$b \to \mu^+\mu^-$ and $b \to s\mu^+\mu^-$ at the LHC

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(on behalf of the LHCb collaboration)

FPCP – Kibbutz Maale Hachamisha – May 26th, 2011

Rare B Physics @ LHCb

Are we crazy?

forward detector

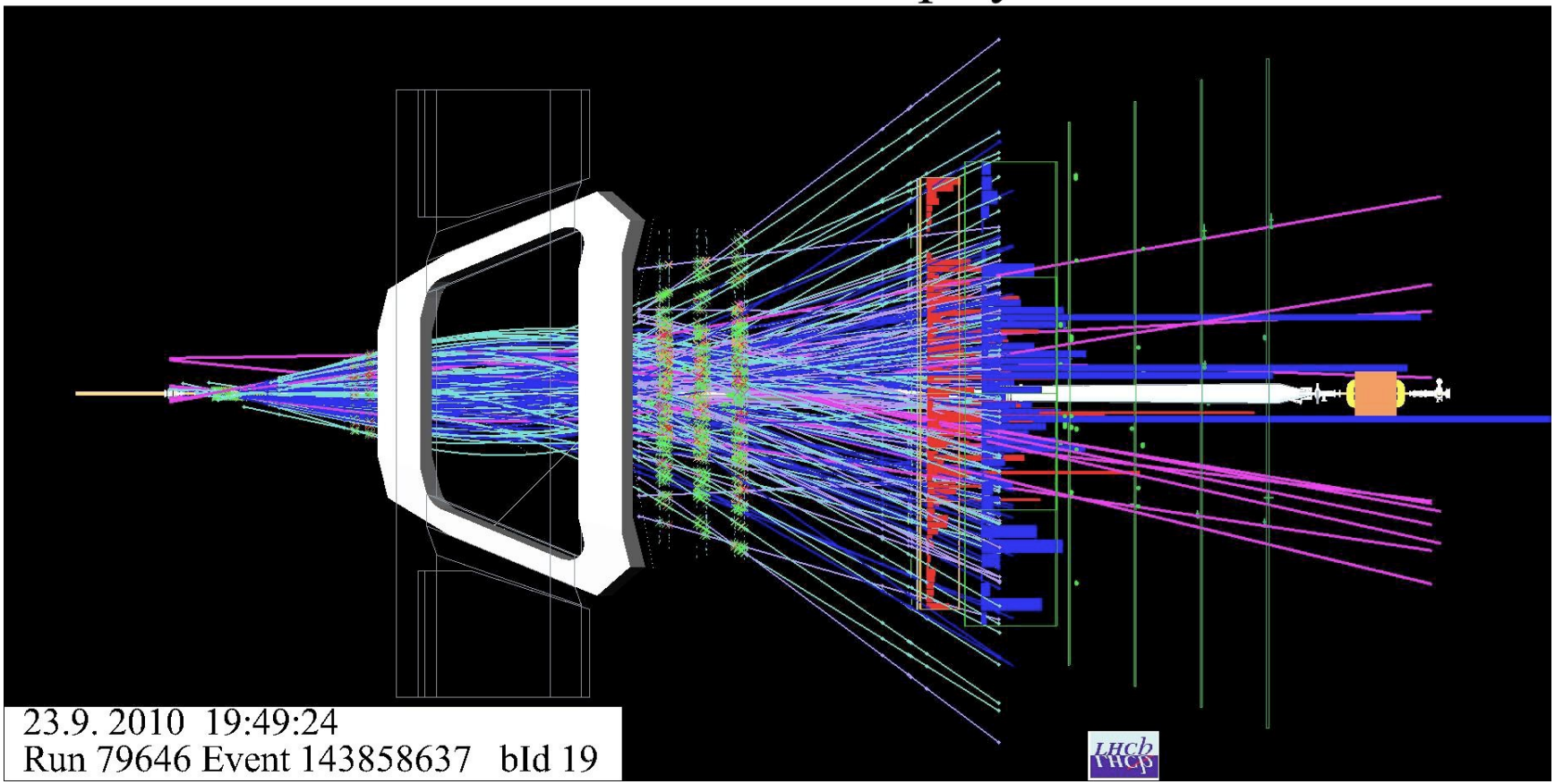
80 tracks per event

high pileup conditions (~2.5 pp interactions/crossing)

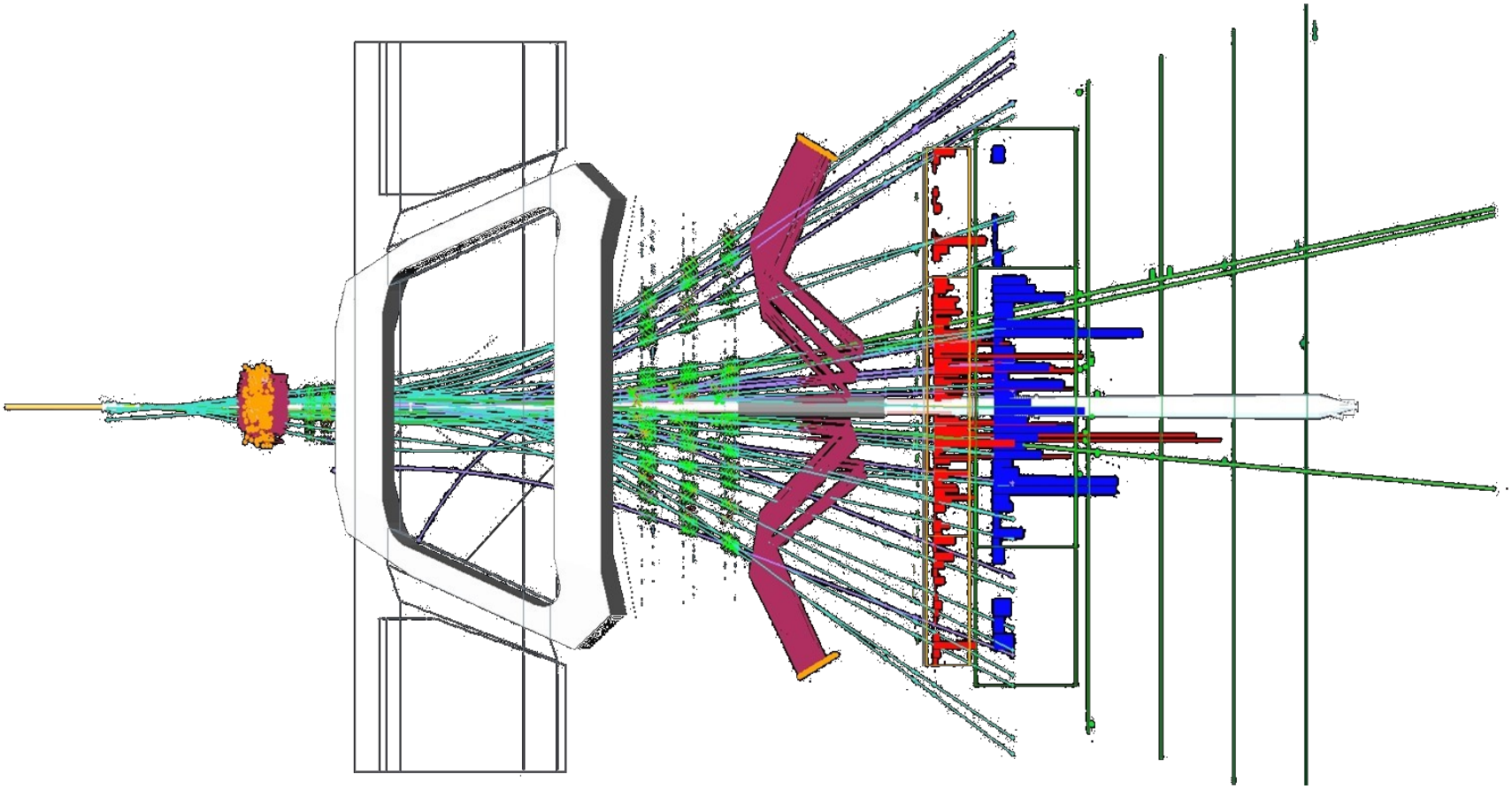
σ(pp, inelastic) @ √s=7 TeV ~ 60 mb

only 1/200 events contains a b quark (interested in BR ~ 10^{-5} – 10^{-9})

LHCb Event Display

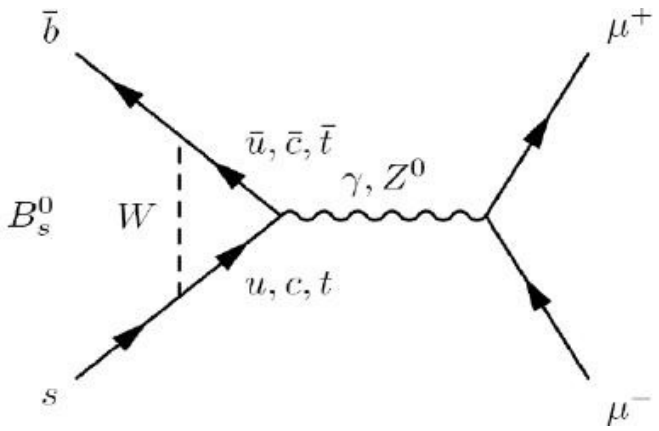


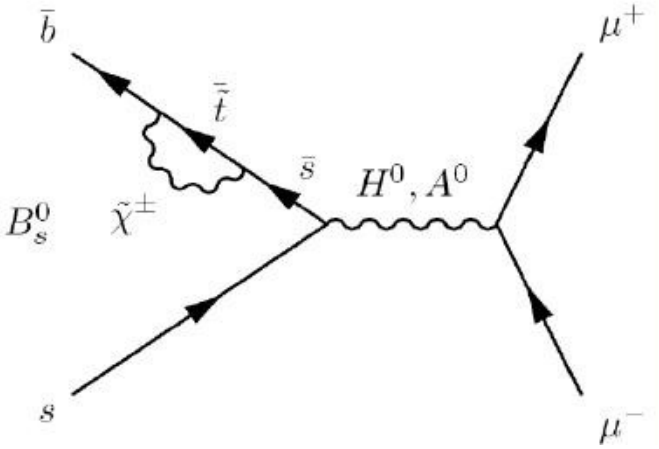
$B_{s/d} \rightarrow \mu^+\mu^-$



Introduction

Doubly suppressed decay: **FCNC process** and **helicity suppressed.**

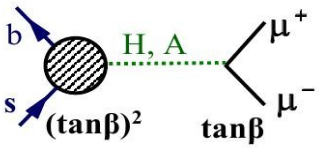




A.J.Buras: arXiv:1012.1447
E. Gamiz et al: Phys.Rev.D 80 (2009) 014503

Mode	SM
$B_s \to \mu^+\mu^-$	$3.2 \pm 0.2 \times 10^{-9}$
$B^0 \to \mu^+\mu^-$	$0.10 \pm 0.01 \times 10^{-9}$

