Search for New Physics in $B_{(s,d)} \to \mu^+\mu^-$ decays at LHCb

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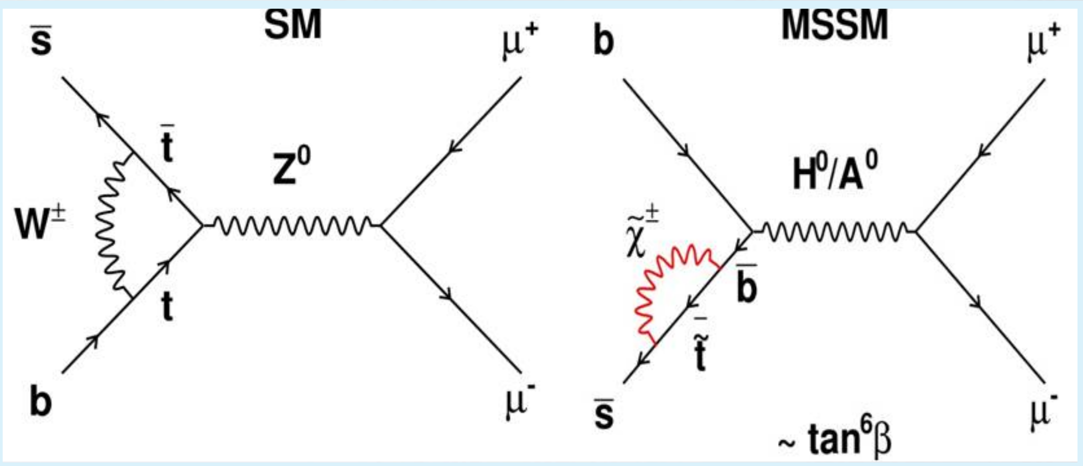
A First Glimpse of the Tera Scale

$B_{s,d} \to \mu^+\mu^-$ probe for NP

$B_{s,d} \to \mu\mu$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

$$BR(B_q \to l^+l^-) \approx \frac{G_F^2 \alpha^2 M_{B_q}^3 f_{B_q}^2 \tau_{B_q}}{64\pi^3 \sin^4\theta_W} |V_{tb}V_{tq}^*|^2 \sqrt{1 - \frac{4m_l^2}{M_{B_q}^2}}$$
$$\left\{ M_{B_q}^2 \left(1 - \frac{4m_l^2}{M_{B_q}^2}\right) c_S^2 + \left[M_{B_q} c_P + \frac{2m_l}{M_{B_q}} (c_A - c_A') \right]^2 \right\}.$$



Double suppressed decay: helicity and FCNC

↳ very small BR in SM but well predicted:

$BR(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$

$BR(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$

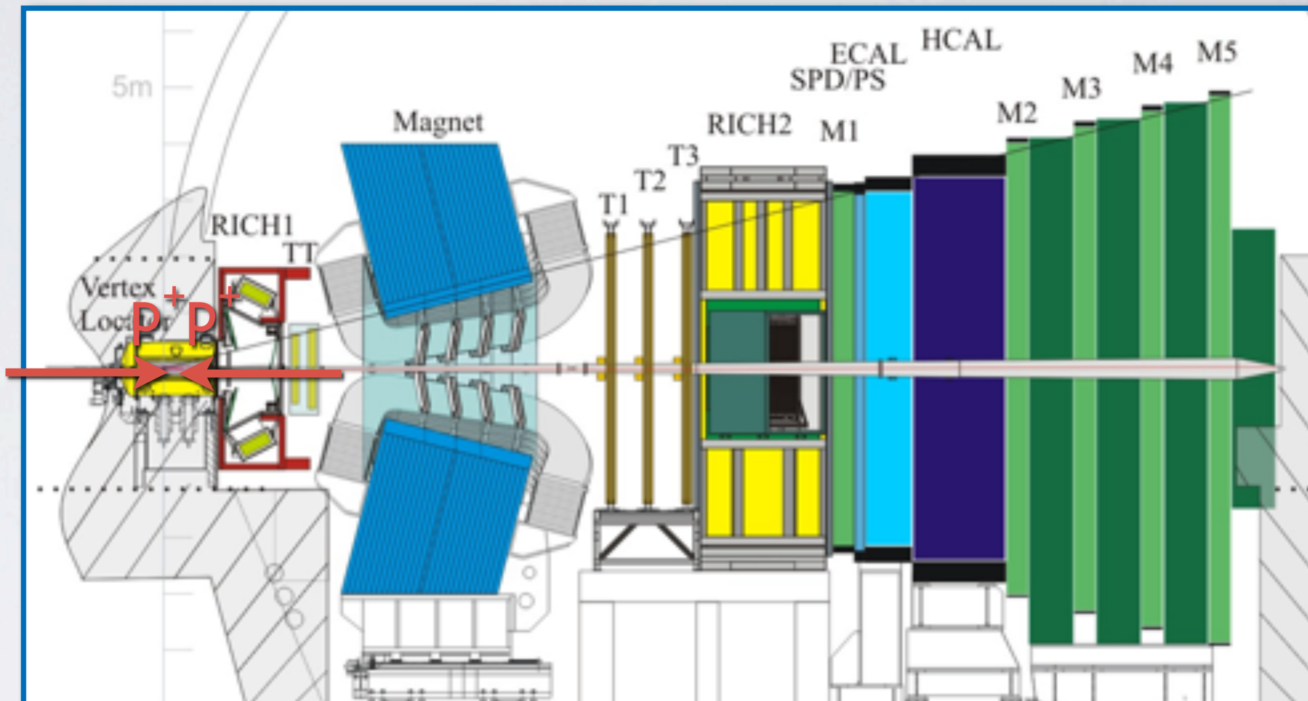
↳ sensitive to NP effects in scalar/pseudoscalar Higgs sector:

$BR(B_{(d,s)} \to \mu^+\mu^-) \propto \tan^6\beta / M_A^4$ MSSM large tanβ approximation

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

LHCb benefit from:

- Large cross section:
  - $\sigma(pp \rightarrow bbX)$ @ 7TeV ~ 300μb
- Large acceptance for B decays: $1.9 < \eta < 4.9$
  - $\varepsilon_{acc}(B_{s,d} \rightarrow \mu^+\mu^-) \sim 10\%$
- Very efficient muon trigger
- Good particle ID, tracking and reconstruction



LHCb already published one analysis based on $37pb^{-1}$ from 2010 data

Physics Letter B 699 (2011)330-340

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

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

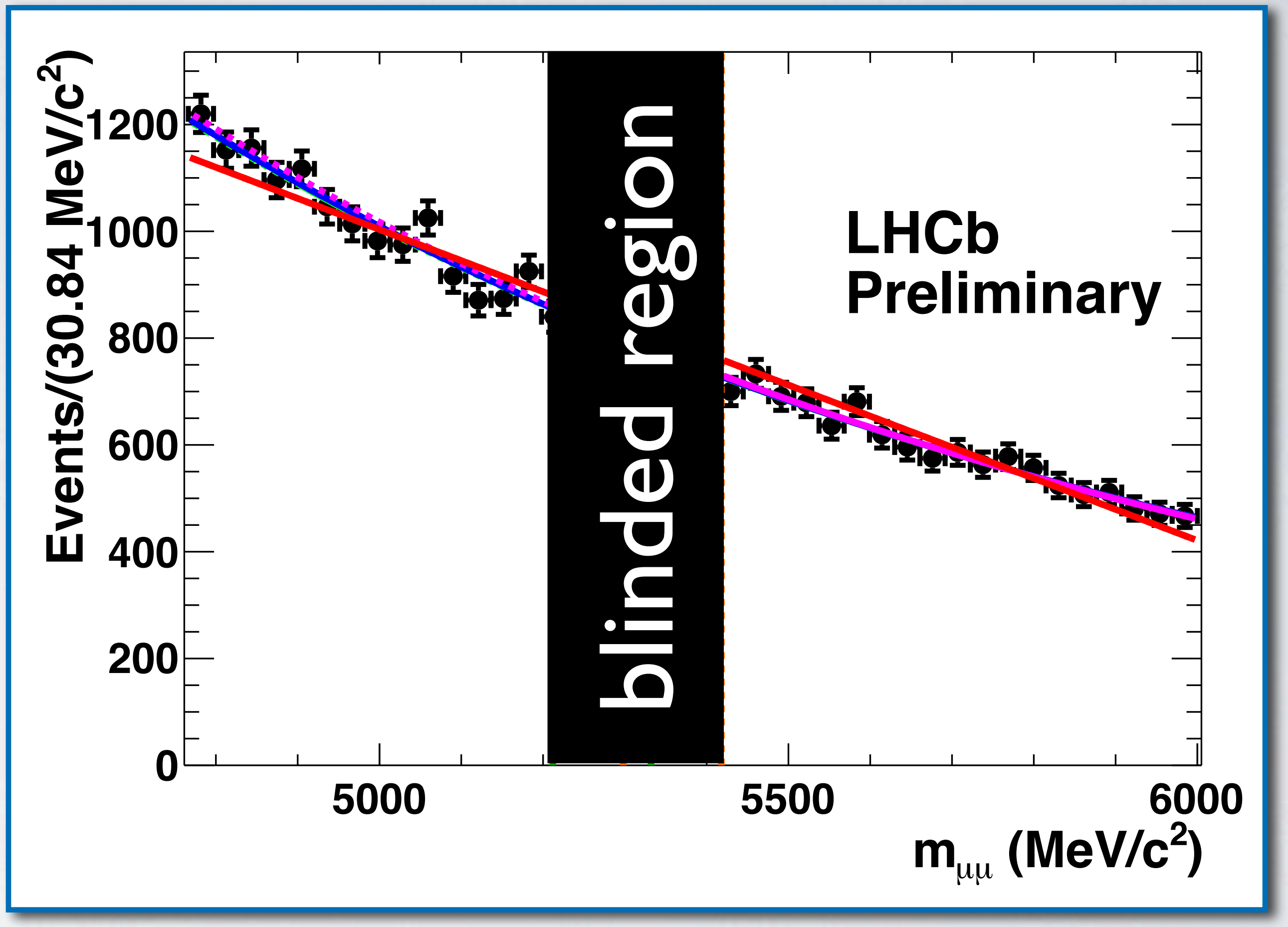
we present an update based on $300\ pb^{-1}$ from the first 3 months of 2011

