Rare Decays in LHCb

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(on behalf of the LHCb Collaboration)

Introduction

- LHCb results on rare B decays

- Why do we search for them?

  - $B_d \to K^* \mu\mu$: Branching ratio, angular observables (LHCb-CONF-2011-038)

  - Branching ratios of $B_{d,s} \to \mu\mu$ (update with respect to EPS, with 370 (2011)+ 37(2010) pb^{-1}), to be submitted to PLB

  - Branching ratio of $B_s \to \varphi\gamma$ (LHCb-CONF-2011-055)

Indirect Approach

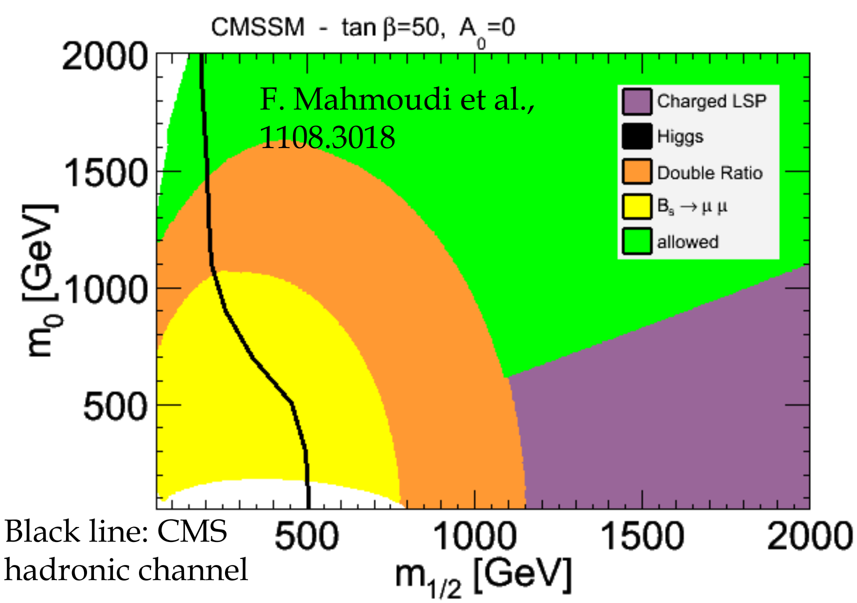
- B,D, K decays can access NP through new virtual particles entering in the loop → indirect search (for example SUSY particles affecting $B_{d,s} \rightarrow \mu\mu$)

- Indirect approaches can access higher energy scales and see NP effects earlier:

    - CPV in Kaons → 3^{rd} quark family. Neutral Currents → Z^0…

    - New heavy particles may reveal themselves in flavour physics ….

(Or the absence of non SM effects in flavor physics can constrain NP)



Black line: CMS hadronic channel

Angular analysis of $B_d \to K^* \mu\mu$

LHCb-CONF-2011-038

$B_d \rightarrow K^*\mu\mu$

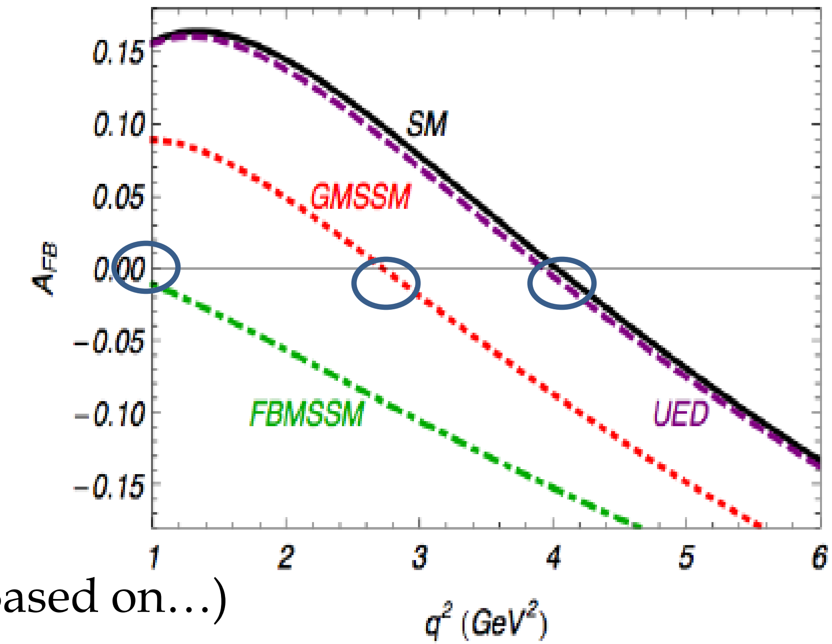
LHCb-CONF-2011-038

- $B_d \rightarrow K^*\mu\mu$: decay described by 3 angles: (θ_L, θ_K and φ) and the dimuon invariant mass squared q^2.

Sensitive to NP:

- right-handed currents.
- new scalar / pseudo-scalar operators.

by probing helicity structure of the decay through angular observables.



(Based on…)

W.Altmannshofer et al. [JHEP 0901:019 (2009)]

Analysis strategy

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- Select signal events mainly via a Boosted Decision Tree (BDT) + special vetoes for specific backgrounds

- Correct for biases (reconstruction/selection/trigger) using simulation

    - Correction applied event by event (model independent)

    - Validated on data via control channels (mainly $B_d \rightarrow J/\psi(\mu\mu)\ K^*(K^+\pi^-)$)

- Fit for observables

- Focus on theoretically clean observables: F_L, A_{FB}, and yield in bins of q^2 (dimuon invariant mass squared)

Selection

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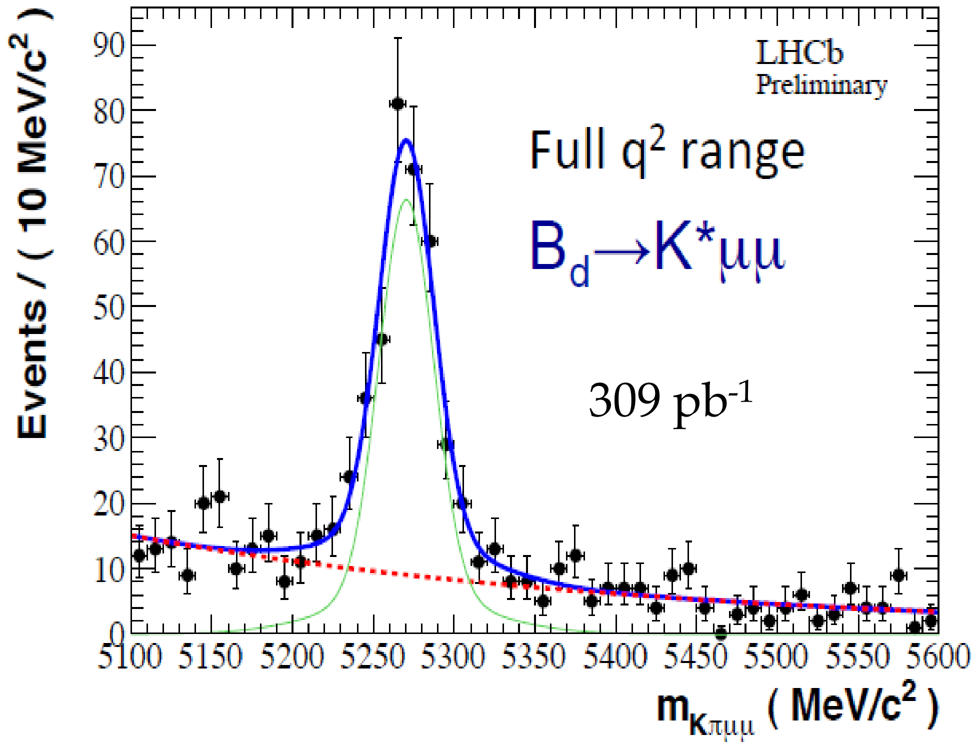
- Remove charmonium resonaces:
  - $2946 < m_{\mu\mu} < 3176$ MeV (J/ψ veto)
  - $3586 < m_{\mu\mu} < 3776$ MeV (ψ(2S) veto)