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



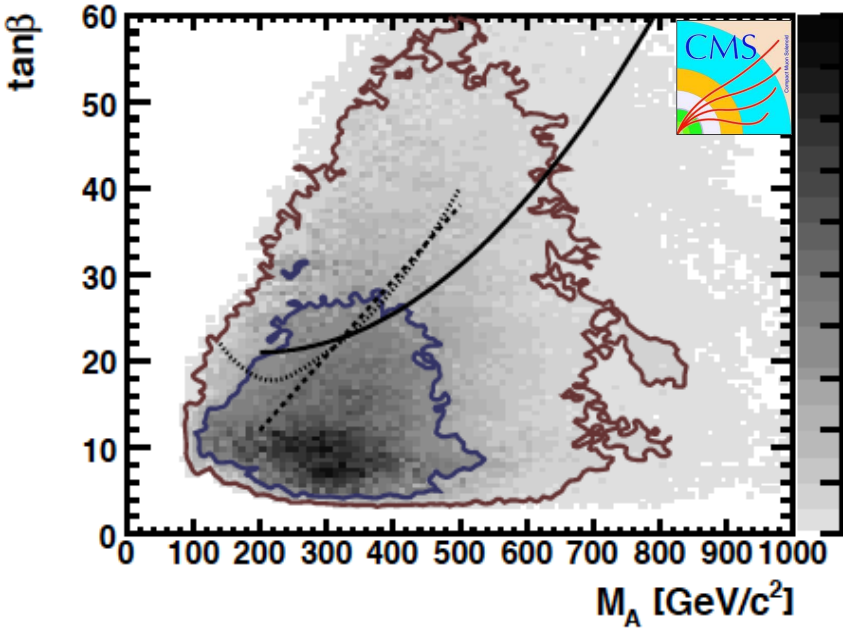
sensitive to contributions in the **scalar/pseudo-scalar sector**

highly interesting to probe **extended Higgs** models and **high tanβ**

limit or measurement of $B_{s,d} \to \mu\mu$ will strongly constrain tanβ vs M_A plane

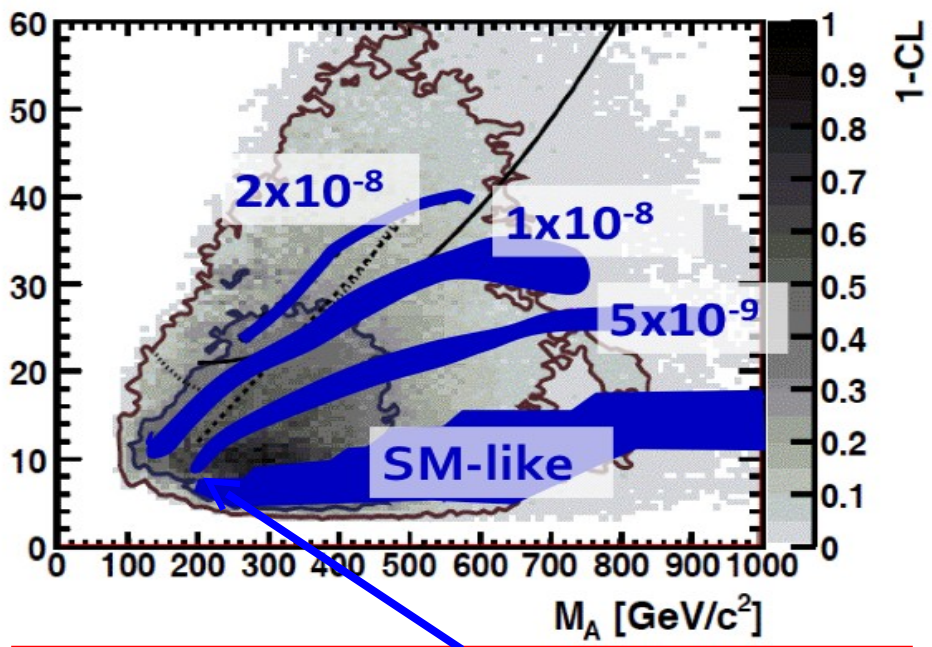
Status and Reach

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



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

LHCb calculation using SuperIso/SoftSUSY, Comput. Phys.Comm. 143, 305 (arXiv: 08083144)

Limits from Tevatron @ 95% CL:

CDF (~3.7 fb^{-1}): $B_s(B_d) \to \mu\mu$ < $43(7.6) \times 10^{-9}$

DO (~6.1 fb^{-1}): $B_s \to \mu\mu$ < 51×10^{-9}

factor > 10 from SM

CDF: Public note 9892 – D0: PLB 693, 593 (2010)

LHCb – Analysis Strategy

Selection

Muon-based trigger

Soft selection to reduce size of dataset

similar for control samples

Blind signal region

Signal and background discrimination

Geometrical Likelihood (GL)

Multivariate classifier combining topological and kinematic information

Flat distribution between 0 and 1 for signal

Invariant Mass

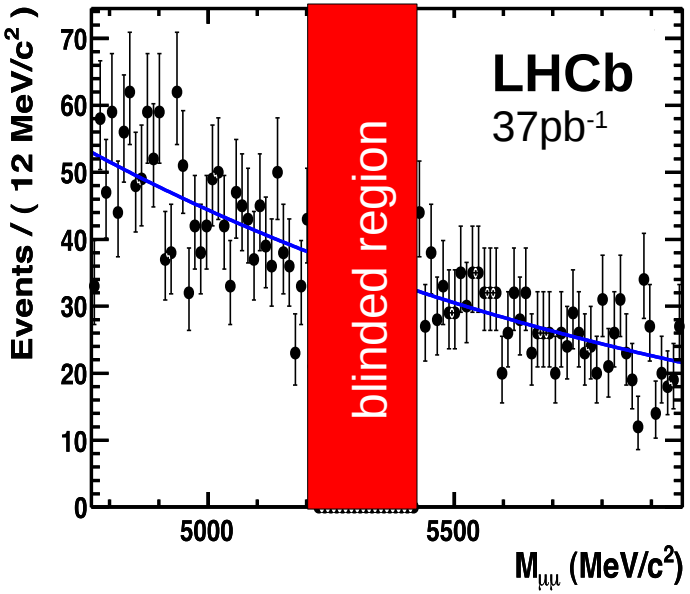
Normalization

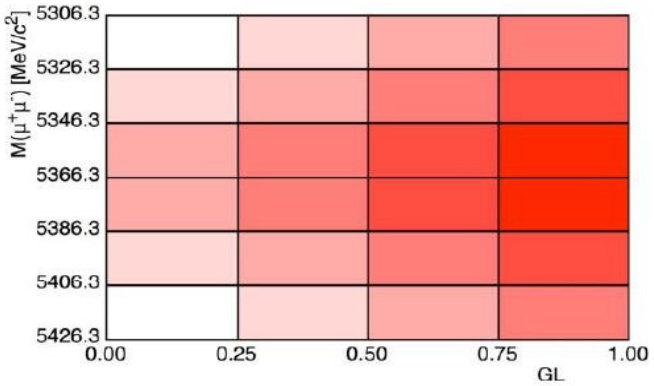
Translate number of observed events in branching fraction measurement by normalizing with channels of known BR

Extraction of the limit

Extract observation / exclusion measurement using the modified frequentist CL_s method in bins of mass and GL

T. Junk, Nucl. Instrum. Meth. A 434 (1999), 435





Selection and Background

Soft selection:

Pairs of opposite charged muons with high quality tracks, making a common vertex very displaced with respect to the PV and $M_{\mu\mu}$ ±600 MeV/c^2

Expected after selection (BR=BR^{SM}):

