Search for the rare decays $B^0_d \rightarrow \mu^+\mu^-$ and $B_s \rightarrow \mu^+\mu^-$ with LHCb

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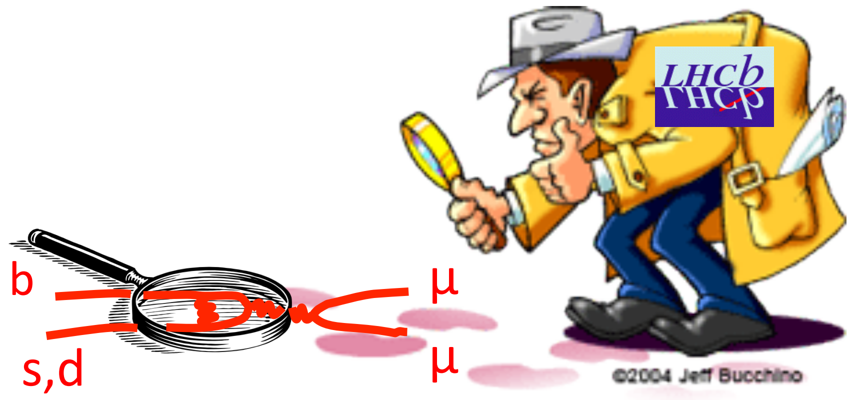
on behalf of the LHCb Collaboration

Les XXV Rencontres de Physique de la Vallee d'Aoste

Outline

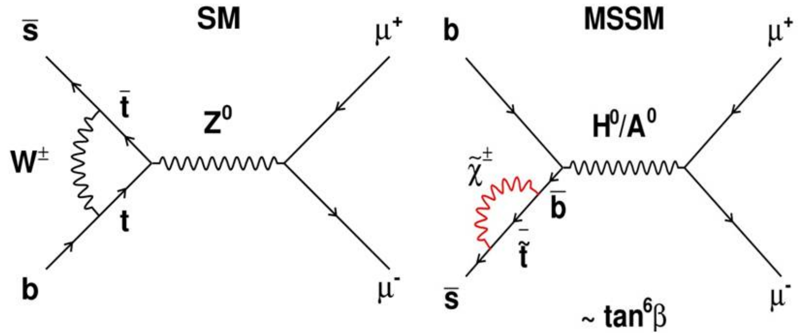
- Brief theoretical introduction
- Experimental status
- LHCb skills for the search for rare decays $B_{s,d} \rightarrow \mu\mu$
- Analysis strategy
- Results
- Outlook



The LHCb hunt for non-SM Higgs(es)

$B_{(d,s)} \rightarrow \mu\mu$ 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: **FCNC process** and **helicity suppressed**:

→ **very small in the Standard Model but very well predicted:**

$B_s \rightarrow \mu^+\mu^- = (3.2 \pm 0.2) \times 10^{-9}$ | $B_d \rightarrow \mu^+\mu^- = (1.0 \pm 0.1) \times 10^{-10}$

Buras et al., arXiv:1007.5291

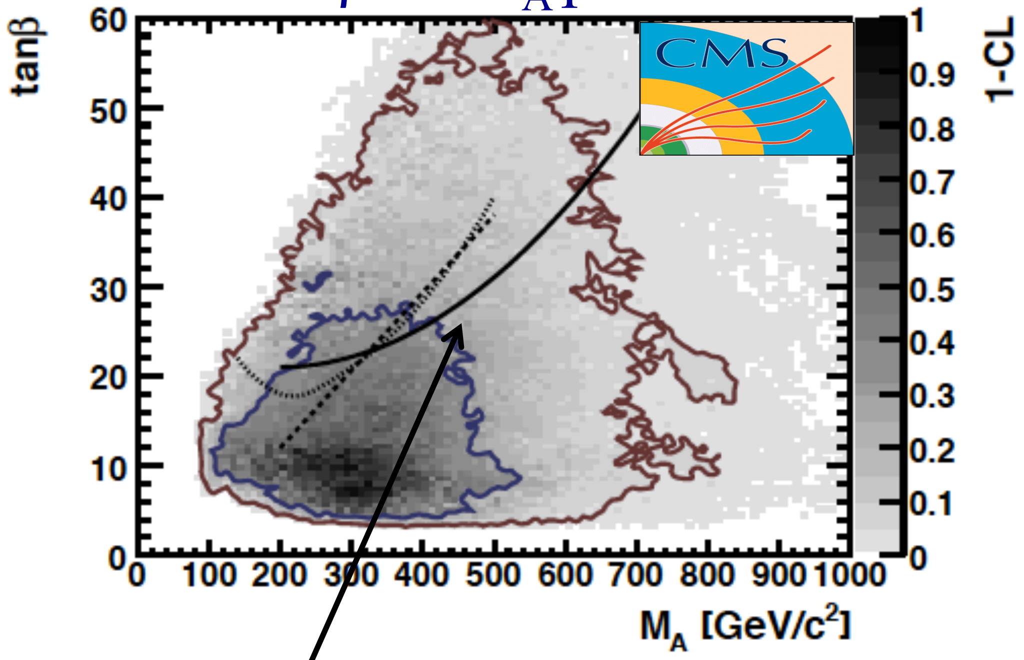
→ **sensitive to New Physics** contributions in the **scalar/pseudo-scalar sector:**

$$(c_{S,P}^{MSSM})^2 \propto \left(\frac{m_b m_\mu \tan^3\beta}{M_A^2}\right)^2$$

MSSM, large tanβ approximation

The LHCb hunt for non-SM Higgs(es)

tanβ vs M_A plane

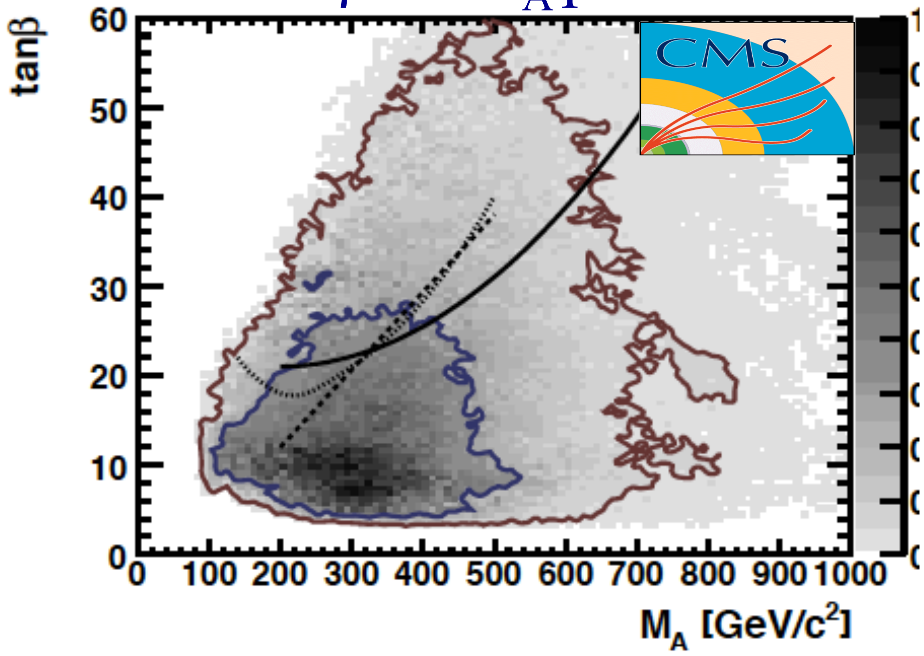


Best fit contours in tanβ vs M_A plane in the NUHM1 model *[O. Buchmuller et al, arxiv:0907.5568]*

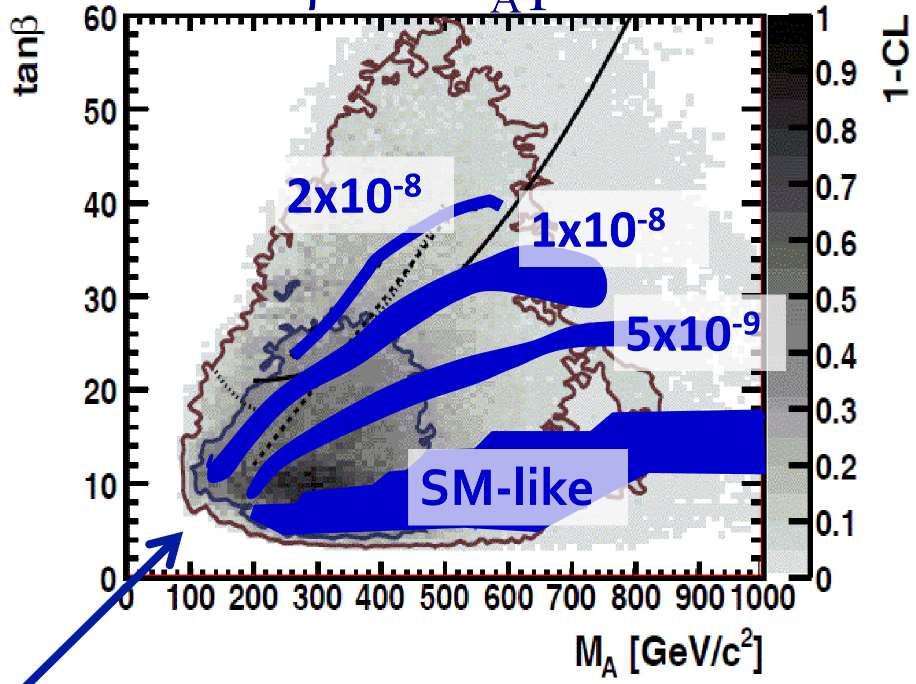
5σ discovery contours for observing the **heavy MSSM Higgs bosons H, A** in the three decay channels **H,A→$\tau^+\tau^-$ → jets (solid line), jet+μ (dashed line)**, **Jet+e (dotted line)** **assuming 30-60 fb^{-1} collected by CMS.**

The LHCb hunt for non-SM Higgses

tanβ vs M_A plane



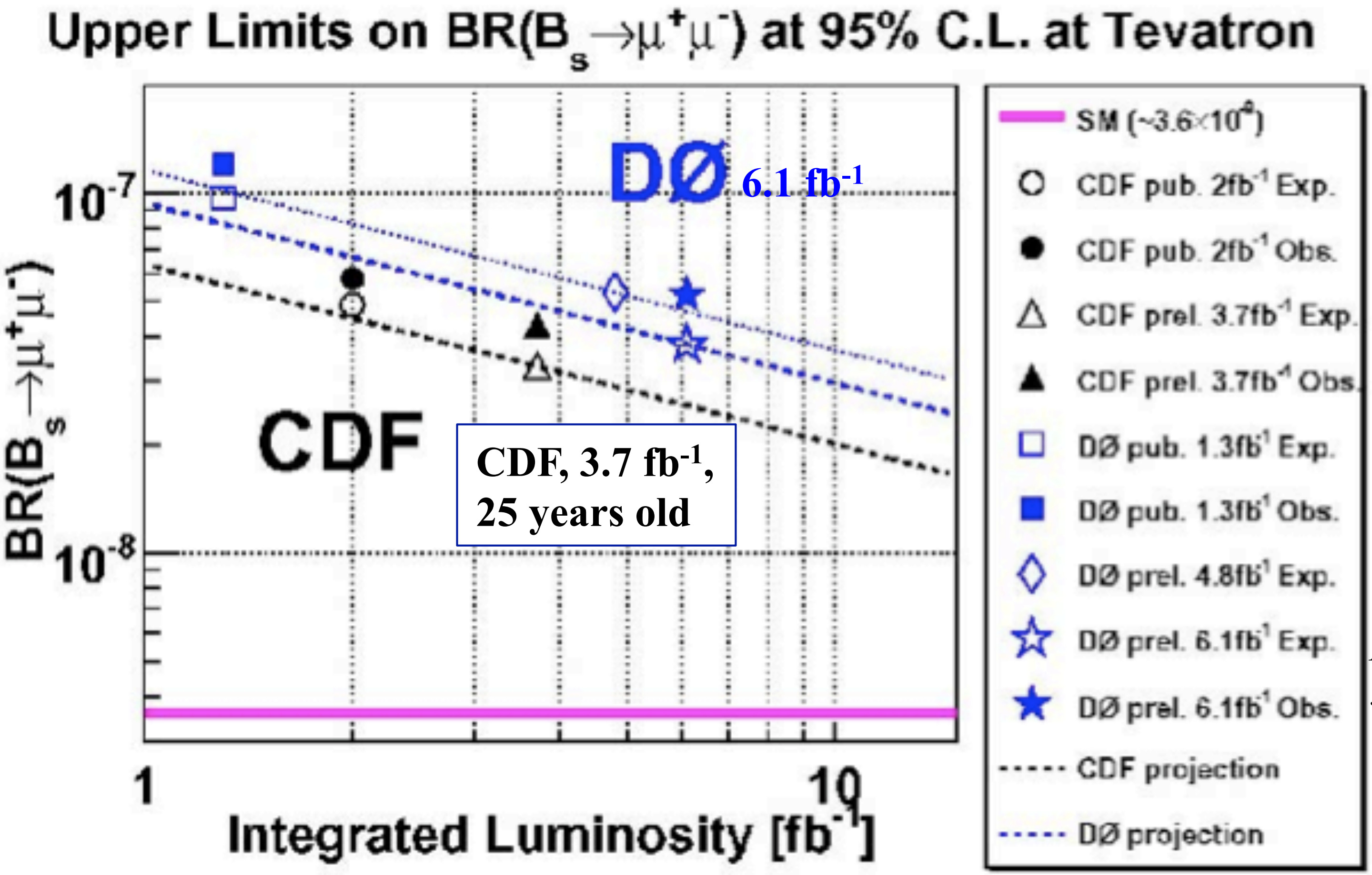
tanβ vs M_A plane



Regions compatible with
BR($B_s \rightarrow \mu\mu$) = 2×10^{-8}, 1×10^{-8}, 5×10^{-9} and SM.

