Rare Beauty, Charm and Tau decays at LHCb

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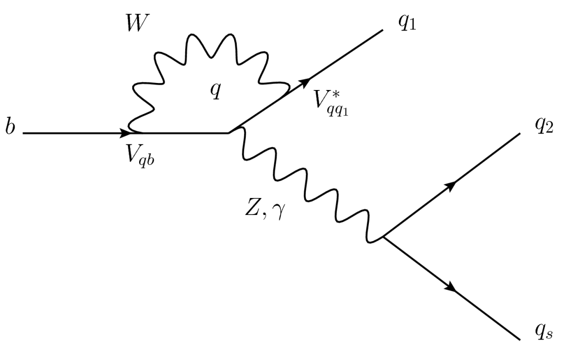
on behalf of the LHCb collaboration

Outline

- Introduction to rare decays
- Branching Ratios
    - Measurements and limits
- Angular analysis on $B_d \to K^{*0}\mu^+\mu^-$
- Isospin asymmetry on $B_d \to K^{(*0)}\mu^+\mu^-$
- Conclusions

NP through rare B and D decays

- FCNC ($\Delta F = 1$ and $\Delta F = 2$) in the SM are suppressed and only produced at loop-level.
  - Promising to look for new contributions in the loop from heavy particles.
  - NP can enhance BR or modify Lorentz structure
  - Explore the transitions:
    - $b \to s l^+ l^-$
    - $b \to d l^+ l^-$
    - $b \to s\gamma$



- Indirect searches are complementary to the results from GP experiments.

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

LHCb-CONF-2012-05

- Very suppressed in the SM with a prediction $O(10^{-13} - 10^{-11})$
  [Phys. Rev. D66 (2002) 014009]
- Correlated with the D^0 mixing in some NP models through
  - $x_D = \Delta M_D/\Gamma_D$ [Phys. Rev. D79 (2009) 114030]
- Analysis based on D*-tagged samples with 0.9 fb^{-1}. Provides clean samples.
  - Selects $D^{*+} \to D^0(\mu^+\mu^-)\pi^+$

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{N_{D^{*+}\to D^0(\mu^+\mu^-)\pi^+}}{N_{D^{*+}\to D^0(\pi^+\pi^-)\pi^+}} \times \frac{\epsilon^{TRIG}_{\pi\pi}}{\epsilon^{TRIG}_{\mu\mu}} \times \frac{\epsilon^{RECO}_{\pi\pi}}{\epsilon^{RECO}_{\mu\mu}} \times \frac{\epsilon^{SEL}_{\pi\pi}}{\epsilon^{SEL}_{\mu\mu}} \times \mathcal{B}(D^0 \to \pi^+\pi^-)$$

- Two-dimensional fit to the D^0 mass and D^{*+} - D^0 mass difference.

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

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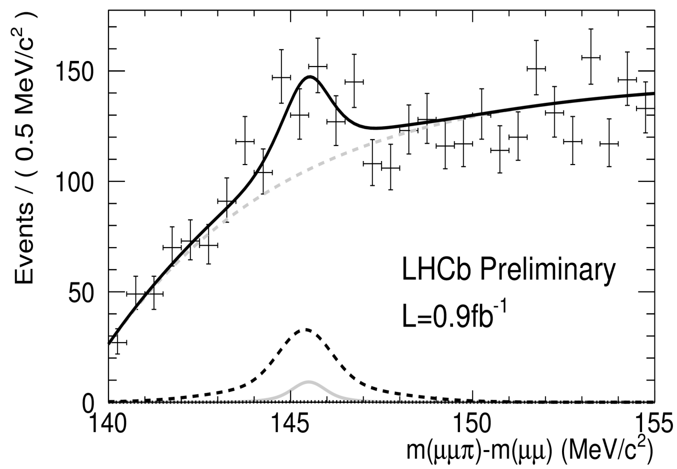
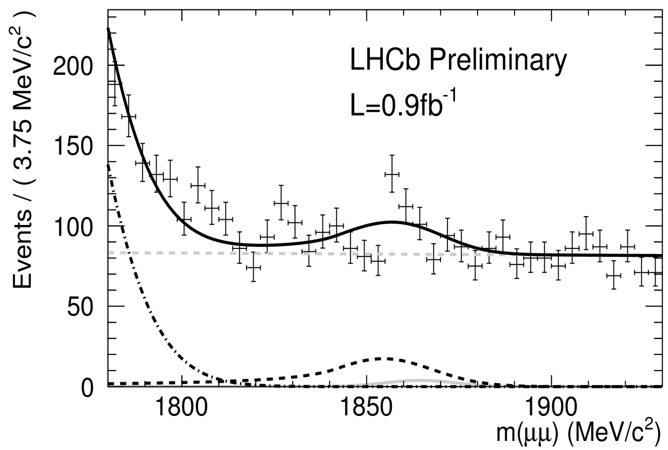
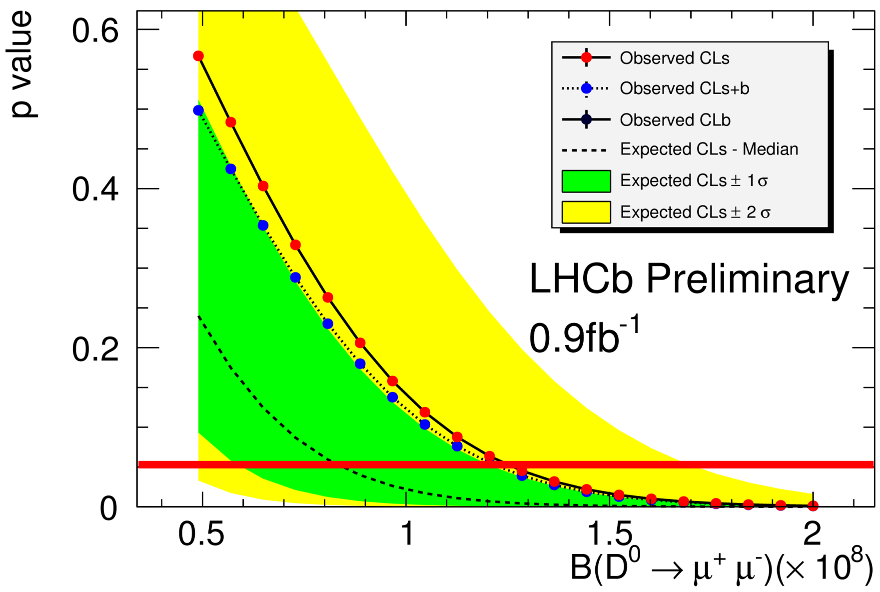






LHCb result. World best limit

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

Previous best limit by Belle

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.4 \times 10^{-7} \text{ at } 90\% \text{ CL}$$

[Phys. Rev. D81 (2010) 091102]