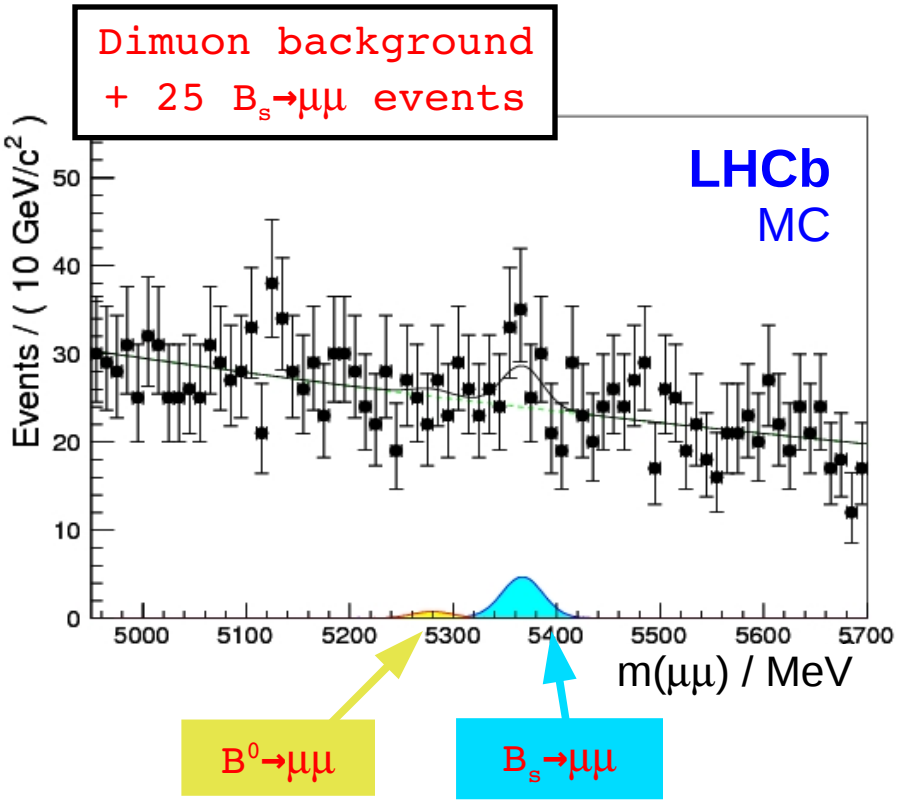
$B_s(B^0)\to\mu\mu$: 0.3 (0.04) events

Rejects most of the background

~300 background events in the signal windows m($B_{d,s}$) ±60 MeV/c^2

~3000 background events in $M_{\mu\mu}$ ±600 MeV/c^2

Signal region: tight mass window+GL>0.5

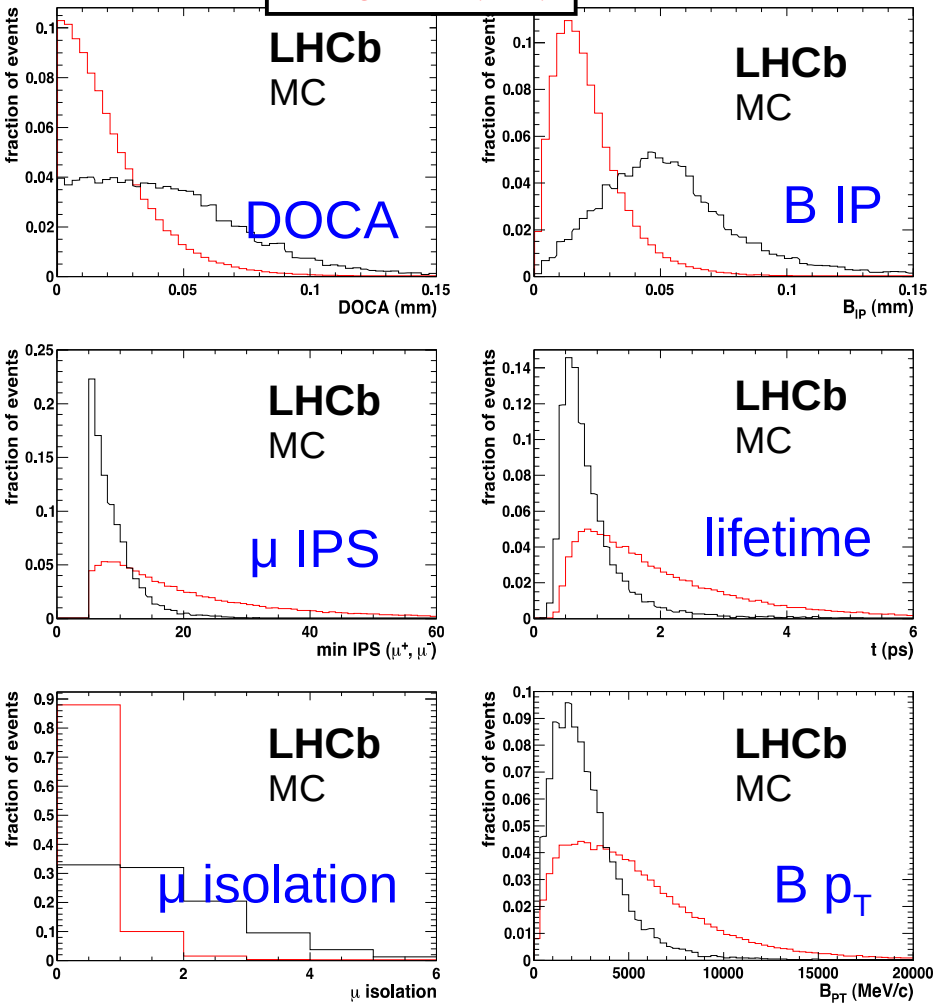


bb→μμX	fake + muon	peaking background
90%	10%	negligible
Double semileptonics and cascade decays	~0.3% from double fake	Double misID from B→hh': ~0.1(0.2) events in $B_s(B^0)$ sig region misID well described by MC $\varepsilon(hh\to\mu\mu) \sim (3.5\pm0.9)\times10^{-5}$

Geometrical Likelihood

GL Input Variables

Sig/BG (MC)



MC $B_s \to \mu\mu$

MC $b\bar{b} \to \mu\mu X$

Combination of kinematic and topological variables

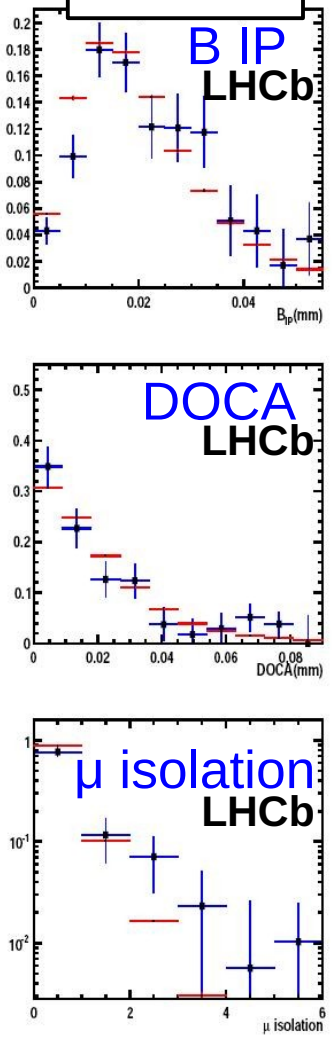
Variables decorrelated before building the Geometrical Likelihood

Optimization and training using MC

Signal $B_s \to \mu\mu$

Background $b\bar{b} \to \mu\mu X$

Data/MC



MC B→hh'

DATA B→hh'

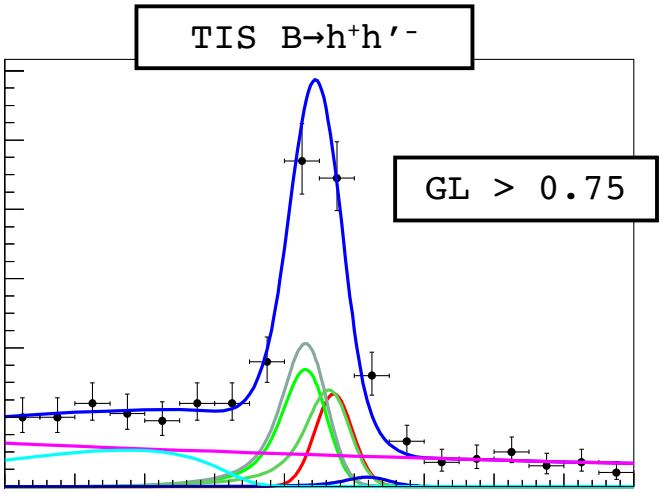
GL Calibration

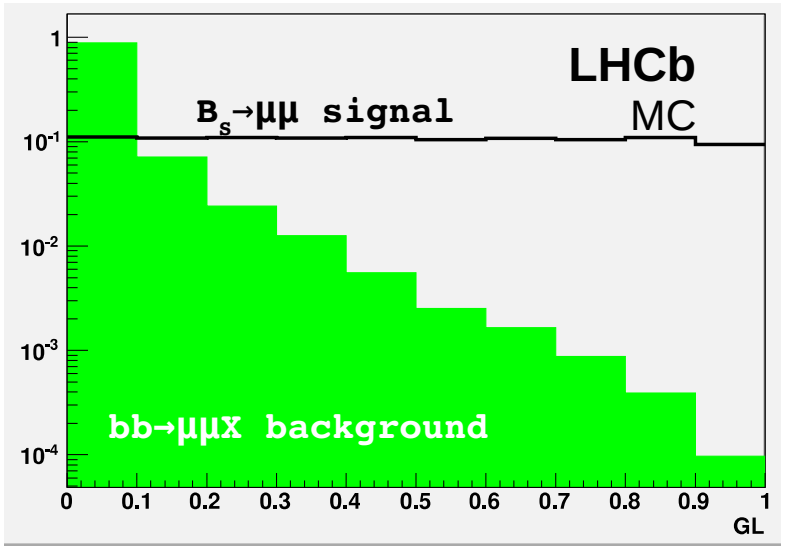
$B \to h^+h'^-$ used for GL calibration

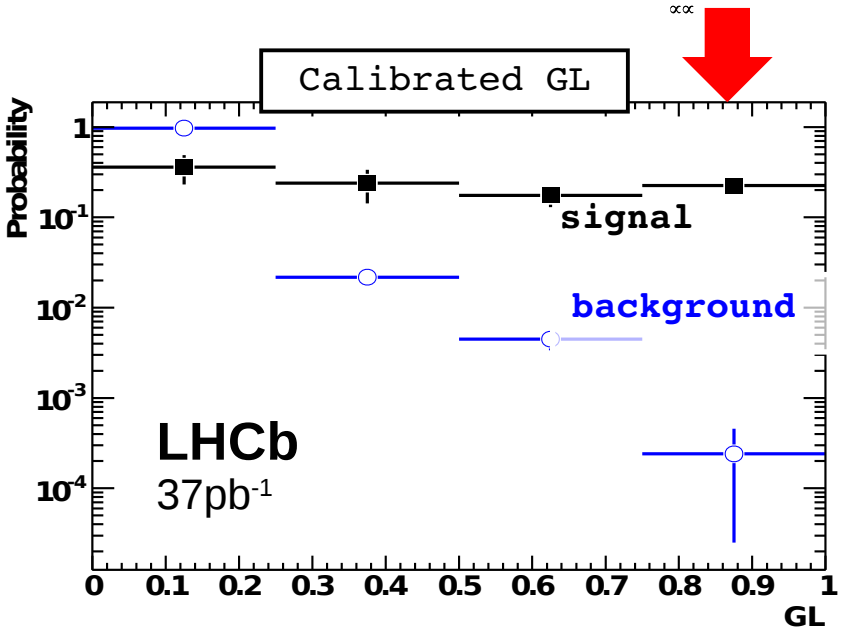
- Very similar decay topology
- Different trigger
  - Use events triggered independently of signal (TIS) to avoid trigger bias

Fit all $B \to h^+h'^-$ channels simultaneously in bins of GL

(BR constrained to PDG values)





