Search for the rare decays $B^0_s \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow \mu^+\mu^-$

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LHCb Collaboration

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ABSTRACT

A search for the decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ is performed with about 37 pb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV collected by the LHCb experiment at the Large Hadron Collider at CERN. The observed numbers of events are consistent with the background expectations. The resulting upper limits on the branching ratios are $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 5.6 \times 10^{-8}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.5 \times 10^{-8}$ at 95% confidence level.

1. Introduction

Within the Standard Model (SM) exclusive dimuon decays of the B^0 and B_s^0 mesons[1] are rare as they occur only via loop diagrams and are helicity suppressed. New Physics models, especially those with an extended Higgs sector, can significantly enhance the branching fractions, although in some models the rates are lowered.

The amplitudes contributing to the branching ratio $\mathcal{B}(B_q^0 \to \mu^+\mu^-)$ (where $q = d, s$ for the B^0 and B_s^0 mesons respectively) can be expressed in terms of the scalar (c_S), pseudoscalar (c_P) and axial vector (c_A) Wilson coefficients in a completely general approach [1]. Within the SM, the contributions of c_S and c_P are negligible while c_A is calculated with an accuracy of a few percent [2]. The dominant contribution stems from an electroweak penguin with a Z^0 decaying into two muons. However, the accuracy of the SM prediction for $\mathcal{B}(B_q^0 \to \mu^+\mu^-)$ is limited by the knowledge of the decay constants of the B_q^0 mesons. This limitation can be reduced by normalizing to the well-measured mass differences of the B_q^0 mesons. Using this approach [3], the SM predictions are

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{SM} = (0.32 \pm 0.02) \times 10^{-8},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)_{SM} = (0.010 \pm 0.001) \times 10^{-8}.$$

Many extensions to the SM predict a very different Higgs sector. For instance, within the Minimal Supersymmetric SM (MSSM) in the large $\tan\beta$ approximation [4], $c_{S,P}^{MSSM} \propto \tan^3\beta/M_A^2$, where M_A denotes the pseudoscalar Higgs mass and $\tan\beta$ the ratio of Higgs vacuum expectation values. The most restrictive limits on the search for $B_q^0 \to \mu^+\mu^-$ have so far been achieved at the Tevatron, due to the large $b\bar{b}$ cross-section at hadron colliders. The best limits at 95% C.L. published so far are obtained using 6.1 fb^{-1} by the D0 Collaboration [5], $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 5.1 \times 10^{-8}$, and using 2 fb^{-1} by the CDF Collaboration [6], $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 5.8 \times 10^{-8}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-8}$. The CDF Collaboration has also presented preliminary results [7] with 3.7 fb^{-1}, that lower the limits to $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 4.3 \times 10^{-8}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 0.76 \times 10^{-8}$.

The LHCb experiment is well suited for such searches due to its good invariant mass resolution, vertex resolution, muon identification and trigger acceptance. In addition, LHCb has a hadronic trigger capability which provides large samples of $B_q^0 \to h^+h'^-$ decays, where h and h' stand for a hadron (kaon or pion). These are used as control samples in order to reduce the dependence of the results on the simulation.

The measurements in this Letter use about 37 pb^{-1} of integrated luminosity collected by LHCb between July and October 2010 at $\sqrt{s} = 7$ TeV. Assuming the SM branching ratio, about 0.7 (0.08) $B_s^0 \to \mu^+\mu^-$ ($B^0 \to \mu^+\mu^-$) are expected to be reconstructed using the $b\bar{b}$ cross-section, measured within the LHCb acceptance, of 75 ± 14 μb [8].

2. The LHCb detector

The LHCb detector [9] is a single-arm forward spectrometer with an angular coverage from approximately 10 mrad to 300

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[1] In this Letter the inclusion of charge-conjugate states is implicit.

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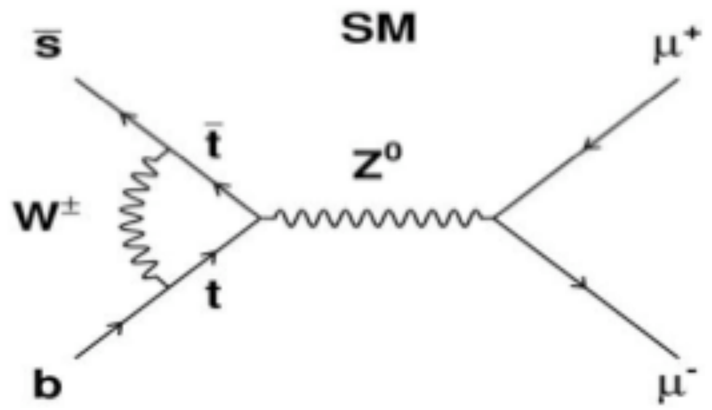
SM prediction and New Physics

Branching ratio of $B^0_{s,d} \rightarrow \mu^+\mu^-$ in SM

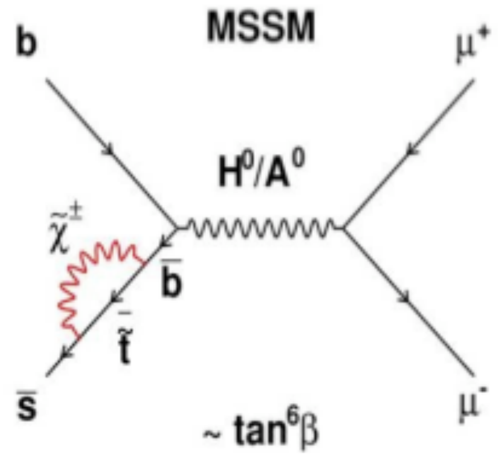
$$\mathcal{B}(B^0_s \to \mu^+\mu^-)_{SM} = (0.32 \pm 0.02) \times 10^{-8},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)_{SM} = (0.010 \pm 0.001) \times 10^{-8}.$$



Example: MSSM
(with R-parity conservation)

$$BR(B_S \to \mu^+\mu^-) \propto \frac{\tan^6\beta}{m_A^4}$$

→ limit or measurement of $B_{s,d} \rightarrow \mu\mu$ will strongly constrain $\tan\beta$ vs M_A plane



B→μμ is one of the Golden mode for NP in LHCb

2. The LHCb detector

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Physics Letters B

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LHCb Collaboration

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ABSTRACT

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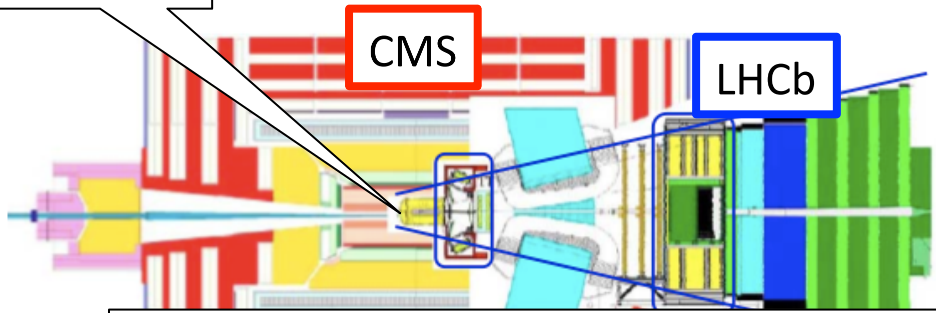
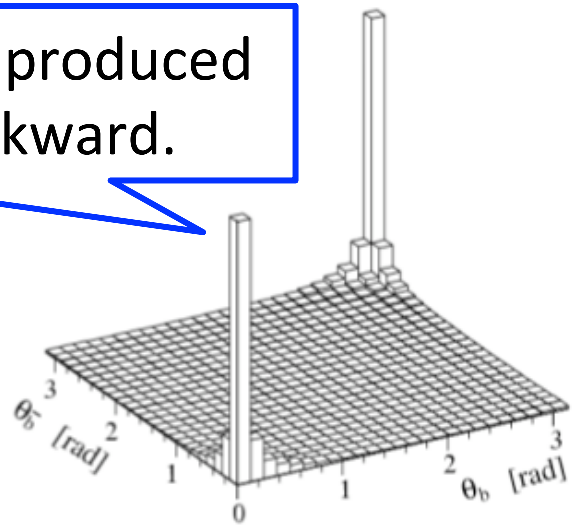
3. Analysis strategy

4. Event selection

LHCb

bb pairs are predominantly produced in the same forward or backward.



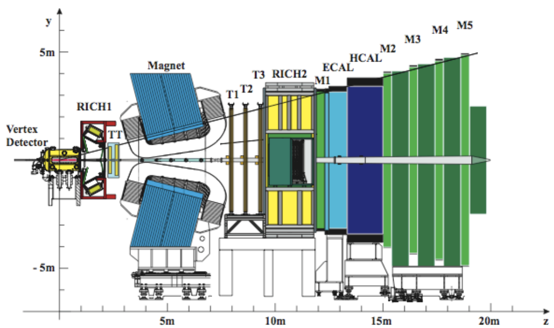


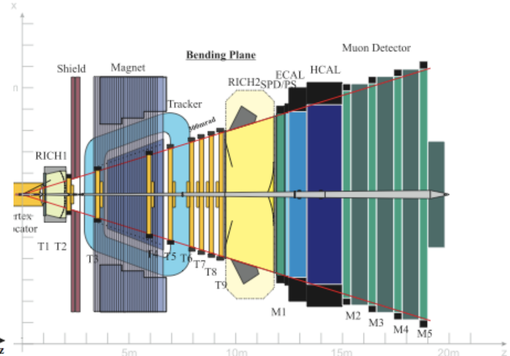
4π detector (CMS) and LHCb detector

Rough estimate for B acceptance: compare $B^{\pm} \rightarrow J/\psi K^{\pm}$ yield with CDF / D0

- **LHCb**
  N^{signal}: $12{,}366 \pm 403^{stat+syst}$ ($0.037 fb^{-1}$)
- **CDF** $_{(CMU-CM(U+X))}$
  N^{signal}: $19{,}762 \pm 203^{stat+syst}$ ($3.7 fb^{-1}$)

10-300mrad in the bending plane (horizontal)
10-250mrad in the non-bending plane (vertical)

