Rare Decays

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Brookhaven Forum 2013

May 02, 2013

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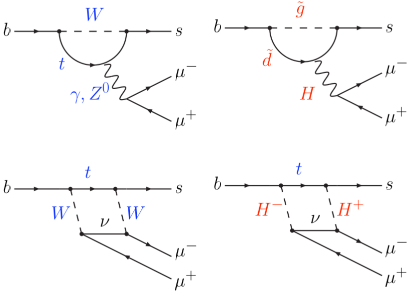
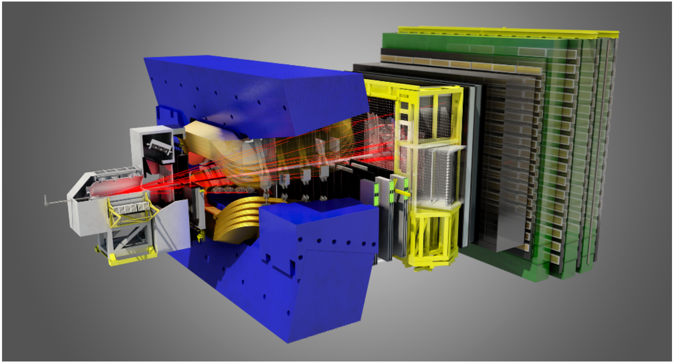
Rare decays

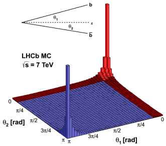
- fundamental tools for indirect searches of new physics
- Indirectly probing higher energy scales than directly accessible
- ⋆ FCNC, $\Delta F = 1$, are forbidden at tree level in the SM.
  - proceed via loop diagrams.
  - In extensions to the SM these processes can receive contributions from "new" virtual particles.
- ⋆ Suppressed or forbidden in SM $\rightarrow$ sensitive to NP effects

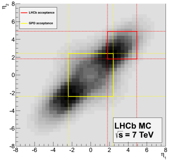


SM NP

- Large $b\bar{b}$ cross section $\sigma(pp \to b\bar{b}X)$ @ 7TeV $= 284 \pm 53\mu b$ [LHCb, PLB 694 209]
- Large acceptance for b hadron decays
- Efficient and flexible trigger (particularly μ trigger for analyses presented here)
- good particle ID, tracking and reconstruction







Rare B decays

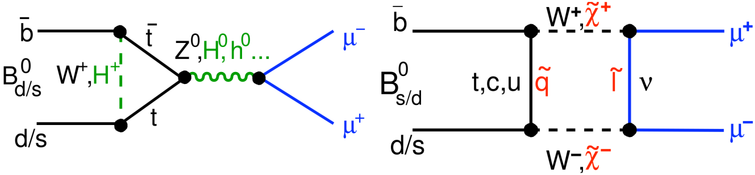
- $B^0_{(s)} \to \mu^+\mu^-$
- $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$

Semileptonic $b \to sl^+l^-$ decays

- $B^0 \to K^*\mu^+\mu^-$
- $B^0 \to K^*e^+e^-$

- $K^0_S \to \mu^+\mu^-$

- $B^0 \to \mu\mu$ and $B^0_s \to \mu\mu$ are GIM and helicity suppressed in the SM
- Standard Model BR predictions have a very good accuracy.
  [A. Buras et al. arXiv:1303.3820]: $BR(B^0 \to \mu\mu) = (1.07 \pm 0.10) \times 10^{-10}$,
  [De Bruyn et al. [PRL 109, 041801]]: $BR(B^0_s \to \mu\mu) = (3.54 \pm 0.30) \times 10^{-9}$
- $B^0 \to \mu\mu$ and $B^0_s \to \mu\mu$ are sensitive to possible NP contributions $\Rightarrow$ probe of NP models with extended Higgs sectors.
  e.g. in MSSM, branching fraction scales $\approx \tan^6\beta / M_A^4$



- Today: updated search including: 1fb^{-1} at 7TeV and 1.1fb^{-1} at 8TeV

PRL110, 021801 (2013)