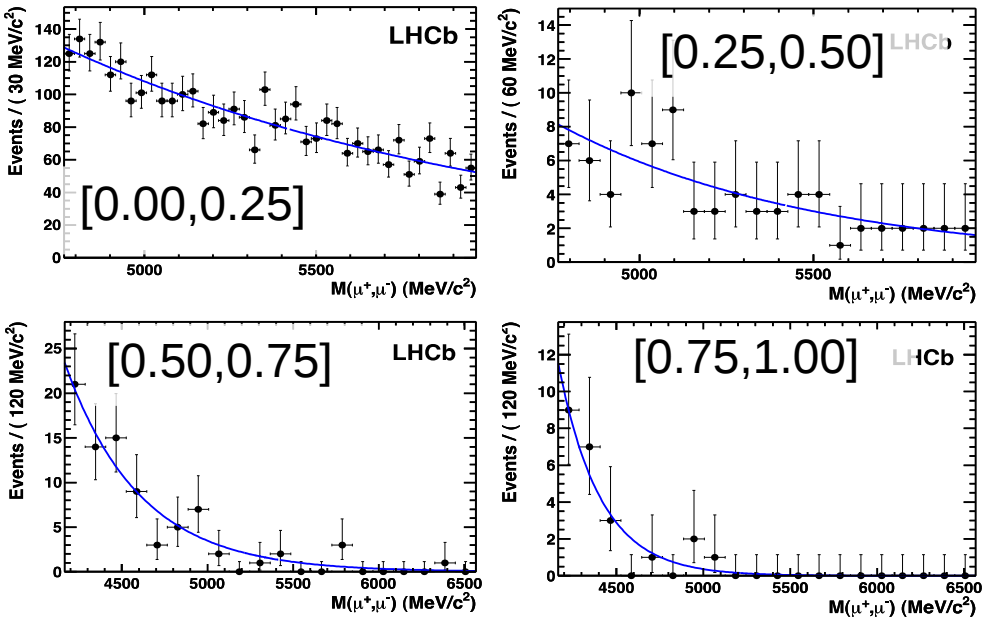


Signal distribution in GL flat within the uncertainties

GL for Background

Expected background in signal region extracted from a fit to mass sidebands divided in GL bins

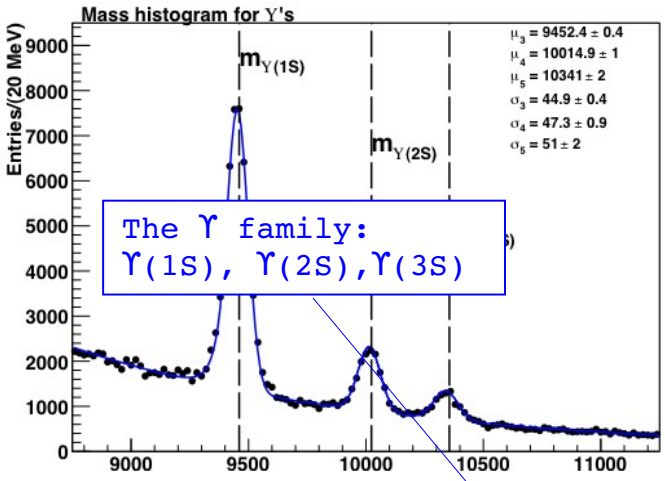
Invariant mass in GL bins

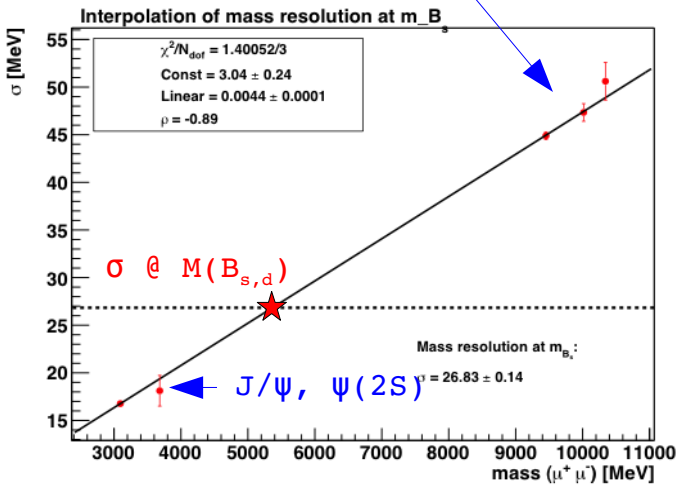


Expected background events in $B_{s,d}$ mass regions

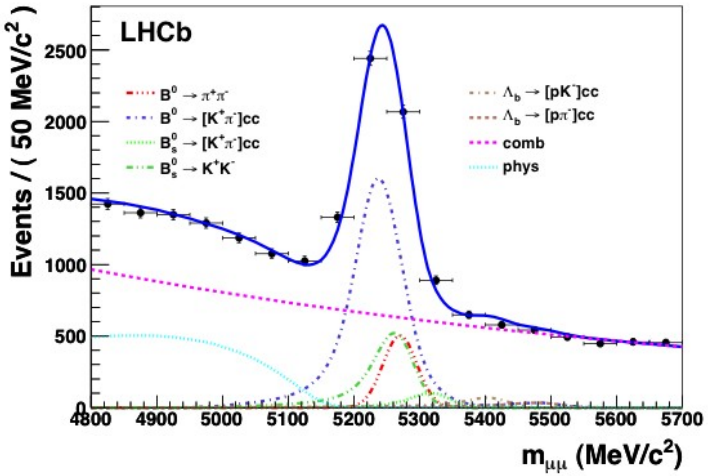
GL	$B_s \rightarrow \mu\mu$	$B^0 \rightarrow \mu\mu$
[0.00 - 0.25]	329.1±6.4	351.6±6.6
[0.25 - 0.50]	7.4 ± 1	$8.3^{+1.1}_{-1.0}$
[0.50 - 0.75]	$1.51^{+0.41}_{-0.35}$	$1.85^{+0.45}_{-0.39}$
[0.75 -1.00]	$0.08^{+0.10}_{-0.05}$	$0.13^{+0.13}_{-0.07}$

Invariant Mass





$\sigma = 26.8 \pm 0.1^{stat} \pm 1.0^{syst}$ MeV/c²



$\sigma = 25.8 \pm 1.0^{stat} \pm 2.7^{syst}$ MeV/c²

$\sigma(B_{s,d}) = 26.7 \pm 0.9^{stat+syst}$ MeV/c²

	mass resolution J/ψ→μμ	mass resolution B→hh (μμ)
LHCb	13 MeV	27 MeV
CMS	28-48 MeV	53 MeV (MC)
ATLAS	40-110 MeV	
D0	65 MeV	120 MeV
CDF		24 MeV

BR Normalization

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

Normalization factors from three channels: $B^+ \to J/\psi K^+$, $B^0 \to \pi^- K^+$, $B_s \to J/\psi \phi$

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

different efficiencies, f_s/f_d dependance,

+ very different systematic uncertainties

average:

$\alpha(B_s \to \mu\mu) = 8.6 \pm 1.1 \times 10^{-9}$ **$\alpha(B^0 \to \mu\mu) = 2.24 \pm 0.16 \times 10^{-9}$**

Currently use **HFAG average of LEP/Tevatron** value: **$f_d/f_s = 3.71 \pm 0.47$**

LHCb: Measure f_d/f_s **See Walter's talk for details**

in the relative yields of $B^0 \to DK$ or $B^0 \to D\pi$ to $B_s \to D_s\pi$

Fleischer et al, Phys.Rev.D83,014017 (2011)

LHCb-CONF-2011-013

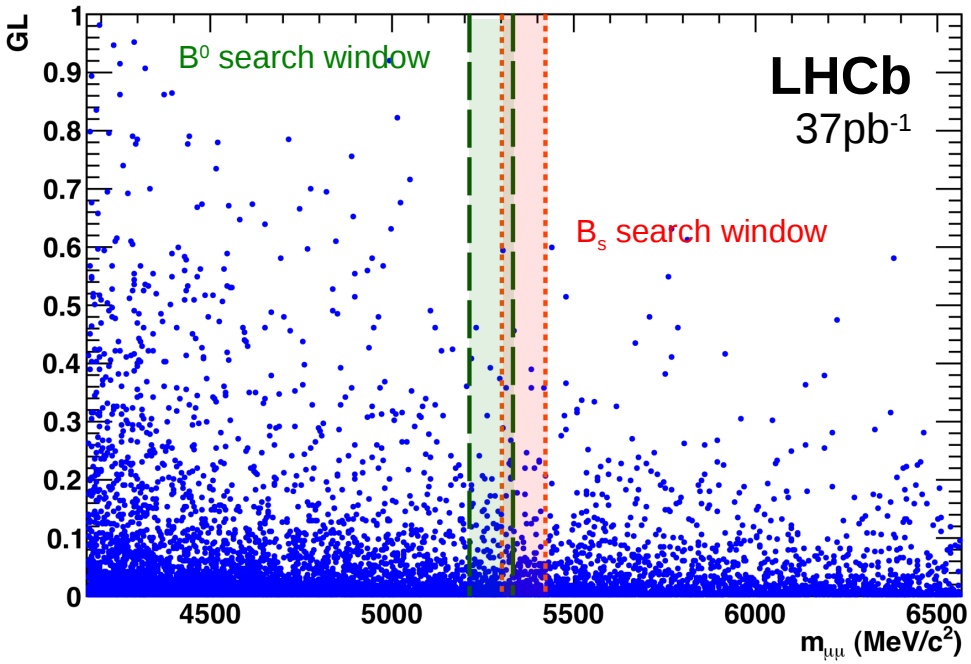
$f_d/f_s = 4.02 \pm 0.52$ preliminary

(using $B^0 \to D^{\pm}p^{\pm}$)

also preliminary result from semileptonics:

$f_d/f_s = 3.84 \pm 0.34$ preliminary

What to do with an open box



Events are classified in 2D plane: Invariant Mass, GL

Calculate expected limit using toy MC techniques

Shows reach of the measurement

Evaluate the compatibility of measurement with

B only hypothesis [CL_B]

quote observation

S+B hypothesis

[$CL_S=CL_{S+B}/CL_B$]

quote exclusion limit

Errors of normalization factors and PDF parameters are included as nuisance parameters in limit calculation

