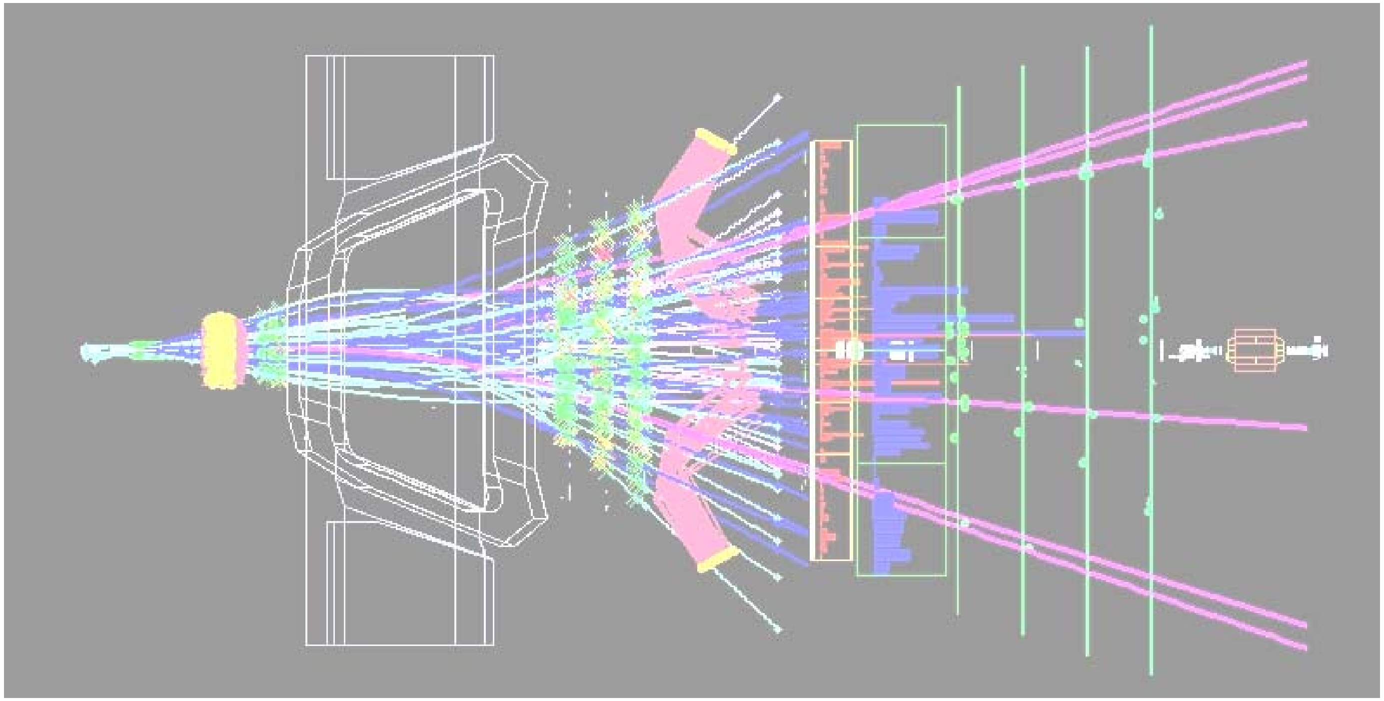
# Search for the very rare decays $B_{s/d} \to \mu^+\mu^-$ at LHCb

**Justine Serrano**

**Centre de Physique des Particules de Marseille**

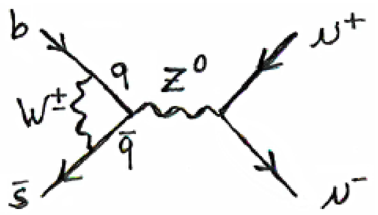
**On behalf of the LHCb collaboration**



**EPS-HEP, July 22th 2011, Grenoble**

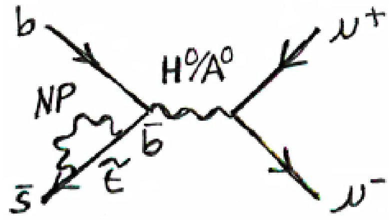
# Interest of $B_{s/d} \to \mu^+\mu^-$

- FCNC and helicity suppressed decays




- Precise SM prediction:
  - $BR(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$
  - $BR(B_d \to \mu^+\mu^-) = (1.1 \pm 0.1) \times 10^{-10}$

  A.J.Buras: arXiv:1012.1447,
  E. Gamiz et al: Phys.Rev.D 80 (2009) 014503

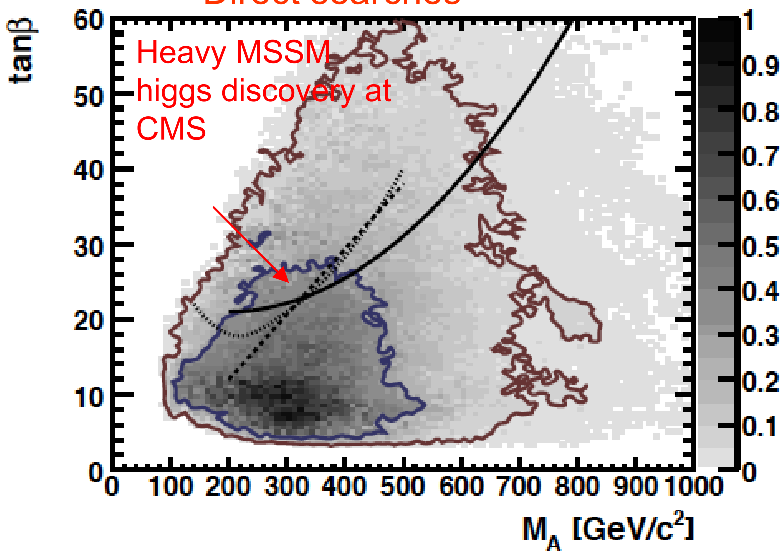



- BR very sensitive to new physics

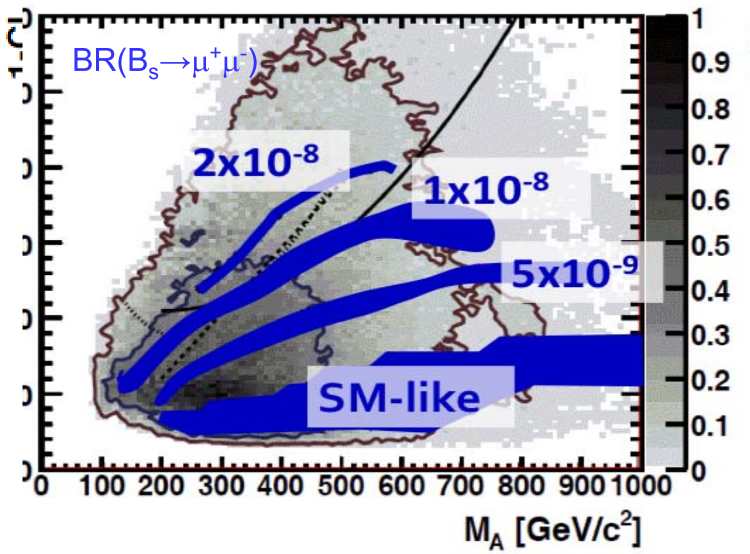
  Ex: NUHM1 model

O. Buchmuller et al, arxiv:0907.5568

Direct searches




Indirect searches

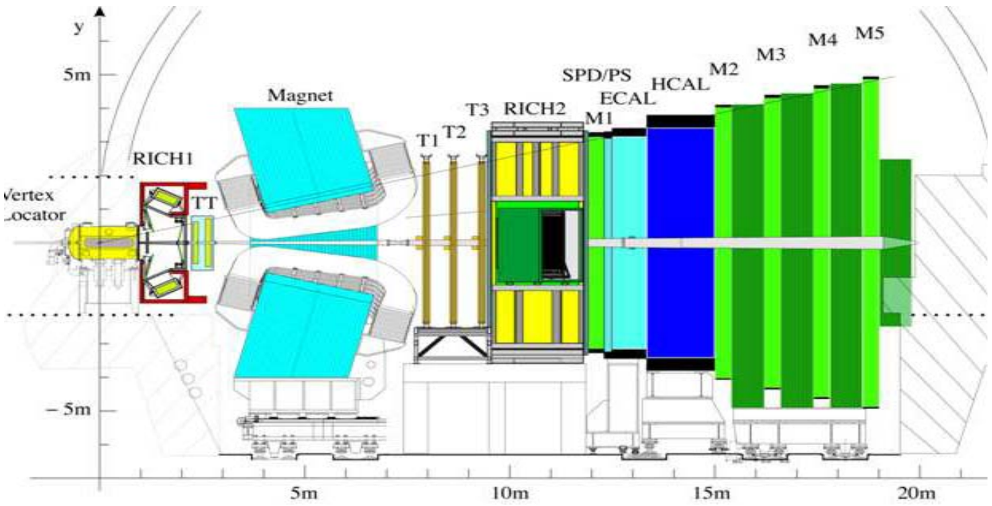



using SuperIso/SoftSUSY, Comput. Phys.Comm. 143, 305 (arXiv: 0808314)

# $B_{s/d}\rightarrow\mu^+\mu^-$ at LHCb

LHCb benefit from:

- Large $b\bar{b}$ cross section
- Large acceptance for B decays
- Very efficient muon trigger, good particle ID, tracking and reconstruction




LHCb already published one analysis based on 37 $pb^{-1}$ from 2010 data
*Physics Letter B 699 (2011)330-340*