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

Current experimental results

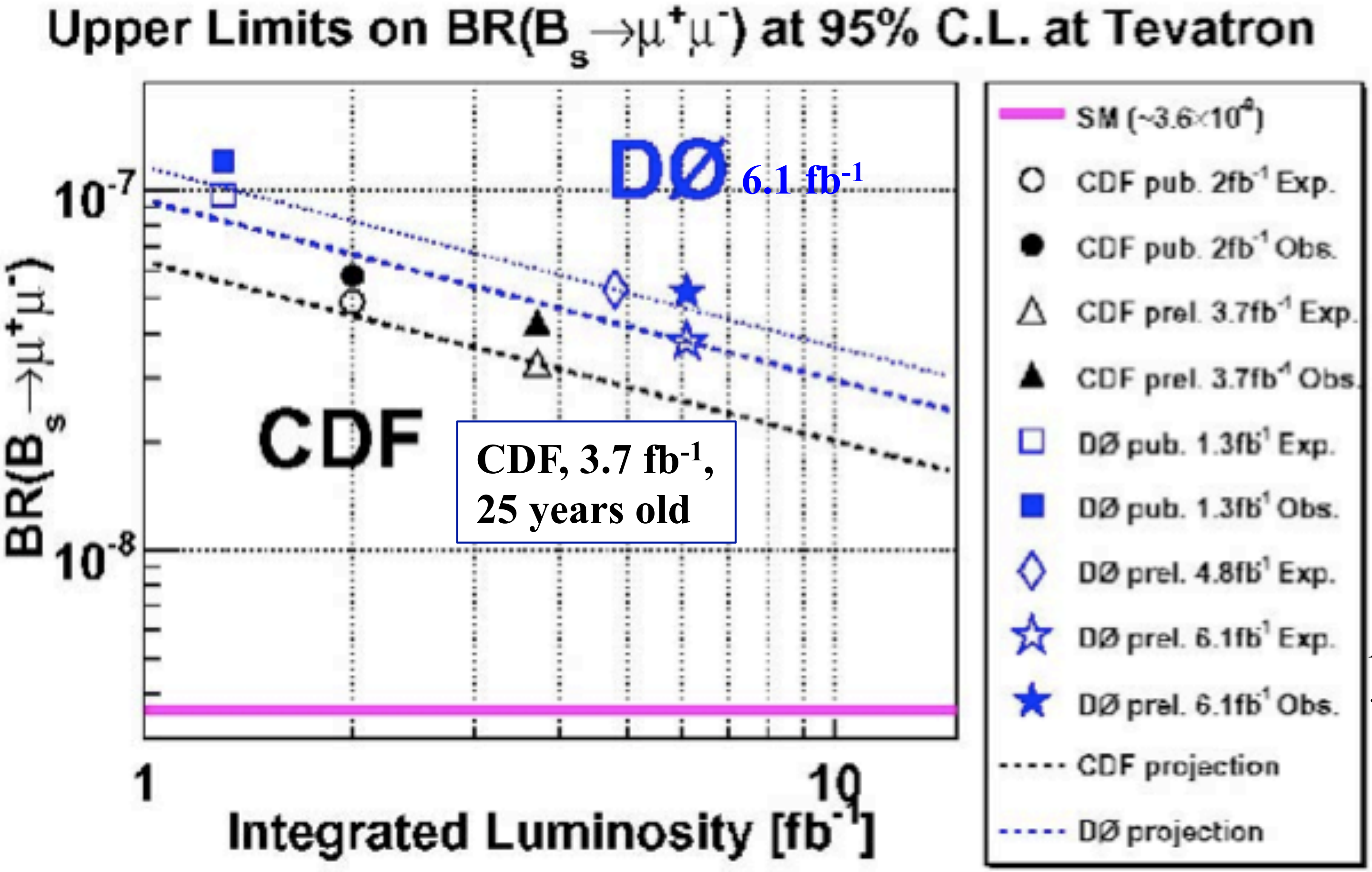


PLB 693, 539 (2010)

- Limits from Tevatron @ 95% CL:
  - CDF (~3.7 fb^{-1}): B_S (B_d) → μμ < **43 (7.6) ×10^{-9}**
  - D0 (~6.1 fb^{-1}): B_S→μμ < **51×10^{-9}**

Current experimental results

LHCb,
10 months old
37 pb^{-1}
(33 pb^{-1}
collected in
15 days!)



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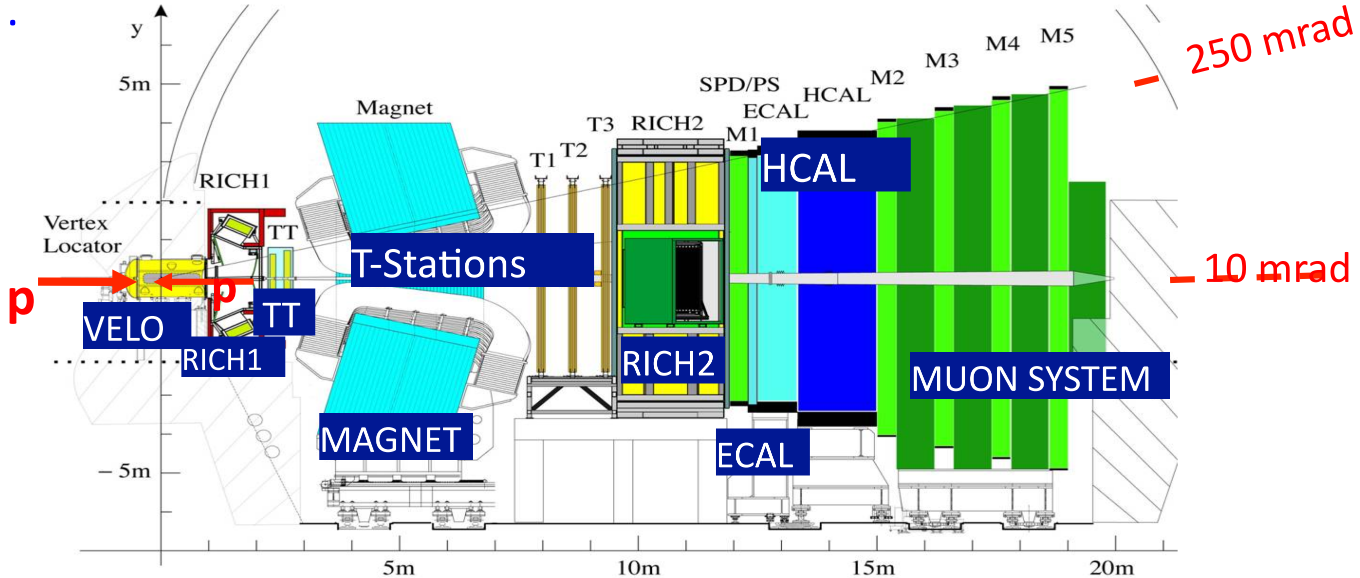
$B_{s,d} \rightarrow \mu\mu$ @ LHCb

LHCb skills for the search of the $B_{s,d} \rightarrow \mu\mu$:

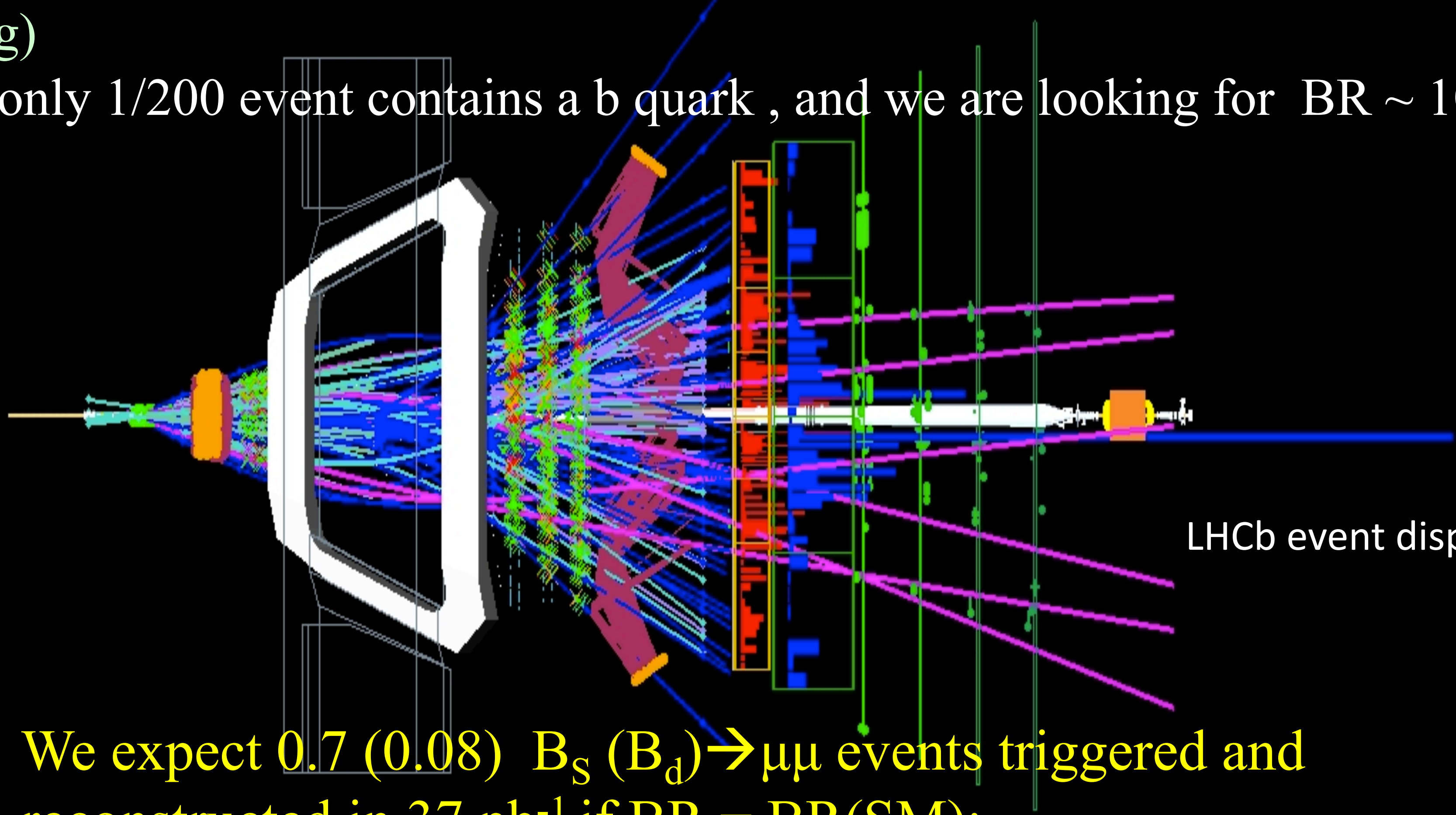
- ❒ Huge cross section: **$\sigma(pp \rightarrow bbX)$ @ 7 TeV ~ 300 μb**
- ❒ Large acceptance (bb are produced forward/backward):
  - LHCb acceptance **$1.9<\eta<4.9$** (CDF: $|\eta|<1$; D0: $|\eta|<2$)
  - **→ ε(acceptance) for $B_{sd} \rightarrow \mu\mu$ ~ 10%**
- ❒ Large boost: **→ average flight distance of B mesons ~ 1 cm**

…. A huge amount of very displaced b's…….



…. But in a harsh environment!

- σ(pp, inelastic) @ $\sqrt{s}$=7 TeV ~ 60 mb
    - 80 tracks per event in 'high'-pileup conditions (~2.5 pp interactions Xing)
    - only 1/200 event contains a b quark , and we are looking for BR ~ 10^{-9}



LHCb event display

We expect 0.7 (0.08) B_S (B_d)→μμ events triggered and reconstructed in 37 pb^{-1} if BR = BR(SM):

→ Our problem is clearly the background..

Key ingredients for $B_{s,d} \rightarrow \mu\mu$

1) Efficient trigger:

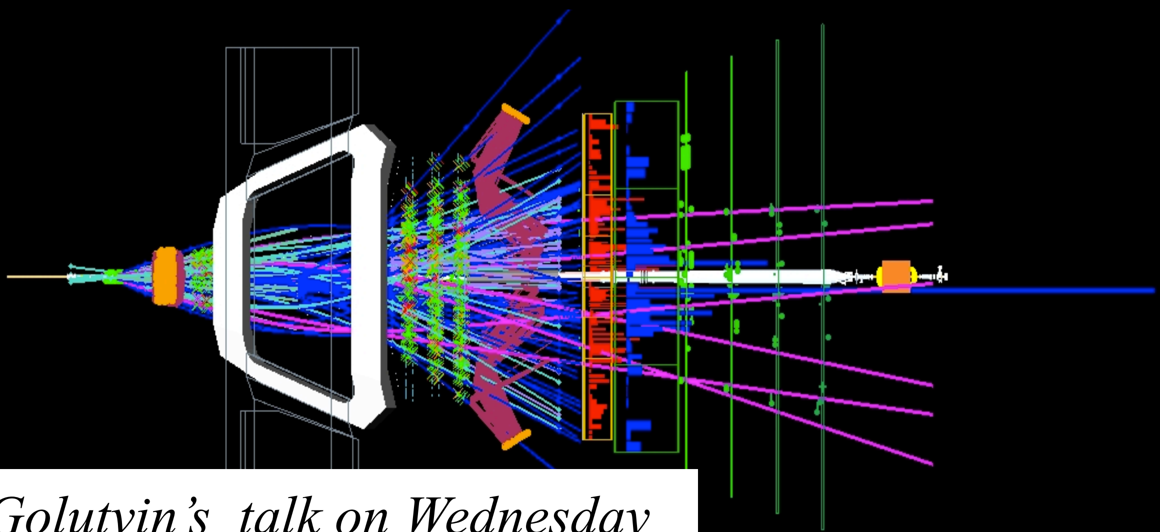
- to identify leptonic final states

2) Background reduction:

- Very good mass resolution : dp/p~ 0.35% → 0.55% for p=(5-100) GeV/c
- Particle identification: $\varepsilon(\mu \rightarrow \mu)$ ~ 98% for $\varepsilon(h \rightarrow \mu)$< 1% for p>10 GeV/c

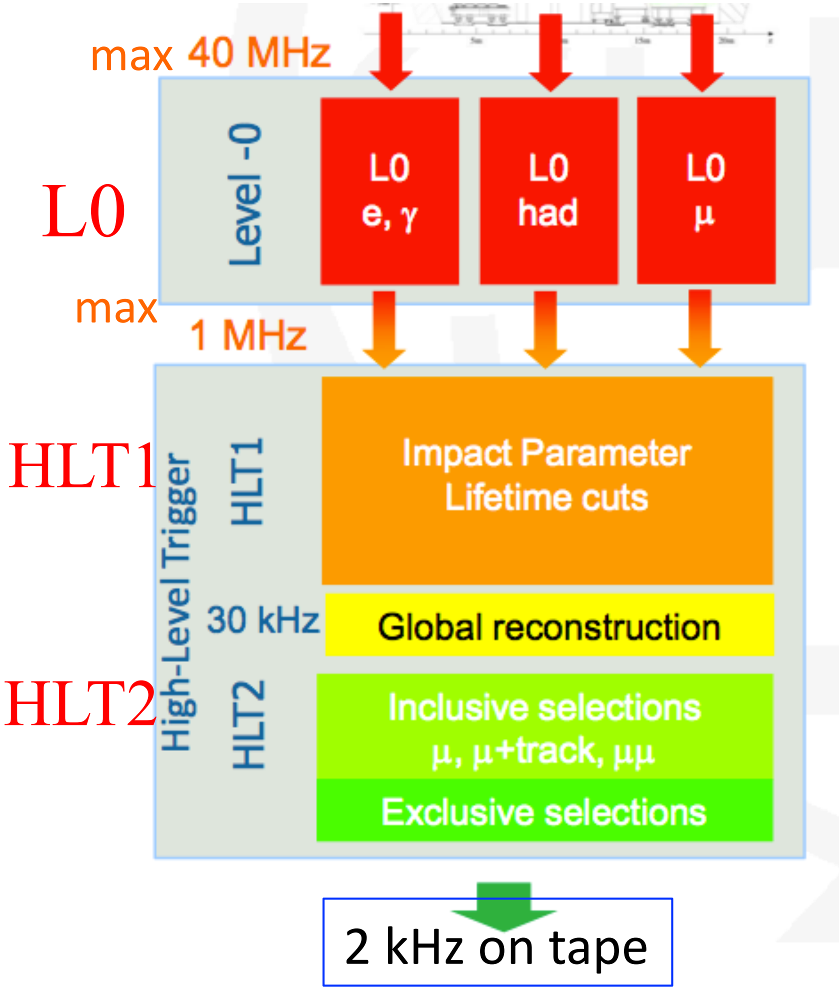
3) Excellent vertex & IP resolution:

- to separate signals from background : σ(IP)~ 25 μm @ p_T=2 GeV/c



See Andrey Golutvin's talk on Wednesday

Trigger for $B_{s,d} \rightarrow \mu\mu$



	Muon Lines
L0	Single- μ: **p_T> 1.4 GeV/c** μμ: **p_{T1}>0.48 GeV/c** **p_{T2}>0.56 GeV/c**
HLT1	single-μ: p_T>0.8 GeV/c IP>0.11 mm IPS> 5
HLT2	Several dimuon lines with $M_{\mu\mu}$ cuts and/or displaced vertex

+ Global Event Cuts for events with high multiplicity

- Half of the bandwidth (~1 kHz) given to the muon lines
- p_T cuts on muon lines kept very low → ε(trigger $B_{sd} \rightarrow \mu\mu$) ~ 90%
- Trigger rather stable during the whole period (despite L increased by ~10^5)

Analysis strategy

- Soft selection:

  - reduces the dataset to a manageable level

- Discrimination between S and B via Multi Variate Discriminant variable (GL) and Invariant Mass (IM)

  - events in the sensitive region are classified in bins of a 2D plane Invariant Mass and the GL variables