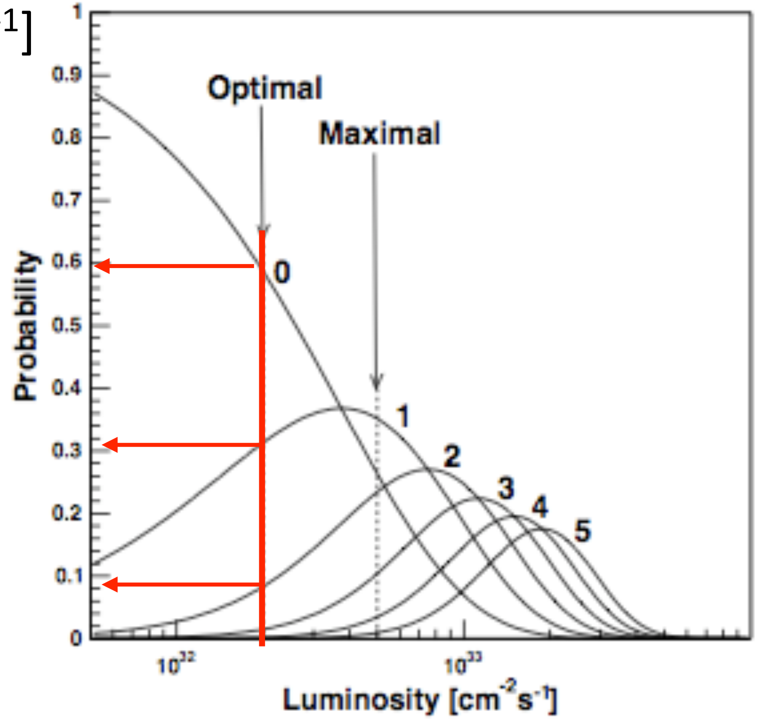


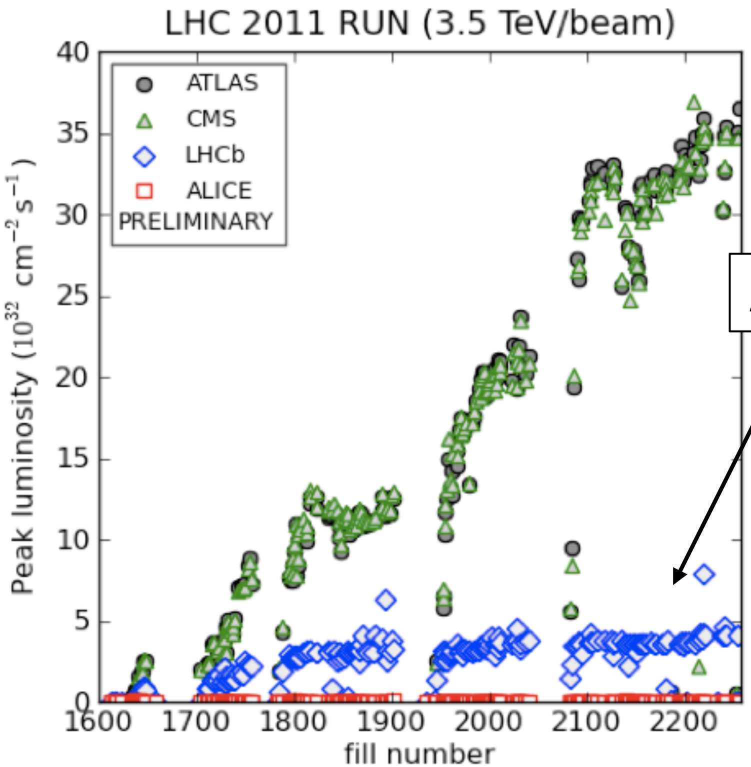


Luminosity

LHCb 's luminosity is tuned to 2 x 10^{32}[$cm^{-2}s^{-1}$] (defocusing the beams)

0 [events/cross] (~60%)
1 [events/cross] (~30%)
2 [events/cross] (~10%)





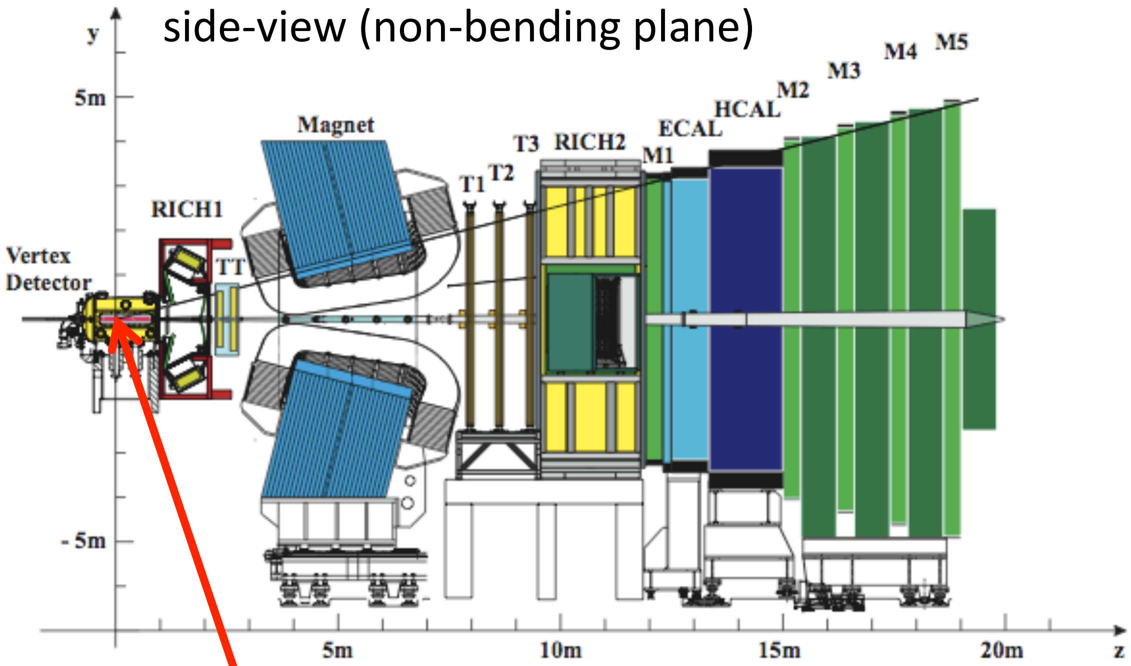
ATLAS & CMS

LHCb

2 x 10^{32} [$cm^{-2}s^{-1}$] = 200 [$\mu b^{-1}s^{-1}$]
200[$ub^{-1}s^{-1}$] x 10^{7}[s/year] = 2[fb^{-1}]
bb cross section@14 TeV ~500[μb]
@7 TeV ~300[μb]
→ ~10^{12}[bb/year]

Detector (1/4)

side-view (non-bending plane)



Vertex locator
(silicon micro strip)

reconstruct
primary vertex (b production)
& secondary vertex (b, c decay)

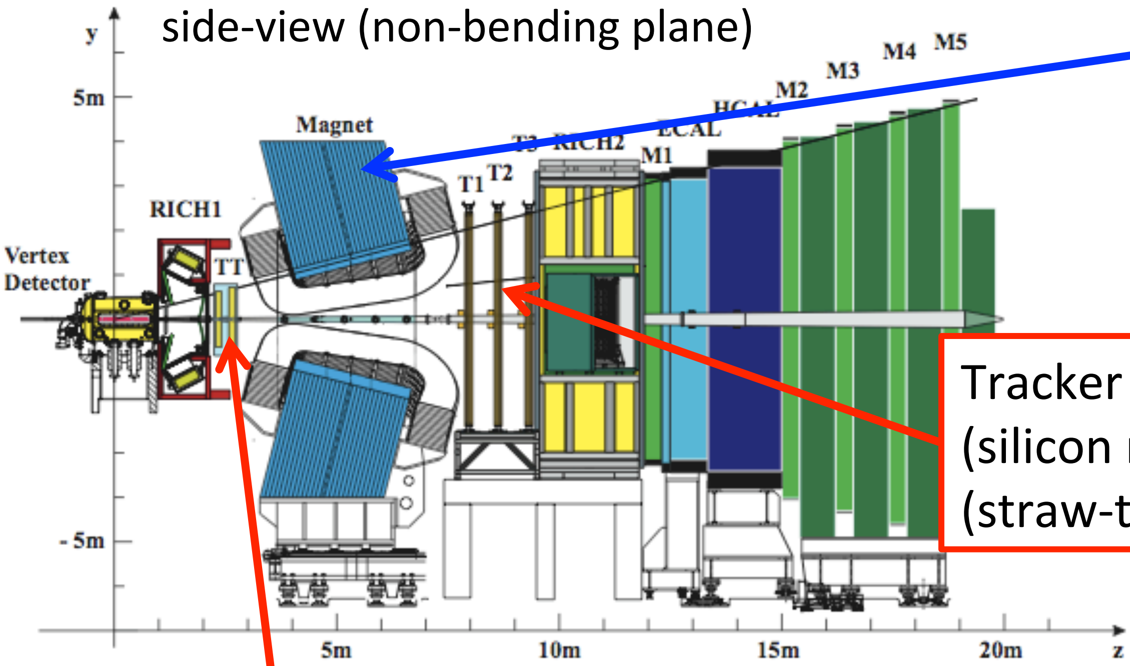
Primary vertex resolutions (25 tracks):

	LHCb [μm]	ATLAS [μm]	CMS [μm]
σ(x)	15.8	60	20-40
σ(y)	15.2	60	20-40
σ(z)	76	100	40-60

Impact parameter resolution (Belle)

$\sigma_{xy} = 19 \oplus 50/(p\beta \sin^{3/2}\theta)$ μm and $\sigma_z = 36 \oplus 42/(p\beta \sin^{5/2}\theta)$ μm.

Detector (2/4)



A warm dipole magnet
$$\int Bdl = 4\mathrm{Tm}$$

Tracker stations (3 layers)
(silicon micro strip for small angle region)
(straw-tubes for large angle region)

Trigger Tracker
(4 layers of
silicon micro strip)

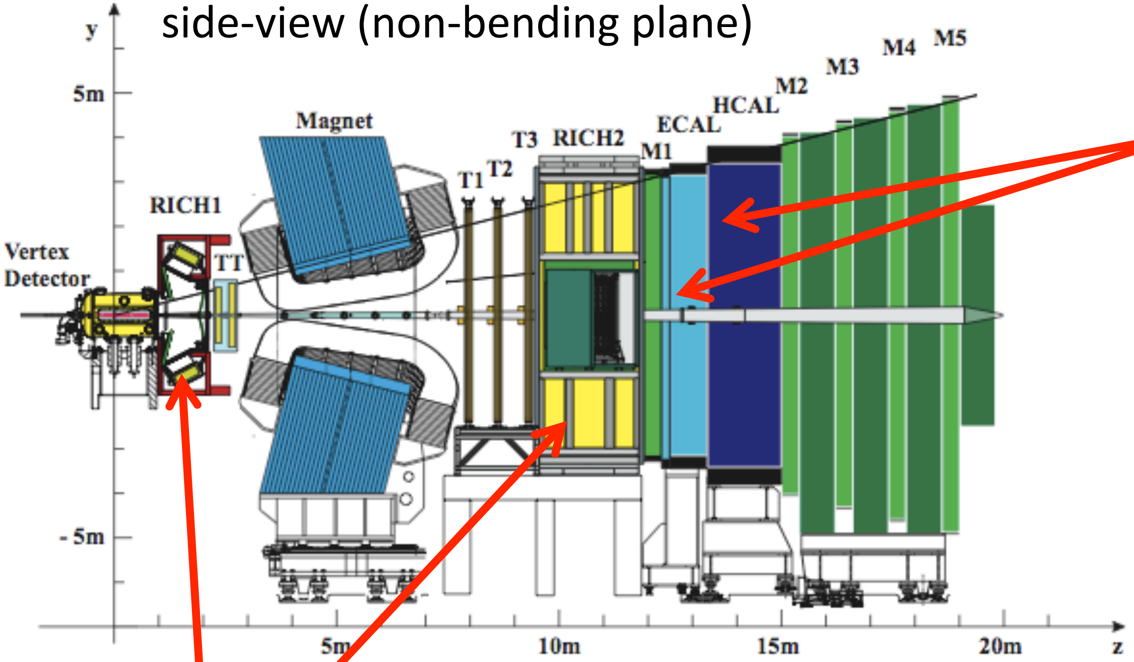
$\delta p/p$ = 0.35 % (@5GeV/c)
= 0.5 % (@100GeV/c)

	momentum resolution	mass resolution $J/\psi \to \mu\mu$
LHCb	$\delta p/p$ = 0.4-0.6 %	13 MeV
CMS	$\delta pt/pt$ = 1-3 %	40 MeV
ATLAS	$\delta pt/pt$ = 5-6 %	71 MeV