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

LHCb has already collected $1fb^{-1}$

Analysis strategy

- Selection
  - muon-based trigger
  - Soft selection to reduce size of dataset
  - Blind signal region (M_{Bd}-60MeV, M_{Bs} +60MeV)



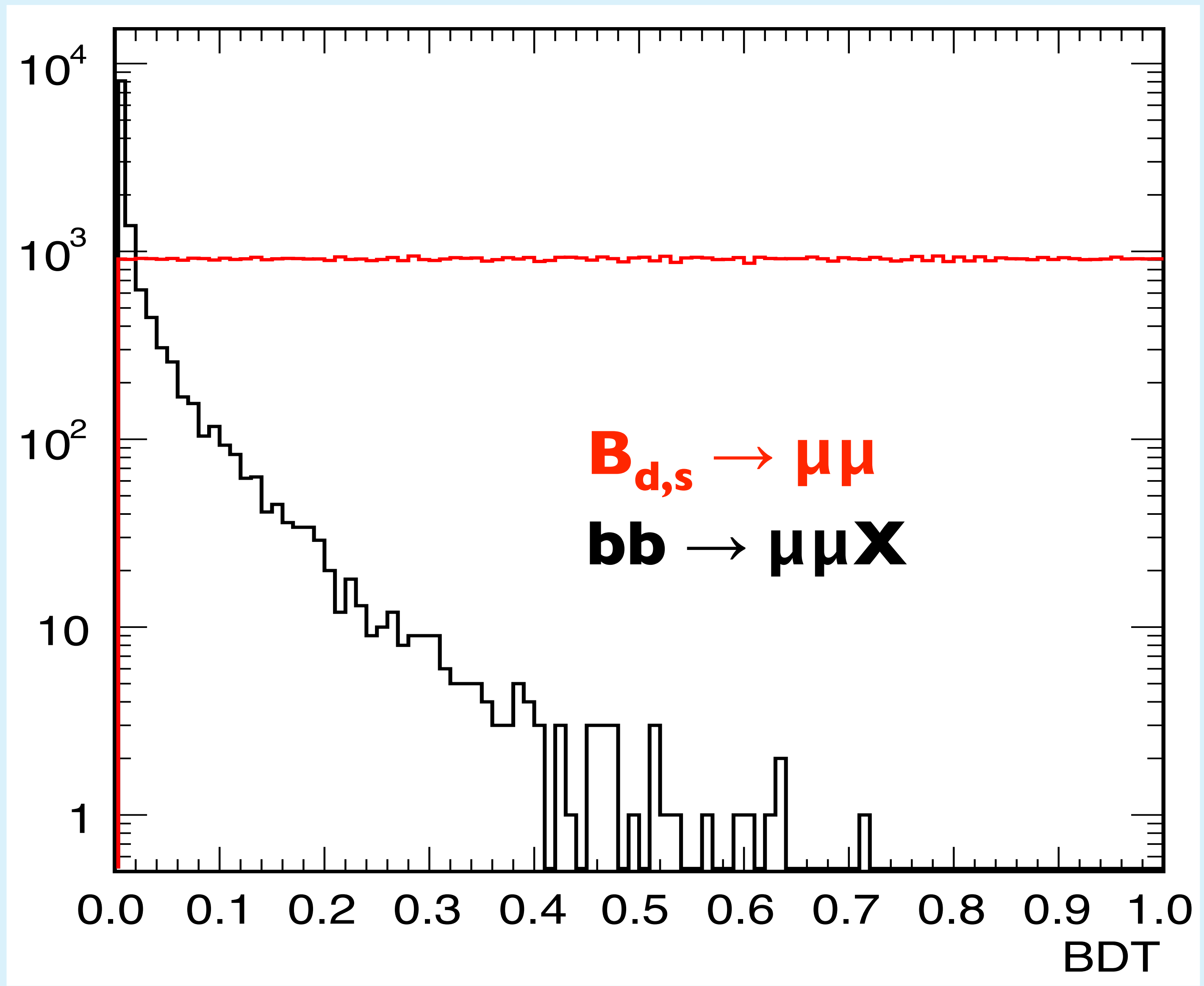
- Signal/background discrimination:
  - MVA classifier BDT combining kinematic and geometrical properties
  - Invariant mass $m_{\mu\mu}$
- Data driven calibration through control channels to get signal and background expectations
- Normalization: convert a number of observed events into a branching fraction by normalizing to channels of known BR
- Results:
  - Extract observation / exclusion measurement using the modified frequentist CLs method in bins of mass and BDT

Boosted Decision Tree

Our main background is combinatorial from two real muons

- reduce it by using MVA classifier built using 9 variables related to the geometry and kinematic of the event
  - B impact parameter, B lifetime, muon isolation, DOCA, B Pt, minimum impact parameter of the muons
  - B isolation
  - Polarization variable
  - Minimum Pt of the muons

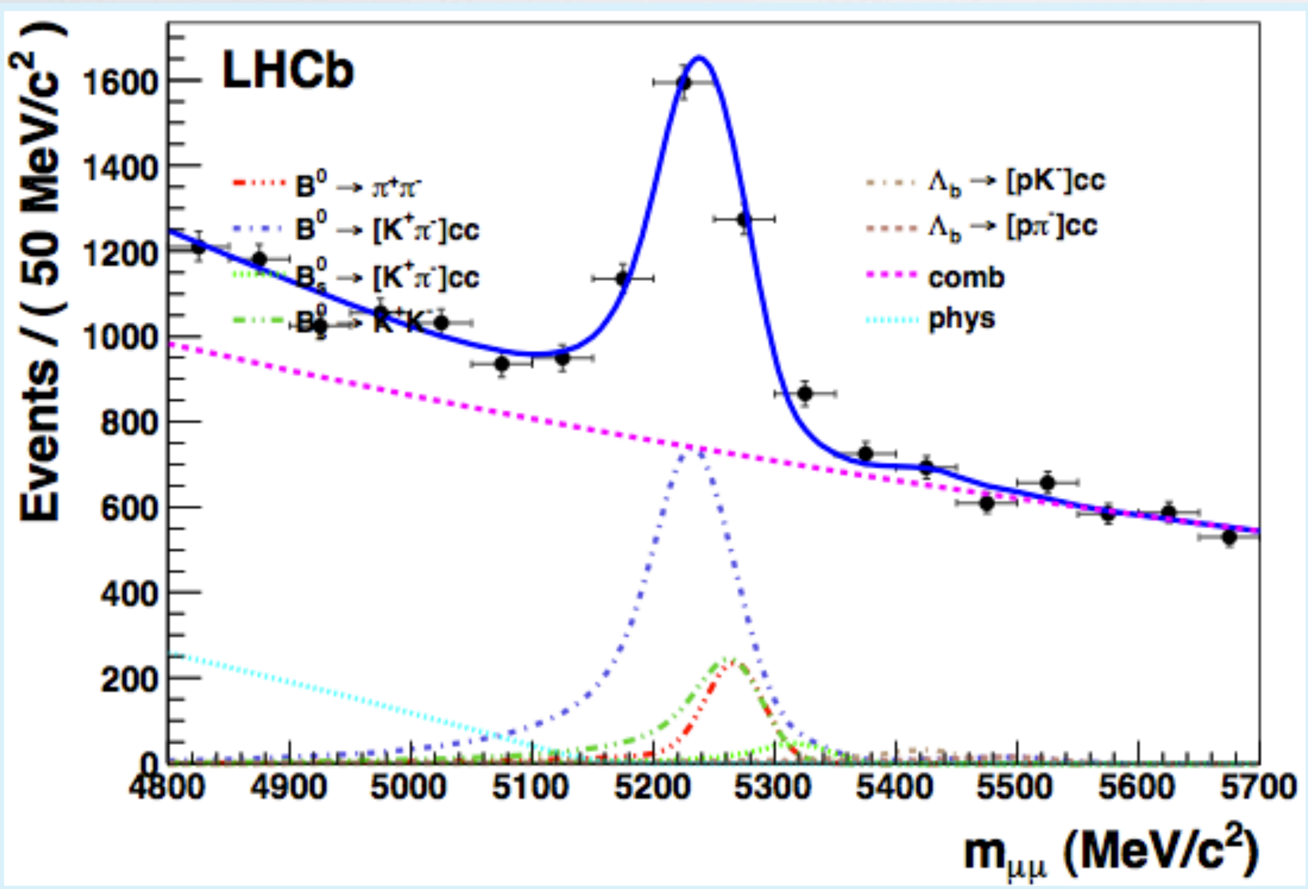
- Choice of variables to avoid correlation with invariant mass
- Optimization and training on MC, using $B_s \to \mu^+\mu^-$ and $bb \to \mu\mu X$

