Rare Decays @ LHCb

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On behalf of the LHCb Collaboration

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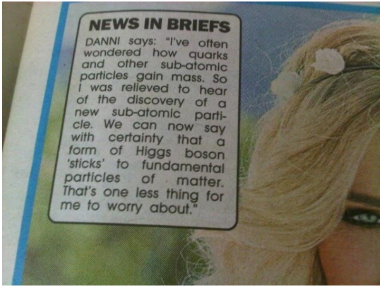
WHAT THIS TALK IS NOT ABOUT



Well, almost...

Outline

- Rare leptonic decays
  - $B^0_{(s)} \to \mu^+\mu^-$ [PRL 108, 231801 (2012)]
  - $D^0 \to \mu^+\mu^-$ [LHCb-CONF-2012-005]
  - $\tau \to \mu\mu\mu$ [LHCb-CONF-2012-015]
  - $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ [LHCb-CONF-2012-010]
- Rare semi-leptonic decays
  - $B^0 \to K^{*0}\mu^+\mu^-$ (angular analysis) [LHCb-CONF-2012-008]
  - $B \to K^{(*)}\mu^+\mu^-$ (isospin asymmetry) [arXiv:1205.3422]
  - $B^+ \to \pi^+\mu^+\mu^-$ [LHCb-CONF-2012-006]
- Rare radiative decays
  - $B^0 \to K^{*0}\gamma$ (CP asymmetry) [LHCb-CONF-2012-004]

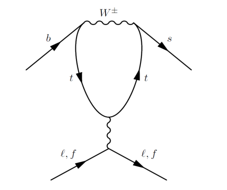
All results obtained with $\sim 1\,fb^{-1}$

INTRODUCTION

Flavor Changing Neutral Currents

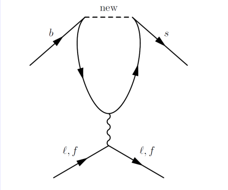
- FCNC processes prohibited at tree level within SM.

SM



$b \to sf\bar{f}$
$(b \to df\bar{f})$

Hypothetical NP scenario



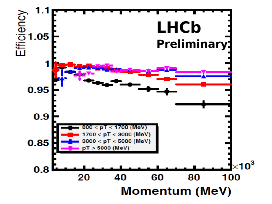
- Measure effect of possible new particles entering (for instance) the loop:
  - branching fractions ($\mathcal{B}$),
  - angular distributions,
  - asymmetries (CP, isospin).

- Complementary approach to direct searches (ATLAS/CMS).

INTRODUCTION

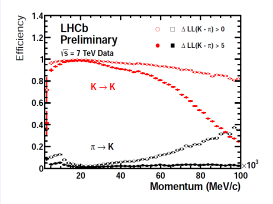
Muon and Hadron ID

good muon identification



- $\epsilon(\mu) > 97\% (p_T > 1.7\,GeV)$

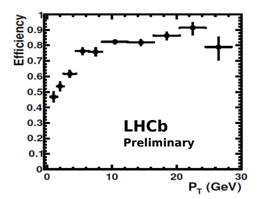
good K-π separation



- Low $\pi \to K$ misID

Muon Trigger

good muon trigger efficiency



- Low trigger p_T thresholds for muons (0.5 GeV for di-muons)

INTRODUCTION

B (D) Selection Criteria

- Decay vertex displaced from PV, large track impact parameter with respect to PV
- Quality of decay vertex and tracks
- B(D) meson candidate required to come from a PV
- Low systematics, fairly clean environment for a hadronic machine

$\mathcal{B}$ Measurements Strategy

- Normalize $\mathcal{B}$ to modes with similar trigger and geometrical features;
  $$\frac{\mathcal{B}(signal)}{\mathcal{B}_{norm}} = \frac{\epsilon_{norm}}{\epsilon_{signal}} \times \frac{N_{signal}}{N_{norm}}$$
- When necessary use the LHCb measured f_s/f_d value $(0.267^{+0.021}_{-0.020})$ LHCb-CONF-2011-034
- Use control channels to avoid using simulation (ie. to calibrate multivariate classifiers, evaluate trigger efficiencies, etc)
- 'Blind' analysis to avoid biases
- CL_s method [A. Read, J. Phys. **G28** (2002)] to extract limits

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  - $\tau \to \mu\mu\mu$
  - $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$
- Rare semi-leptonic decays
  - $B^0 \to K^{*0}\mu^+\mu^-$ (angular analysis)
  - $B \to K^{(*)}\mu^+\mu^-$ (isospin asymmetry)
  - $B^+ \to \pi^+\mu^+\mu^-$
- Rare radiative decays
  - $B^0 \to K^{*0}\gamma$ (CP asymmetry)

