

# Ricerca di effetti di nuova fisica nel decadimento $B_{s,d} \rightarrow \mu\mu$ a LHCb

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

The LHCb Collaboration<sup>1</sup>

## Abstract

A search for the decays  $B_s^0 \rightarrow \mu^+ \mu^-$  and  $B^0 \rightarrow \mu^+ \mu^-$  is performed with about  $37 \text{ pb}^{-1}$  of  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$  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  $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 5.6 \times 10^{-8}$  and  $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 1.5 \times 10^{-8}$  at 95% confidence level.

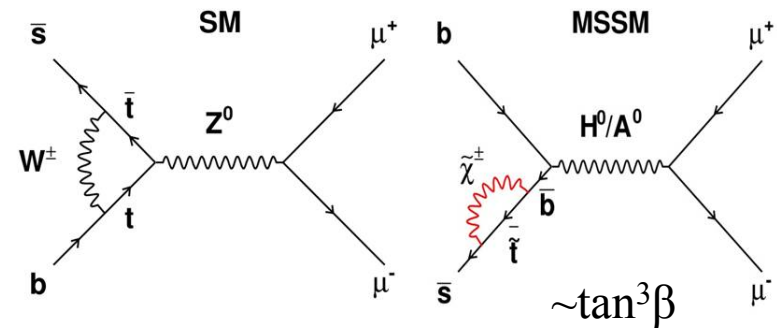
*arXiv:1103.2465 , accettato da Phys. Lett. B*

- *Motivazioni*
- *Strategia di analisi*
- *Risultati*

# $B_{s,d} \rightarrow \mu^+ \mu^-$ : sensibilità alla Nuova Fisica

Il decadimento  $B_{s,d} \rightarrow \mu\mu$  permette di esplorare lo spazio delle fasi del settore Higgs esteso nel MSSM, con un approccio complementare alle ricerche dirette

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



→ Decadimento doppio soppresso nello Standard Model (FCNC e elicità), predizioni accurate:

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

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

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

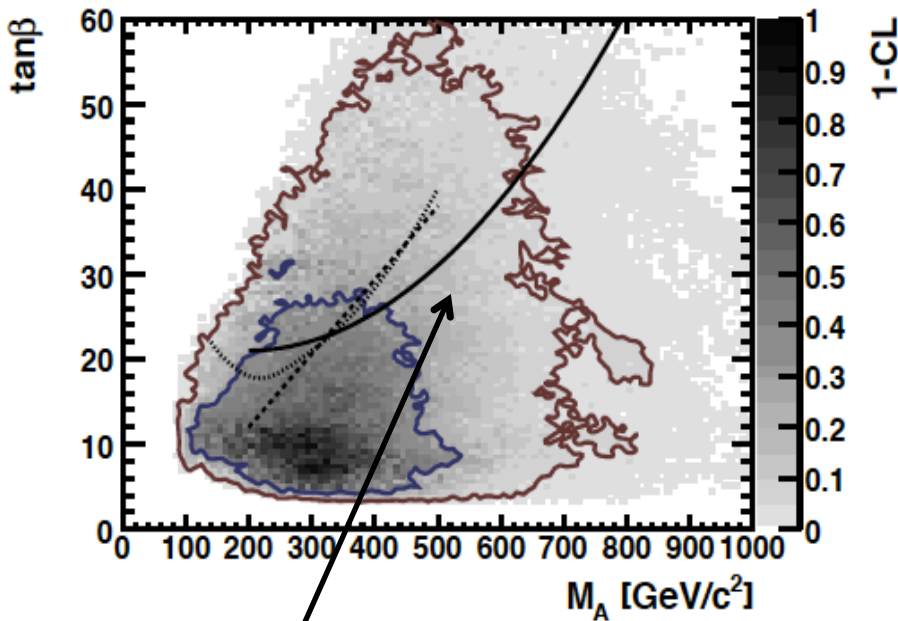
→ sensibile a effetti di Nuova Fisica nel settore scalare/pseudo-scalare:

$$BR(B_{s,d} \rightarrow \mu^+ \mu^-) \propto \tan^6 \beta / M_A^4 \quad \text{MSSM, sensibilità a } \tan \beta \text{ elevati}$$

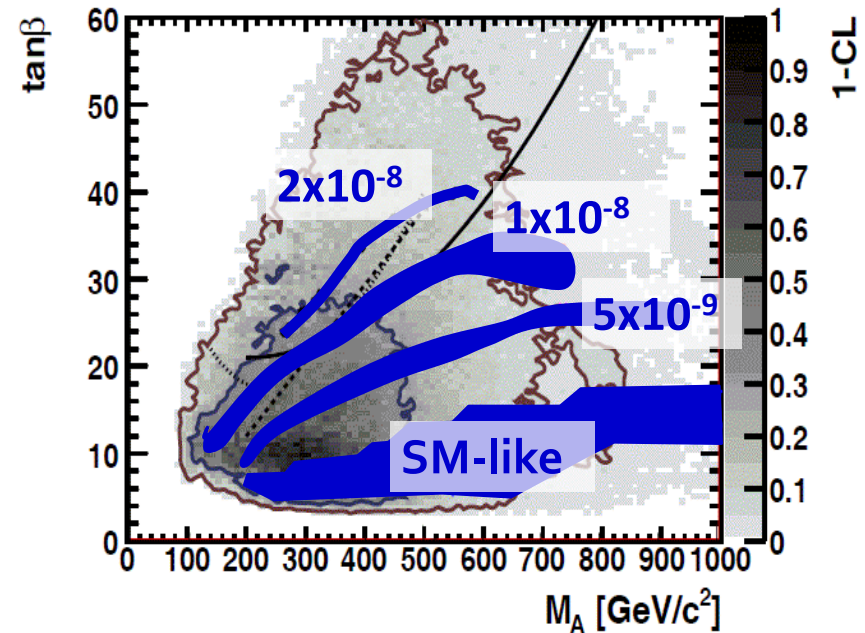
# $B_{s,d} \rightarrow \mu^+ \mu^-$ : sensibilità alla Nuova Fisica

## Risultati di un fit al modello NUHM1 nel piano $\tan\beta$ vs $M_A$

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



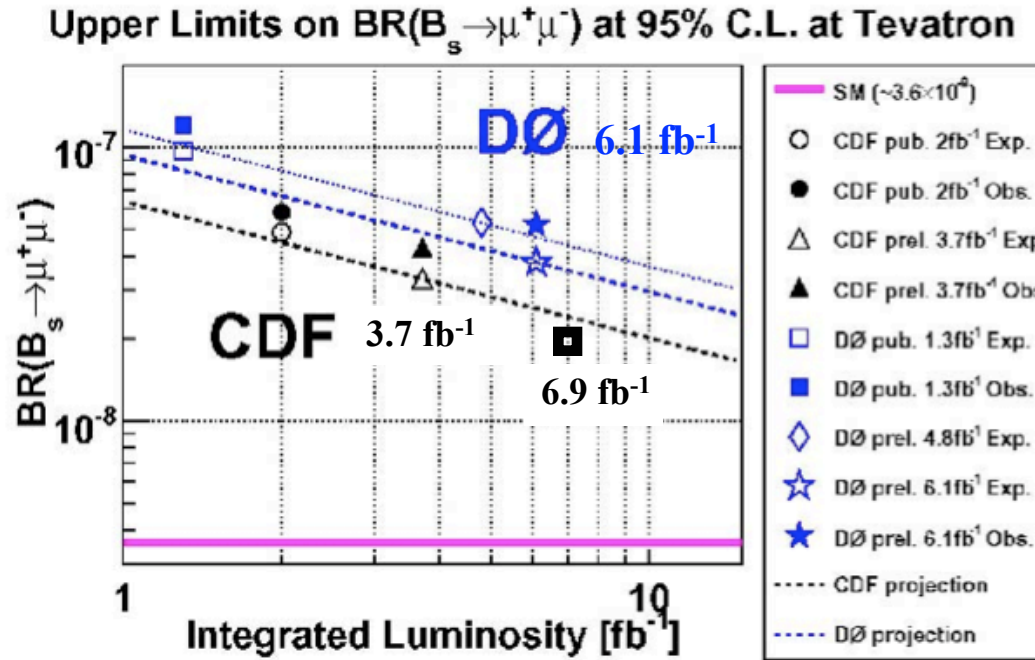
osservazione diretta di  $H/A \rightarrow \tau\tau$  ( $5\sigma$ )



Regioni compatibili con  $BR(B_s \rightarrow \mu\mu) = 2 \times 10^{-8}$ ,  $1 \times 10^{-8}$ ,  $5 \times 10^{-9}$  e SM.

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

# Risultati sperimentali dal Tevatron



PLB 693, 539 (2010)

**Limiti  
osservati**

**CDF ( $\sim 3.7 \text{ fb}^{-1}$ ):  $B_s (B_d) \rightarrow \mu\mu < 43 (7.6) \times 10^{-9}$  al 95% CL**  
**D0 ( $\sim 6.1 \text{ fb}^{-1}$ ):  $B_s \rightarrow \mu\mu < 51 \times 10^{-9}$**

CDF ha migliorato l'analisi, ed ha un limite aspettato  $B_s \rightarrow \mu\mu < 2 \times 10^{-8}$  su  $6.9 \text{ fb}^{-1}$

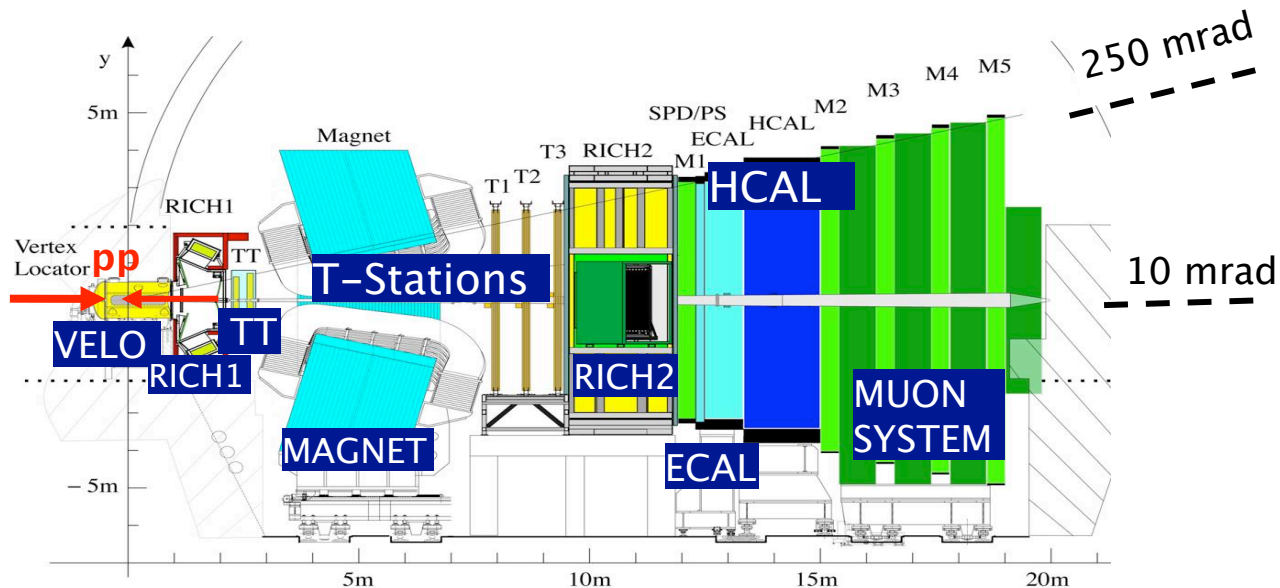
Kong, Beauty 2011

**risultato di LHCb da  $37 \text{ pb}^{-1}$  acquisiti nel 2010**

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

- Sezione d'urto:  $\sigma(pp \rightarrow b\bar{b}X)$  @ 7 TeV  $\sim 300 \mu\text{b}$  *LHCb, PLB 694 (2010)*
- Accettanza (le coppie  $b\bar{b}$  sono prodotte a piccolo angolo):  $1.9 < \eta < 4.9$ 
  - $\epsilon(\text{acceptance} \times \text{reco})$  per  $B_{s,d} \rightarrow \mu\mu \sim 10\%$  *SM: 0.7 eventi  $B_s \rightarrow \mu\mu$*
- Boost: distanza di volo dei mesoni B  $\sim 1$  cm