- Treat peaking bkgs with a specific set of criteria (reduced to ~3% of the signal)
  - $B_d \rightarrow J/\psi(\mu\mu)\, K^*(K^+\pi^-)$ swapping μ-π

- Combinatorial bkg reduced with a BDT



- Mass lineshape is exponential for background, double gaussian for signal

Results: differential BR

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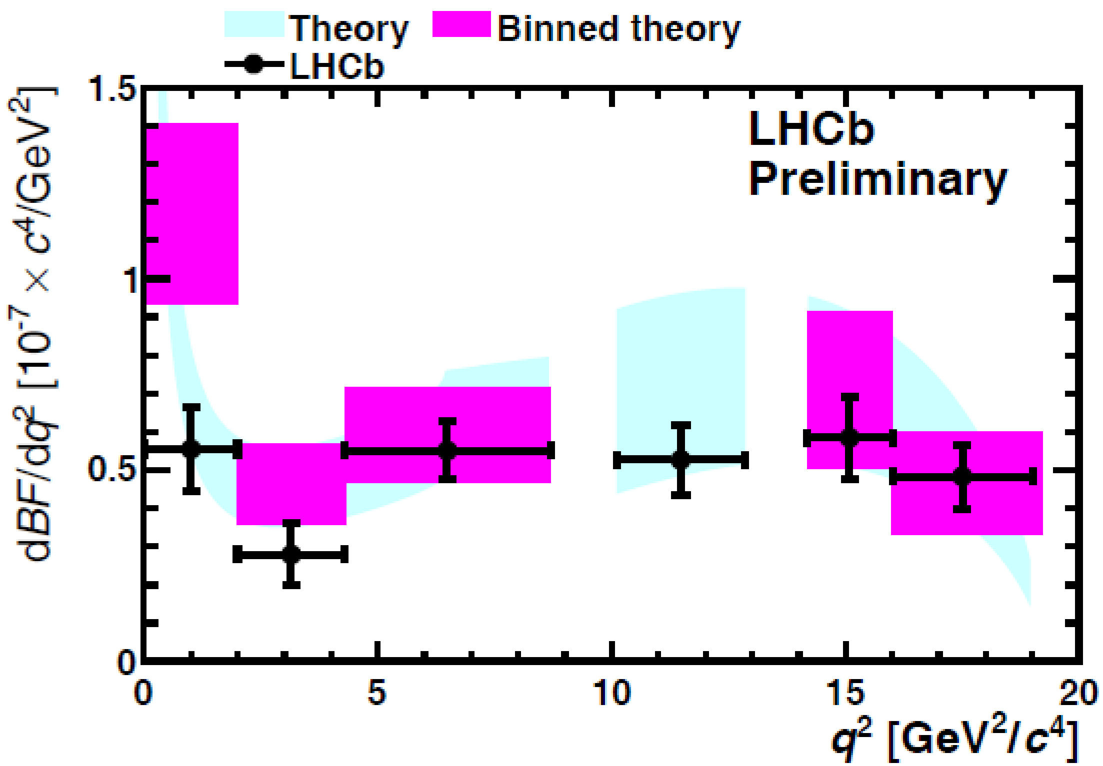

Theory prediction C.Bobeth et al. 1006.5013 hep-ph , U.Egede et al. 0807.2589

Angular observables

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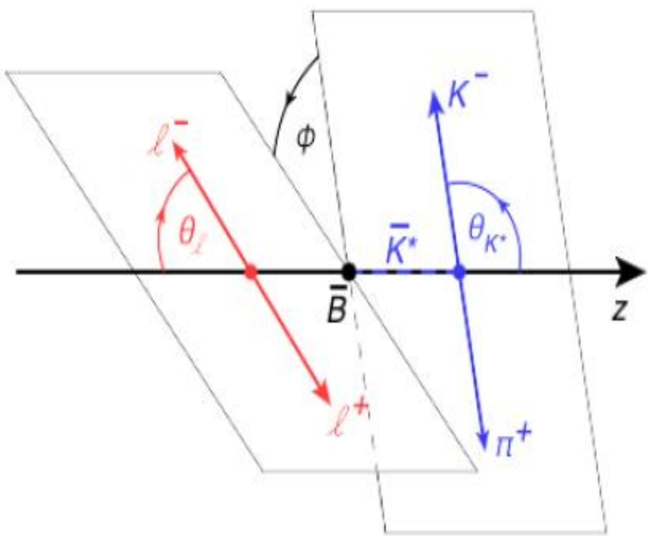
- Unbinned maximum likelihood fit in dimuon mass bins with event by event weights

- Simultaneous fit in a θ_L, θ_K (and invariant mass) to extract $\mathbf{A_{FB}}$ and $\mathbf{F_L}$ using the following 2 expressions:

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_\ell \, dq^2} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_K \, dq^2} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

- The angular distribution of the background is modeled using 2nd order polynomials