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

Motivation

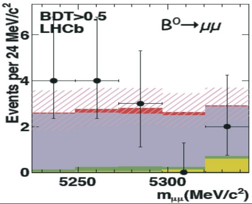
- Low uncertainty in SM predictions [A. Buras *et al.*, JHEP 1010 (2010)] [E. Gamiz *et al.*,Phys. Rev. D 80 (2009) 014503]:

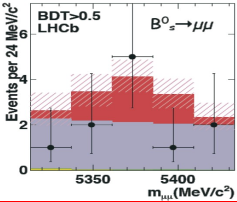
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9} \times 1.1(*)$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (0.10 \pm 0.01) \times 10^{-9}$$

- Sensitive to NP scalar and/or pseudo-scalar contributions (extended Higgs sectors)
- (*)De Bruyn *et al.*, arXiv:1204.1735

Analysis

- Candidates classified according to: invariant mass and MVA BDT
- BDT: 9 variables describing event topology/kinematics trained on MC and calibrated on data





Combinatorial background
(from semilept B decays)
Peaking background
(from $B \to hh'$)
Cross-feed
SM signal
$\epsilon(hh \to \mu\mu)$ 3.5×10^{-5}

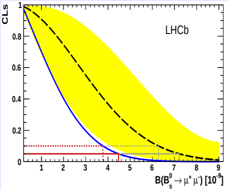
$B^0_{(s)} \to \mu^+\mu^-$

Results

Limits are extracted from data and expectations with the CL$_s$ method:

$B^0_s \to \mu^+\mu^-$ upper limit (95% C.L.)

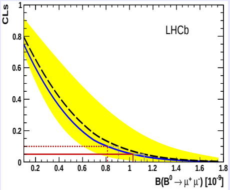
Exp. SM+Bkg	7.2×10^{-9}
Obs.	4.5×10^{-9}



- Data **compatible with Bkg+SM within 1σ**
- **p-value** (1-CL$_b$) = 18%

$B^0 \to \mu^+\mu^-$ upper limit (95% C.L.)

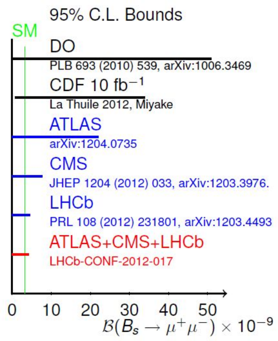
Exp. Bkg Only	1.1×10^{-9}
Obs.	1.0×10^{-9}



Yellow: region 68% compatible with bkg (B_d) or bkg + SM (B_s) signal hypothesis.
Dashed line: expected median.
Blue line: observed CL$_s$.

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

New: Combination CMS–ATLAS–LHCb



LHCb-CONF-2012-017
Upper Limits (95% C.L.):

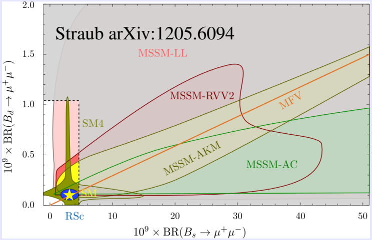
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) < 4.2 \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 8.1 \times 10^{-10}$$

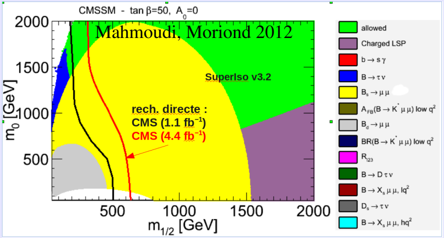
LHCb limit dominating the combination
Approaching $\mathcal{B}(B^0_s \to \mu^+\mu^-)$ SM prediction.

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

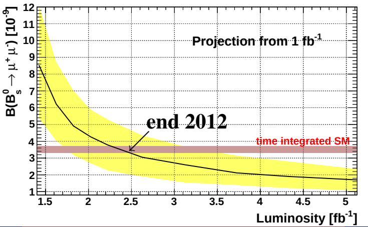
Implications and Prospects

These results put **stringent constraints** of physics beyond the SM:





Prospect for a **3σ observation**:



OUTLINE

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  - $B^0_{(s)} \to \mu^+\mu^-$
  - $D^0 \to \mu^+\mu^-$ [LHCb-CONF-2012-005]
  - $\tau \to \mu\mu\mu$
  - $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$
- Rare semi-leptonic decays
  - $B^0 \to K^{*0}\mu^+\mu^-$ ($\mathcal{A}_{FB}$)
  - $B \to K^{(*)}\mu^+\mu^-$ (isospin asymmetry)
  - $B^+ \to \pi^+\mu^+\mu^-$
- Rare radiative decays
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$D^0 \to \mu^+\mu^-$