→  $12\text{k } B^+ \rightarrow J/\psi(\mu\mu)K^+$  con  $0.037 \text{ fb}^{-1}$  *CDF  $\sim 20\text{k}$  con  $3.7 \text{ fb}^{-1}$   
note 9892*



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

## 1) Trigger di muoni

- identificazione degli stati finali muonici con efficienza  $\sim 90\%$

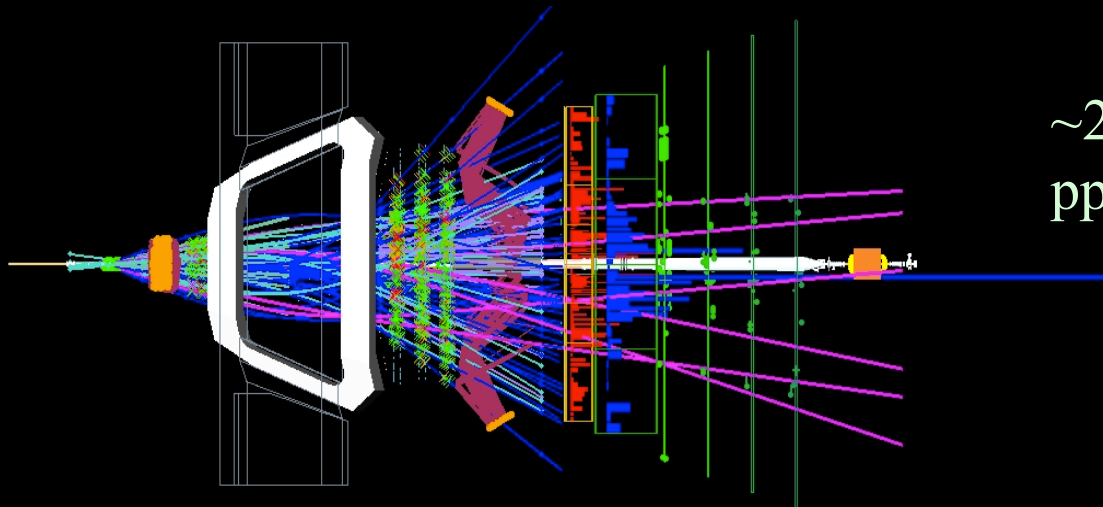
## 2) Reiezione del fondo

- Ottima risoluzione in massa :  $dp/p \sim 0.35\% \rightarrow 0.55\%$  per  $p=(5-100)$  GeV/c
- Identificazione di muoni:  $\varepsilon(\mu \rightarrow \mu) \sim 98\%$  con  $\varepsilon(h \rightarrow \mu) < 1\%$  per  $p > 10$  GeV/c

## 3) Risoluzione di vertice & parametro d'impatto

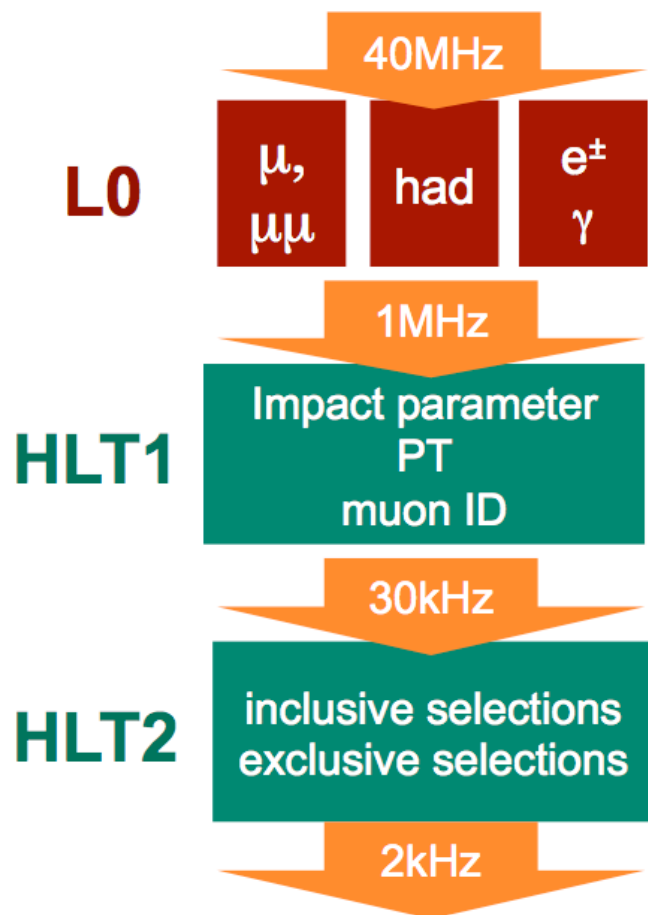
- Separazione del segnale dal fondo prompt :  $\sigma(\text{IP}) \sim 25 \mu\text{m}$  @  $p_T=2$  GeV/c

LHCb event display



$\sim 2.5$  interazioni  
pp per crossing

# Trigger sui muoni

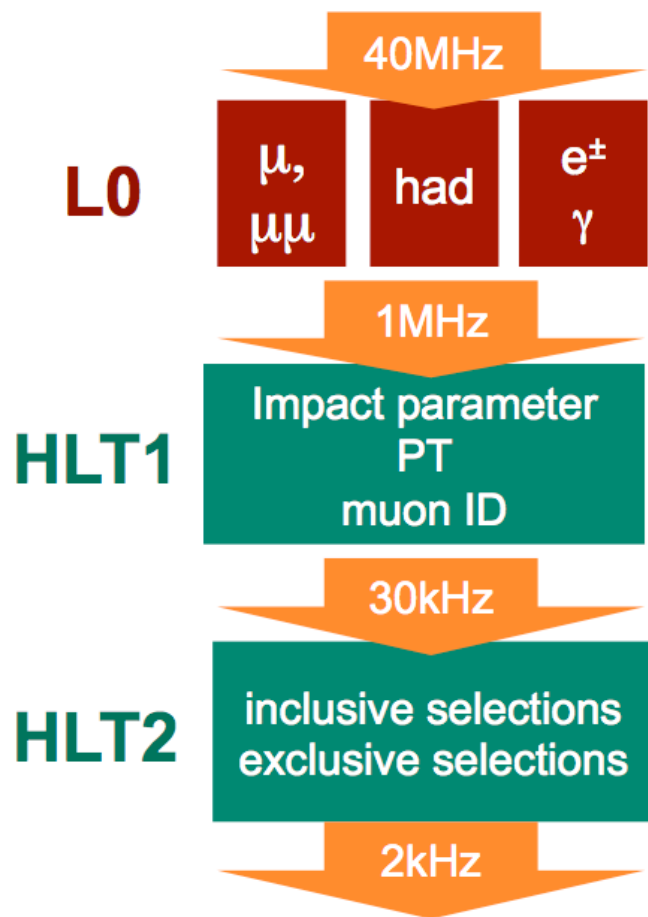


	Linee Muoniche
<b>L0</b>	Single- $\mu$ : $p_T > 1.4 \text{ GeV}/c$ $\mu\mu$ : $p_{T1} > 0.56 \text{ GeV}/c$ $p_{T2} > 0.48 \text{ GeV}/c$
<b>HLT1</b>	single- $\mu$ : $p_T > 0.8 \text{ GeV}/c$ $IP > 0.11 \text{ mm}$ single- $\mu$ : $p_T > 1.8 \text{ GeV}/c$ (no IP)
<b>HLT2</b>	Diverse linee con tagli in $M_{\mu\mu}$ e/o vertici secondari

- 50% della banda ( $\sim 1 \text{ kHz}$ ) dedicata alle linee muoniche
- tagli in  $p_T$  nelle linee muoniche molto soft  $\rightarrow \epsilon(\text{trigger } B_{sd} \rightarrow \mu\mu) \sim 90\%$
- Condizioni di trigger stabili durante l'intera presa dati (incremento di  $L \sim 10^5$ )



# Trigger sui muoni



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# Strategia di analisi

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- **Preselezione**
- **Discriminazione segnale/fondo mediante 2 criteri**
  - **Massa invariante** della coppia di muoni,  $M_{\mu\mu}$
  - **Likelihood Geometrica**, GL, contenente l'informazione topologica e cinematica dell'evento
- **Calibrazione delle likelihoods dai dati**
- **Normalizzazione**
  - conversione del numero di eventi osservati in una frazione di decadimento, BR, utilizzando canali di BR noto
- **Estrazione del limite**
  - confronto degli eventi osservati con l'aspettazione per fondo e segnale, in funzione di  $BR_{sig}$ ; utilizzo del metodo **CLs binnato** per associare un livello di probabilità all'esclusione (osservazione) del valore assunto per  $BR_{sig}$

# Preselezione

Coppie di muoni di carica opposta, accoppiati in un vertice secondario, nell'intervallo di massa invariante [4769-5969] MeV/c<sup>2</sup>

- Efficienza per il segnale elevata: ~50%
- Reiezione di gran parte del fondo: ~300 eventi nella regione di segnale

$$M(B_{s,d}) \pm 60 \text{ MeV}/c^2$$

→ fondo dominato da eventi  $bb \rightarrow \mu\mu X$

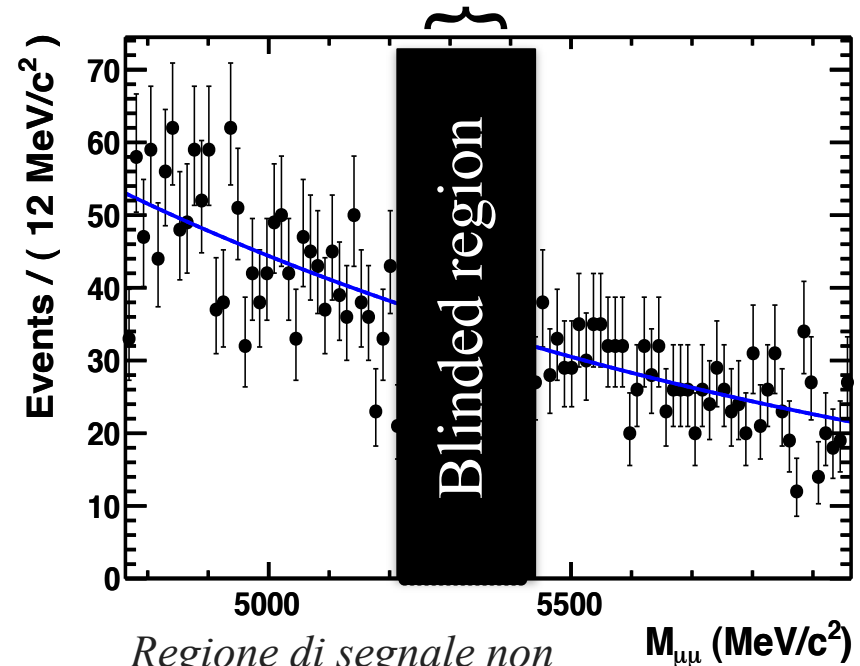
(decadimento doppio semi-leptonico o processi in cascata)