Belle $\delta pt/pt = 0.2pt \oplus 0.3/\beta$ %

Detector (3/4)

side-view (non-bending plane)



Calorimeter system
ECAL + HCAL
ID high E_T hadron, e, gamma
→ "L0" trigger

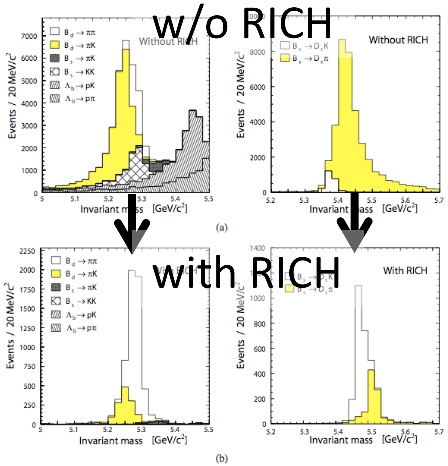
ECAL

$$\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E[\mathrm{GeV}]}} \oplus 1.5\%$$

HCAL

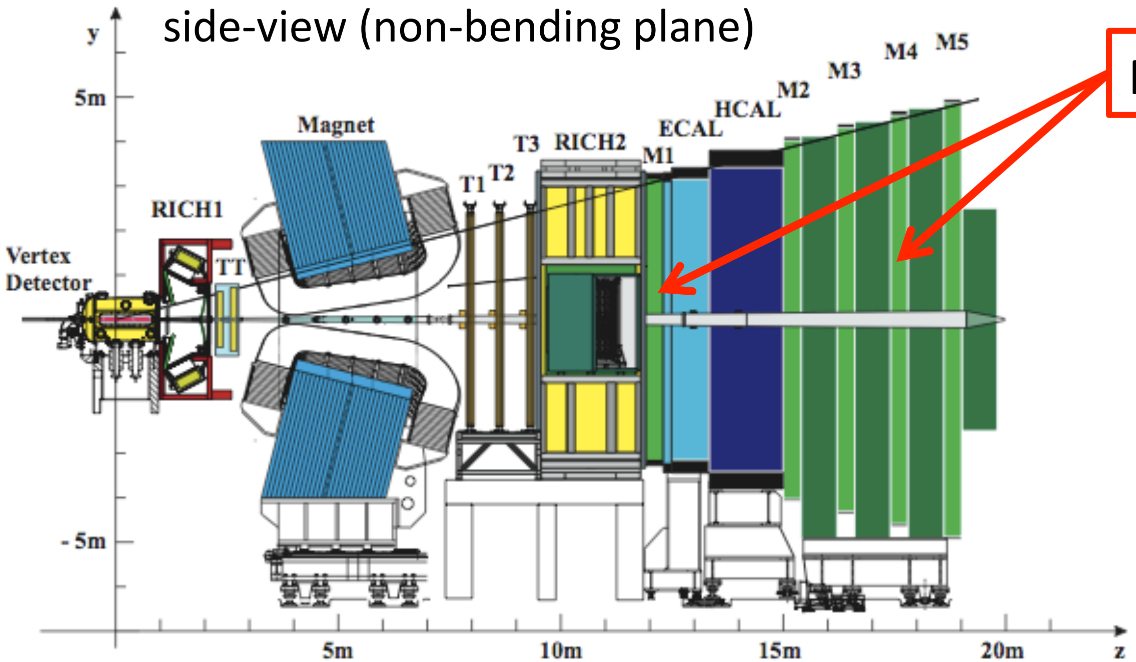
$$\frac{\sigma_E}{E} = \frac{80\%}{\sqrt{E[\mathrm{GeV}]}} \oplus 10\%$$

RICH system
Charged hadron ID
(p range: 2 – 100 GeV)



LHCb	**ECAL**	**HCAL**
	$25X_0$	----
	$1.2\lambda_I$	$5.6\lambda_I$
Belle	**ECL**	**KLM**
	$16X_0$	----
	$0.8\lambda I$	$3.9\lambda I$

Detector (4/4)



Muon systems (1+ 4 layers)

Gold-plated CP sensitive decays

$$B_d^0 \to J/\psi(\mu^+\mu^-)K_s^0$$

$$B_s^0 \to J/\psi(\mu^+\mu^-)\phi$$

Golden modes for New Physics:

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

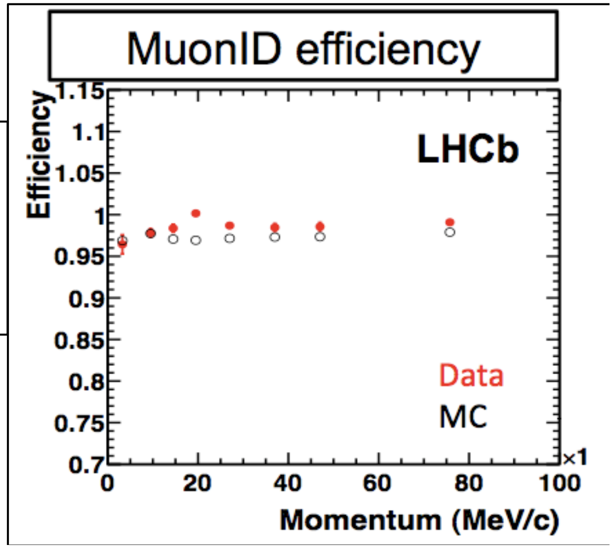
$$B \to K^*\mu^+\mu^-$$

- Performance in the kinematic range of $B_s \to \mu\mu$:

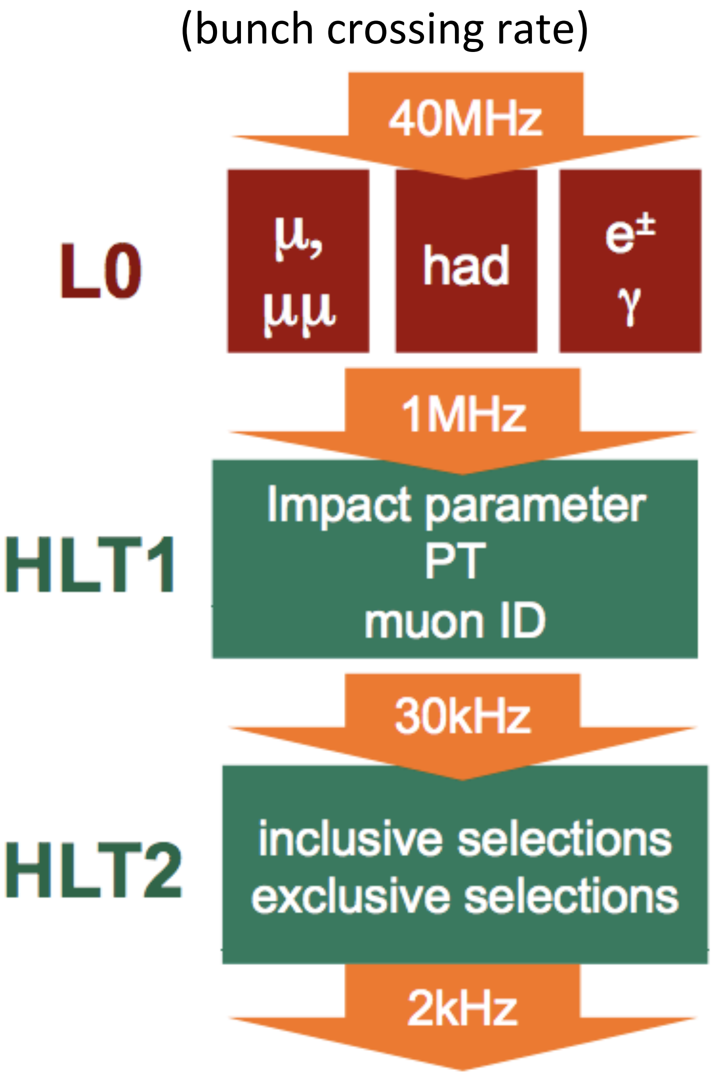
$\varepsilon(\mu \to \mu) \sim (97.1 \pm 1.3)\%$

$\varepsilon(h \to \mu) \sim (7.1 \pm 0.5)\ 10^{-3}$

$\varepsilon(hh \to \mu\mu) \sim (3.5 \pm 0.9)\ 10^{-5}$



Trigger



L0 trigger

Pileup system → discriminate single pp interactions

calorimeter trigger for gamma, e, hadron

muon trigger

(Single mu: pt>1.4GeV

or di mu: pt > 0.48 GeV, 0.56GeV)

High Level Trigger 1+2

using L0 information, tracking, vertexing

ex. for muon

pt > 1.8GV

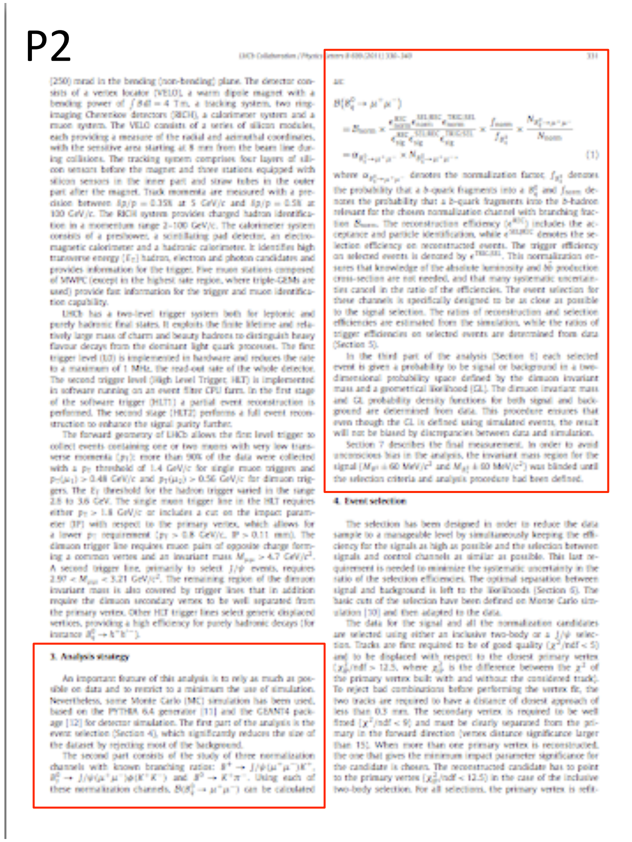
or IP > 0.11mm, Pt> 0.8GeV

for di muon

invariant mass is calculated

3. Analysis strategy

P2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3. Analysis strategy

An important feature of this analysis is to rely as much as possible on data and to restrict to a minimum the use of simulation. Nevertheless, some Monte Carlo (MC) simulation has been used, based on the PYTHIA 6.4 generator [11] and the GEANT4 package [12] for detector simulation. The first part of the analysis is the event selection (Section 4), which significantly reduces the size of the dataset by rejecting most of the background.