Signal $D^0 \to \mu^+\mu^-$: light solid (compatible with 0)
Bkg $D \to \pi^+\pi^-$: dark dashed (can be predicted from data)

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

LHCb-CONF-2012-006

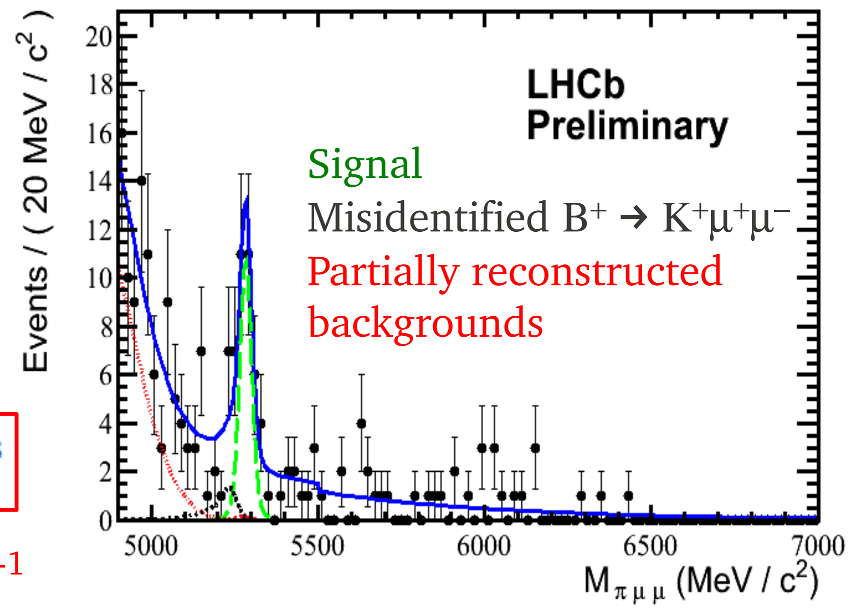
- $b \to dl^+l^-$ transition never observed before.
- In SM is suppressed by $|V_{td}/V_{ts}| \to BR = (1.96\pm0.21)\times10^{-8}$ [Commun. Th. Phys. 50 (2008) 696]
  - Suppression may not appear in NP scenarios.

$$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-) = \frac{N_{B^+\to\pi^+\mu^+\mu^-}}{N_{B^+\to J/\psi K^+}} \times \frac{\epsilon_{B^+\to J/\psi K^+}}{\epsilon_{B^+\to\pi^+\mu^+\mu^-}} \times \mathcal{B}(B^+ \to J/\psi K^+)$$

- Rarest B decay observed by LHCb
  - 5.2σ significance
  - $25.3^{+6.7}_{-6.4}$ events

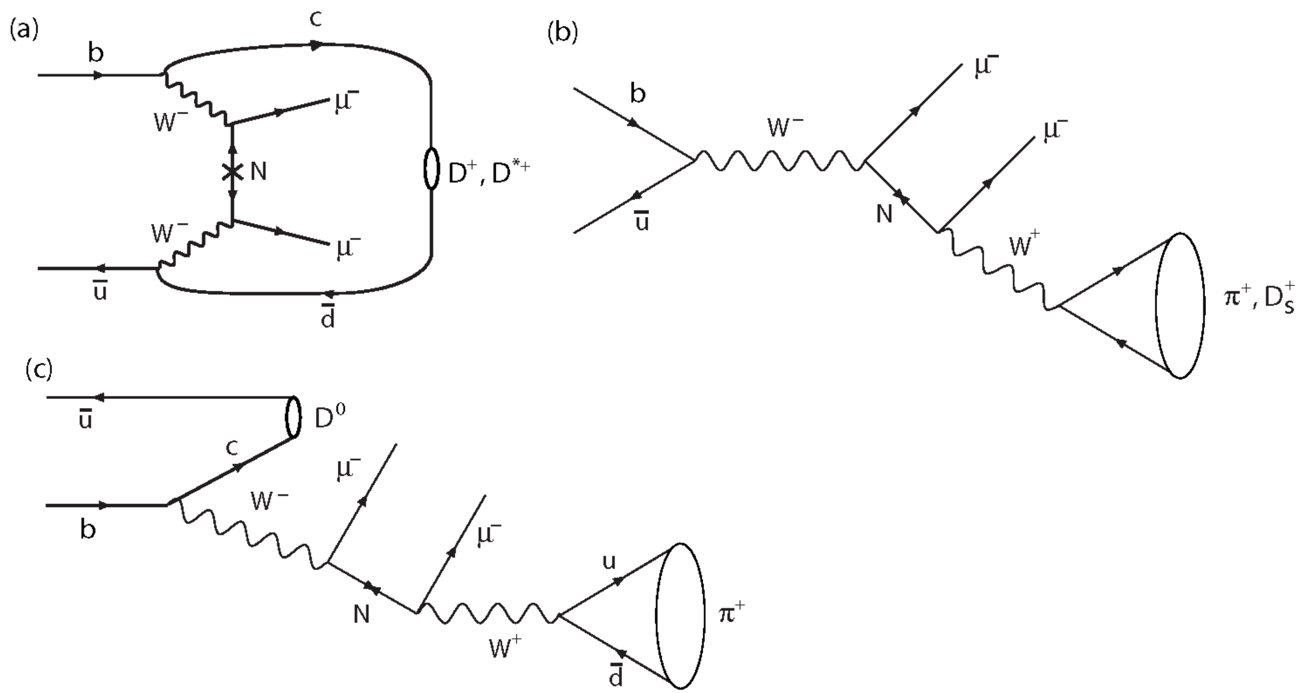
$$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-) = 2.4 \pm 0.6(\text{stat}) \pm 0.2(\text{syst}) \times 10^{-8}$$

First BR measurement of this channel with 1.0 fb^{-1}



Majorana neutrino

- Processes mediated through Majorana neutrino with 2 same-sign muons in final state → Lepton Number Violation processes:
  - Virtual neutrino (a) → D^+ , D^{*+}
  - On-shell neutrino (b,c) → π^+, K^+, D^+_s, $D^0\pi^+$



