

Rare decays at LHCb

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(on behalf of the LHCb collaboration)

Outline



- Motivations
- LHCb detector
- General analysis strategy
- Recent results for rare decays from LHCb
- Conclusion

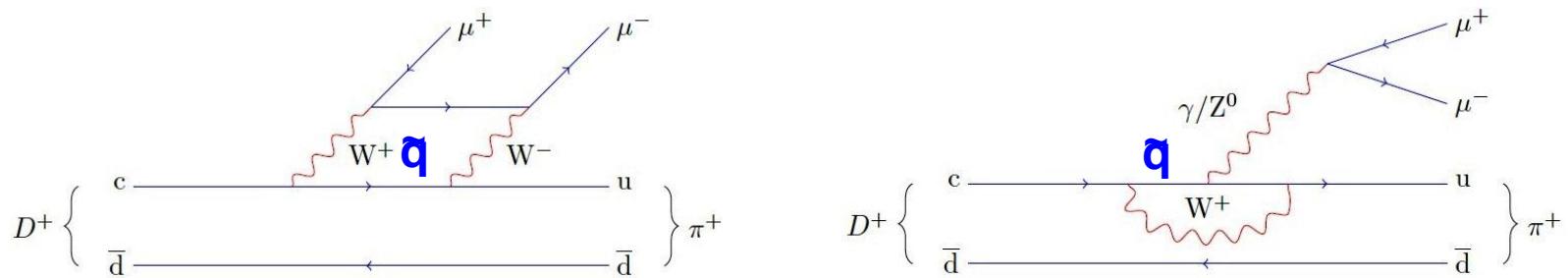
Motivations



Flavor Changing Neutral Currents (FCNC) are **very suppressed** in the Standard model

Ex. of FCNC: $b \rightarrow s$, $b \rightarrow d$, $c \rightarrow u$

ONLY FROM LOOP DIAGRAMS



→ Suppression (loops, GIM, helicity, ...) → Good probe for **New Physics**

New Physics: new particles in the loop



- enhancement of BF
- distortion of angular distributions
- asymmetries (CP, FB, Isospin)

Rare decay at LHCb



➤ Branching fraction measurements

- $B^0_{(s)} \rightarrow \mu^+ \mu^-$ [LHCb-PAPER-2012-043]
- $\tau^- \rightarrow \mu^+ \mu^- \mu^-$ [LHCb-CONF-2012-015]
- $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ [LHCb-CONF-2012-006]
- $D^0 \rightarrow \mu^+ \mu^-$ [LHCb-CONF-2012-005]
- $K_s \rightarrow \mu^+ \mu^-$ [LHCb-PAPER-2012-024]

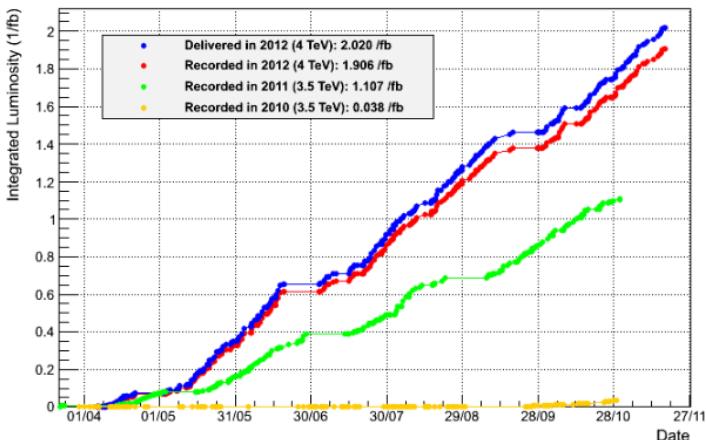
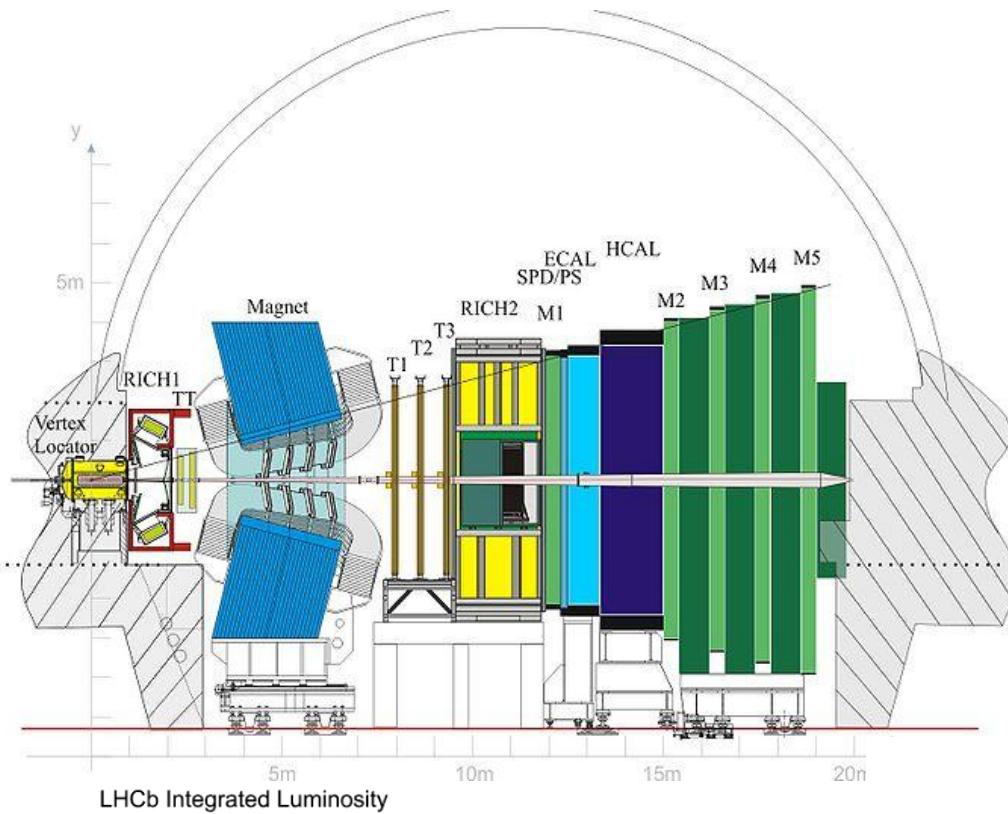
➤ Angular analysis

- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-CONF-2012-008]

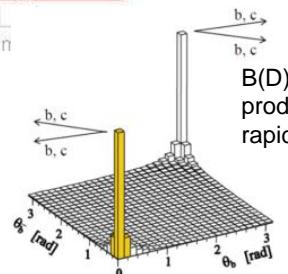
➤ Asymmetries

- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-PAPER-2012-021]
- $B \rightarrow K^{(*)} \mu^+ \mu^-$ [JHEP (2012) 133]

LHCb detector



LHCb **delivered (2.0/fb)** and **recorded** luminosity in 2012,
+1.1/fb indicates recorded luminosity in 2010-2011

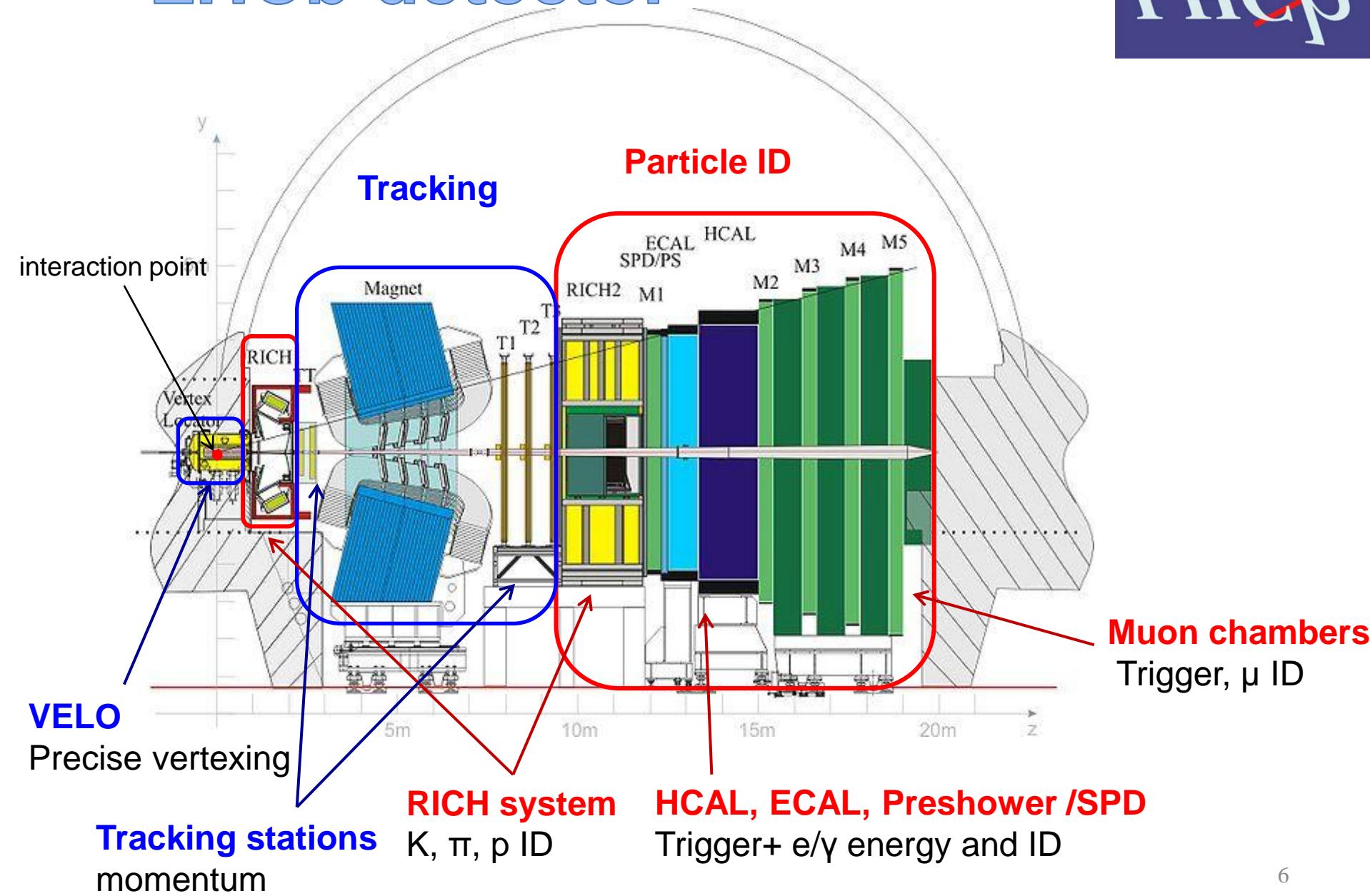


Designed for precise study of CP-violation, flavor-physics:

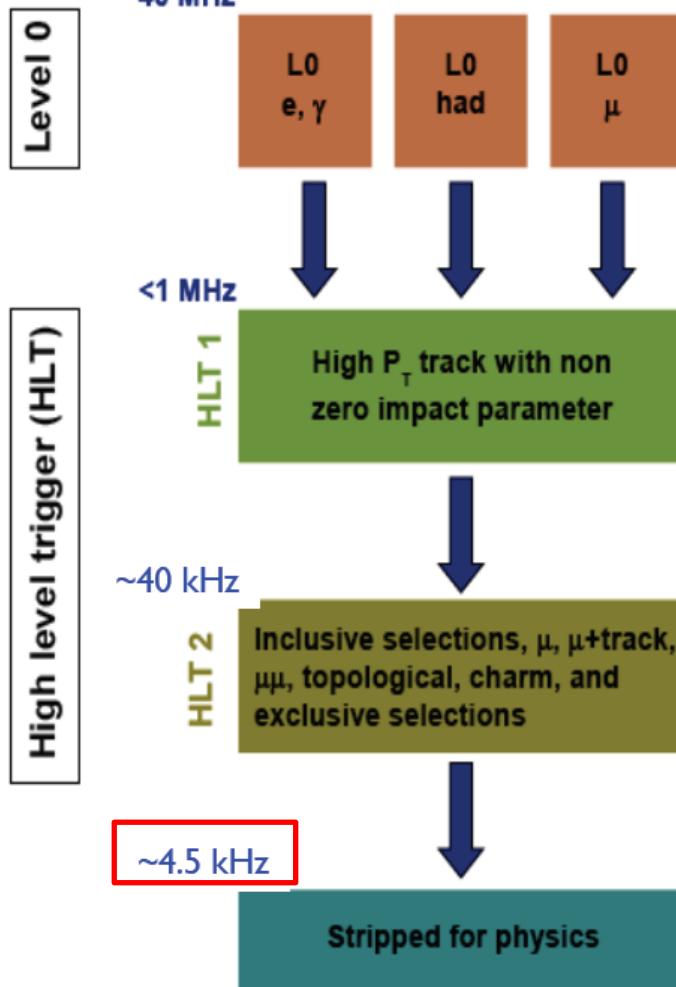
- forward geometry
- precise momentum and mass reconstruction
- precise vertex reconstruction,
- lifetime reconstruction
- Adapted and highly configurable trigger system
- identification: π , K , μ

$2 < \eta < 5$ (15 – 300 mrad)
 Design luminosity $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

LHCb detector



LHCb trigger



L0 Hardware Trigger 40 MHz \rightarrow 1 MHz

- Search for high p_t , μ , e , γ , hadron candidates
CALO $p_t > 3.6$ GeV, MUON $p_t > 1.4$ GeV

High Level Software Trigger Farm

- HLT1: Add Impact parameter cuts
- HLT2: Global event reconstruction.
Exclusive or inclusive offline-like selection (lines)

Adaptation to

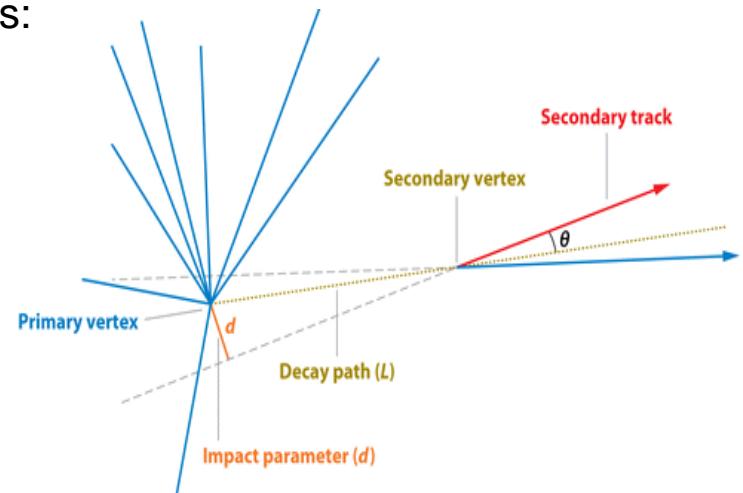
- physics priorities
- variation of beam conditions

General analysis strategy



■ Selection:

- combinatorial background: Multivariate Analysis:
 - displaced vertex*
 - high p_t particles*
 - B (D) come from the primary vertex*
 - quality of displaced vertex*
 - daughters' track quality*
 - isolation*
- peaking background: particle identification
Ex: $B \rightarrow \pi\pi$ for $B \rightarrow \mu\mu$, with $\pi \leftrightarrow \mu$



■ Normalized Measurements to help controlling the systematics

$$BF_{(signal)} = BF_{(norm)} \frac{\varepsilon_{(norm)}}{\varepsilon_{(signal)}} \frac{N_{(signal)}}{N_{(norm)}}$$

Ex. : $B^0 \rightarrow K^{0*} \mu^+ \mu^-$
and $B^0 \rightarrow K^{0*} J/\psi$

■ Efficiencies : MC+ extensive data-driven corrections & systematics

$J/\psi \rightarrow \mu\mu$, $D \rightarrow K\pi$, $\Lambda \rightarrow p\pi$, $K_s \rightarrow \pi\pi$: reconstruction, PID, trigger efficiencies ...

■ Control $\pi \leftrightarrow \mu$ misidentification :

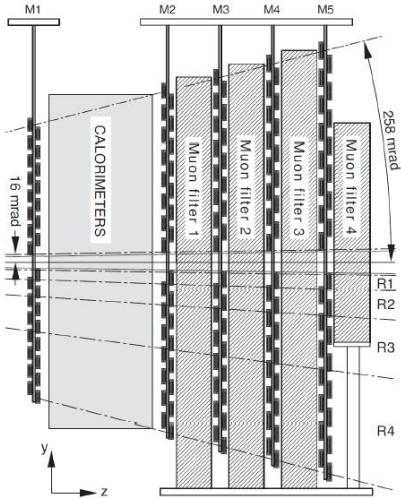
- MC
- control from data $\pi \leftrightarrow \mu$: $D \rightarrow K\pi$, with π swapped with μ

■ Blind analyses, Upper limits from the CLs method [A. Read, J. Phys. G28 (2002)]

Muon particle identification



High muon/hadron discriminative power based on the Muon System

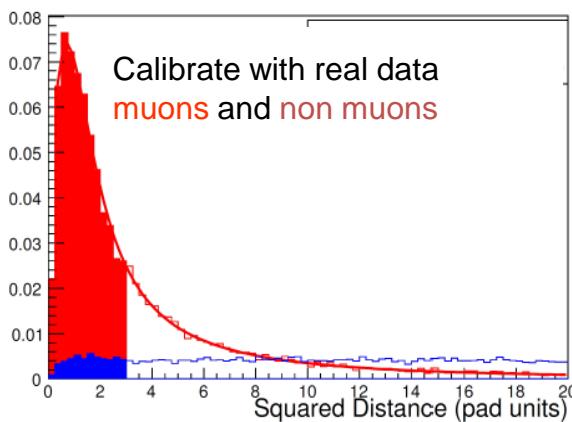


Calo ($6.2 \lambda_l$) + 3 iron absorbers (8cm thick, $20 \lambda_l$)

- Easy for a μ to traverse 3 to 5 stations (depending on its p)
- Difficult for a pion or kaon

Tracks extrapolated from the tracking system

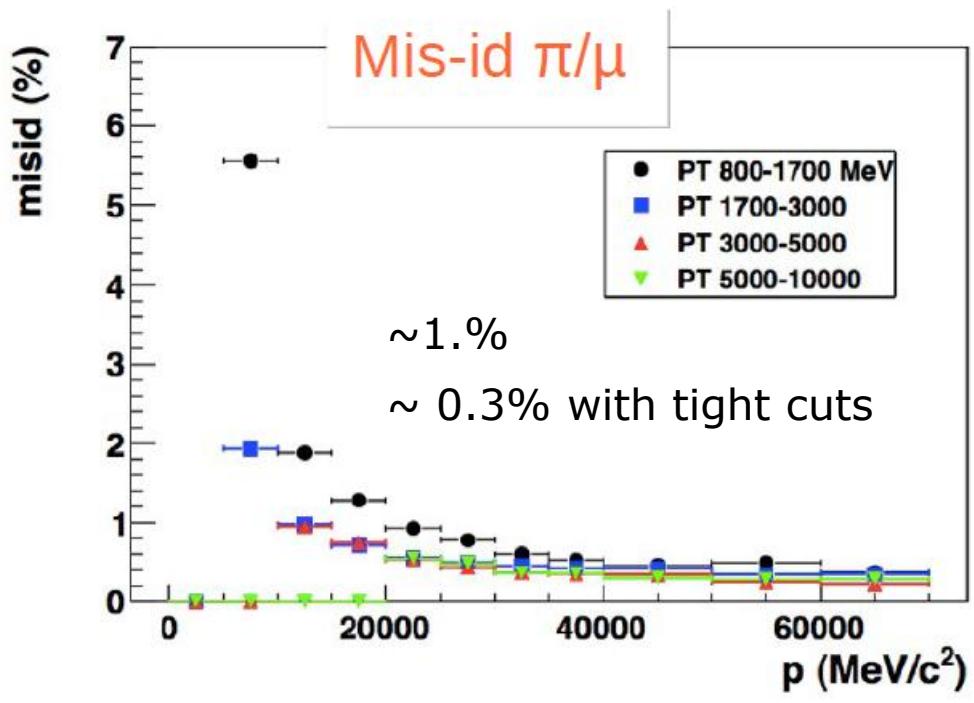
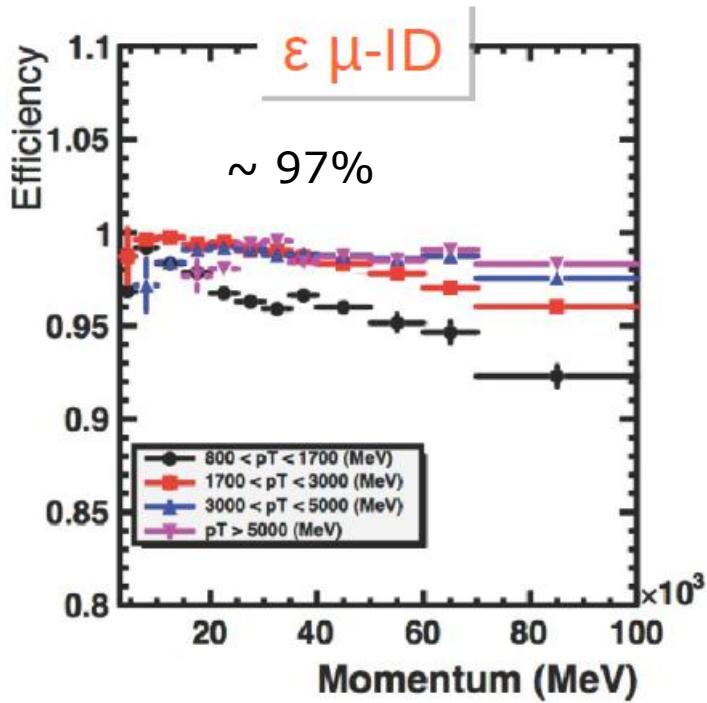
- Easier to find hits close to it if this is a real μ
- Typical distribution of the Average squared distance,
used to build a *muon likelihood*



$$D^2 = \frac{1}{N} \sum_{i=0}^N \left\{ \left(\frac{x_{closest,i} - x_{track}}{pad_x} \right)^2 + \left(\frac{y_{closest,i} - y_{track}}{pad_y} \right)^2 \right\}$$

Can be combined with other likelihoods
based on the muon's signature in the
RICH and Calorimeter.

Muon particle identification



Rare decay at LHCb



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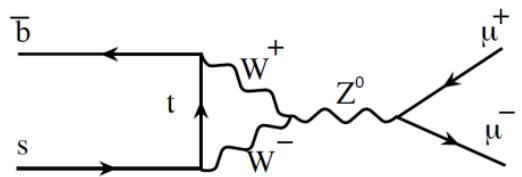
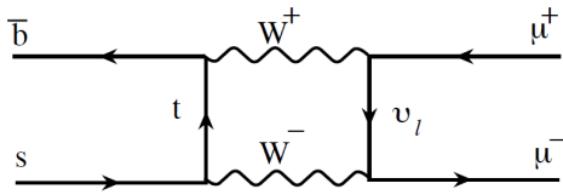
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$B^0_{(s)} \rightarrow \mu^+ \mu^-$



FCNC and helicity suppressed !