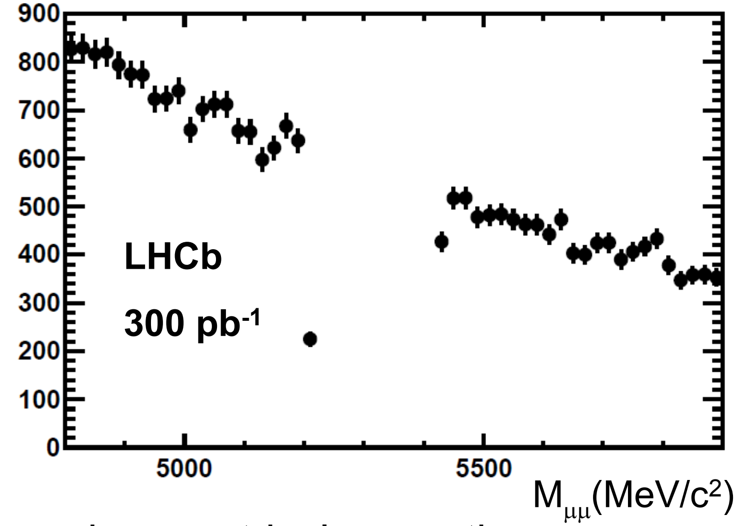
Observed BR($B_s\rightarrow\mu^+\mu^-$) < 4.3 x $10^{-8}$ (5.6 x $10^{-8}$) @ 90 (95)% CL   Expected: 5.1 (6.5)

Observed BR($B_d\rightarrow\mu^+\mu^-$) < 1.2 x $10^{-8}$ (1.5 x $10^{-8}$) @ 90 (95)% CL   Expected: 1.4 (1.8)

Here we present an update on 300 $pb^{-1}$ from 2011 data

Assuming SM, we expect after selection 3.2 (0.32) $B_s$ ($B_d$) events in 300 $pb^{-1}$

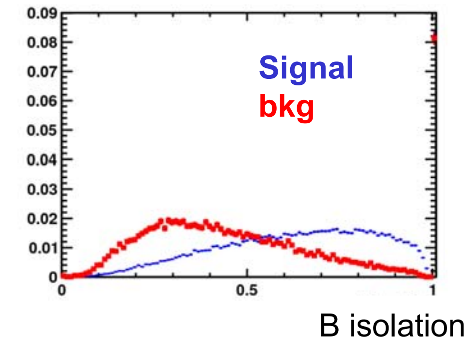
# Analysis strategy

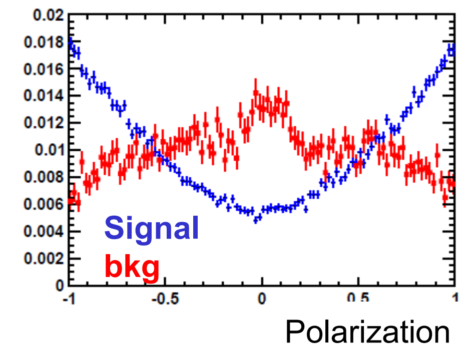



- Selection
  - muon-based trigger
  - Soft selection to reduce size of dataset
  - Similar to control channels
  - Blind signal region ($M_{Bd}$-60MeV, $M_{Bs}$+60MeV)
- Signal and background discrimination:
  - NEW boosted decision tree combining kinematic and geometrical properties
  - Invariant mass
- Data driven calibration through control channels to get signal and background expectations
- Translate number of observed events into branching fraction measurement by normalizing with channels of known BR
- Results:
  - Extract observation / exclusion measurement using the modified frequentist CLs method in bins of mass and BDT

# Boosted decision tree

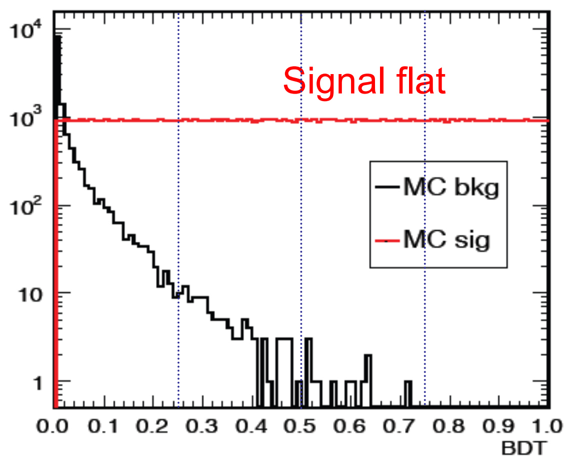
- Use 9 input variables:
  - B impact parameter, B lifetime, muon isolation, DOCA, B Pt, minimum impact parameter of the muons — Already in previous analysis
  - B isolation
  - Polarization variable
  - Minimum Pt of the muons — New

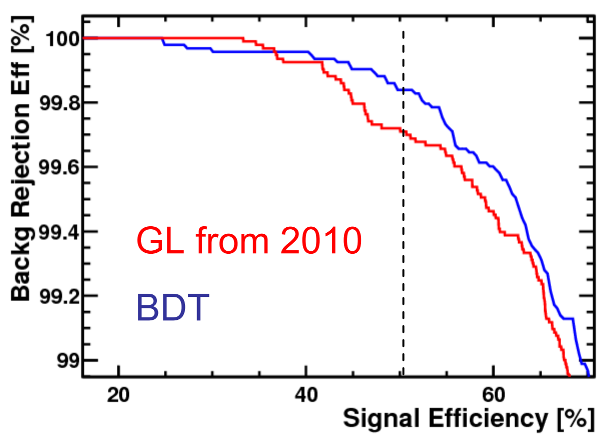



- Choice of variables to avoid correlation with invariant mass
- Optimization and training on MC, using $B_s \to \mu^+\mu^-$ and $bb \to \mu\mu X$ background

Background peaked at 0

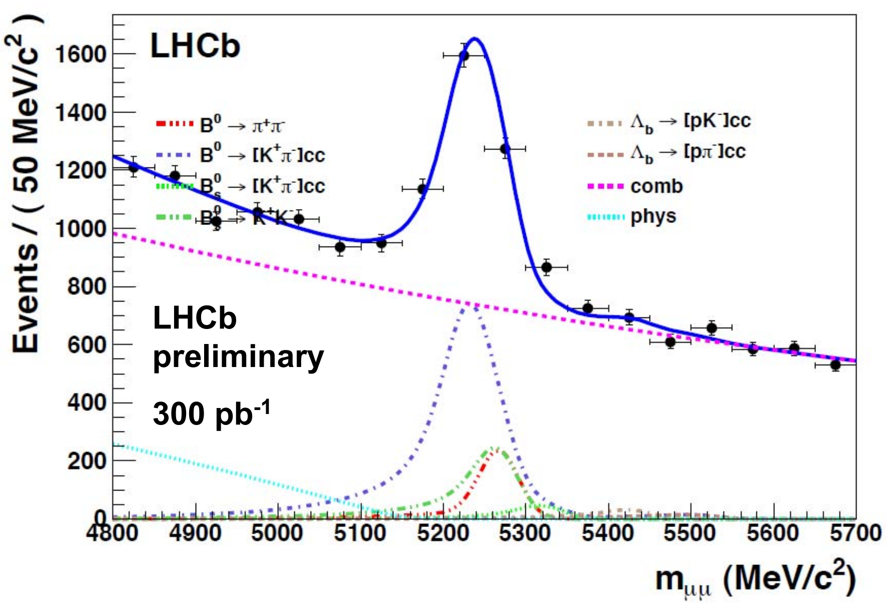


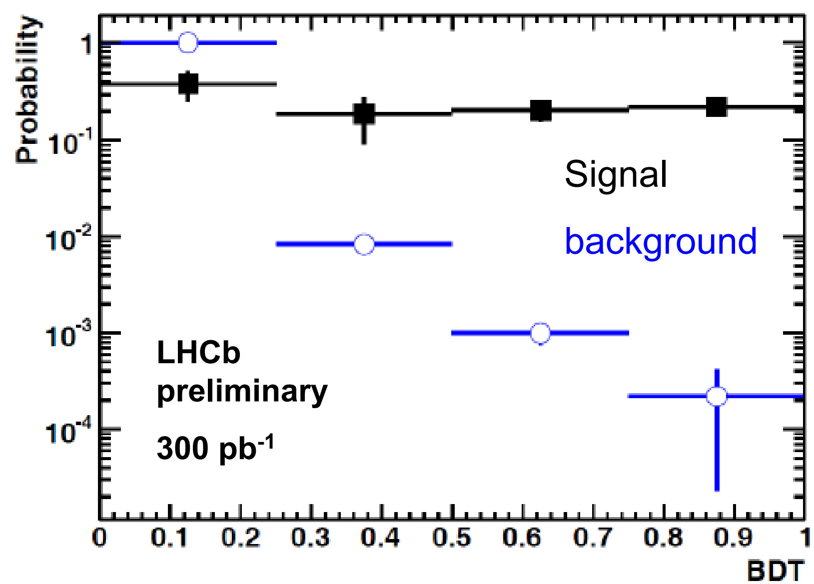



# Calibration of BDT

- For the signal we use data $B_{d/s} \to h^+h^-$
  - Same topology as $B_s \to \mu^+\mu^-$
  - However are selected by hadronic triggers that can bias the shape of variables
    $\to$ Use only events triggered independently of the signal (TIS)