Results: A_{FB}, F_L

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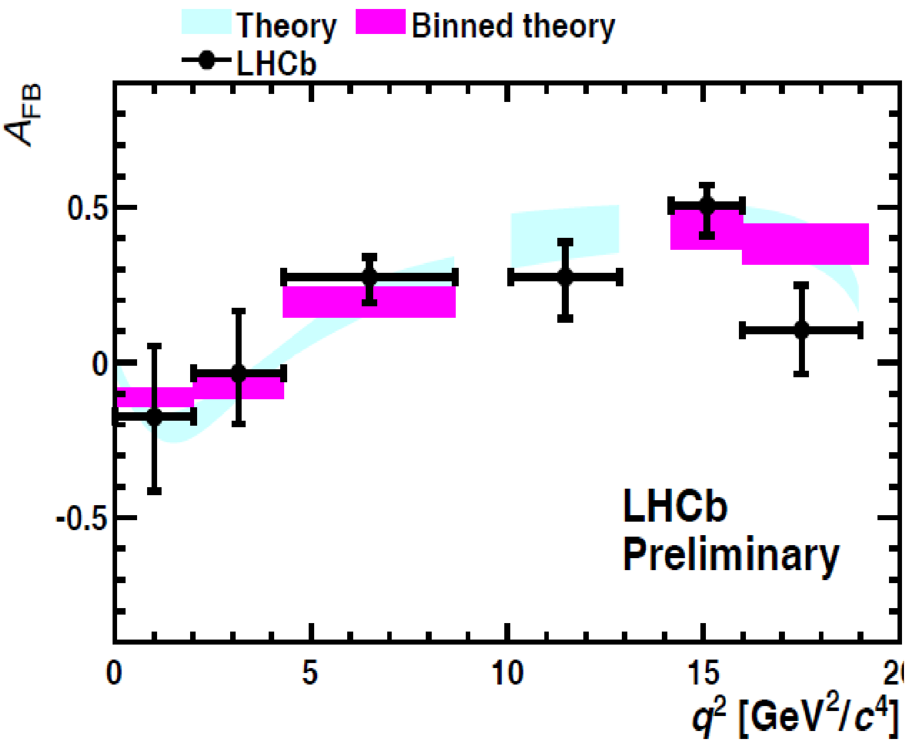
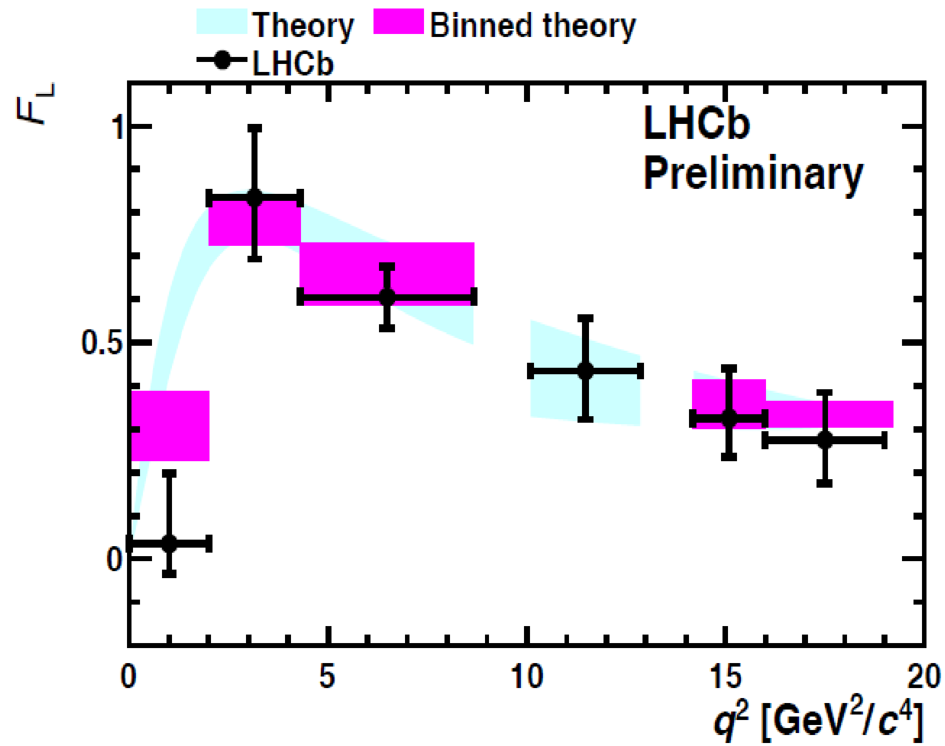




Theory prediction C.Bobeth et al. 1006.5013 hep-ph , U.Egede et al. 0807.2589

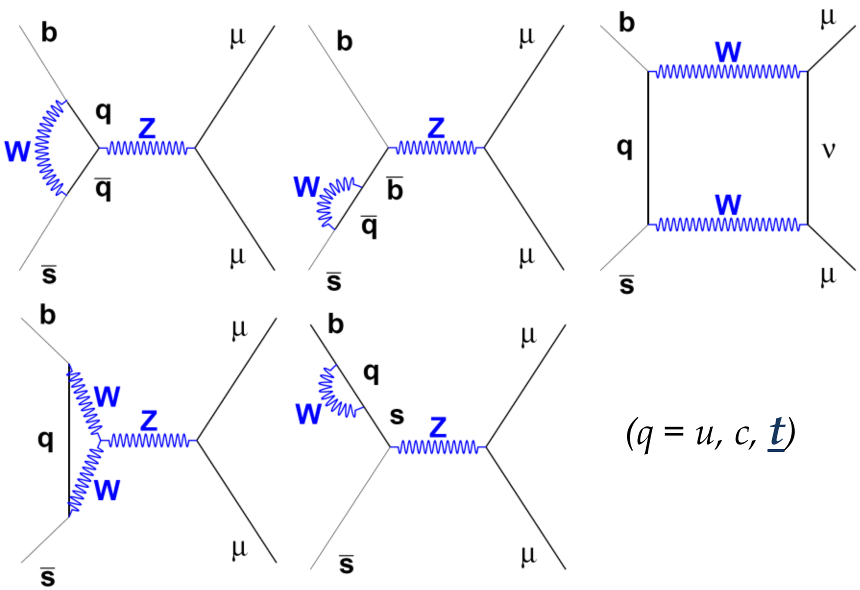
Search for $B_{s,d} \to \mu\mu$

(to be submitted to PLB)

SM and New Physics

This decay is very suppressed in SM :

$BR(B_s \to \mu\mu)$ $(3.2\pm0.2)\times10^{-9}$
$BR(B_d \to \mu\mu)$ $(1.0\pm0.1)\times10^{-10}$

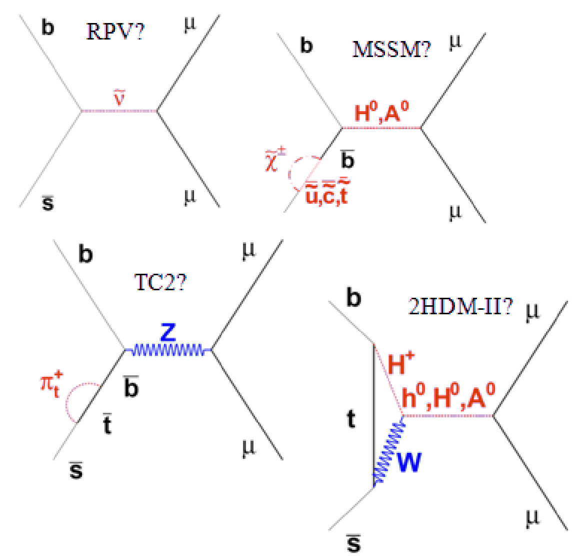


$(q = u, c, \underline{t})$

But in NP models it can be different from SM by orders of magnitude

→ ***Whatever the actual value is, it will have an impact on NP searches***

+?