The second part consists of the study of three normalization channels with known branching ratios: $B^+ \to J/\psi(\mu^+\mu^-)K^+$, $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ and $B^0 \to K^+\pi^-$. Using each of these normalization channels, $\mathcal{B}(B_q^0 \to \mu^+\mu^-)$ can be calculated as:

$$\mathcal{B}(B_q^0 \to \mu^+\mu^-) = \mathcal{B}_{norm} \times \frac{\epsilon_{norm}^{REC}\epsilon_{norm}^{SEL|REC}\epsilon_{norm}^{TRIG|SEL}}{\epsilon_{sig}^{REC}\epsilon_{sig}^{SEL|REC}\epsilon_{sig}^{TRIG|SEL}} \times \frac{f_{norm}}{f_{B_q^0}} \times \frac{N_{B_q^0\to\mu^+\mu^-}}{N_{norm}} = \alpha_{B_q^0\to\mu^+\mu^-} \times N_{B_q^0\to\mu^+\mu^-}, \quad (1)$$

where $\alpha_{B_q^0\to\mu^+\mu^-}$ denotes the normalization factor, $f_{B_q^0}$ denotes the probability that a b-quark fragments into a B_q^0 and f_{norm} denotes the probability that a b-quark fragments into the b-hadron relevant for the chosen normalization channel with branching fraction $\mathcal{B}_{norm}$. The reconstruction efficiency (ϵ^{REC}) includes the acceptance and particle identification, while $\epsilon^{SEL|REC}$ denotes the selection efficiency on reconstructed events. The trigger efficiency on selected events is denoted by $\epsilon^{TRIG|SEL}$. This normalization ensures that knowledge of the absolute luminosity and $b\bar{b}$ production cross-section are not needed, and that many systematic uncertainties cancel in the ratio of the efficiencies. The event selection for these channels is specifically designed to be as close as possible to the signal selection. The ratios of reconstruction and selection efficiencies are estimated from the simulation, while the ratios of trigger efficiencies on selected events are determined from data (Section 5).

In the third part of the analysis (Section 6) each selected event is given a probability to be signal or background in a two-dimensional probability space defined by the dimuon invariant mass and a geometrical likelihood (GL). The dimuon invariant mass and GL probability density functions for both signal and background are determined from data. This procedure ensures that even though the GL is defined using simulated events, the result will not be biased by discrepancies between data and simulation.

Section 7 describes the final measurement. In order to avoid unconscious bias in the analysis, the invariant mass region for the signal ($M_{B^0} \pm 60$ MeV/c^2 and $M_{B_s^0} \pm 60$ MeV/c^2) was blinded until the selection criteria and analysis procedure had been defined.

4. Event selection

The selection has been designed in order to reduce the data sample to a manageable level by simultaneously keeping the efficiency for the signals as high as possible and the selection between signals and control channels as similar as possible. This last requirement ...

4. Event selection

5. Evaluation of the normalization factor

6. Signal and background likelihoods

4. Event selection

P2

P3

Purpose :
Soft selection to reduce size of dataset.
(signal efficiency → as high as possible
sample efficiency → as similar as possible to signal efficiency)

μ ID using "muon stations".
Good quality events (tracks, vertex) are selected.

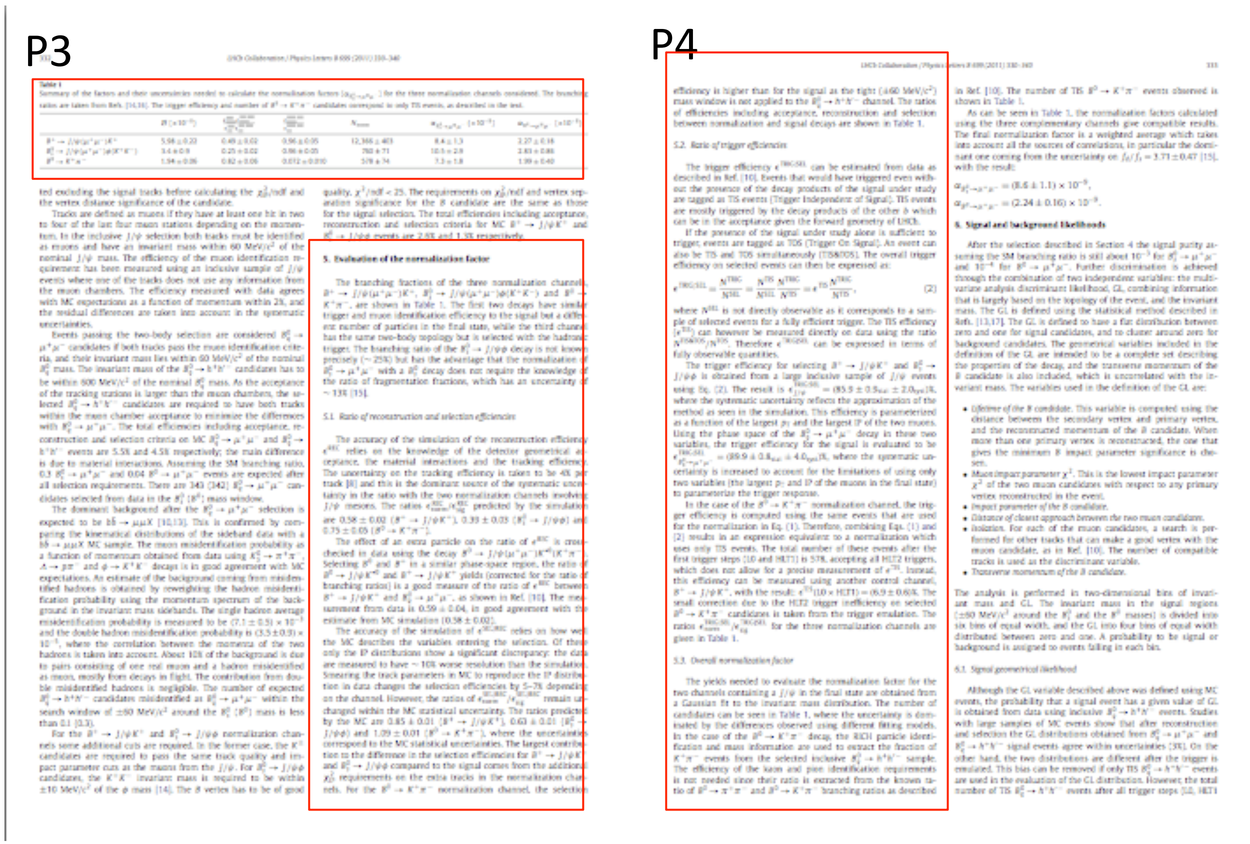
Condition for signal candidate:
$\Delta M < 60 MeV/c2$

After all selections ...

343 (342) Bs (Bd)→mu+mu- candidates are remain.
In those candidates, 0.3 (0.04) events are expected.

Dominant background :
~90% bb → mu mu X
~10% fake + mu

5. Evaluation of the normalization factor



Concept of normalization

$$BR_{signal} = \frac{N'_{signal}}{N'_{total}} = \frac{N_{signal} / \varepsilon_{signal}}{N'_{total}}$$

$N_{signal} = \varepsilon_{signal} * N'_{signal}$
N : detected #
N' : occurred #

sample:
normalization with
well known events.

$$N'_{total} = L * \sigma \quad \text{or} \quad N'_{total} = \frac{N_{sample} / \varepsilon_{sample}}{BR_{sample}}$$

$$= \frac{N_{signal} / \varepsilon_{signal}}{L * \sigma}$$

1) Rely on MC
2) Many systematics

✕

$$= BR_{sample} * \frac{N_{signal} / \varepsilon_{signal}}{N_{sample} / \varepsilon_{sample}}$$

1) Rely on data > MC
2) Many systematics cancel

○

$$\mathcal{B}(B_q^0 \to \mu^+\mu^-) = \mathcal{B}_{\text{norm}} \times \frac{\epsilon_{\text{norm}}^{\text{REC}} \epsilon_{\text{norm}}^{\text{SEL|REC}} \epsilon_{\text{norm}}^{\text{TRIG|SEL}}}{\epsilon_{\text{sig}}^{\text{REC}} \epsilon_{\text{sig}}^{\text{SEL|REC}} \epsilon_{\text{sig}}^{\text{TRIG|SEL}}} \times \frac{f_{\text{norm}}}{f_{B_q^0}} \times \frac{N_{B_q^0 \to \mu^+\mu^-}}{N_{\text{norm}}}$$

exact formula of Br

HFAG average of LEP/Tevatron value
$f_d/f_s = 3.71 \pm 0.47$

Three independent normalization channels used:

$B^{\pm} \to J/\psi(\mu\mu) K^{\pm}$	$B_s \to J/\psi(\mu\mu) \phi(KK)$	$B^0 \to K^+\pi^-$
BR = 5.98×10^{-5} (±3.7%)	BR = 3.35×10^{-5} (±26%)	BR = 1.94×10^{-5} (±3.1%)
• Similar trigger and PID • Tracking efficiency (+1track) dominates error on efficiency ratio • f_d/f_s dominates overall uncertainty	• Similar trigger and PID • Tracking efficiency (+2tracks) dominates error on efficiency ratio • BR dominates overall uncertainty	• Different trigger → **use events triggered independent of signal** • Identical topology • Uncertainty from f_d/f_s, trigger, mass fit