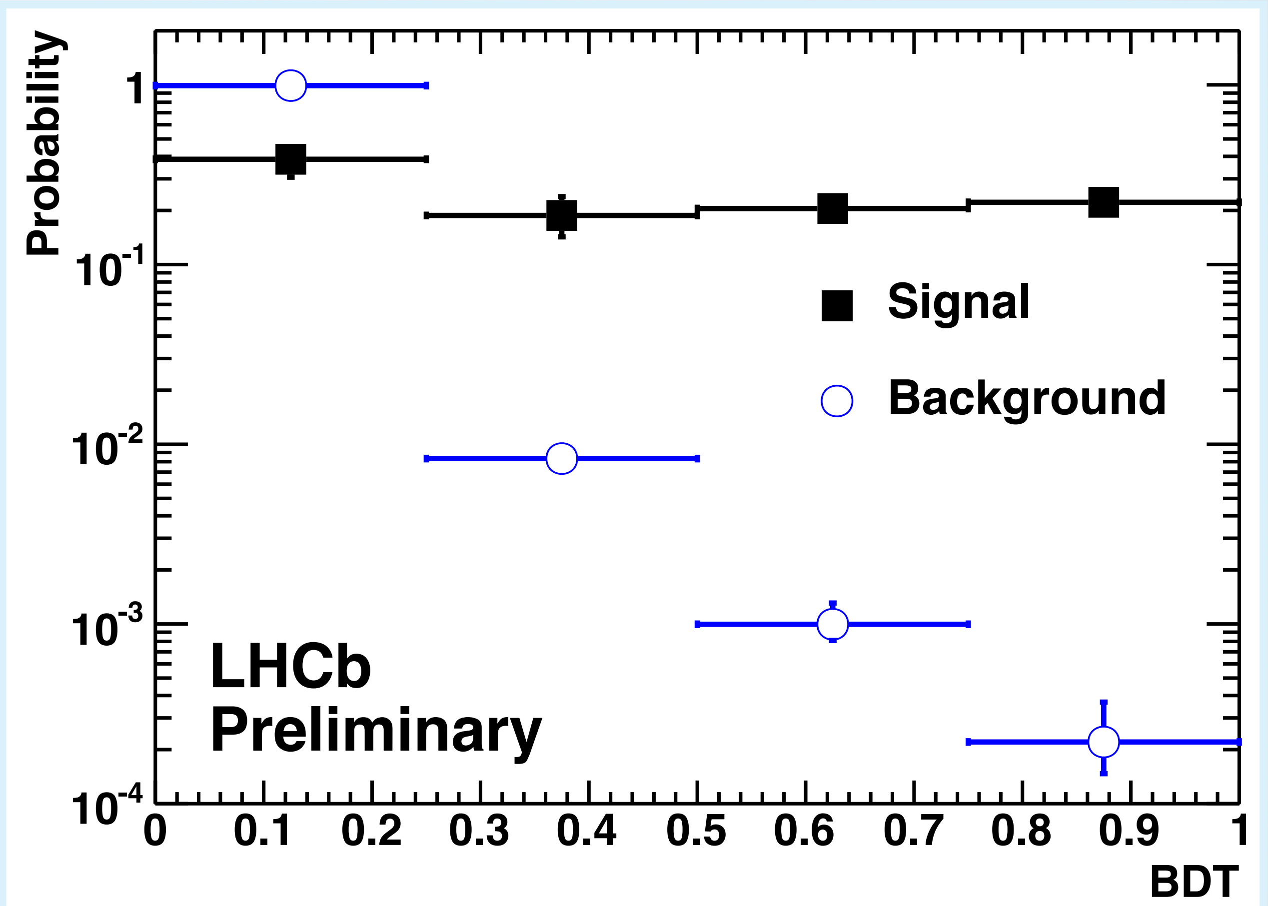


BDT calibration

The BDT response is calibrated on data using:

- for signal we use $B_{(d,s)} \to h^+h^-$ events
  - same topology as $B_{(d,s)} \to \mu^+\mu^-$
  - selected with hadronic trigger: use of events triggered independently of the signal (TIS)
- for background events in the mass sidebands



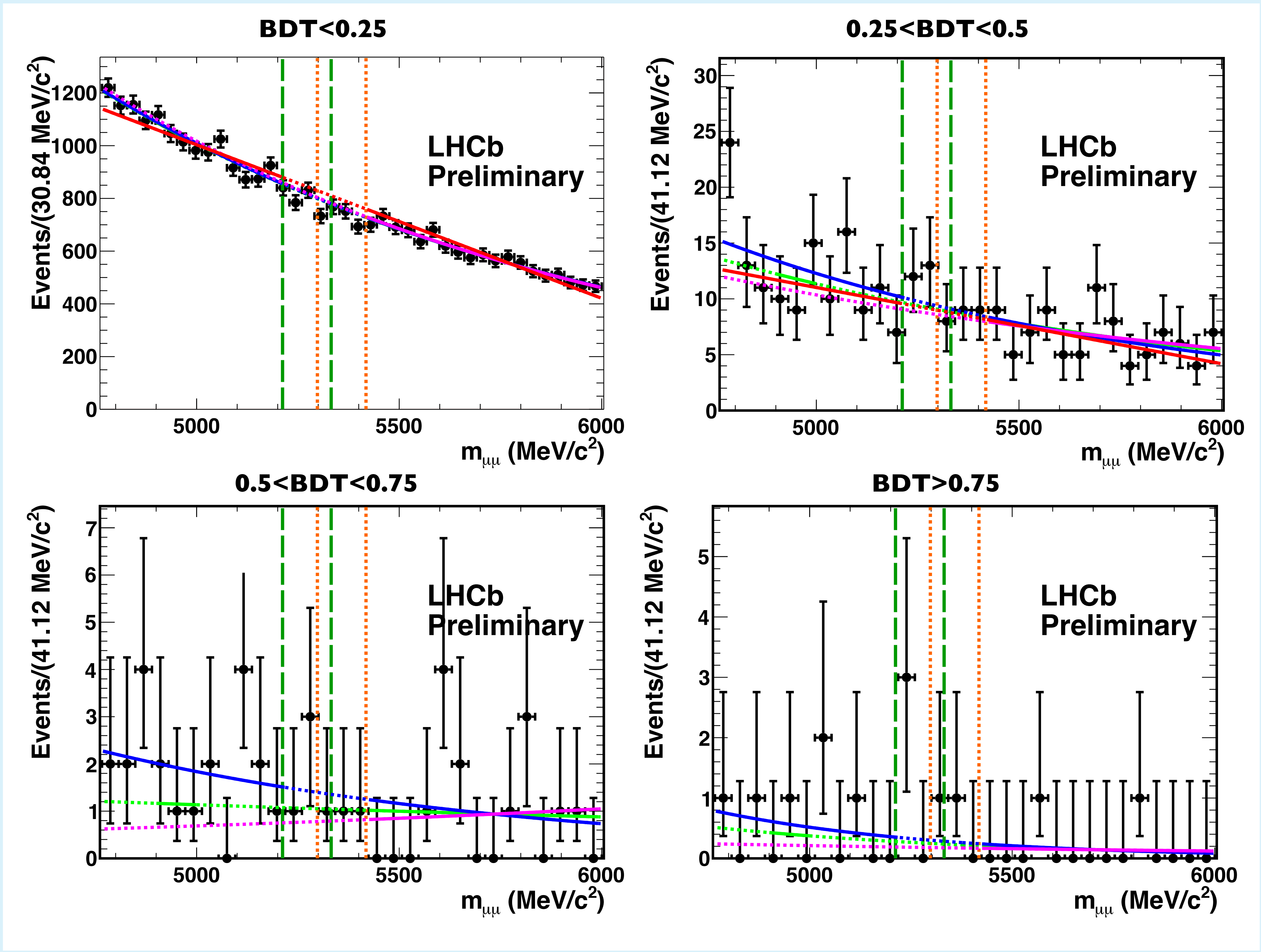


Background expectations

- The expected background events in signal regions are extracted from a fit of the mass sidebands divided in BDT bins
- Systematics evaluated using different fit functions and ranges