- Normalization:

  Convert the signal PDFs into a number of expected signal events by normalizing to channels of known BR

- Extraction of the limit:

  - assign to each observed event a probability to be S+B or B-only as a function of the BR($B_{s,d} \rightarrow \mu\mu$) value; exclude (observe) the assumed BR value at a given confidence level using the **CLs binned method.**

Soft selection

Soft selection:

(pairs of opposite charged muons with high quality tracks, making a common vertex very displaced with respect to the PV and $M_{\mu\mu}$ in the range [4769-5969] MeV/c^2)

1) Keeps high efficiency for signals:

After selection **$B_s(B_d) \rightarrow \mu\mu$ events expected (if BR=BR(SM)): 0.3 (0.04)**

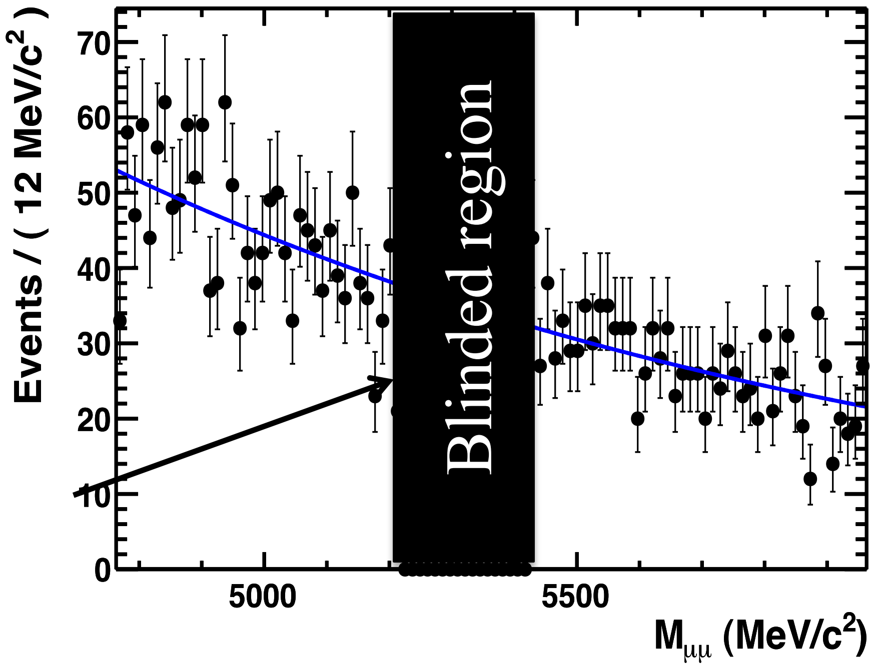
3) Rejects most of the background

→ ~ 3000 background events in the large mass range [4769-5969] MeV/c^2

~ 300 background events in the signal windows

$M(B_{s,d}) \pm$ 60 MeV

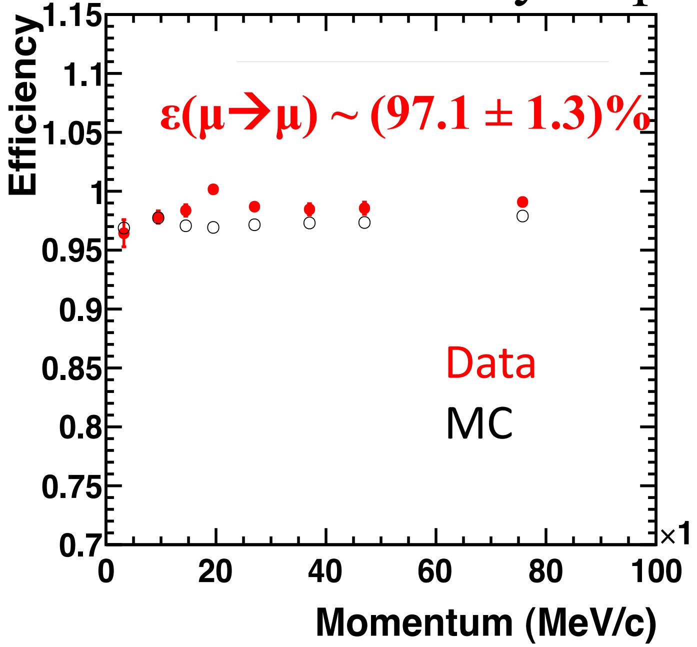
Signal regions blinded up to the analysis end



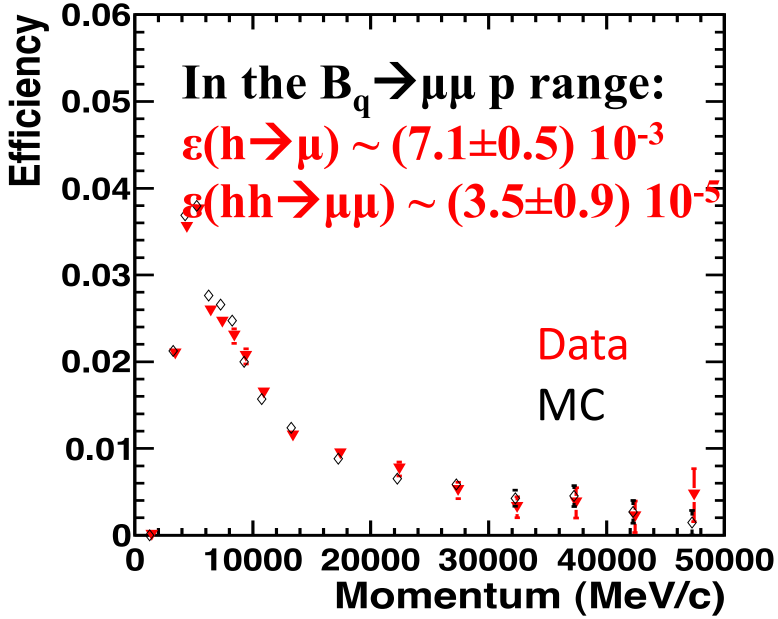
MuonID performance & background composition

Performance measured with pure samples of $J/\psi \rightarrow \mu\mu$, $K_s \rightarrow \pi\pi$, $\varphi \rightarrow KK$, $\Lambda \rightarrow p\,\pi$

MuonID efficiency vs p



π →μ misidentification rate vs p



We are dominated by the $b\bar{b} \rightarrow \mu\mu X$ component

(double semi-leptonic decays and cascade processes)

fake+μ ~ 10% and double fake ~0.3%

Peaking background (B→hh') fully negligible

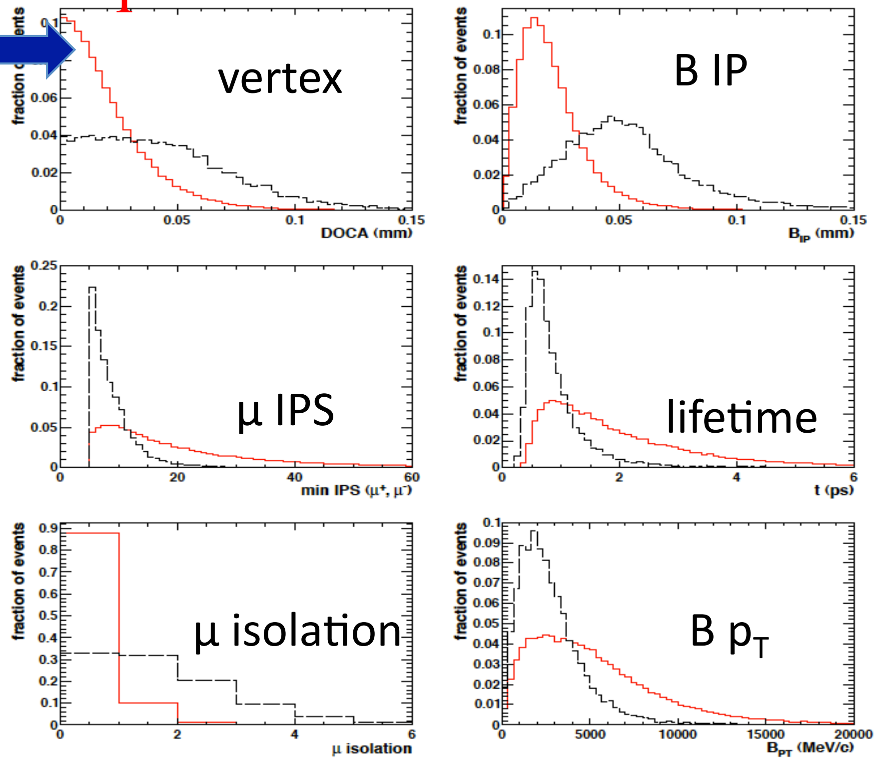
(< 0.1 events in signal regions)

MVA: Geometrical Likelihood (GL)

Our main background is combinatorial background from two real muons:

→ reduce it by using variables related to the "geometry" of the event: (vertex, pointing, μ IPS, lifetime, mu-isolation) + p_T of the B

Input Variables to the GL



- MC $B_{d,s} \rightarrow \mu\mu$

- MC $bb \rightarrow \mu\mu X$

Geometrical Likelihood (GL)

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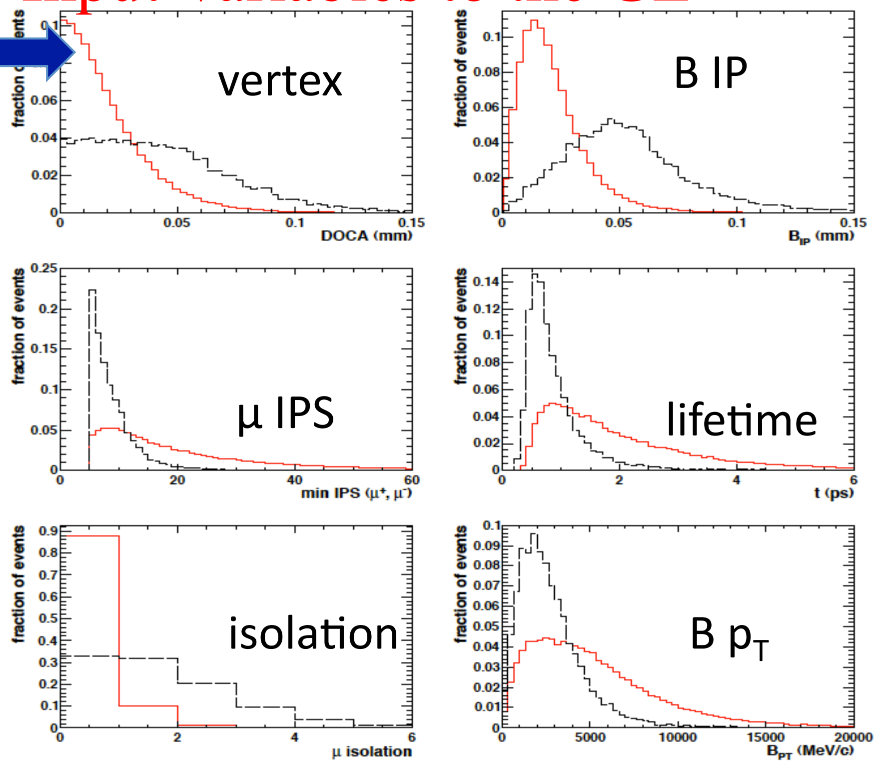
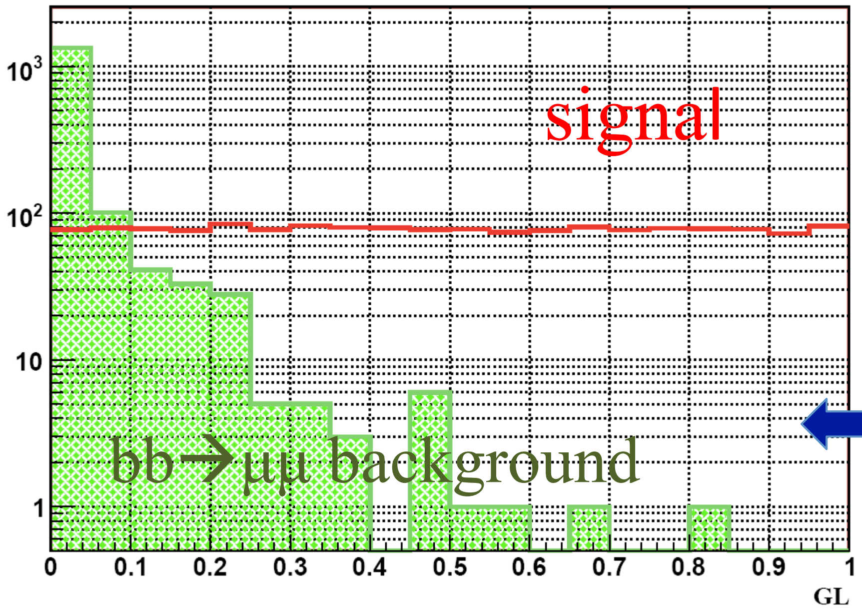
→ reduce it by using variables related to the "geometry" of the event: (vertex, pointing, μ IPS, lifetime, mu-isolation) + p_T of the B

Input Variables to the GL



Geometrical Likelihood (MC)



Variables are decorrelated and a Multi Variate Variable is built:

→ flat for signal

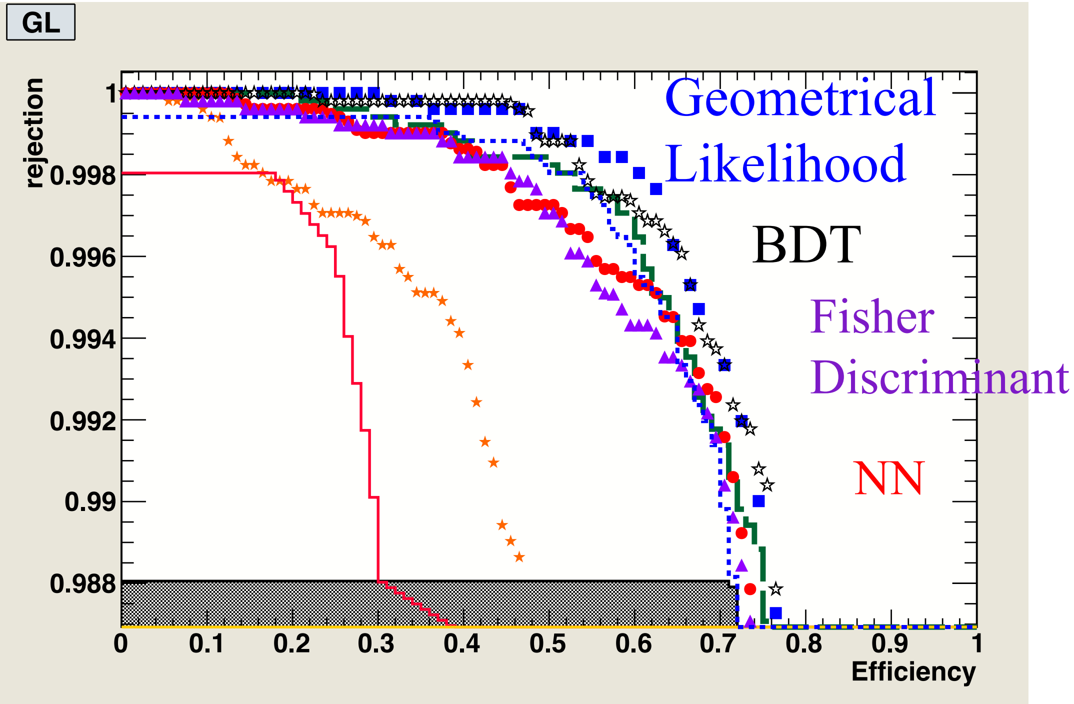
→ peaked at zero for background

Geometrical Likelihood (GL)