Results

	$\mathcal{B}$ ($\times 10^{-5}$)	$\frac{\epsilon^{REC}_{norm}\epsilon^{SEL\|REC}_{norm}}{\epsilon^{REC}_{sig}\epsilon^{SEL\|REC}_{sig}}$	$\frac{\epsilon^{TRIG\|SEL}_{norm}}{\epsilon^{TRIG\|SEL}_{sig}}$	N_{norm}	$\alpha_{B^0_s\to\mu^+\mu^-}$ ($\times 10^{-9}$)	$\alpha_{B^0\to\mu^+\mu^-}$ ($\times 10^{-9}$)
$B^+ \to J/\psi(\mu^+\mu^-)K^+$	5.98 ± 0.22	0.49 ± 0.02	0.96 ± 0.05	$12{,}366 \pm 403$	8.4 ± 1.3	2.27 ± 0.18
$B^0_s \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$	3.4 ± 0.9	0.25 ± 0.02	0.96 ± 0.05	760 ± 71	10.5 ± 2.9	2.83 ± 0.86
$B^0 \to K^+\pi^-$	1.94 ± 0.06	0.82 ± 0.06	0.072 ± 0.010	578 ± 74	7.3 ± 1.8	1.99 ± 0.40

- Normalization factors from three channels consistent
  → take the **weighted average**

$$\alpha_{B_S\to\mu\mu} = 8.6 \pm 1.1 \times 10^{-9}$$
$$\alpha_{B^0\to\mu\mu} = 2.24 \pm 0.16 \times 10^{-9}$$

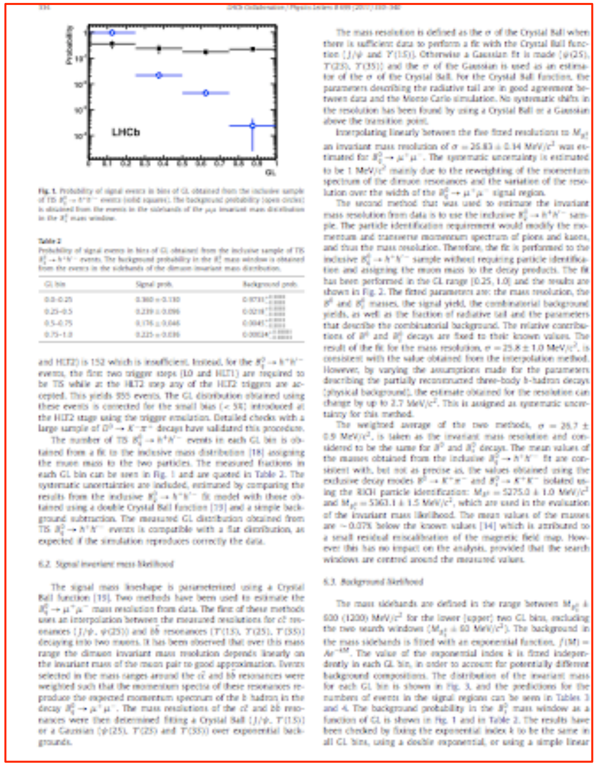
(dominated by $B^\pm \to J/\psi K^\pm$)

→ used for expectation of
# of signal events

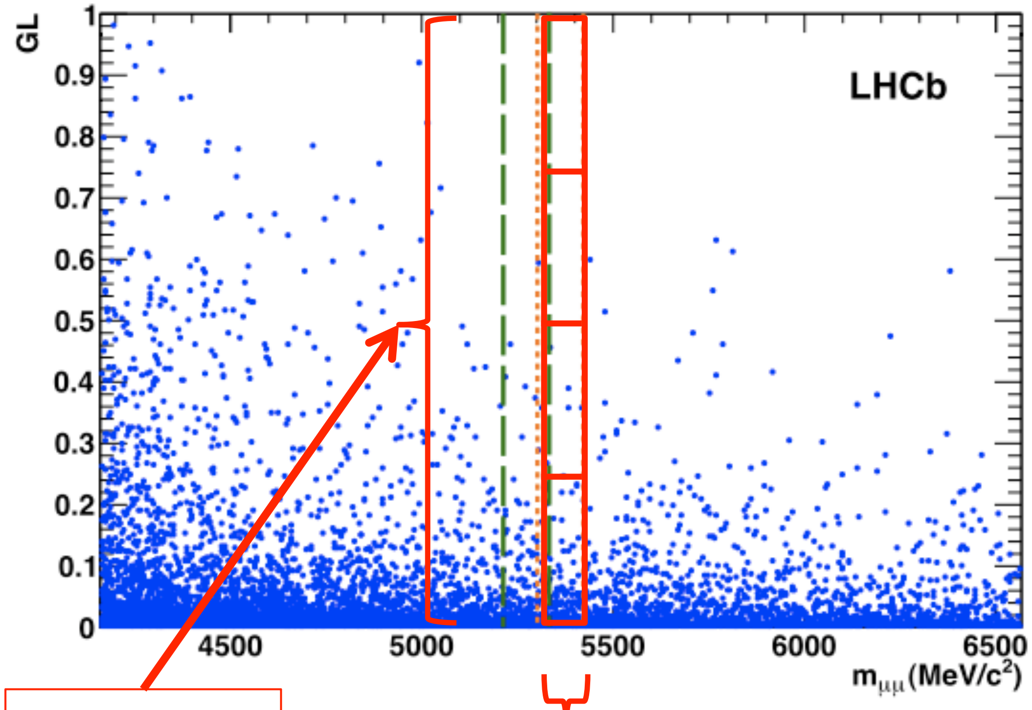
6. Signal and background likelihoods

P4

P5



Events are classified in two dimensional plane.
invariant mass
geometrical likelihood (GL)

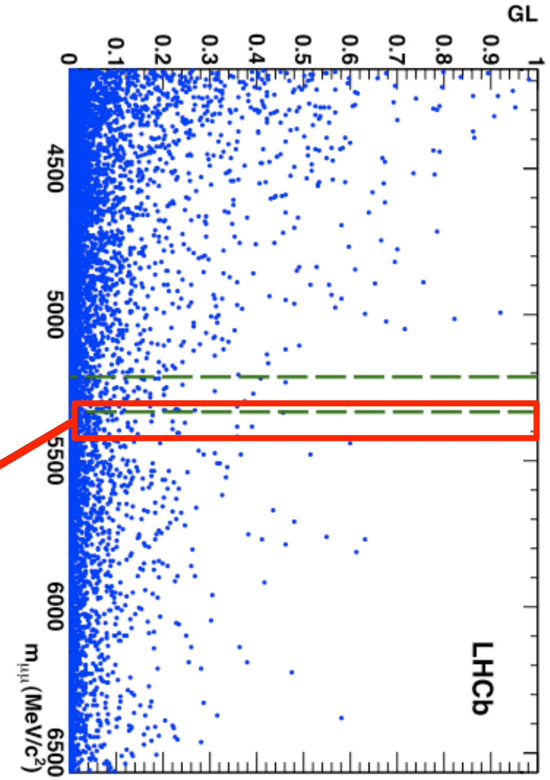


GL → 4 bins

Δm → 6 bins

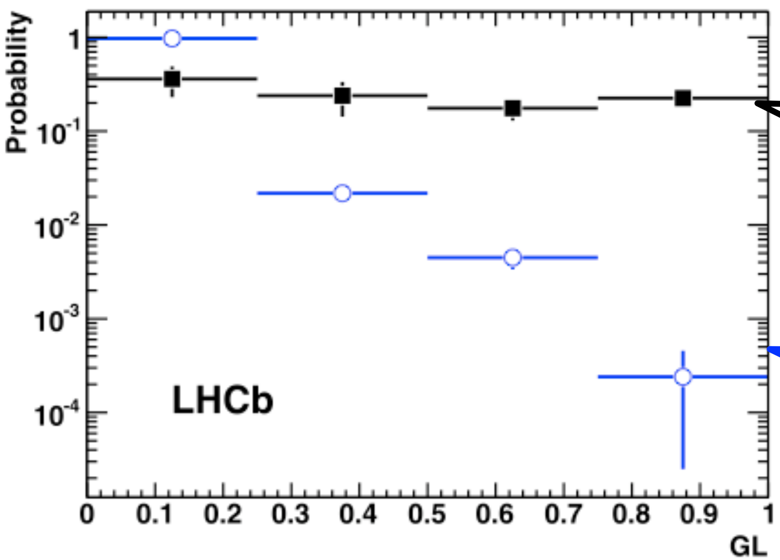
expected signals & BGs are calculated

GL:
Obtained from data using inclusive $B^0 \rightarrow h^+h'^-$
Agree with distribution obtained from $B^0 \rightarrow \mu^+\mu^-$



variables used for GL:
Lifetime & pt of the B
Impact parameter of μ, B
distance of μμ ... etc