Selection

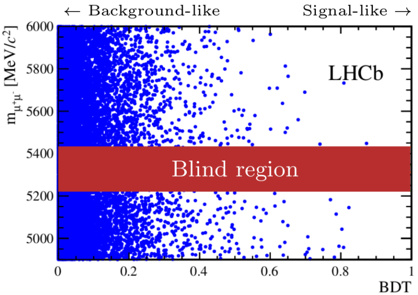
- Pairs of opposite muons.
- Displaced Vertex
- $4.9 < m_{\mu\mu} < 6.0$ GeV/c^2
- p_T, IP and quality cuts

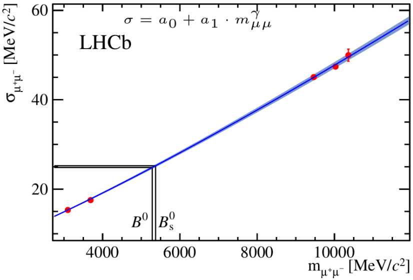
- BDT vs $m_{\mu\mu}$: Search in a 2D plane

Control channels

$B^0_{(s)} \to hh$: mass peak position
$X \to \mu\mu$: mass peak resolution

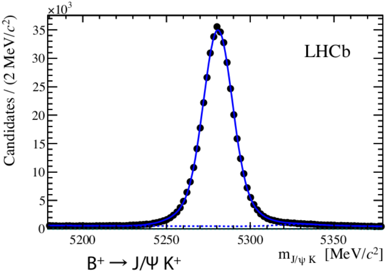
- $\sigma_{B^0} = (24.6 \pm 0.4)$ MeV/c^2
- $\sigma_{B^0_s} = (25.0 \pm 0.4)$ MeV/c^2





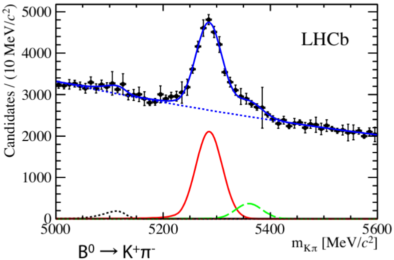
PRL110, 021801 (2013)

- Two channels are averaged for normalization (compatible)



$B^+ \to J/\Psi K^+$

Similar trigger, different topology



$B^0 \to K^+\pi^-$

Different trigger, same topology

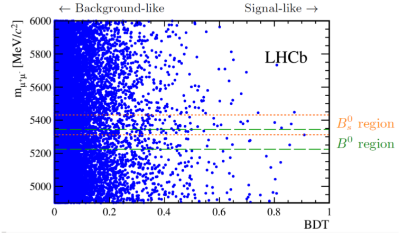
- Number of observed events is translated to BR

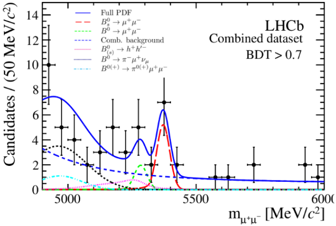
$$BR(B^0_{(s)} \to \mu^+\mu^-) = BR_{norm} \times \frac{\epsilon^{rec}_{norm}\epsilon^{sel}_{norm}}{\epsilon^{rec}_{sig}\epsilon^{sel}_{sig}} \frac{\epsilon^{trg}_{norm}}{\epsilon^{trg}_{sig}} \times \frac{f_{norm}}{f_{d(s)}} \times \frac{N_{B^0_{(s)}\to\mu^+\mu^-}}{N_{norm}}$$

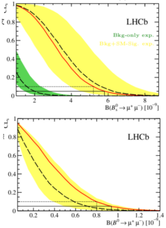
MC - Data - $f_d/f_s = 0.256 \pm 0.020$, from LHCb (PRD 85 (2012) 032008)

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

PRL110, 021801 (2013)







- Using 1fb^{-1} at $\sqrt{s} = 7\text{TeV}$ and 1.1fb^{-1} at $\sqrt{s} = 8\text{TeV}$ of data, LHCb finds the first evidence of $B_s \to \mu^+\mu^-$ decay.
- Signal incompatible with the background-only hypothesis at 3.5σ

$$BR(B^0_s \to \mu^+\mu^-) = (3.2^{+1.4}_{-1.2}(\text{stat})^{+0.5}_{-0.3}(\text{syst})) \times 10^{-9}$$