→ fondo di picco ( $B \rightarrow hh'$ )

completamente trascurabile

(< 0.1 eventi nella regione di segnale)

- Fondo stimato dalle sidebands



Regione di segnale non accessibile fino all'approvazione finale dell'analisi

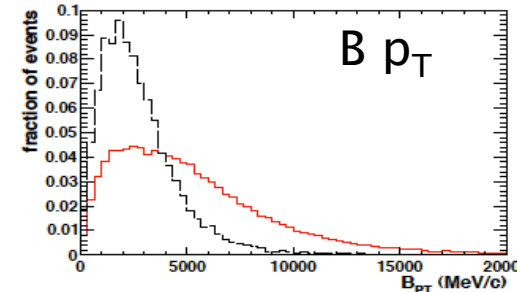
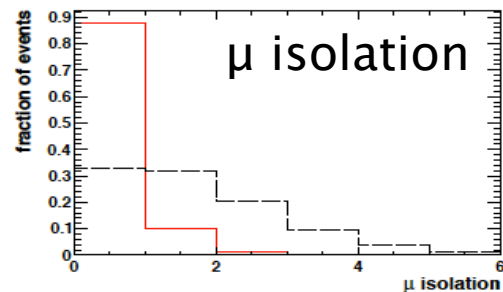
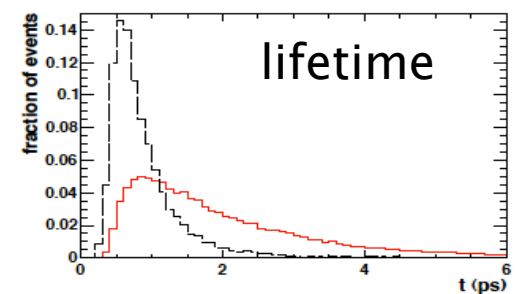
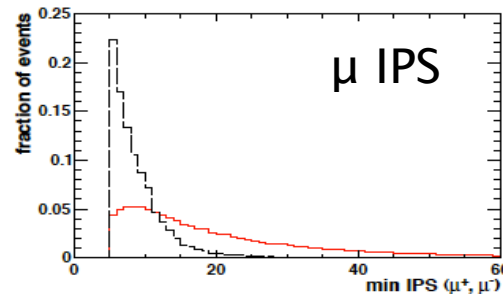
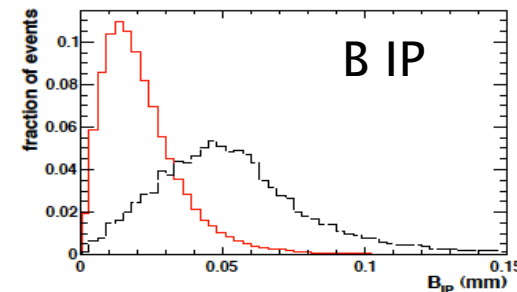
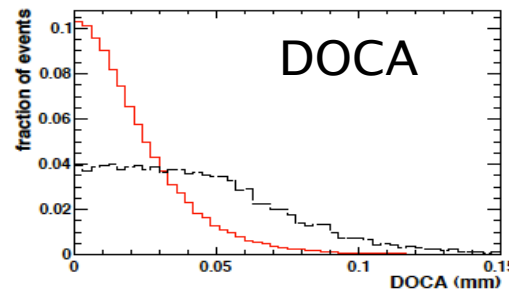
# Likelihood Geometrica

Fondo combinatorio dominato da coppie di muoni da  $b$  (o  $c$ )

→ reiezione mediante  
variabili legate alla topologia  
e alla cinematica dell'evento

- Le variabili sono decorrelate e combinate in una likelihood, definita piatta per il segnale e piccata a 0 per il fondo
- Per la definizione della likelihood si fa uso esclusivo di campioni MC  $B_s \rightarrow \mu\mu$  e  $bb \rightarrow \mu\mu X$

variabili di ingresso alla GL, MC



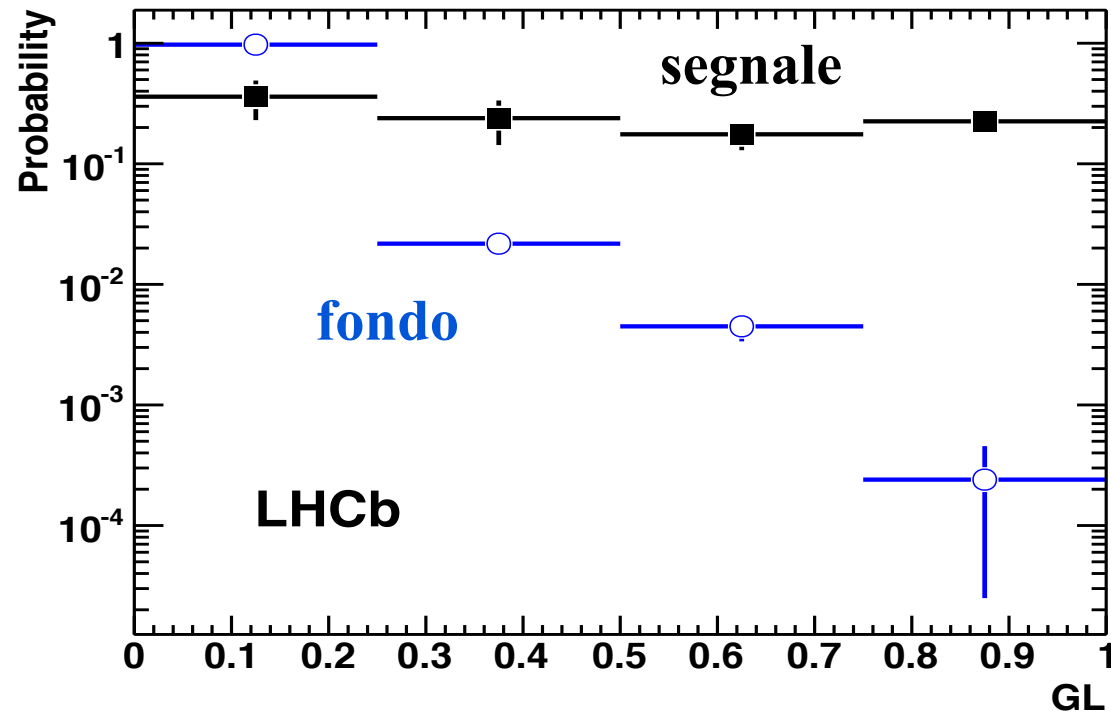
$B_{d,s} \rightarrow \mu\mu$   $bb \rightarrow \mu\mu X$

# Likelihood Geometrica

La GL è calibrata dai dati, per evitare di introdurre bias dal MC

a) per il segnale si usano  
decadimenti  $B_{d,s} \rightarrow h^+ h'^-$   
*stessa topologia*

b) per il fondo si usano le  
sidebands di massa  
*fondo di picco trascurabile*



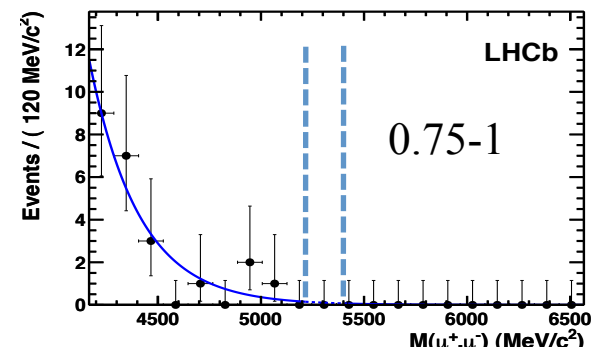
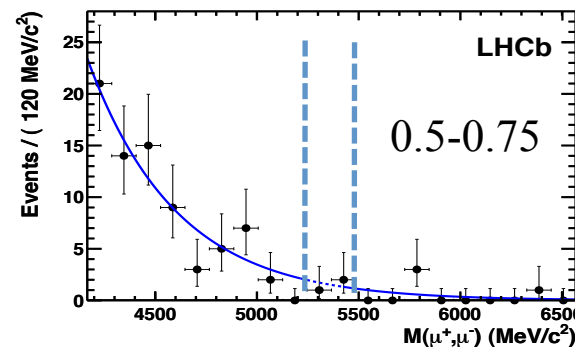
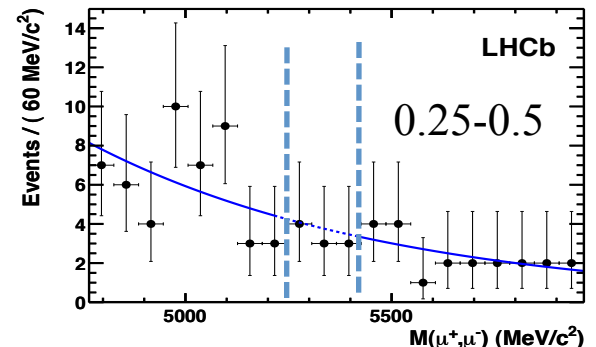
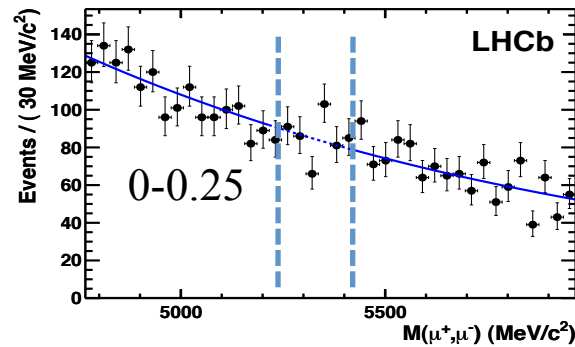
*analisi effettuata in 4 bins di GL*

# Stima del fondo

Il fondo aspettato nelle regioni di segnale è estratto da un fit alle sidebands di massa per ciascuno dei bin in GL

Fondo aspettato nella regione di massa del  $B_s$

GL bin	$B_s \rightarrow \mu\mu$
0-0.25	$329.1 \pm 6.4$
0.25-0.5	$7.4 \pm 1.0$
0.5-0.75	$1.51^{+0.41}_{-0.35}$
0.75-1	$0.08^{+0.10}_{-0.05}$