Majorana neutrino

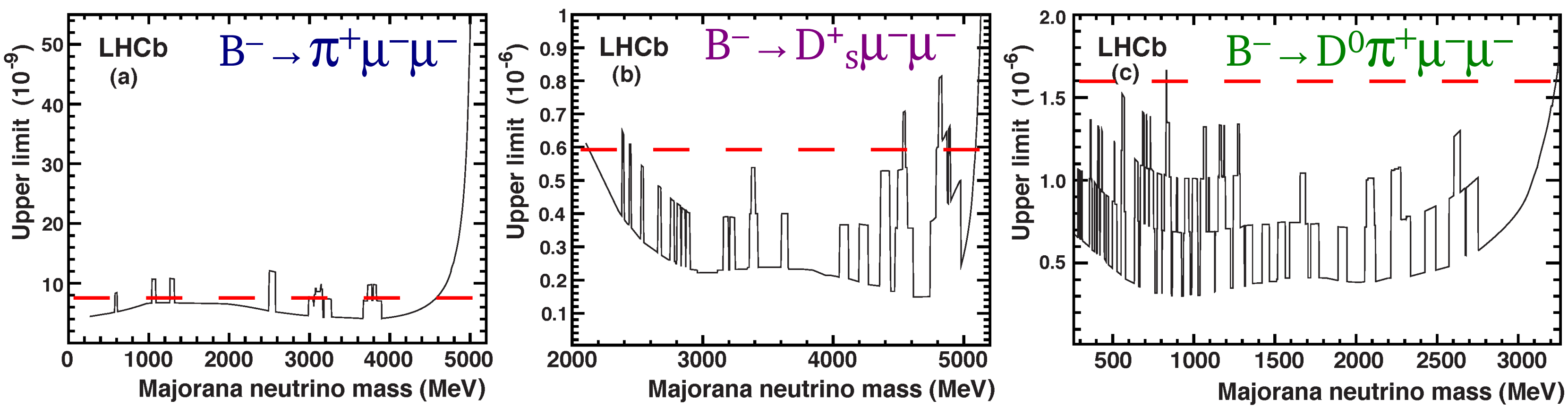
[PR Lett. 108 101601 (2012)] [arXiv:1201.5600] (to be published in Phys.Rev. D)

- Use $B^- \to J/\psi K^-$ and $B^- \to \psi(2S)(\to \pi^+\pi^- J/\psi)K^-$ as control channels.
- No signal for any of the channels have been found.

$$\mathcal{B}(B^- \to D\mu^-\mu^-) < 6.9 \times 10^{-7} \text{ at } 95\% \text{ CL}$$
$$\mathcal{B}(B^- \to D^{*+}\mu^-\mu^-) < 2.4 \times 10^{-6} \text{ at } 95\% \text{ CL}$$
$$\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 1.3 \times 10^{-8} \text{ at } 95\% \text{ CL}$$
$$\mathcal{B}(B^- \to K^+\mu^-\mu^-) < 5.4 \times 10^{-8} \text{ at } 95\% \text{ CL}$$
$$\mathcal{B}(B^- \to D_s^+\mu^-\mu^-) < 5.8 \times 10^{-7} \text{ at } 95\% \text{ CL}$$
$$\mathcal{B}(B^- \to D^0\pi^+\mu^-\mu^-) < 1.5 \times 10^{-6} \text{ at } 95\% \text{ CL}$$

Most restrictive limits to-date

Sample of 0.036 fb^{-1} & 0.41 fb^{-1}



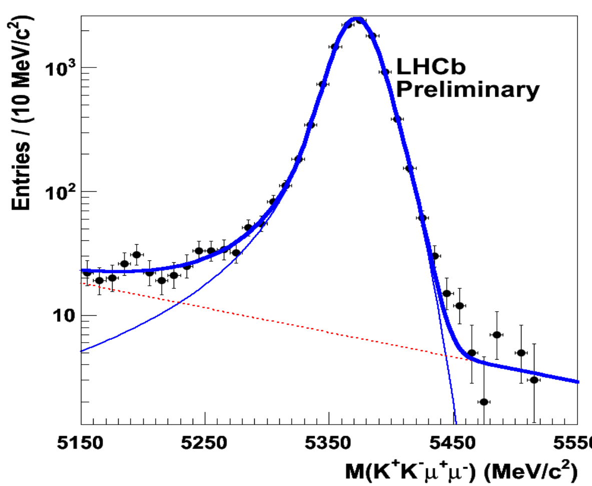
$B_s \to \phi\mu^+\mu^-$

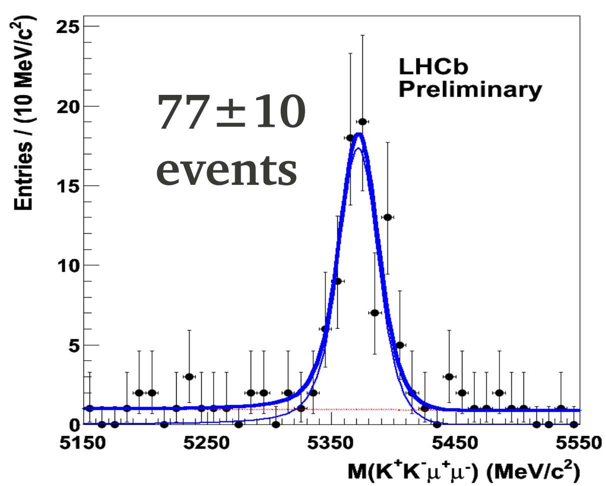
LHCb-CONF-2012-003

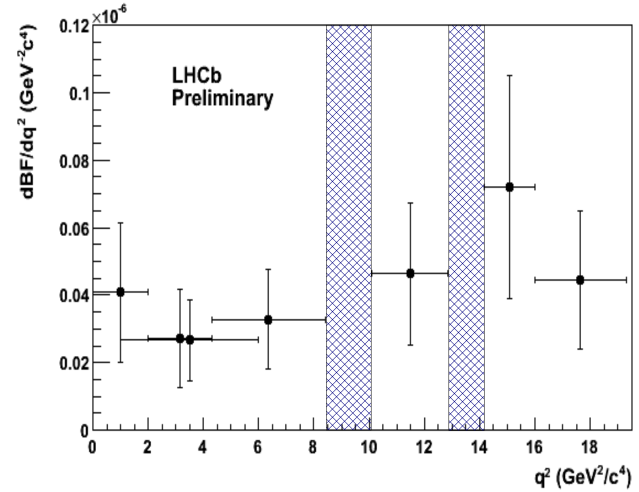
- Measure the branching fraction $B_s \to \phi\mu^+\mu^-$ normalised to $B_s \to J/\psi\phi$

$$\frac{\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = \frac{N_{B_s^0\to\phi\mu^+\mu^-}}{N_{B_s^0\to J/\psi\phi}} \times \frac{\epsilon_{B_s^0\to J/\psi\phi}}{\epsilon_{B_s^0\to\phi\mu^+\mu^-}} \times \mathcal{B}(J/\psi \to \mu^+\mu^-)$$

- SM prediction is 1.61×10^{-6} [J. Phys. G29 (2003) 1103]
- Measure in 6 bins of di-muon invariant mass (q^2) + 1 bin in range [1-6] GeV^2/c^4 using 1.0 fb^{-1}







$$\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-) = 0.78 \pm 0.10(\text{stat}) \pm 0.06(\text{syst}) \pm 0.28\mathcal{B} \times 10^{-6}$$

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

- Experimental limits approaching the SM predictions with 1.0 fb^{-1}.