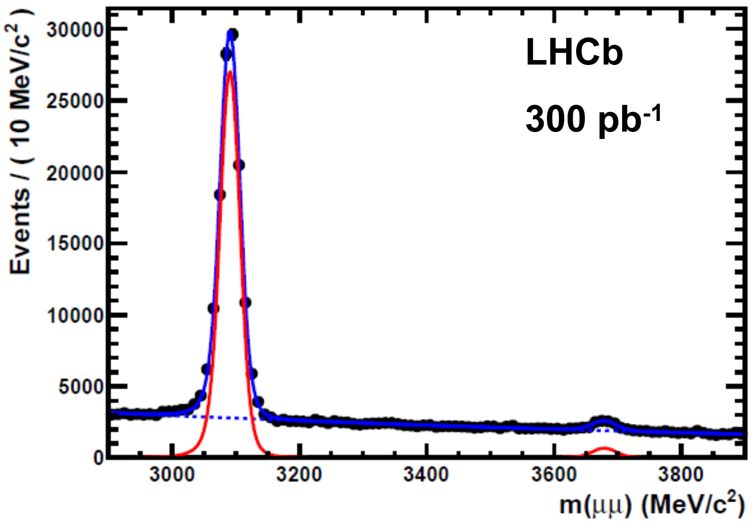
- Background: data sidebands

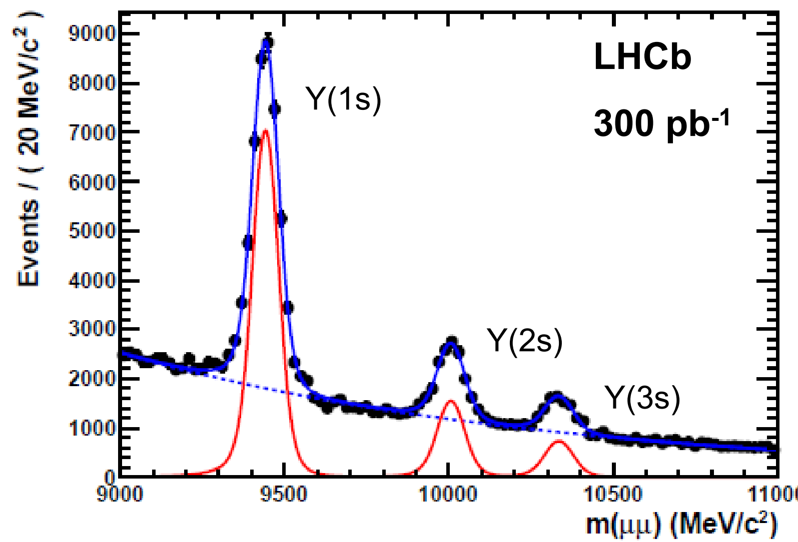


# Calibration of invariant mass

- Invariant mass: modeled by a Crystal Ball
  - Resolution: use interpolation of dimuon resonances (J/ψ, ψ(2s), Y's), crosschecked with inclusive and exclusive $B_{d/s} \rightarrow h^+h^-$
  - Mean: from exclusive $B_s \rightarrow K^+K^-$ and $B^0 \rightarrow K^+\pi^-$




$\sigma(B_s)$ = (24.6±0.2±1.0) MeV/$c^2$

$\sigma(B_d)$ = (24.3±0.2±1.0) MeV/$c^2$

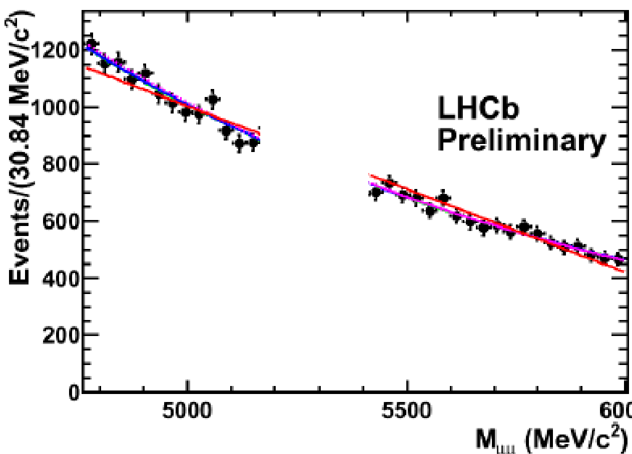
# Background expectation I

- Combinatorial background expectation extracted from a fit to the mass sidebands in bins of BDT
- Systematics evaluated using different fit functions and ranges

BDT<0.25

$B_s$=2968±69

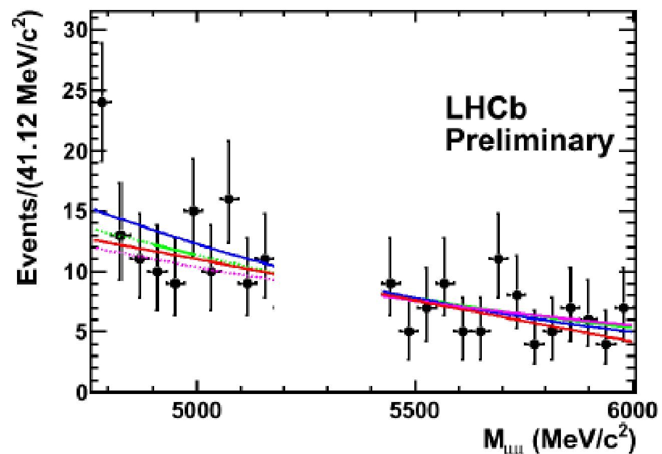
$B_d$=3175±72




0.25<BDT<0.5

$B_s$=25.0±2.5

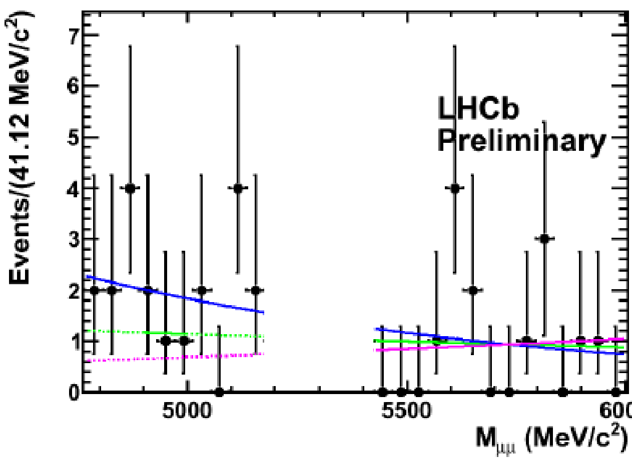
$B_d$=26.6±2.5




0.5<BDT<0.75

$B_s$=3.0±0.9

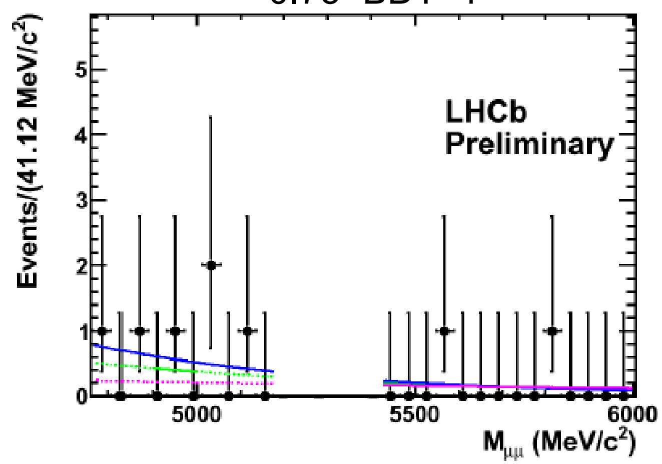
$B_d$=3.1±0.8




0.75<BDT<1

$B_s$=0.7±0.4

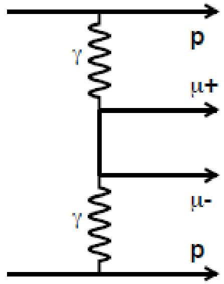
$B_d$=0.7±0.4



# Background expectation II

- Most of background is due to real muons from $bb \rightarrow \mu\mu X$ events

- Also found a bkg component coming from photoproduction
  - Isolated muons, possible high mass
  - But very low Pt
  - ⇨ efficiently removed by pT(B)> 500 MeV/c




- Background due to misidentified muons from $B_{d/s} \rightarrow h^+h^-$ decays
  - Evaluated from $B_{d/s} \rightarrow h^+h^-$ MC reweighted according to misID probablity measured in data
  - Cross checked with $B_{d/s} \rightarrow h^+h^-$ data, requiring one muon in the final state

We expect:

2.5±0.5 misID events in $B_d$ region ⇨ 0.6±0.1 per BDT bin

0.5±0.4 misID events in $B_s$ region ⇨ 0.01±0.011 per BDT bin

# Normalization

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

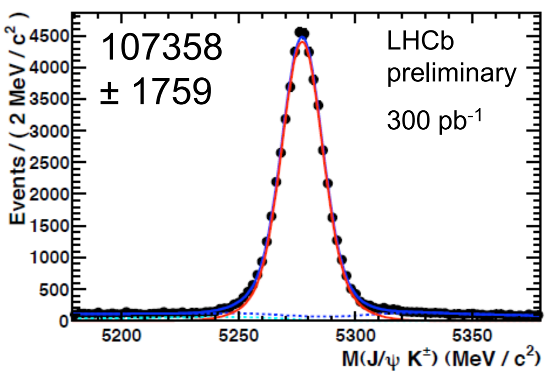
Evaluated from MC, cross checked with data

Measured in data

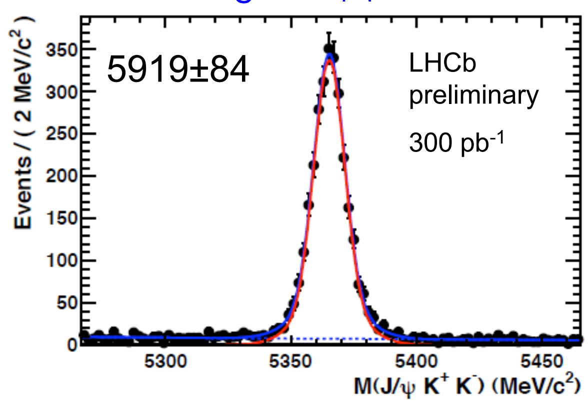
Ratio of probability for a b-quark to hadronize into a given meson

- 3 normalization channels used:

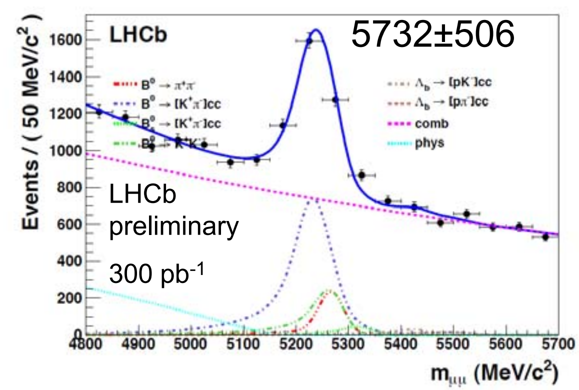
$B^+\to J/\psi K^+$




$B_S\to J/\psi\phi$




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




Average:

$\alpha(B_s\to\mu^+\mu^-) = 9.84 \pm 0.91 \times 10^{-10}$

$\alpha(B_d\to\mu^+\mu^-) = 2.89 \pm 0.15 \times 10^{-10}$

# fs/fd

- Previously we used the HFAG average from LEP/Tevatron. Better to use the value corresponding to the LHC energy.