background probability in the B^0_s mass window



Signal
~25% for each

BG
cluster around 0

→ used for expectation of # of signal events

Mass resolution are calculated in two ways

1) interpolation J/ψ, ψ(2S), Υ(1S), Υ(2S), Υ(3S) → $\mu^+\mu^-$

CB function fit   Gaussian fit

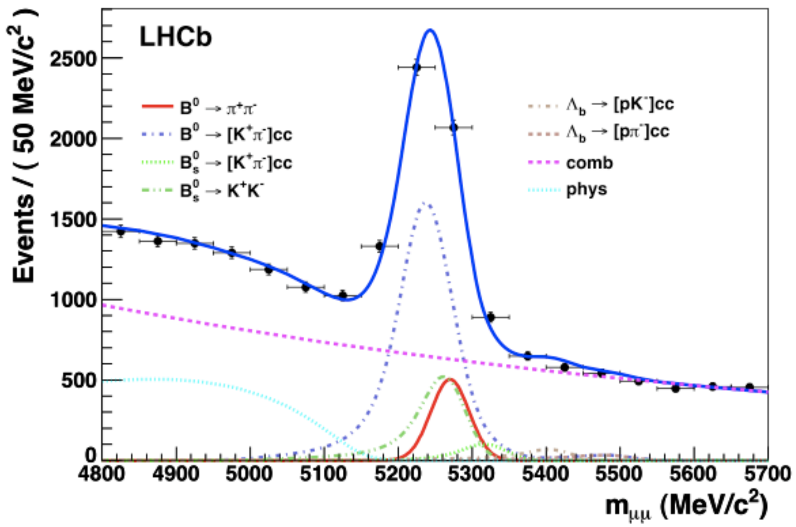
→ σ = 26.83 ± 0.14 MeV

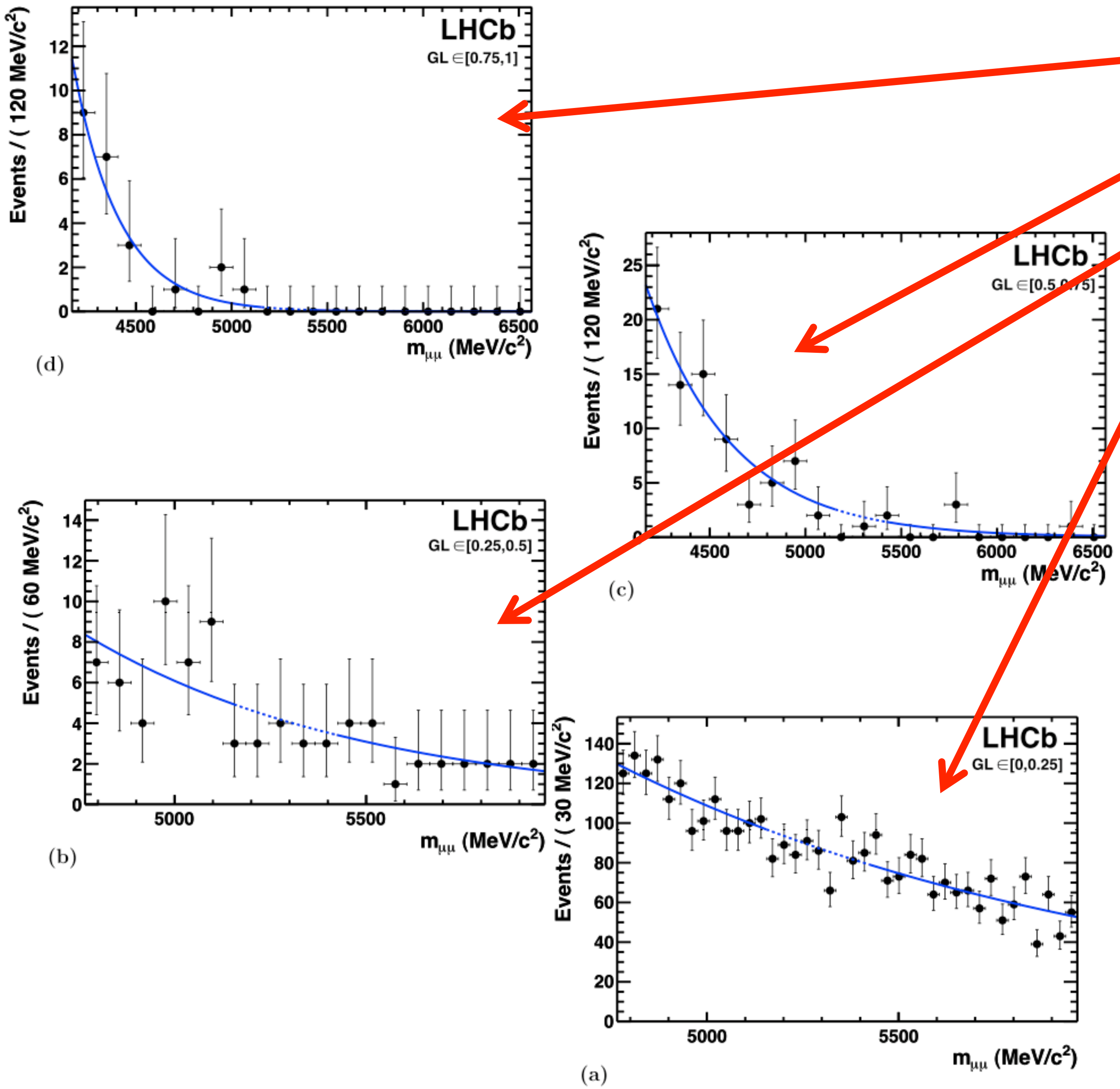
2) inclusive $B^0_q \rightarrow h^+h'^-$ reconstruction

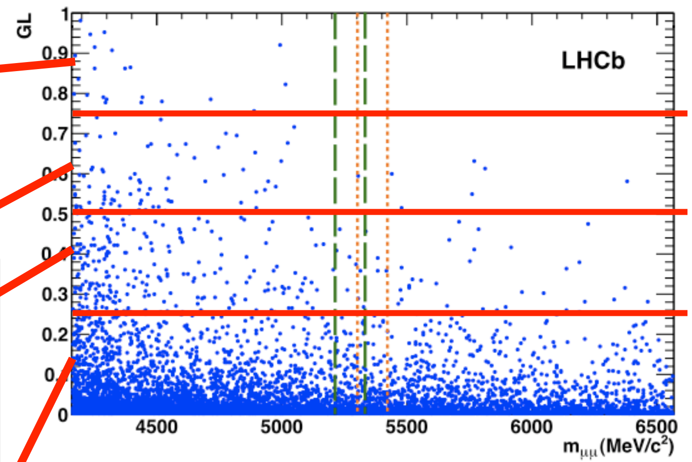
→ σ = 25.8 ± 1.0 MeV

σ = 26.7 ± 0.9 MeV

→ used for expectation of # of signal events







Sideband region

±1200MeV for upper GL bins

±600MeV for lower GL bins

(fitted with A*exp[-k*x])

→ used for expectation of # of BG events

B^0_s prediction for the number of events in the signal region

Invariant mass bin (MeV/c^2)		GL bin [0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	Exp. bkg.	$56.9^{+1.1}_{-1.1}$	$1.31^{+0.19}_{-0.17}$	$0.282^{+0.076}_{-0.065}$	$0.016^{+0.021}_{-0.010}$
	Exp. sig.	$0.0076^{+0.0034}_{-0.0030}$	$0.0050^{+0.0027}_{-0.0020}$	$0.0037^{+0.0015}_{-0.0011}$	$0.0047^{+0.0015}_{-0.0010}$
	Observed	39	2	1	0
[−40, −20]	Exp. bkg.	$56.1^{+1.1}_{-1.1}$	$1.28^{+0.18}_{-0.17}$	$0.269^{+0.072}_{-0.062}$	$0.0151^{+0.0195}_{-0.0094}$
	Exp. sig.	$0.0220^{+0.0084}_{-0.0081}$	$0.0146^{+0.0067}_{-0.0054}$	$0.0107^{+0.0036}_{-0.0027}$	$0.0138^{+0.0035}_{-0.0025}$
	Observed	55	2	0	0
[−20, 0]	Exp. bkg.	$55.3^{+1.1}_{-1.1}$	$1.24^{+0.17}_{-0.16}$	$0.257^{+0.069}_{-0.059}$	$0.0139^{+0.0179}_{-0.0086}$
	Exp. sig.	$0.038^{+0.015}_{-0.015}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0060}_{-0.0044}$
	Observed	73	0	0	0
[0, 20]	Exp. bkg.	$54.4^{+1.1}_{-1.1}$	$1.21^{+0.17}_{-0.16}$	$0.246^{+0.066}_{-0.057}$	$0.0128^{+0.0165}_{-0.0080}$
	Exp. sig.	$0.038^{+0.015}_{-0.015}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0060}_{-0.0044}$
	Observed	60	0	0	0
[20, 40]	Exp. bkg.	$53.6^{+1.1}_{-1.0}$	$1.18^{+0.17}_{-0.15}$	$0.235^{+0.063}_{-0.054}$	$0.0118^{+0.0152}_{-0.0073}$
	Exp. sig.	$0.0220^{+0.0084}_{-0.0081}$	$0.0146^{+0.0067}_{-0.0054}$	$0.0107^{+0.0036}_{-0.0027}$	$0.0138^{+0.0035}_{-0.0025}$
	Observed	53	2	0	0
[40, 60]	Exp. bkg.	$52.8^{+1.0}_{-1.0}$	$1.14^{+0.16}_{-0.15}$	$0.224^{+0.060}_{-0.052}$	$0.0108^{+0.0140}_{-0.0068}$
	Exp. sig.	$0.0076^{+0.0031}_{-0.0027}$	$0.0050^{+0.0025}_{-0.0019}$	$0.0037^{+0.0013}_{-0.0010}$	$0.0047^{+0.0013}_{-0.0010}$
	Observed	55	1	0	0

B^0_d prediction for the number of events in the signal region

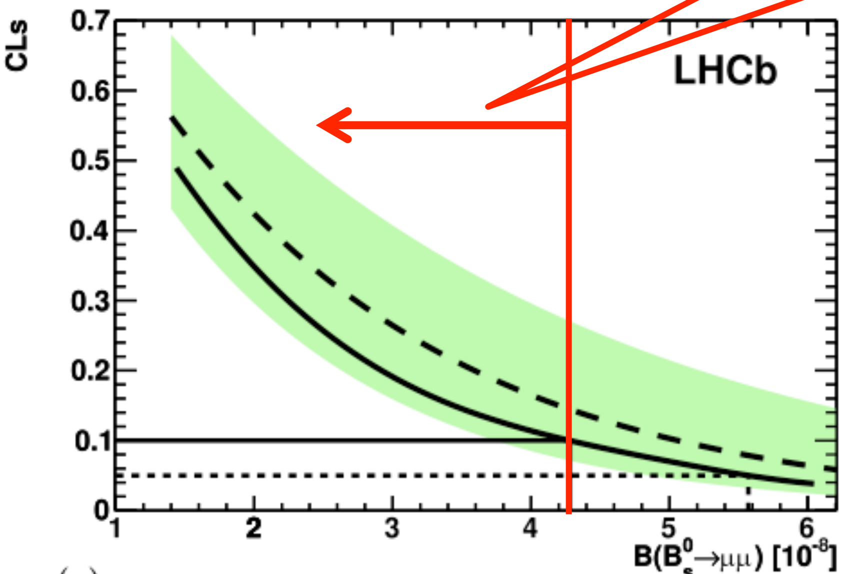
Invariant mass bin (MeV/c^2)		GL bin [0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	Exp. bkg.	$60.8^{+1.2}_{-1.1}$	$1.48^{+0.19}_{-0.18}$	$0.345^{+0.084}_{-0.073}$	$0.024^{+0.027}_{-0.014}$
	Exp. sig.	$0.00090^{+0.00036}_{-0.00035}$	$0.00060^{+0.00029}_{-0.00023}$	$0.00044^{+0.00016}_{-0.00012}$	$0.00056^{+0.00015}_{-0.00011}$
	Observed	59	2	0	0
[−40, −20]	Exp. bkg.	$59.9^{+1.1}_{-1.1}$	$1.44^{+0.19}_{-0.17}$	$0.329^{+0.080}_{-0.070}$	$0.022^{+0.024}_{-0.013}$
	Exp. sig.	$0.00263^{+0.00093}_{-0.00093}$	$0.00174^{+0.00076}_{-0.00061}$	$0.00128^{+0.00038}_{-0.00030}$	$0.00164^{+0.00035}_{-0.00025}$
	Observed	67	0	0	0
[−20, 0]	Exp. bkg.	$59.0^{+1.1}_{-1.1}$	$1.40^{+0.18}_{-0.17}$	$0.315^{+0.077}_{-0.067}$	$0.020^{+0.022}_{-0.012}$
	Exp. sig.	$0.0045^{+0.0017}_{-0.0017}$	$0.0030^{+0.0014}_{-0.0011}$	$0.00219^{+0.00067}_{-0.00054}$	$0.00280^{+0.00060}_{-0.00045}$
	Observed	56	2	0	0
[0, 20]	Exp. bkg.	$58.1^{+1.1}_{-1.1}$	$1.36^{+0.18}_{-0.16}$	$0.300^{+0.073}_{-0.064}$	$0.019^{+0.021}_{-0.011}$
	Exp. sig.	$0.0045^{+0.0017}_{-0.0017}$	$0.0030^{+0.0014}_{-0.0011}$	$0.00219^{+0.00067}_{-0.00054}$	$0.00280^{+0.00060}_{-0.00045}$
	Observed	60	0	0	0
[20, 40]	Exp. bkg.	$57.3^{+1.1}_{-1.1}$	$1.33^{+0.17}_{-0.16}$	$0.287^{+0.070}_{-0.061}$	$0.017^{+0.019}_{-0.010}$
	Exp. sig.	$0.00263^{+0.00093}_{-0.00093}$	$0.00174^{+0.00076}_{-0.00061}$	$0.00128^{+0.00038}_{-0.00030}$	$0.00164^{+0.00035}_{-0.00025}$
	Observed	42	2	1	0
[40, 60]	Exp. bkg.	$56.4^{+1.1}_{-1.1}$	$1.29^{+0.17}_{-0.16}$	$0.274^{+0.067}_{-0.058}$	$0.0158^{+0.0175}_{-0.0094}$
	Exp. sig.	$0.00090^{+0.00033}_{-0.00032}$	$0.00060^{+0.00027}_{-0.00021}$	$0.00044^{+0.00014}_{-0.00011}$	$0.00056^{+0.00013}_{-0.00010}$
	Observed	49	2	0	0