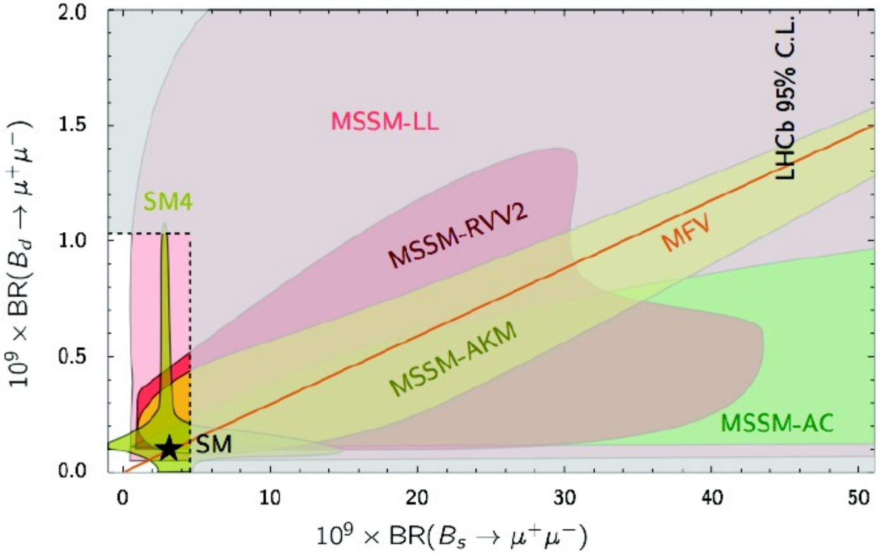
SM
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = 3.2 \pm 0.2 \times 10^{-9}$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) = 0.10 \pm 0.01 \times 10^{-9}$$

[JHEP 1010 (2010) 009]

LHCb
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) < 4.5 \times 10^{-9} \text{ at } 95\% \text{ CL}$$
$$\mathcal{B}(B^0_d \to \mu^+\mu^-) < 1.0 \times 10^{-9} \text{ at } 95\% \text{ CL}$$

[arXiv:1203.4493] To be published by PRL

- Some NP models have reduced BR for $B_s \to \mu^+\mu^-$ with respect to SM.



Strong constraints on NP models.

[arXiv:1107.0266v1]

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

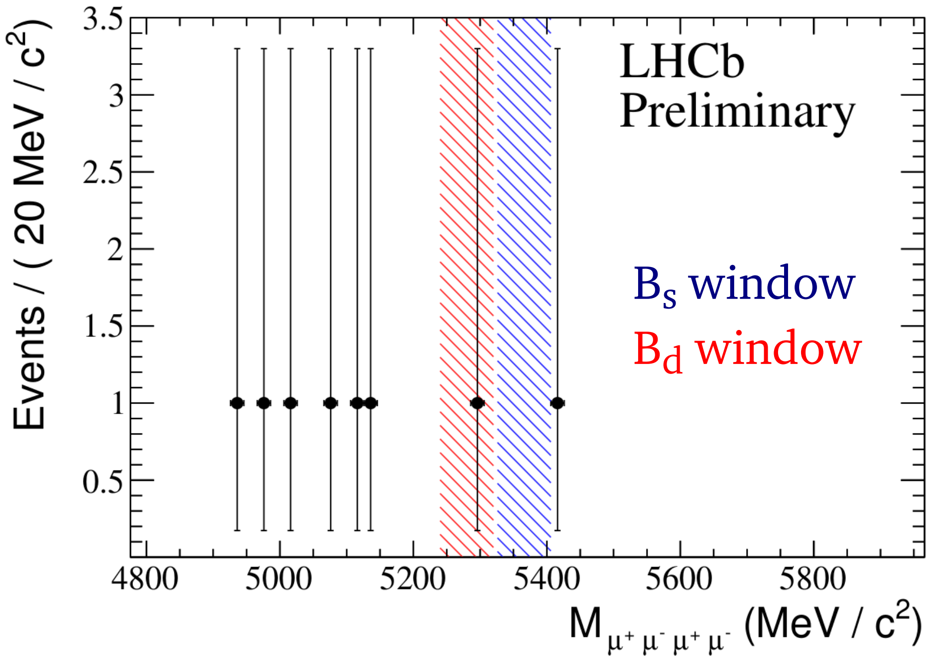
LHCb-CONF-2012-010

- SM prediction for B_s is BR $< 10^{-10}$ [Phys. Rev. D70 (2004) 114028]

$$\frac{\mathcal{B}(B^0_{s,d} \to \mu^+\mu^-\mu^+\mu^-)}{\mathcal{B}(B^0_d \to J/\psi K^{*0})} = \frac{N_{B^0_{s,d}\to\mu^+\mu^-\mu^+\mu^-}}{N_{B^0_d \to J/\psi K^{*0}}} \times \frac{\epsilon_{B^0_d \to J/\psi K^{*0}}}{\epsilon_{B^0_{s,d}\to\mu^+\mu^-\mu^+\mu^-}} \times \mathcal{B}(J/\psi \to \mu^+\mu^-) \times \mathcal{B}(K^{*0} \to K^+\pi^-)$$

- First searches of these decays. Use 1.0 fb^{-1}

Non-resonant window



$$\mathcal{B}(B^0_d \to \mu^+\mu^-\mu^+\mu^-) < 5.4 \times 10^{-9} \text{ at } 95\% \text{ CL}$$

$$\mathcal{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 1.3 \times 10^{-8} \text{ at } 95\% \text{ CL}$$

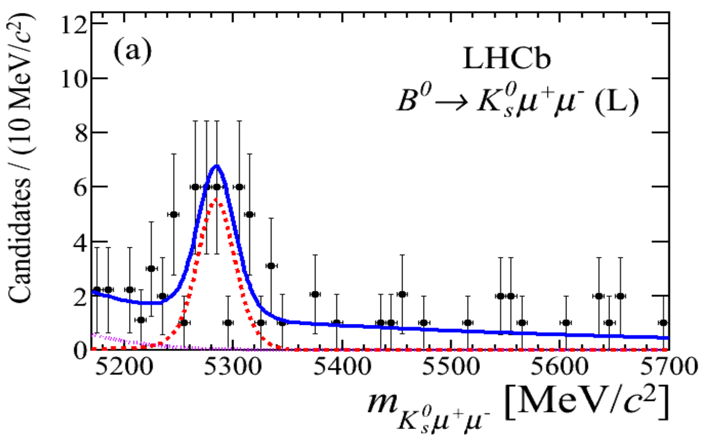
One event on B_d mass window compatible with background expectations.