- fs/fd is measured at LHCb with hadronic decays
  - $B^0 \rightarrow D^- K^+$ and $B_s \rightarrow D_s^- \pi^+$

$$f_s / f_d = 0.250 \pm 0.024_{stat} \pm 0.017_{syst} \pm 0.017_{theo}$$

  - $B^0 \rightarrow D^- \pi^+$ and $B_s \rightarrow D_s^- \pi^+$

$$f_s / f_d = 0.256 \pm 0.014_{stat} \pm 0.019_{syst} \pm 0.026_{theo}$$

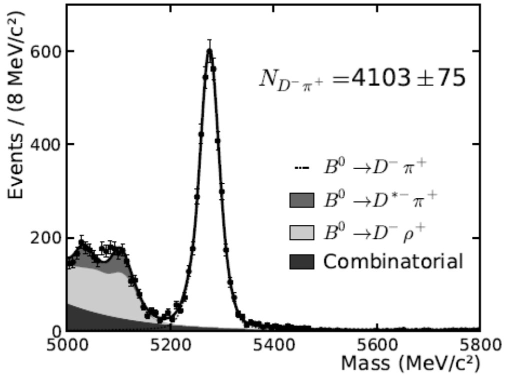
- And semileptonic decays (preliminary, see talk by M. Artuso)

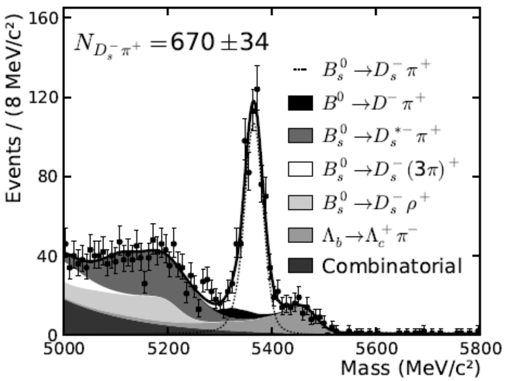
$$\frac{f_s}{f_d + f_u} = 0.134 \pm 0.004^{+0.011}_{-0.010}$$