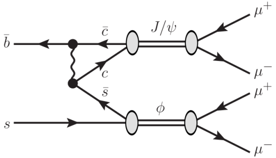
- No significant evidence is found for the $B^0 \to \mu^+\mu^-$ decay.

$$BR(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10} @\ 95\,\%\ \text{CL}$$

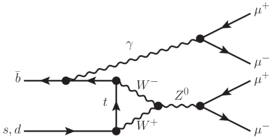
arXiv:1303.1092

- Strongly suppressed in the SM, two contributions:
  - Resonant $B_s^0 \to J/\psi(\to \mu\mu)\phi(\to \mu\mu)$, with a $BR = (2.4 \pm 0.9) \times 10^{-8}$, excluded in the analysis
  - Non-resonant $B^0_{(s)} \to \mu\mu\gamma(\to \mu\mu)$, with $BR < 10^{-10}$ [PRD 70 (2004) 114028]
- In NP models, scalar and pseudoscalar particles enhance the BR via $B \to PS$
- Particular sensitivity to sgoldstino-mediated decays in the MSSM

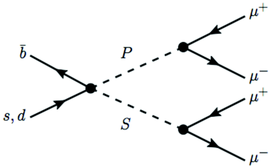
$B_s^0 \to J/\psi(\to \mu\mu)\phi(\to \mu\mu)$



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



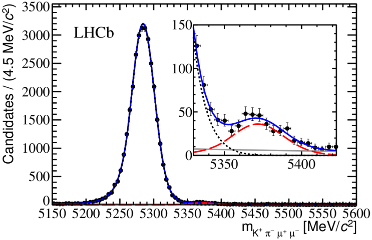
$B \to PS$



arXiv:1303.1092

- 4 muons with high IP_{χ^2}, good vertex and tight PID cuts ($\epsilon_\mu = 78.5\,\%$, $\epsilon_{\pi\to\mu} = 1.4\,\%$)
- Resonant $B^0_s \to J/\psi(\to \mu\mu)\phi(\to \mu\mu)$: removed and used as control channel for the selection.
- Only considered combinatorial background (peaking negligible)
- Normalization channel: $B^0 \to J/\psi(\to \mu\mu)K^*(\to K\pi)$
  same selection except the PIDs

$$BR(B^0_{(s)} \to 4\mu) = BR(B^0 \to J/\psi K^*) \times \kappa \times \frac{\epsilon_{B^0 \to J/\psi K^*}}{\epsilon_{B^0_{(s)} \to 4\mu}} \times \frac{f_d}{f_{d(s)}} \times \frac{N_{B^0_{(s)} \to 4\mu}}{N_{B^0 \to J/\psi K^*}}$$



MC

κ: correction for the S-wave exclusion

$f_d/f_s = 0.256 \pm 0.020$, from LHCb (PRD 85 (2012) 032008)

arXiv:1303.1092

- Analysis on 1fb^{-1} of 2011 data.
- Upper limits at 90 % (95 %) CL

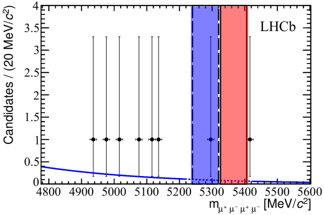
$$BR(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 1.2(1.6) \times 10^{-8}$$

$$BR(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 5.3(6.6) \times 10^{-9}$$

- Upper limits at 90 % (95 %) CL in MSSM models ($m_P = 214.3\,\text{MeV/c}^2$, $m_S = 2.5\,\text{GeV/c}^2$)

$$BR(B^0_s \to SP \to 4\mu) < 1.2(1.6) \times 10^{-8}$$

$$BR(B^0 \to SP \to 4\mu) < 5.1(6.3) \times 10^{-9}$$



arXiv:1304.6325, PRL110, 031801 (2013)