■ SM prediction

$$BF(B^0 \rightarrow \mu\mu) = (1.07 \pm 0.10) \cdot 10^{-10} \text{ [A. Buras et al., JHEP 1010 (2010)]}$$

$$BF(B_s^0 \rightarrow \mu\mu)_{<t>} = (3.54 \pm 0.30) \cdot 10^{-9} \text{ [arXiv:1204.1735]}$$

■ Previous limits [arXiv:1203.4493, LHCb-CONF-2012-017]

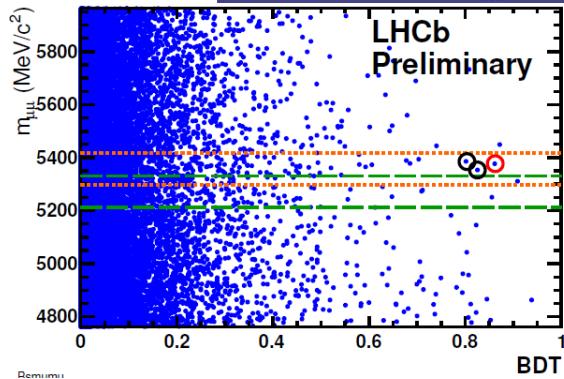
$$BF(B_s^0 \rightarrow \mu\mu) < 4.5 \text{ (4.2)} \cdot 10^{-9} @ 95\% \text{ CL LHCb (LHC)}$$

$$BF(B^0 \rightarrow \mu\mu) < 1.0 \text{ (0.9)} \cdot 10^{-9} @ 95\% \text{ CL LHCb (LHC)}$$

$$B^0_{(s)} \rightarrow \mu^+ \mu^-$$



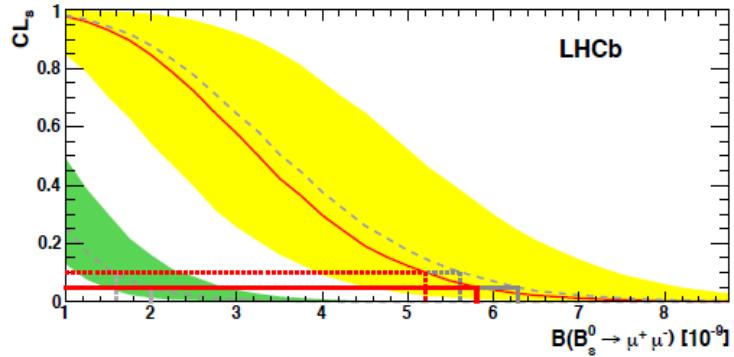
- Selection: 2 stage BDT selection
- Geometric BDT response and B-mass
 - Events are studied in a 2D binned plane (BDT response, mass($\mu\mu$))
 - calibrated from data ($B^0 \rightarrow K^+\pi^-$, $\pi^+\pi^-$ and $B_s^0 \rightarrow K^+K^-$, $K\pi^+$ - with similar kinematics)
- Exclusive backgrounds: $B \rightarrow h^+h^-$, $B^0 \rightarrow \pi^-\mu^+\bar{\nu}_\mu$, $B_{(s)}^0 \rightarrow h^+h^-$,
 $B_s^0 \rightarrow K^-\mu^+\bar{\nu}_\mu$, $\Lambda_b^0 \rightarrow p^+\mu^+\bar{\nu}_\mu$, $B_c^+ \rightarrow J/\psi(\mu\mu)\mu^+\bar{\nu}_\mu$,
 $B_s^0 \rightarrow \mu\mu\gamma$, $B^{0(+)} \rightarrow \pi^{0(+)}\mu\mu$ ($\pi - \mu$ misID: MC + $D \rightarrow K\pi$)
- Normalization modes: $B^+ \rightarrow J/\psi K^+$, $B^0 \rightarrow K^+\pi^-$
- The main systematic uncertainties in each bin : BDT calibration



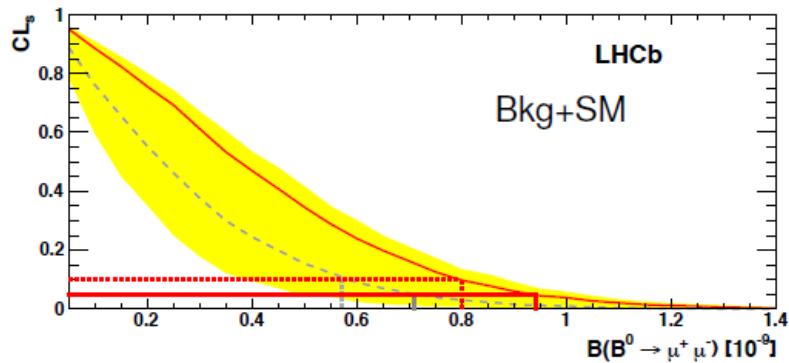


Combined Upper limits

Upper limits with 2011 + 2012 data:



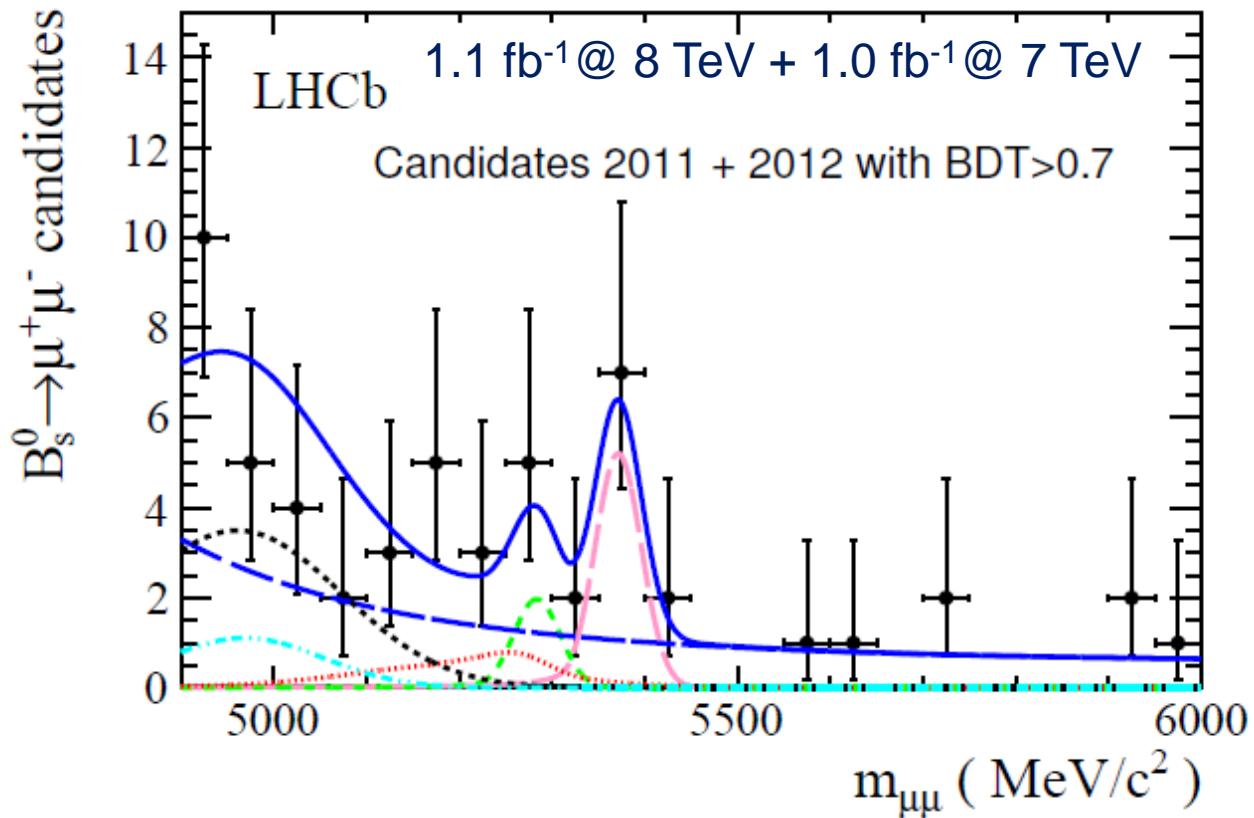
Limit	at 90 % C.L.	at 95 % C.L.
Exp. bkg+SM	$5.6 \cdot 10^{-9}$	$7.2 \cdot 10^{-9}$
Exp. bkg	$1.6 \cdot 10^{-9}$	$2.8 \cdot 10^{-9}$
Observed	$5.2 \cdot 10^{-9}$	$8.9 \cdot 10^{-9}$



Limit	at 90 % C.L.	at 95 % C.L.
Exp. bkg+SM	$5.8 \cdot 10^{-10}$	$7.1 \cdot 10^{-10}$
Exp. bkg	$5.0 \cdot 10^{-10}$	$6.0 \cdot 10^{-10}$
Observed	$8.0 \cdot 10^{-10}$	$9.4 \cdot 10^{-10}$

$B^0_{(s)} \rightarrow \mu^+ \mu^-$

LHCb
LHCb-PAPER-2012-043



$$\text{BF}(B_s^0 \rightarrow \mu\mu) = (3.17^{+1.45}_{-1.18} \text{ (stat.)} \pm 0.23 \text{ (syst.)}) \cdot 10^{-9}$$

$$\text{BF}(B^0 \rightarrow \mu\mu) = (3.43^{+3.54}_{-2.94} \text{ (stat.)} \pm 0.80 \text{ (syst.)}) \cdot 10^{-10}$$

→ 3.5 σ stat. significance with respect to the bkg-only predictions

First evidence of $B_s^0 \rightarrow \mu\mu$

Consistent with SM!

Rare decay at LHCb



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➤ Asymmetries

- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-PAPER-2012-021]
- $B \rightarrow K^{(*)} \mu^+ \mu^-$ [JHEP (2012) 133]

$\tau^- \rightarrow \mu^+ \mu^- \mu^-$



Process with charged lepton flavor violation (cLFV)

- SM prediction

$$BF(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 10^{-40}$$

- NP predictions [Acta Phys Pol B41 (2010) 657]

$$\text{Little Higgs: } < 10^{-7}$$

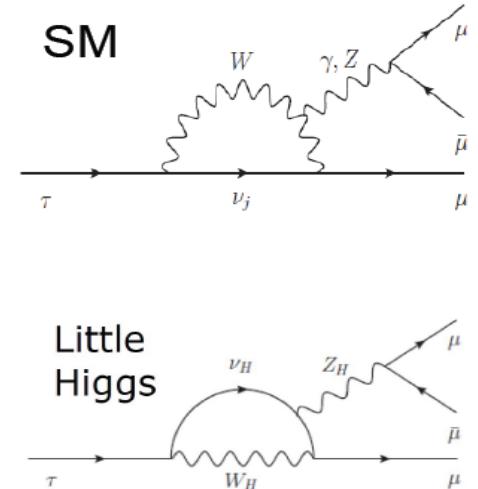
- Previous Measurements [PDG]

$$BF(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 2.1 \cdot 10^{-8} @ 90\% \text{ CL}$$

$\sim 10^{11} \tau^-$ in LHCb per year (dominantly from D_s^+ decays)

- Challenging mode: maximize sensitivity by using a 3-D event classification
 - τ^- invariant mass (6 bins)
 - Geom. MVA (geo & kin info, 5 bins)
 - PID MVA (muon PID, 5 bins)

Dedicated combination of muon likelihoods from the muon system, RICH and CALO, optimized to have no correlation with Geom MVA
- BDT calibrated with real data using $D_s^- \rightarrow \varphi(\mu^+ \mu^-) \pi^-$ (signal shape PDFs, MVA), which is also the normalization mode