- We compute the average: lhcb-conf-2011-034

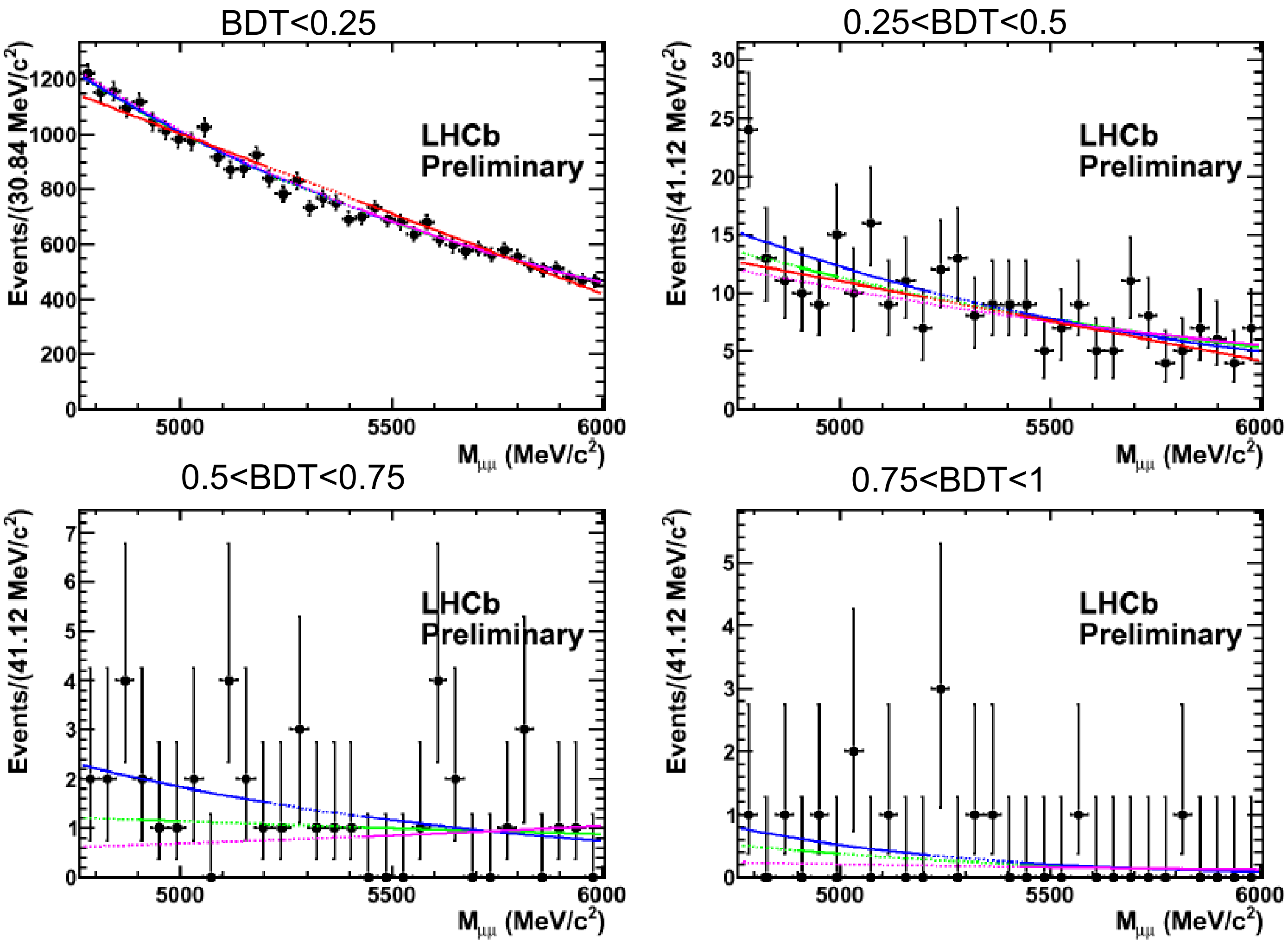
$$f_s / f_d = 0.267^{+0.021}_{-0.020}$$

arXiv:1106.4435
submitted to PRL



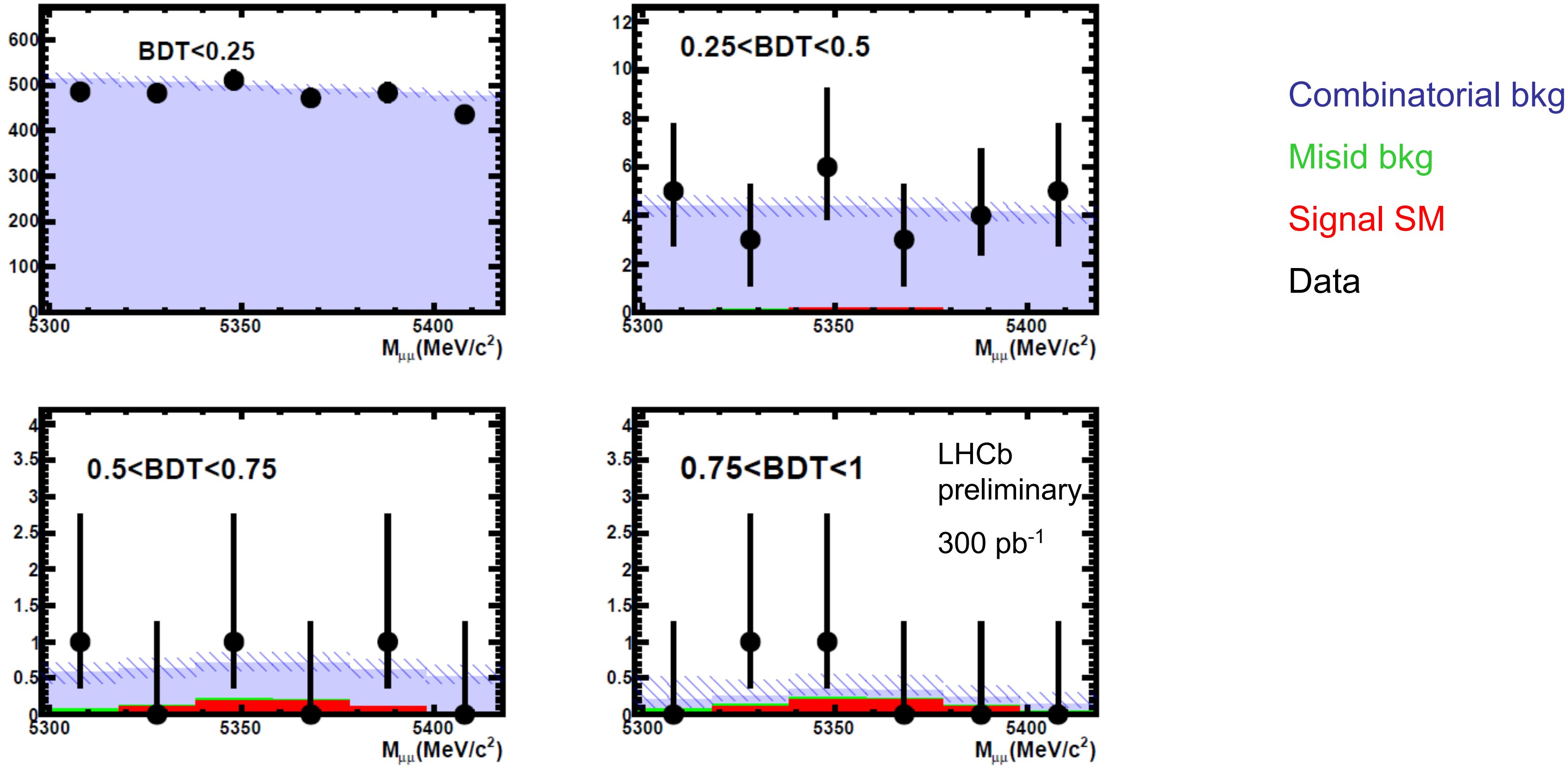



# Open the box




No excess seen

# $B_s$ region

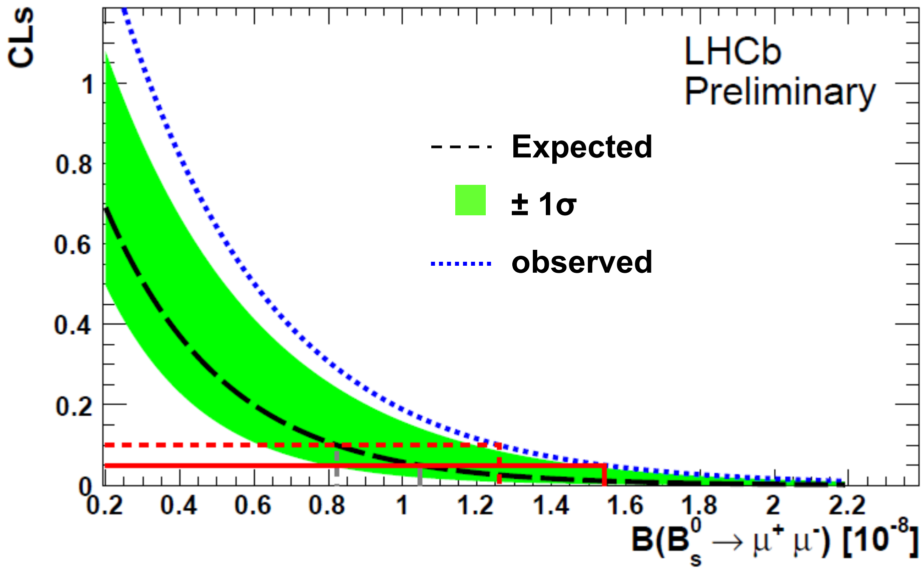



| | BDT<0.25 | 0.25<BDT<0.5 | 0.5<BDT<0.75 | 0.75<BDT |
|---|---|---|---|---|
| Exp.combinatorial | 2968 ± 69 | 25 ± 2.5 | 2.99 ± 0.89 | 0.66 ± 0.40 |
| Exp. SM signal | 1.26 ± 0.13 | 0.61 ± 0.06 | 0.67 ± 0.07 | 0.72 ± 0.07 |
| Observed | 2872 | 26 | 3 | 2 |