Expected background events in B_d e B_s mass region

BDT bin	$B_s \to \mu^+\mu^-$	$B_d \to \mu^+\mu^-$
0-0.25	2968±69	3175±72
0.25-0.5	25.0±2.5	26.6±2.5
0.5-0.75	3.0±0.9	3.1±0.8
0.75-1	0.7±0.4	0.7±0.4

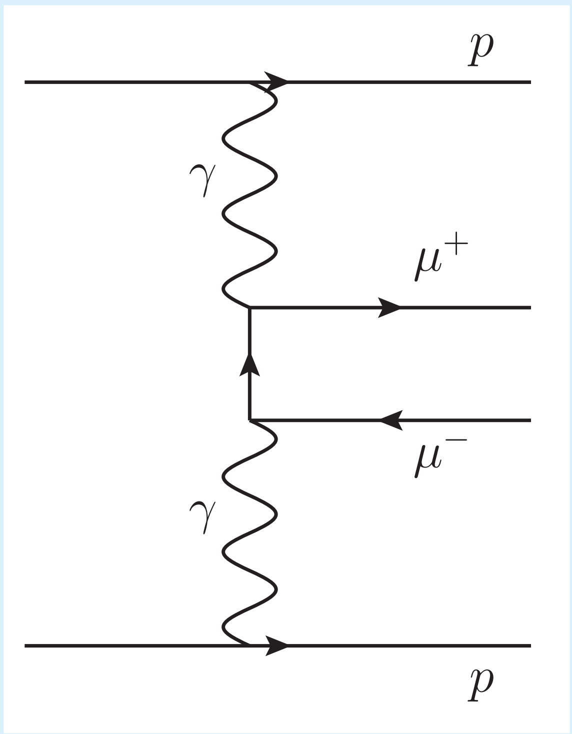


Other bkg sources

The dominant background is due to real muons from bb→μμX events.

The other sources of background are:

- proton-proton photoproduction
  - Isolated muons, possible high mass
  - But very low Pt efficiently removed by pT(B)> 500 MeV/c



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

expected:

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 → 0.1±0.1 per BDT bin

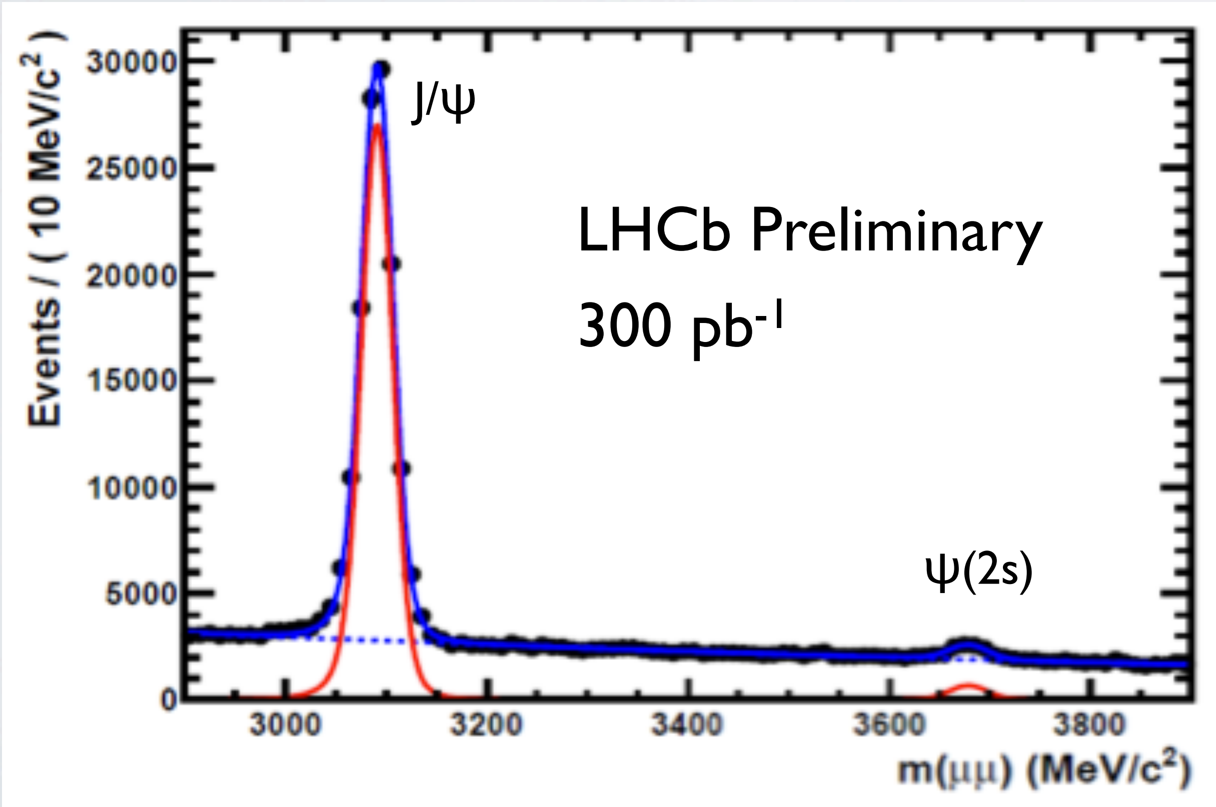
Signal Invariant Mass

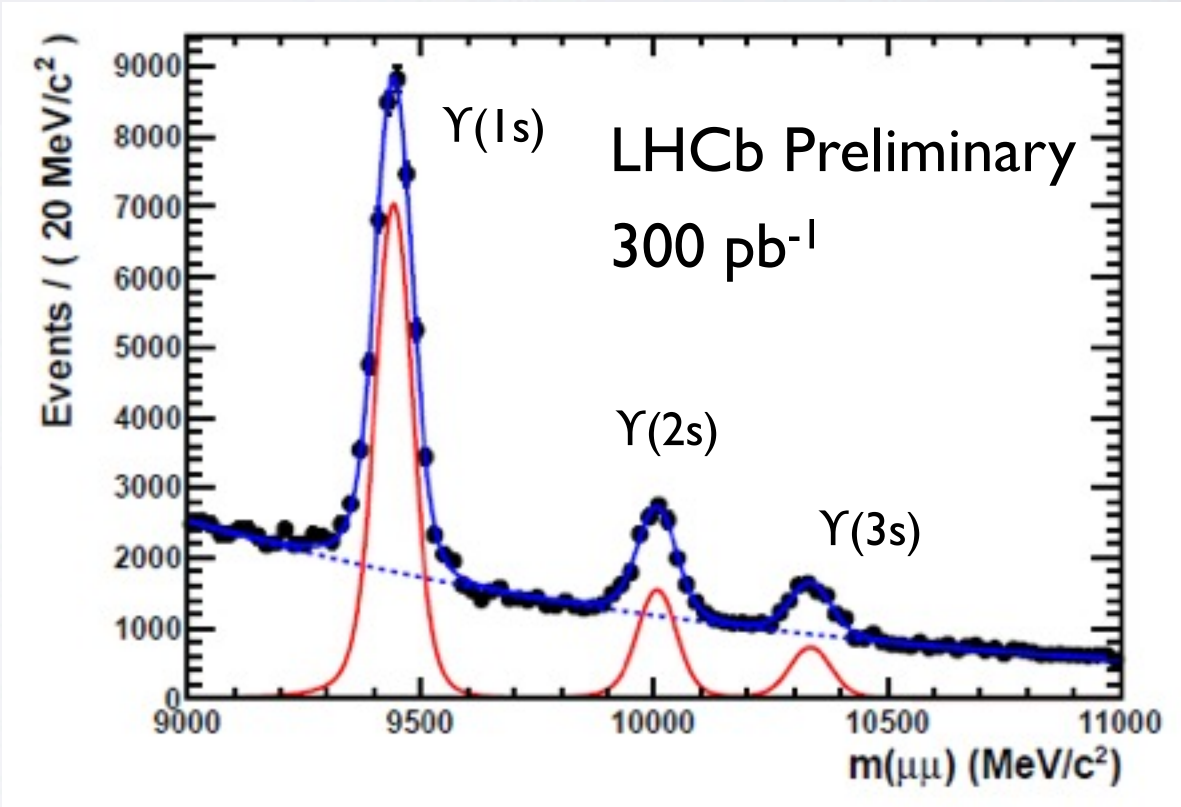
The invariant mass is modeled with a Crystal Ball

- Resolution: obtained from interpolation of the σ's of dimuon resonances (J/ψ, ψ(2s), Υ's), crosschecked with inclusive and exclusive $B_{d/s} \rightarrow h^+h^-$
- Mean: obtained from exclusive $B_s \rightarrow K^+K^-$ and $B^0 \rightarrow K^+\pi^-$

