

# Latest flavour physics results from LHCb

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(on behalf of the LHCb collaboration)

LAL, Orsay

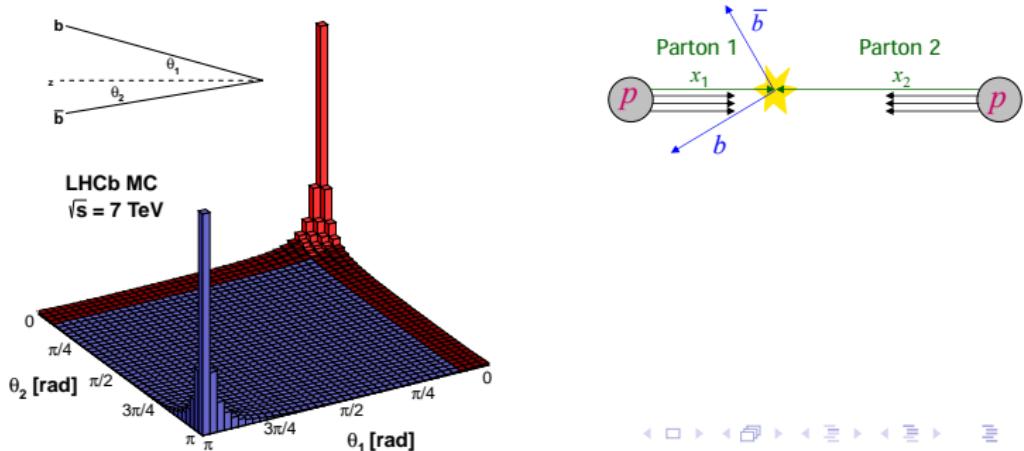
LATEST RESULTS FROM THE LHC @ CERN, 12/07/2012

# List of LHCb talks given at ICHEP

- B* baryons at LHCb [\[link\]](#)
- B* meson decays to final states containing charmonia at LHCb [\[link\]](#)
- Charm production and rare charm decays at LHCb [\[link\]](#)
- Studies of charm mixing and CP violation at LHCb [\[link\]](#)
- Searches for very rare decays to purely leptonic final states at LHCb [\[link\]](#)
- Studies of the electroweak penguin transitions  $b \rightarrow s(d)\mu^+\mu^-$  at LHCb [\[link\]](#)
- Radiative *B* decays at LHCb [\[link\]](#)
- Measurement of  $\phi_s$  at LHCb [\[link\]](#)
- Measurement of *b* hadron lifetimes and effective lifetimes at LHCb [\[link\]](#)
- Flavour tagging at LHCb and measurements of *B* meson oscillations [\[link\]](#)
- Measurements of  $B \rightarrow DK^{(*)}$  decays to constrain the CKM angle  $\gamma$  at LHCb [\[link\]](#)
- Hadronic *b* decays to open charm final states at LHCb [\[link\]](#)
- Measurements of CP violation in charmless two-body *B* decays at LHCb [\[link\]](#)
- Multibody charmless *B* decays at LHCb [\[link\]](#)
- Studies of asymmetries in semileptonic *B* decays at LHCb [\[link\]](#)
- Measurements with electroweak gauge bosons at LHCb [\[link\]](#)
- Studies of soft QCD at LHCb [\[link\]](#)
- The LHCb upgrade [\[link\]](#)
- Onia production and polarisation at LHCb [\[link\]](#)

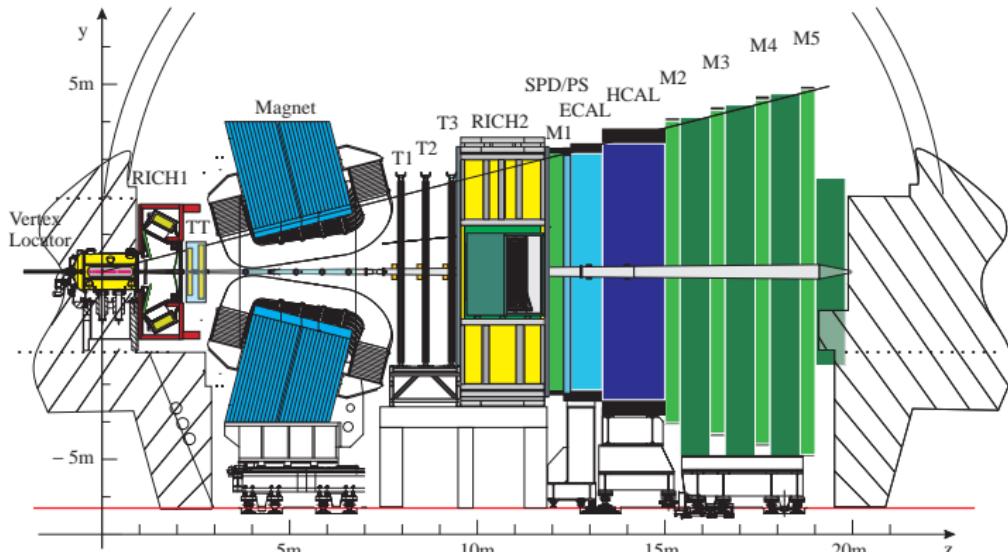
# $b$ and $c$ production at LHC

- Large production cross-sections @  $\sqrt{s} = 7$  TeV
  - $\sigma_{pp}^{\text{inel}} \sim 60$  mb [JINST 7 (2012) P01010]
  - $\sigma(pp \rightarrow c\bar{c}X) \sim 6$  mb [LHCb-CONF-2010-013]
  - $\sigma(pp \rightarrow b\bar{b}X) \sim 0.3$  mb [PLB 694 (2010) 209], c.f.  $\sigma(e^+e^- \rightarrow b\bar{b}) \sim 1$  nb @  $\Upsilon(4S)$   
⇒ LHC is a Flavour Factory!
- In high energy collisions,  $b\bar{b}/c\bar{c}$  pairs are produced predominantly in forward or backward directions



# LHCb detector

- Forward spectrometer ( $2 < \eta < 5$ ), dedicated to flavour physics



## Vertex Locator

$\sigma_{PV,x/y} \sim 10 \mu\text{m}$ ,  $\sigma_{PV,z} \sim 60 \mu\text{m}$

## Tracking (TT, T1-T3)

$\Delta p/p$ : 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c

## RICHs

$\epsilon(K \rightarrow K) \sim 95\%$ , mis-ID rate ( $\pi \rightarrow K$ )  $\sim 5\%$

## Muon system (M1-M5)

$\epsilon(\mu \rightarrow \mu) \sim 97\%$ , mis-ID rate ( $\pi \rightarrow \mu$ ) = 1 – 3%