$\pm 600 \text{ MeV}$

$\pm 1200 \text{ MeV}$

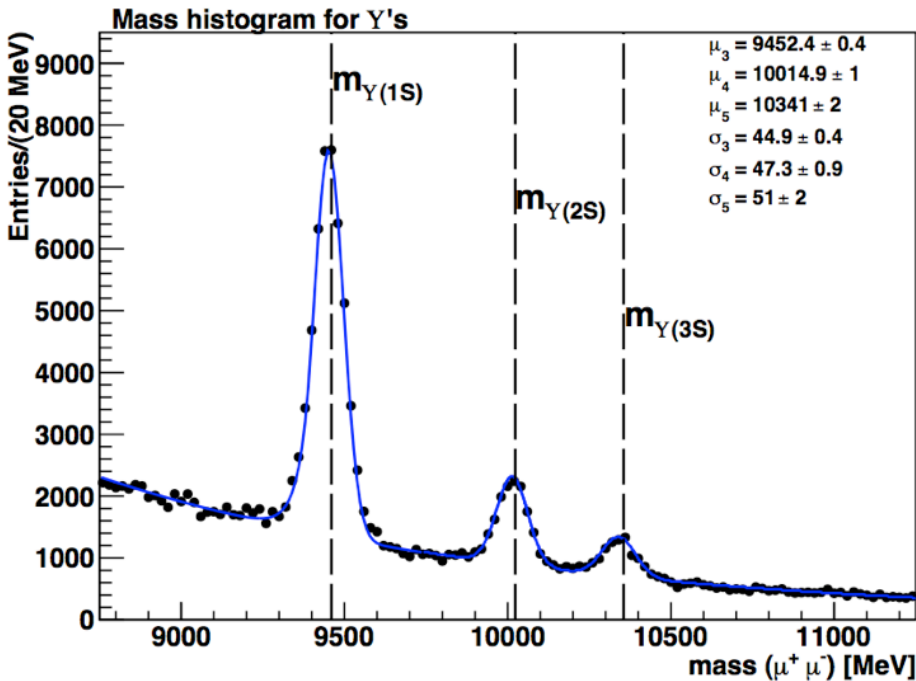
*ad alta GL il fondo aspettato è molto basso*

# Calibrazione della massa invariante $B_{d,s}$

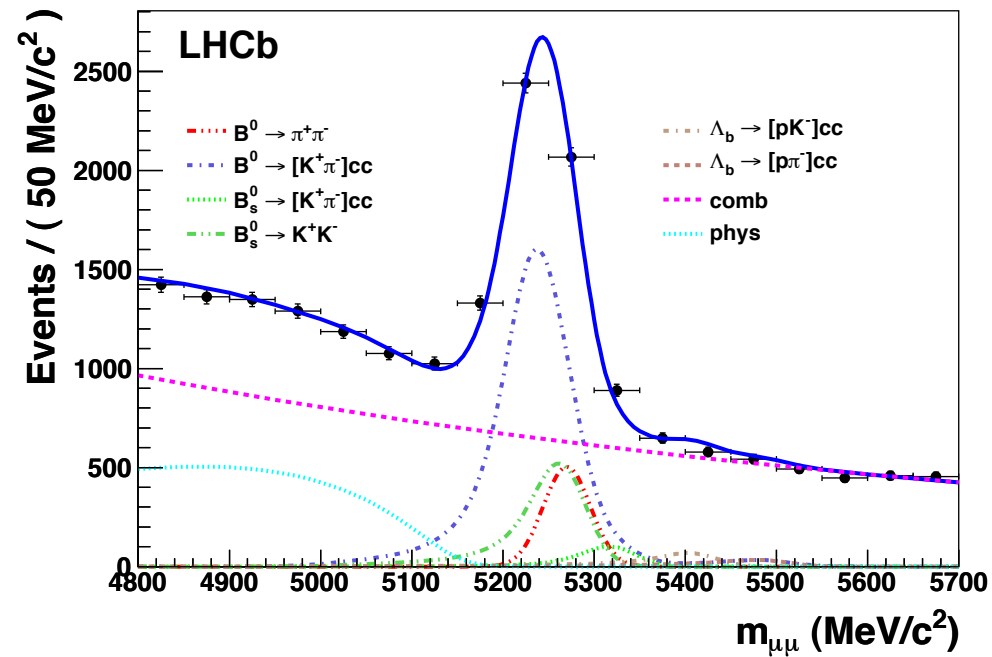
I valori centrali sono ottenuti da  $B_d \rightarrow K^+ \pi^-$  and  $B_s \rightarrow K^+ K^-$  (usando il RICH)

La risoluzione di massa è ottenuta dai dati mediante due metodi:

1) Interpolazione dalle risonanze in 2 muoni ( $J/\psi$ ,  $\psi(2s)$ ,  $\Upsilon$ 's)



2) Fit al campione inclusivo  $B \rightarrow hh'$  (no RICH)



I risultati da entrambi i metodi, in accordo tra loro, sono mediati:

$$\sigma = 26.7 \pm 0.9_{\text{stat+syst}} \text{ MeV}/c^2$$

# Normalizzazione

La PDF di segnale (GL e massa invariante) è tradotta in un numero di eventi aspettati normalizzandosi ad un canale noto ( $BR_{\text{cal}}$ ):

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

## Tre canali indipendenti

**1)  $BR(B^+ \rightarrow J/\psi(\mu^+ \mu^-) K^+) = (5.98 \pm 0.22) 10^{-5}$   $\Delta BR = 3.7\%$**

Trigger e PID simili al segnale. Sistematica sul rapporto di efficienze dominata dal tracciamento (+1 traccia);  $f_d/f_s$ , noto con un'incertezza del 13%, domina l'errore totale.

**2)  $BR(B_s \rightarrow J/\psi(\mu^+ \mu^-) \phi(K^+ K^-)) = (3.4 \pm 0.9) 10^{-5}$   $\Delta BR = 26\%$**

Trigger e PID simili al segnale. Sistematica sul rapporto di efficienze dominata dal tracciamento (+2 tracce); l'incertezza sul BR dominata l'errore totale.

**3)  $BR(B^0 \rightarrow K^+ \pi^-) = (1.94 \pm 0.06) 10^{-5}$   $\Delta BR = 3.1\%$**

Topologia identica al segnale. Contributi all'incertezza totale dall'efficienza del trigger adronico, dal rapporto  $f_d/f_s$  e dal conteggio degli eventi.



# $f_d/f_s$ : presente e futuro

Al momento usiamo la media  
HFAG dei risultati

LEP/Tevatron:  $f_d/f_s = 3.71 \pm 0.47$

[http://www.slac.stanford.edu/xorg/hfag/osc/end\\_2009/#FRAC](http://www.slac.stanford.edu/xorg/hfag/osc/end_2009/#FRAC)

## Risultati preliminary da LHCb:

1)  $f_d/f_s$  dai rapporti di  $B^0 \rightarrow D^+ K^-$  (e  $B^0 \rightarrow D^+ \pi^-$ ) su  $B_s^0 \rightarrow D_s^+ \pi^-$ ,  $35 \text{ pb}^{-1}$ :

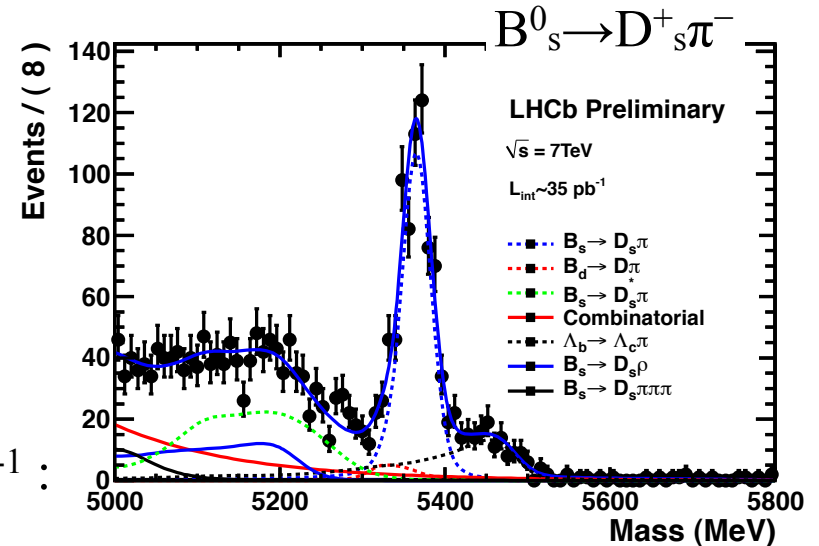
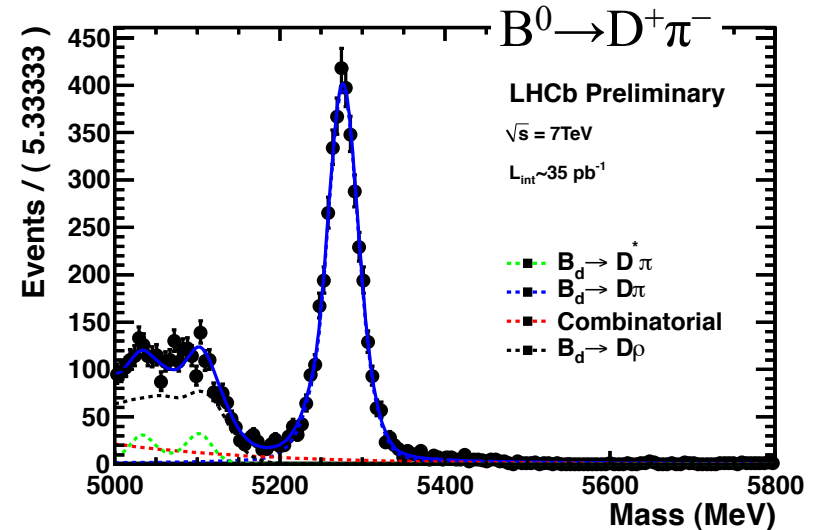
$$f_d/f_s = 4.02 \pm 0.52 \quad \text{usando } B^0 \rightarrow D^+ \pi^-$$

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

*LHCb-CONF-2011-013*

2)  $f_d/f_s$  dai decadimenti semileptonici,  $3 \text{ pb}^{-1}$ :

$$f_d/f_s = 3.84 \pm 0.34$$



# Normalizzazione: risultati

$$BR = \underbrace{BR_{cal}}_{\text{black circle}} \times \underbrace{\frac{\epsilon_{cal}^{REC} \epsilon_{cal}^{SEL|REC} \epsilon_{cal}^{TRIG|SEL}}{\epsilon_{sig}^{REC} \epsilon_{sig}^{SEL|REC} \epsilon_{sig}^{TRIG|SEL}}}_{\text{blue oval}} \times \frac{f_{cal}}{f_{B_s^0}} \times \frac{N_{B_s^0 \rightarrow \mu^+ \mu^-}}{N_{cal}} = \underbrace{\alpha}_{\text{red circle}} \times N_{B_s^0 \rightarrow \mu^+ \mu^-}$$