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

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





Normalization

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

Evaluated on MC, crosschecked on data

measured on data

probabilities ratio of a b-quark to hadronize into a given meson

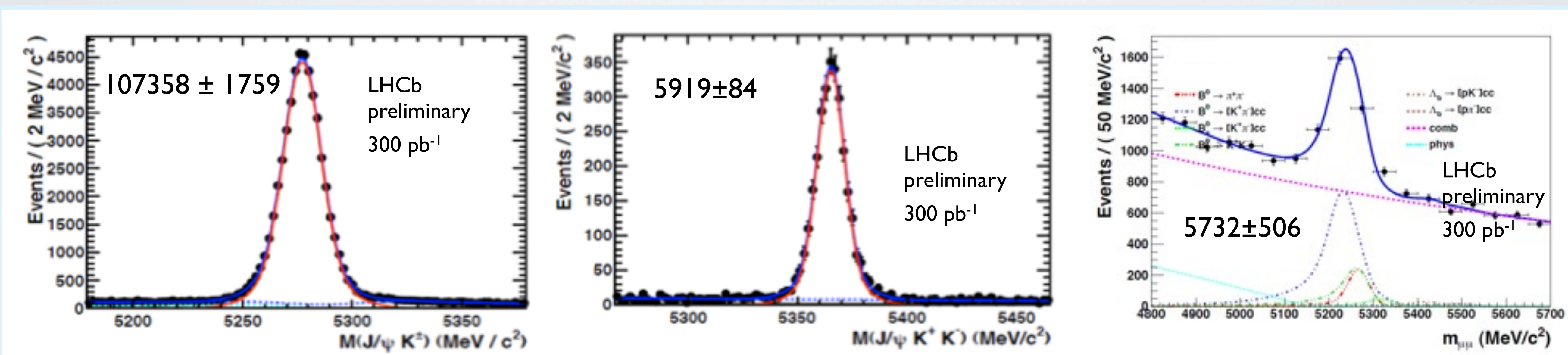
Three complementary channels are used for the normalization:

$\mathrm{BR}(B^+\to J/\psi(\mu^+\mu^-)K^+) = (6.01\pm0.21)\times10^{-5}$

$\mathrm{BR}(B_s\to J/\psi(\mu^+\mu^-)\varphi(K^+K^-)) = (3.4\pm0.9)\times10^{-5}$

$\mathrm{BR}(B^0\to K^+\pi^-) = (1.94\pm0.06)\times10^{-5}$

$$\alpha_{B^0_s\to\mu^+\mu^-} = (9.84 \pm 0.91) \times 10^{-10}\,,$$
$$\alpha_{B^0\to\mu^+\mu^-} = (2.89 \pm 0.15) \times 10^{-10}\,.$$



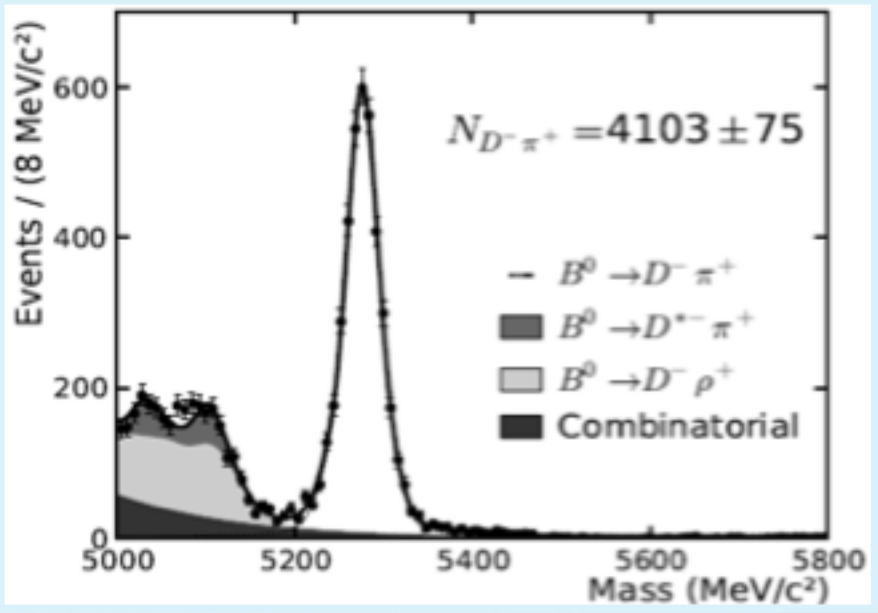
f_s/f_d at LHCb

Our previous result used the HFAG average from LEP/Tevatron.
This ratio is now evaluated at LHCb

- fs/fd is measured at LHCb with hadronic decays $B^0 \to D^{\pm}K^{\mp}$ or $B^0 \to D^{\pm}\pi^{\mp}$ and $B_s \to D_s^{\pm}\pi^{\mp}$

$$f_s/f_d = 0.253 \pm 0.017^{\mathrm{stat}} \pm 0.017^{\mathrm{syst}} \pm 0.020^{\mathrm{theo}}$$

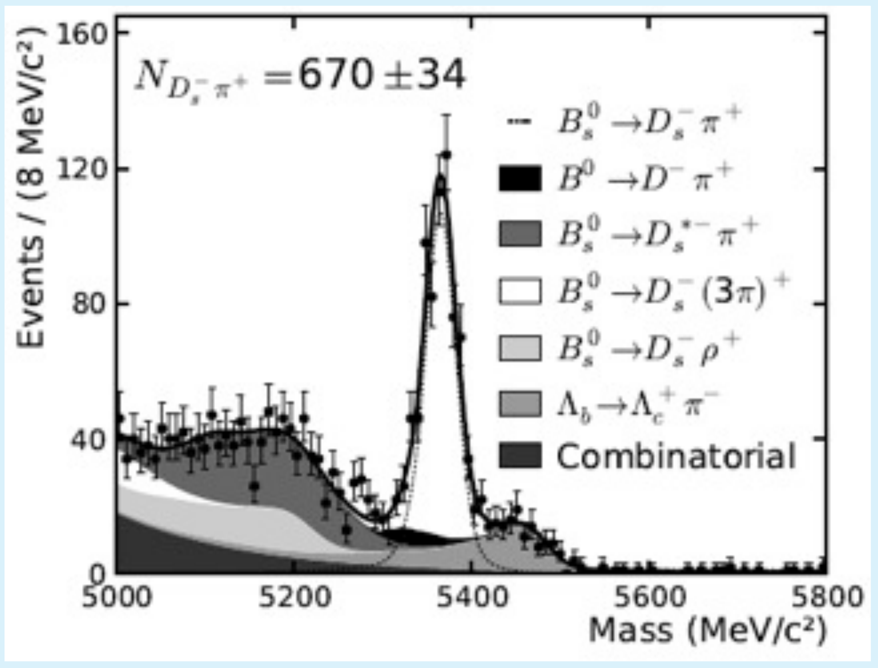
Phys.Rev.D 83, 014017 (2011)