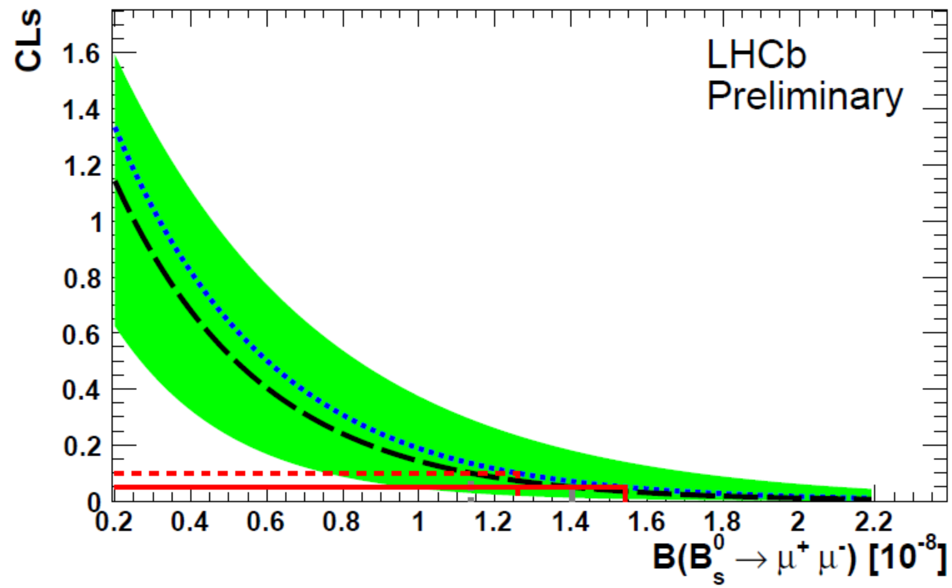
misID background : 0.01±0.011 per bin

# Limit on BR($B_s \to \mu^+\mu^-$)

Background only

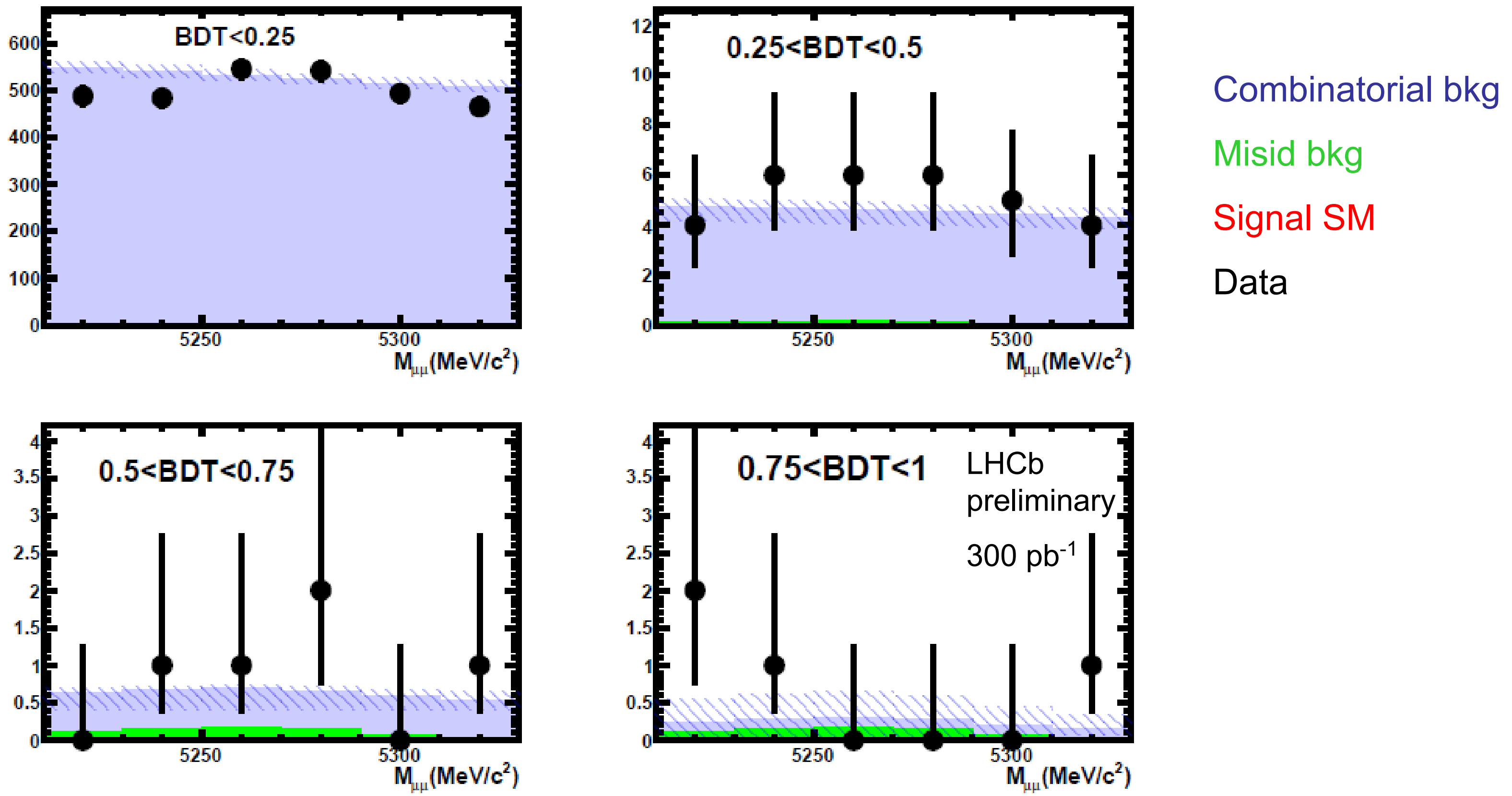



SM included



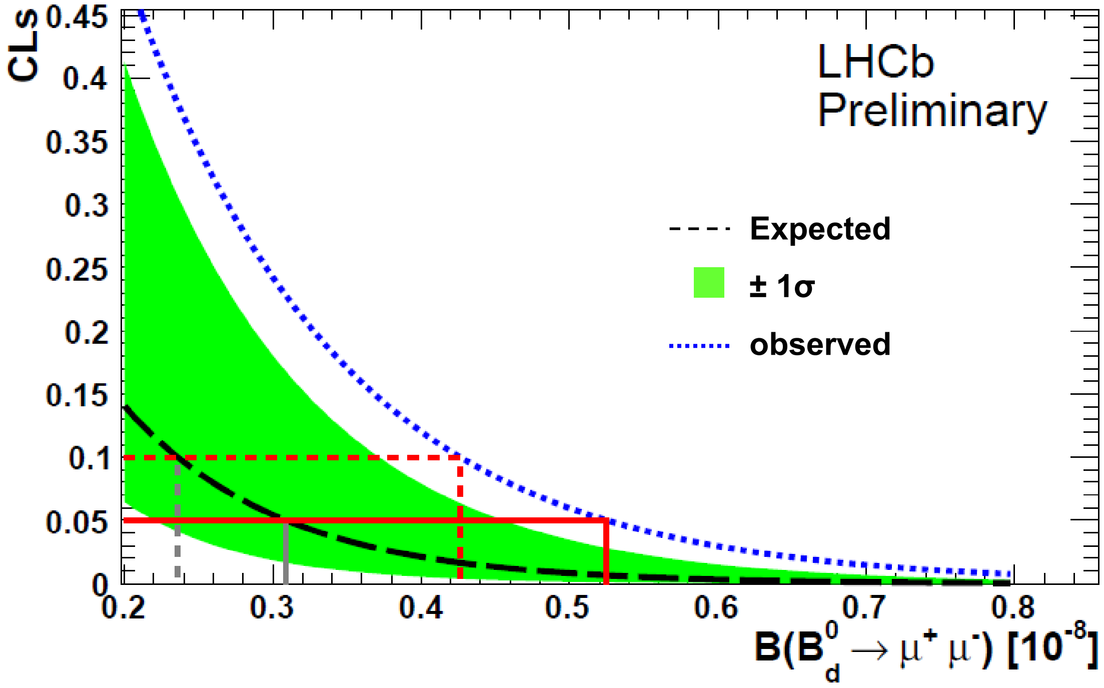

| | Bkg only 90 (95) %CL | SM signal 90 (95) %CL | CLb |
|---|---|---|---|
| Expected stat+syst | 0.8 (1.0) $\times 10^{-8}$ | 1.2 (1.5) $\times 10^{-8}$ | |
| Observed stat+syst | 1.3 (1.6) $\times 10^{-8}$ | | 0.86 |

# $B_d$ region




| | BDT<0.25 | 0.25<BDT<0.5 | 0.5<BDT<0.75 | 0.75<BDT |
|---|---|---|---|---|
| Exp.combinatorial | 3175 ± 72 | 26.6 ± 2.5 | 3.1 ± 0.8 | 0.7 ± 0.4 |
| Exp. MisID | 0.6± 0.1 | 0.6± 0.1 | 0.6± 0.1 | 0.6± 0.1 |
| Observed | 3025 | 31 | 5 | 4 |

# Limit on BR($B_d \rightarrow \mu^+\mu^-$)




| | Bkg only 90(95) %CL | CLb |
|---|---|---|
| Expected stat+syst | 2.4 (3.1) $\times 10^{-9}$ | |
| Observed stat+syst | 4.2 (5.2) $\times 10^{-9}$ | 0.90 |

# Summary

- LHCb presents new preliminary results with 300pb$^{-1}$ on BR($B_{s/d} \to \mu^+\mu^-$)

  BR($B_s \to \mu^+\mu^-$) < 1.3 x10$^{-8}$ (1.6 x10$^{-8}$) @ 90 (95)% CL

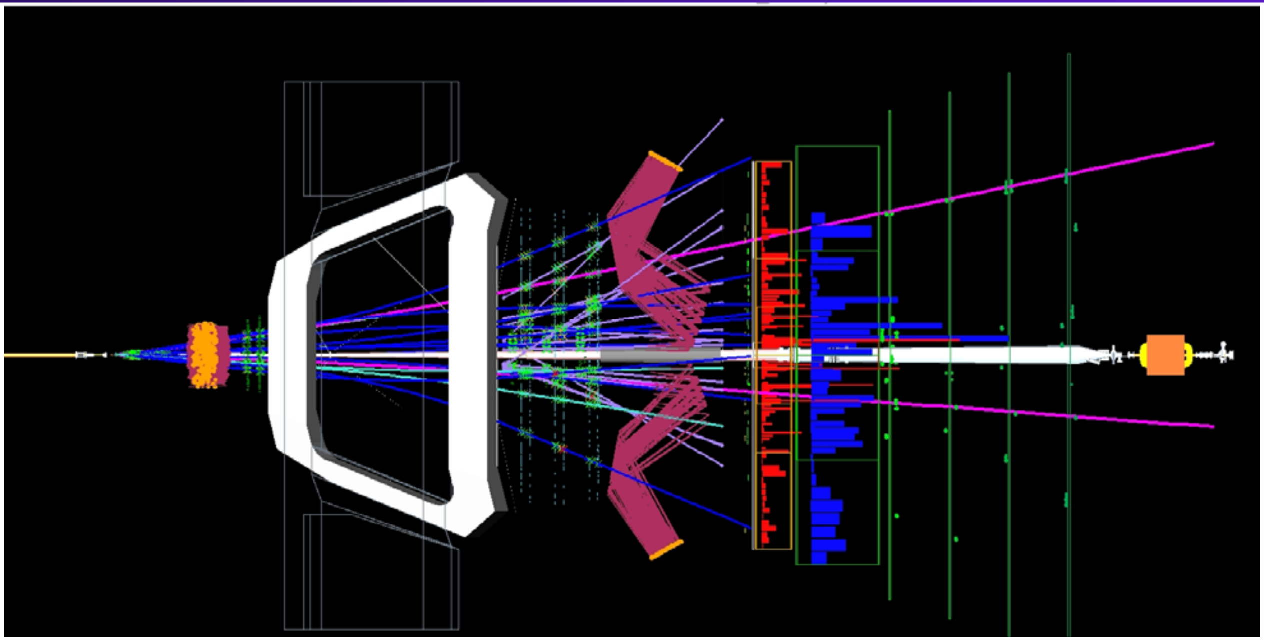
  BR($B_d \to \mu^+\mu^-$) < 4.2 x10$^{-9}$ (5.2 x10$^{-9}$) @ 90 (95)% CL

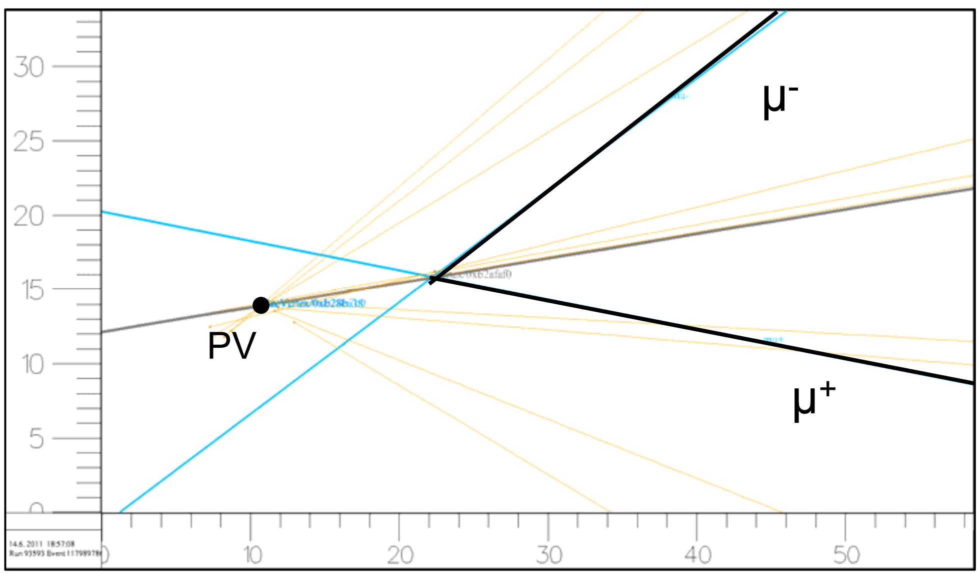
- Combined results with 2010 data (37pb$^{-1}$):

  BR($B_s \to \mu^+\mu^-$) < 1.2 (1.5) x10$^{-8}$ @ 90 (95)% CL

- We do not confirm the excess seen by CDF

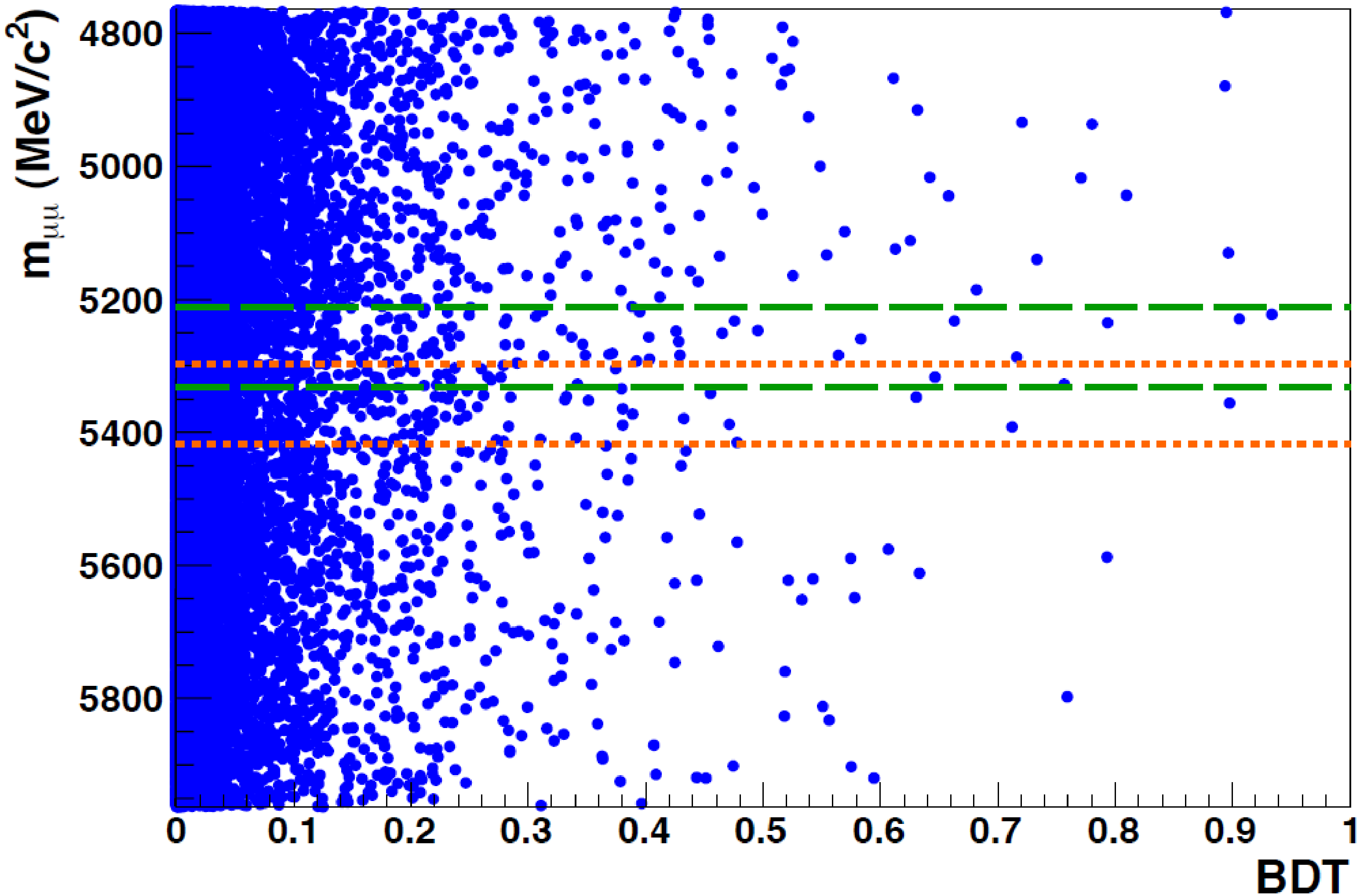
# A nice signal candidate!