Results

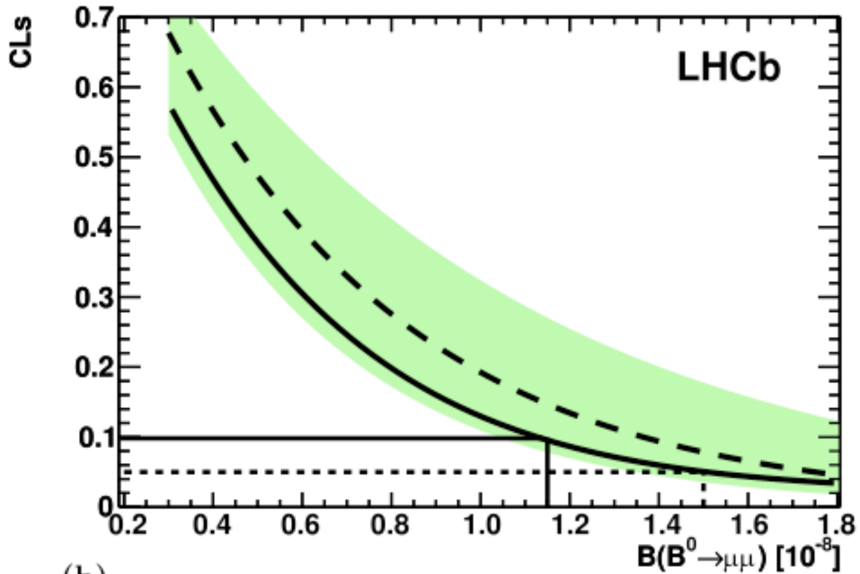
Green shaded area
CL_b: BG only hypothesis
compatible within 1σ

Solid (Dashed) line
CL_s: Signal + BG hypothesis
Observed (Expected)

CLs is higher than 0.1 at BR < 4.3 x 10-8
→ The area BR > 4.3 x 10-8 is excluded at CL 90%.



(a)



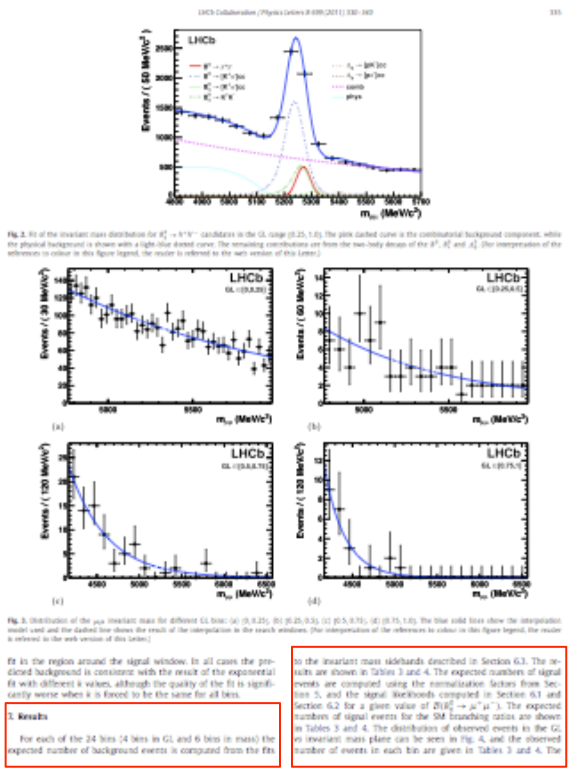
(b)

BR Bs0→mumu
< 4.3(5.6) x 10^{-8} @ 90(95)%CL

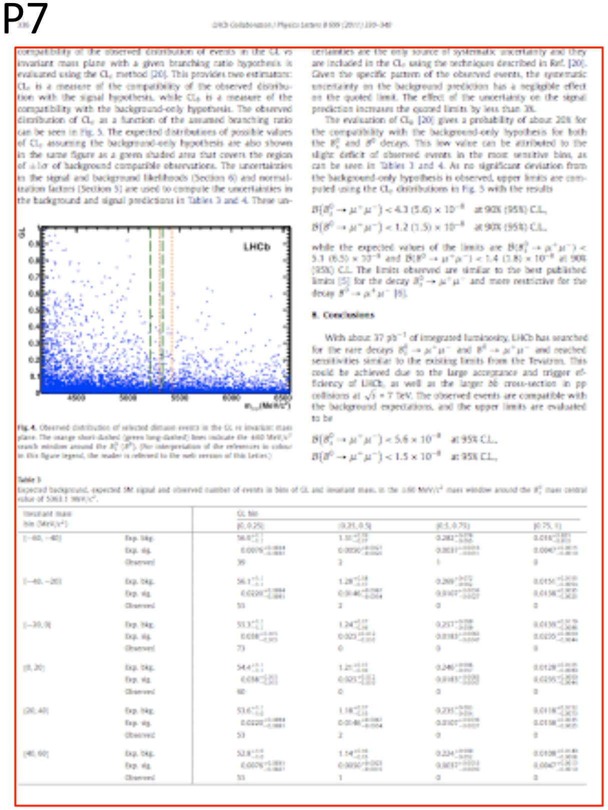
BR Bd0→mumu
< 1.2(1.5) x 10^{-8} @ 90(95)%CL

7. Results & 8. Conclusions

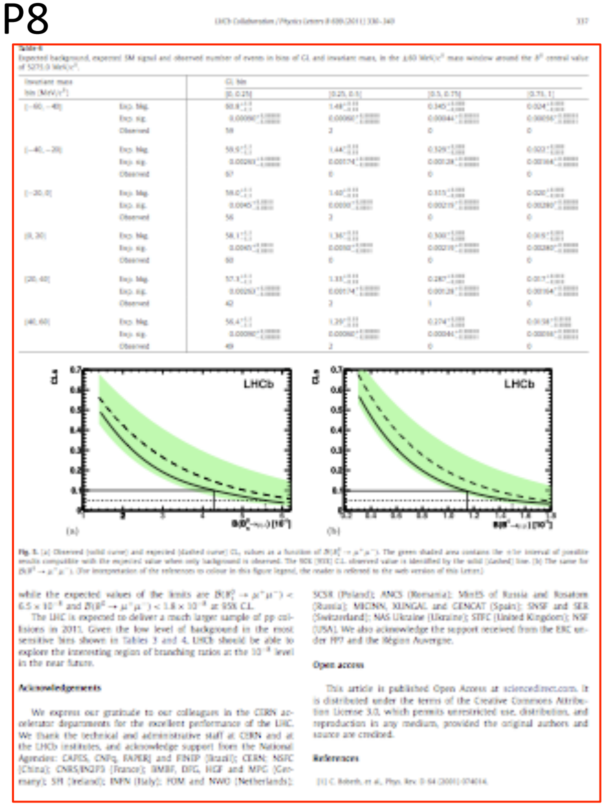
P6



P7



P8



- First LHCb result (0.037 fb^{-1})

$$BR(B_s \to \mu^+\mu^-) < 4.3\ (5.6)\ \ 10^{-8}\ @\ 90\ (95\%\ CL)$$

$$BR(B^0 \to \mu^+\mu^-) < 1.2\ (1.5)\ \ 10^{-8}\ @\ 90\ (95\%\ CL)$$

latest result (at EPS July 2011)

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{SM} = (0.32 \pm 0.02) \times 10^{-8},$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)_{SM} = (0.010 \pm 0.001) \times 10^{-8}.$$

CDF 7fb-1 @√s=1.96TeV

0.46 x 10-8 < Br(Bs→μμ) < 3.9 x 10^{-8} @ 90% C.L.

Br(Bd→μμ) < 0.6 x 10^{-8} @ 95%C.L.

Events observed !?

CMS 1.14fb-1 @√s=7TeV

Br(Bs→μμ) < 1.6(1.9) x 10^{-8} @ 90(95)%C.L.

Br(Bd→μμ) < 0.37(0.46) x 10^{-8} @ 90(95)%C.L.