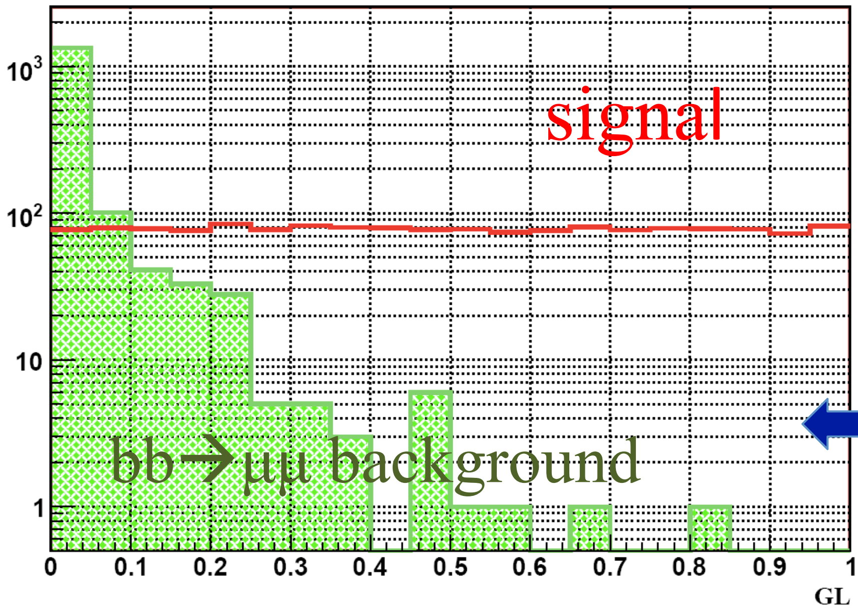
Optimization & training with MC

Calibration of the shape with data (see later)

GL: Rejection vs Efficiency profile



Geometrical Likelihood (MC)



Variables are decorrelated and a Multi Variate Variable is built:

→ flat for signal

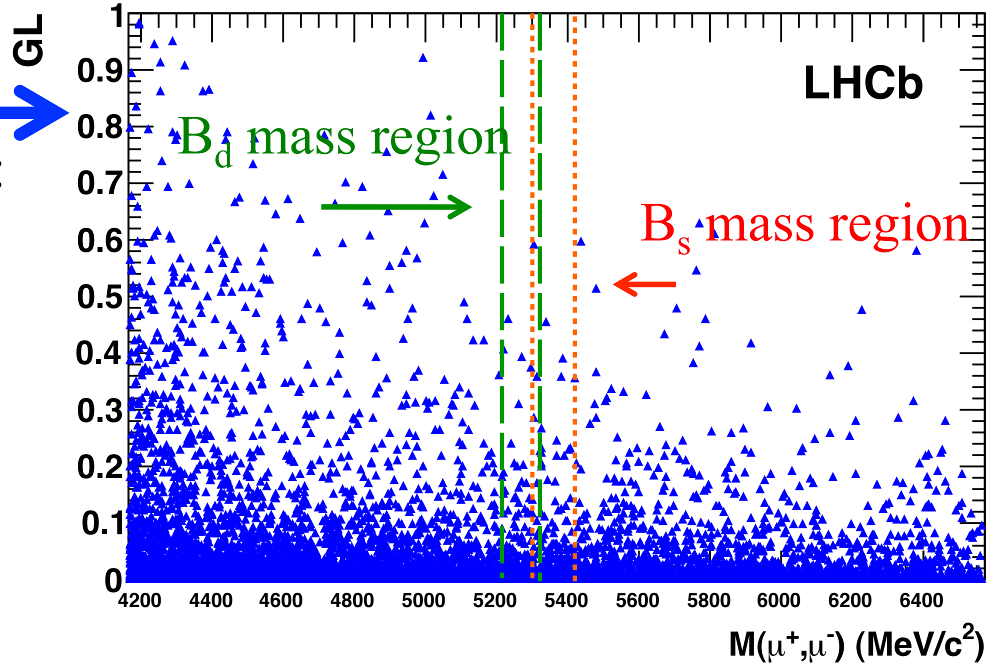
→ peaked at zero for background

Measure the BR/Upper limit: the CL_s binned method

Geometrical Likelihood vs Mass

1) Events are classified in 2D plane GL vs mass.
2) Signal regions are divided in bins: and for each bin the compatibility is computed with the:

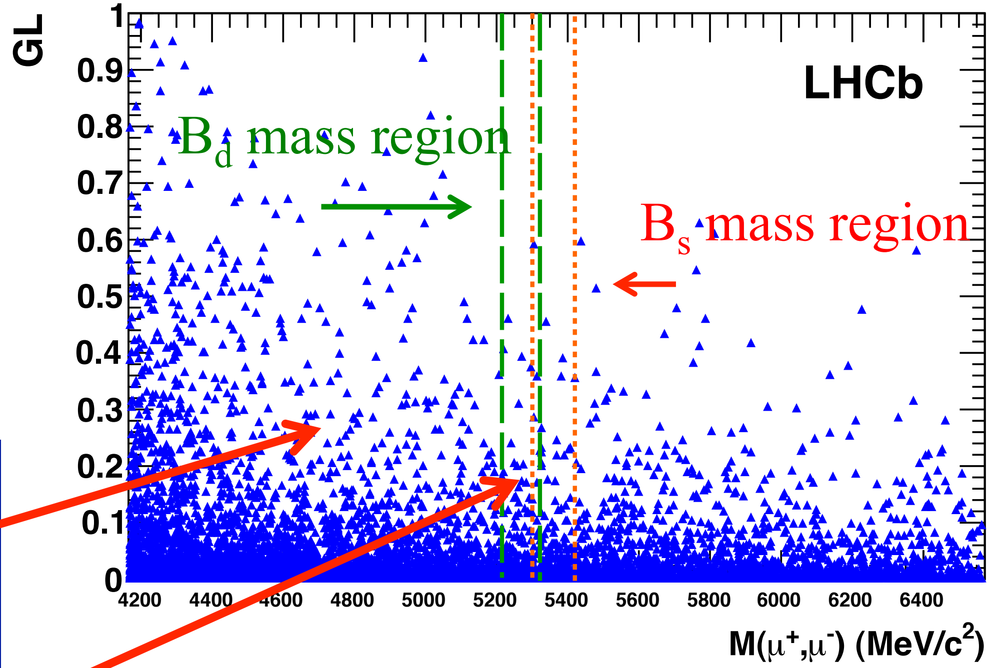
- S+B hypothesis [CL_{S+B}]
- B only hypothesis [CL_B]



- $CL_S = CL_{S+B}/CL_B$ = compatibility with the signal hypothesis
→Used to compute the exclusion
- CL_B = (in)compatibility with the background hypothesis
→ Used for observation

Measure the BR/Upper limit: the CL_s binned method

Geometrical Likelihood vs Mass



→Expected background events:

→ Use mass sidebands

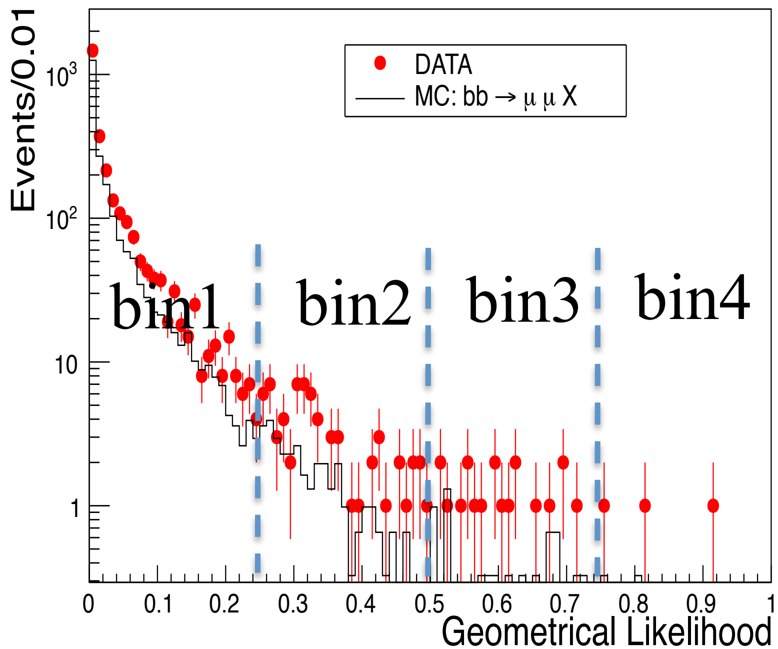
→ Expected signal events:

→ Need PDFs (Mass and GL) and an absolute normalization factor (for a given BR)

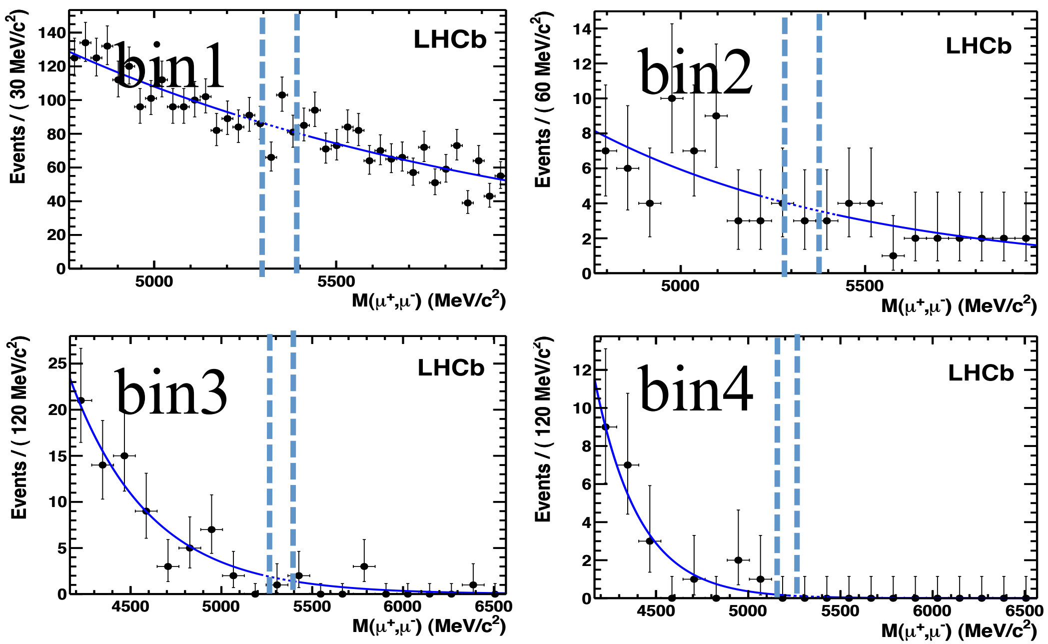
Expected background in signal regions

The expected background events in signal regions are extracted from a fit of the mass sidebands divided in GL bins

Background GL in mass sidebands



Invariant mass in GL bins



Sidebands for bin1-bin2: ± 600 MeV around the $B_{s,d}$ mass

Sidebands for bin3-bin4: ±1200 MeV around the $B_{s,d}$ mass

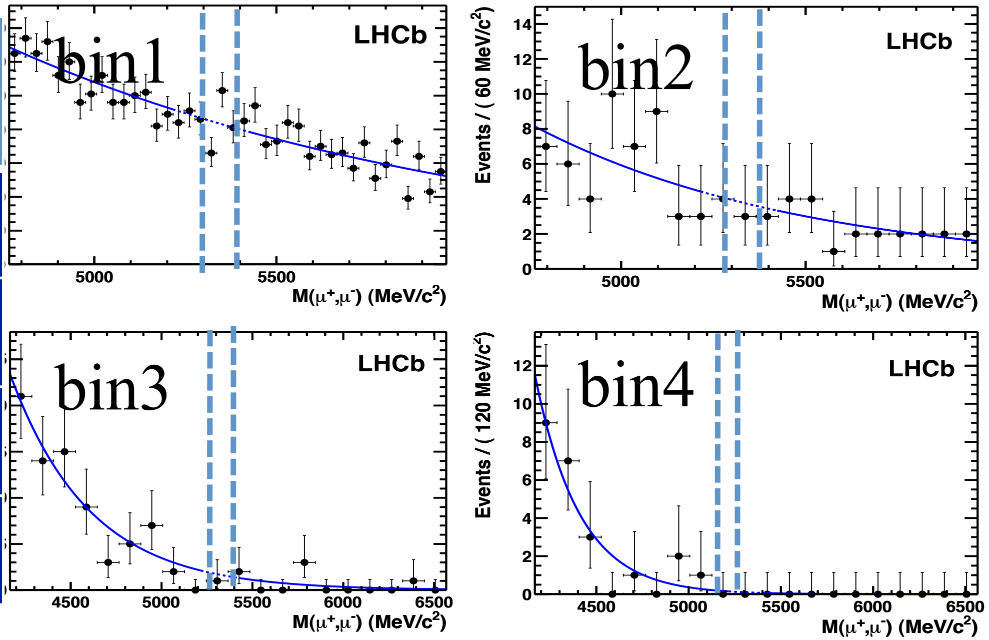
Expected background in signal regions

The expected background events in signal regions are extracted from a fit of the mass sidebands divided in GL bins

Expected (observed) background events in $B_{s,d}$ mass regions

GL bin	$B_s \rightarrow \mu\mu$	$B_d \rightarrow \mu\mu$
bin1	329.1±6.4 (335)	351.6±6.6 (333)
bin2	7.4 ± 1 (7)	$8.3^{+1.1}_{-1.0}$ (8)
bin3	$1.51^{+0.41}_{-0.35}$ (1)	$1.85^{+0.45}_{-0.39}$ (1)
bin4	$0.08^{+0.10}_{-0.05}$ (0)	$0.13^{+0.13}_{-0.07}$ (0)

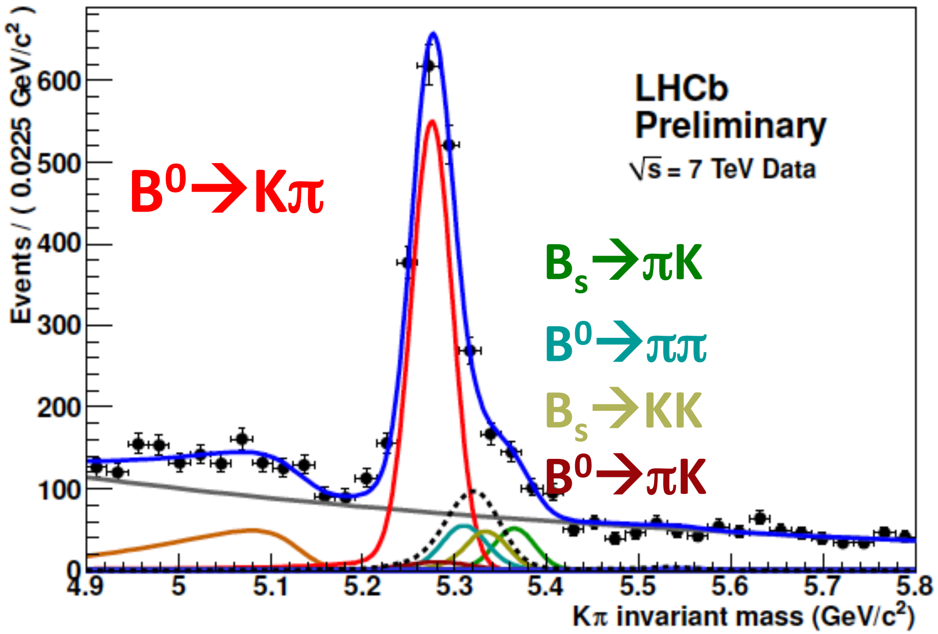
Invariant mass in GL bins

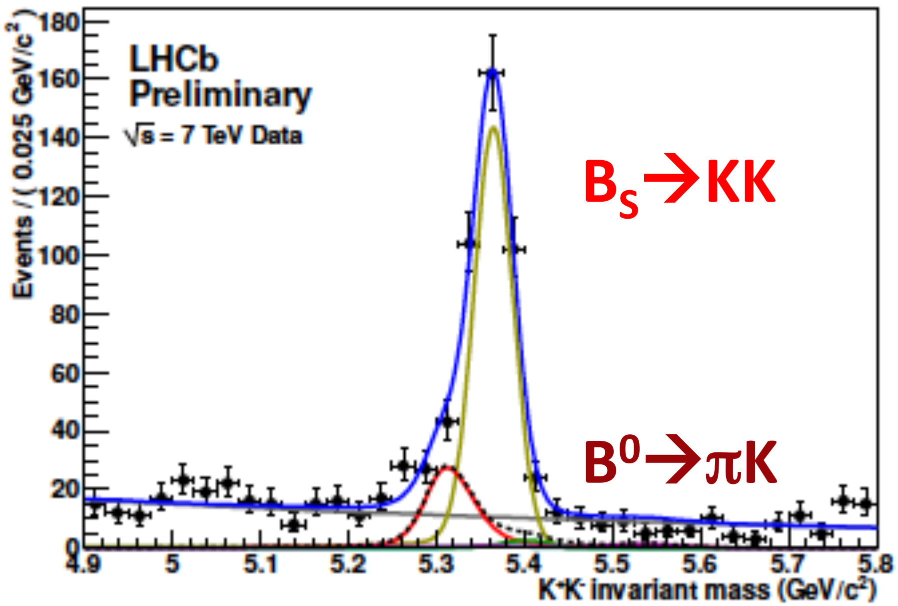


Signal Invariant Mass calibration

- The $B_{s,d}$ mass line shapes are described by Gaussian + Crystal Ball
  → parameters (μ,σ) calibrated with B→hh' and dimuon resonances