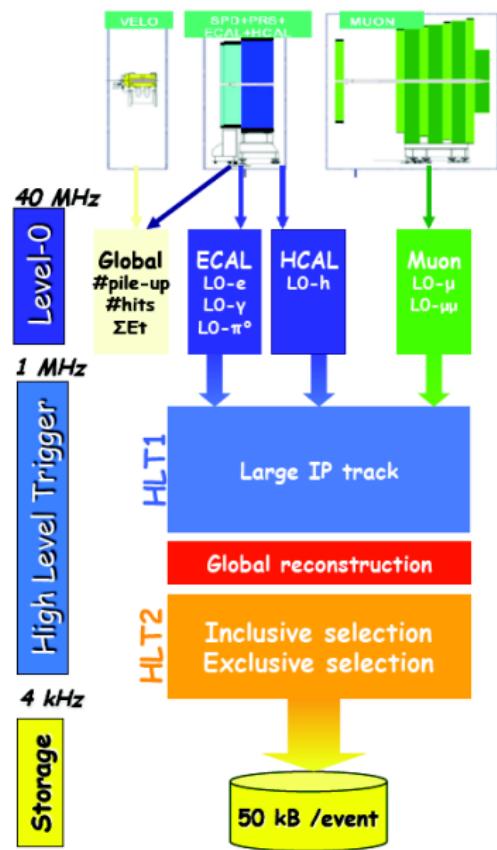
## ECAL

$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$  ( $E$  in GeV)

## HCAL

$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$  ( $E$  in GeV)

# LHCb trigger system



- **Level-0, Hardware**

- ▶ Fully synchronous at 40 MHz
- ▶ Selection of high  $p_T$  particles
  - ★  $p_T(\mu) > \sim 1.5 \text{ GeV}/c$ ,
  - $p_T(\mu_1) \times p_T(\mu_2) > \sim (1.5 \text{ GeV}/c)^2$
  - ★  $E_T(h, e, \gamma) > 3 - 4 \text{ GeV}$

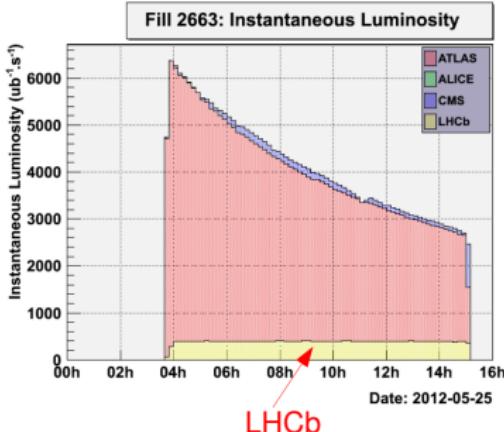
- **High Level Trigger (HLT), software**

- ▶ Runs  $\sim 30 \text{ k}$  processes
- ▶ Stage 1, add tracking info, impact parameter cuts
- ▶ Stage 2, full reconstruction + selections

# LHCb data taking

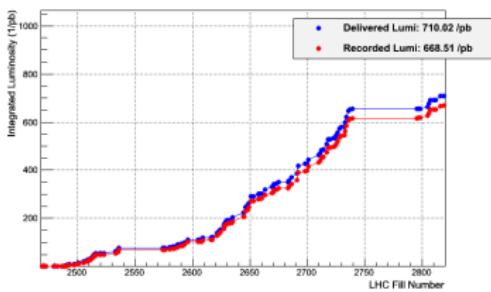
- Luminosity levelling

- ▶  $\mathcal{L} = 4 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  (2× design)
- ▶ Continuously adjust beam overlaps in collision region, luminosity kept flat at optimal level



- Integrated luminosity

- ▶ 2012:  $0.67 \text{ fb}^{-1}$  @  $\sqrt{s} = 8 \text{ TeV}$  recorded so far
- ▶ 2011:  $1 \text{ fb}^{-1}$  @  $\sqrt{s} = 7 \text{ TeV}$
- ▶ 2010:  $37 \text{ pb}^{-1}$  @  $\sqrt{s} = 7 \text{ TeV}$



# Strategies of indirect searching for NP

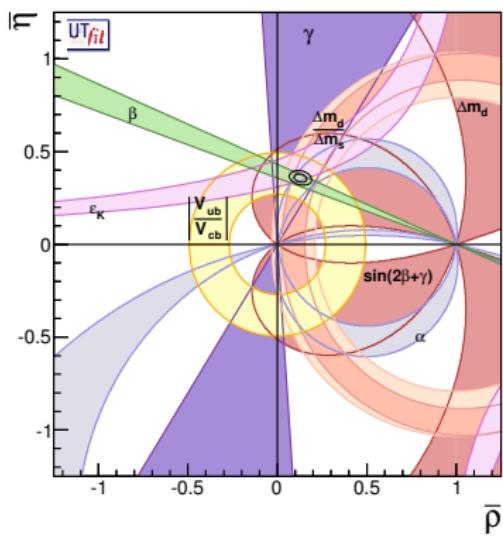
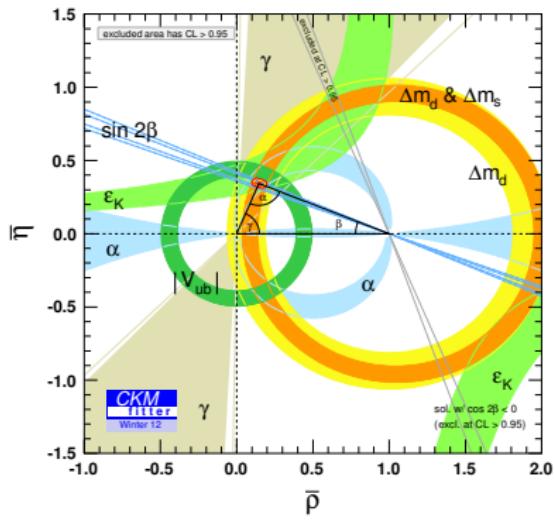
- Measure FCNC transitions, where New Physics is more likely to emerge, and compare to predictions
  - E.g., OPE expansion for  $b \rightarrow s$  transitions

$$\mathcal{H}_{\text{eff}} = -\frac{4 G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_{i=1 \dots 10, S, P} (C_i O_i + C'_i O'_i) + \text{h.c.}$$

- New Physics may
    - modify short-distance Wilson coefficients  $C^{(')}$
    - add new operators  $\sum_j C_j^{\text{NP}} O_j^{\text{NP}}$
- and change the decay rates, angular distributions, etc

## Strategies of indirect searching for NP (cont.)

- Precision measurements of elements of the CKM matrix
    - ▶ Extract all CKM angles and sides in many different ways, any inconsistency will be a sign of New Physics

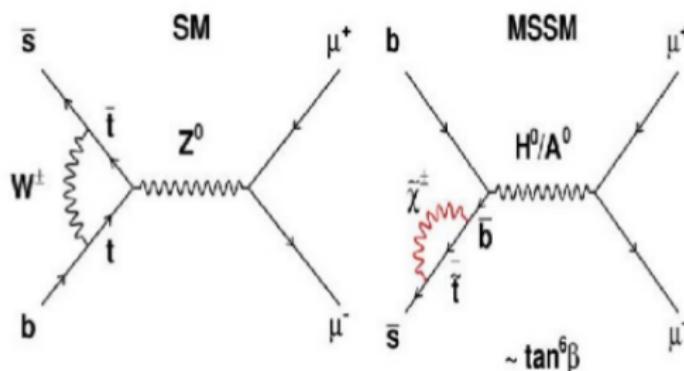


# LHCb results presented in this talk

- Rare decays
  - ▶ Search for  $B_{(s)}^0 \rightarrow \mu^+ \mu^-$  decays
  - ▶  $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ ,  $\mathcal{A}_{\text{FB}} \dots$
  - ▶ ...
- CP Violation
  - ▶ Mixing-induced CPV in  $B_s^0$  decays
  - ▶  $a_{\text{sl}}^s$
  - ▶ CPV in charm decays
  - ▶ Towards  $\gamma$
  - ▶ ...