	$B$ ( $\times 10^{-5}$ )	$\frac{\epsilon_{norm}^{REC} \epsilon_{norm}^{SEL REC}}{\epsilon_{sig}^{REC} \epsilon_{sig}^{SEL REC}}$	$\frac{\epsilon_{norm}^{TRIG SEL}}{\epsilon_{sig}^{TRIG SEL}}$	$N_{norm}$	$\alpha_{B_s^0 \rightarrow \mu^+ \mu^-}$ ( $\times 10^{-9}$ )	$\alpha_{B^0 \rightarrow \mu^+ \mu^-}$ ( $\times 10^{-9}$ )
$B^+ \rightarrow J/\psi K^+$	$5.98 \pm 0.22$	$0.49 \pm 0.02$	$0.96 \pm 0.05$	$12366 \pm 403$	$8.4 \pm 1.3$	$2.27 \pm 0.18$
$B_s^0 \rightarrow J/\psi \phi$	$3.4 \pm 0.9$	$0.25 \pm 0.02$	$0.96 \pm 0.05$	$760 \pm 71$	$10.5 \pm 2.9$	$2.83 \pm 0.86$
$B^0 \rightarrow K^+ \pi^-$	$1.94 \pm 0.06$	$0.82 \pm 0.06$	$0.072 \pm 0.010$	$578 \pm 74$	$7.3 \pm 1.8$	$1.99 \pm 0.40$

I tre canali di normalizzazione danno risultati compatibili:  
 → Media pesata tenendo conto delle sistematiche correlate

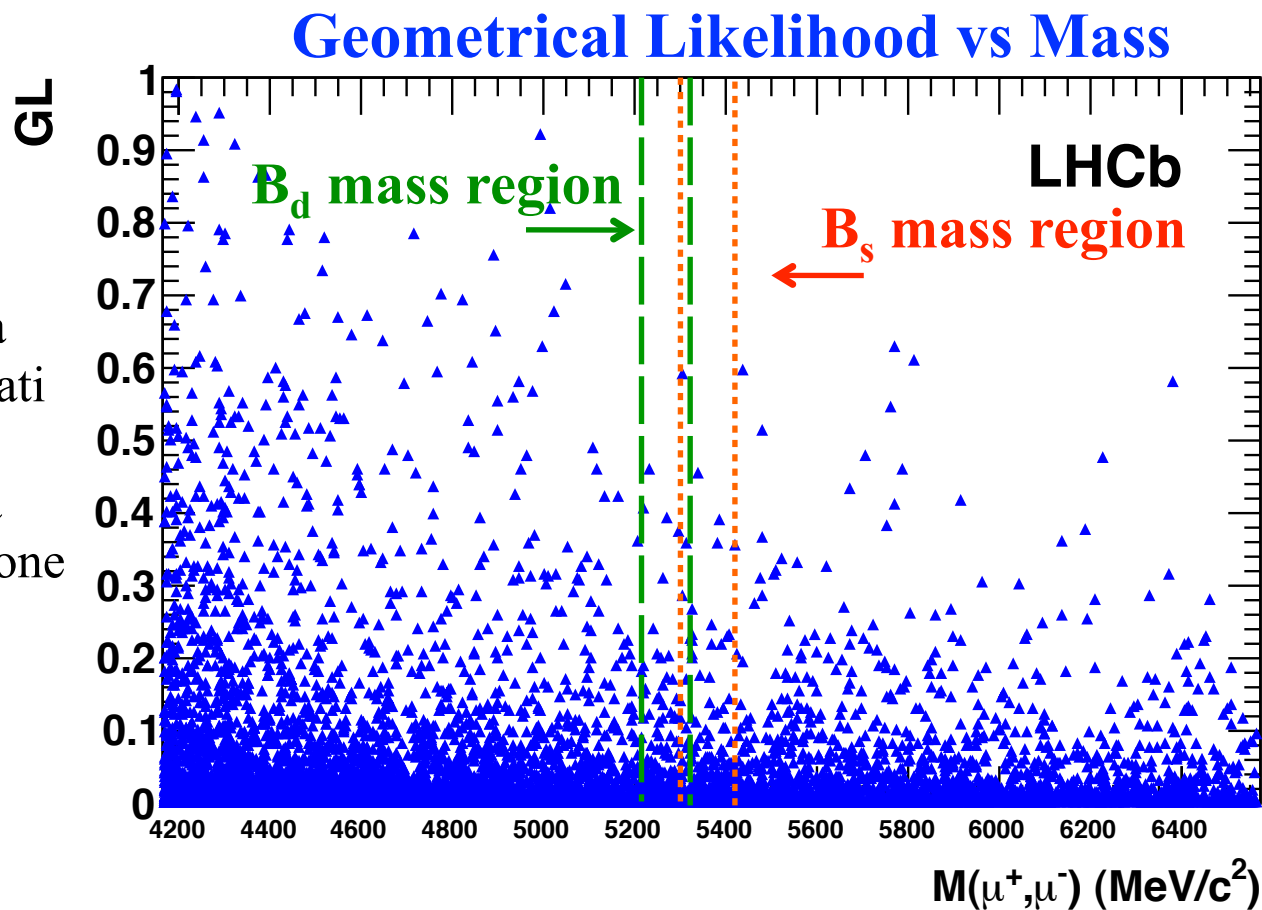


$$\alpha_{B_s^0 \rightarrow \mu^+ \mu^-} = (8.6 \pm 1.1) \times 10^{-9}$$

$$\alpha_{B^0 \rightarrow \mu^+ \mu^-} = (2.24 \pm 0.16) \times 10^{-9}$$

# Distribuzione degli eventi osservati

- 1) Conteggio degli eventi in 4 bins di GL  $\times$  6 bins di massa
- 2) Per ciascun bin si calcola il segnale ed il fondo aspettati
- 3) Si valuta la compatibilità tra osservazione e aspettazione
  - in ipotesi S+B [ $CL_{S+B}$ ]
  - in ipotesi B [ $CL_B$ ]



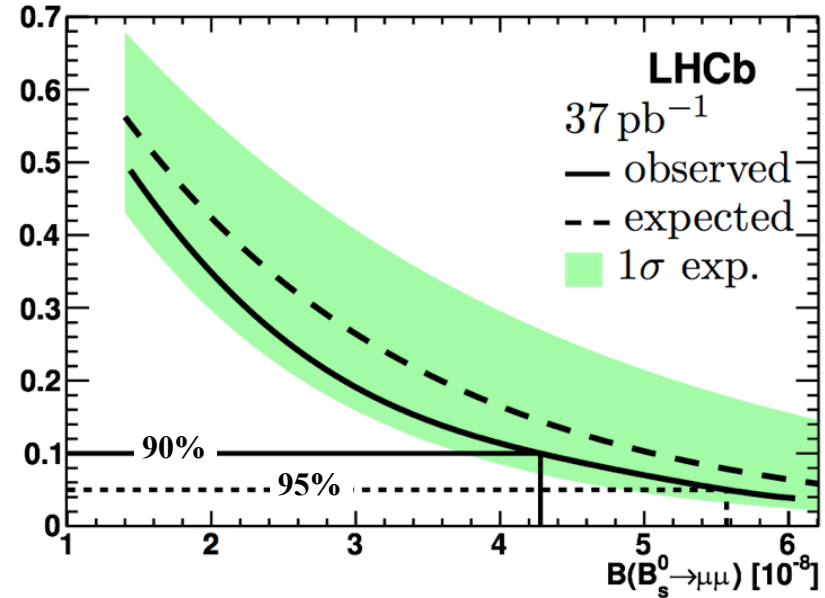
**$CL_S = CL_{S+B} / CL_B =$  compatibilità con l'ipotesi segnale**  
 **$\rightarrow$  Usato per calcolare l'esclusione**

# Limite sul BR( $B_s \rightarrow \mu^+ \mu^-$ )

Observed distribution of events

		GL bin				CLs
		[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]	
Mass bin (MeV/c <sup>2</sup> )	[-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	
sum		335	7	1	0	
bkg exp.		329	7.36	1.51	0.081	

CLs vs BR( $B_s \rightarrow \mu\mu$ )



**BR( $B_s \rightarrow \mu\mu$ ) < 4.3 (5.6)  $\times 10^{-8}$  al 90% (95%) CL, con 37 pb<sup>-1</sup>**

**limite aspettato < 5.1 (6.5)  $\times 10^{-8}$**

*arXiv:1103.2465, accettato da Phys. Lett. B*

CDF BR( $B_s \rightarrow \mu\mu$ ) < 4.3  $\times 10^{-8}$  at 95% CL, con 3.7 fb<sup>-1</sup> *Public note 9892 (2009)*

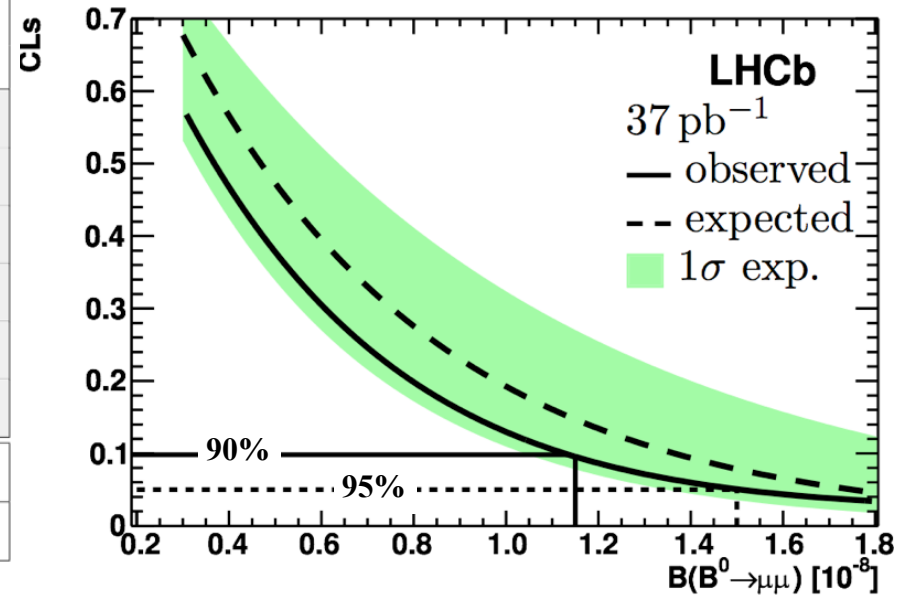
D0 BR( $B_s \rightarrow \mu\mu$ ) < 5.1  $\times 10^{-8}$  at 95% CL, con 6.1 fb<sup>-1</sup> *Phys. Lett. B 693 (2010)*

# Limite sul BR( $B_d \rightarrow \mu^+ \mu^-$ )

Observed distribution of events

		GL bin			
		[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
Mass bin (MeV/c <sup>2</sup> )	[-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
sum		333	8	1	0
bkg exp.		353	8.9	1.85	0.12

CLs vs BR( $B_d \rightarrow \mu\mu$ )



