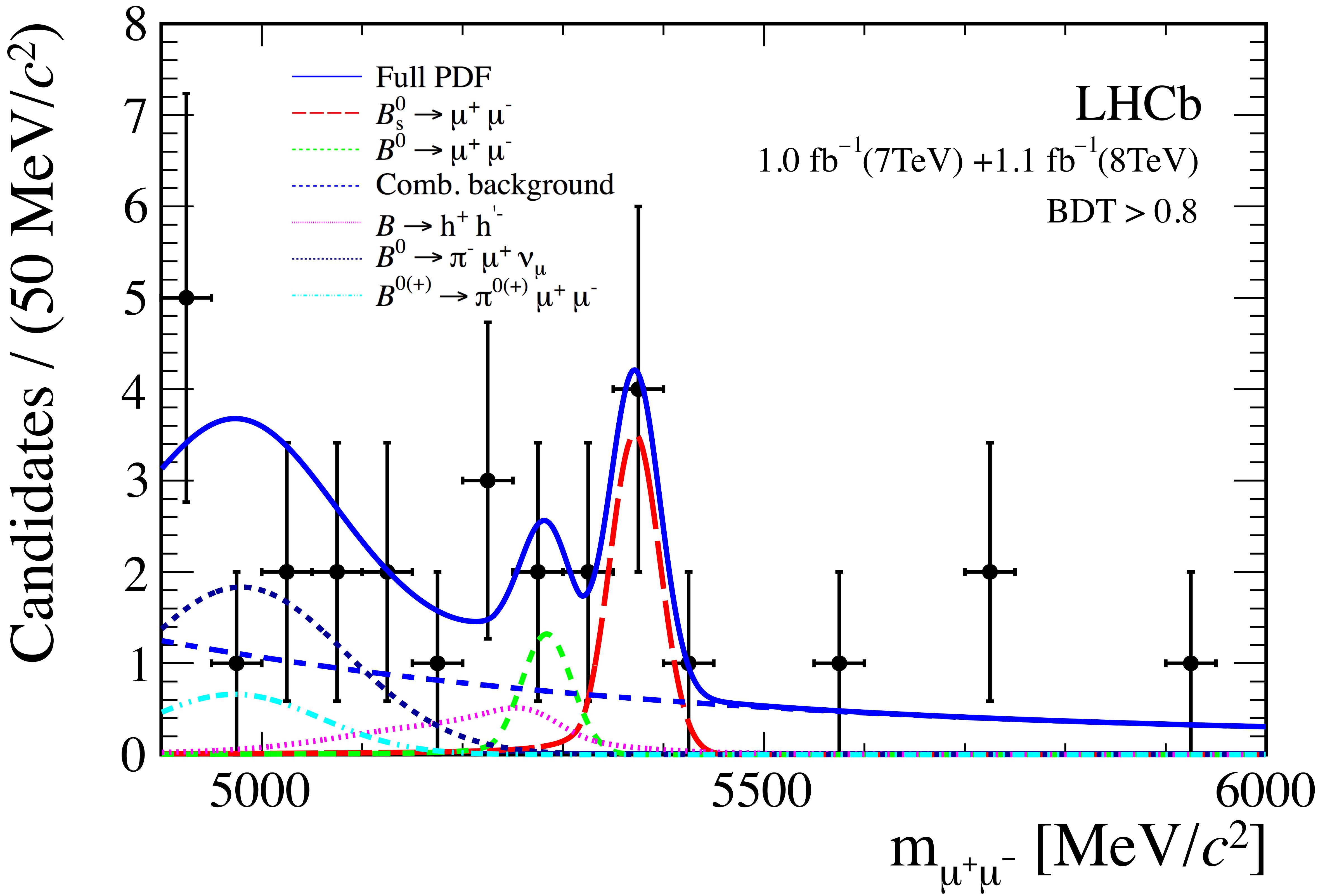
Combined dataset: BDT>0.5



Combined dataset: BDT>0.7



Combined dataset: BDT>0.8



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

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

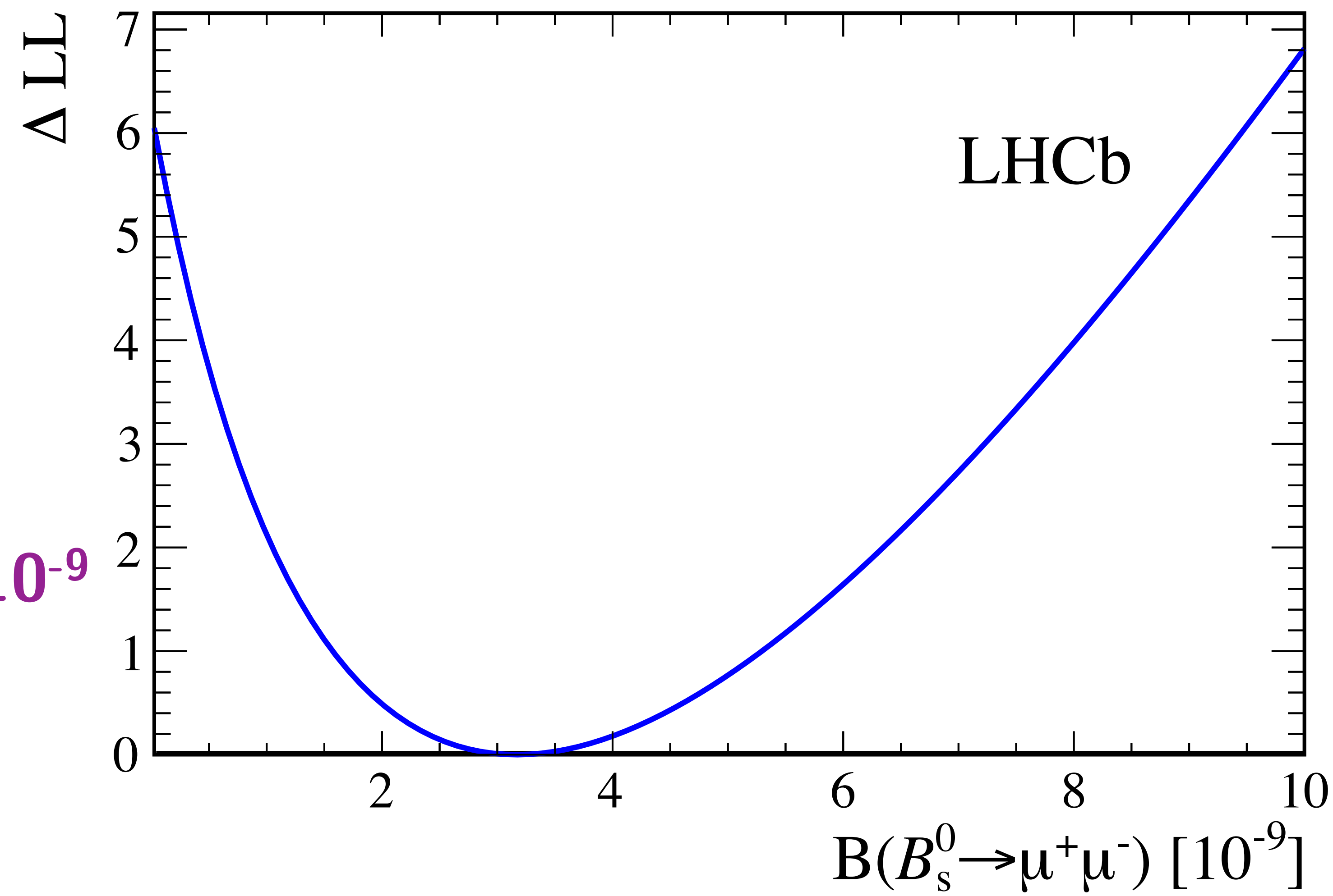
$BR(B^0_s \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$

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

syst from nuisance parameters and background models:

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

fully dominated by stat error



profile likelihood with nuisance parameters floated within their errors

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

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

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

p-value: 0.11

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

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

p-value: 9×10^{-4}

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

Summary

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

An excess of $B^0_s \to \mu^+\mu^-$ signal above background expectation is found, with a p-value of 5.3×10^{-4}, corresponding to $3.5\ \sigma$