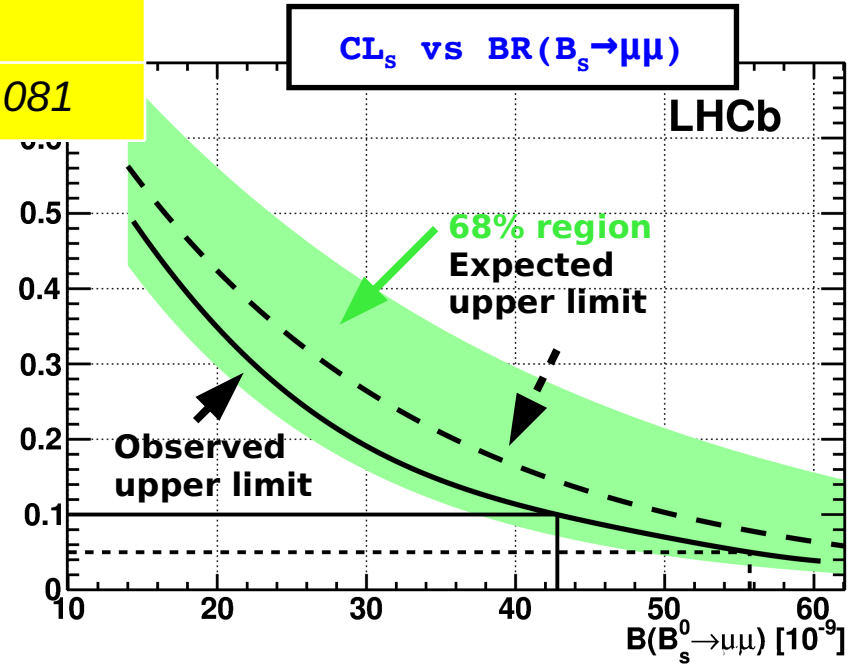
Limits: $B_s \to \mu\mu$

ΔM \ GL	[0.-0.25]	[0.25-0.5]	[0.5-0.75]	[0.75-1.]
[-60,-40]	39	2	1	0
[-40,-20]	55	2	0	0
[-20, 0]	73	0	0	0
[0 , 20]	60	0	0	0
[20, 40]	53	2	0	0
[40, 60]	55	1	0	0
(TOTAL)	*335*	*7*	*1*	*0*
(bkg exp.)	*329*	*7.36*	*1.51*	*0.081*

Observed limit:

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

Expected are: 5.1 (6.5)



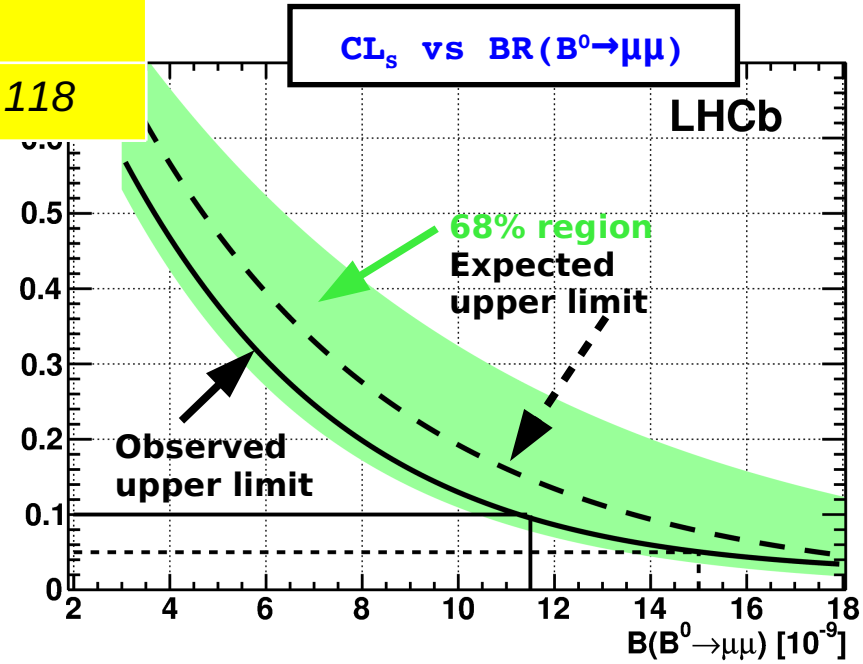
Limits: $B^0 \to \mu\mu$

ΔM \ GL	[0.-0.25]	[0.25-0.5]	[0.5-0.75]	[0.75-1.]
[-60,-40]	59	2	0	0
[-40,-20]	67	0	0	0
[-20, 0]	56	2	0	0
[0 , 20]	60	0	0	0
[20, 40]	42	2	1	0
[40, 60]	49	2	0	0
(TOTAL)	*333*	*8*	*1*	*0*
(bkg exp.)	*352*	*8.29*	*1.85*	*0.118*

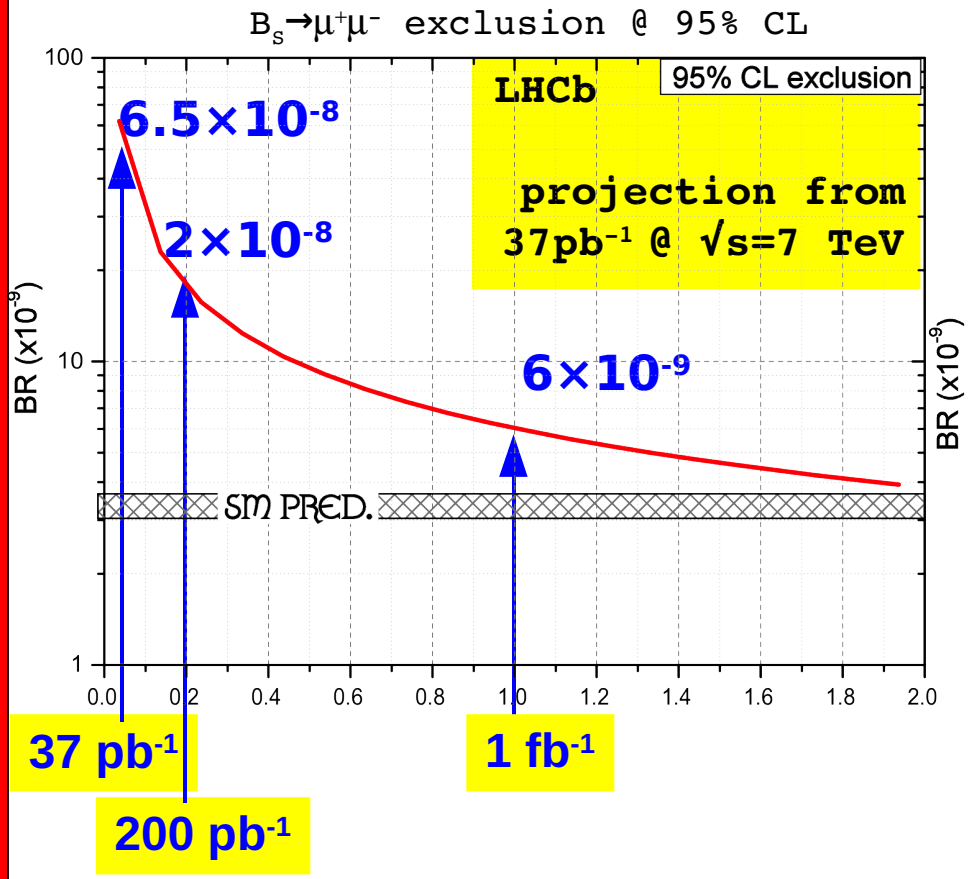
Observed limit:

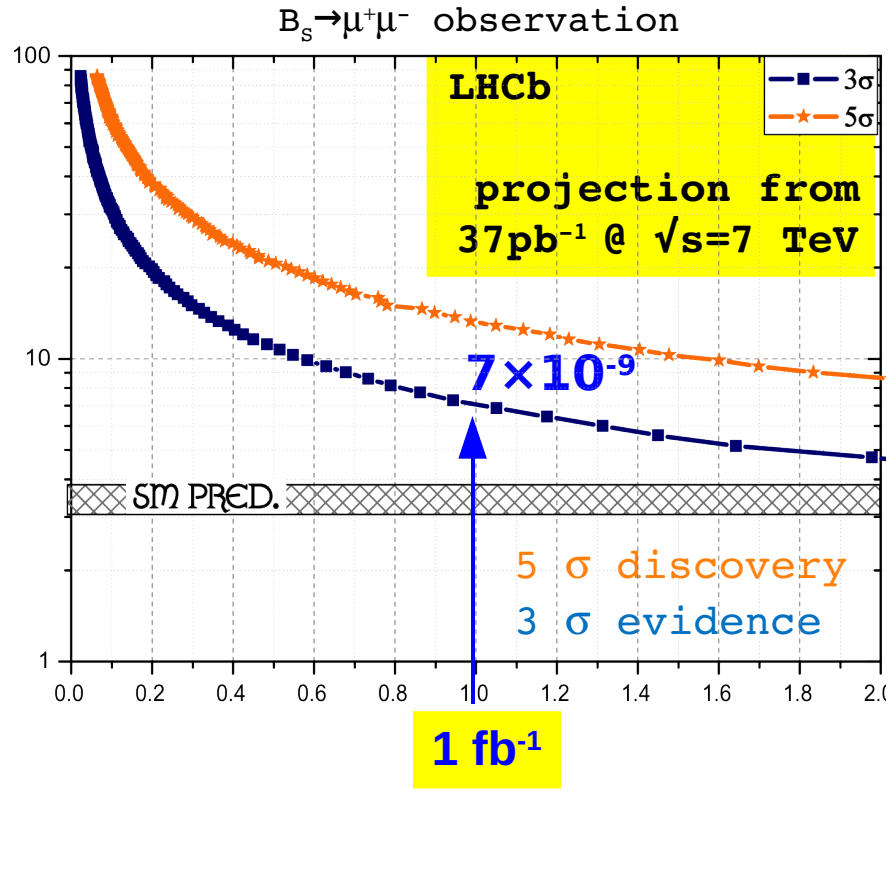
$BR(B^0 \to \mu\mu) < 1.2\ (1.5) \times 10^{-8}$ @ 90 (95%) CL

Expected are: 1.4 (1.8)