1) $M(B_d)$, $M(B_s)$ average values from $B_d \to K\pi$ and $B_s \to KK$ samples

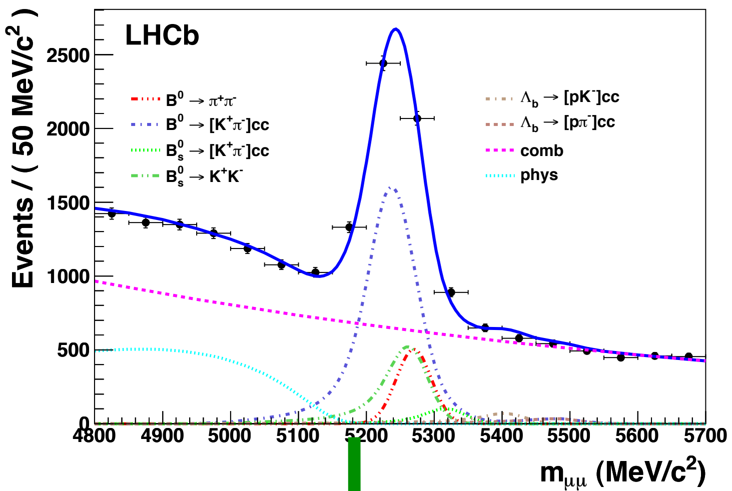




Signal Invariant Mass calibration

Mass resolutions $\sigma(M(B_{d,s}))$ from :

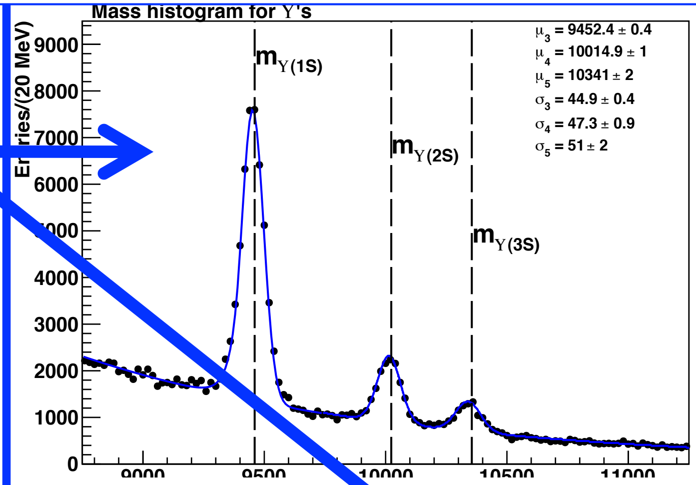
1) B→hh' inclusive sample:
2) Interpolation from dimuon resonances

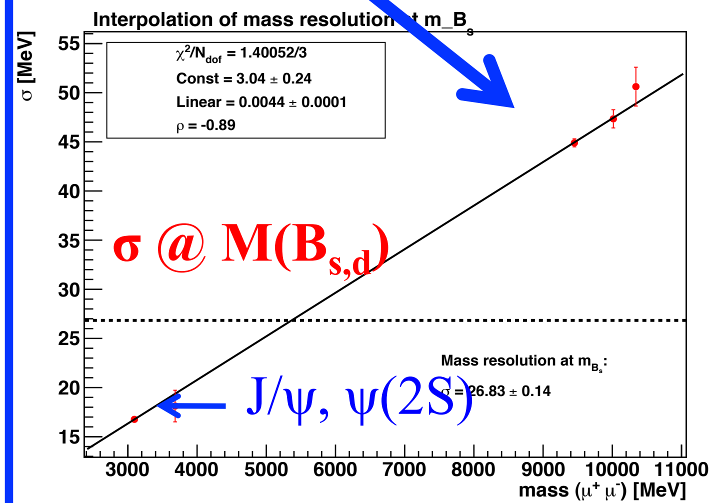


- similar kinematics/topology
- Selection identical to the signal one:

→Avoid to use the PID and use only events triggered by the other b to avoid bias in the phase space [eg resolution]

The ϒ family: ϒ(1S), ϒ(2S), ϒ(3S)

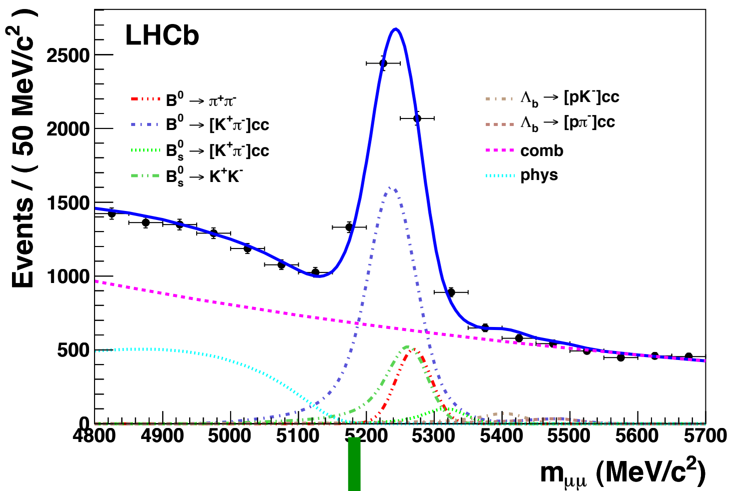




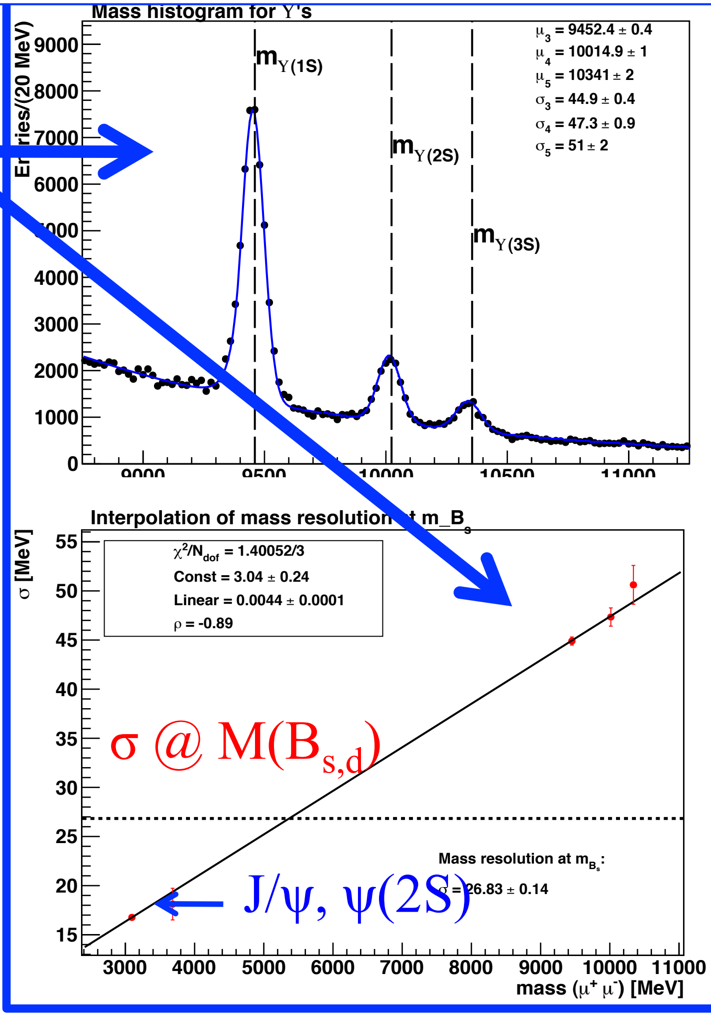
Signal Invariant Mass calibration

Mass resolutions $\sigma(M(B_{d,s}))$ from :

1) B→hh' inclusive sample:
2) Interpolation from dimuon resonances



The Υ family: Υ(1S), Υ(2S), Υ(3S)

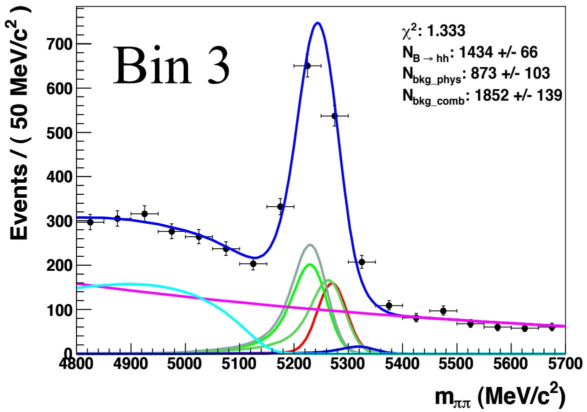


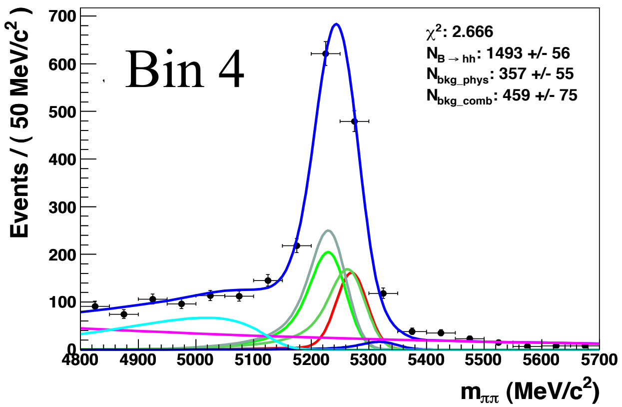
The two methods give compatible results:
$\sigma(M) = 26.7 \pm 0.9$ MeV/c^2

CDF (D0) : σ(M) ~ 24 (120) MeV/c²

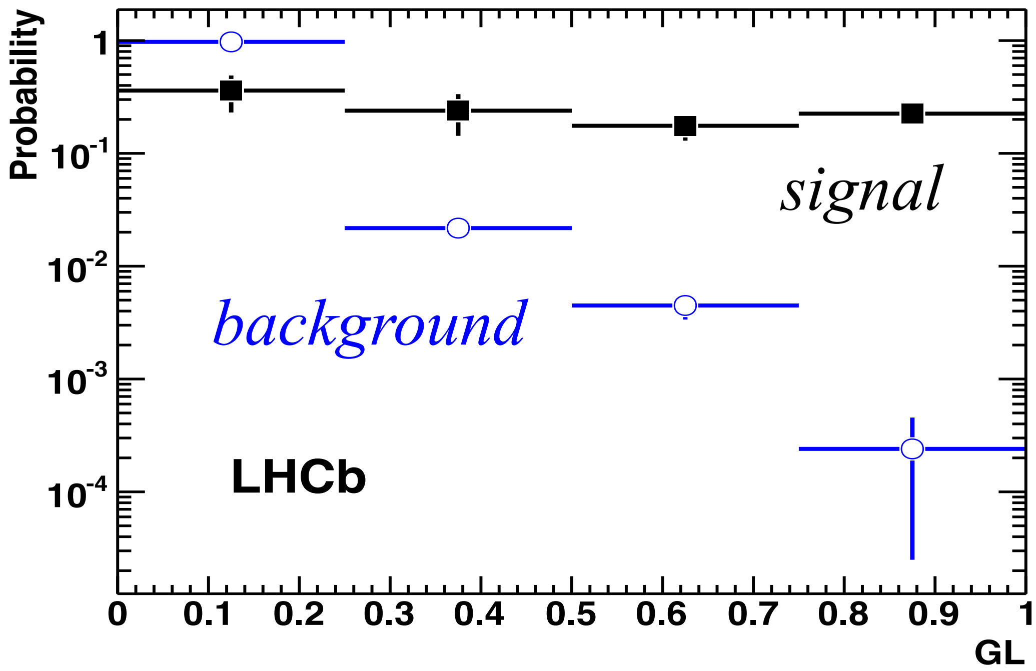
Geometrical Likelihood calibration

B→ hh' sample is also used to calibrate the GL shape with data





The GL signal shape is given by the fractional yield of B→hh' in each GL bin.



GL shape for signal extracted from B→ hh' is flat as expected.
Systematic error dominated by the fit model.

Analysis strategy

- Soft selection:

  - reduces the dataset to a manageable level

- Discrimination between S and B via Multi Variate Discriminant variable (GL) and Invariant Mass (IM)

  - events in the sensitive region are classified in bins of a 2D plane Invariant Mass and the GL variables

- Normalization:

  Convert the signal PDFs into a **number of expected signal events** by normalizing to channels of known BR:

  → selection as similar as possible with the signal to minimize systematic uncertainties.