Many interesting observables which allow to constrain NP

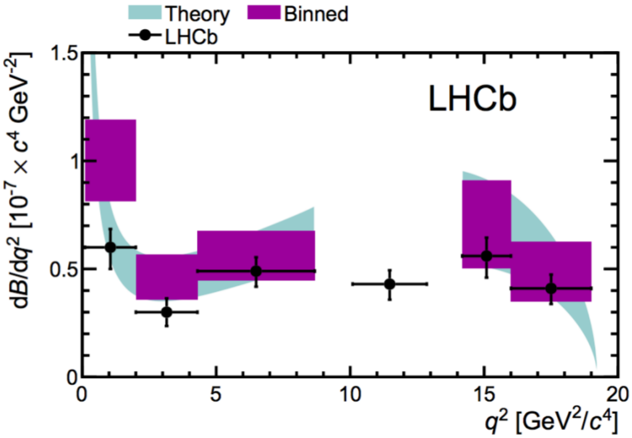
- Angular distribution, described by 3 angles (θ_l, θ_K and ϕ) and q^2
- A_{FB} zero-crossing point, largely free from form-factor uncertainties
- Differential BR, which suffers from larger hadronic uncertainties
- CP asymmetry, predicted to be $O(10^{-3})$ in the SM but could be enhanced in NP models (see JHEP 01 (2009) 019, JHEP 11 (2011) 122)

Analysis strategy for 2011 data (1fb^{-1})

- All observables measured in bins of q^2
- Due to limited statistic, use $\hat{\phi} = \phi + \pi$ if $\phi < 0$, otherwise $\hat{\phi} = \phi$ to obtain simplified angular expression (4 observables: A_{FB}, F_L, S_3 and A_9)
- Use $B^0 \to J/\psi K^*$ for normalization in BR measurement and for correction of production and detection asymmetries in A_{CP}

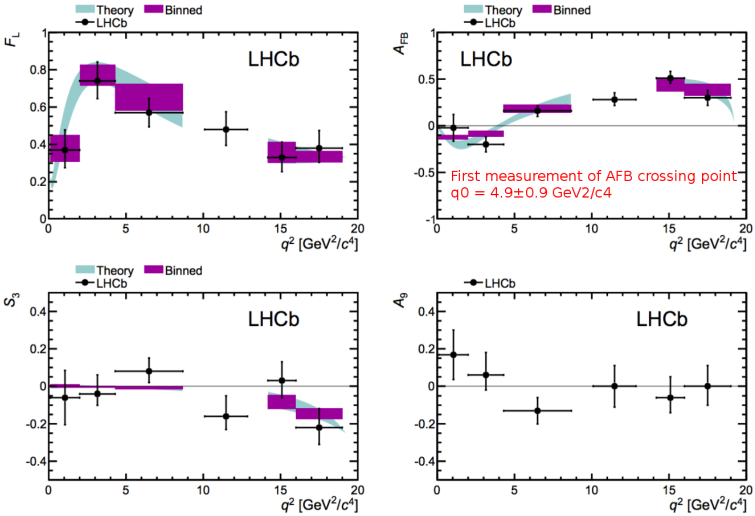
arXiv:1304.6325, PRL110, 031801 (2013)

- Sensitivity to NP limited by hadronic uncertainties



- Most precise measurement to date, consistent with SM

arXiv:1304.6325, PRL110, 031801 (2013)



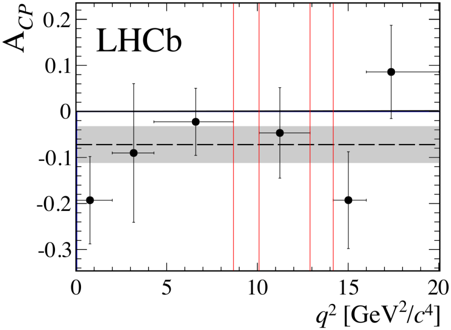
- Most precise measurement to date, consistent with SM

arXiv:1304.6325, PRL110, 031801 (2013)