SM and New Physics

Scenario	would point to ...
$BR(B_s \rightarrow \mu\mu) >> SM$	Big enhancement from NP in scalar sector, SUSY high tanβ
$BR(B_s \rightarrow \mu\mu) \neq SM$	SUSY (C_S, C_P) , ED's, LHT, TC2 (C_{10})…
$BR(B_s \rightarrow \mu\mu) \sim SM$	Anything (→ rule out regions of parameter space that predict sizable departures from SM. Obviously)
$BR(B_s \rightarrow \mu\mu) << SM$	NP in scalar sector, but full MSSM ruled out. NMSSM (Higgs singlet) good candidate
$BR(B_s \rightarrow \mu\mu) / BR(B_d \rightarrow \mu\mu) \neq SM$	CMFV ruled out. New FCNC sources fully independent of CKM matrix (RPV SUSY, ED's etc…)

Analysis strategy

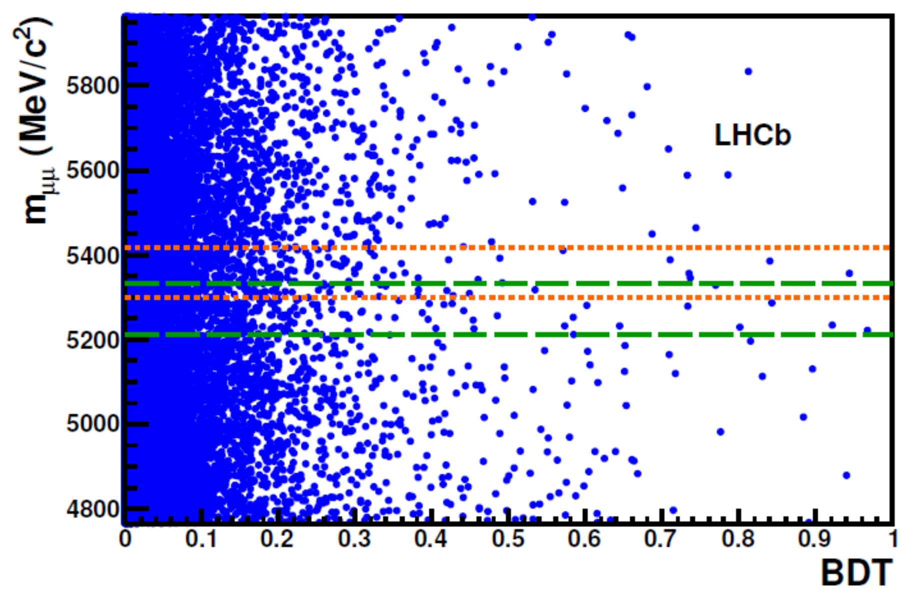
(to be submitted to PLB)

- Selection cuts in order to reduce the amount of data to analyze. LHCb trigger selects > 90% of the signal that is interesting for the offline analysis.

- Classification of $B_{s,d} \rightarrow \mu\mu$ events in bins of a 2D space

    - Invariant mass of the μμ pair

    - Boosted Decision Tree combining geometrical and kinematical information about the event.
        - Flat distributed for signal, background peaks at 0

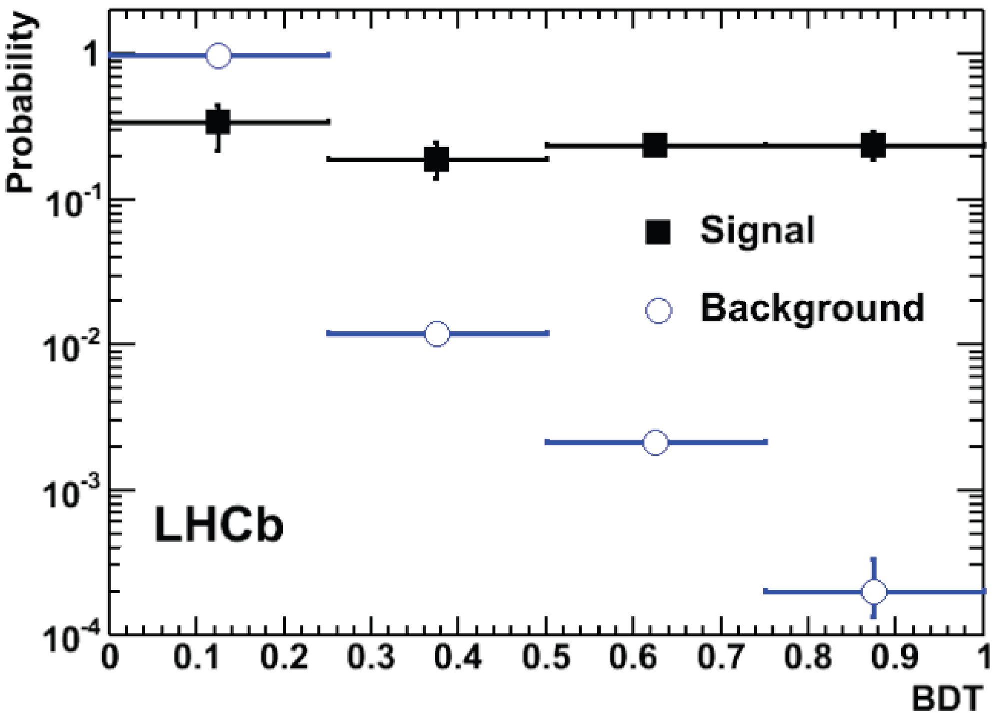


- Control channels to get signal and background expectations w/o relying on simulation

- Compare expectations with observed distribution. Results combined using CL_s method

Boosted Decision Tree

(to be submitted to PLB)



- S-B separation relies strongly on this variable
- Trained using MC samples of $B_s \to \mu\mu$ signal and bb $\to \mu\mu$ background.
- Distributions taken from data to not rely on the simulation

- Distribution of signal is obtained by looking at B $\to h^+h^-$ in real data
- Background distribution is obtained from data by interpolating from mass sidebands in BDT bins