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

- $\mathcal{B}(B^0_{(s)} \rightarrow \mu^+ \mu^-)$  very small in SM, due to helicity suppression, and  $|V_{td(s)}|$ . Theoretical predictions\* [Buras et al., arXiv:1007.5291]
  - ▶  $\mathcal{B}(B^0_s \rightarrow \mu^+ \mu^-) = (3.2 \pm 0.2) \times 10^{-9}$
  - ▶  $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (1.0 \pm 0.1) \times 10^{-10}$



- Can be strongly enhanced in many NP models

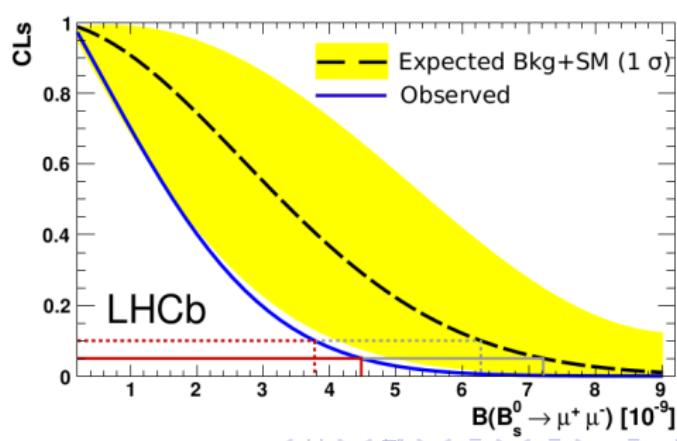
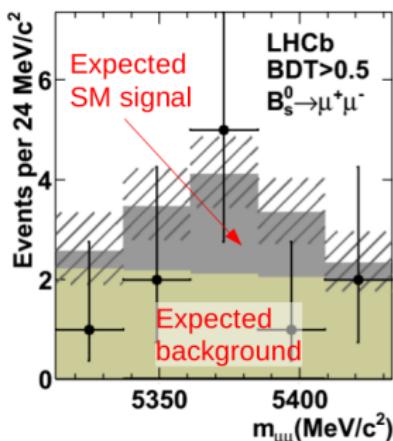
- ▶ E.g., MSSM with large  $\tan\beta$ ,  $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)^{\text{MSSM}} \propto \frac{\tan^6 \beta}{M_A^4}$

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\*values at  $t = 0$ , should be enlarged by  $\sim 10\%$  to get time integrated branching ratio [Bruyn et al., arXiv:1204.1735]

# $B_s^0 \rightarrow \mu^+ \mu^-$ , latest results

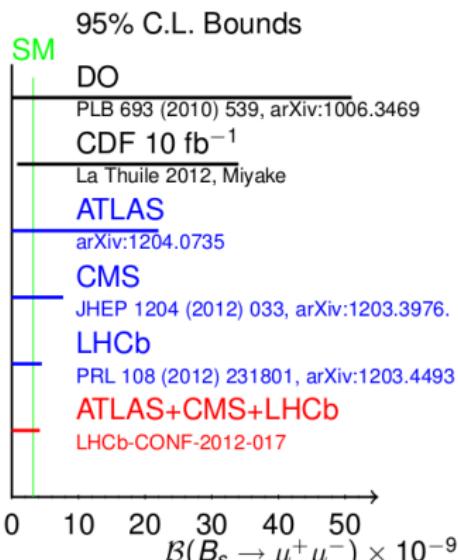
- Analysis based on BDT, data divided into bins of BDT response and  $\mu\mu$  mass.
  - BDT response and signal line-shape calibrated from data using  $B \rightarrow hh$  and  $\{J/\psi, \psi(2S), \Upsilon\} \rightarrow \mu^+ \mu^-$  decays.
- No excess above the expectation of SM signal + background
- Upper limit obtained with the CLs technique
  - $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 4.5 \times 10^{-9}$  at 95% CL
  - $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 1.0 \times 10^{-9}$  at 95% CL



# $B_s^0 \rightarrow \mu^+ \mu^-$ , ATLAS+CMS+LHCb combination

[LHCb-CONF-2012-017,CMS-PAS-BPH-12-009,ATLAS-CONF-2012-061]

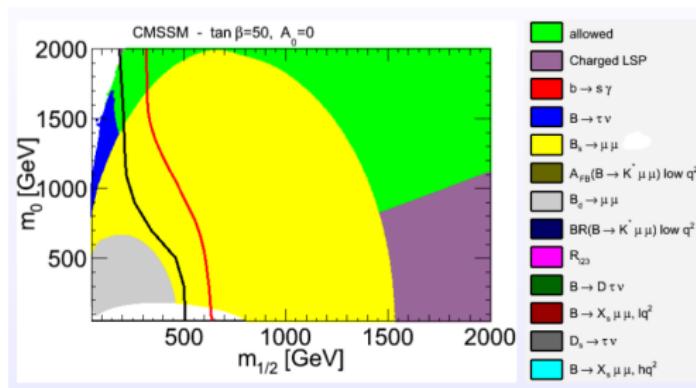
- Combined upper limits, presented for the first time at ICHEP!
  - ▶  $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 4.2 \times 10^{-9}$  at 95% CL
  - ▶  $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 8.1 \times 10^{-10}$  at 95% CL
- $p$ -value of 5% to be compatible with the background only hypothesis



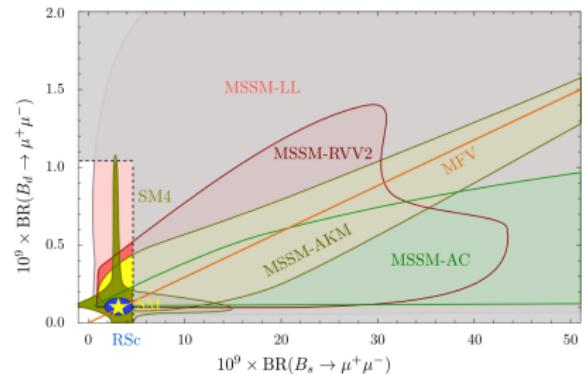
# Implications, examples

- Stringent constraint on New Physics models, e.g.,
  - TeV-scale CMSSM at high  $\tan\beta$  largely excluded

[Mahmoudi, Moriond QCD]



[Straub, arXiv:1205.6094]

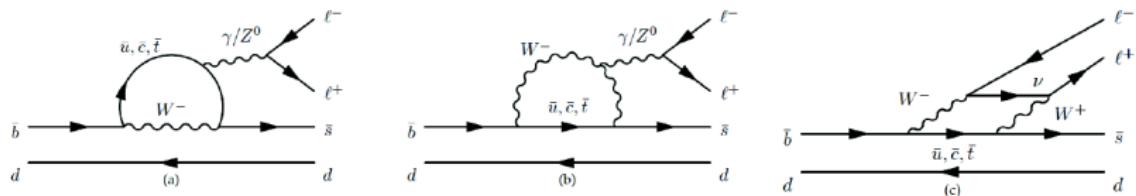


# Other very rare decays

- Search for  $B_{(s)}^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ , **first limits!** Preliminary upper limit, [LHCb-CONF-2012-010]
  - ▶  $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-) < 1.3 \times 10^{-8}$  at 95% CL,
  - ▶  $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-) < 5.4 \times 10^{-9}$  at 95% CL
- Search for  $\tau^- \rightarrow \mu^+ \mu^- \mu^-$ , **the first time at a hadron collider!** Preliminary upper limit [LHCb-CONF-2012-015]
  - ▶  $\mathcal{B}(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 7.8(6.3) \times 10^{-8}$  at 95% (90%) CL,  
comparable with Belle results [PLB 687 (2010) 139]
  - ▶  $\mathcal{B}(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 2.1 \times 10^{-8}$  at 90% CL