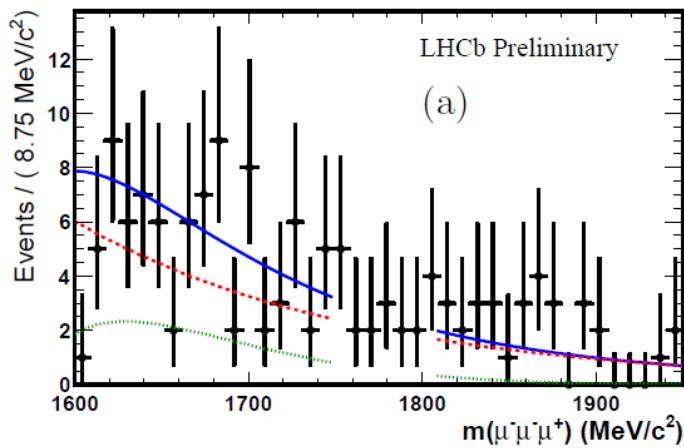


$\tau^- \rightarrow \mu^+ \mu^- \mu^-$

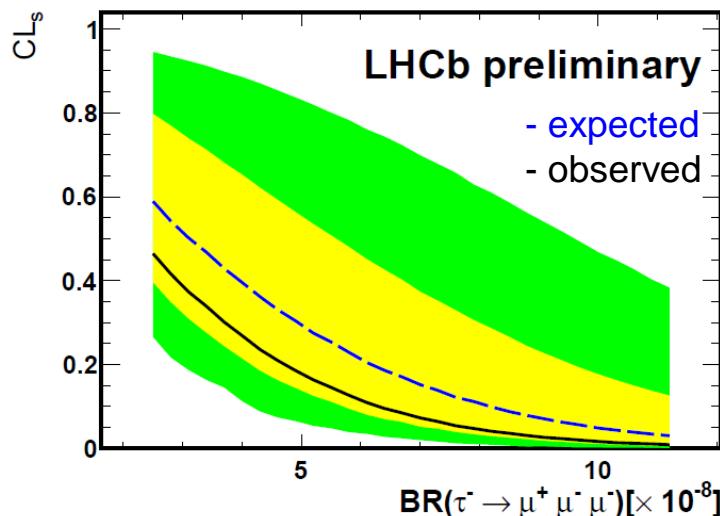
1.0 fb⁻¹ @ 7 TeV



[LHCb-CONF-2012-015]



- combinatorial
- $D_s^- \rightarrow \eta (\mu^+ \mu^- \gamma) \mu^- \nu_\mu$
- combined bkg



$$BF(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 6.3 \cdot 10^{-8} \text{ @ 90% CL}$$

Important conclusions:

- Possible to measure at hadron collider
- LHCb is sensitive enough

Rare decay at LHCb



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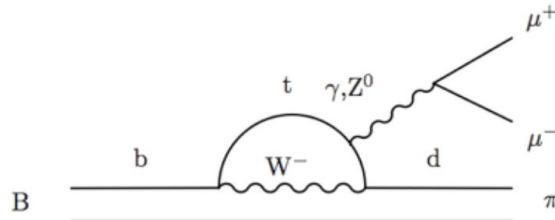
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- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-PAPER-2012-021]
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$B^+ \rightarrow \pi^+ \mu^+ \mu^-$



■ SM prediction

$$BF(B^+ \rightarrow \pi^+ \mu\mu) = (2.0 \pm 0.2) \cdot 10^{-8} \text{ [arXiv:0711.0321]}$$

■ Previous Limit

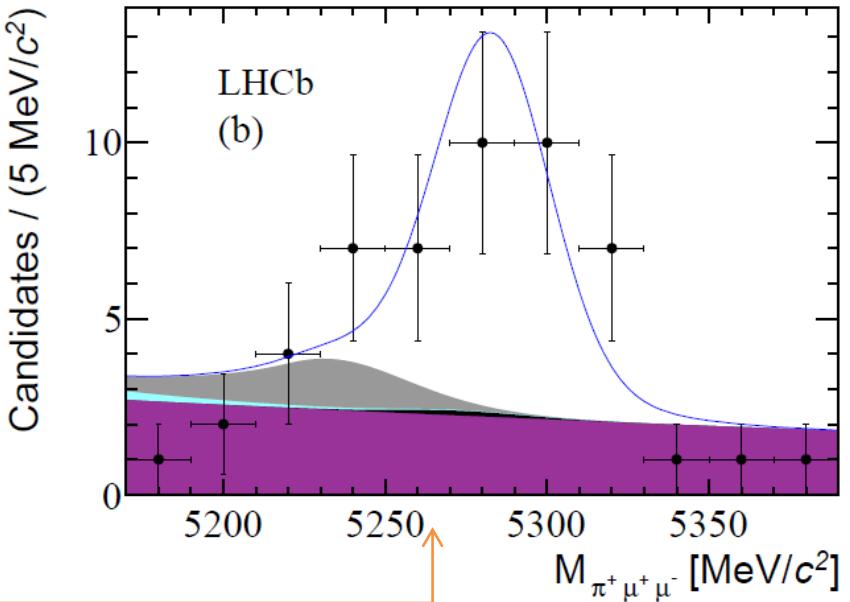
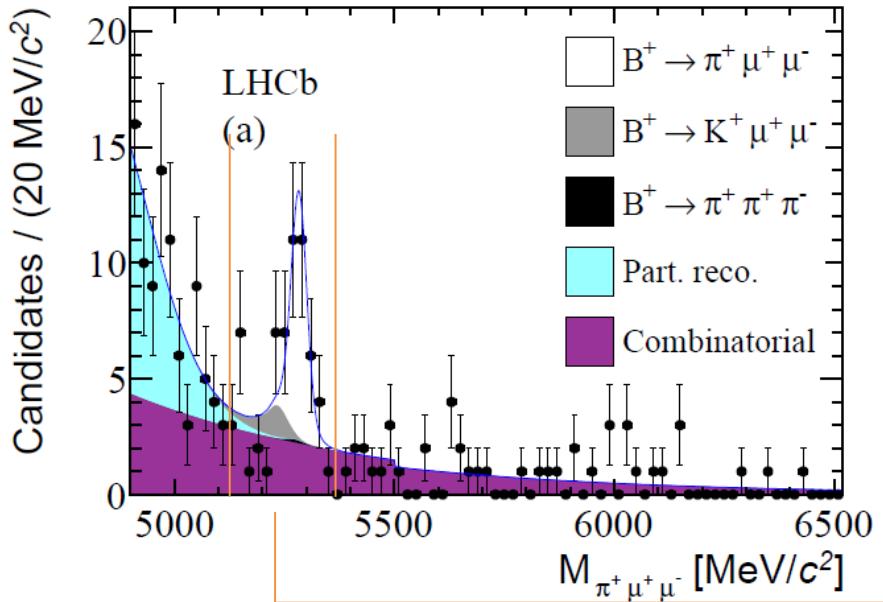
$$BF(B^+ \rightarrow \pi^+ \mu\mu) < 6.9 \cdot 10^{-8} @ 90\% \text{ CL [arXiv:0804.3656]}$$

- Exclusive backgrounds : $B^+ \rightarrow \pi^+ \pi^+ \pi^-$, $B^+ \rightarrow K^+ \mu\mu$, partially reconstructed backgrounds are outside the signal window
- Normalization modes: $B^+ \rightarrow J/\psi K^+$
- Main source of systematic uncertainty: limited sizes of the simulated samples

$B^+ \rightarrow \pi^+ \mu^+ \mu^-$



1.0 fb⁻¹ @ 7 TeV



$25^{+6.7}_{-6.4}$ events!
 5.2σ significance

$$\text{BF}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (2.3 \pm 0.6(\text{stat.}) \pm 0.1(\text{syst.})) \cdot 10^{-8}$$

First observation of $b \rightarrow d l^+ l^-$!

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$D^0 \rightarrow \mu^+ \mu^-$



FCNC in charm sector – GIM mechanism

- SM prediction [G. Burdman et al., PR D66 (2002)]

$$BF(D^0 \rightarrow \mu\mu) \approx 2.7 \cdot 10^{-5} \text{ BF}(D^0 \rightarrow \gamma\gamma)$$

$$BF(D^0 \rightarrow \mu\mu) > 10^{-13}$$

- Ex. of NP model : R-parity violation models:

$$\mathcal{B}_{D^0 \rightarrow \mu^+ \mu^-}^{R_p} \leq 4.8 \times 10^{-9} \left(\frac{300 \text{ GeV}}{m_{\tilde{d}_k}} \right)^2$$

supersymmetric partner of
down-type quarks

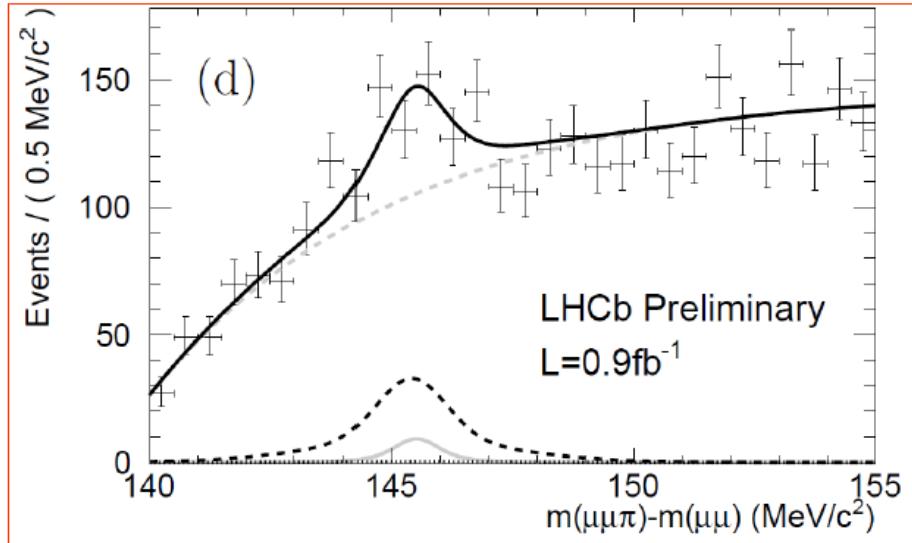
- Previous Limit

$$BF(D^0 \rightarrow \mu\mu) < 1.4 \cdot 10^{-7} @ 90\% \text{ CL}$$

- D^* -tagged sample: $D^* \rightarrow D^0(\rightarrow \mu\mu) \pi^+$
- 2D fit: $\Delta m = m(D^{*+}) - m(D^0)$ & $m(D^0)$
- Peaking background : $D^* \rightarrow D^0(\rightarrow \pi\pi) \pi^+$
- Normalization mode: $D^* \rightarrow D^0(\rightarrow \pi\pi) \pi^+$

$D^0 \rightarrow \mu^+ \mu^-$

LHCb
LHCb



Comb. background:

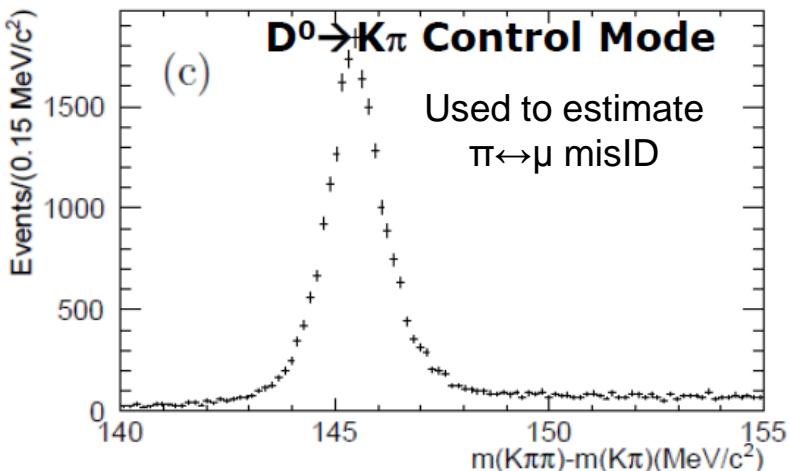
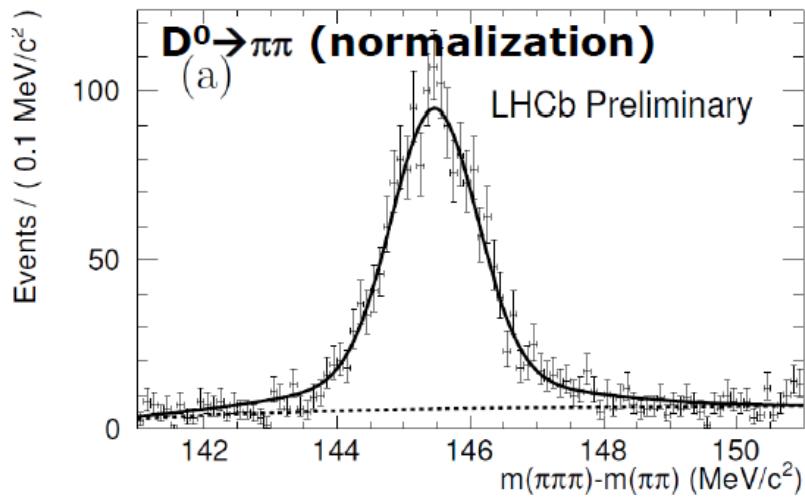
Reduced by Boosted Decay Tree
(PT 's + topology).

Peaking backgrounds ($D \rightarrow \pi\pi$)

Muon ID.

Fitted & controlled using $D \rightarrow K\pi$ with $\pi \leftrightarrow \mu$

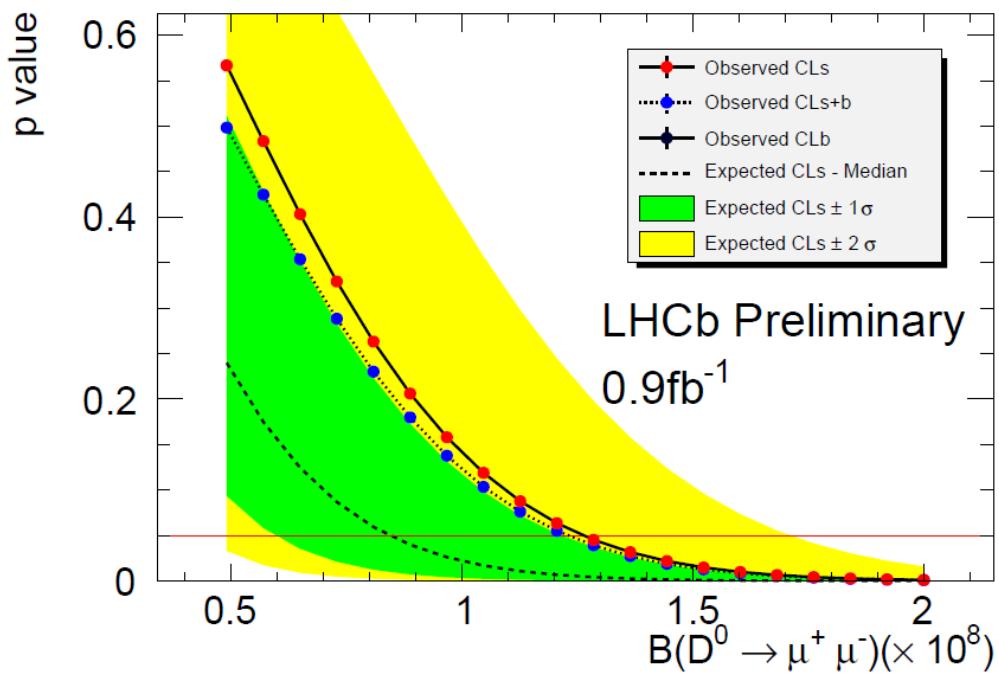
Signal



$D^0 \rightarrow \mu^+ \mu^-$



[LHCb-CONF-2012-005]



$\text{BF}(D^0 \rightarrow \mu\mu) < 1.3 \cdot 10^{-8} \text{ @ 95\% CL}$

Update in preparation!

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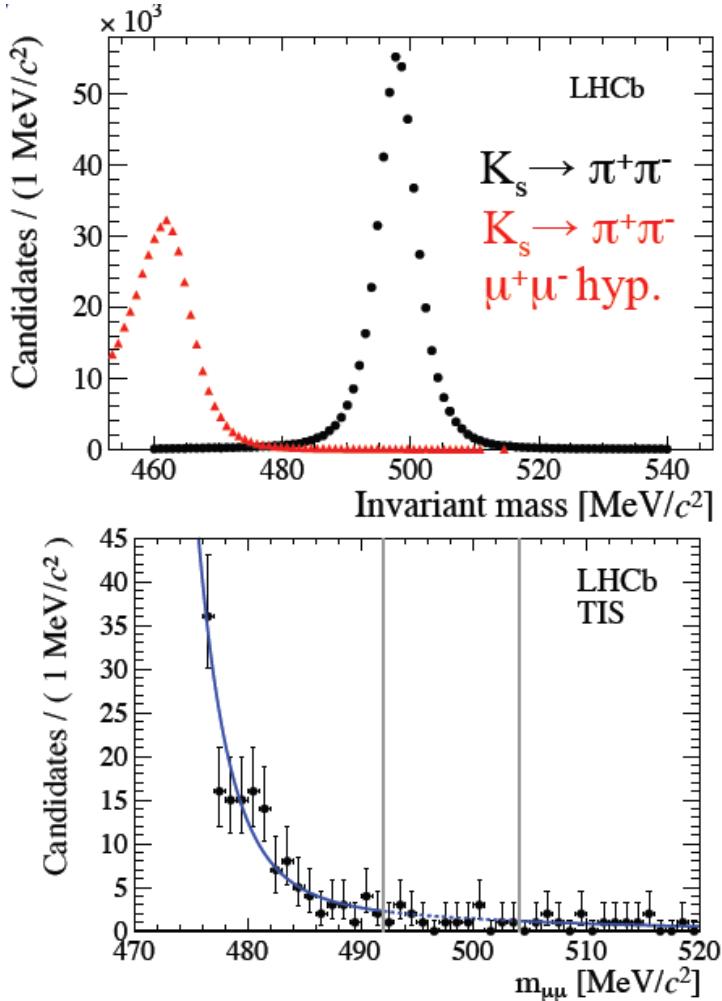


- SM prediction [JHEP 0401(2004)]
$$BF(K_s \rightarrow \mu\mu) = (5.0 \pm 1.5) \cdot 10^{-12}$$
- $K_L \rightarrow \mu\mu$ and $K_s \rightarrow \mu\mu$ receive different contributions
 - K_L is observed, dominated by long-distance
 - K_s dominated by short-distance
- Previous Limit from 1973 : [PLB 44 217]
$$BF(K_s \rightarrow \mu\mu) < 3.2 \cdot 10^{-7} @ 90\% \text{ CL}$$

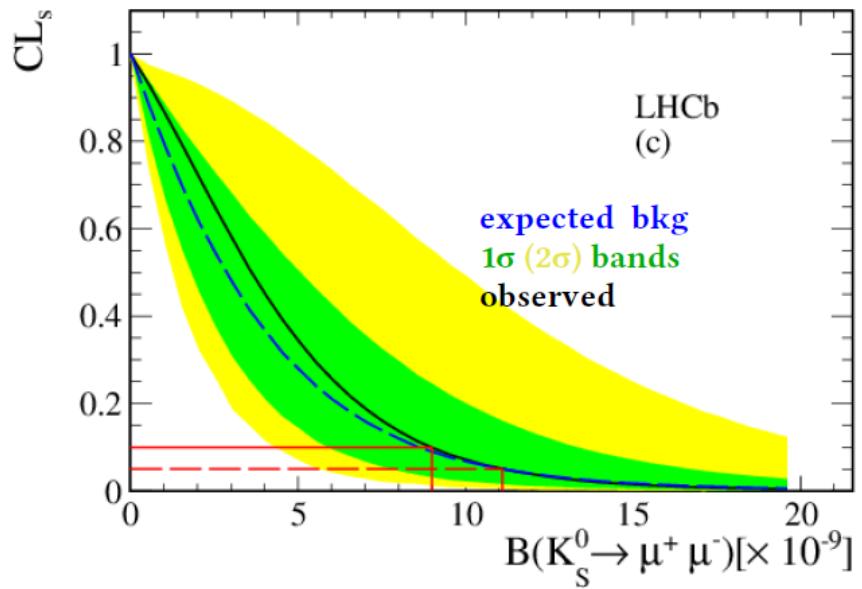
- LHCb mass resolution exploited to discriminate $K_s \rightarrow \pi^+ \pi^-$ with both π 's mis-id as μ 's
 - Reject peaking background : $K_s \rightarrow \pi^+ \pi^-$
 - $K_L \rightarrow \mu^+ \mu^-$, too long lived to leave hits in tracking system \rightarrow negligible
- Normalization mode: $K_s \rightarrow \pi^+ \pi^-$

$K_s \rightarrow \mu^+ \mu^-$

LHCb
LHCb
~~CDF~~



1.0 fb $^{-1}$ @ 7 TeV



$BF(K_s \rightarrow \mu\mu) < 9 \cdot 10^{-9} @ 90\% CL$

New world best limit
Factor ~35 of improvement

Rare decay at LHCb



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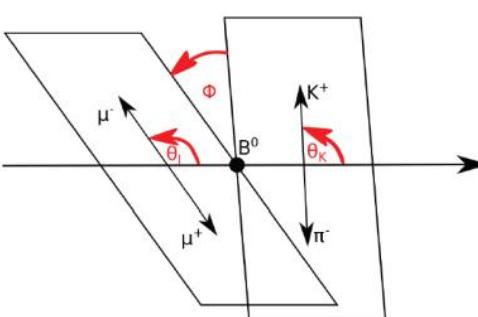
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$B^0 \rightarrow K^{*0} \mu^+ \mu^-$

LHCb
LHC CP

Angular analysis: Full description by $(\cos \theta_\ell, \cos \theta_K, \varphi)$ and $q^2 = m^2(\mu\mu)$

Simplified but still sensitive using a φ folding: $\varphi' = \varphi + \pi$, $\varphi < 0$

$$\frac{1}{\Gamma} \frac{d^4\Gamma}{d \cos \theta_\ell d \cos \theta_K d\hat{\phi} dq^2} = \frac{9}{16\pi} \left[F_L \cos^2 \theta_K + \frac{3}{4} (1 - F_L) (1 - \cos^2 \theta_K) - \right.$$


$$F_L \cos^2 \theta_K (2 \cos^2 \theta_\ell - 1) + \frac{1}{4} (1 - F_L) (1 - \cos^2 \theta_K) (2 \cos^2 \theta_\ell - 1) +$$

$$\left(S_3 (1 - \cos^2 \theta_K) (1 - \cos^2 \theta_\ell) \cos 2\hat{\phi} + \frac{4}{3} A_{FB} (1 - \cos^2 \theta_K) \cos \theta_\ell + \right.$$

$$\left. S_9 (1 - \cos^2 \theta_K) (1 - \cos^2 \theta_\ell) \sin 2\hat{\phi} \right]$$