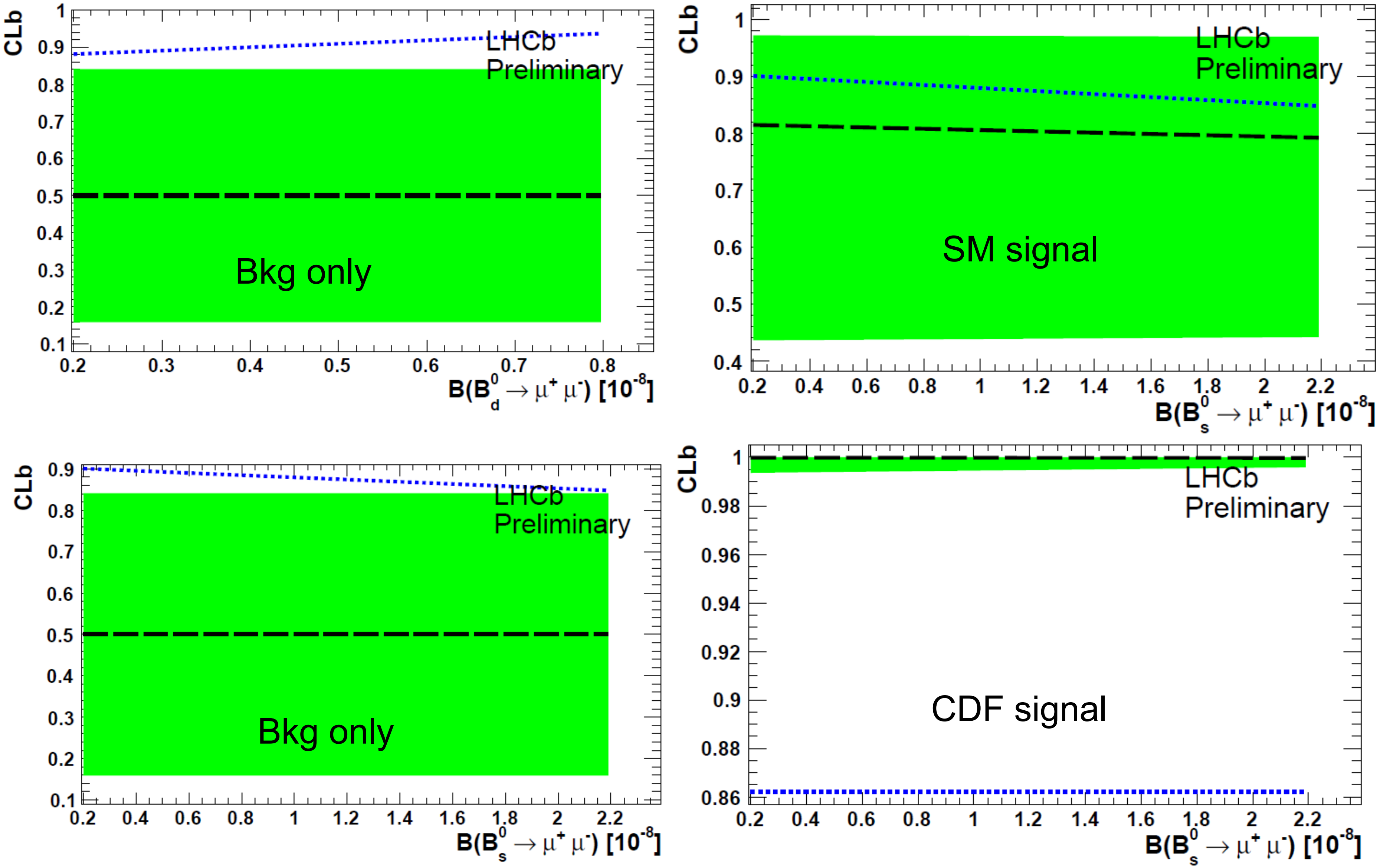

Mμμ = 5.357 GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for *p*T > 0.5 GeV

# backup



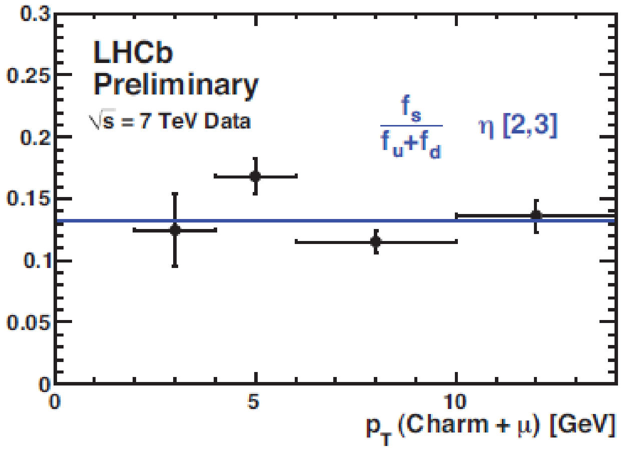
$m_{\mu\mu}$ (MeV/c$^2$)
4800
5000
5200
5400
5600
5800
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
BDT

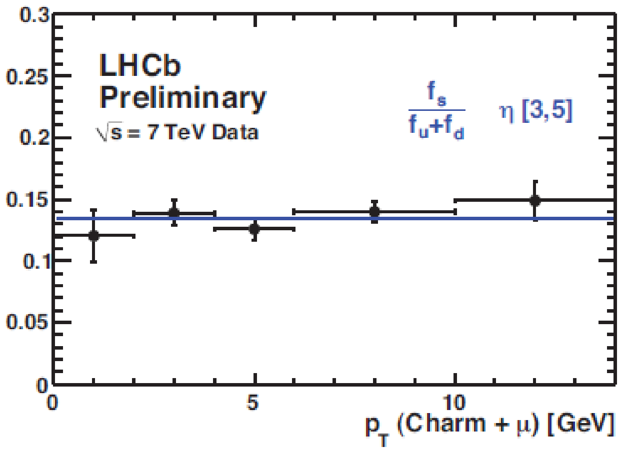
# CLb


CLb
LHCb
Preliminary
Bkg only
$B(B_d^0 \to \mu^+ \mu^-)$ [$10^{-8}$]
CLb
LHCb
Preliminary
SM signal
$B(B_s^0 \to \mu^+ \mu^-)$ [$10^{-8}$]
CLb
LHCb
Preliminary
Bkg only
$B(B_s^0 \to \mu^+ \mu^-)$ [$10^{-8}$]
CLb
LHCb
Preliminary
CDF signal
$B(B_s^0 \to \mu^+ \mu^-)$ [$10^{-8}$]