Introduction

- Suppression of FCNC in charm sector driven by GIM mechanism;
- SM prediction: $10^{-13} < \mathcal{B}(D^0 \to \mu^+\mu^-) < 6 \times 10^{-11}$ [G. Burdman *et al.*, PR **D66** (2002)];
- Enhancement in NP models through presence down-type SUSY particles (R parity violating MSSM): $\mathcal{B}(D^0 \to \mu^+\mu^-) < 4.8 \times 10^{-9} \times \left(\frac{300\,MeV}{m_d}\right)$ [E. Golowich *et al.*, PR **D79** (2009)] (m_d down-type quark superpartner's mass)
- Pre-LHC limit:
  Belle @ 90% CL $\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.4 \times 10^{-7}$ [E. Petric *et al.*, PR **D81** (2010) 091102]
  BaBar $[0.6, 8.1]x10^{-}7$ arXiv:1206.5419

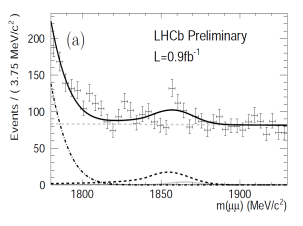
Analysis

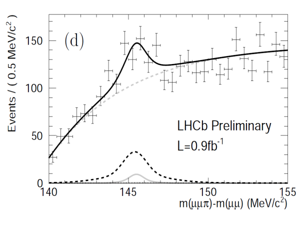
- Select D* samples ($D^{*+} \to D^0(\to x^+x'^-)\pi^+, x = \mu, K, \pi$)
- Main backgrounds: combinatorial background from semileptonic b- and c- hadron decays (reduced with MVA BDT)
  Peaking mis-identified $D^{*+} \to D^0(\to h^+h'^-)\pi^+$ (reduced with tight PID requirements).
    - $D^{*+} \to D^0(\to \pi^+\pi^-)\pi^+$
    - $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$

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

Results

- $\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}}{N_{D^{*+}\to D^0(\to\pi^+\pi^-)\pi^+}} \times \frac{\epsilon_{\pi\pi}}{\epsilon_{\mu\mu}} \times \mathcal{B}(D^0 \to \pi^+\pi^-)$,
- extracting yields from 2D fit: m(D^0) vs m(D^{*+}-D^0)





4 components:

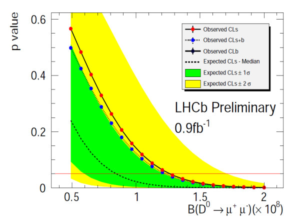
signal (continuous light),

combinatorial background (dashed light)

$D^{*+} \to D^0(\to \pi^+\pi^-)\pi^+$ (dashed dark)

$D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ (dashed dotted)

$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3 \times 10^{-8}$ @ 95% CL (World Best)



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$\tau \to \mu\mu\mu$

Introduction

- LFV decay, ν oscillations, extremely suppressed within SM (in the charged sector: BR<10^{-40}) and beyond current experimental sensitivities.
- cLFV largely enhanced in several NP scenarios in τ more than in μ decays:

$$\mathcal{B}(\tau \to \mu\mu\mu) < 10^{-7} \text{ Little Higgs}$$

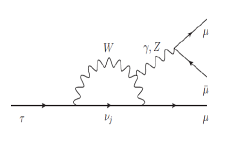
[M. Blanke *et al.*, Acta Phys. Pol **B41** (2010) 657]

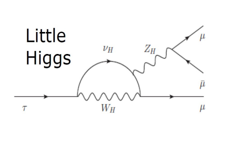
- Current limits at 90% CL:

$$\text{BaBar } \mathcal{B}(\tau \to \mu\mu\mu) < 3.3 \times 10^{-8}$$
$$\text{Belle } \mathcal{B}(\tau \to \mu\mu\mu) < 2.1 \times 10^{-8}$$

[PDG, J Phys **G37** (2010) 075021]

- Large $\sigma_\tau^{prod} \sim 80\mu b$ at LHC



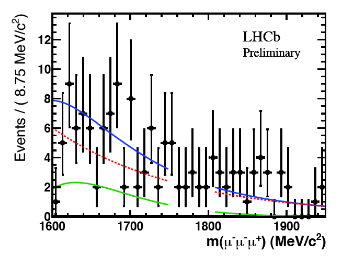


Analysis

- Loose selection + further event classification in a 3D space:
  - MVA BDT (geo and kin info) to reduce combinatorial background (5 bins)
  - MVA BDT (PID) to estimate compatibility with μ hypothesis (5 bins)
  - Invariant mass $m_{\mu\mu\mu}$ (6 bins)