- And semileptonic decays

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

LHCb-CONF-2011-028



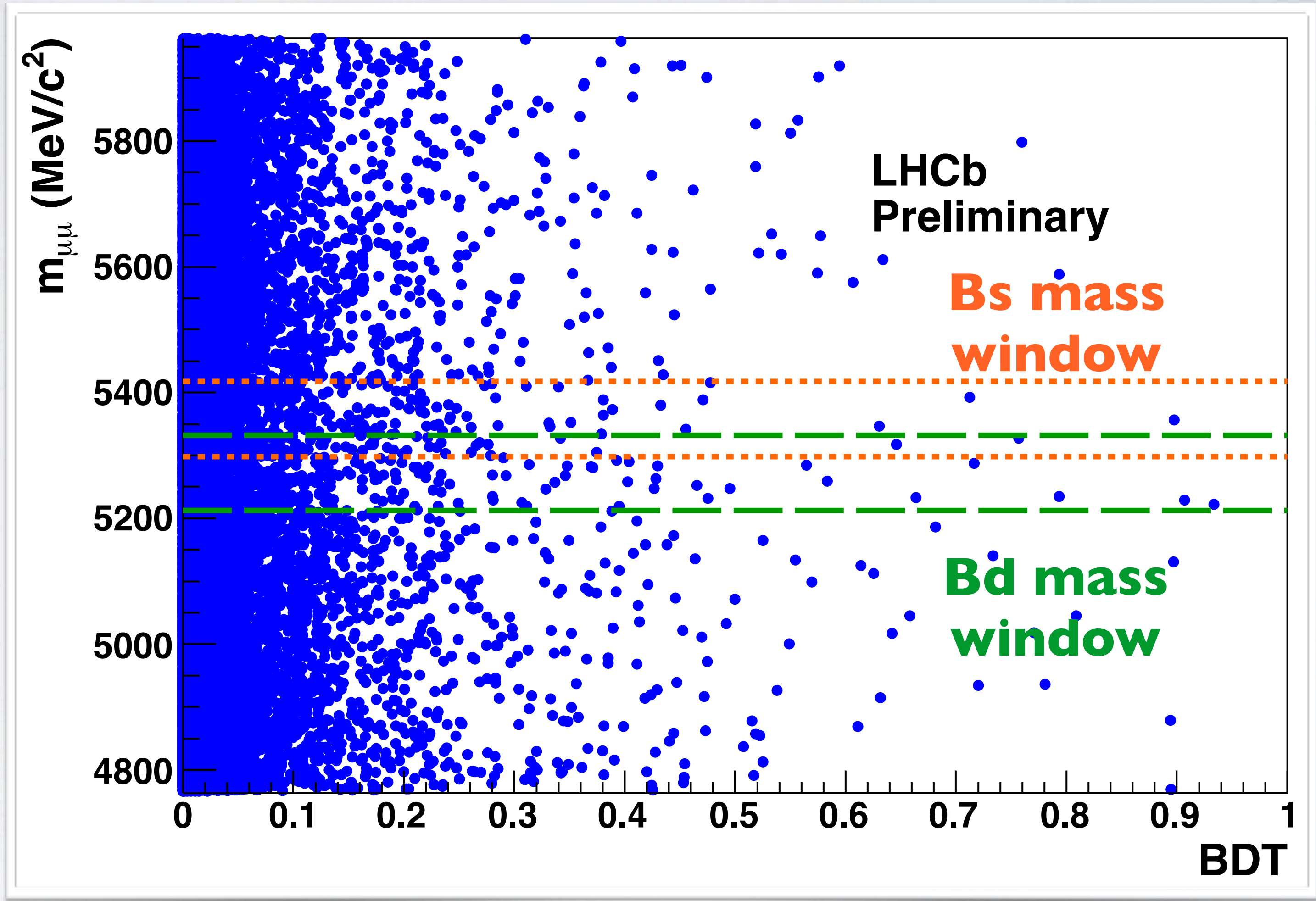
- We compute the average:

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

LHCb-CONF-2011-034

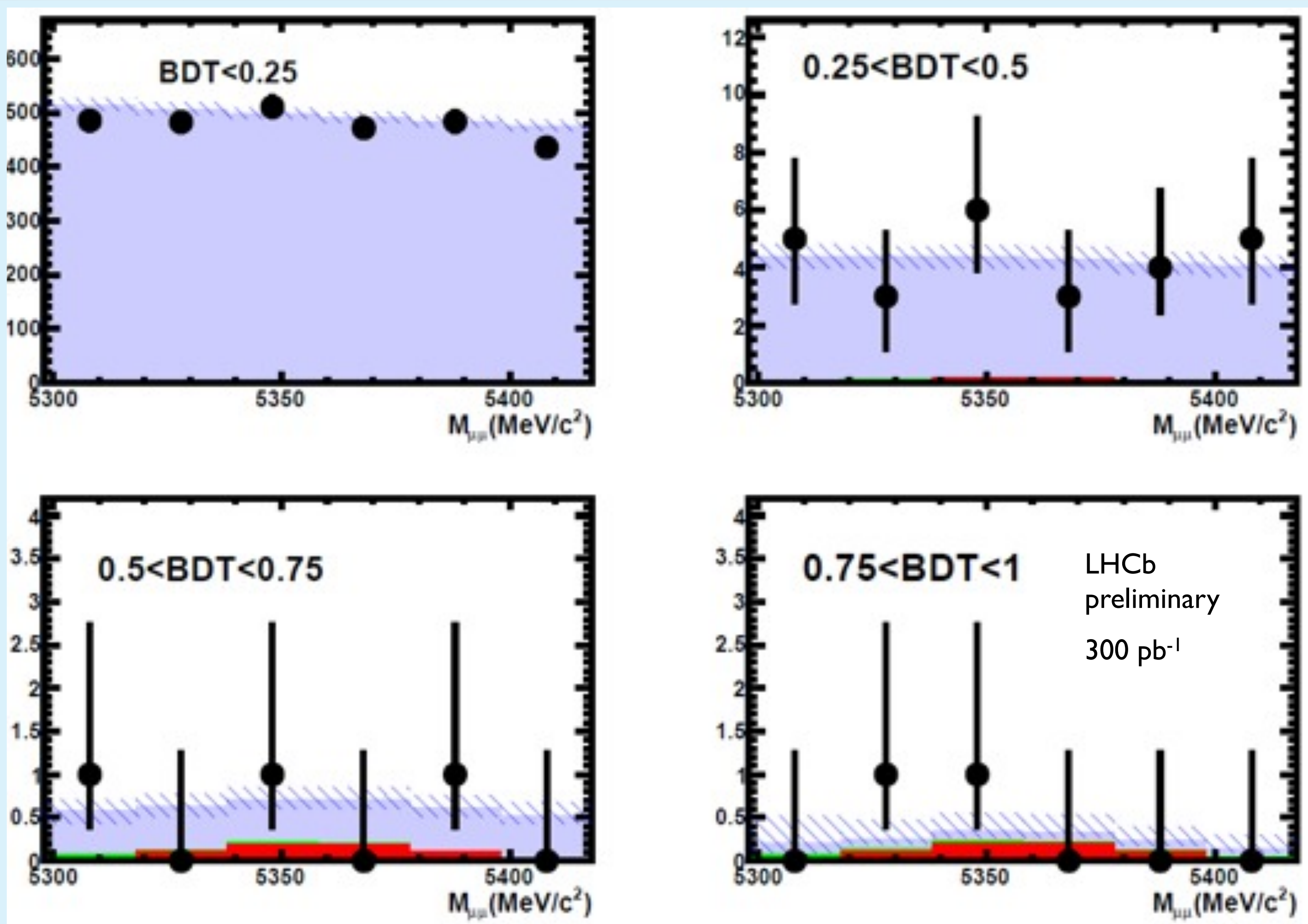
Observed distribution of events

- Count the events in 4 BDT and 6 $m_{\mu\mu}$ bins
- For each bin compute the expected signal and background yields
- Evaluate compatibility between observed and expected with:
  - **S+B hypothesis [CL_{S+B}]**
  - **B only hypothesis [CL_B]**



$CL_S = CL_{S+B}/CL_B$ compatibility with the signal hypothesis
☞ Used to compute the exclusion