- Average over magnet polarities to cancel left-right asymmetry
- A_{CP} integrated over the full q^2

$$A_{CP} = -0.072 \pm 0.040(\text{stat}) \pm 0.005(\text{syst})$$

- A_{CP} binned in q^2 consistent with the SM within 1.8σ
- Most precise measurement to date



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

arXiv:1304.3035

Comparison with $B^0 \to K^{(*)0} \mu^+ \mu^-$

- Low dilepton mass ($= q^2$) has higher sensitivity to photon polarization
- Complementary due to more sensitivity to C_7' than C_9'
- Easier theoretical formalism due to negligible lepton mass
- Worst resolution due to sizeable bremβtrahlung effects

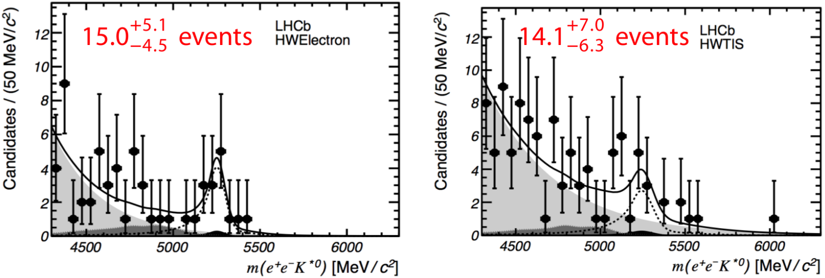
Study differential BR in $30 < m_{ee} < 1000\,\mathrm{MeV/c^2}$

- Avoid huge contamination from $B^0 \to K^* \gamma$
- Below $30\,\mathrm{MeV/c^2}$ angles are hard to measure due to multiple scattering

Next step angular analysis.

arXiv:1304.3035

- Analysis on 1fb^{-1} of 2011 data. Observation of the signal decay with 4.6σ significance.

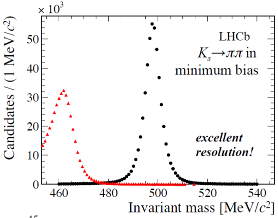


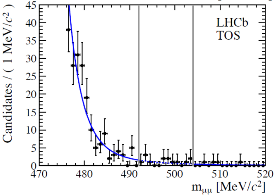
- Systematic uncertainties below statistical ones
- Measurement of BR at low q^2

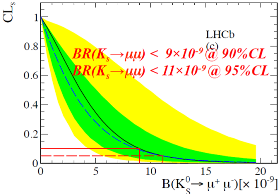
$$BR(B^0 \to K^{*0} e^+ e^-)^{30-1000\ \text{MeV/c}^2} = (3.1^{+0.9}_{-0.8}{}^{+0.2}_{-0.3} \pm 0.2) \times 10^{-7}$$

JHEP 01 (2013) 090

- In SM: $BR(K_S^0 \to \mu\mu) = (5.0 \pm 1.5) \times 10^{-12}$
- 10^{13} K_S^0 per fb^{-1} @ LHCb
- background: μ from interations with the VELO (Vertex Locator) and doubled misidentified $K_S^0 \to \pi\pi$.
- Candidates classified in bins of BDT, compared to signal and background expectation
- $K_S^0 \to \pi\pi$ used to train the BDT and also as normalization sample
- Thirty times better than previous measurement!







- First evidence (3.5σ) of $B_s^0 \to \mu^+\mu^-$

  $BR(B_s^0 \to \mu^+\mu^-) = (3.2^{+1.4}_{-1.2}(\text{stat})^{+0.5}_{-0.3}(\text{syst})) \times 10^{-9}$
- Upper Limits on:
  $B^0 \to \mu^+\mu^-$,
  $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$, $B^0 \to \mu^+\mu^-\mu^+\mu^-$,
  $K_S^0 \to \mu^+\mu^-$
- (Differential) BR in t he $B^0 \to K^* l^+ l^-$ analyses
  Angular analyses consistent with SM
  First measurement of A_{FB} crossing point in $B^0 \to K^*\mu^+\mu^-$.

- LHCb is a wonderful environment for rare decay analyses.