$\tau \to \mu\mu\mu$

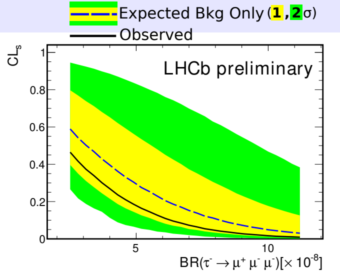
Results



$\longleftarrow$(Highest 4 2D bins in BDT(Geo-Kin) and BDT(PID))
Total, Combinatorial, $D_s^- \to \eta(\mu\mu\gamma)\mu^-\nu_\mu$

$$\mathcal{B}(\tau \to \mu\mu\mu) =$$
$$\mathcal{B}(D_s^- \to \phi(\mu\mu)\pi^-) \times \frac{f(\tau^-(D_s^+))}{\mathcal{B}(D_s^- \to \tau^-\nu_{\bar{\mu}})} \times \frac{\epsilon_{norm}}{\epsilon_{sig}} \times \frac{N_{sig}}{N_{norm}}$$

$$N_{norm} \equiv N_{D_s^- \to \phi(\mu\mu)\pi^-} = 45500 \pm 400_{\text{stat}} \pm 800_{\text{syst}}$$



Expected CL$_s$ as a function of $\mathcal{B}(\tau \to \mu\mu\mu)$ under bkg-only hypothesis; 68% and 95%

Observed:
$\mathcal{B}(\tau \to \mu\mu\mu) < 6.3(7.8) \times 10^{-8}$ at 90(95)% CL
Close to B-factories sensitivity. Proof of principle: measurement can be made in hadronic environment (LHCb upgrade)

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  - $B^0_{(s)} \to \mu^+\mu^-$
  - $D^0 \to \mu^+\mu^-$
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  - $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ [LHCb-CONF-2012-010]
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  - $B^0 \to K^{*0}\mu^+\mu^-$ ($\mathcal{A}_{FB}$)
  - $B \to K^{(*)}\mu^+\mu^-$ (isospin asymmetry)
  - $B^+ \to \pi^+\mu^+\mu^-$
- Rare radiative decays
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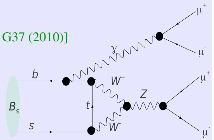
$B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$

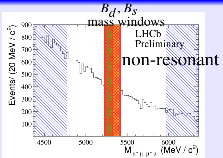
Motivations

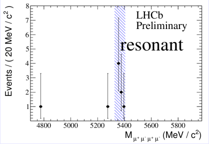
- In SM, large contribution from resonant $B^0_s \to J/\psi(\mu^+\mu^-)\phi(\mu^+\mu^-)$ $(\mathcal{B} = 2.3 \pm 0.9) \times 10^{-8})$ [PDG, J. Phys. G37 (2010)]
- From other SM processes: $\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-\gamma^*(\mu^+\mu^-) \sim 10^{-10} - 10^{-11}$ [D. Melikhov, N. Nikitin, PR **D70** (2004)]
- Enhancement possible in scenarios with new particles ($\to \mu\mu$)



Strategy: a cut and count analysis

- **Resonant** candidates $B^0_s \to J/\psi\phi(\to \mu\mu\mu\mu)$ used to optimize the selection (observed yield compatible with SM)
- For non-resonant mode, expected background: $0.38^{+0.23}_{-0.17}$ in B^0, $0.30^{+0.22}_{-0.20}$ in B^0_s
- Normalization to $B^0 \to J/\psi(\mu^+\mu^-)\bar{K}^{0*}(K^+\pi^-)$

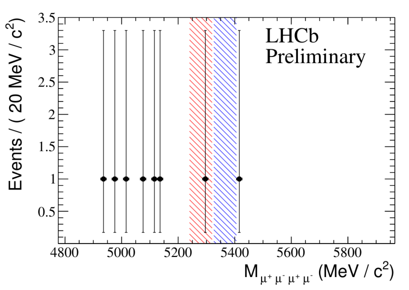




$B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$

Results

- Unblinded event distribution in the **non-resonant** mass window
- **Compatible with background** expectation



- Preliminary upper limits (95%C.L.) extracted with the CL_s method:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 1.3 \times 10^{-8}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 5.4 \times 10^{-9}$$

- **First** limits on these processes.

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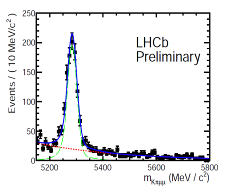
$B^0 \to K^{*0}\mu^+\mu^-$

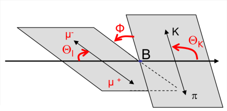
Yield extraction

- Sensitive to magnetic and vector and axial semileptonic penguin operators C7, C9, and C10
- Goal: measure angular observables (NP)
- Yield extraction: loose selection + MVA BDT (Topology, Kinematics, PID)
- Peaking backgrounds: $B^0 \to K^{*0}J/\psi\ (\pi \to \mu, \mu \to \pi)$, $B_s^0 \to \phi\mu^+\mu^-$ $(1.5 \pm 0.5)\%$
- Yield = 900 ± 34 (more than BaBar+Belle+CDF)



Angular analysis

- Decay described with 3 angles $(\theta_l, \theta_k, \phi)$ and dimuon mass q^2
- Parametrized in terms of angular observables



$$\frac{1}{\Gamma}\frac{d^4\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\hat{\phi}\, dq^2} = \frac{9}{16\pi}\Big[F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) + F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell +$$