$B_s \to \mu^+\mu^-$ search region



Combinatorial bkg

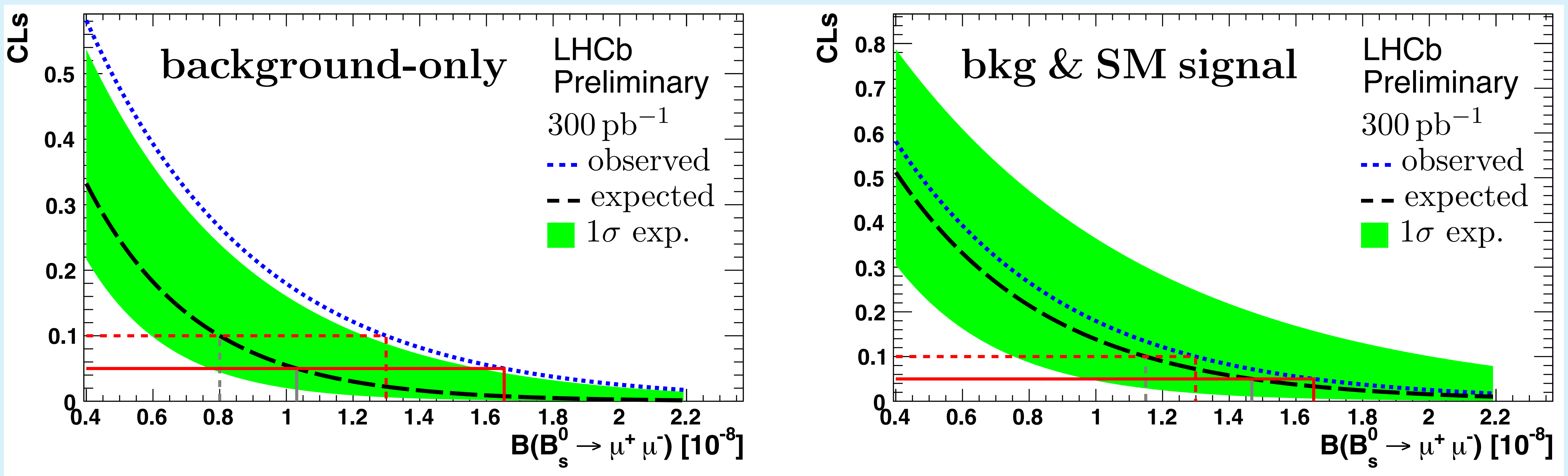
Misid bkg

Signal SM

Data

	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

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



Preliminary results from 300pb^{-1} of data at $\sqrt{s}$ = 7 TeV

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

expected limit, bkg only < 0.8(1.0)x10^{-8}

expected limit, bkg+SM < 1.2(1.5)x10^{-8}

Combined 2010+2011 dataset BR< 1.2(1.5)x10^{-8}

Observed limit @ CMS with 1.14fb^{-1} <1.6(1.9)x10^{-8} @ 90%(95%) CL

LHCb+CMS < 0.9(1.1)x10^{-8} @ 90%(95%) CL

LHCb-CONF-2011-047

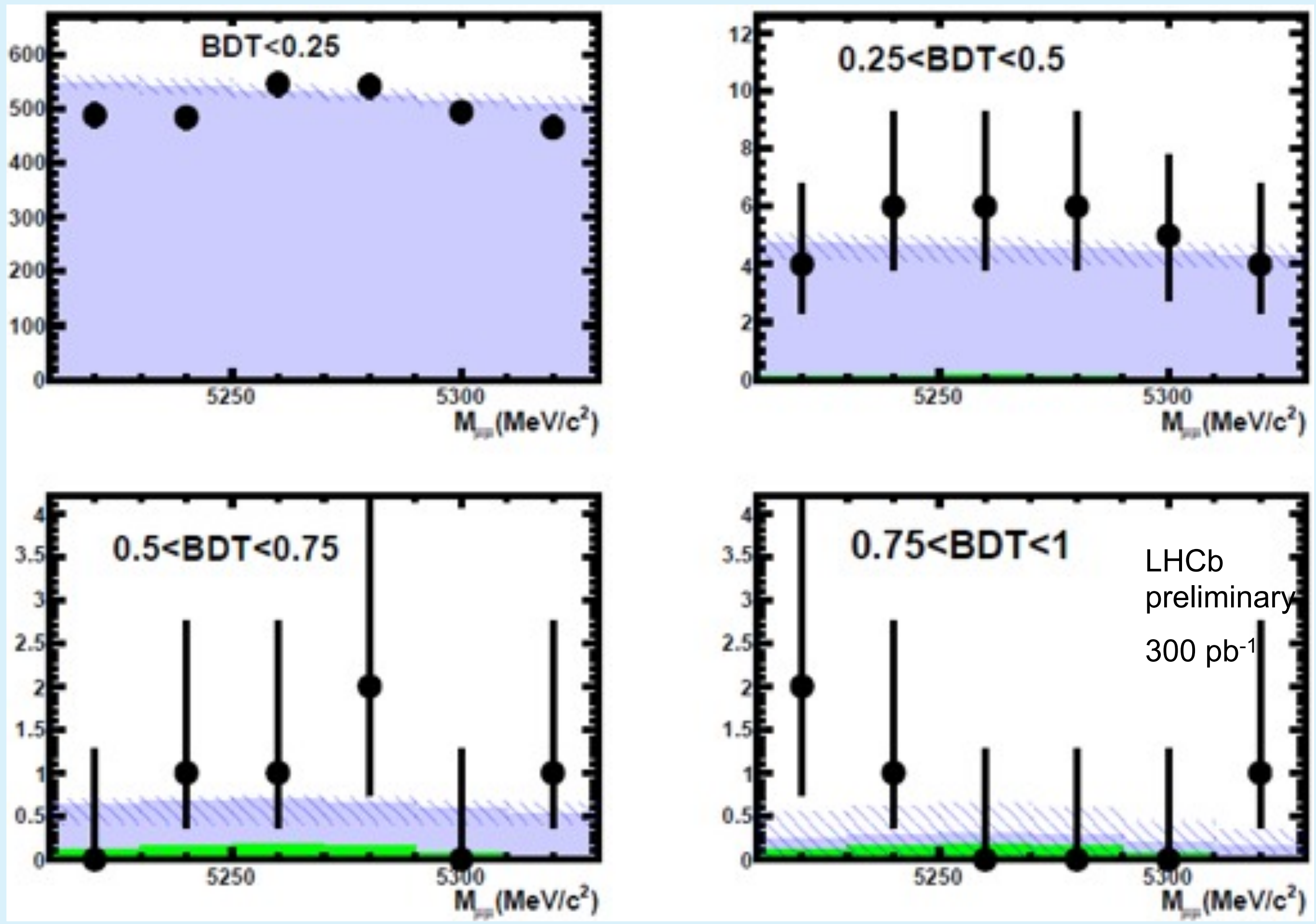
CERN-PH-EP-2011-120, sub. to PRL

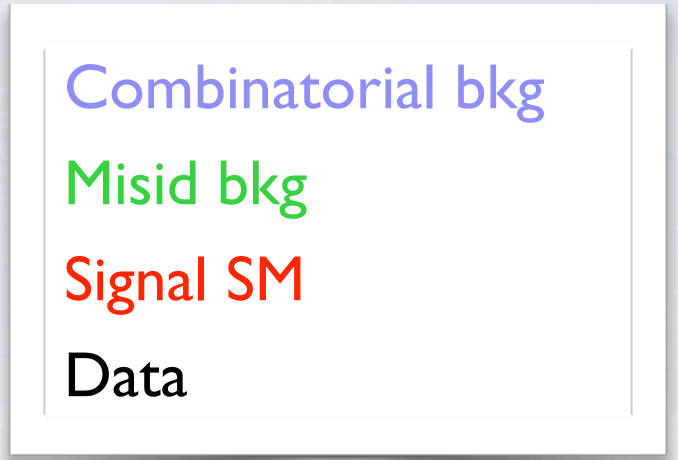
CDF result with 7fb^{-1}

0.46x10^{-8} < BR < 3.9x10^{-8} @ 90% CL (BR=1.8$^{+1.1}_{-0.9}$) x 10^{-8}

hep-ex/1107.2304

$B_d \to \mu^+\mu^-$ search 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

Preliminary results from $300 pb^{-1}$ of data at $\sqrt{s}$ = 7 TeV

$BR(B_d \to \mu^+\mu^-) < 4.2(5.2)\times10^{-9}$ @90% (95%)C.L.

expected limit $<2.4(3.1)\times10^{-9}$

Conclusions

- LHCb presents new preliminary results with $300pb^{-1}$ on $BR(B_{s/d}\to\mu^+\mu^-)$ improving the previous results by a factor ~4

$$BR(B_s \to \mu^+\mu^-)<1.3(1.6)\times10^{-8} \text{ @90\% (95\%)C.L.}$$
$$BR(B_d \to \mu^+\mu^-)<4.2(5.2)\times10^{-9} \text{ @90\% (95\%)C.L.}$$

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

$$BR(B_s\to\mu^+\mu^-) < 1.2\ (1.5)\times10^{-8} \text{ @ 90 (95)\% CL}$$

- + CMS observations:

$$BR(B_s \to \mu^+\mu^-)<0.9(1.1)\times10^{-8} \text{ @ 90\%(95\%) CL}$$

- The excess seen by CDF has not been confirmed
- With the data collected in 2011 ($1fb^{-1}$) we might have a 3σ SM evidence