- Extraction of the limit/measure the BR:

  - assign to each observed event a probability to be S+B or B-only as a function of the BR($B_{s,d} \rightarrow \mu\mu$) value; exclude (observe) the assumed BR value at a given confidence level

Normalization

- The signal PDFs can be translated into a number of expected signal events by normalizing to a channel with known BR

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

Three different channels used:

1) BR($B^+ \to J/\psi(\mu^+\mu^-) K^+$) = (5.98±0.22) 10^{-5} 3.7% uncertainty

→ Similar trigger and PID. Tracking efficiency (+1 track) dominates the systematic in the ratio of efficiencies. Needs f_d/f_s as input: 13% uncertainty

2) BR($B_s \to J/\psi(\mu^+\mu^-) \varphi(K^+K^-)$) = (3.35±0.9) 10^{-5} 26% uncertainty

Similar trigger and PID. Tracking efficiency (+2 tracks) dominates the systematic

3) BR($B^0 \to K^+\pi^-$) = (1.94±0.06) 10^{-5} 3.1% uncertainty

Same topology in the final state. Different trigger dominate the syst. Needs f_d/f_s

Normalization Factors: breakdown

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

	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon^{\mathrm{REC}}_{\mathrm{norm}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{norm}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{sig}}}$	$\frac{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{norm}}}{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{sig}}}$	N_{norm}	$\alpha_{B^0_s\to\mu^+\mu^-}$ $(\times 10^{-9})$	$\alpha_{B^0\to\mu^+\mu^-}$ $(\times 10^{-9})$
$B^+ \to J/\psi K^+$	5.98 ± 0.22	0.49 ± 0.02	0.96 ± 0.05	12366 ± 403	8.4 ± 1.3	2.27 ± 0.18
$B^0_s \to J/\psi\phi$	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

We use **f_d/f_s=3.71±0.47**, a recent combination of LEP+Tevatron data by HFAG, with 13% uncertainty, dominated by LEP measurements

http://www.slac.stanford.edu/xorg/hfag/osc/end_2009/#FRAC

The normalization with three different channels is equivalent to perform three different analyses with different systematic uncertainties

Normalization: results

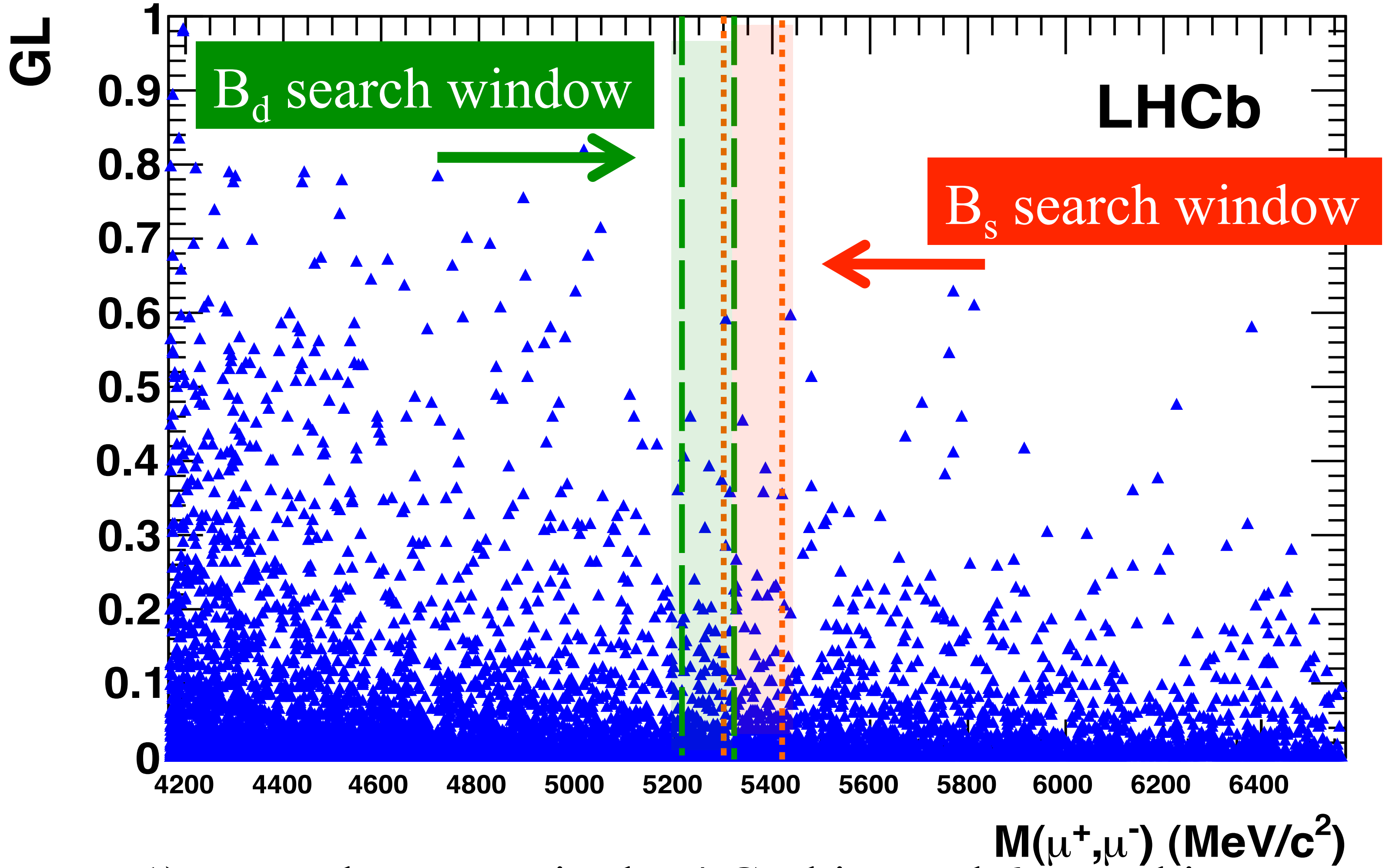
$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon^{\mathrm{REC}}_{\mathrm{cal}}\epsilon^{\mathrm{SEL|REC}}_{\mathrm{cal}}\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{cal}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\epsilon^{\mathrm{SEL|REC}}_{\mathrm{sig}}\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{sig}}}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

	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon^{\mathrm{REC}}_{\mathrm{norm}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{norm}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{sig}}}$	$\frac{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{norm}}}{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{sig}}}$	N_{norm}	$\alpha_{B^0_s\to\mu^+\mu^-}$ $(\times 10^{-9})$	$\alpha_{B^0\to\mu^+\mu^-}$ $(\times 10^{-9})$
$B^+ \to J/\psi K^+$	5.98 ± 0.22	0.49 ± 0.02	0.96 ± 0.05	12366 ± 403	8.4 ± 1.3	2.27 ± 0.18
$B^0_s \to J/\psi \phi$	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

The three normalization channels give compatible results:
→ Weighted average accounting for correlated systematic uncertainties

$$\alpha_{B^0_s\to\mu^+\mu^-} = (8.6 \pm 1.1) \times 10^{-9}\,;$$
$$\alpha_{B^0\to\mu^+\mu^-} = (2.24 \pm 0.16) \times 10^{-9}$$

Look inside the box….



1) count the events in the 4 GL bins and 6 mass bins,
2) compare observed events with the expected number of signal and background events

$B_s \rightarrow \mu\mu$ search window

Geometrical Likelihood Bins

Invariant Mass bins (MeV/c^2)

Invariant Mass bins (MeV/c^2)		[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.	$56.1^{+1.1}_{-1.1}$	$1.28^{+0.18}_{-0.17}$	$0.269^{+0.072}_{-0.062}$	$0.015^{+0.020}_{-0.009}$
	Exp. sig.	$0.0220^{+0.0084}_{-0.0079}$	$0.0146^{+0.0066}_{-0.0053}$	$0.0107^{+0.0036}_{-0.0026}$	$0.0138^{+0.0034}_{-0.0024}$
	Observed	55	2	0	0
[−20, 0]	Exp. bkg.	$55.3^{+1.1}_{-1.1}$	$1.24^{+0.17}_{-0.16}$	$0.257^{+0.069}_{-0.059}$	$0.014^{+0.018}_{-0.009}$
	Exp. sig.	$0.038^{+0.015}_{-0.014}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0059}_{-0.0042}$
	Observed	73	0	0	0
[0, 20]	Exp. bkg.	$54.4^{+1.1}_{-1.1}$	$1.21^{+0.17}_{-0.16}$	$0.246^{+0.066}_{-0.057}$	$0.013^{+0.017}_{-0.008}$
	Exp. sig.	$0.03761^{+0.015}_{-0.015}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0060}_{-0.0044}$
	Observed	60	0	0	0
[20, 40]	Exp. bkg.	$53.6^{+1.1}_{-1.0}$	$1.18^{+0.17}_{-0.15}$	$0.235^{+0.063}_{-0.054}$	$0.012^{+0.015}_{-0.007}$
	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.	$52.8^{+1.0}_{-1.0}$	$1.15^{+0.16}_{-0.15}$	$0.224^{+0.060}_{-0.052}$	$0.011^{+0.014}_{-0.007}$
	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

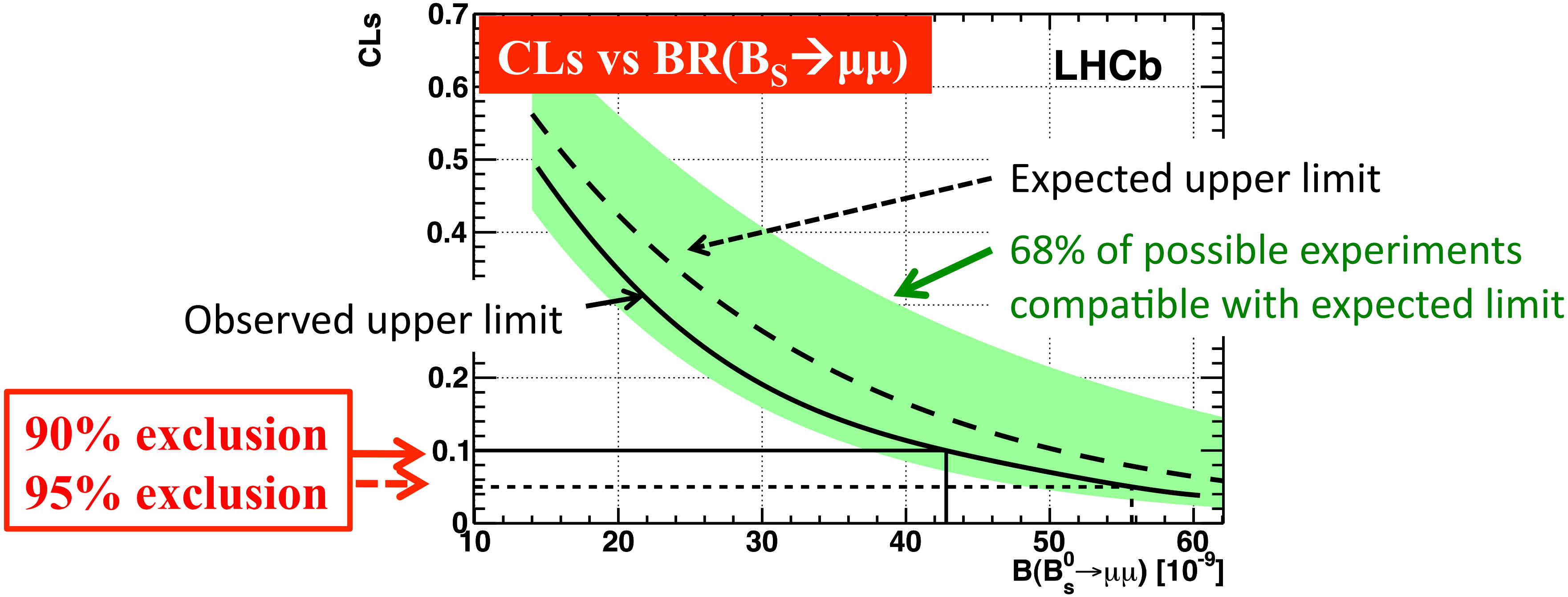
$B_d \rightarrow \mu\mu$ search window

Geometrical Likelihood Bins

Invariant Mass bins (MeV/c^2)

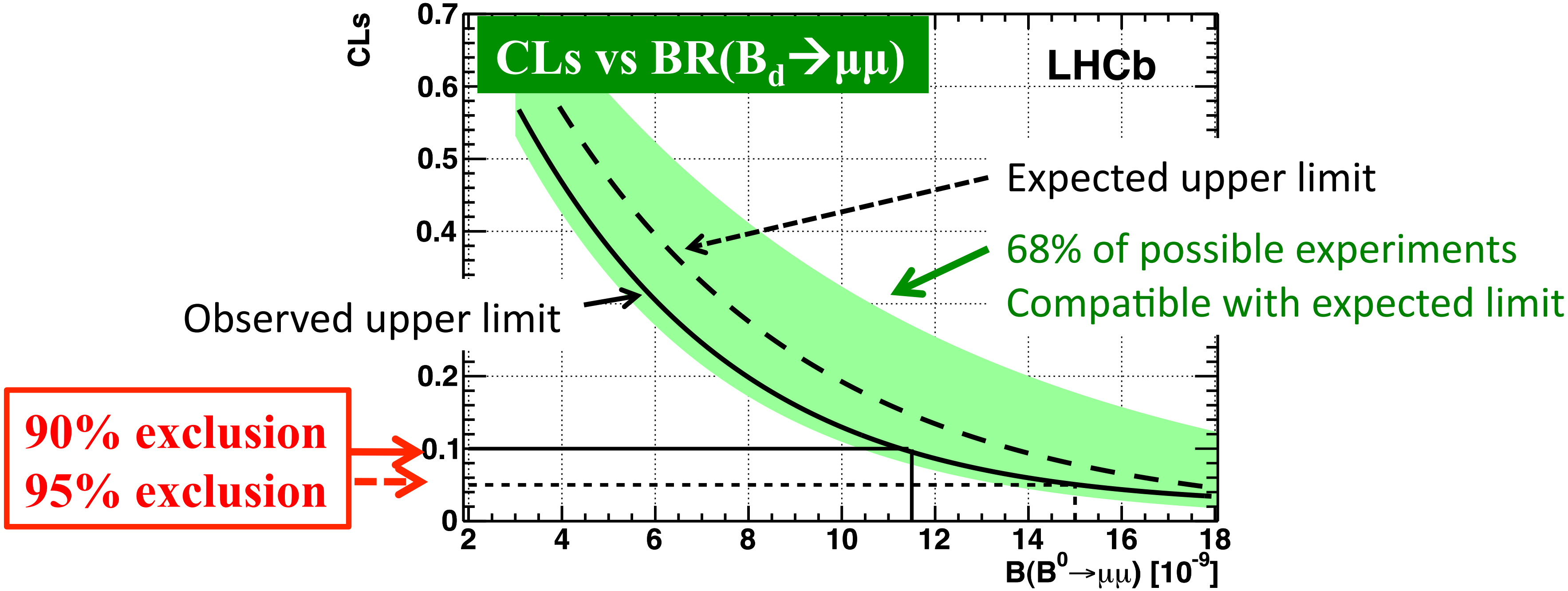
		[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	Exp. bkg.	$60.8^{+1.2}_{-1.1}$	$1.48^{+0.19}_{-0.18}$	$0.345^{+0.084}_{-0.073}$	$0.024^{+0.027}_{-0.014}$
	Exp. sig.	$0.0009^{+0.0004}_{-0.0003}$	$0.0006^{+0.0003}_{-0.0002}$	$0.0004^{+0.0002}_{-0.0001}$	$0.0006^{+0.0002}_{-0.0001}$
	Observed	59	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.	$0.0026^{+0.009}_{-0.009}$	$0.0017^{+0.0008}_{-0.0006}$	$0.0013^{+0.0004}_{-0.0003}$	$0.0016^{+0.0004}_{-0.0002}$
	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.	$0.0026^{+0.0009}_{-0.0009}$	$0.0017^{+0.0008}_{-0.0006}$	$0.0013^{+0.0004}_{-0.0003}$	$0.0016^{+0.0004}_{-0.0002}$
	Observed	42	2	1	0
[40, 60]	Exp. bkg.	$56.4^{+1.1}_{-1.1}$	$1.29^{+0.17}_{-0.16}$	$0.274^{+0.067}_{-0.058}$	$0.016^{+0.018}_{-0.009}$
	Exp. sig.	$0.0009^{+0.0003}_{-0.0003}$	$0.0006^{+0.0003}_{-0.0002}$	$0.0004^{+0.0001}_{-0.0001}$	$0.0006^{+0.0002}_{-0.0001}$
	Observed	49	2	0	0