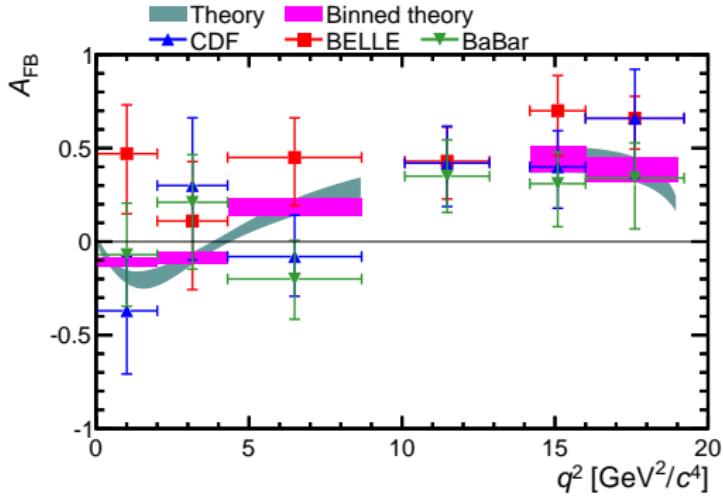
$$B^0 \rightarrow K^{*0} \mu^+ \mu^-$$

- $b \rightarrow s \ell^+ \ell^-$  processes also governed by FCNCs, rates and angular distributions of many exclusive processes sensitive to NP

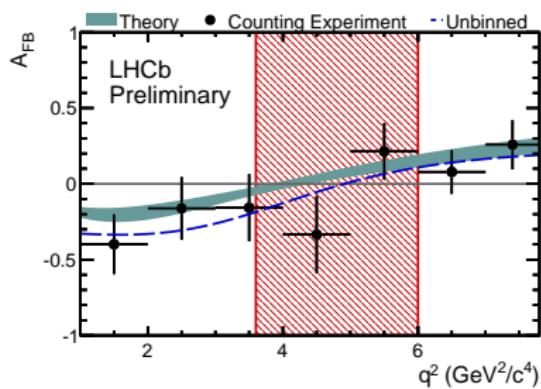
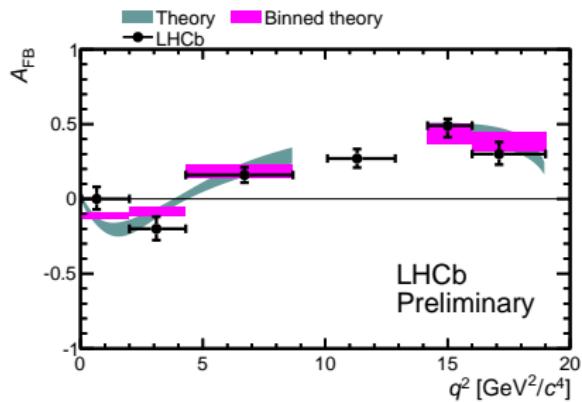


- Queen among them is  $B \rightarrow K^{*0} \mu^+ \mu^-$ , superb laboratory for NP tests
  - ▶ Many kinematic variables
  - ▶ Experimentally clean signature
  - ▶ Clean theoretical predictions (at least at low  $q^2$ )

- $\mathcal{A}_{\text{FB}}$ , the forward-backward asymmetry of the dimuon system
- Zero crossing point well predicted in SM,  $4 - 4.3 \text{ GeV}^2/c^4$   
[Bobeth et al., arXiv:1105.0376], and sensitive to NP
- No clear crossing point in previous measurements, hints of NP?



- Measured as function of  $q^2$ ,  
veto  $B^0 \rightarrow K^{*0}\{J/\psi, \psi(2S)\}$ ,
- The first measurement of zero crossing point!  
 $q_0^2 = 4.9^{+1.1}_{-1.3} \text{ GeV}^2/c^4$ , consistent with SM predictions  
 $4 - 4.3 \text{ GeV}^2/c^4$  [Bobeth et al., arXiv:1105.0376]



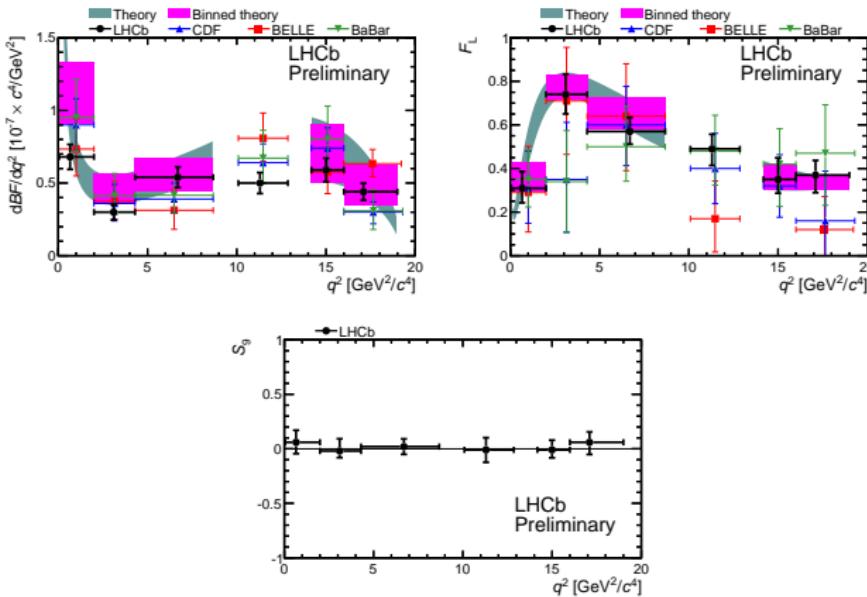
# $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ , differential $\mathcal{B}$ and angular analysis

- Other variables, good agreements

[LHCb-CONF-2012-008]

with SM predictions and previous measurements

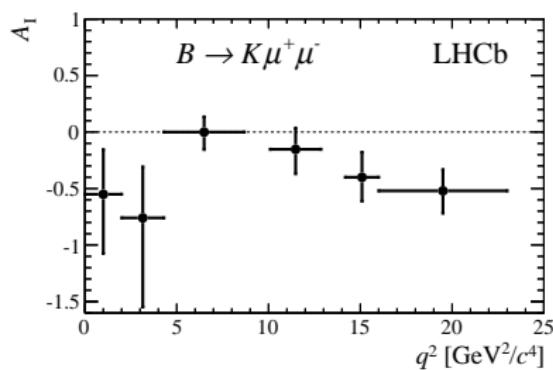
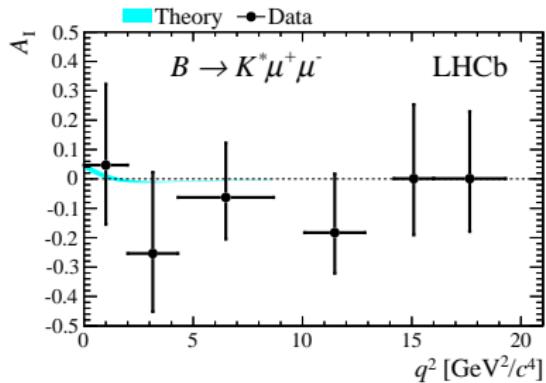
- $F_L$ , the fraction of the  $K^{*0}$  longitudinal polarization
- $S_9$ , a T-odd asymmetry