**BR( $B_d \rightarrow \mu\mu$ ) < 1.2 (1.5)  $\times 10^{-8}$  al 90% (95%) CL, with 37 pb<sup>-1</sup>**

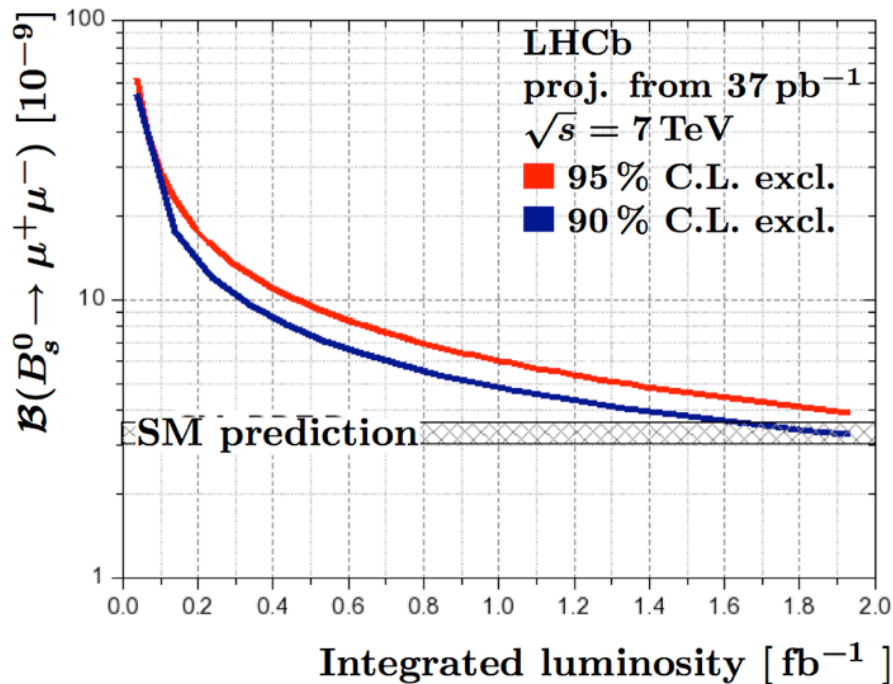
**expected limit < 1.4 (1.8)  $\times 10^{-8}$**

*arXiv:1103.2465, accettato da Phys. Lett. B*

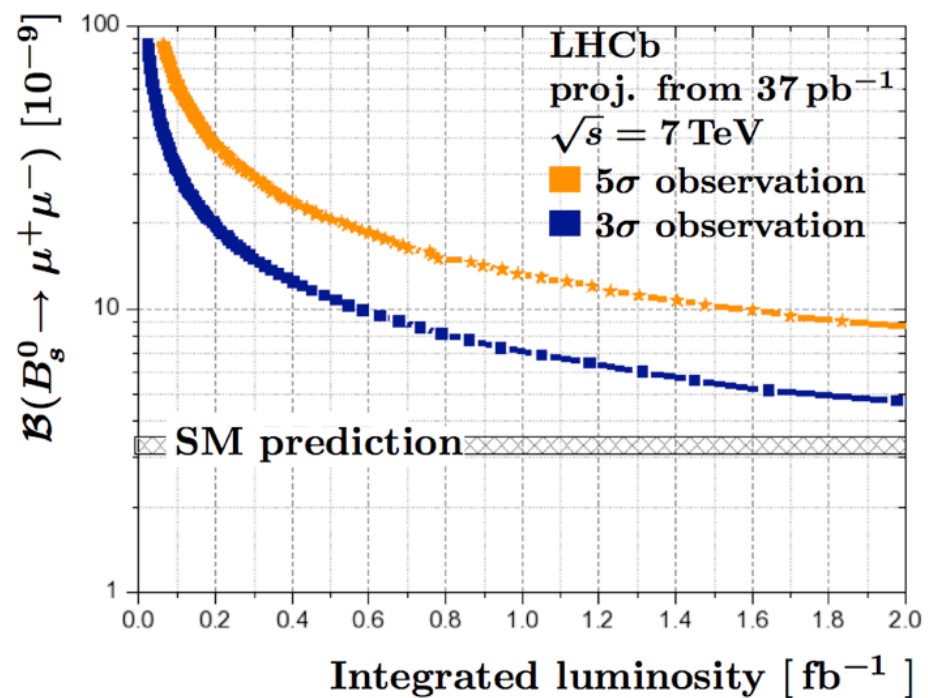
CDF BR( $B_d \rightarrow \mu\mu$ ) < 0.76  $\times 10^{-8}$  at 95% CL, with 3.7 fb<sup>-1</sup> *Public note 9892 (2009)*

# $B_s \rightarrow \mu^+ \mu^-$ : prospettive nel biennio 2011-2012

esclusione



osservazione



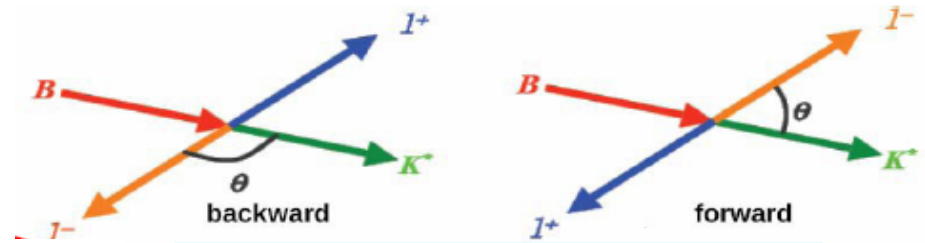
- ci aspettiamo di integrare  $\leq 1 \text{ fb}^{-1}$  nel 2011, e  $\sim 2 \text{ fb}^{-1}$  entro il 2012
- *i risultati ottenuti suggeriscono ottime prospettive per esplorare nei prossimi due anni lo spazio delle fasi per la ricerca di nuova fisica fino alle previsioni SM!*

# Prospettive nei decadimenti rari: $B_d \rightarrow K^* \mu^+ \mu^-$ !!

L'asimmetria forward-backward nel decadimento  $B_d \rightarrow K^* l^+ l^-$  è molto sensibile a contributi di nuova fisica

Le misure più recenti sono consistenti tra loro e con lo SM

I presenti errori di misura non consentono però di escludere scenari di nuova fisica (flipped- $C_7$  scenario)



$$A_{FB}(s = m_{\mu^+ \mu^-}^2) = \frac{N_F - N_B}{N_F + N_B}$$



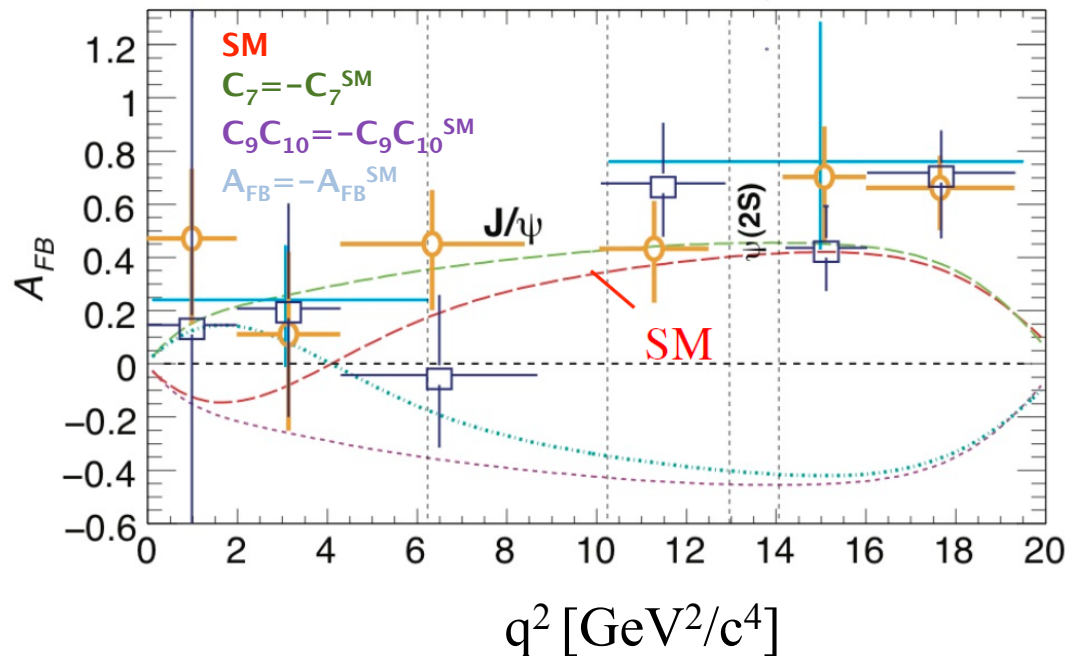
250  $K^* l^+ l^-$   
80% of data



100  $K^* l^+ l^-$   
75% of data



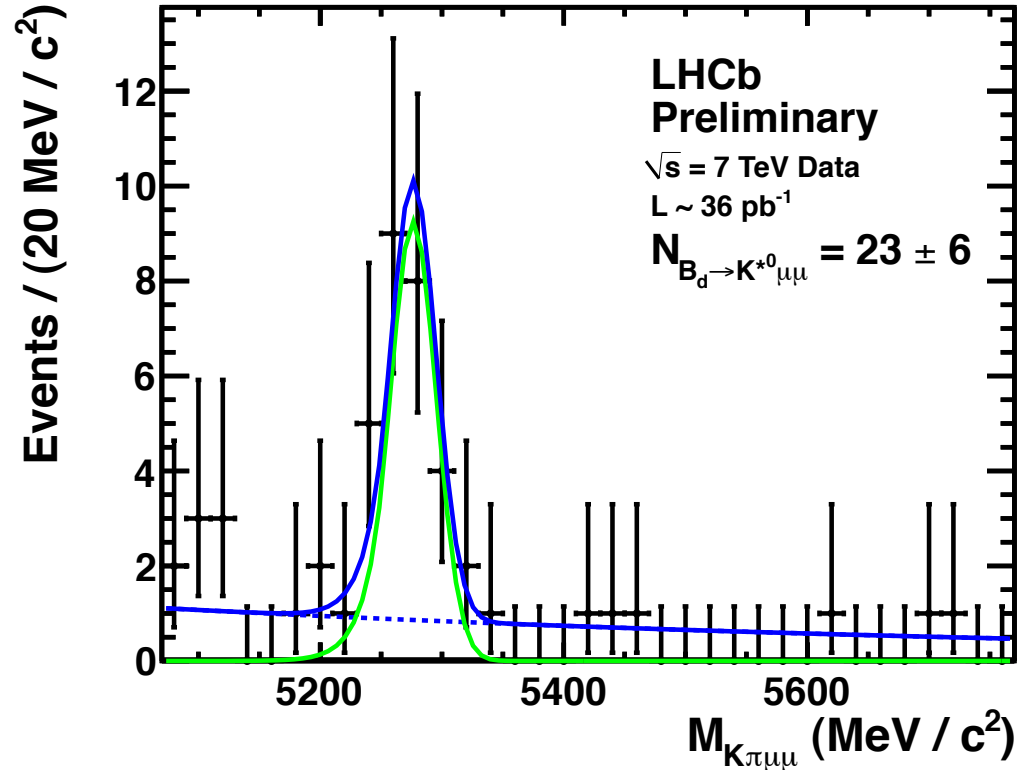
100  $K^* \mu^+ \mu^-$   
4.4  $\text{fb}^{-1}$



# Osservazione del $B_d \rightarrow K^* \mu^+ \mu^-$ a LHCb

$23 \pm 6$  eventi osservati su un campione di  $36 \text{ pb}^{-1}$  ( $\text{BR} \sim 10^{-6}$ ), in linea con le previsioni

*Con  $300 \text{ pb}^{-1}$  si prevede di essere competitivi con le misure esistenti*