Future Outlook @ LHCb



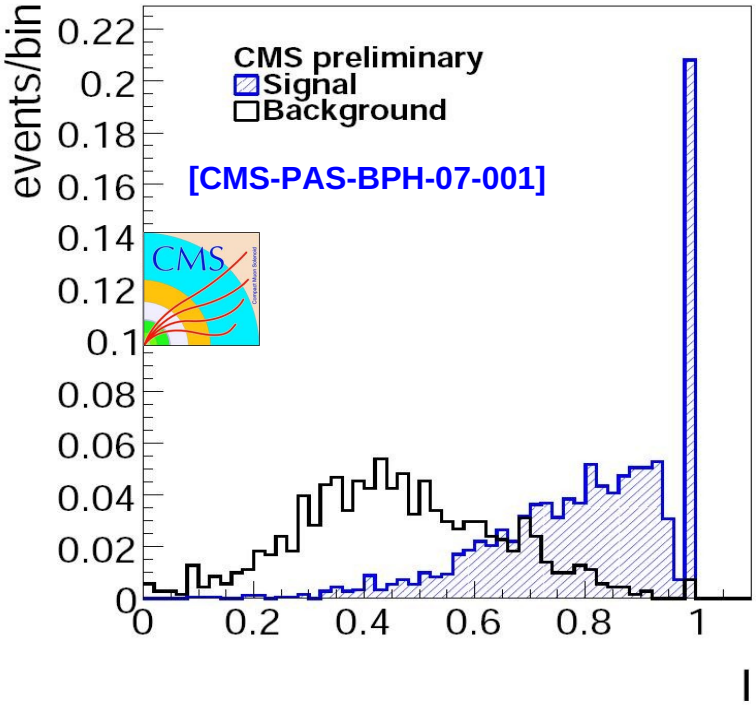


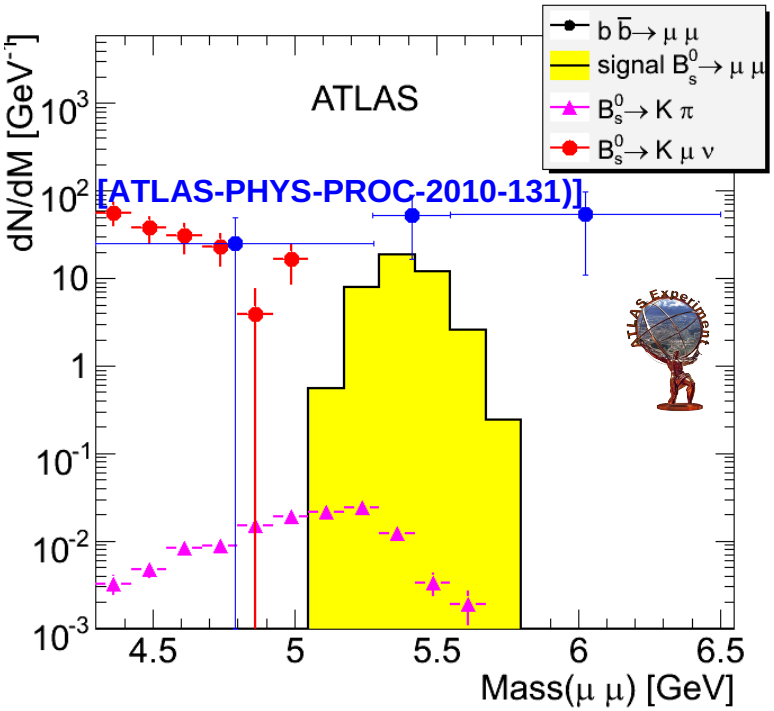
With the data collected in 2011 we will be able to explore the region BR ~6-10×10^{-9}

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

$B_s \rightarrow \mu\mu$ @ GPD

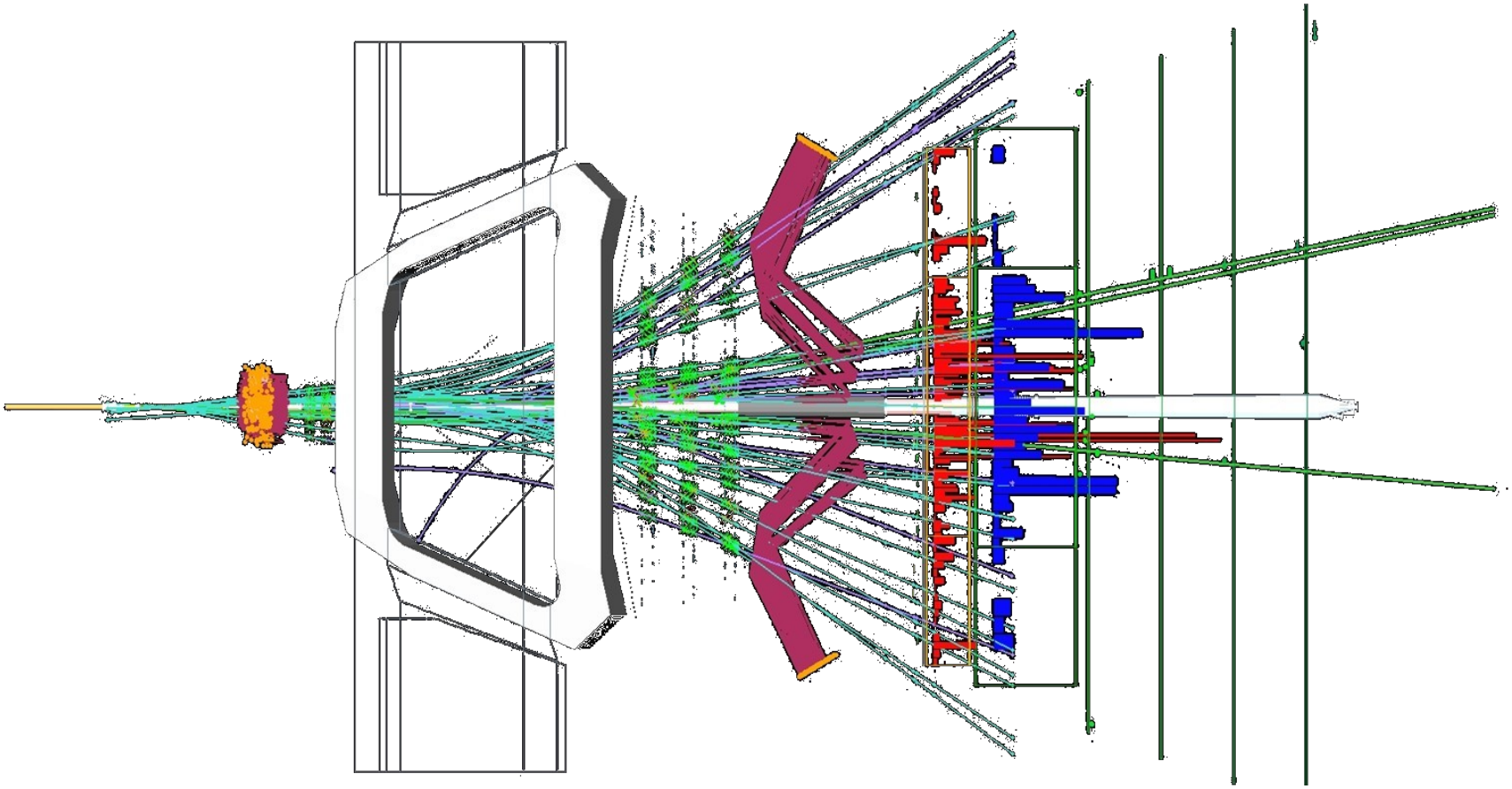
Still blind. Cut based analysis (grid search):
PT, pointing, B isolation, secondary vertex displacement...



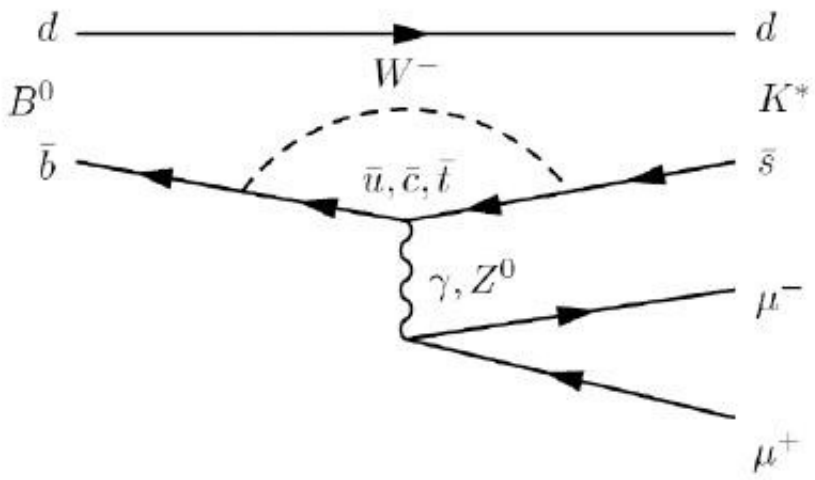


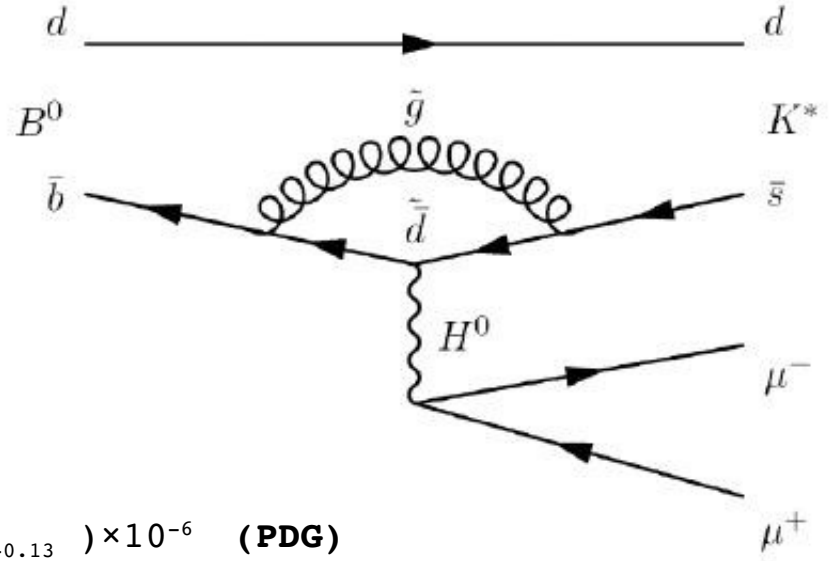
Experiment	N sig	N bkg	90% CL limit
ATLAS (10 fb^{-1}) σ(bb)=500 μb	5.7 events	14^{+13}_{-10} events (only bb→μμ)	-------
CMS (1 fb^{-1}) σ(bb)=500 μb	2.36 events	6.53 events (2.5 bb→μμ)	<1.6×10^{-8} (official) <~1.0×10^{-8} (LHCb MF estimate)