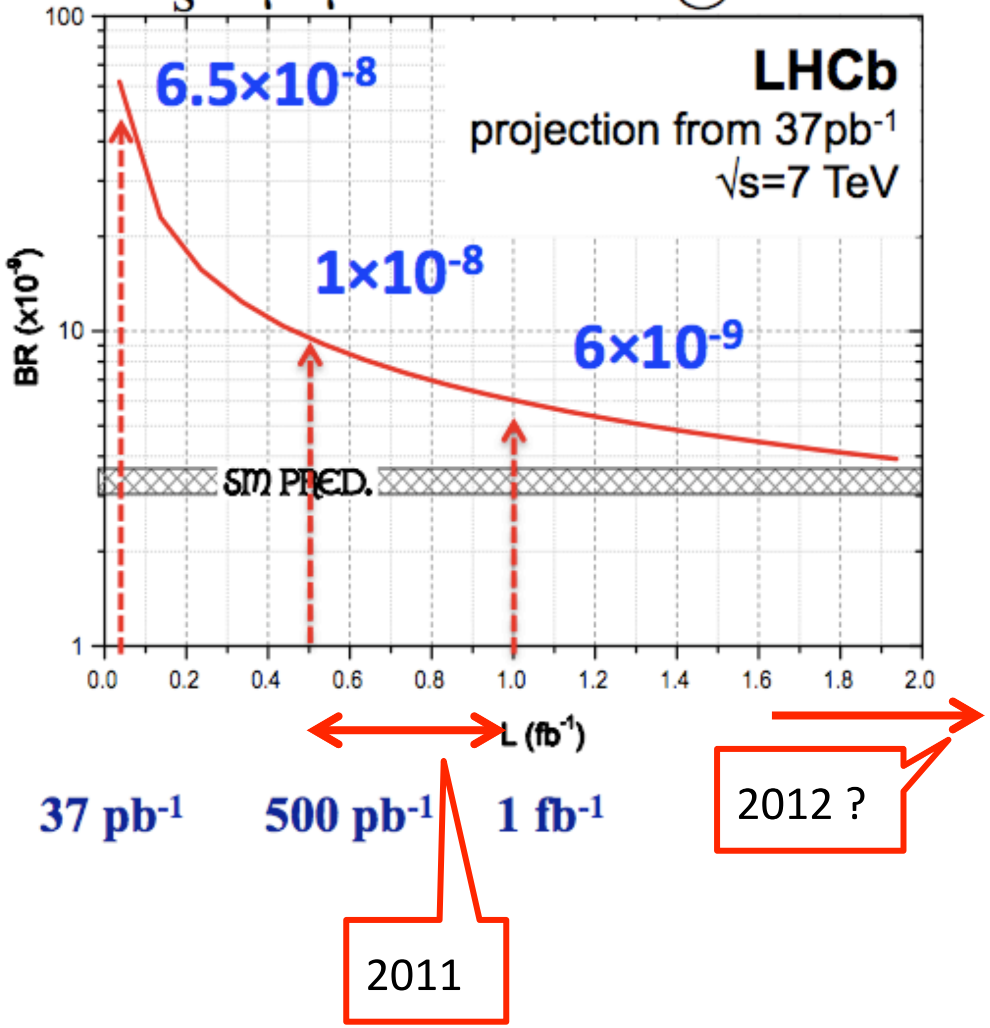
LHCb 0.3fb-1 @√s=7TeV

Br(Bs→μμ) < 1.3(1.6) x 10^{-8} @ 90(95)%C.L.

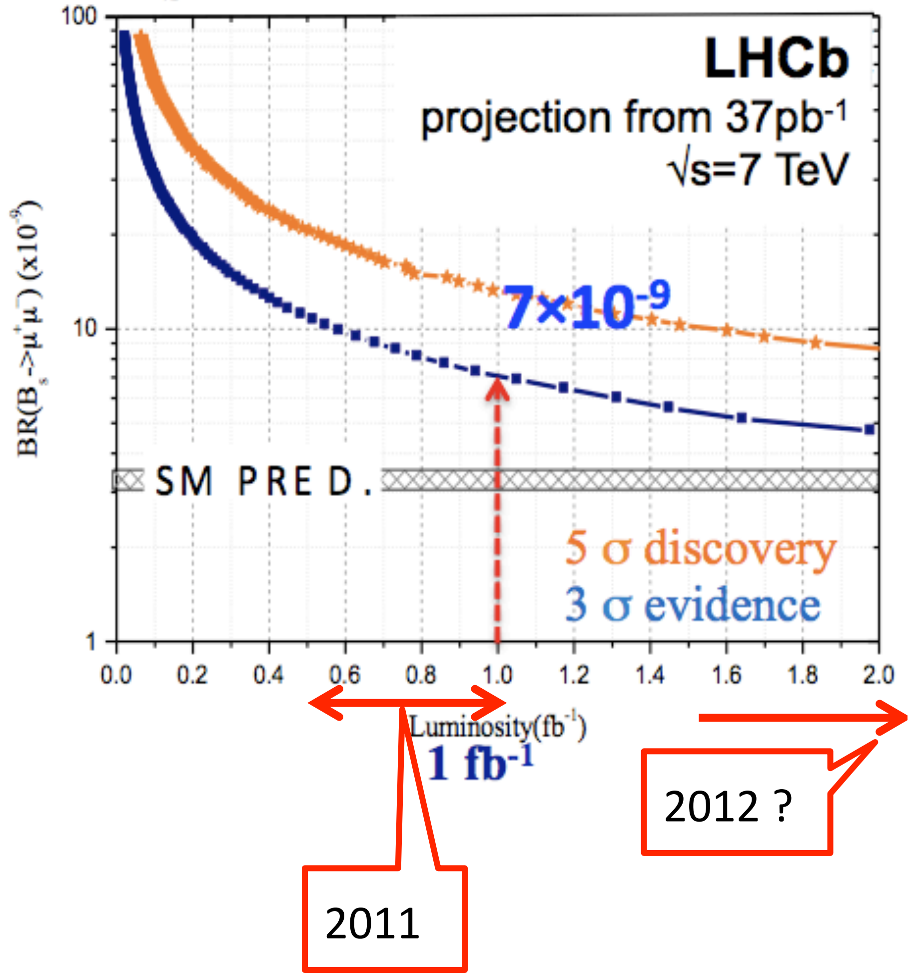
Br(Bd→μμ) < 0.42(0.52) x 10^{-8} @ 90(95)%C.L.

Future prospects

$B_S \rightarrow \mu^+\mu^-$ exclusion @ 95% CL



$B_S \rightarrow \mu^+\mu^-$ observation



Back up

VELO

21 stations

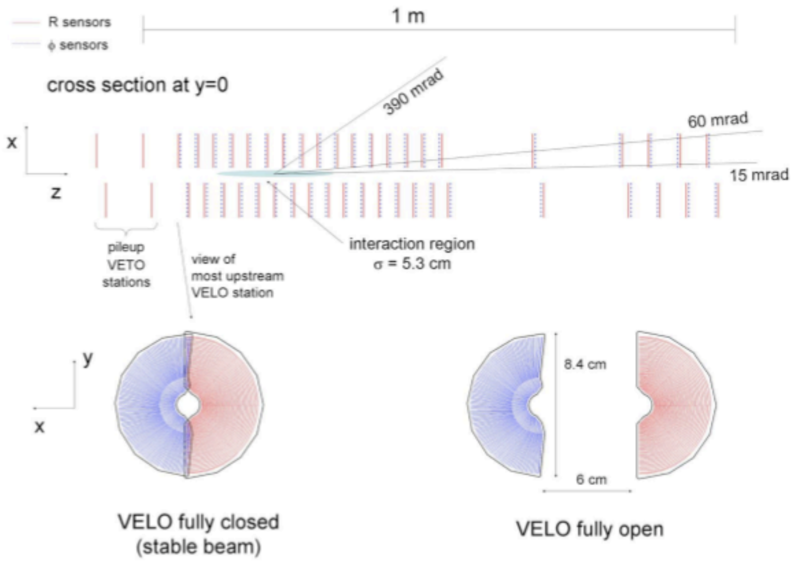
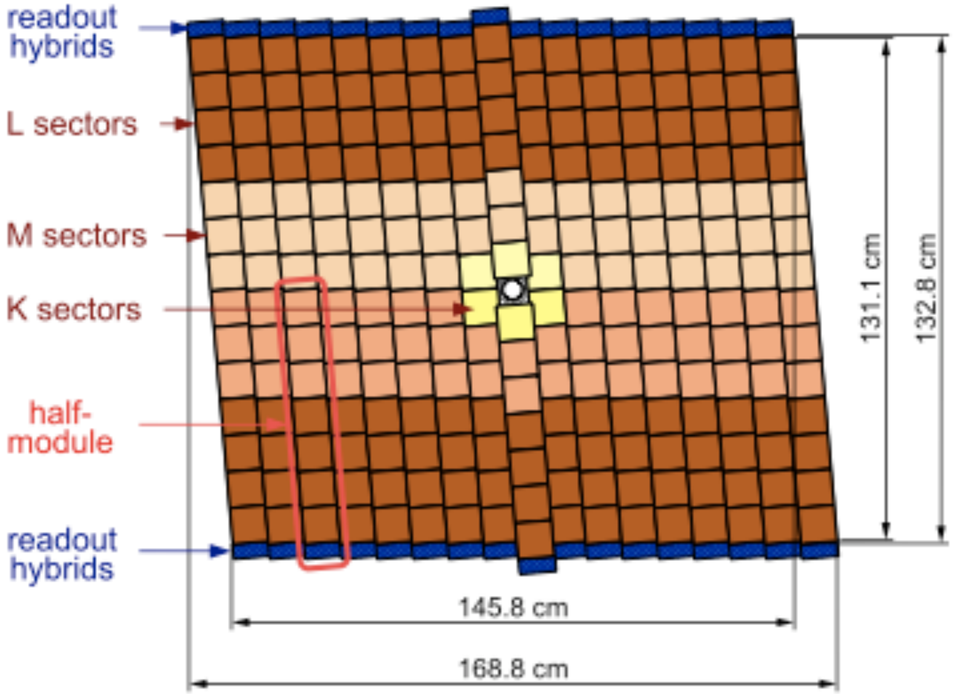


Table 5.1: Principal characteristics of VELO sensors.

	R sensor	ϕ-sensor
number of sensors	42 + 4 (VETO)	42
readout channels per sensor	2048	2048
sensor thickness	300 μm	300 μm
smallest pitch	40 μm	38 μm
largest pitch	102 μm	97 μm
length of shortest strip	3.8 mm	5.9 mm
length of longest strip	33.8 mm	24.9 mm
inner radius of active area	8.2 mm	8.2 mm
outer radius of active area	42 mm	42 mm
angular coverage	182 deg	$\approx$ 182 deg
stereo angle	-	10–20 deg
double metal layer	yes	yes
average occupancy	1.1%	1.1/0.7% inner/outer

the *pile-up veto system* and are described in section 7.1. The VELO sensors are placed at a radial distance from the beam which is smaller than the aperture required by the LHC during injection and must therefore be retractable. The detectors are mounted in a vessel that maintains vacuum around

TT


readout hybrids
L sectors
M sectors
K sectors
half-module
readout hybrids
145.8 cm
168.8 cm
131.1 cm
132.8 cm

bibliography

The LHCb Detector at the LHC
The LHCb Collaboration

Search for the very rare decays Bs/d → μ+μ- at LHCb
Justine Serrano

Search for $B^0_{s(d)} \rightarrow \mu^+ \mu^-$ with CMS
Urs Langenegger

Updated Search for Bs/Bd → μ+μ– at CDF
Thomas Kuhr

http://lpc.web.cern.ch/lpc/lumiplots.htm

(Many materials from this slide)
Search for the rare decays Bs→ μ+μ- and B0→ μ+μ– with the LHCb Experiment
Johannes Albrecht

Panning for the Golden Decay $B^0_s \rightarrow J/\psi\phi$ at LHCb
Jan Amoraal