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

[arXiv:1205.3422]

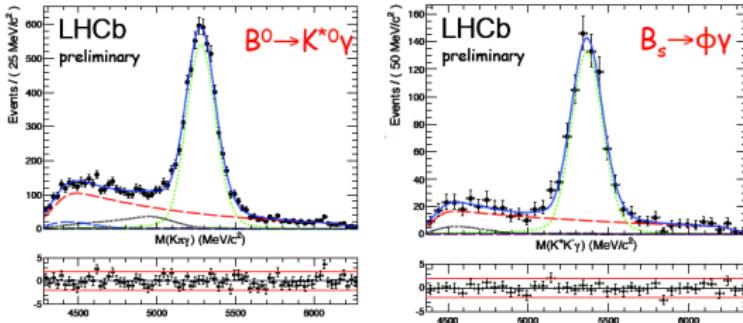
- $\mathcal{A}_I = \frac{\Gamma(B^0 \rightarrow K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \rightarrow K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \rightarrow K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \rightarrow K^{(*)+}\mu^+\mu^-)}$
- Both  $B \rightarrow K^{(*)}\mu^+\mu^-$  results agree with previous measurements
- Result for  $B \rightarrow K^*\mu^+\mu^-$  in agreement with SM expectation
- **Result for  $B \rightarrow K\mu^+\mu^-$  differs from naive expectation of  $\mathcal{A}_I = 0$  by more than  $4\sigma$ , no theory explanation of this yet...**



# Radiative $b \rightarrow s\gamma$ decays

[LHCb-PAPER-2012-019]

- Again FCNC, New Physics can affect  $\mathcal{B}$ ,  $\mathcal{A}_{CP}$ , isospin asymmetry, photon helicity
- $B^0 \rightarrow K^{*0}\gamma$ ,  $B_s^0 \rightarrow \phi\gamma$  signals, mass resolution  $\sim 90$  MeV/ $c^2$ , dominated by ECAL



- World best measurements, preliminary

$$\frac{\mathcal{B}(B^0 \rightarrow K^{*0}\gamma)}{\mathcal{B}(B_s^0 \rightarrow \phi\gamma)} = 1.31 \pm 0.07 \pm 0.04 \pm 0.10 \left( \frac{f_d}{f_s} \right)$$

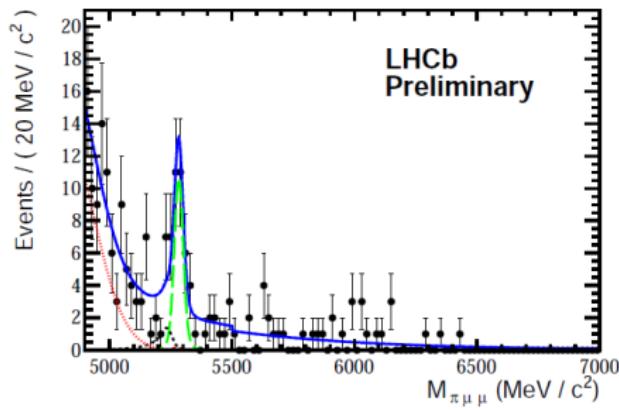
$$\mathcal{B}(B_s^0 \rightarrow \phi\gamma) = (3.3 \pm 0.3) \times 10^{-5}$$

$$\mathcal{A}_{CP}(B^0 \rightarrow K^{*0}\gamma) = 0.008 \pm 0.017 \pm 0.009$$

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

[LHCb-CONF-2012-006]

- $b \rightarrow d \ell^+ \ell^-$  transitions
- SM prediction  $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (1.96 \pm 0.21) \times 10^{-8}$   
[Song et al., Commun. Theor. Phys. 50 (2008) 696]
- $25.3^{+6.7}_{-6.4}$  signal events,  $5.2\sigma$ !  
**the rarest  $B$  decay observed to date!**
- Preliminary result:  $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (2.4 \pm 0.6 \pm 0.2) \times 10^{-8}$



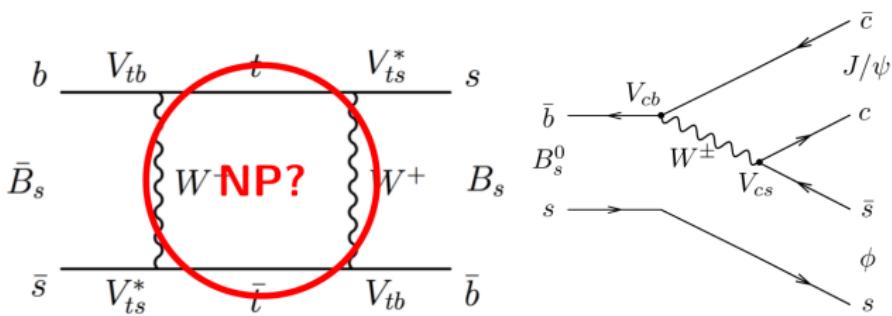
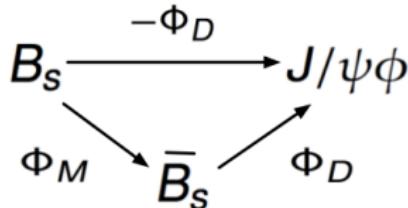
# Search for $D^0 \rightarrow \mu^+ \mu^-$

[LHCb-CONF-2012-005]

- Extremely rare decay
  - $\mathcal{B}^{SM}(D^0 \rightarrow \mu^+ \mu^-) < O(10^{-11})$ , dominated by long-distance contributions
  - Can be strongly enhanced in NP models
  - Previous limits
    - Belle,  $\mathcal{B}(D^0 \rightarrow \mu^+ \mu^-) < 1.4 \times 10^{-7}$  at 90% CL [PRD 81(2010) 091102]
    - BaBar,  $\mathcal{B}(D^0 \rightarrow \mu^+ \mu^-) \in [0.6, 8.1] \times 10^{-7}$  at 90% CL [arXiv:1206.5419]
- LHCb analysis
  - Using  $D^{*+}$ -tagged signal, multi-variate analysis
  - Normalize to  $D^{*+} \rightarrow D^0(\pi^+ \pi^-)\pi^+$ , single-event sensitivity is  $(1.96 \times 0.23) \times 10^{-10}$
  - Double-misID probability,  $P(\pi\pi \rightarrow \mu\mu) = 2.7 \times 10^{-5}$
  - Preliminary,  $\mathcal{B}(D^0 \rightarrow \mu^+ \mu^-) < 1.3(1.1) \times 10^{-8}$  at 95 (90)% CL, factor 10 improvement compared to the Belle result, not in agreement with the Babar result
- CMS,  $\mathcal{B}(D^0 \rightarrow \mu^+ \mu^-) < 5.4 \times 10^{-7}$  at 90% CL [CMS-PAS-BPH-11-017]