**Sistematica principale: bias introdotto dall'accettazione del rivelatore, dal trigger e dalla selezione:**

**→ campione di controllo  $B_d \rightarrow J/\psi(\mu\mu)K^*$  (stesso stato finale)**

**ottimo accordo tra dati e MC osservato finora**



# ... e osservazione del $B^+ \rightarrow K^+ \mu^+ \mu^-$

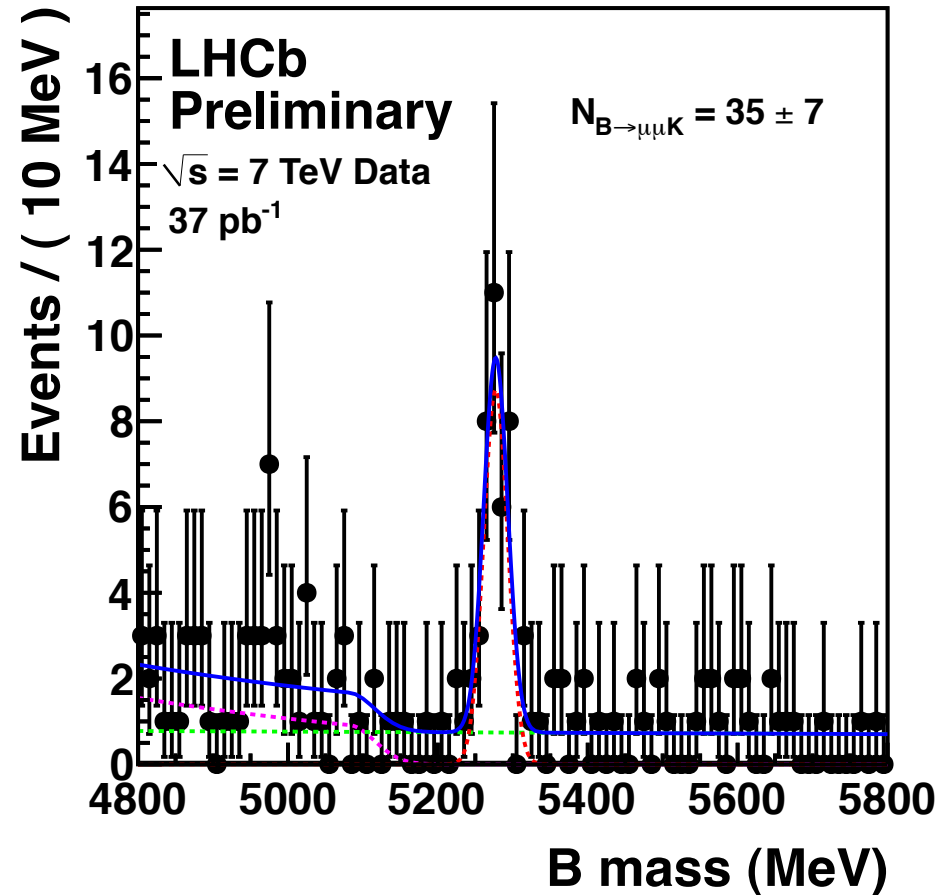
$35 \pm 7$  eventi in  $37 \text{ pb}^{-1}$

È il decadimento più raro del B osservato finora ad LHCb,  $\text{BR} \sim 5 \times 10^{-7}$  !

Motivazione: verificare la predizione SM  $\Rightarrow \text{BR}(B \rightarrow K e e) / \text{BR}(K \mu \mu) \sim 1$

**Importante: lo SM non prevede asimmetria forward-backward**

**$\Rightarrow$  complementarità con il  $K^* \mu \mu$**



- L'analisi di  $37 \text{ pb}^{-1}$  acquisiti nel 2010 a  $\sqrt{s} = 7 \text{ TeV}$  ha permesso di porre limiti stringenti sul decadimento  $B_{s,d} \rightarrow \mu^+ \mu^-$ :

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

$$\text{BR}(B_d \rightarrow \mu\mu) < 1.5 \times 10^{-8} @ 95\% \text{ CL}$$

*arXiv:1103.2465, accettato  
da Phys. Lett. B*

- I risultati di LHCb sono competitivi con i limiti osservati al Tevatron, che si basano su una luminosità integrata  $\sim 100$  volte maggiore

**I risultati ottenuti suggeriscono ottime prospettive per esplorare nei prossimi due anni lo spazio delle fasi per la ricerca di nuova fisica fino alle previsioni SM!**

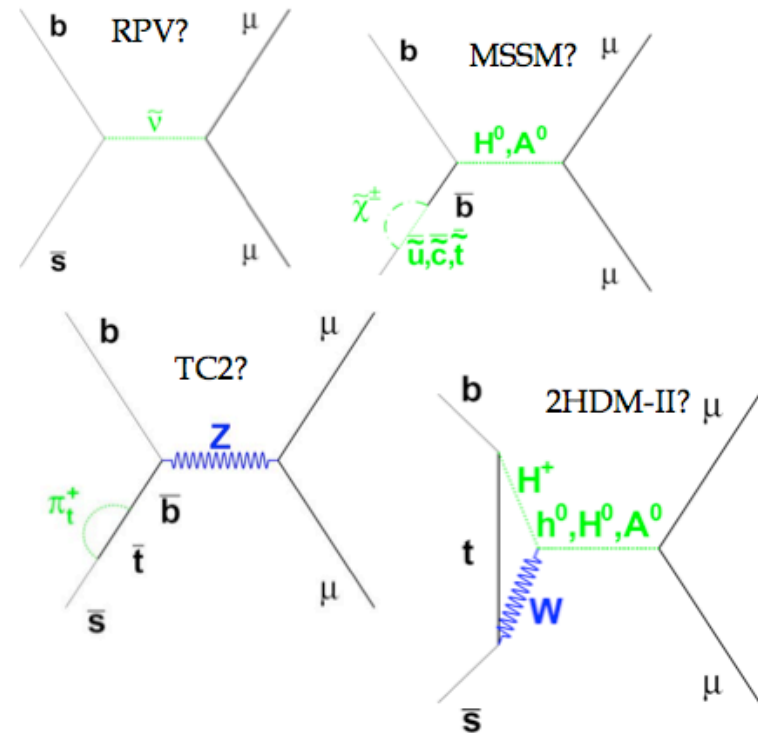


# Backup

# New Physics effects

NP can contribute to this decay rate (specially SUSY at high  $\tan\beta$  ( $\tan\beta = v_u/v_d$ )):

- More than one Higgs  $\rightarrow$  contributions to  $C_{S,P}$ 
  - 2HDM-II : BR proportional to  $\tan^4\beta$
  - SUSY (MSSM): above + extra  $\tan^6\beta$  +...
- RPV SUSY: tree level diagrams
- Technicolor (TC2), Little Higgs (LHT) ... modify  $C_{10}$ .



NP can modify the BR from  $<$  SM up to current experimental u.l.

*D. Martinez Santos, Moriond EW 2011*

# New Physics effects

**Maximal Enhancements of  $S_{\psi\phi}$ ,  $\text{Br}(B_s \rightarrow \mu^+\mu^-)$  and  $K^+ \rightarrow \pi^+\nu\bar{\nu}$**

(without taking correlation between them)

Model	Upper Bound on $(S_{\psi\phi})$	Enhancement of $\text{Br}(B_s \rightarrow \mu^+\mu^-)$	Enhancement of $\text{Br}(K^+ \rightarrow \pi^+\nu\bar{\nu})$
CMFV	0.04	20%	20%
MFV	0.04	1000%	30%
LHT	0.30	30%	150%
RS	0.75	10%	60%
4G	0.80	400%	300%
AC	0.75	1000%	2%
RVV	0.50	1000%	10%

Large  
RH Currents

RS = RS with custodial protections

AC = Agashe, Carone

RVV = Ross, Velasco-Sevilla, Vives (04)