Probe NP: tests SM's chirality & presence of \mathcal{CP} phases

A_{FB} – forward-backward asymmetry

F_L – fraction of K^{*0} longitudinal polarization

S_3 – asymmetry in K^{*0} transverse polarization

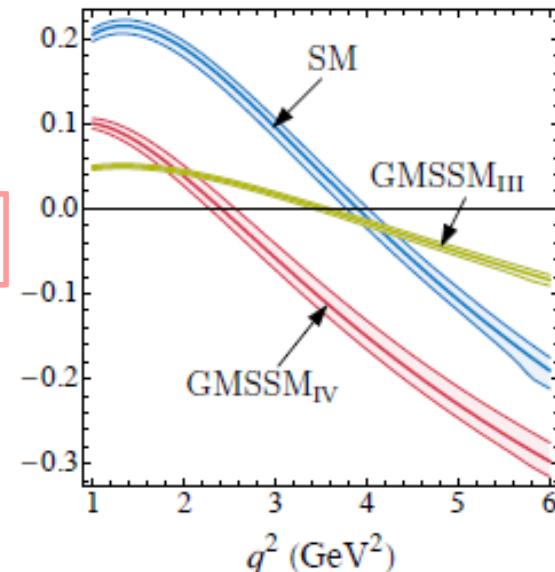
S_9 – T-odd asymmetry

Zero point $q^2_0 : A_{FB}(q^2_0)=0$: clean and sensitive to NP

■ SM: $q^2_0 = (4.4-4.3) \text{ GeV}^2/c^2$

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

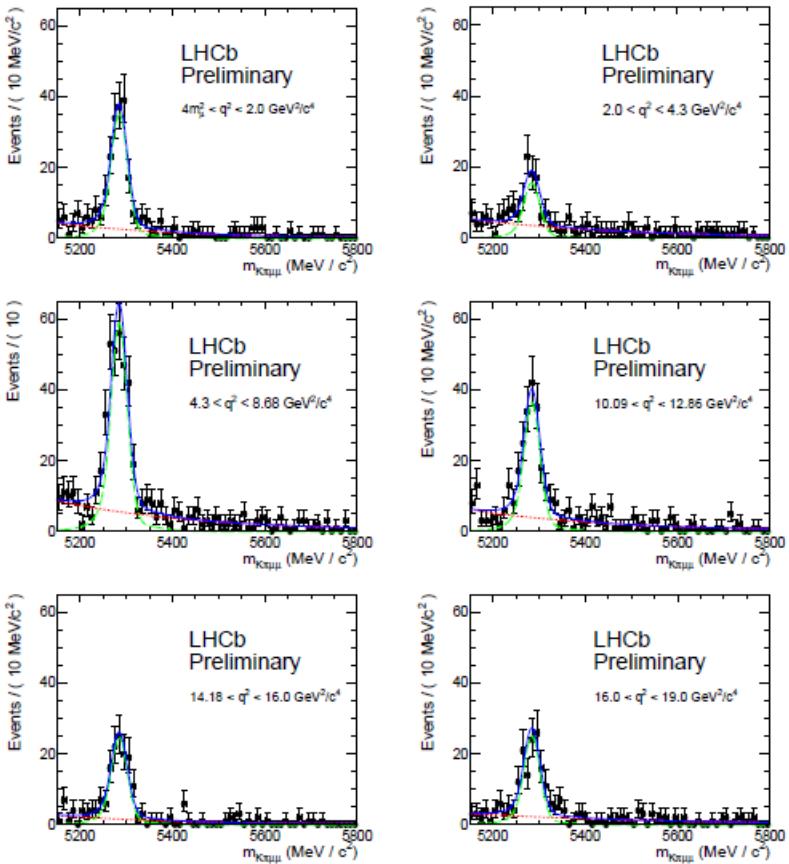
$$S_6 = 4/3 A_{FB}$$



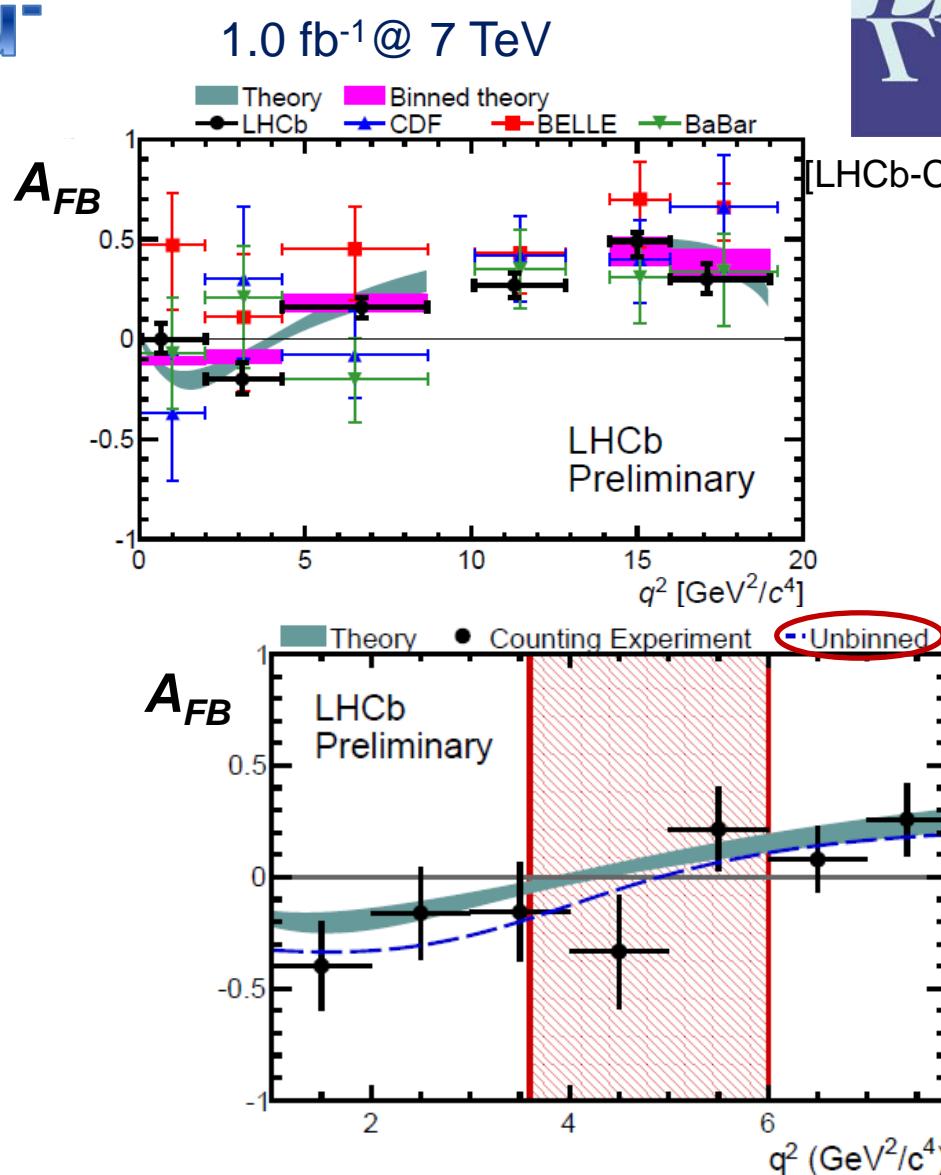
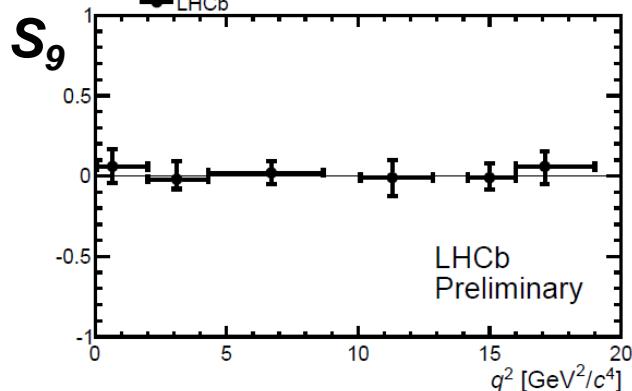
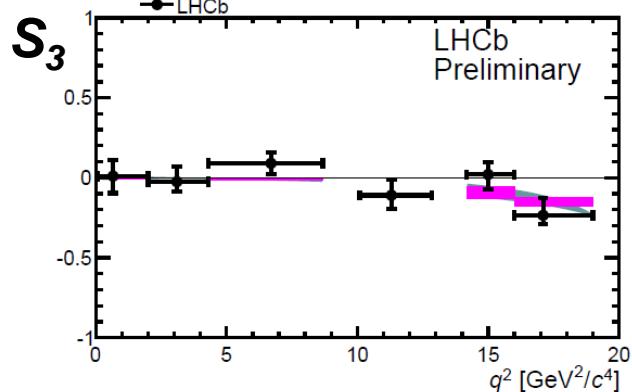
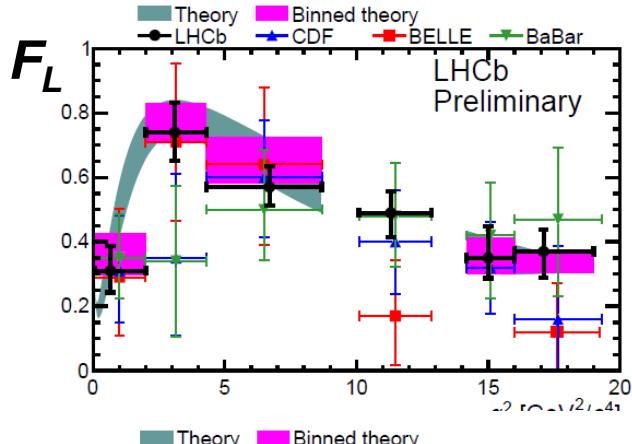
$B^0 \rightarrow K^{*0} \mu^+ \mu^-$



- 900 ± 34 signal events
- Peaking background: $B_s^0 \rightarrow \varphi \mu^+ \mu^-$, $B_s^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-$
- Normalization mode: $B^0 \rightarrow J/\psi K^{*0}$
- Simultaneous fit to all angles and B-mass in 6 q^2 bins
 - measure A_{FB} , F_L , S_3 , S_9
- Detailed angular acceptance determination
 - Avoid PT in BDT
 - Use data driven corrections ($B^0 \rightarrow J/\psi K^{*0}$ useful control mode)
 - Dominates the systematics



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



First measurement : $q^2_0 = (4.9_{-1.3}^{+1.1}) \text{ GeV}^2/\text{c}^2$

Consistent with SM!