Results: $B_s \rightarrow \mu\mu$



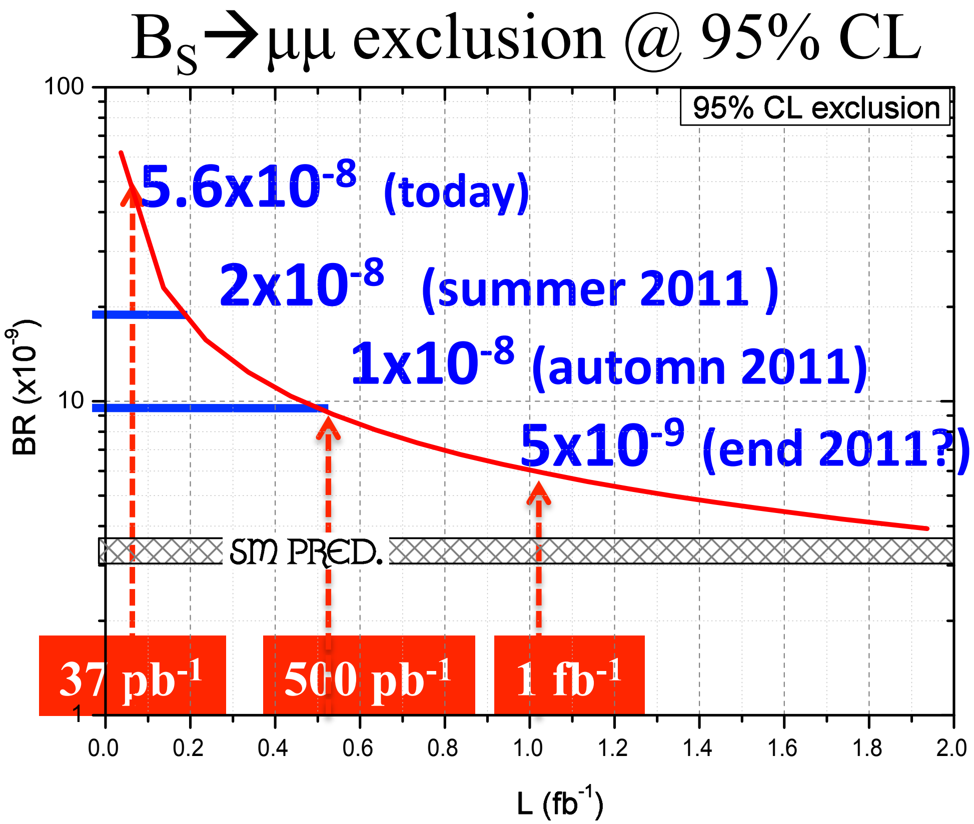
		@ 90% CL	@ 95% CL
LHCb	Observed (expected), **37 pb^{-1}**	**< 43** **(51)** **x10^{-9}**	**< 56** **(65)** **x10^{-9}**
D0	World best published, **6.1 fb^{-1}** PLB 693 539 (2010)	**< 42 x10^{-9}**	**< 51 x10^{-9}**
CDF	Preliminary, **3.7 fb^{-1}** Note 9892	**< 36 x10^{-9}**	**< 43 x 10^{-9}**

Results: $B^0_d \rightarrow \mu\mu$



		@ 90% CL	@ 95% CL
LHCb	Observed (expected) **37 pb^{-1}**	**< 12** (14) **x10^{-9}**	**< 15** (18) **x10^{-9}**
CDF	World best, **2 fb^{-1}** PRL 100 101802 (2008)	**< 15 x10^{-9}**	**< 18 x10^{-9}**
CDF	Preliminary, **3.7 fb^{-1}** Note 9892	**< 7.6 x10^{-9}**	**< 9.1 x 10^{-9}**

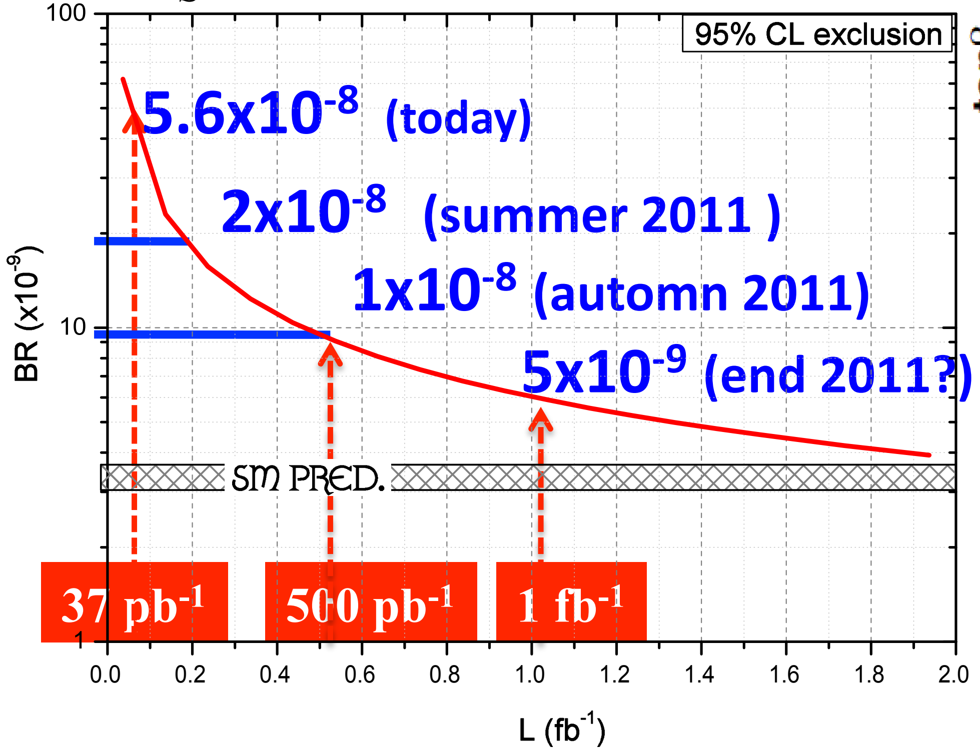
$B_s \rightarrow \mu\mu$: LHCb reach in 2011



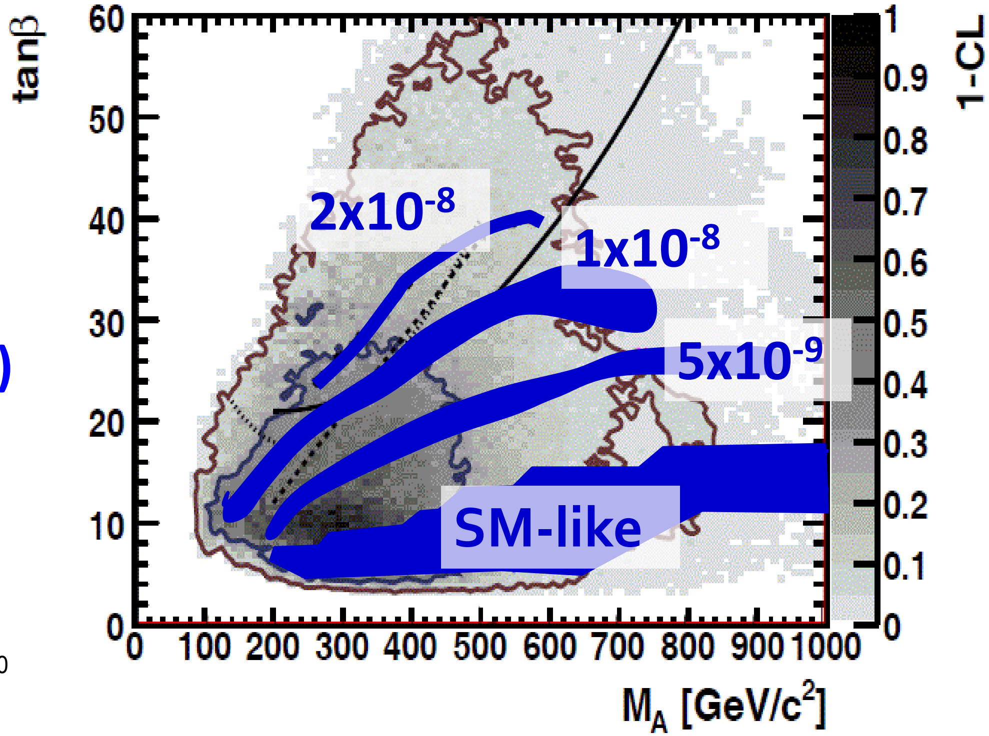
With the data collected in 2011 we will be able to explore the very interesting region of BR~ 10^{-8} and below

$B_s \to \mu\mu$: LHCb reach in 2011

$B_S \to \mu\mu$ exclusion @ 95% CL



tanβ vs m_A plane:

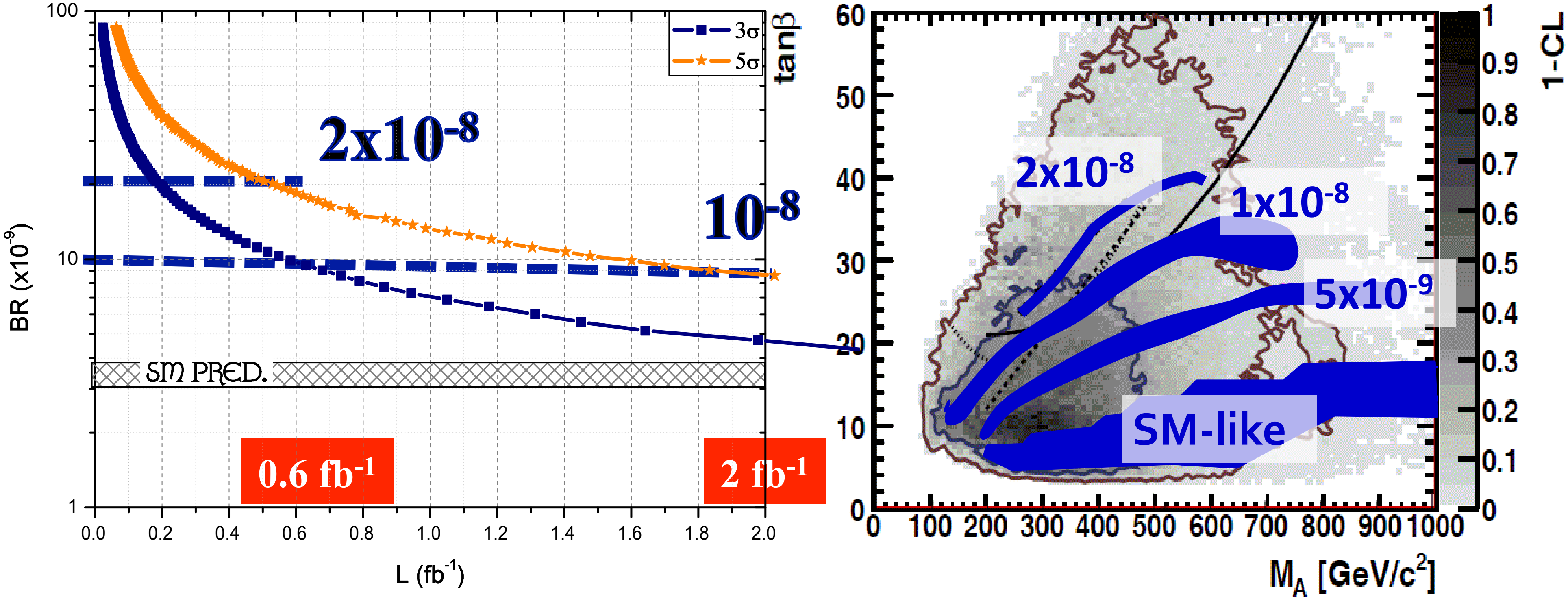


With the data collected in 2011 we will be able to explore the very interesting region of BR~ 10^{-8} and below

$B_s \rightarrow \mu\mu$: LHCb reach in 2011

$B_s \rightarrow \mu\mu$ 3σ observation/5σ discovery

tanβ vs m_A plane:



With the data collected in 2011-2012 we will be able to have a 5σ discovery if BR>10^{-8}

Conclusions

- With only 37 pb^{-1} LHCb has shown an amazing potential to search for New Physics in the scalar/pseudo-scalar sector.

- **The LHCb results:**

$BR(B_s \rightarrow \mu\mu) < 43$ (56) x 10^{-9} @ 90% (95%) CL
$BR(B^0_d \rightarrow \mu\mu) < 12$ (15) x 10^{-9} @ 90% (95%) CL

Paper to be submitted to Phys. Lett. B

are **very close to the best world limits from Tevatron with ~100 (CDF) -200 (D0) times less luminosity.**

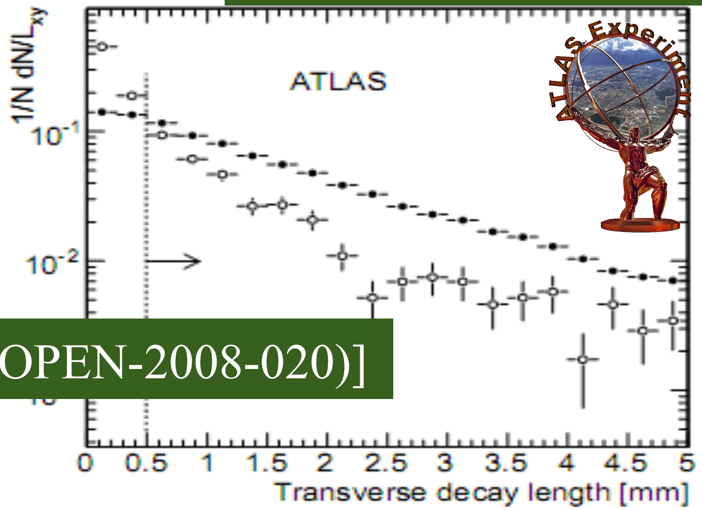
The 2011-2012 run will allow LHCb to explore the very interesting range of BR down to 5×10^{-9} and possibly discover New Physics.

STOP

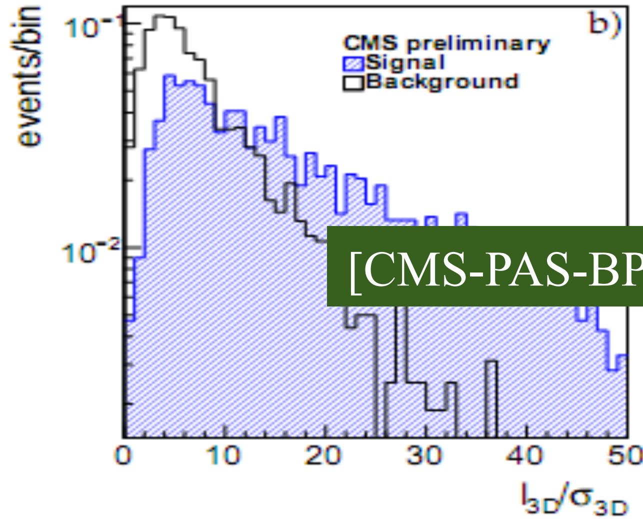
$B_s \to \mu\mu$ @ ATLAS/CMS

Cut based analysis: separate signal from background by using high discriminant variables such as pointing , isolation and secondary vertex displacement:

Eg: Distance of flight and distance of flight significance:



[CERN-OPEN-2008-020)]



[CMS-PAS-BPH-07-001 (2009)]

Experiment	N sig	N bkg	90% CL limit in absence of signal
ATLAS (10 fb^{-1}) σ(bb)=500 ub	5.6 events	14^{+13}_{-10} events (only $bb \to \mu\mu$)	-------
CMS (1 fb^{-1}) σ(bb)=500 ub	2.36 events	6.53 events (2.5 $bb \to \mu\mu$)	$< 1.6 \times 10^{-8}$

Ratio of fragmentation fractions

We use $f_d/f_s=3.71\pm0.47$, a recent combinaton of LEP+Tevatron data by HFAG, with 13% uncertainty, dominated by LEP measurements

B species	Z^0 fractions [%]	Tevatron fractions [%]
$B^{\pm}$	40.4 ± 1.2	33.3 ± 3.0
B^0	40.4 ± 1.2	33.3 ± 3.0
B_s	10.9 ± 1.2	12.1 ± 1.5
Λ_b	8.3 ± 2.0	21.4 ± 6.8

HFAG: http://www.slac.stanford.edu/xorg/hfag/osc/end_2009/#FRAC
Tevatron results from PLB, 667,1 (2008)

LHCb will measure them with semileptonic decays and hadronic $B_{(s)}\rightarrow Dh$ decays *(Phys.Rev.D83, 014017 (2011))*

Normalization factors: systematic uncertainties

	ε(REC)xε(SEL)	ε(TRIG)	fd/fs	N	BR	total
$B^{\pm} \rightarrow J/\psi\ K^{\pm}$	4%	5%	13%	3%	4%	15%
$B_S \rightarrow J/\psi\phi$	8%	5%	--	9%	26%(*)	28%
$B^0_d \rightarrow K\pi$	7%	14%	13%	13%	3%	23%