Spares

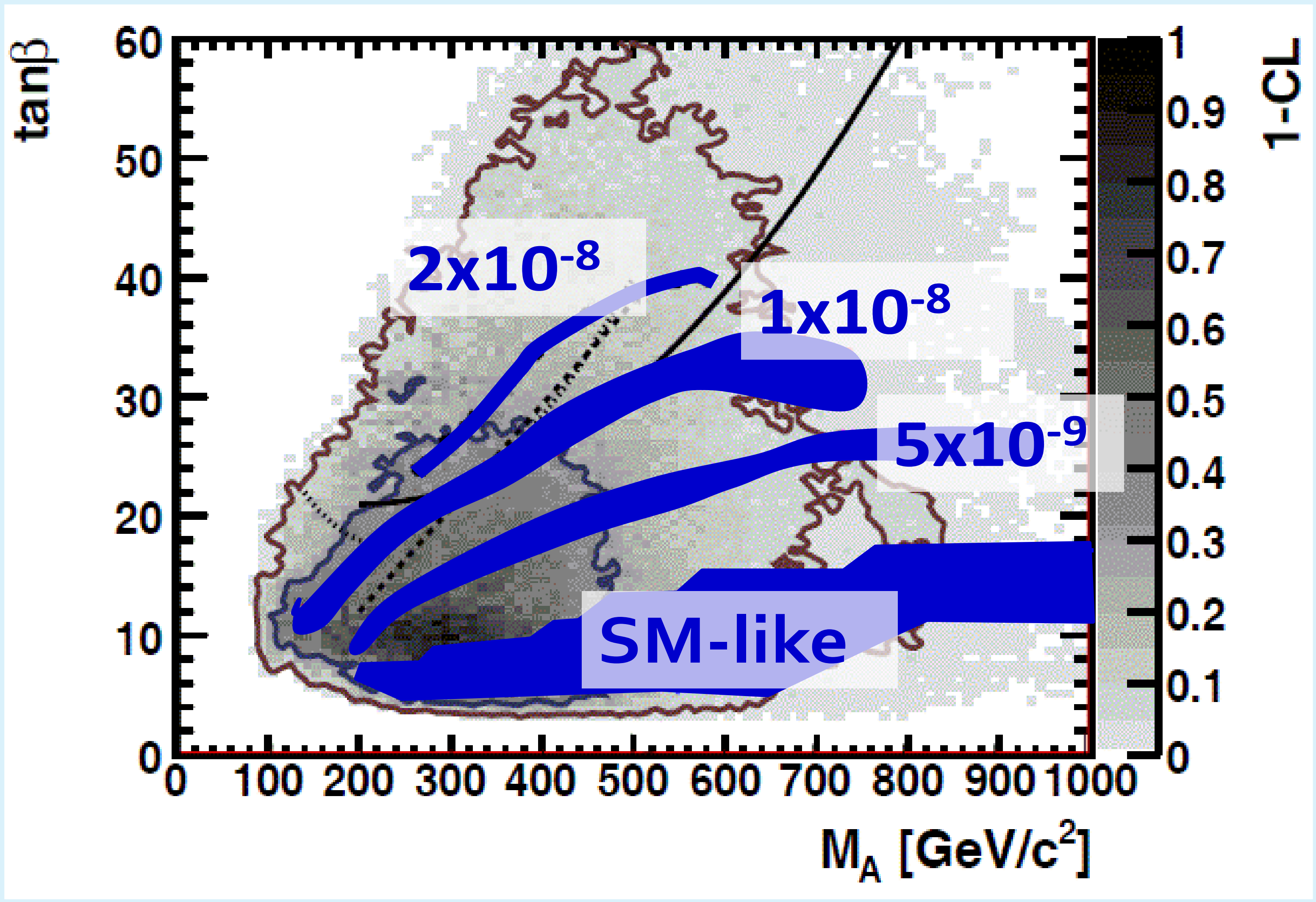
NUHM1

Best fit contours in tanβ vs M_A plane in the NUHM1 model

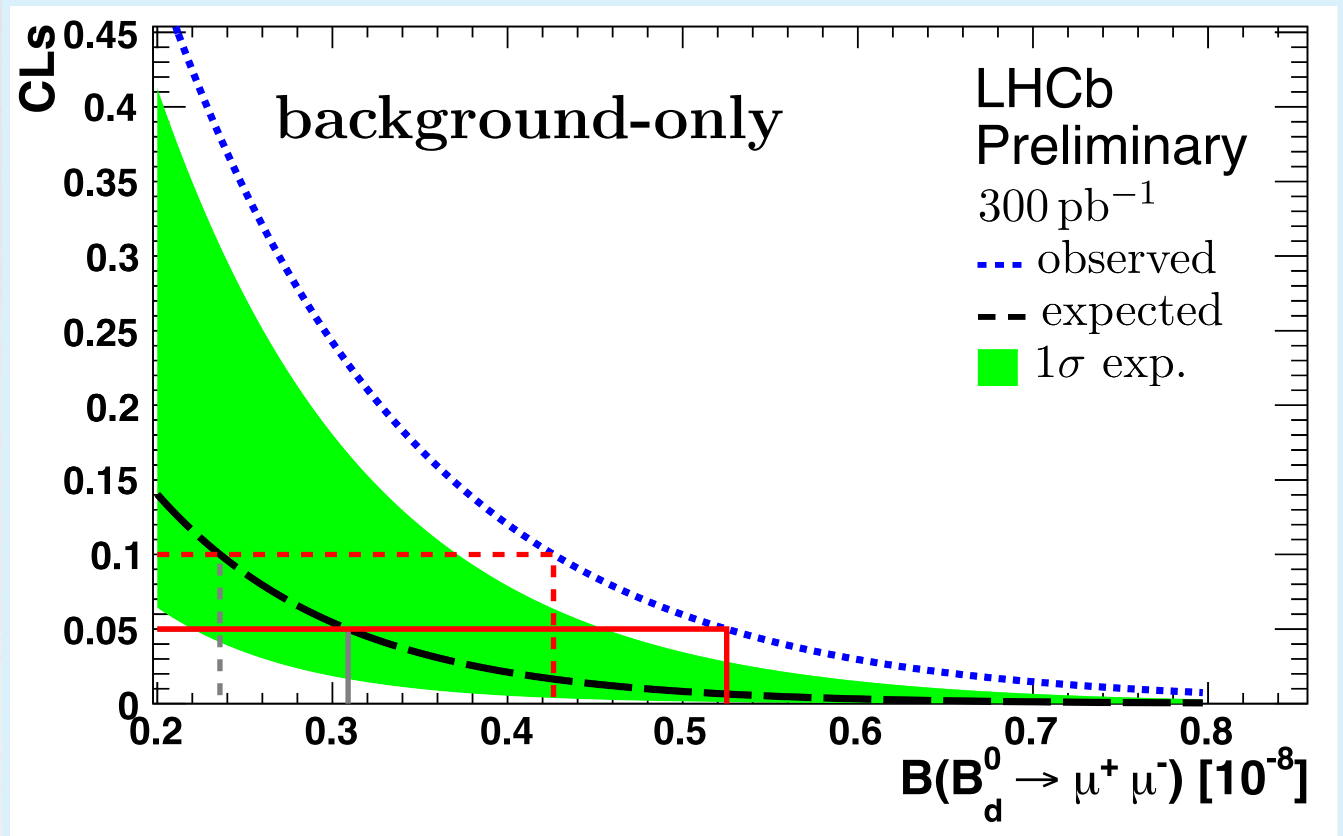
O. Buchmuller et al, Eur. Phys. J. C64 (2009)

Regions compatible with $BR(B_s \to \mu\mu) = 2x10^{-8}, 1x10^{-8}, 5x10^{-9}$ and SM

LHCb calculation using F. Mahmoudi, SuperIso, arXiv: 08083144



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



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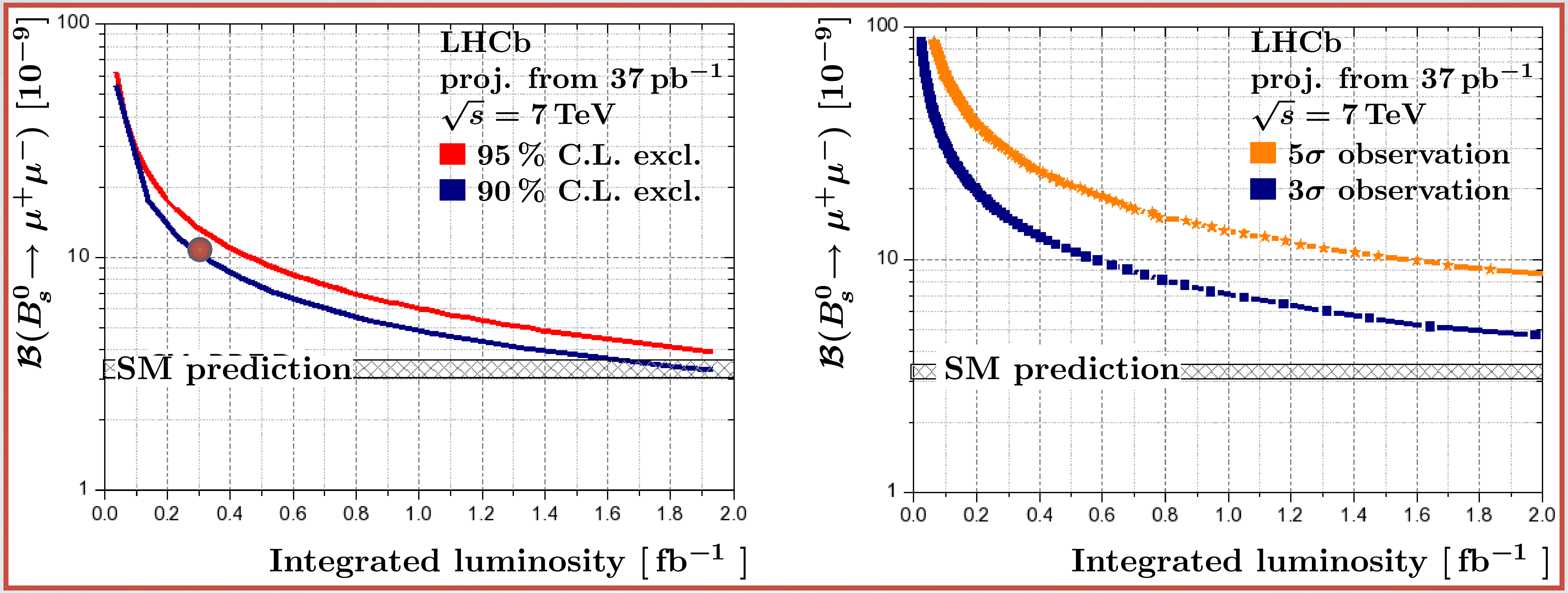
expected limit <2.4(3.1)x10^{-9}

Prospects

Extrapolation based on the $37pb^{-1}$ collected in 2010 and analysed with the 2010-analysis.



LHCb is going to access a very interesting region with the 2012 run