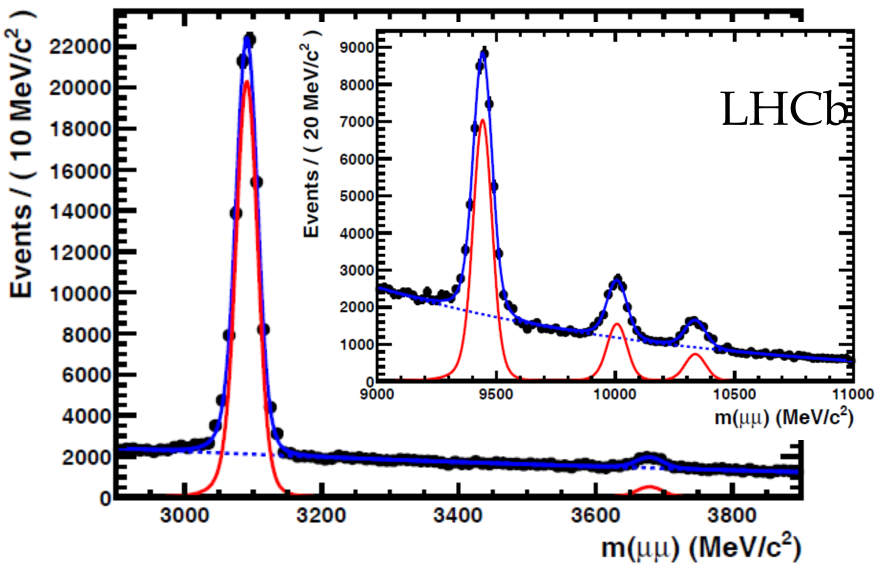
Invariant Mass

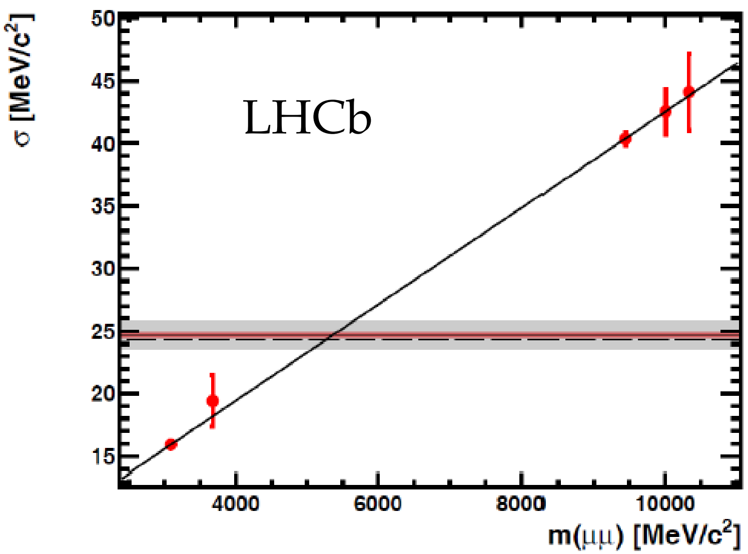
(to be submitted to PLB)

- Signal distribution depends on the actual mass resolution of LHCb in the B mass region (resolution depends on mass, almost linearly)

- Measured in data by **interpolating from di-muon resonances** (J/ψ (m<mB) , Υ (m>mB)…) **crosscheck** looking at **$B \rightarrow h^+h^-$** ($B_{d,s} \rightarrow K^+\pi^-$, $B_d \rightarrow \pi^+\pi^-$, $B_s \rightarrow K^+K^-$)

- μμ background yield in mass bins is interpolated from mass sidebands





$$\sigma = 24.6 \pm 0.2 \pm 1.0 \ \ \mathrm{MeV}/c^2$$

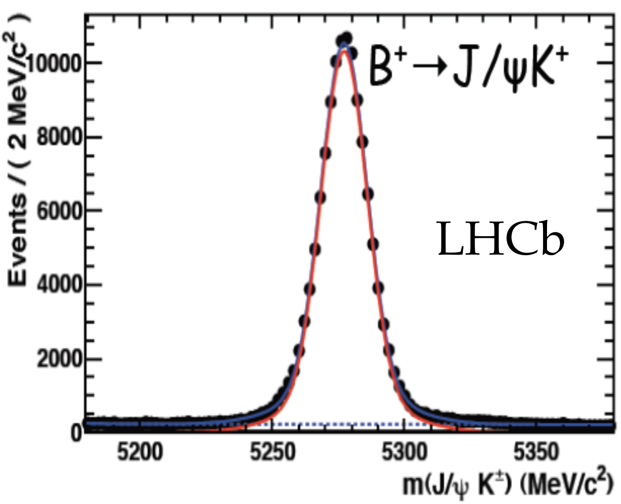
Normalization

(to be submitted to PLB)

$$\mathrm{BR} = \mathrm{BR_{cal}} \times \frac{\epsilon_{\rm cal}^{\rm REC}\,\epsilon_{\rm cal}^{\rm SEL|REC}\,\epsilon_{\rm cal}^{\rm TRIG|SEL}}{\epsilon_{\rm sig}^{\rm REC}\,\epsilon_{\rm sig}^{\rm SEL|REC}\,\epsilon_{\rm sig}^{\rm TRIG|SEL}} \times \frac{f_{\rm cal}}{f_{B^0_s}} \times \frac{N_{B^0_s\to\mu^+\mu^-}}{N_{\rm cal}} = \alpha \times N_{B^0_s\to\mu^+\mu^-}$$

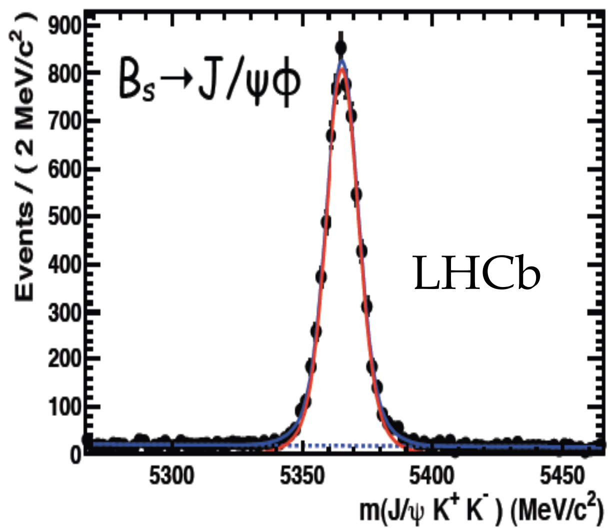
Ratio of probabilities of b quark to hadronize into the different mesons.
for $B_s \to \mu\mu$ normalization to Bd or B+ mode: 3.75±0.29 [arXiv:1106.4435 [hep-ex]]

- Three channels are used, each one with different (dis)advantages:



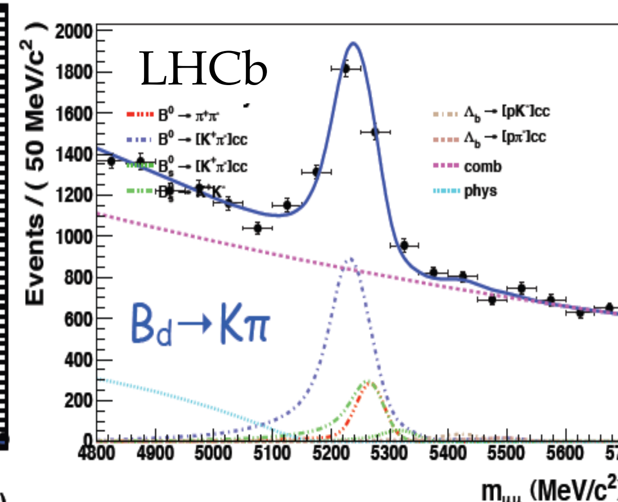
$\alpha(\mathrm{Bd}) = (2.22\pm0.11)\mathrm{x}10^{-10}$