$\mathcal{A}_{FB}$, forward-backward asymmetry (θ_l)

F_L, fraction of K^{*0} longitudinally polarized

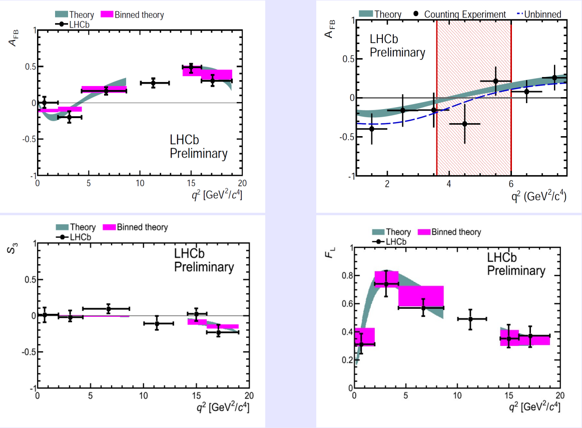
S_3, asymmetry in K^{*0} transverse polarization

$\mathcal{A}_{IM}$, T-odd CP

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

Observables in bins of q^2

- Fit in 4D (3 angles + B^0 mass).



- Errors including syst uncertainties,
- A_{FB} pre-LHC: consistency, large uncertainty [BaBar, PRL **102** (2009), 091803], [CDF, arXiv:1108:0695v1], [Belle, PRL **103** (2009) 171801]
- Theory predictions from [C. Bobeth *et al.*, arXiv:1105.0376]

- Most precise (preliminary) measurements up to date; compatible with SM
- Zero-crossing point, $q_0^2 = 4.9^{+1.1}_{-1.3}\ GeV^2/c^4$; compatible with SM: $3.9 - 4.3\ GeV^2/c^4$

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  - $B^+ \to \pi^+\mu^+\mu^-$
- **Rare radiative decays**
  - $B^0 \to K^{*0}\gamma$ (CP asymmetry)

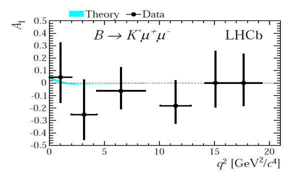
Isospin asymmetry

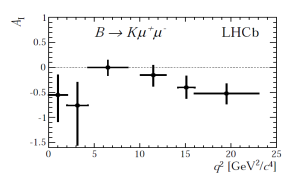
Introduction

- Definition: $A_I \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}$
- Within SM, $A_I \sim 0$ (being $\mathcal{O}(10\%)$ at $q^2 \to 0$ for $B^0 \to K^{*0}\mu^+\mu^-$)
  [T. Feldman and J. Matias, JHEP **01** (2003) 074]
- Pre-LHC experimental status: [BaBar, PRL **102** (2008)], [Belle, PRL **103** (2009)],[CDF, PRL **107** (2011)]
  overall consistent with SM (but 3.9σ from SM in combined BaBar $K^{(*)}$ below J/ψ).

Analysis

- Selection optimized to have consistent samples and Yields extracted through fit q^2 bins.
- Consistent with SM and Belle/Babar in $B \to K^*\mu^+\mu^-$
- BUT discrepancy in $B \to K\mu^+\mu^-$. Naive average over the q^2 bins gives a 4.4σ effect. Unexpected! More statistics is needed.





OUTLINE

- Rare leptonic decays
  - $B^0_{(s)} \to \mu^+\mu^-$
  - $D^0 \to \mu^+\mu^-$
  - $\tau \to \mu\mu\mu$
  - $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$
- Rare semi-leptonic decays
  - $B^0 \to K^{*0}\mu^+\mu^-$ (angular analysis)
  - $B \to K^{(*)}\mu^+\mu^-$ (isospin asymmetry)
  - $B^+ \to \pi^+\mu^+\mu^-$ [LHCb-CONF-2012-006]
- Rare radiative decays
  - $B^0 \to K^{*0}\gamma$ (CP asymmetry)

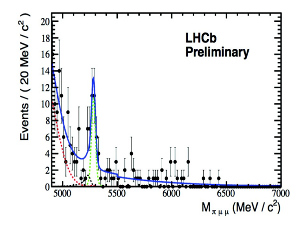
$B^+ \to \pi^+\mu^+\mu^-$

Introduction

- $b \to d\mu\mu$ transition never observed before. SM prediction:
  $$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-) = (1.96 \pm 0.21) \times 10^{-8}$$ [S. Hai-Zhen *et al.*, CTP **50** (2008) 696]
- Previous best limit from Belle $\mathcal{B} < 6.9 \times 10^{-8}$@$90\%CL$ [PRD 78 (2008) 011101]

Analysis

- MVA BDT to suppress combinatorial background
- yield extracted by means of EML fit:
  - mis-identified $B^+ \to K^+\mu^+\mu^-$
  - partially reconstructed background
  - combinatorial background (not shown)
  - signal using $B^+ \to J/\psi K^+$ as a proxy
- $25.3^{+6.7}_{-6.4}$ events (syst included), 5.2σ significance



- Normalize to $B^+ \to J/\psi K^+$:
  $\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-) = (2.4 \pm 0.6_{(stat)} \pm 0.2_{(syst)}) \times 10^{-8}$ - Preliminary

  Rarest B decay ever observed.