# fs/fd

Independance versus η checked with semileptonic decays

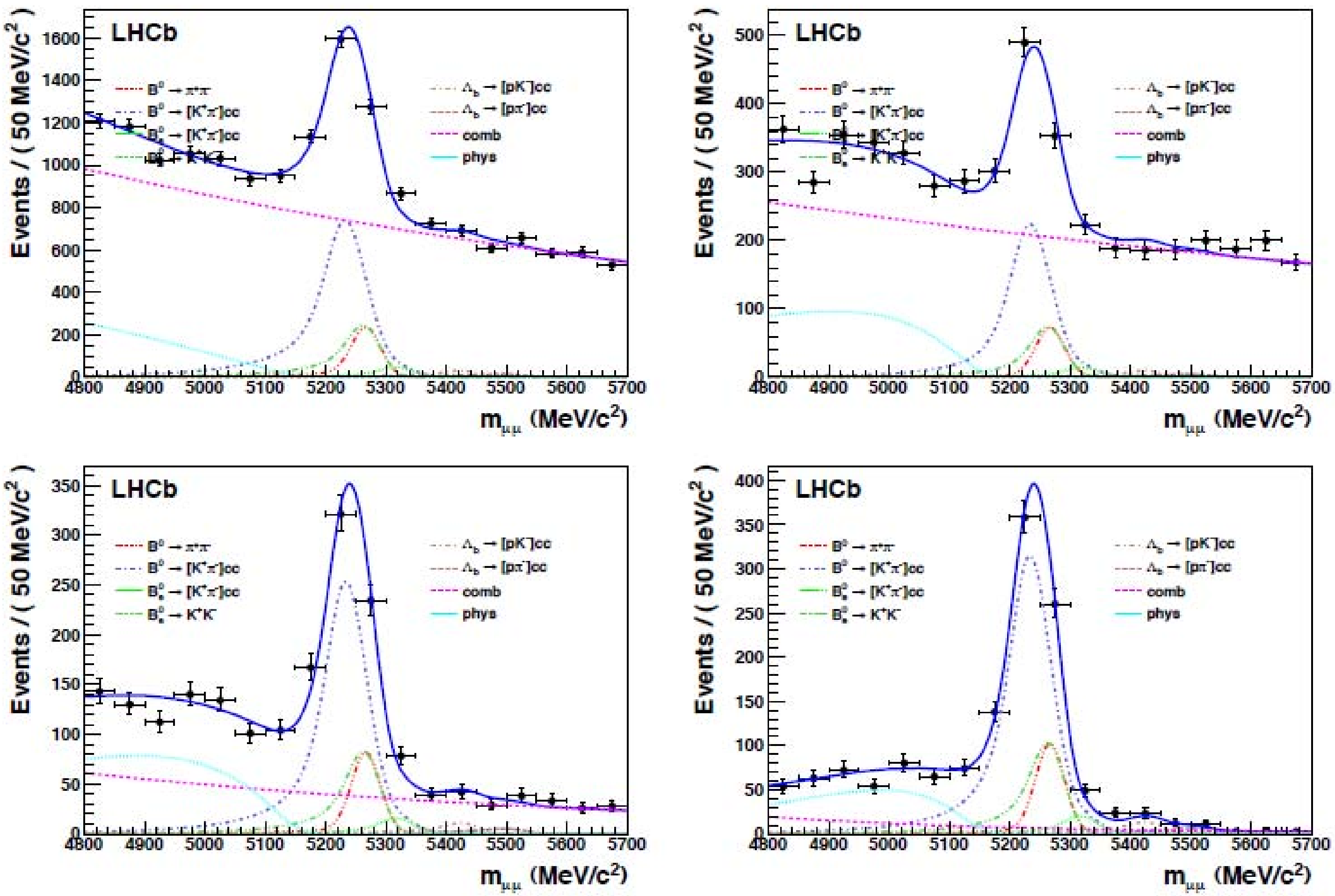



Summary of systematics and theoretical errors of the 3 LHCb measurements

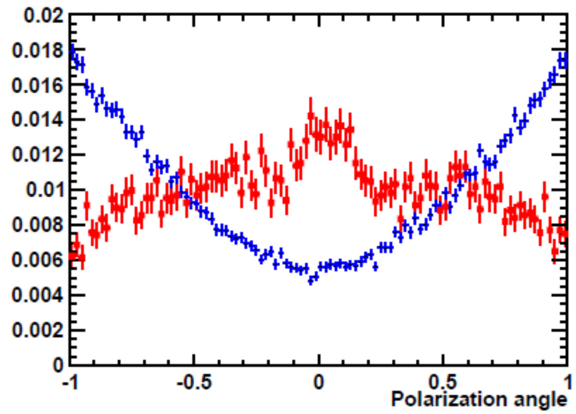
| Source | Error(%) | | | |
|---|---|---|---|---|
| | $(f_s/f_d)_{\rm sl}$ | $(f_s/f_d)_{\rm h1}$ | $(f_s/f_d)_{\rm h1}$ | |
| Bin dependent error | 1.0 | - | - | Uncorrelated |
| Semileptonic decay modelling | 3.0 | - | - | Uncorrelated |
| Backgrounds | 2.0 | - | - | Uncorrelated |
| Fit model | - | 2.8 | 2.8 | Uncorrelated |
| Trigger Simulation | - | 2.0 | 2.0 | Uncorrelated |
| Tracking Efficiency | 2.0 | - | - | Uncorrelated |
| $B_s^0 \to D^0 K^+ X \mu \overline{\nu}_\mu$ | $^{+4.1}_{-1.1}$ | - | - | Uncorrelated |
| Particle Identification Calibration | 1.5 | 1.0 | 2.5 | Correlated |
| $D$ Lifetimes | 1.5 | 1.5 | 1.5 | Correlated |
| $\mathcal{B}(D_s^+ \to K^+ K^- \pi^+)$ | 4.9 | 4.9 | 4.9 | Correlated |
| $\mathcal{B}(D^+ \to K^- \pi^+ \pi^-)$ | 1.5 | 1.5 | 1.5 | Correlated |
| SU(3) and form factors | | 6.1 | 6.1 | Correlated (had) |
| $W$-exchange | - | - | 7.8 | Uncorrelated |

# BDT calibration

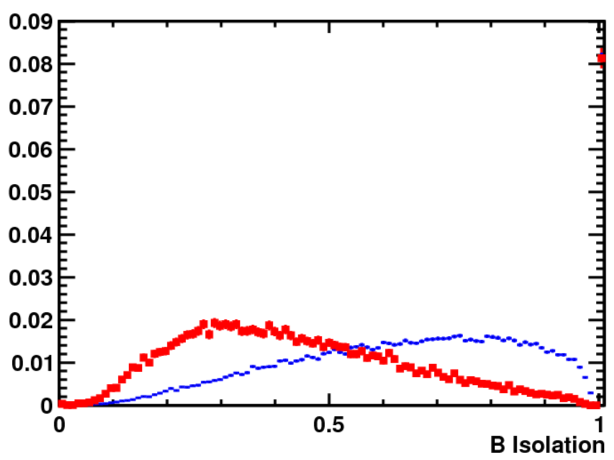


# New variables

Angle between the vector perpendicular to both the beam and the B momenta, and the muon momenta in the B rest frame




For signal ~polarization modula pi/2



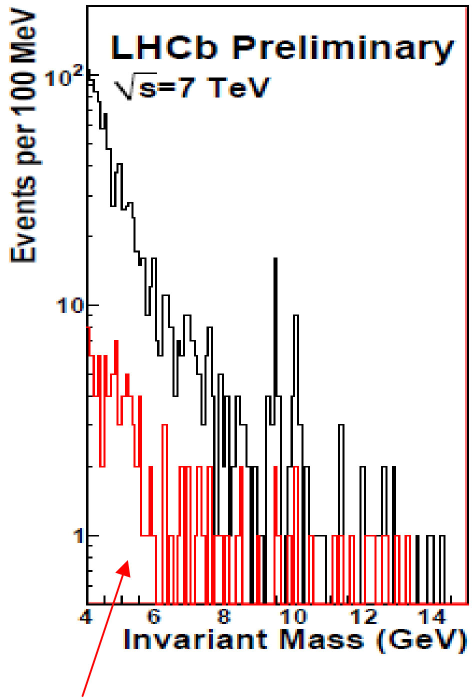

$pT_B/(pT_B+\Sigma_{\vartheta,\varphi}\, pT_{tr})$

Summing on the tracks for which

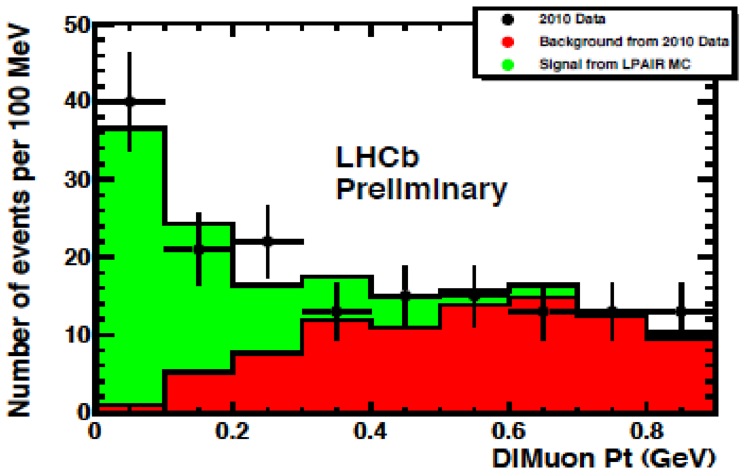
$$\sqrt{\delta\eta^2 + \delta\phi^2} < 1.0$$

# Photoproduction background

LHCb-CONF-2011-022




Event containing only 2 muons




All pT< 700MeV

These events can look like signal if they are associated to a wrong PV

Cut a B(PT)>500 MeV removes ~100% of this background but only 1.8% of signal

# Normalization

| $B^{\pm}\to J/\psi(\mu\mu)\, K^{\pm}$ | $B_s\to J/\psi(\mu\mu)\, \phi(KK)$ | $B^0\to K^+\pi^-$ |
|---|---|---|
| BR = $6.01\times10^{-5}$ (±3.5%) | BR = $3.35\times10^{-5}$ (±26%) | BR = $1.94\times10^{-5}$ (±3.1%) |
| • Similar trigger and PID<br>• Tracking efficiency (+1track) dominates error on efficiency ratio<br>• $f_d/f_s$ dominates overall uncertainty | • Similar trigger and PID<br>• Tracking efficiency (+2tracks) dominates error on efficiency ratio<br>• BR dominates overall uncertainty | • Different trigger → **use events triggered independent of signal**<br>• Identical topology<br>• Uncertainty from $f_d/f_s$, trigger, mass fit |

| | $\alpha(B_s\to\mu\mu)$ $10^{-9}$ | $\alpha(B^0\to\mu\mu)$ $10^{-10}$ |
|---|---|---|
| $B^{\pm}\to J/\psi\, K^{\pm}$ | 1.0±0.1 | 2.58±0.16 |
| $B_s\to J/\psi\phi$ | 1.3±0.4 | 3.4±1.0 |
| $B^0\to K^+\pi^-$ | 0.92±0.14 | 2.46±0.32 |