$\alpha(\mathrm{Bs}) = (0.83\pm0.11)\mathrm{x}10^{-9}$



$\alpha(\mathrm{Bd}) = (2.95\pm0.84)\mathrm{x}10^{-10}$

$\alpha(\mathrm{Bs}) = (1.10\pm0.30)\mathrm{x}10^{-9}$



$\alpha(\mathrm{Bd}) = (1.93\pm0.33)\mathrm{x}10^{-10}$

$\alpha(\mathrm{Bs}) = (0.72\pm0.14)\mathrm{x}10^{-9}$

Results

(to be submitted to PLB)

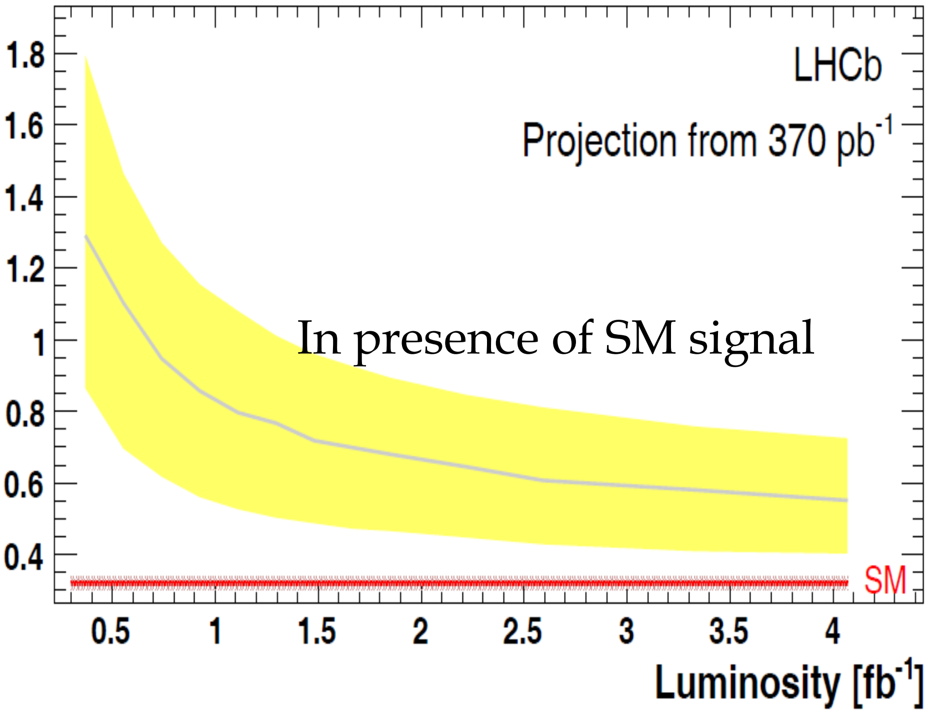
$B_s \to \mu\mu$	at 90% CL	at 95% CL
Expected BR limit (bkg. + SM hypothesis)	1.1×10^{-8}	1.4×10^{-8}
Observed BR limit	1.3×10^{-8}	1.6×10^{-8}

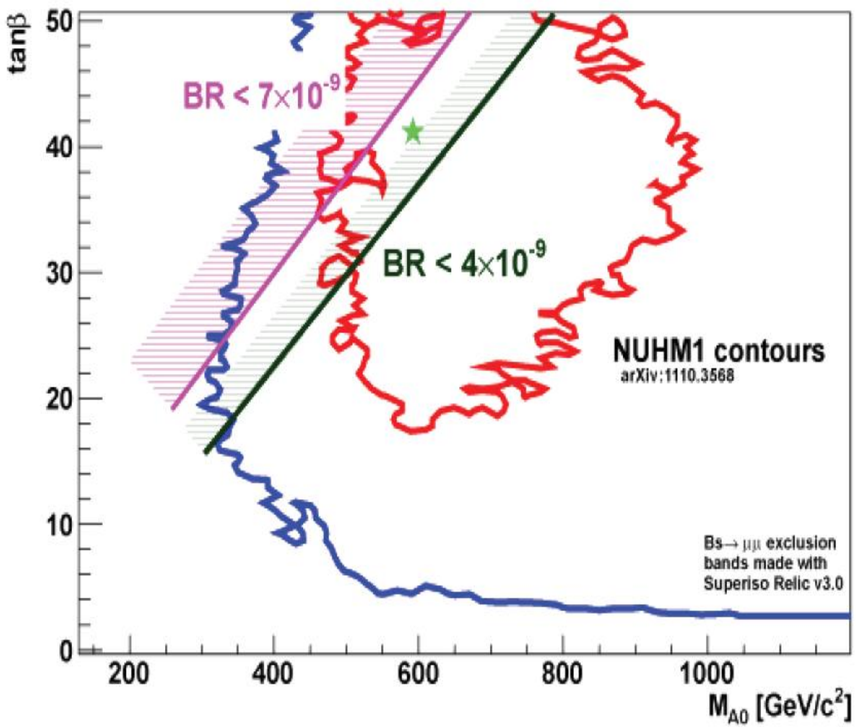
$B^0 \to \mu\mu$	at 90% CL	at 95% CL
Expected BR limit (bkg. only hypothesis)	2.5×10^{-9}	3.2×10^{-9}
Observed BR limit	3.0×10^{-9}	3.6×10^{-9}

Combining 2010 (PLB 699 (2011) 330) +2011 analysis: ~400 pb^{-1} in total:

	at 90% CL	at 95% CL
Observed BR($B^0 \to \mu\mu$) limit	2.6×10^{-9}	3.2×10^{-9}
Observed BR($B_s \to \mu\mu$) limit	1.2×10^{-8}	1.4×10^{-8}

Extrapolated sensitivity





$B_s \to \mu\mu$ will continue to constrain NP scenarios.
A 3σ evidence is possible between winter conferences and end of 7 TeV run