Outline

- Rare leptonic decays
  - $B^0_{(s)} \to \mu^+\mu^-$
  - $D^0 \to \mu^+\mu^-$
  - $\tau \to \mu\mu\mu$
  - $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$
- Rare semi-leptonic decays
  - $B^0 \to K^{*0}\mu^+\mu^-$ (angular analysis)
  - $B \to K^{(*)}\mu^+\mu^-$ (isospin asymmetry)
  - $B^+ \to \pi^+\mu^+\mu^-$
- Rare radiative decays
  - $B^0 \to K^{*0}\gamma$ (CP asymmetry) [LHCb-CONF-2012-004]

$B^0 \to K^{*0}\gamma$

CP asymmetry

- In SM, B radiative decays proceed at leading order via electromagnetic penguins transitions
- Extensions of the SM predict additional one-loop contributions (sensitive to NP)

$\mathcal{A}_{CP}^{SM}(B^0 \to K^{*0}\gamma) = -0.0061 \pm 0.0043$ [Y. Keum *et al.*, PRD **72** (2005) 014013]

$\mathcal{A}_{CP}^{EXP}(B^0 \to K^{*0}\gamma) = -0.016 \pm 0.022 \pm 0.007$ [BaBar, PRL **103** (2009) 211802]

LHCb: $\mathcal{A}_{CP}^{EXP} = \mathcal{A}_{CP}^{RAW} - \mathcal{A}_{K\pi}^{Det} - \kappa\mathcal{A}_{B^0}^{Prod}$;

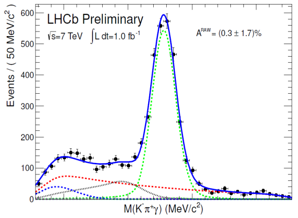
$\mathcal{A}_{CP}^{RAW} \equiv \frac{N(\bar{B}^0)-N(B^0)}{N(\bar{B}^0)+N(B^0)} = 0.003 \pm 0.017_{stat} \pm 0.007_{syst}$,

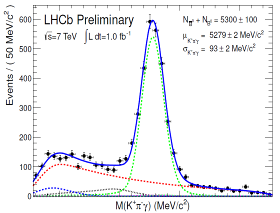
$-\mathcal{A}_{K\pi}^{Det} \equiv \frac{\epsilon(K^-\pi^+)-\epsilon(K^+\pi^-)}{\epsilon(K^-\pi^+)+\epsilon(K^-\pi^+)} = 0.010 \pm 0.002$,

$-\kappa\mathcal{A}_{B^0}^{Prod} = -0.004 \pm 0.005$;

$\mathcal{A}_{CP}^{EXP} = 0.008 \pm 0.017_{stat} \pm 0.009_{syst}$ - Preliminary

Most precise measurement





signal (dashed)

combinatorial background (dashed)

$B \to K^{*0}\pi^0 X$ (dashed)

$B^{+,0} \to K^{*0}\pi^{+,0}\gamma$ (dotted)

Conclusions

- Rare decays are powerful ways to search for NP beyond the SM
- LHCb strongly performing and very well positioned in this field
- World Best Limits on the measurements of $\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-)$, $\mathcal{B}(D^0 \to \mu^+\mu^-)$
- First observation of $B^+ \to \pi^+\mu^+\mu^-$
- Most precise measurements of angular observables and $\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma)$.
- Still... consistency with SM in FCNC... but severe constraints on NP models... though the isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$ decays...
- All measurements are still statistically limited - expect further improvements.

BACKUP

Backup

- Significant NP BR enhancement in $B_s \to \mu^+\mu^-$ has been ruled out by the LHC, we are getting close to the SM value

  $\Rightarrow$ It's important to understand the central value and uncertainty of the SM predictions
- So far we used Buras prediction BR($B_s \to \mu^+\mu^-$)= (3.2±0.2) x10^{-9}

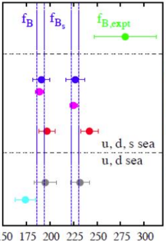
$$\mathcal{B}(B_q \to \mu^+\mu^-) = 4.36 \cdot 10^{-10} \frac{\tau_{B_q}}{\hat{B}_q} \frac{Y^2(v)}{S(v)} \Delta M_q$$

with B_s= 1.33 ± 0.06 E. Gamiz et al: Phys.Rev.D 80 (2009) 014503

- Other possibility: take advantage of the improvement in f_{Bs} from Lattice :

$$BR(B_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^2} f_{B_s}^2 m_{B_s}^3 |V_{tb}V_{ts}^*|^2 \tau_{B_s} \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} \times \left\{ \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) |C_{Q_1} - C'_{Q_1}|^2 + \left| (C_{Q_2} - C'_{Q_2}) + 2(C_{10} - C'_{10}) \frac{m_\mu}{m_{B_s}} \right|^2 \right\} . \quad (2.4)$$