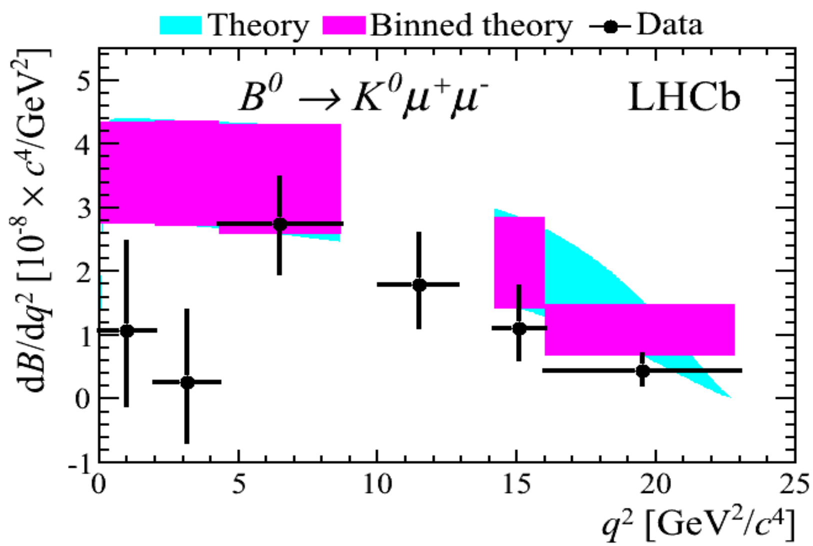
World best limit

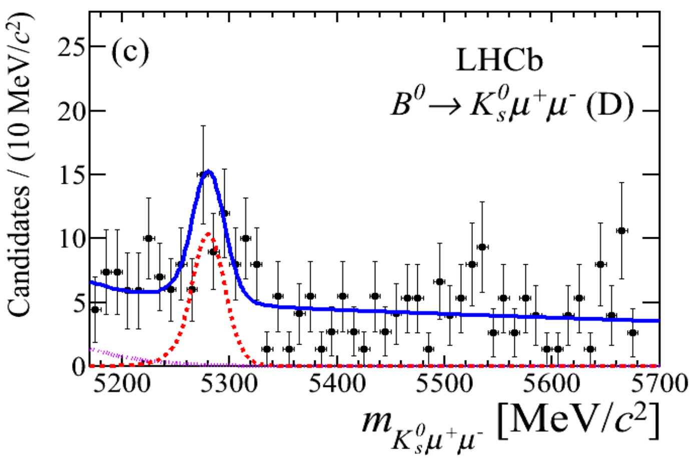
$B_d \to K_s \mu^+\mu^-$

[arXiv:1205.3422]
To be published by JHEP

- Spin-off from the isospin asymmetry measurement with 1.0 fb^{-1}.
  - First observation of this mode → 5.7σ significance







LHCb measurement

$$\mathcal{B}(B^0_d \to K^0\mu^+\mu^-) = (0.31^{+0.07}_{-0.06}) \times 10^{-6}$$

SM prediction $\mathcal{B}(B^0_d \to K^0\mu^+\mu^-) = (0.35 \pm 0.12) \times 10^{-6}$

[Phys. Rev. D66 (2002) 034002]

$\tau^- \to \mu^+\mu^-\mu^-$

LHCb-CONF-2012-015

- Lepton Flavour Violation decay with SM prediction below experimental reach.

$$\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) = \mathcal{B}(D_s^- \to \phi(\mu^+\mu^-)\pi^-) \times \frac{f(\tau^-(D_s^-))}{\mathcal{B}(D_s^- \to \tau^-\nu_{\bar{\tau}})} \times \frac{\epsilon_{cal}^{REC*SEL}\epsilon_{cal}^{TRIG|SEL}}{\epsilon_{sig}^{REC*SEL}\epsilon_{sig}^{TRIG|SEL}} \times \frac{N_{sig}}{N_{cal}}$$

- First measurement of this channel on a hadronic environment.

LHCb result with 1.0 fb^{-1}

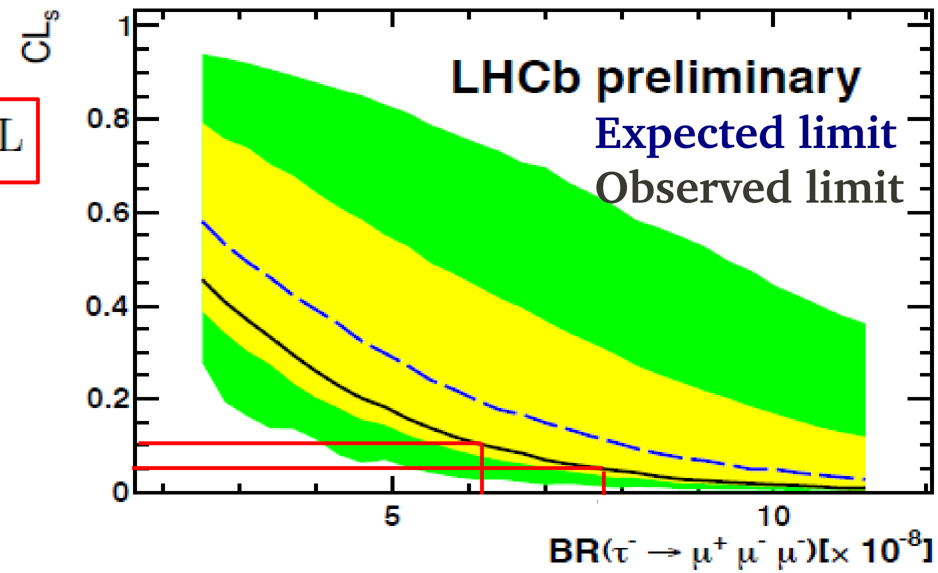
$$\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) < 6.3(7.8) \times 10^{-8} \text{ at } 90(95)\% \text{ CL}$$

Already comparable with the current best upper limit from Belle

Belle result

$$\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) < 2.1 \times 10^{-8} \text{ at } 90\% \text{ CL}$$