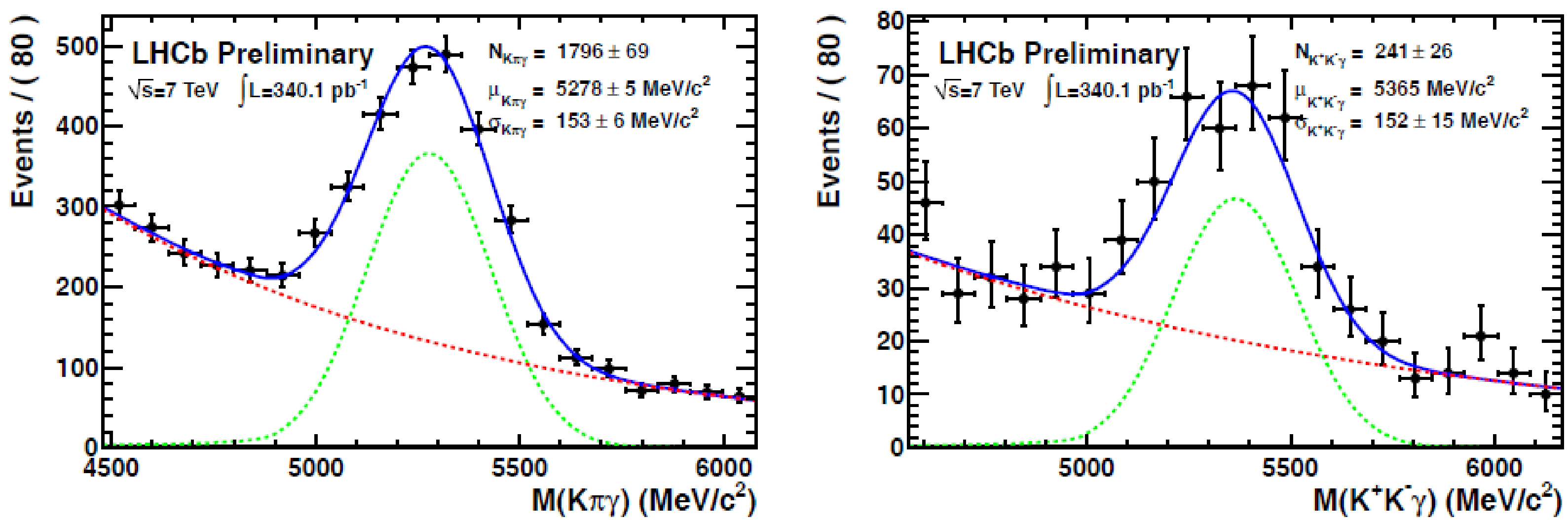
Measurement of the BR($B_s \to \varphi\gamma$)

LHCb-CONF-2011-055

$B_s \to \varphi\gamma$

LHCb-CONF-2011-055

- Measurement of the ratio $BR(B_d \to K^{*0}\gamma)$ / $BR(B_s \to \varphi\gamma)$
- Requires detailed study of specific backgrounds



SM expectation:

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.0 \pm 0.2$$

LHCb (preliminary):

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.52 \pm 0.15(\text{stat}) \pm 0.10(\text{syst}) \pm 0.12(f_s/f_d)$$

Conclusions

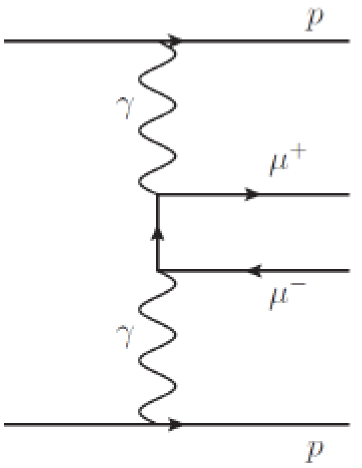
- $B_d \to K^*\mu\mu$ results from LHCb show very good agreement with SM prediction. But still arriving to the interesting level of precision.

- $BR(B_s \to \mu\mu) < 14 \times 10^{-9}$ @ 95% CL, still room for further constraints. Signal evidence can be there between Moriond and end of 7 TeV run.

- Preliminary $BR(B_s \to \varphi\gamma)$ measured within 2σ of SM prediction.

Backup

Dimuon from diphoton production, in combination with other primary vertex. Features:



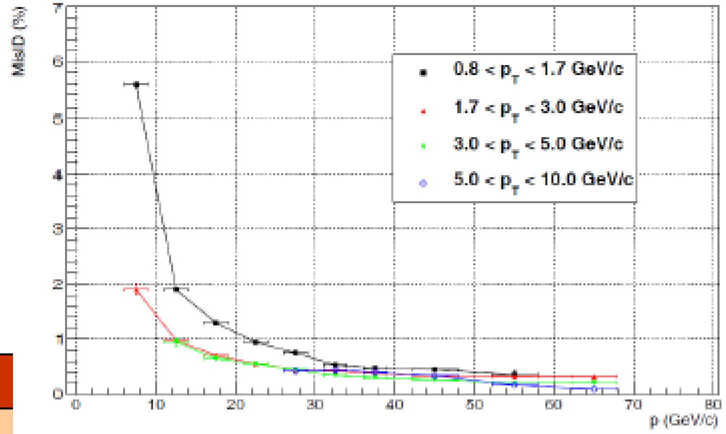
- B mass: combinatorial, can reach large masses
- BDT response ~flat, as the fake flight distance can be large
- $B(p_T)$ is soft: killed with cut $B(p_T) > 0.5$ GeV/c

Peaking background $B \to hh \to \mu\mu$ (both hadrons misidentified as muons)

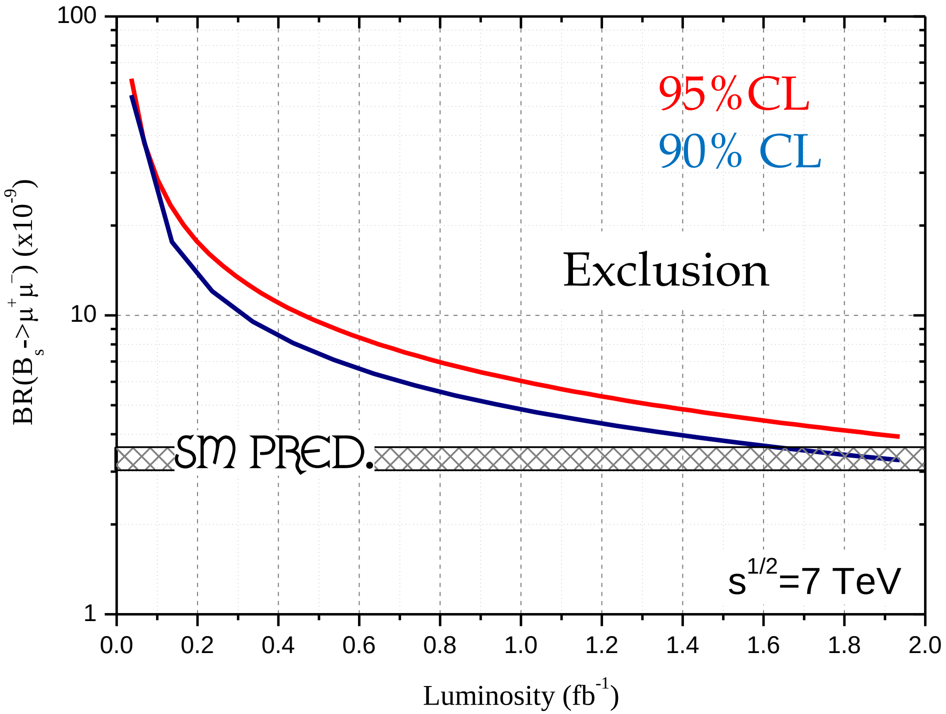
- Measure $K \to \mu$ and $\pi \to \mu$ misID using calibration sample $D^0 \to K\pi$
- Convolute misID with the hadron p, p_T phase space of $B \to hh'$, obtained from MC
- Total number expected in both mass windows:

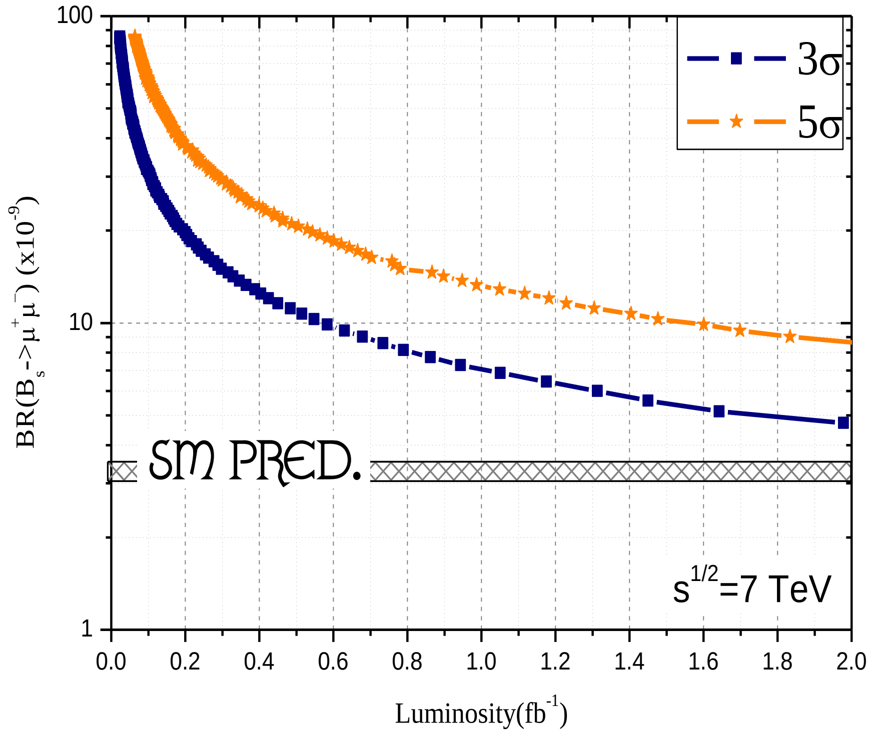
B^0	B_s
5.0±1.0	1.0±0.4

Example: $\pi \to \mu$ misID rate vs p, p_T



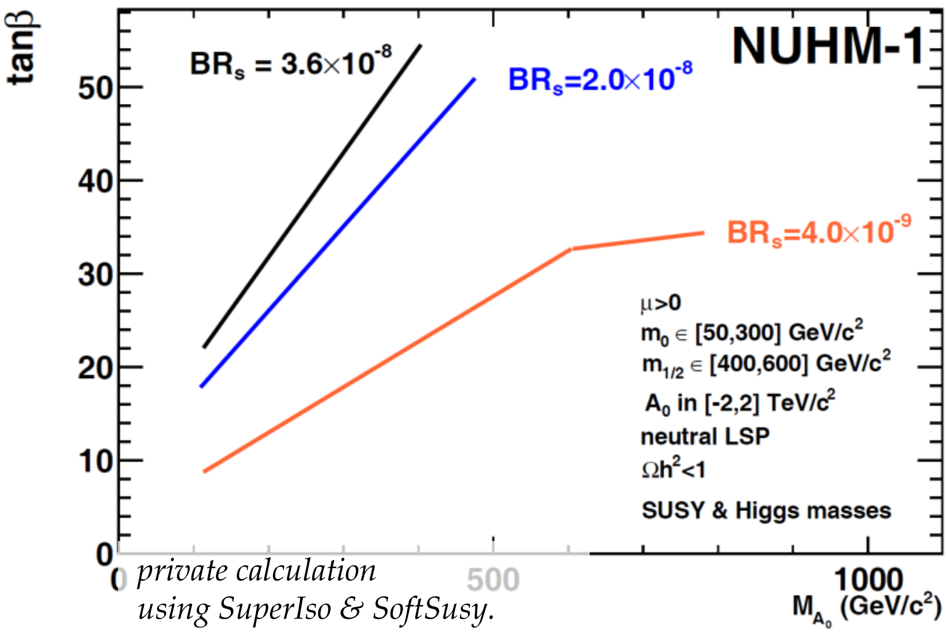
Extrapolated sensitivity





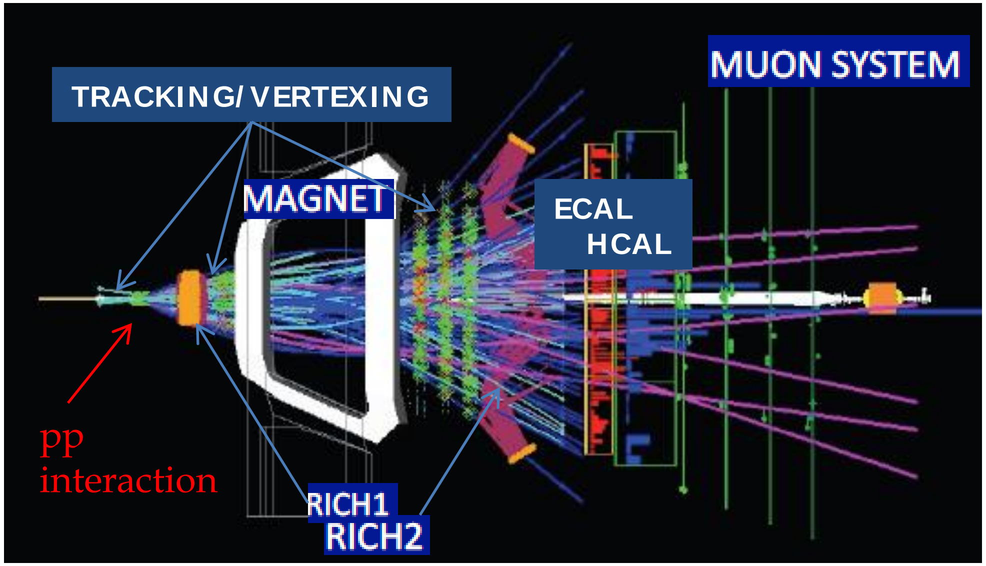
LHCb can provide **VERY** interesting results in one year from now!

$B_s \to \mu\mu$



private calculation
using SuperIso & SoftSusy.
Collider Cross Talk Apr. 14 2011

LHCb



- Low angle spectrometer
- Very efficient trigger
- Good particle identification performance
- Precise reconstruction:
  - Separation production vertex – decay vertex σ(IP)~ 25 μm
  - Invariant mass Δp/p ~0.35-0.55%

- $B_{s,d} \rightarrow \mu\mu$ signature:
  - Hits in muon detector
  - μμ pair has B invariant mass
  - geometrical & kinematical signature: pt, detachment of decay vertex