C.Davies,arXiv:1203.3862



- N. Mahmoudi et al (arXiv:1205.1845): (3.53±0.38) x10^{-9} using f_{Bs} = (234±10)MeV
- C. Davies (arXiv:1203.3862): (3.32±0.25)x10^{-9} using f_{Bs} = (227±4)MeV

Which value of f_{Bs} should we use?

- De Bruyn et al (arXiv:1204.1735): Need to take into account the B_s mixing
  - Theoretically: CP-average at t=0
  - Experimentally: CP-average integrated over t

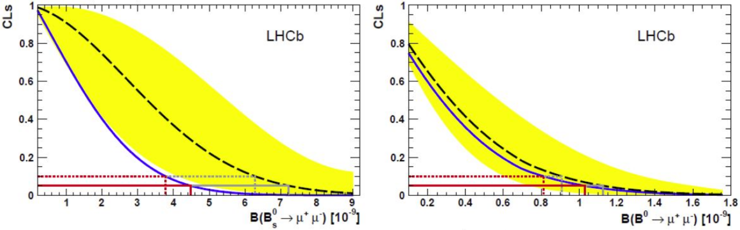
$$\mathrm{BF}(B_s \to f)_{\mathrm{theo}} = \left[\frac{1-y_s^2}{1+\mathcal{A}^f_{\Delta\Gamma}\, y_s}\right] \mathrm{BF}(B_s \to f)_{\mathrm{exp}} \qquad y_s = \frac{\Delta\Gamma_s}{2\Gamma_s}$$

0.911±0.014 for $B_s \to \mu^+\mu^-$ using y_s from *LHCb-CONF-2012-002*

$BR_{theo}(B_s \to \mu^+\mu^-) < 4.5 * 0.911 = 4.1 \times 10^{-9}$ @ 95% CL

- LHCb ($1fb^{-1}$):

PRL 108, 231801 (2012)

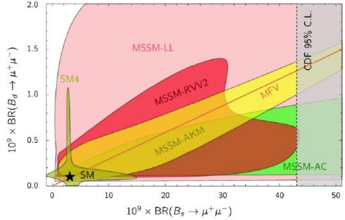


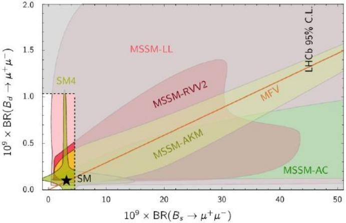
Linit at 95% CL	$B_d \to \mu^+\mu^-$	$B_s \to \mu^+\mu^-$
Expected bkg only	1.1×10^{-9}	3.4×10^{-9}
Expected bkg+MS		7.2×10^{-9}
Observed	1.0×10^{-9}	4.5×10^{-9}

2010

Straub Moriond 2012, arXiv:1205.6094

2011

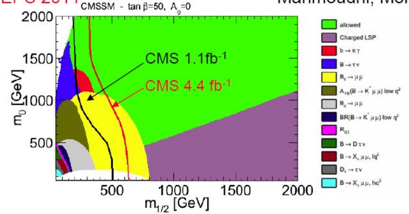


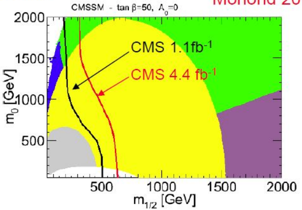


EPS 2011

Mahmoudhi, Moriond 2012

Moriond 2012





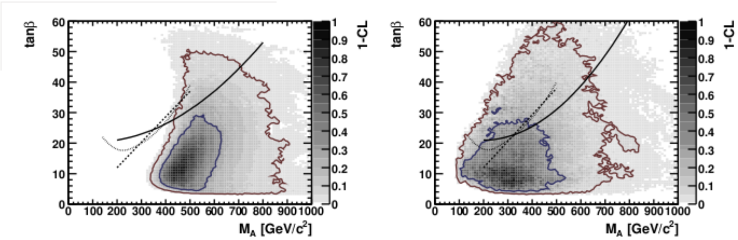
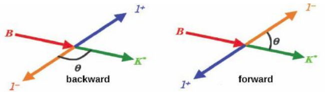