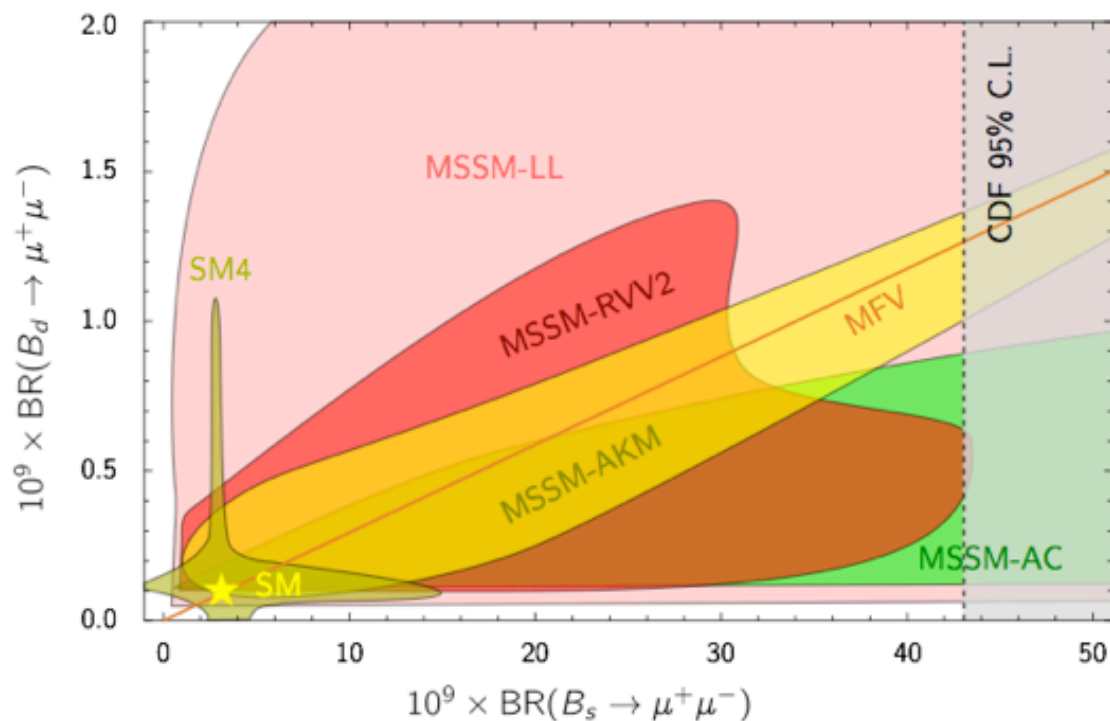
$U(1)_F$

$SU(3)_F$

# New Physics effects

$B_s \rightarrow \mu^+ \mu^-$  vs.  $B_d \rightarrow \mu^+ \mu^-$

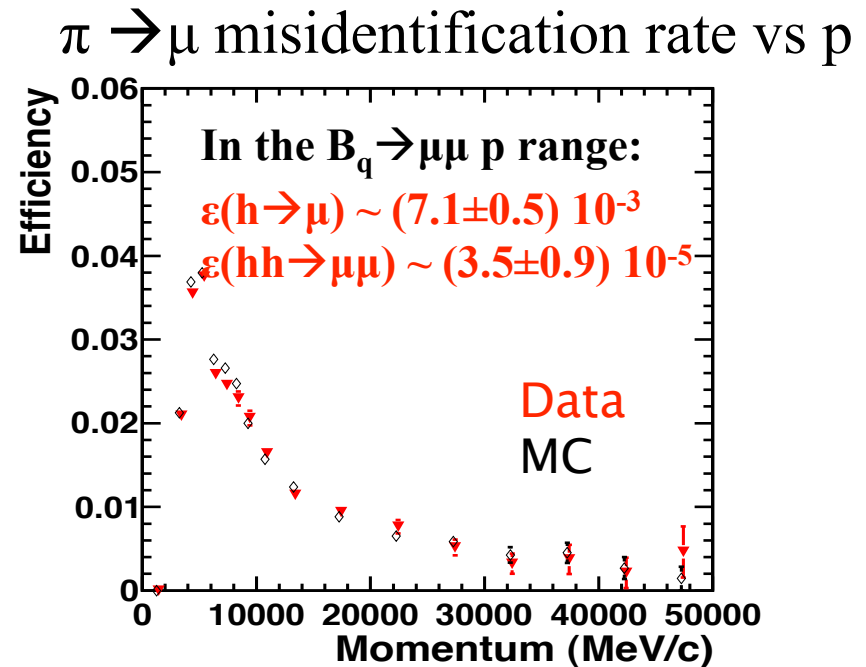
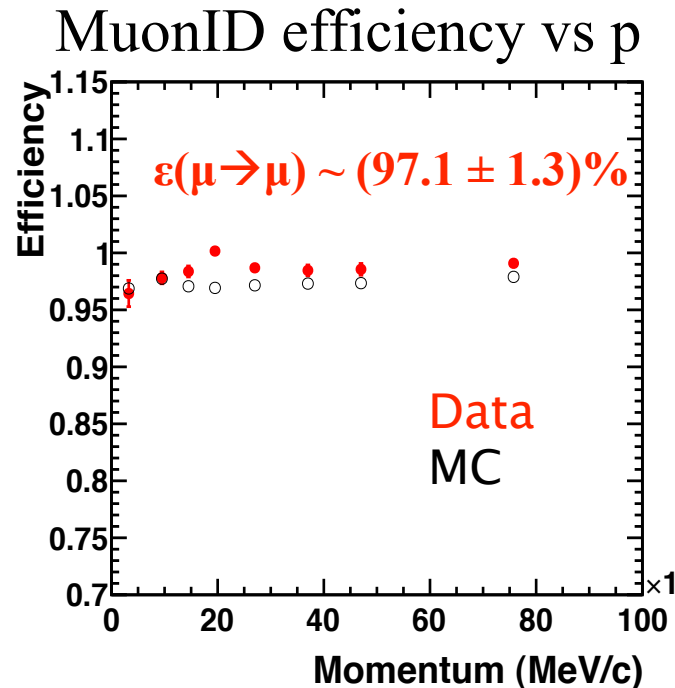
A stringent test of the MFV paradigm:  $\frac{\text{BR}(B_s \rightarrow \mu^+ \mu^-)}{\text{BR}(B_d \rightarrow \mu^+ \mu^-)} = \frac{|V_{ts}|^2}{|V_{td}|^2}$



4th generation SM [Buras et al. 1002.2126] SUSY flavour models [Altmannshofer et al. 0909.1333]

# MuonID performance & background composition

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



**We are dominated by the  $bb \rightarrow \mu\mu X$  component**  
(double semi-leptonic decays and cascade processes)  
fake+ $\mu \sim 10\%$  and double fake  $\sim 0.3\%$   
**Peaking background ( $B \rightarrow hh'$ ) fully negligible**  
( $< 0.1$  events in signal regions)

# Ratio of fragmentation fractions

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

Quantity		in $Z$ decays	at Tevatron	combined
Mixing probability	$\bar{\chi}$	$0.1259 \pm 0.0042$	$0.147 \pm 0.011$	$0.1284 \pm 0.0069$
$B^+$ or $B^0$ fraction	$f_u = f_d$	$0.403 \pm 0.009$	$0.339 \pm 0.031$	$0.404 \pm 0.012$
$B_s^0$ fraction	$f_s$	$0.103 \pm 0.009$	$0.111 \pm 0.014$	$0.109 \pm 0.012$
$b$ -baryon fraction	$f_{\text{baryon}}$	$0.090 \pm 0.015$	$0.211 \pm 0.069$	$0.083 \pm 0.020$
Correlation between $f_s$ and $f_u = f_d$		$-0.523$	$+0.426$	$-0.475$
Correlation between $f_{\text{baryon}}$ and $f_u = f_d$		$-0.870$	$-0.984$	$-0.854$
Correlation between $f_{\text{baryon}}$ and $f_s$		$+0.035$	$-0.582$	$-0.053$

[HFAG: http://www.slac.stanford.edu/xorg/hfag/osc/end\\_2009/#FRAC](http://www.slac.stanford.edu/xorg/hfag/osc/end_2009/#FRAC)

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



# Normalization factors: systematic uncertainties

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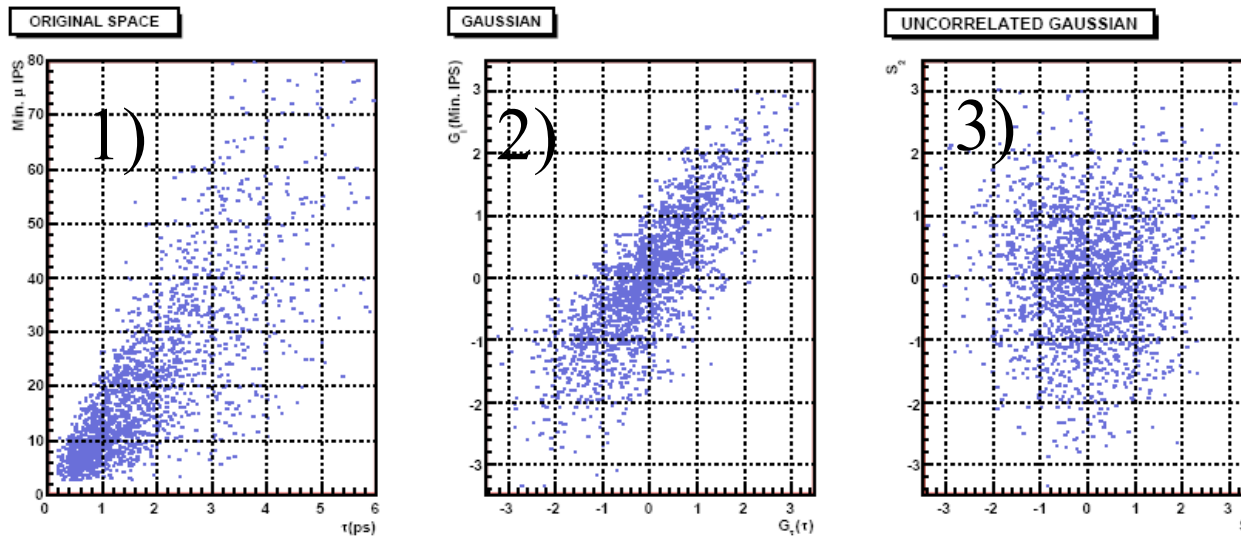
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	$\epsilon(\text{REC}) \times \epsilon(\text{SEL})$	$\epsilon(\text{TRIG})$	fd/fs	N	BR	total
$B^\pm \rightarrow J/\psi K^\pm$	4%	5%	13%	3%	4%	15%
$B_S \rightarrow J/\psi \phi$	8%	5%	--	9%	26%(*)	28%
$B_d^0 \rightarrow K\pi$	7%	14%	13%	13%	3%	23%

(\*) from Belle @  $\Upsilon(5S)$ : [arXiv:0905.4345](https://arxiv.org/abs/0905.4345)

# Geometrical Likelihood

- How the decorrelation is done:
  - 1). Input variables  $\rightarrow$  2) Gaussian variables
    - $\rightarrow$  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:  
 $\rightarrow$  Build  $\chi^2$

$\rightarrow$  Transformation under signal hypothesis:  $\chi^2_S$

$\rightarrow$  Transformation under background hypothesis:  $\chi^2_B$

Discriminating variable:  $GL = \chi^2_S - \chi^2_B \rightarrow$  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  $SPD < 450 / 900$   
 $\rightarrow$  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 <sup>-1</sup>
1b	1.0 / 600	1.0 / 0.4 / 600	2.26 / 600	1 pb <sup>-1</sup>
2	1.4 / 900	0.56 / 0.48 / 900	2.6 / 900	2.3 pb <sup>-1</sup>
3a	1.4 / 900	0.56 / 0.48 / 900	3.6 / 900	17.3 pb <sup>-1</sup>
3b	1.4 / 900	0.56 / 0.48 / 900	3.6 / 450	11.9 pb <sup>-1</sup>

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  $mass > 4.7 \text{ GeV}/c$

# Background composition: peaking background from $B \rightarrow hh$ '

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

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

The peaking background is fully negligible

Our dominant background is combinatorial of  $\mu\mu X$  with  $\sim 10\%$  contamination from  $\mu$ +fakes [again combinatorial].

# Summary of parameters entering in the limit computation

## Signal parameters

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

## Background parameters

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

# Geometrical Likelihood Bins

$B_s \rightarrow \mu\mu$  search window

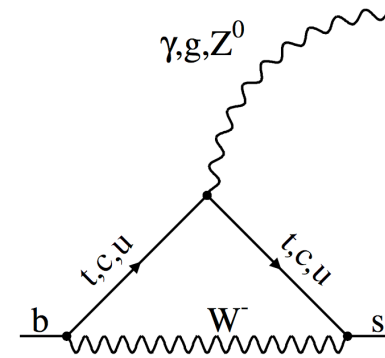
Invariant Mass bins ( $\text{MeV}/c^2$ )

		GL bin				
		[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]	
Invariant mass bin ( $\text{MeV}/c^2$ )	[-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 38	

$B_d \rightarrow \mu\mu$ search window		Geometrical Likelihood Bins				
		[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]	
Invariant Mass bins (MeV/c <sup>2</sup> )	[-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.	$0.0026^{+0.0009}_{-0.0009}$	$0.0017^{+0.0008}_{-0.0006}$	$0.0013^{+0.0004}_{-0.0003}$	$0.0016^{+0.0004}_{-0.0002}$
		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	

# Search for right-handed currents in $b \rightarrow s \gamma$

Main goal, is to measure the photon polarization (mostly left-handed in SM,  $A_R/A_L \sim m_s/m_b$ ) and  $CP$ -violation parameters  $C$  and  $S$  in  $B_s \rightarrow \phi \gamma$



$$\Gamma(B_q(\bar{B}_q) \rightarrow f^{CP} \gamma) \propto e^{-\Gamma_q t} \left( \cosh \frac{\Delta\Gamma_q t}{2} - \mathcal{A}^\Delta \sinh \frac{\Delta\Gamma_q t}{2} \pm \right. \\ \left. \pm C \cos \Delta m_q t \mp S \sin \Delta m_q t \right)$$

F. Muheim, Y. Xie, and R. Zwicky, Phys. Lett. B664:174-179, 2008

$B_s$  is sensitive to  $A^\Delta \approx 2A_R/A_L$

Expect to improve present experimental picture with  $\sim 500 \text{ pb}^{-1}$

**$B_s \rightarrow \phi \gamma$  first observed by Belle, with  $\text{BR} \sim 6 \times 10^{-5}$**

*Phys. Rev. Lett.* 100 121801 (2008)



# $B_d \rightarrow K^* \gamma$ observed

Reference point for the measurement of the other radiative decays and as calibration signal (calorimeter energy scale, photon trigger)

Direct  $CP$  asymmetry: less than 1% in SM, compared to 3% experimental accuracy (PDG08 & HFAG 2008)

Photon polarization:  $CP$ -violation parameters  $C$  and  $S$  from time-dependent  $CP$ -asymmetries (no sensitivity to  $A^\Delta$  for  $B_d$ )