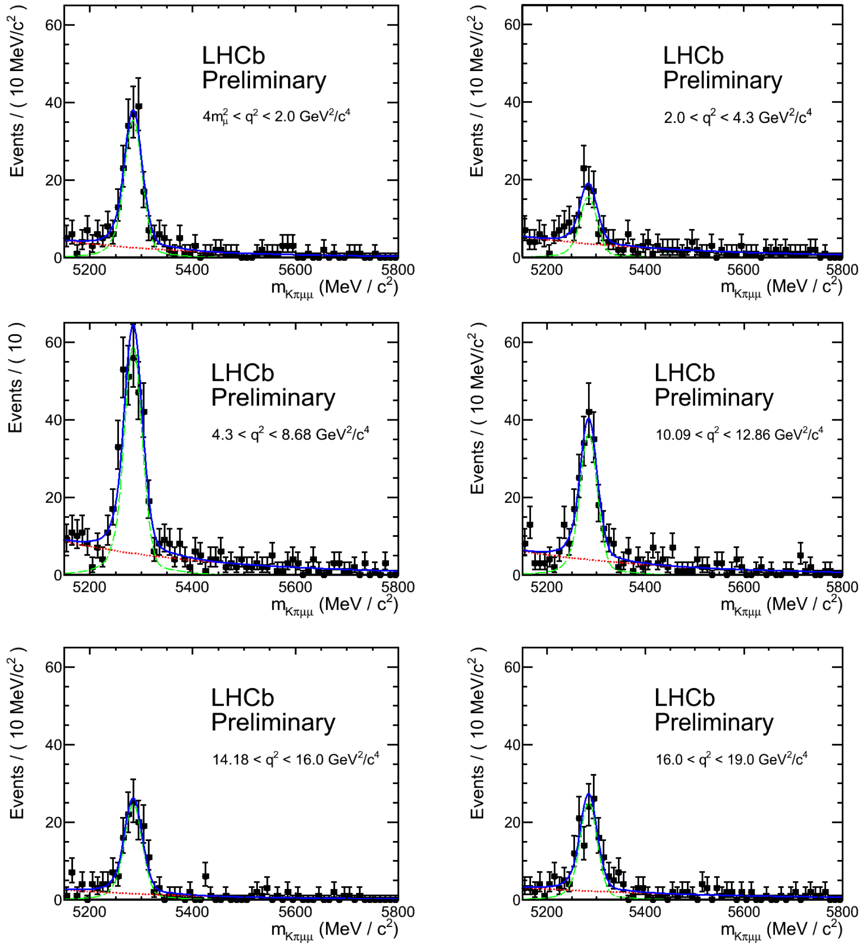
[J. Phys. G37 (2010) 075021]

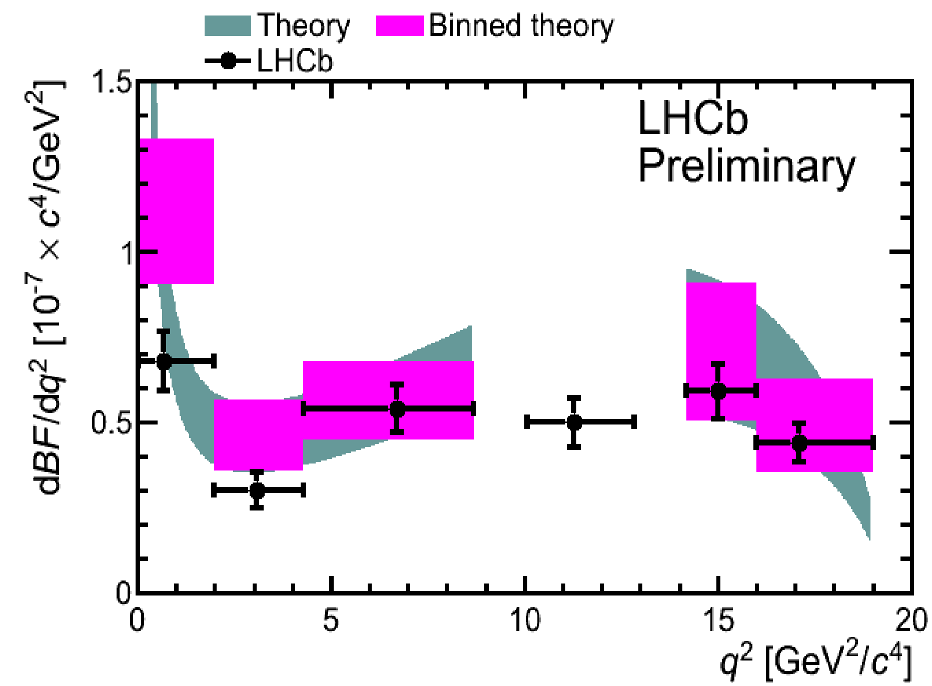


Differential BR $B_d \to K^{*0}\mu^+\mu^-$

LHCb-CONF-2012-008

- Differential BR as a function of q^2. Normalise with $B_d \to K^{*0}J/\psi$





Most precise measurement to-date.
Consistent with the SM predictions.
Use the full 1.0 fb^{-1}

900±34 events

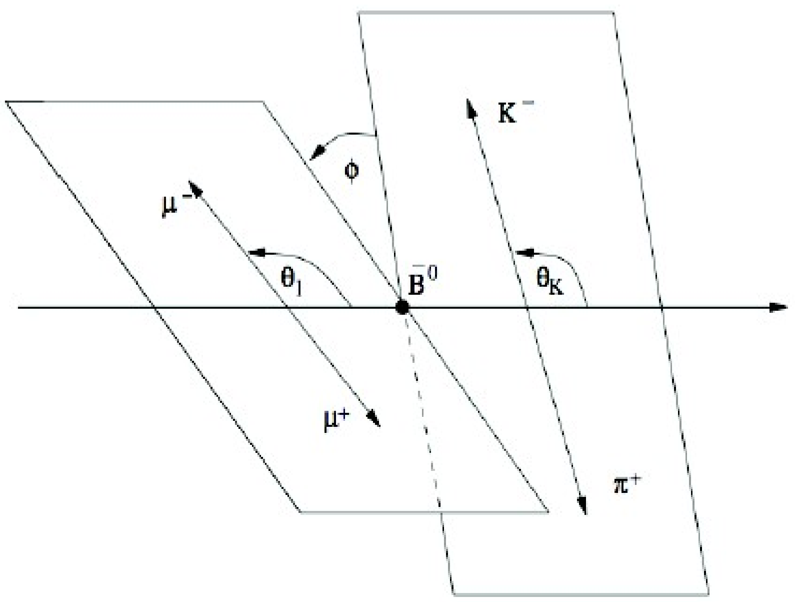
Angular analysis $B_d \to K^{*0}\mu^+\mu^-$

LHCb-CONF-2012-008

- Angular distribution parametrised by 6 q^2-dependent parameters.
- Not enough statistics yet to perform a full angular fit.
  - Fold the distribution $\hat{\phi}=\phi+\pi$ if $\phi<0$ and $\hat{\phi}=\phi$ if $\phi>0$