(*) from Belle @ Υ(5S): arXiv:0905.4345

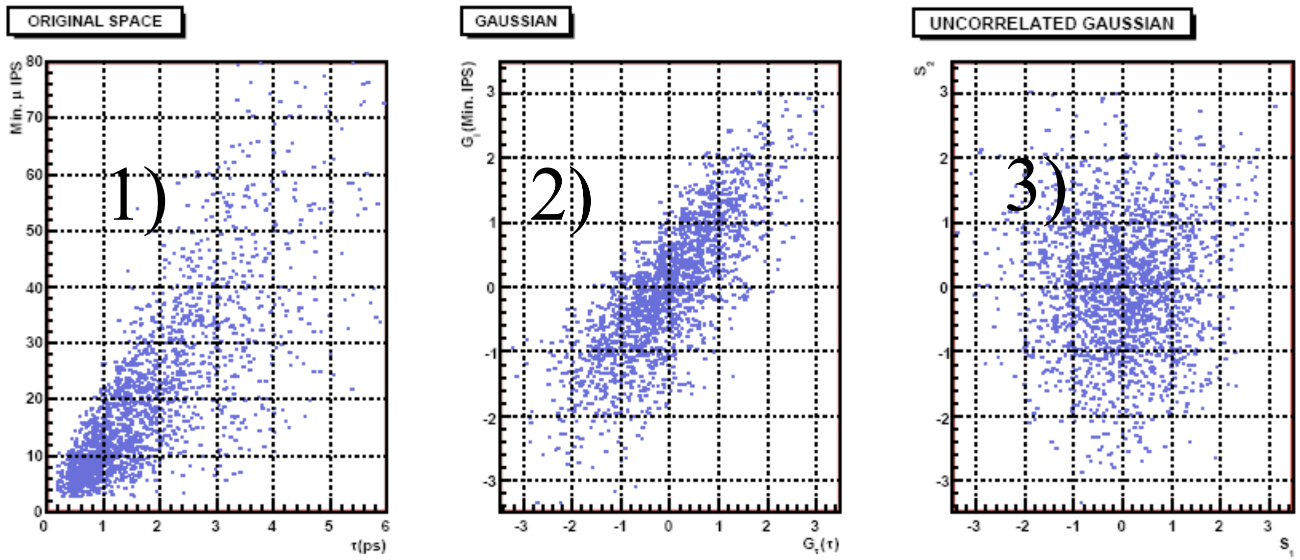
Geometrical Likelihood

- How the decorrelation is done:

1). Input variables → 2) Gaussian variables

→ In this space the correlations are more linear: easier to decorrelate

3) Decorrelation is applied and the variables are re-gaussianized



Gaussian and independent variables:
→ Build χ2

→Tranformation under signal hypothesis: χ^2_S

→Transformation under background hypothesis: χ^2_B

Discriminating variable: GL = $\chi^2_S - \chi^2_B$ → kept flat for signal

Trigger configurations

Data samples grouped in 5 trigger categories:

- Muon lines stable for 90% of the data set
- Hadron lines: 80% of L taken with L0(h) ET>3.6 and SPD<450 /900

→ important for calibration/normalization channels

L0:

TCK category	$L0-\mu$ p_T (GeV/c) / nSPD	$L0-di\mu$ p_{T1} (GeV/c) / p_{T2} (GeV/c) / nSPD	$L0-hadron$ p_T (GeV/c) / nSPD	integrated luminosity
1a	1.0/ -	1.0 / 0.4 / -	2.26 / -	2.2 pb^{-1}
1b	1.0 / 600	1.0 / 0.4 / 600	2.26 / 600	1 pb^{-1}
2	1.4 / 900	0.56 / 0.48 / 900	2.6 / 900	2.3 pb^{-1}
3a	1.4 / 900	0.56 / 0.48 / 900	3.6 / 900	17.3 pb^{-1}
3b	1.4 / 900	0.56 / 0.48 / 900	3.6 / 450	11.9 pb^{-1}

HLT1:

TCK category	Hlt1SingleMuonNoIP p_T (GeV/c) / prescale	Hlt1TrackMuon p_T/ IP (mm)/ IPS	Hlt1TrackAllL0 p_T (GeV/c) / IP/ IPS
1a	1.35 / 1	-	-
1b	1.35 / 1	-	-
2	1.8 / 1	800 / 0.11 / 5	1450 / 0.11 / $\sqrt{50}$
3a	1.8 / 0.2–1	800 / 0.11 / 5	1850 / 0.11 / $\sqrt{50}$
3b	1.8 / 0.2–1	800 / 0.11 / 5	1850 / 0.11 / $\sqrt{50}$

HLT2: HLT2UnbiasedB2mumu Line: 2 identified muons with mass>4.7GeV/c

Background composition: peaking background from B→hh'

- The fake rate probability has been convoluted with the p-spectrum of the dominant B→ hh modes. In all cases we expect <0.4 events in ±600 MeV mass range and <0.1 events in the search window.

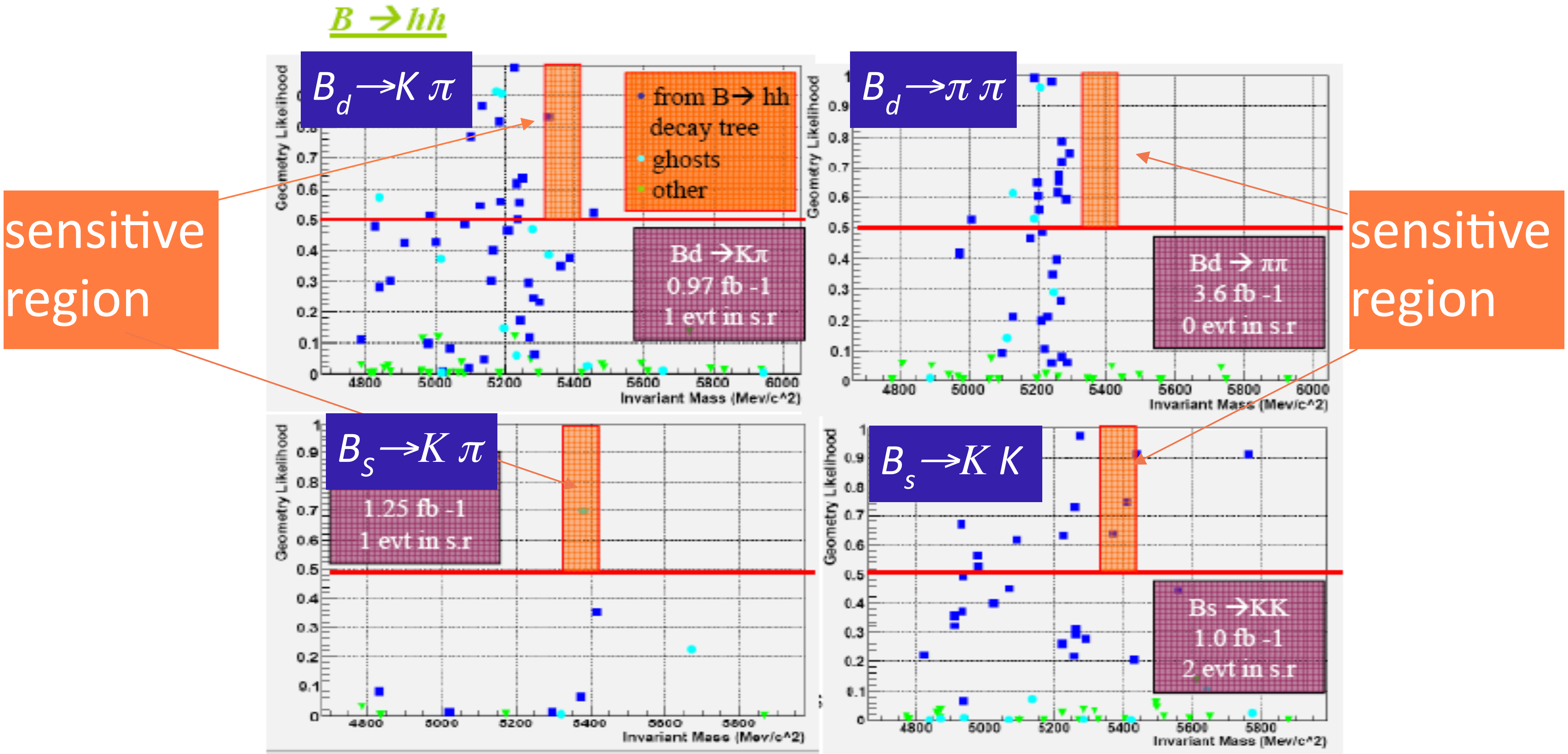
channel	double misID $\Delta m_{B_s^0} < 600 MeV$	double misID, $\Delta m_{B_s^0} < 60 MeV$	double misID, $\Delta m_{B^0} < 60 MeV$
$B^0 \to K^+\pi^-$	0.37 ± 0.09	< 0.02	0.14 ± 0.06
$B_s^0 \to K^+K^-$	0.13 ± 0.06	0.05 ± 0.03	0.03 ± 0.03
$B_s^0 \to \pi^+\pi^-$	0.06 ± 0.03	< 0.01	0.06 ± 0.03

The peaking background is fully negligible

Our dominant background is combinatorial of μμX with ~10% contamination from μ+fakes [again combinatorial].

Background from B→hh modes

B→ hh background in the Geometry Likelihood vs M(μμ) plane

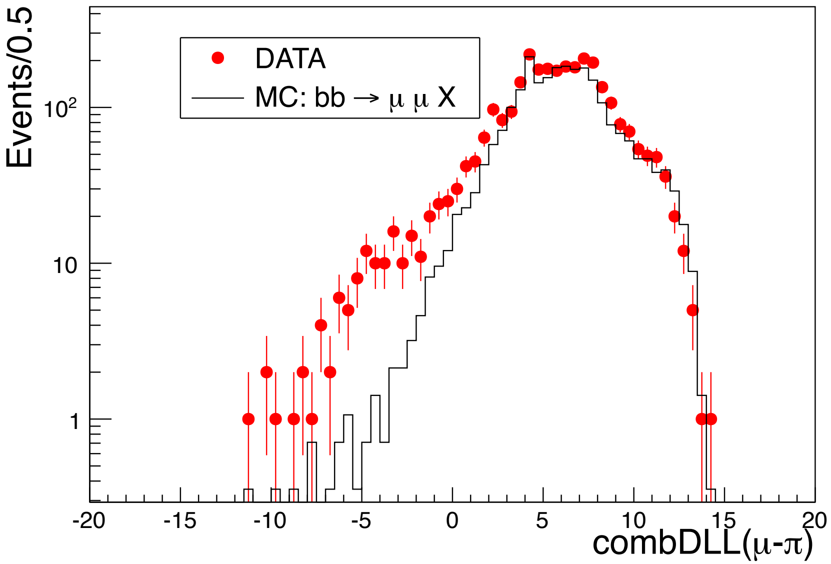


B→ hh background in the sensitive region is completely negligible with respect the bb→μμ component

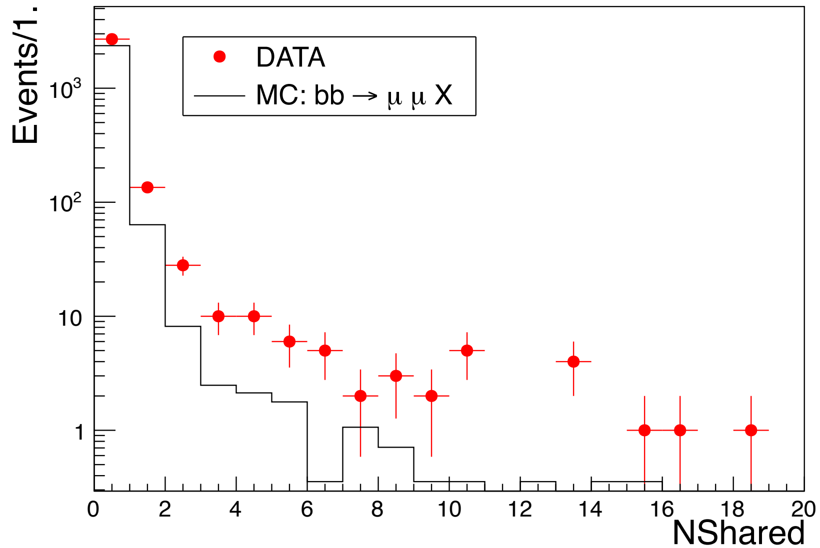
Background composition

- The background after the selection is dominated by real muons (mostly bb→μμX component):

MuonID Likelihood



Number of Muon Hits shared between tracks



Exact knowledge of the background level in MC is not required as the background in the signal region is anyhow extracted from sidebands of the mass distribution in data

Normalization Factors: breakdown

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

	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon^{\mathrm{REC}}_{\mathrm{norm}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{norm}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{sig}}}$	$\frac{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{norm}}}{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{sig}}}$	N_{norm}	$\alpha_{B^0_s\to\mu^+\mu^-}$ $(\times 10^{-9})$	$\alpha_{B^0\to\mu^+\mu^-}$ $(\times 10^{-9})$
$B^+ \to J/\psi K^+$	5.98 ± 0.22	0.49 ± 0.02	0.96 ± 0.05	12366 ± 403	8.4 ± 1.3	2.27 ± 0.18
$B^0_s \to J/\psi\phi$	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

Ratio of reconstruction and selection efficiencies for $B^0 \to K\pi$ is close to 1 (differences due different interaction probability with material)

Ratio of trigger efficiencies for $B^0 \to K\pi$ is low because $B \to K\pi$ is required to be triggered by the other b

Ratio of trigger efficiencies for channels with J/ψ is close to 1

Summary of parameters entering in the limit computation

Signal parameters

Normalizations	
f_d/f_s	3.71±0.47
$\alpha_{B_s^0\to\mu^+\mu^-}$	$(8.6 \pm 1.1) \times 10^{-8}$
$\alpha_{B^0\to\mu^+\mu^-}$	$(2.24 \pm 0.16) \times 10^{-9}$
Signal $\mathrm{GL_{KS}}$ *p.d.f.*	
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$ (total)	611 ± 76
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$, GL bin 2	228 ± 86
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$, GL bin 3	168 ± 38
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$, GL bin 4	215 ± 23
Signal Mass *p.d.f.*	
Mean value for B^0	5275.01 ± 0.87 MeV/c^2
Mean value for B_s^0	5363.1 ± 1.5 MeV/c^2
Mass resolution	26.71 ± 0.95 MeV/c^2
Crystal Ball transition point	$\alpha = 2.11 \pm 0.05$

Background parameters

Background $\mathrm{GL_{KS}}$ *p.d.f.* for $B_s^0 \to \mu^+\mu^-$	
N^{bkg}, $\mathrm{GL_{KS}}$ bin 1	329.1±6.4
N^{bkg}, $\mathrm{GL_{KS}}$ bin 2	7.4±1.0
N^{bkg}, $\mathrm{GL_{KS}}$ bin 3	1.5±0.4
N^{bkg}, $\mathrm{GL_{KS}}$ bin 4	$0.08^{+0.1}_{-0.05}$
Background $\mathrm{GL_{KS}}$ *p.d.f.* for $B^0 \to \mu^+\mu^-$	
N^{bkg}, $\mathrm{GL_{KS}}$ bin 1	351.6±6.6
N^{bkg}, $\mathrm{GL_{KS}}$ bin 2	8.3±1.0
N^{bkg}, $\mathrm{GL_{KS}}$ bin 3	1.9±0.4
N^{bkg}, $\mathrm{GL_{KS}}$ bin 4	$0.12^{+0.1}_{-0.07}$
Background Mass *p.d.f.* for B^0 and B_s^0	
k, $\mathrm{GL_{KS}}$ bin 1	$-(0.748 \pm 0.051)/$ GeV/c^2
k, $\mathrm{GL_{KS}}$ bin 2	$-(1.36 \pm 0.35)/$ GeV/c^2
k, $\mathrm{GL_{KS}}$ bin 3	$-(2.29 \pm 0.28)/$ GeV/c^2
k, $\mathrm{GL_{KS}}$ bin 4	$-(4.15 \pm 0.91)/$ GeV/c^2