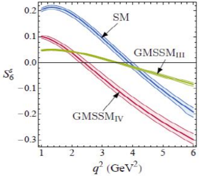
Figure 17. *The correlations between M_A and $\tan\beta$ in the CMSSM (left panel) and in the NUHM1 (right panel). Also shown are the 5-σ discovery contours for observing the heavy MSSM Higgs bosons H, A in the three decay channels $H, A \to \tau^+\tau^- \to$ jets (solid line), jet$+\mu$ (dashed line), jet$+$e (dotted line) at the LHC. The discovery contours have been obtained using an analysis that assumed 30 or 60 fb^{-1} collected with the CMS detector [129,149].*

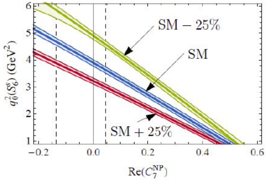
$$A_{FB}(q^2) = \frac{N_F - N_B}{N_F + N_B}$$

$$S_6 = -\frac{4}{3} A_{FB}$$

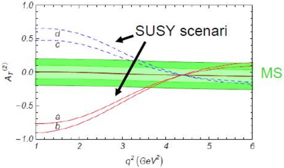


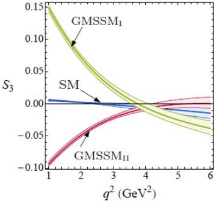
Almannshofer et al
ArXiv:0801.1214v5





Egede et al ArXiv:0807.2589

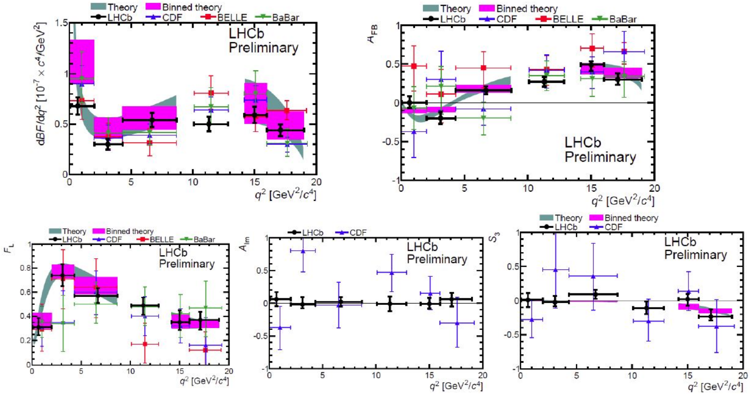




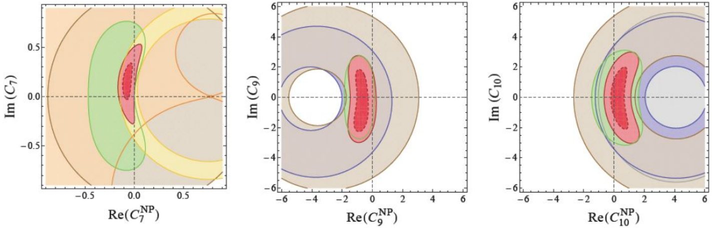
$$A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$$

$$S_3 = (1 - F_L) A_T^2$$

CDF, PRL 108 (2012) Belle, PRL 103 (2009) BaBar prelim., Lake Louise 2012



- Several studies, ex: Straub et al, arXiv:1206.0273
- Model independent constraint $C_i = C_i^{SM} + C_i^{NP}$
- Over constraint Wilson coefficient with many measurement in a global fit

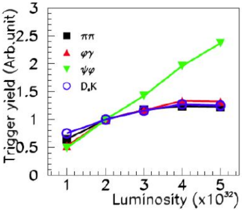


BR($B \to X_s ll$) $A_{CP}(b \to s\gamma)$ BR($B \to X_s\gamma$) $B \to K^*\mu\mu$ BR($B \to K\mu\mu$) BR($B_s \to \mu\mu$)

Red: Combined 1σ,2σ constraints

Wilson coefficients compatible with their SM values at 95%CL

- Main limitation that prevents expoiting higher luminosity is the hardware trigger limiting the output rate at 1 MHz



- Propose to remove the hardware trigger and read out LHCb at 40MHz crossing rate
  - $\Rightarrow$ increase yields by 10-20 at 1-2 10^{33}cm^{2}s^{-1}
  - $\Rightarrow$ aim to collect 50fb^{-1}

- LOI submitted to LHCC in March 2011, physics case endorsed
- Framework TDR submitted in may 2012

CERN/LHCC 2012-007, LHCb TDR 12, 25 May 2012 5 fb^{-1} 50 fb^{-1}

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,fb^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\,\phi$)	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\, f_0(980)$)	0.17 [10]	0.045	0.014	~ 0.01
	$A_{fs}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{eff}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{eff}(B_s^0 \to \phi\gamma)$	–	0.13 %	0.03 %	0.02 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,GeV^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\, A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	8 %	2.5 %	7 %
	$A_I(K\mu^+\mu^-; 1 < q^2 < 6\,GeV^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	$\sim 20°$ [19]	4°	0.9°	negligible
	γ ($B_s^0 \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\, K_S^0$)	0.8° [18]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–