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

$\hat{phi} = phi$



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

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

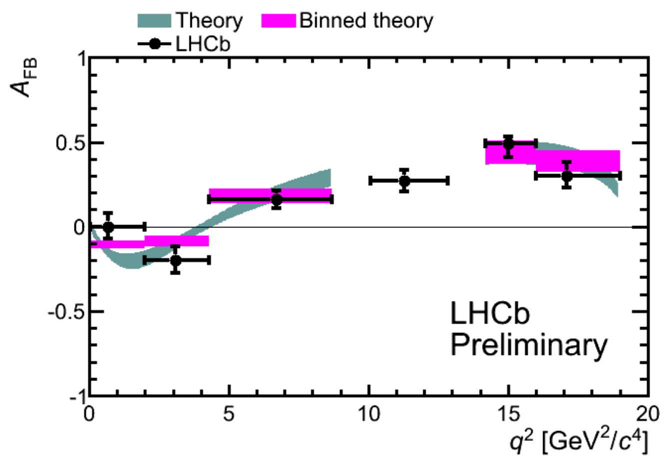
A_{FB}, forward-backward asymmetry

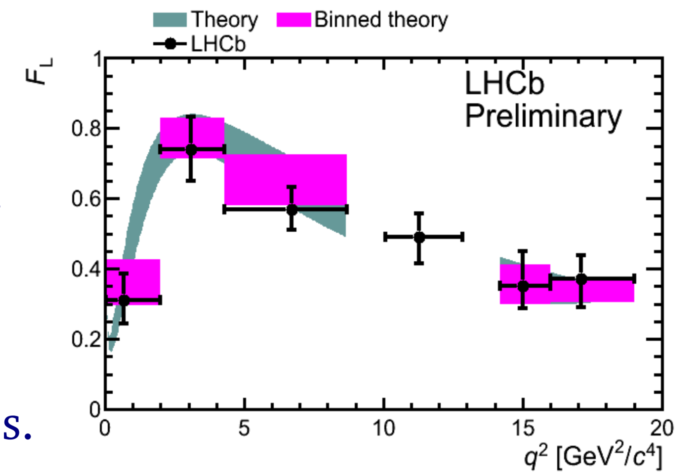
A_{Im}, a T-odd CP asymmetry

Angular analysis $B_d \to K^{*0}\mu^+\mu^-$

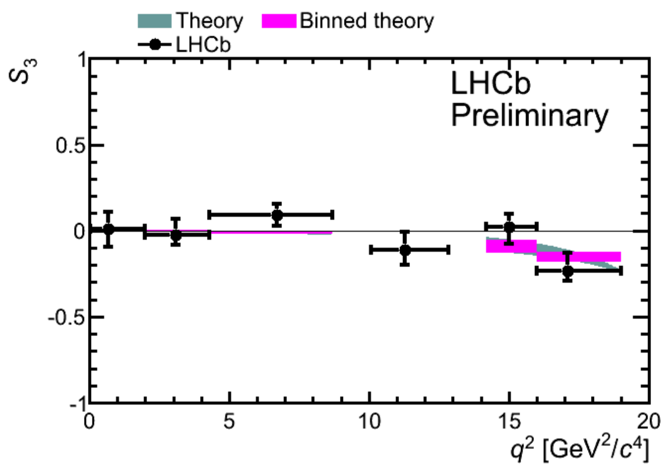
LHCb-CONF-2012-008

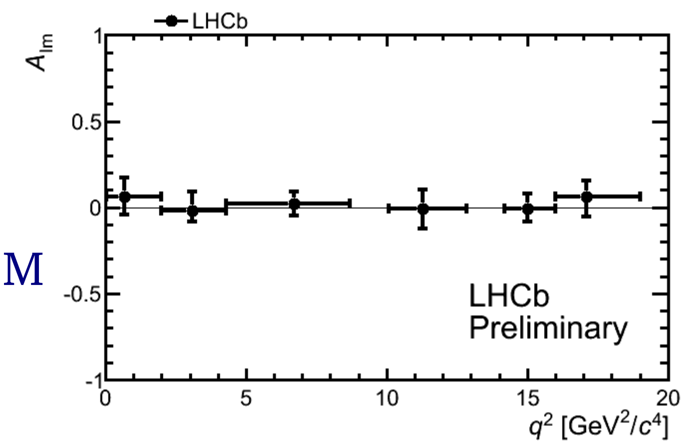
- Angular observables as a function of q^2.





- 4D fit to 3 angles and mass.
- Error bars with systematic uncertainties.
- Most precise measurement to-date using 1.0 fb^{-1}.
- Consistent with the SM predictions.



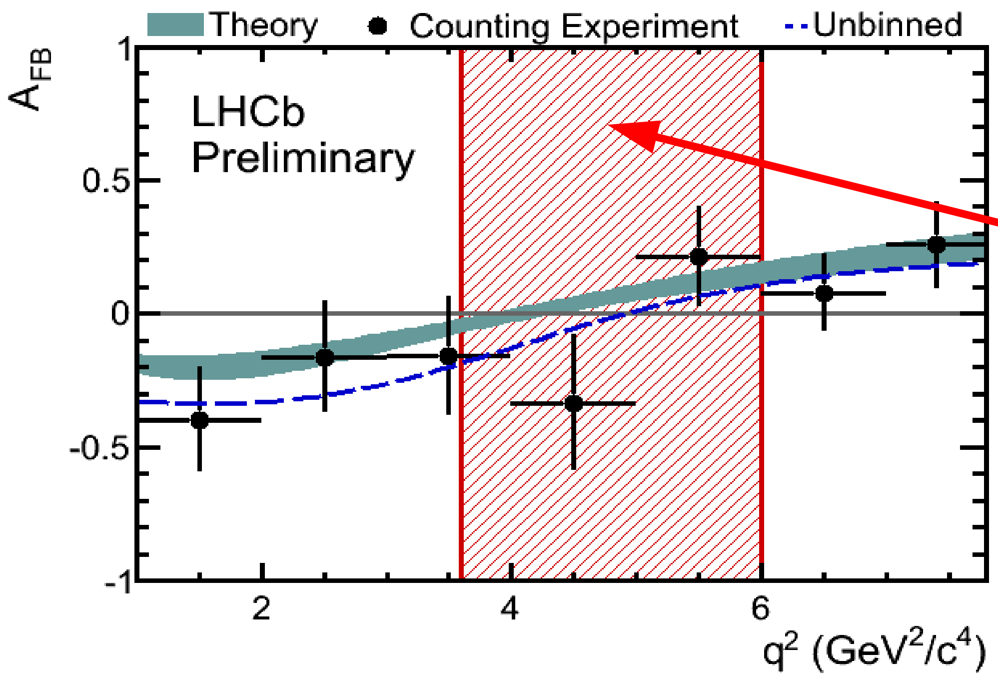


Zero-crossing point $B_d \to K^{*0}\mu^+\mu^-$

LHCb-CONF-2012-008

- In SM forward-backward asymmetry of di-muon system change sign at a well defined value of q^2_0=4.0 – 4.3 GeV^2/c^4
  - Free from form-factor uncertainties

[JHEP 1201 (2012) 107],
[Eur. Phys. J. C41 (2005) 173],
[Eur. Phys. J. C47 (2006) 625]



First measurement of the zero-crossing point.