Rare decay at LHCb



➤ Branching fraction measurements

- $B^0_{(s)} \rightarrow \mu^+ \mu^-$ [LHCb-PAPER-2012-043]
- $\tau^- \rightarrow \mu^+ \mu^- \mu^-$ [LHCb-CONF-2012-015]
- $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ [LHCb-CONF-2012-006]
- $D^0 \rightarrow \mu^+ \mu^-$ [LHCb-CONF-2012-005]
- $K_s \rightarrow \mu^+ \mu^-$ [LHCb-PAPER-2012-024]

➤ Angular analysis

- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-CONF-2012-008]

➤ Asymmetries

- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-PAPER-2012-021]
- $B \rightarrow K^{(*)} \mu^+ \mu^-$ [JHEP (2012) 133]



CP asymmetry

$$\mathcal{A}_{CP} = \frac{\Gamma(\bar{B}^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-) - \Gamma(B^0 \rightarrow K^{*0} \mu^+ \mu^-)}{\Gamma(\bar{B}^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-) + \Gamma(B^0 \rightarrow K^{*0} \mu^+ \mu^-)}$$

The mixture of vector and axial-vector components → Sensitive to NP

- SM prediction [JHEP 07(2008)106, JHEP 01(2009)019]

A_{CP} order of 10^{-3}

- NP [JHEP 1111(2011)122]

A_{CP} enhanced up to ± 0.15

- Previous measurements

$A_{CP}(B^0 \rightarrow K^{*0} l^+ l^-) = -0.10 \pm 0.10(\text{stat.}) \pm 0.01(\text{syst.})$ [PRL 103(2009) 171801]

$A_{CP}(B^0 \rightarrow K^{*0} l^+ l^-) = 0.03 \pm 0.13(\text{stat.}) \pm 0.01(\text{syst.})$ [PRD 86(2012) 032012]

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



- 1.0 fb⁻¹ @ 7 TeV
- Peaking background: $B_s^0 \rightarrow \phi \mu^+ \mu^-$, $B^0 \rightarrow J/\psi K^{*0+}$, $B^+ \rightarrow K^+ \mu^+ \mu^-$
- Control mode: $B^0 \rightarrow J/\psi K^{*0}$
- Measuring :

$$\mathcal{A}_{CP} = \mathcal{A}_{RAW} (B^0 \rightarrow K^{*0} \mu^+ \mu^-) - \mathcal{A}_{RAW} (B^0 \rightarrow J/\psi K^{*0})$$

$$\mathcal{A}_{RAW} = \mathcal{A}_{CP} + \kappa \mathcal{A}_P + \mathcal{A}_D$$

A_D – detection asymmetry: arise from differences $K\pi^+/K^+\pi^-$

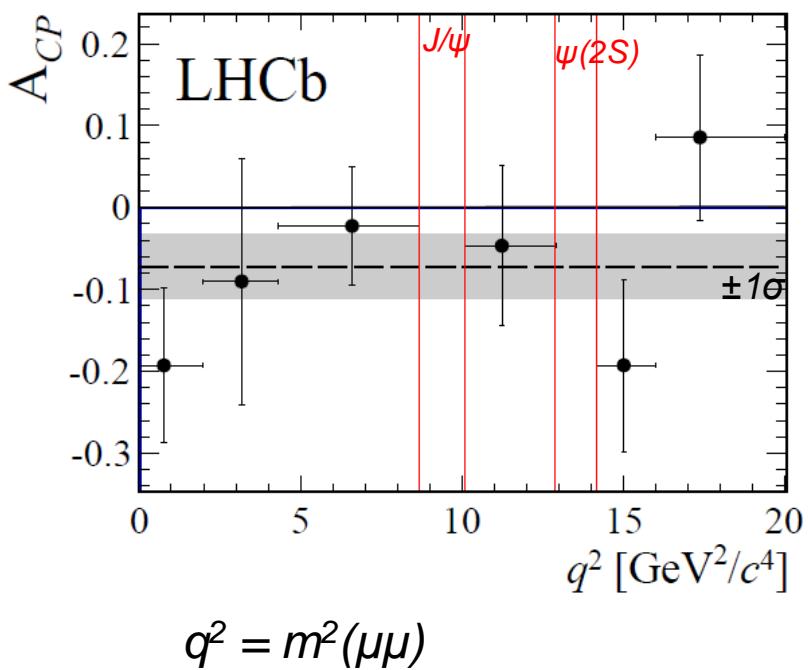
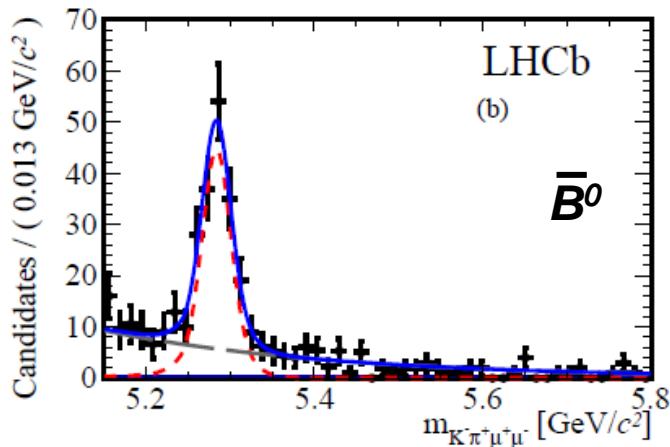
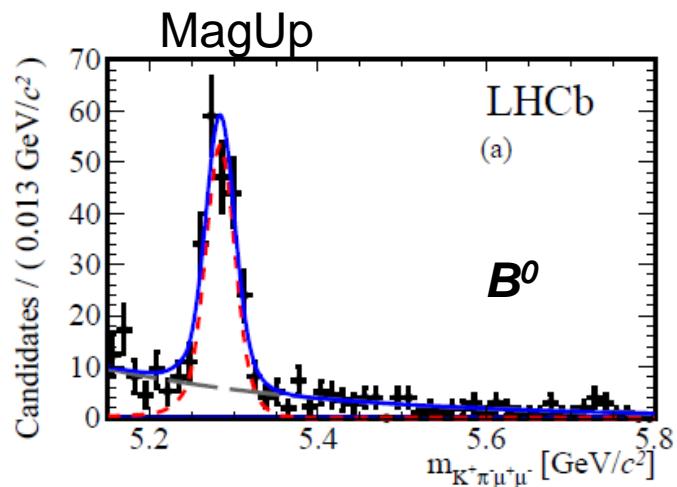
A_P – production asymmetry: from control mode: $B^+ \rightarrow J/\psi K^{*+}$
(assuming CP-asymmetry is small)

κ – factor from B^0 – oscillations

- Use ratio between two magnet polarities to cancel detector effects
- Dominant source of systematic: residual non-cancelling asymmetries from different kinematic of signal and control mode: reweighting kinematic distributions

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

LHCb
LHCb-PAPER-2012-021



$$A_{CP}(B^0 \rightarrow K^{*0} \mu^+ \mu^-) = -0.072 \pm 0.040(\text{stat.}) \pm 0.005(\text{syst.})$$

Consistent with
SM!

Rare decay at LHCb



➤ Branching fraction measurements

- $B^0_{(s)} \rightarrow \mu^+ \mu^-$ [LHCb-PAPER-2012-043]
- $\tau^- \rightarrow \mu^+ \mu^- \mu^-$ [LHCb-CONF-2012-015]
- $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ [LHCb-CONF-2012-006]
- $D^0 \rightarrow \mu^+ \mu^-$ [LHCb-CONF-2012-005]
- $K_s \rightarrow \mu^+ \mu^-$ [LHCb-PAPER-2012-024]

➤ Angular analysis

- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-CONF-2012-008]

➤ Asymmetries

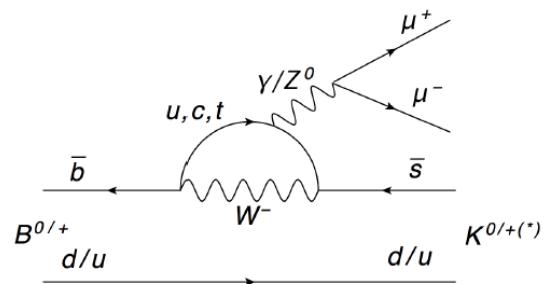
- $B^0 \rightarrow K^{0*} \mu^+ \mu^-$ [LHCb-PAPER-2012-021]
- $B \rightarrow K^{(*)} \mu^+ \mu^-$ [JHEP (2012) 133]

$B \rightarrow K^{(*)} \mu^+ \mu^-$



Isospin asymmetry for $B \rightarrow K^* \mu^+ \mu^-$ and $B \rightarrow K \mu^+ \mu^-$:

$$A_I = \frac{\mathcal{B}(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) - \frac{\tau_0}{\tau_+} \mathcal{B}(B^\pm \rightarrow K^{(*)\pm} \mu^+ \mu^-)}{\mathcal{B}(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) + \frac{\tau_0}{\tau_+} \mathcal{B}(B^\pm \rightarrow K^{(*)\pm} \mu^+ \mu^-)}$$



- SM prediction

$B \rightarrow K^* \mu^+ \mu^- : A_I \sim -1\% \text{ for } q^2 < m^2(J/\psi), A_I \sim O(10\%) \text{ for } q^2 \rightarrow 0$

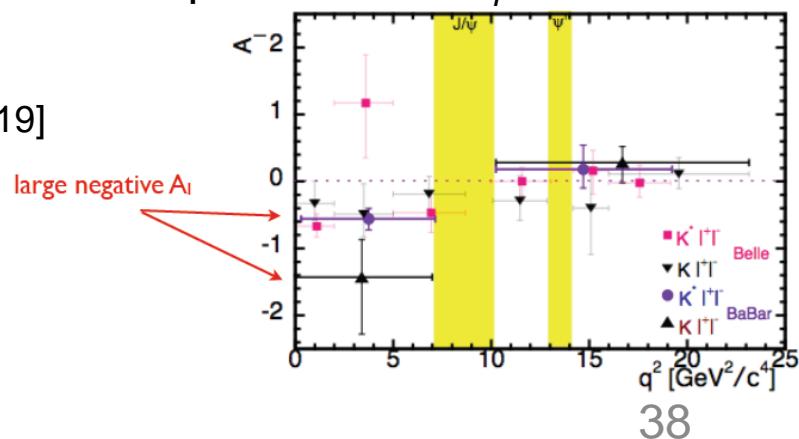
$B \rightarrow K \mu^+ \mu^- : \text{no predictions, expected to be close to 0}$

$$q^2 = m^2(\mu\mu)$$

- Some NP models where d/u-quarks are not spectators $\rightarrow A_I \neq 0$

- Previous measurements [arxiv:0807.4119]

Mode	combined q^2	high q^2
$K \mu^+ \mu^-$	$0.13^{+0.29}_{-0.37} \pm 0.04$	$0.39^{+0.35}_{-0.46} \pm 0.04$
$K^* \mu^+ \mu^-$	$-0.00^{+0.36}_{-0.26} \pm 0.05$	$-0.08^{+0.37}_{-0.27} \pm 0.05$



$B \rightarrow K^{(*)} \mu^+ \mu^-$



[JHEP (2012) 133]

- 1.0 fb^{-1} @ 7 TeV

- Measurement of differential BF:

$$B^+ \rightarrow K^+ \mu \mu \text{ vs } B^0 \rightarrow K^0 \mu \mu$$

$$B^+ \rightarrow K^{*+} (K_s^0 \pi^+) \mu \mu \text{ vs } B^0 \rightarrow K^{*0} \mu \mu$$

K^0 reconstructed as $K_s^0 \rightarrow \pi^+ \pi^-$ - challenging:

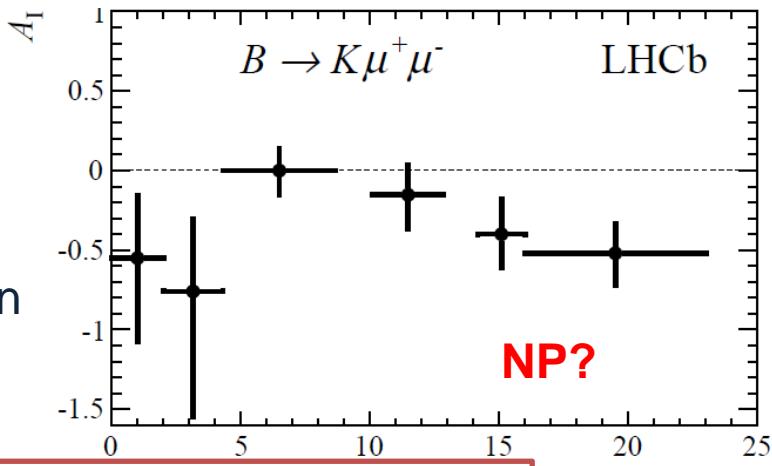
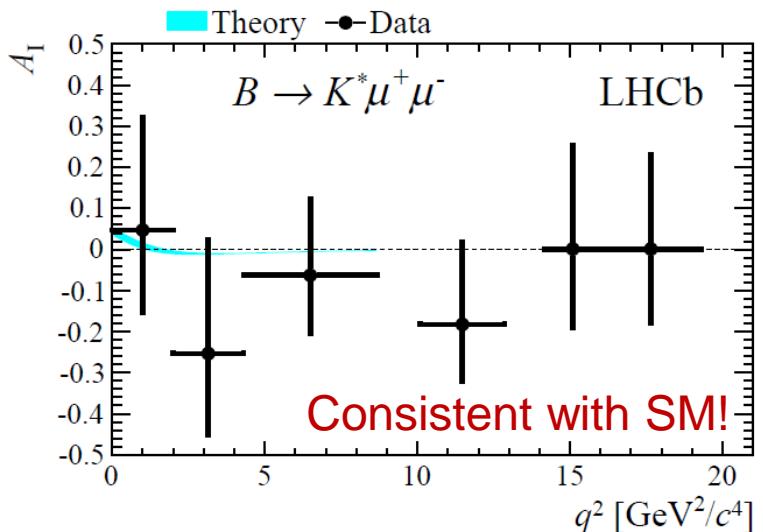
K_s : Low reconstruction efficiency

- Tight selection for decays with higher BF:

uniformity with other channels

- Normalization in each q^2 : $B \rightarrow K^{(*)} J/\psi$

- Main systematic uncertainty: BF of normalization mode



Deviation from 0 integrated across all q^2 4.4σ

SM theoretical prediction needed!