# Mixing-induced CPV in $B_s^0 \rightarrow J/\psi \phi$

- $\phi_s = \phi_M - 2\phi_D$ , phase difference between the  $B_s^0 \rightarrow J/\psi\phi$  decay amplitudes without or with oscillation
  - $\phi_s$  small in SM, sensitive to New Physics contributions to  $B_s$  mixing
    - ▶  $\phi_s = \phi_s^{\text{SM}} + \phi_s^{\text{NP}}$ , with  $\phi_s^{\text{SM}} = -2\beta_s + \delta P = (-0.036 \pm 0.002) \text{ rad}$
    - ▶ Small penguin pollution,  $\delta P \sim 10^{-3} - 10^{-4}$

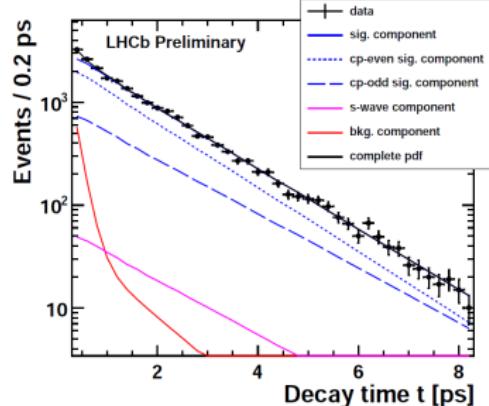
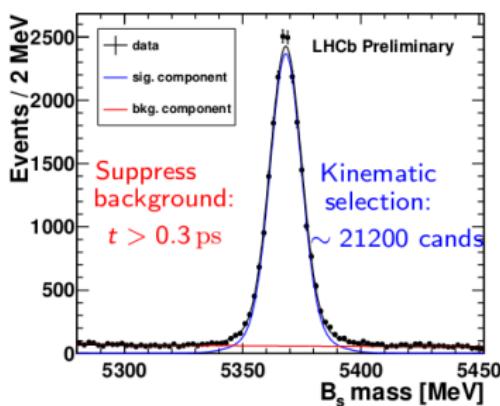


# Measuring $\phi_s$ using $B_s^0 \rightarrow J/\psi\phi$

- $B_s^0 \rightarrow J/\psi\phi$

[LHCb-CONF-2012-002]

- ▶  $P \rightarrow VV$  decay, final states are admixture of CP-odd and CP-even with different lifetime, time-dependent angular fit needed



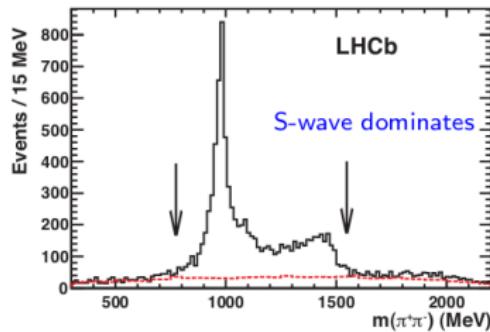
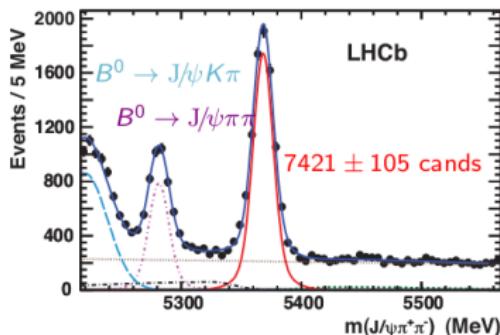
- Two-fold ambiguity resolved using the interference between the  $K^+K^-$  S-wave and P-wave amplitudes [PRL 108 (2012) 241801]
- Preliminary results
  - ▶  $\phi_s^{J/\psi\phi} = (-0.001 \pm 0.101 \pm 0.027) \text{ rad}$
  - ▶  $\Delta\Gamma_s = (0.116 \pm 0.018 \pm 0.006) \text{ ps}^{-1}$ , first  $5\sigma$  non-zero  $\Delta\Gamma_s$ !

# Measuring $\phi_s$ using $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$

[PLB 713 (2012) 378]

- $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$

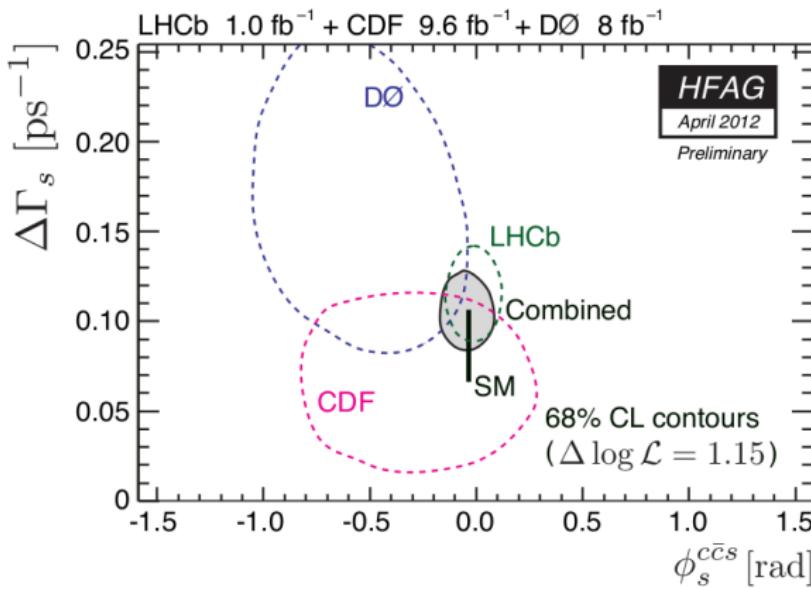
- ▶ Consider  $775 < m(\pi\pi) < 1550$  MeV, angular analysis shows CP-fraction is  $> 97.7\%$  at 95% CL
- ▶ No complex angular analysis!



- $\phi_s^{J/\psi \pi\pi} = (-0.019^{+0.173+0.004}_{-0.174-0.003}) \text{ rad}$
- Simultaneous fit of  $B_s^0 \rightarrow J/\psi \phi$  and  $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ , preliminary
  - ▶  $\phi_s = (-0.002 \pm 0.083 \pm 0.027) \text{ rad}$

# Latest $\phi_s$ combination

- $\phi_s = -0.044^{+0.090}_{-0.085}$  rad,  $\Delta\Gamma_s = +0.105 \pm 0.015$  ps $^{-1}$ , consistent with SM expectation!