$B^0 \rightarrow K^*\mu^+\mu^-$



Introduction



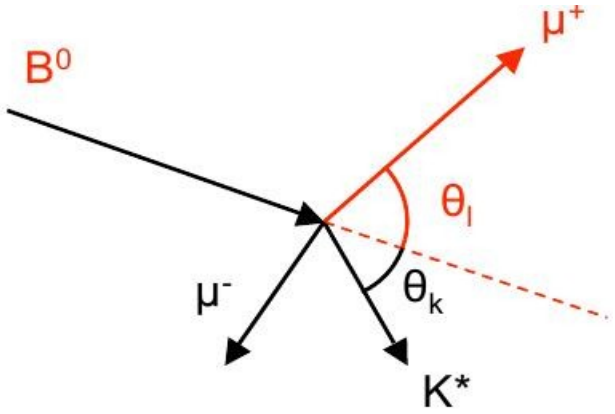


BR $(B^0 \to K^* \mu^+ \mu^-) = (1.05^{+0.16}_{-0.13}) \times 10^{-6}$ **(PDG)**

Another **FCNC mode**, sensitive to magnetic, vector, and axial semileptonic penguin operators: C7, C9, C10

NP can affect composite variables (A_{FB})

$$A_{\mathrm{FB}}(q^2) = \frac{\left.\frac{dN}{dq^2}\right|_{\cos\theta_l>0} - \left.\frac{dN}{dq^2}\right|_{\cos\theta_l<0}}{\left.\frac{dN}{dq^2}\right|_{\cos\theta_l>0} + \left.\frac{dN}{dq^2}\right|_{\cos\theta_l<0}}$$



Hadronic form factors uncertainties under control at low q^2

Zero asymmetry @ $q^2 = 4.36^{+0.33}_{-0.31}$ (GeV/c²)²

Eur. Phys. J. C, 41, 2005,173-188

LHCb – Analysis Strategy

Blind analysis (A_{FB})

Control samples to limit dependence on MC:

- $D \to K\pi\pi\pi$
- $B^0 \to J/\psi(\mu\mu)K^*$
- $B^+ \to J/\psi(\mu\mu)K^+$

Trigger correction

Selection/reconstruction efficiencies

Acceptance

BDT-based selection (high purity):

yield from 1 fb^{-1}: 640+-150

B/S = ~0.2

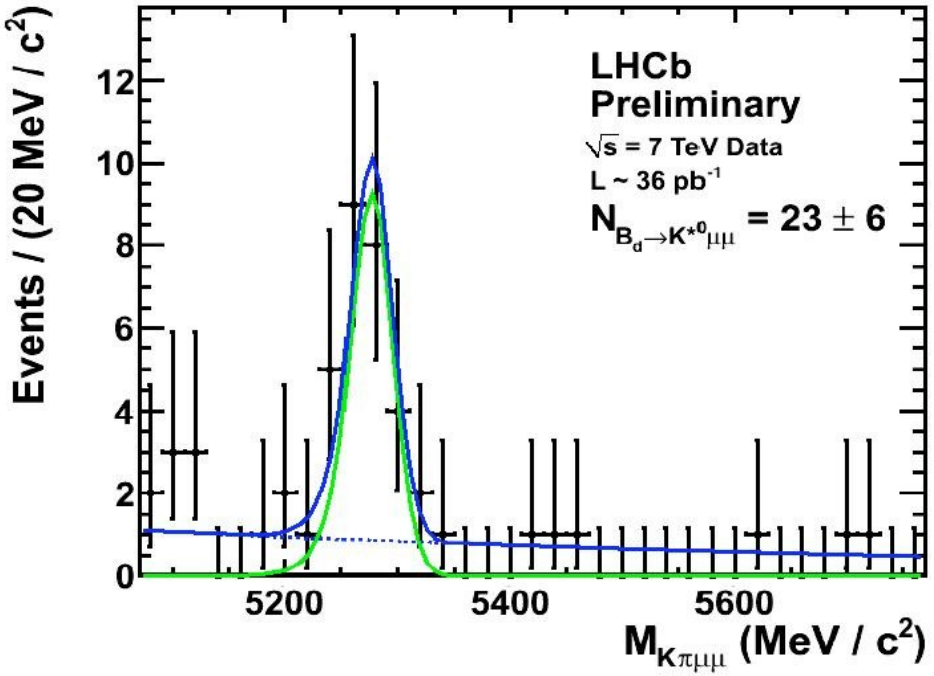
cfr:

BABAR 100, B/S = 0.3

Belle 250, B/S = 0.25

CDF 100, B/S = 0.4

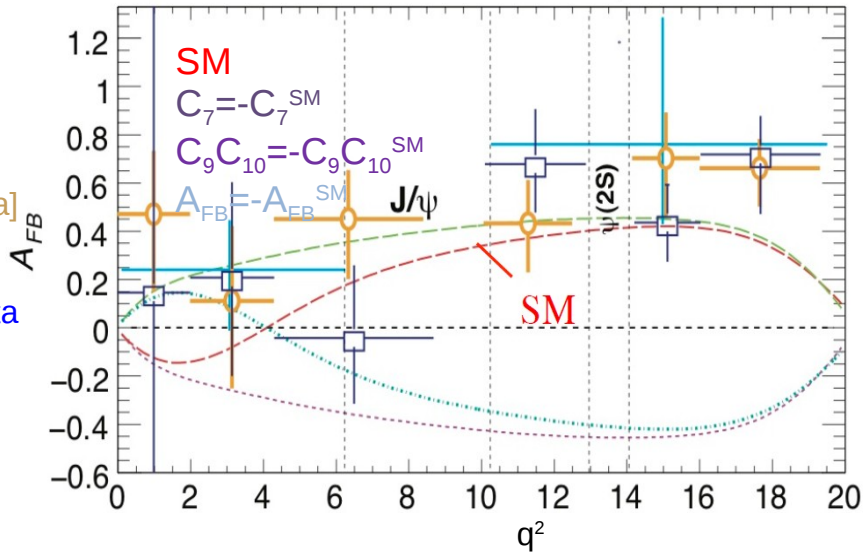
CDF: PRL 106 (2011), 161801



[80% of data]

[75% of data

[4.4 fb^{-1}]



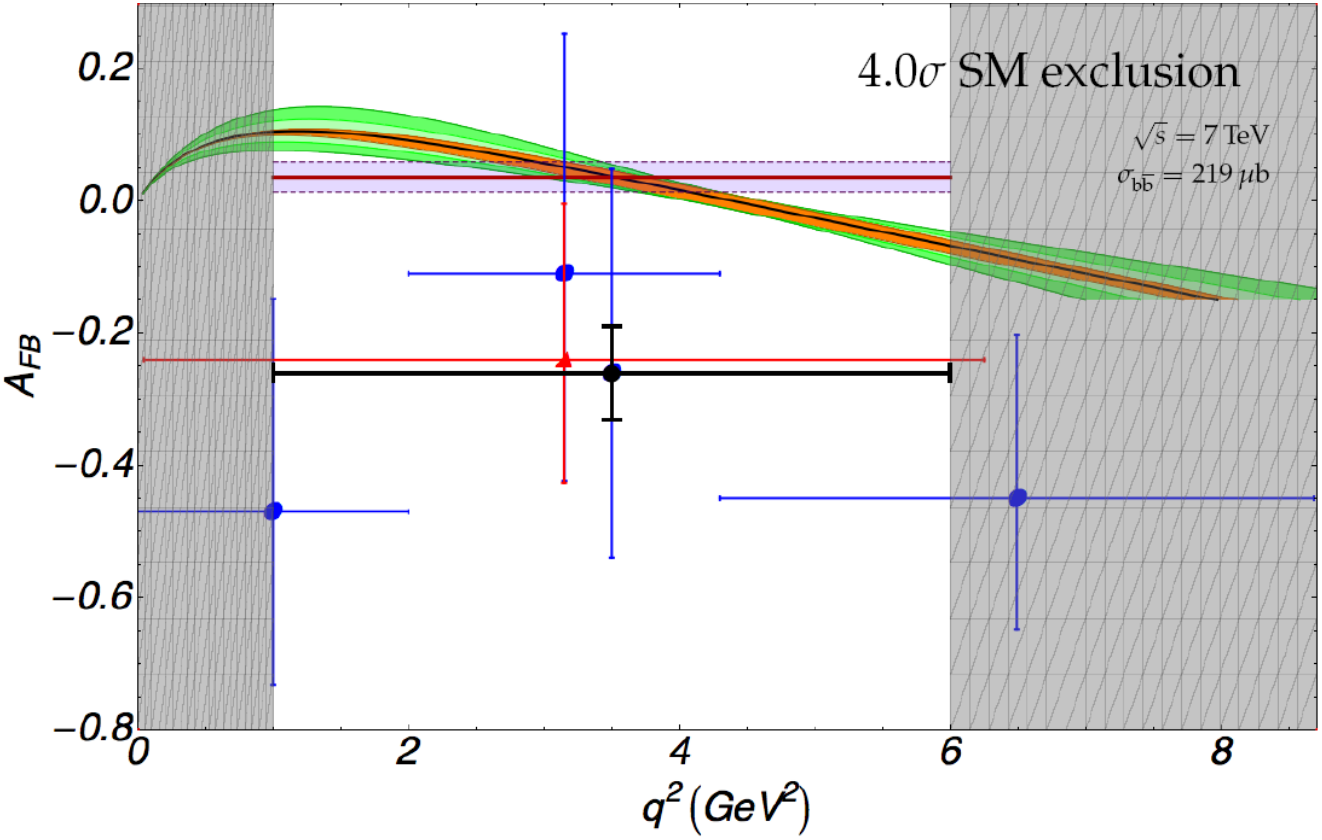
AFB 2011

Estimated error on A_{FB} in most sensitive bin (1-6 GeV^2), assuming Belle's central value

0.2 fb^{-1}: $\sigma(A_{FB})=0.14$ (summer)