Conclusions

- All present measurements are consistent with Standard Model expectations
- No NP has been seen yet but some promising observations
- Results from 1 fb^{-1} of 2011 data are presented
- 1 fb^{-1} of 2011 + 1.1 fb^{-1} of 2012:
First evidence of $B_s \rightarrow \mu\mu$
- New exiting results are expected with 2012 data

Backup



Particle identification

μ PID likelihood

- Muon system information:
 - Hits, track extrapolation to the field of interest (FoI)
- Discrimination variable – *distance*:

$$d^2 = \frac{1}{N_{sts}} \sum_{i=x,y} \sum_{st=2}^5 \left(\frac{e_i(st) - m_i(st)}{ps_i(st)} \right)^2$$

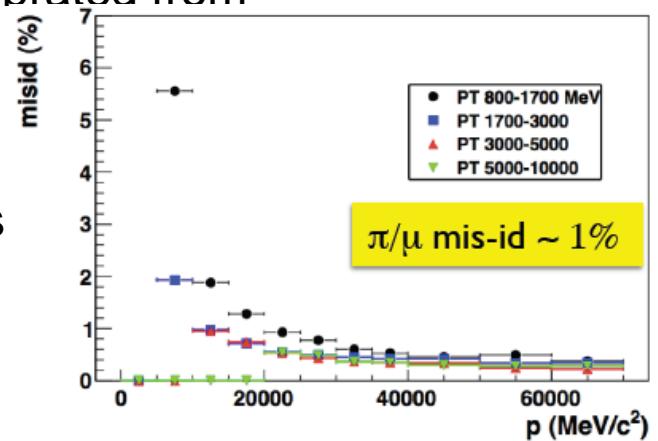
e_i – extrapolated position

m_i – position of the hits

ps – size of the pad

N_{sts} – number of stations with at least one hit in FoI

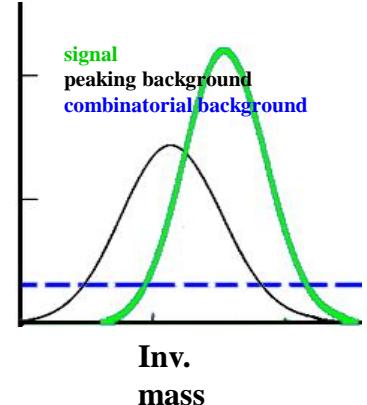
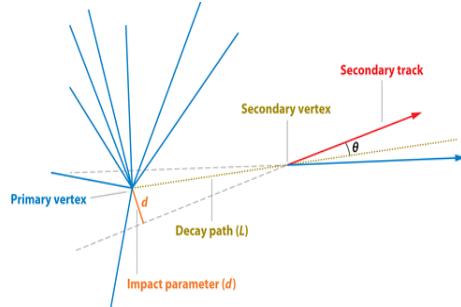
- From calibration set of μ and *non- μ* : probabilités p_μ and $p_{non-\mu}$:
 $DLL = \log [p_\mu / p_{non-\mu}]$
- Likelihood, efficiency and performance are calibrated from data: tag&probe:
 $J/\psi \rightarrow \mu\mu, D \rightarrow K\pi, \Lambda \rightarrow p\pi, K_s \rightarrow \pi\pi$
- Combined with information from other systems (CALO, RICH) ($\mu - \pi$ misID)



Usual analysis strategy



- Selection:
 - combinatorial background: Multivariate Analysis:
 - displaced vertex
 - high p_t particles
 - B (D) come from the primary vertex
 - quality of displaced vertex
 - daughters' track quality
 - isolation
 - peaking background: particle identification(PID) likelihood variables
 - RICH response
 - Muon stations response
 - Calorimeter response



- BF Measurements
 - Normalization to a mode which features are close to the signal's: help controlling the systematics

$$BF_{(signal)} = BF_{(norm)} \frac{\varepsilon_{(norm)}}{\varepsilon_{(signal)}} \frac{N_{(signal)}}{N_{(norm)}}$$

N – observed yields, ε – efficiencies
 - Efficiencies are derived from simulations with extensive data-driven corrections
 - Carefully treated systematic uncertainties
 - Blind analysis
 - CLs method to extract limits [A. Read, J. Phys. G28 (2002)]

Signal discrimination: BDT vs. $M(\mu\mu)$

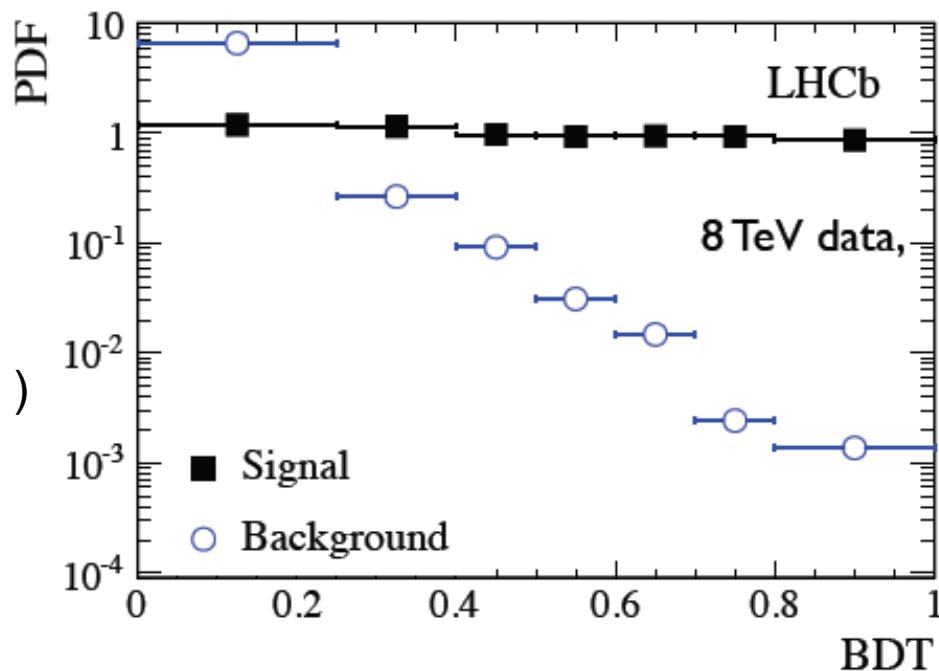
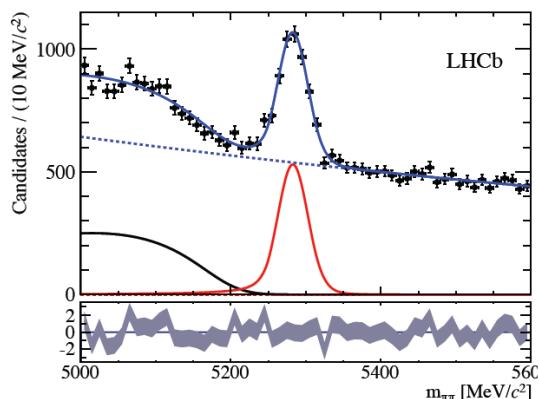
BDT output defined to be flat for signal, and peaked at zero for background

Signal BDT shape from $B^0_{(s)} \rightarrow h^+h'^-$ events, which have same topology as the signal (use sample triggered independent of the signal, to avoid bias)

Background BDT shape is evaluated on the dimuon mass sidebands

Mass position and shape from $B \rightarrow hh$ and dimuon resonances (J/ψ , $\psi(2S)$, $\Upsilon(1,2 \& 3)$)

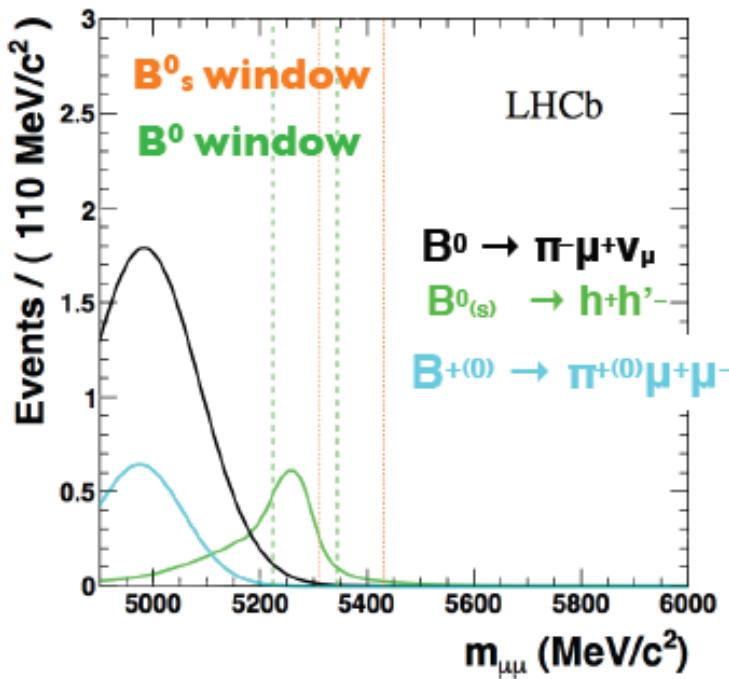
$B^0 \rightarrow \pi^+\pi^-$



Exclusive Background

In the present version of the analysis, we improved the combinatorial background interpolation, by including the relevant exclusive backgrounds as separate component in the fit

- Invariant mass and BDT distributions from high statistics MC samples, weighted by misID probabilities measured on data
- Expected yields evaluated by normalizing to $B^\pm \rightarrow J/\psi K^\pm$



dominant channels:

Yields for [4900-6000] MeV/c², and BDT>0.8

$B^0 \rightarrow \pi^- \mu^+ \nu_\mu$	4.04 ± 0.28
$B^{+(0)} \rightarrow \pi^{+(0)} \mu^+ \mu^-$	1.32 ± 0.39
$B_{(s)}^0 \rightarrow h^+ h^-$	1.37 ± 0.11

these decays are included in the mass sideband fits (constrained to their expected yields)

systematic studies to evaluate the effect of the subdominant channels