$q^2_0 = 4.9^{+1.1}_{-1.3}$ GeV^2/c^4

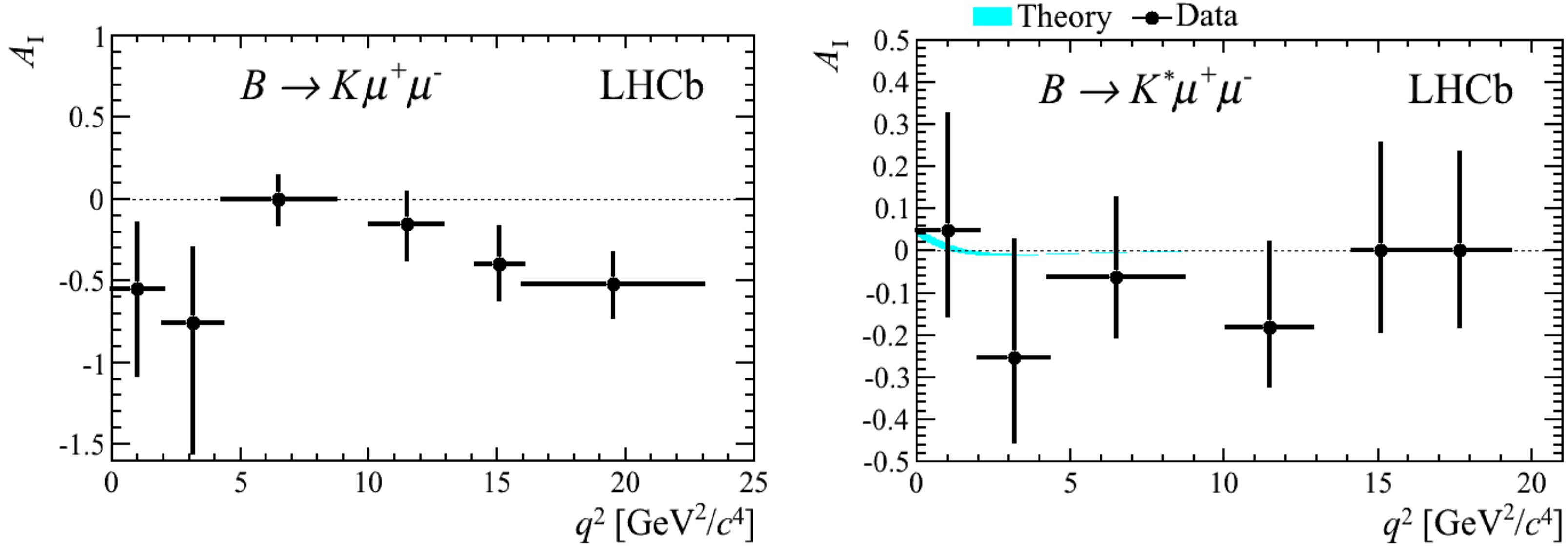
Compatible with SM expectations **(4.0-4.3 GeV^2/c^4)**.

Isospin asymmetry $B_d \to K^{(*)}\mu^+\mu^-$

arXiv:1205.3422, to be published in JHEP

$$A_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

- SM prediction for $B \to K^*\mu^+\mu^-$ is -1% at low q^2 [JHEP 01 (2003) 074]
- No precise determination for $B \to K\mu^+\mu^-$



Significance of the combined deviation from 0 is **4.4σ**

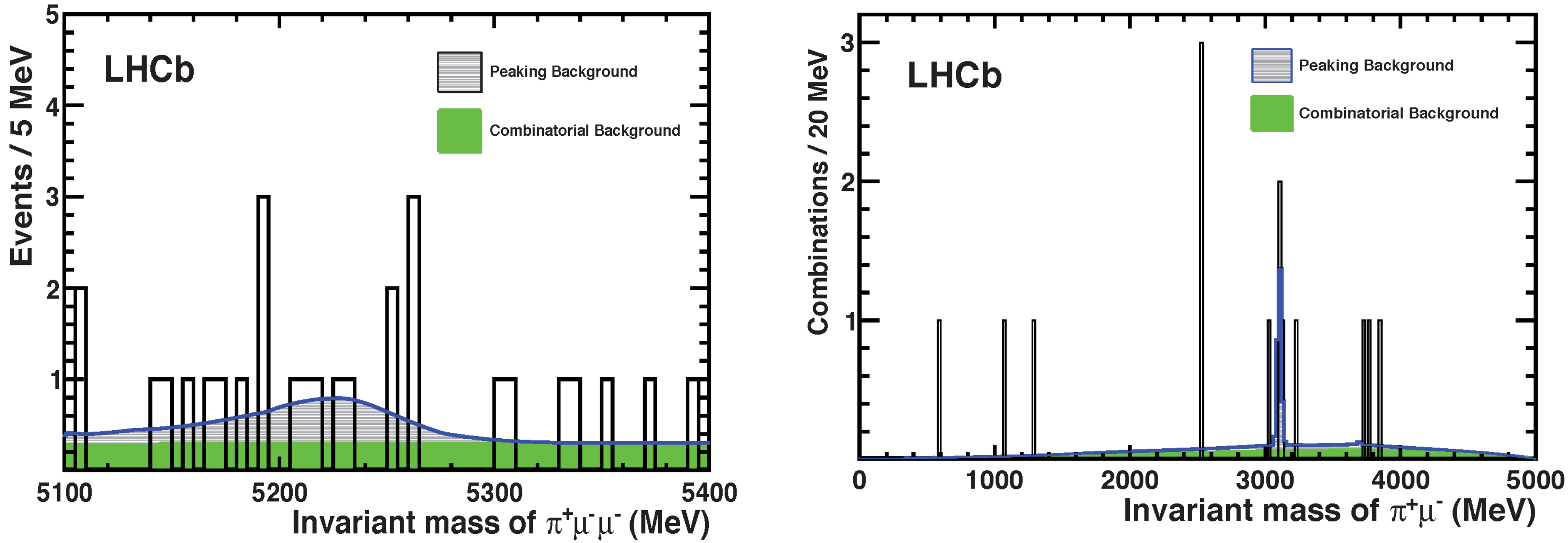
Compatible with BaBar result of **3.9σ** [PRL 102 (2008) 091803]

Conclusions

- LHCb is performing remarkably well and producing many interesting results with 2010 and 2011 data.
  - Branching Ratio limits have been pushed down or studied for the first time.
  - Angular analysis on $B_d \rightarrow K^{*0}\mu^+\mu^-$
  - First measurement of zero-crossing point at $B_d \rightarrow K^{*0}\mu^+\mu^-$
  - Isospin asymmetries on $B_d \rightarrow K^{(*0)}\mu^+\mu^-$
- So far, all results are compatible with the SM predictions, but constraining the NP parameter space at TeV scale.
- Expect to take ~1.5 fb^{-1} of data in 2012.
- More results to come at Summer conferences with full 2011 data.

BACKUP

Majorana neutrino



Events in B- mass window compatible with bkg expectations.