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

A maximum likelihood fit to data yields

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

in agreement with SM expectation

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

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

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

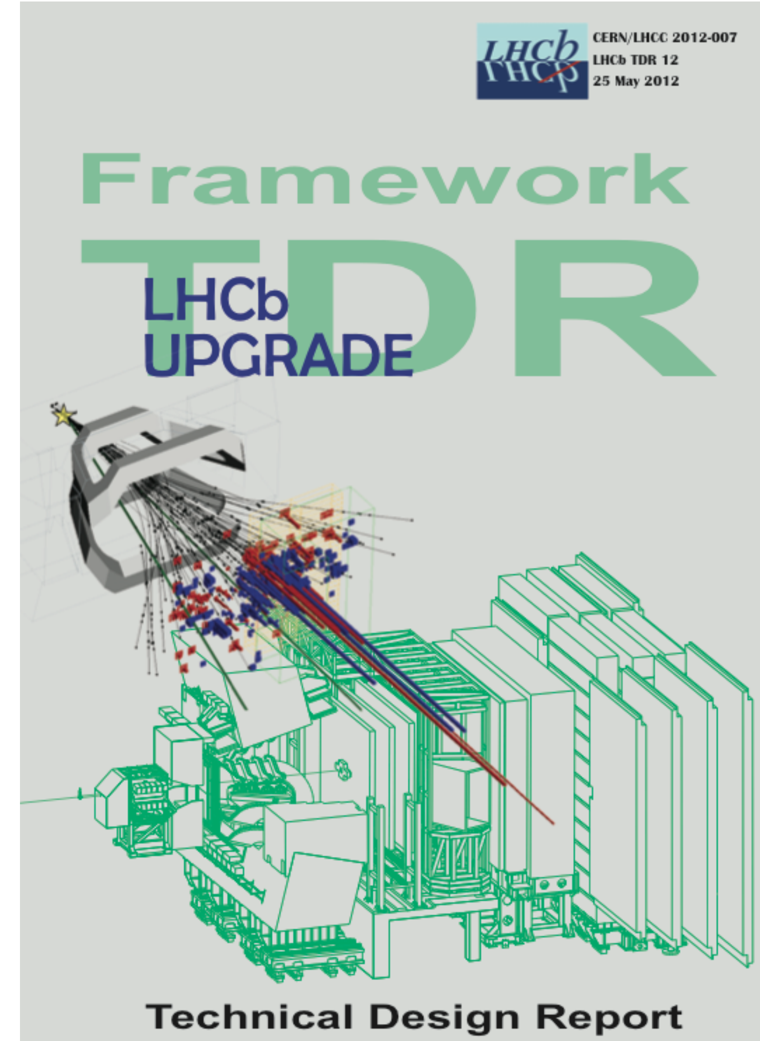
Spares

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 $\sqrt{N}$.

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

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

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 – 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

8 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

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/c^2; loose cut on MVA discriminant
- Signal/Background separation by invariant di-μ 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 $B^0_{(s)} \to h^+ h'^-$ channels ($h=\pi$, K) and for background with IM sidebands
- Normalization with $B^\pm \to J/\psi K^\pm$ and $B^0 \to K^+\pi^-$
  $B^0_s \to J/\psi\varphi$ was dropped as third normalization channel for 8 TeV data, but use $B^0_s \to J/\psi\varphi / B^\pm \to J/\psi K^\pm$ to check $\sqrt{s}$ dependence of f_s/f_d

updated on 8 TeV

Analysis strategy

- Background estimation
  - Combinatorial $bb \to \mu\mu X$
  - Double mis-identified $B^0_{(s)} \to h^+ h'^-$
  - Detailed studies on various exclusive backgrounds

updated on 7 TeV and 8 TeV

Results are provided in terms of:

- Limits and significance determination with CLs method
  - Signal window: $m(B^0_{(s)}) \pm 60$ MeV/c^2

- Unbinned maximum likelihood fit for the branching fraction
  - Use full mass range: [4900-6000] MeV/c^2

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