1.0 fb^{-1}: $\sigma(A_{FB})=0.07$ (end of 2011)

SM prediction
Egede et al JHEP 0811:032
Belle (2009)
PRL 103 171801
BABAR (2009)
PRD 79 031102
LHCb-MC (projection) at 1.0 fb^{-1}



note : σ(bb) meaured to be 1/3 higher than what assumed here

Other Modes & Experiments

LHCb

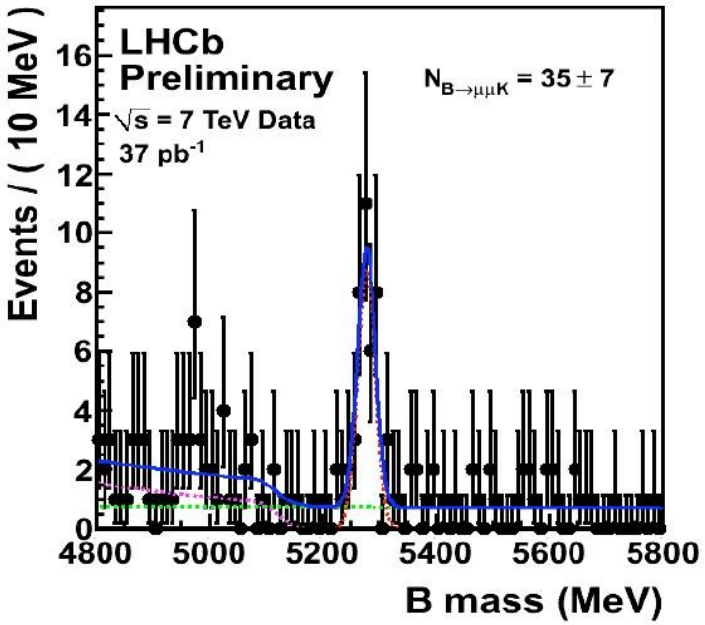
Other $b \to s\mu^+\mu^-$ modes under study:

$B^+ \to K^+\mu^+\mu^-$ as crosscheck for $B^0 \to K^*\mu^+\mu^-$

no AFB expected

Rarest decays seen so far at LHCb
(BR ~ 5 x 10^{-7})

$B^0 \to \phi\mu^+\mu^-$ ...



CMS

Work in progress on:

$B^0 \to K^*\mu^+\mu^-$, $\Lambda_b \to \Lambda\mu^+\mu^-$

No trigger problems expected in 2011/2012

ATLAS

Work in progress on:

$B^0 \to K^*\mu^+\mu^-$, $\Lambda_b \to \Lambda\mu^+\mu^-$, $B^0 \to \phi\mu^+\mu^-$, $B^+ \to K^+\mu^+\mu^-$, $B^+ \to K^{*+}\mu^+\mu^-$

Summary

$B_s \to \mu^+\mu^-$ first LHCb result (0.037 fb^{-1}):

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

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

Phys. Lett. B 669, 330 (2011)

Already now **competitive**

to world's best unpublished (CDF, 3.7 fb^{-1}):

$BR(B_s \to \mu^+\mu^-) < 3.6\ (4.3) \times 10^{-8}$ @ 90 (95% CL)

$BR(B^0 \to \mu^+\mu^-) < 0.60\ (0.76) \times 10^{-8}$ @ 90 (95% CL)

Public CDF note 9892

and to world's best published (D0, 6.1 fb^{-1}):

$BR(B_s \to \mu^+\mu^-) < 5.1 \times 10^{-8}$ @ 95% CL

Phys. Lett B 693, 593 (2010)

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Future (B_s):

2011: LHCb sensitive to the region ~ $0.6\text{–}1.0 \times 10^{-8}$

2012: LHCb 5σ discovery if BR > 10^{-8}

- Looking forward to CDF/D0 updates (this conf?)
  - CDF new expected 95% CL limit (6.9 fb^{-1}): ~2×10^{-8}
- CMS/ATLAS results in the making (summer for CMS?)

$B^0 \to K^*\mu^+\mu^-$ analysis in place

- interesting AFB measurement from LHCb already end of 2011?

Questions?

Backups

Giampiero Mancinelli, CPPM - Marseille

LHCb vs D0/CDF

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

	LHCb	CDF	D0
Luminosity	0.037fb^{-1}	3.7fb^{-1}	6.1fb^{-1}
B+→ J/ψK+	12366	19762	46803
Expected limit @ 95% CL	6.5 10^{-8}	3.3 10^{-8}	4.0 10^{-8}
Observed limit @ 95% CL	5.6 10^{-8}	4.3 10^{-8}	5.1 10^{-8}

With 1/100-1/200 of integrated luminosity, LHCb records ½-¼ $B^{\pm}$ thanks to

- **acceptance & trigger**
- **cross section (factor 3)**
- **boost**
- **mass resolution(D0)**

(better background rejection as well)

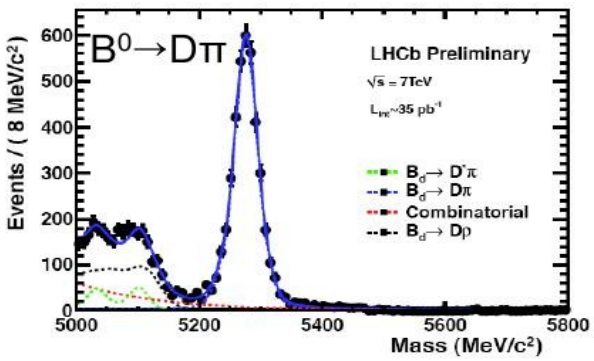
Normalization details

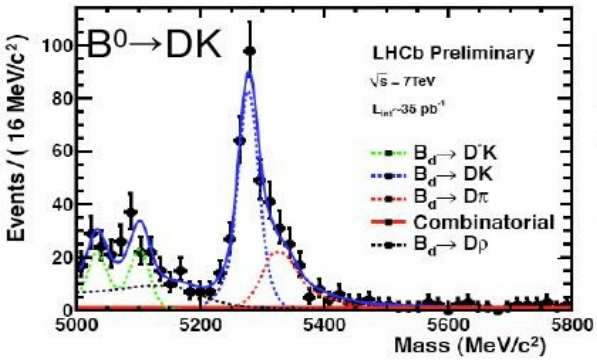
Preliminary results for f_s/f_d from LHC*b* [Moriond 2011 QCD, LHCb-CONF-2011-013]

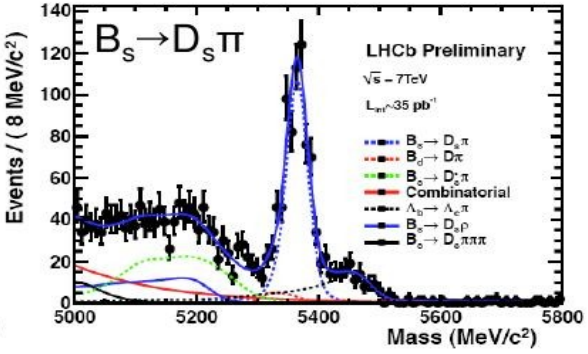
Using ratio of yields of $B_s \to D_s\pi$ to $B^0 \to D\pi$ and $B^0 \to DK$

$f_s/f_d = 0.242 \pm 0.024_{stat} \pm 0.018_{syst} \pm 0.016_{theo}$ with $B^0 \to DK$

$f_s/f_d = 0.249 \pm 0.013_{stat} \pm 0.020_{syst} \pm 0.022_{theo}$ with $B^0 \to D\pi$







	BR 10^{-5}	sel * rec	Trigger	N_{cal}	a($B_s \to$ mm)	a($B^0 \to$ mm)
$B^{\pm} \to J/\psi\, K^{\pm}$	5.98±0.22	0.49±0.02	0.96±0.05	12,366±403	8.4±1.3	2.27±0.18
$B_S \to J/\psi\phi$	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±0.01*	578±74*	7.3±1.8	1.99±0.40

CLs method details

Modified frequentist approach

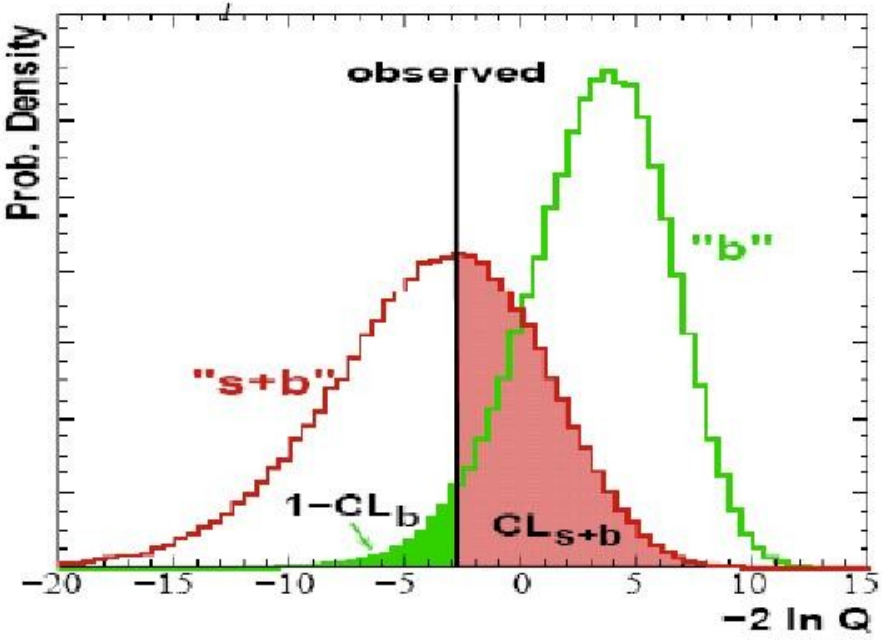
b_i = exp. number of background events

s_i = exp. number of signal events

d_i = observed number of events

$$CL_{s+b} = P(X \leq X_{\text{obs}} | s+b)$$
$$CL_b = P(X \leq X_{\text{obs}} | b)$$

$$CL_s = CL_{s+b}/CL_b$$



$$X = \prod_{i=1}^{n} \frac{P_{\text{pois}}(d_i | \mathrm{E}(d_i) = b_i + s_i)}{P_{\text{pois}}(d_i | \mathrm{E}(d_i) = b_i)}$$

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