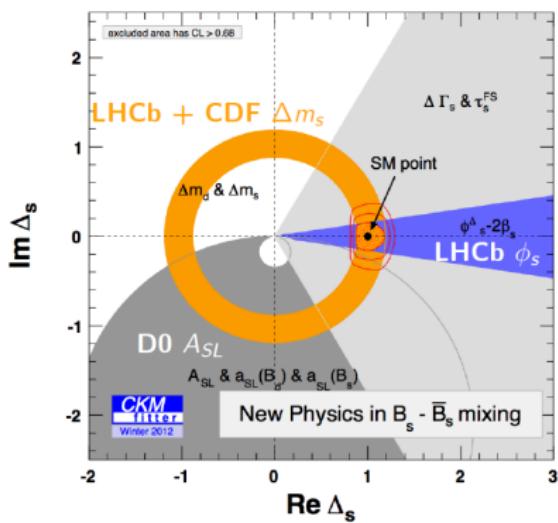


- Not-yet including ALTAS preliminary results [Palestini, ichep 2012]
  - ▶  $\phi_s = (0.22 \pm 0.41 \pm 0.10)$  rad
  - ▶  $\Delta\Gamma_s = 0.053 \pm 0.021 \pm 0.008$  ps $^{-1}$

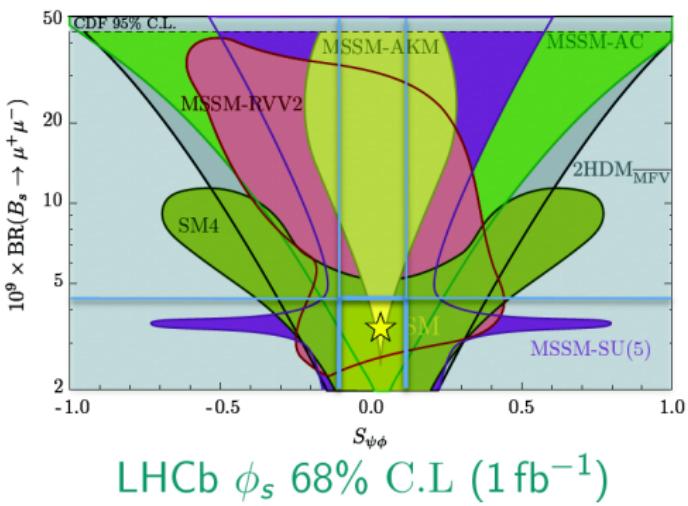
# Implication of $\phi_s$ together with $\mathcal{B}(B_{(s)}^0 \rightarrow \mu^+ \mu^-)$

- Even strong constraint on NP models

[Lenz et al., arXiv:1203.0238]



[Straub, arXiv:1107.0266]



- $a_{\text{sl}} = \frac{\Gamma(\bar{B}(t) \rightarrow f) - \Gamma(B(t) \rightarrow \bar{f})}{\Gamma(\bar{B}(t) \rightarrow f) + \Gamma(B(t) \rightarrow \bar{f})} = \frac{\Delta\Gamma}{\Delta M} \tan\phi_{12}$ ,  $f \neq \bar{f}$  (flavour specific),  
expected to be small in SM [Lenz, arXiv:1205.1444]
  - ▶  $a_{\text{sl}}^s = (1.9 \pm 0.3) \times 10^{-5}$
  - ▶  $a_{\text{sl}}^d = (-4.1 \pm 0.6) \times 10^{-4}$
- Can measure e.g.,  $B_s^0 \rightarrow D_s^- \mu^+ \nu$  Vs.  $\bar{B}_s^0 \rightarrow D_s^+ \mu^- \nu$
- Or look at  $\mu^+ \mu^+$  Vs  $\mu^- \mu^-$ , considering that muons from two  $B$  decays can be like-sign when one mixes and the other decays

# $a_{\text{sl}}$ @ D0

- Using dimuon [PRD 84 (2011) 052007]

$$A_{\text{sl}}^b = (-0.787 \pm 0.172 \pm 0.093)\%$$

3.9 $\sigma$  from SM,  $B_d$  and  $B_s$  mixed, using muon impact parameter to separate dimuons into  $B_d$  and  $B_s$  samples, they found

- $a_{\text{sl}}^s = (-1.81 \pm 1.06)\%$
- $a_{\text{sl}}^d = (-0.12 \pm 0.52)\%$

- New measurements using

$B_s \rightarrow D_s^+ \mu^- \nu$  with  $D_s^+ \rightarrow \phi \pi^+$

[arXiv:1207.1769]

- $a_{\text{sl}}^s = (-1.08 \pm 0.72 \pm 0.17)\%$

- New measurements using

$B_d \rightarrow D^{(*)-} \mu^+ \nu$  with  $D \rightarrow K \pi \pi$

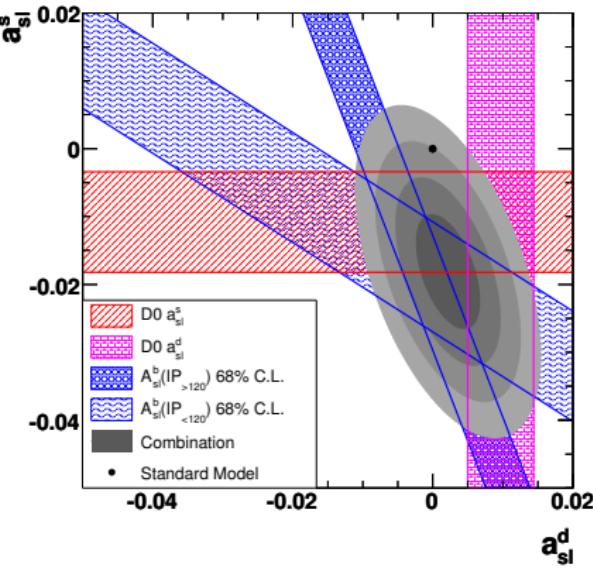
[Bertram, ichep2012]

- $a_{\text{sl}}^d = (0.93 \pm 0.45 \pm 0.14)\%$

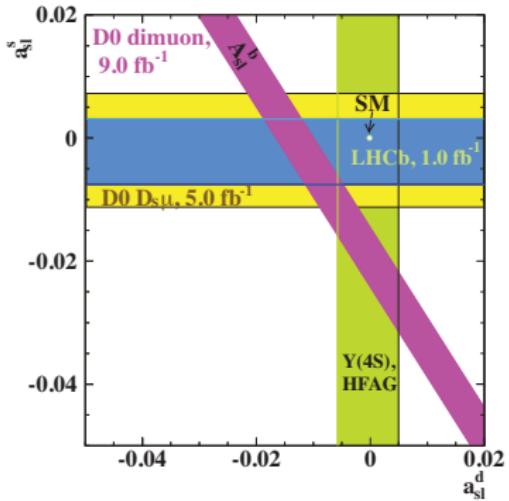
- Combine 3 D0 measurements,

3 $\sigma$  from SM [Bertram, ichep2012]

- $a_{\text{sl}}^s = (-1.81 \pm 0.56)\%$
- $a_{\text{sl}}^d = (0.22 \pm 0.30)\%$



- Presented for the first time at ICHEP!
- Using  $B_s^0 \rightarrow D_s^- \mu^+ \nu$ , with  $D_s^+ \rightarrow \phi(K^+ K^-) \pi^+$ , preliminary results:  
 $a_{\text{sl}}^s = (-0.24 \pm 0.54 \pm 0.33)\%$ , consistent with SM expectation!



- More  $D_s$  decay modes will be added, stay tuned!

# Direct CPV in $B_{(s)} \rightarrow K\pi$

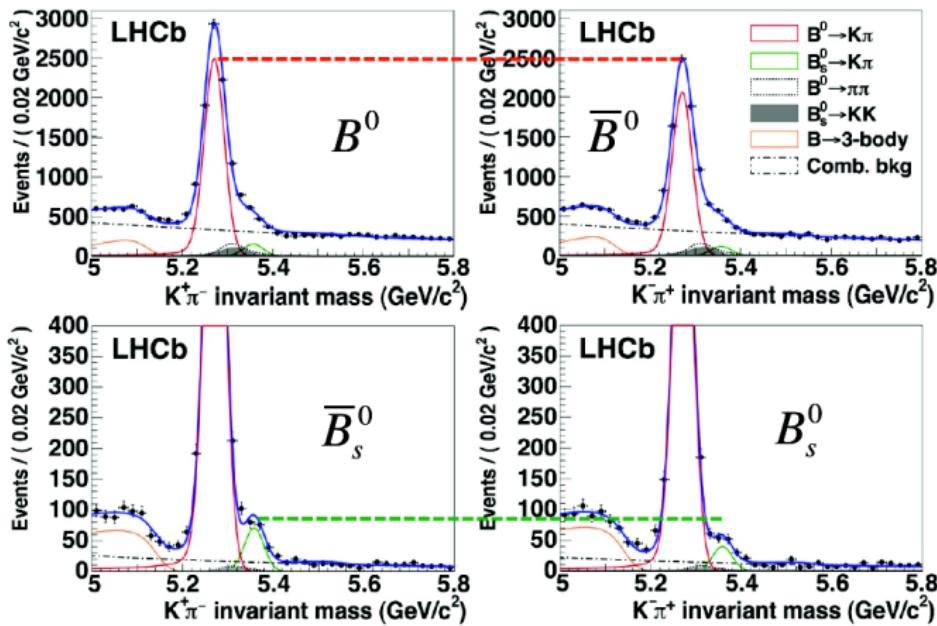
- $\mathcal{A}_{\text{CP}}(B^0 \rightarrow K^+ \pi^-) = -0.088 \pm 0.011 \pm 0.008$

[PRL 108 (2012) 201601]

first observation of direct CPV in  $B$  decays at a hadron collider!

- $\mathcal{A}_{\text{CP}}(B_s^0 \rightarrow K^- \pi^+) = 0.27 \pm 0.08 \pm 0.02$

first evidence of direct CPV in  $B_s^0$  decays!



# Time dependent CPV in $B_{(s)}^0 \rightarrow \pi^+\pi^- (K^+K^-)$

[LHCb-CONF-2012-007]

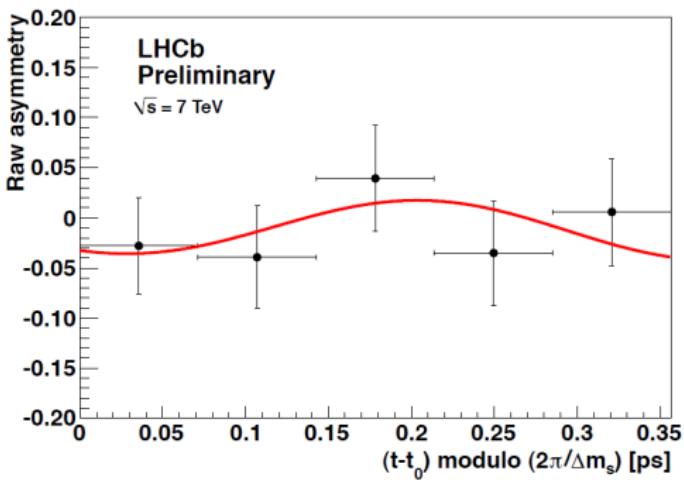
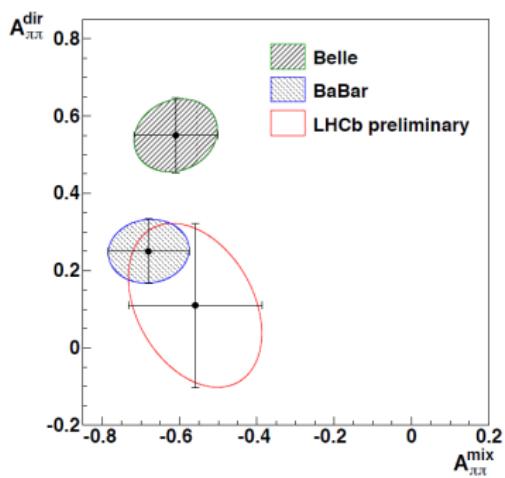
- First evidence of time-dependent CPV at hadron collider for  $B^0 \rightarrow \pi^+\pi^-$
- First CPV measurement for  $B_s^0 \rightarrow K^+K^-$

$$\mathcal{A}_{\pi\pi}^{\text{dir}} = 0.11 \pm 0.21 \pm 0.03$$

$$\mathcal{A}_{KK}^{\text{dir}} = 0.02 \pm 0.18 \pm 0.04$$

$$\mathcal{A}_{\pi\pi}^{\text{mix}} = -0.56 \pm 0.17 \pm 0.03$$

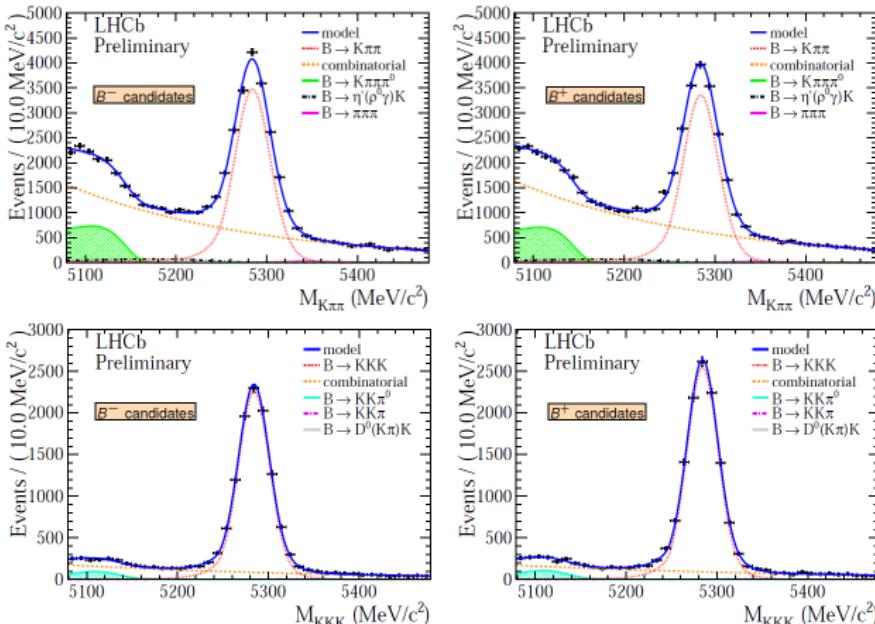
$$\mathcal{A}_{KK}^{\text{mix}} = 0.17 \pm 0.18 \pm 0.05$$



# CPV in $B^+ \rightarrow K^+\pi^+\pi^- (K^+K^-)$

[LHCb-CONF-2012-018]

- Using  $B^\pm \rightarrow J/\psi K^\pm$  as control channel, measured
    - $\mathcal{A}_{\text{CP}}(B^\pm \rightarrow K^\pm \pi^+ \pi^-) = +0.034 \pm 0.009 \pm 0.004 \pm 0.007 (J/\psi K^\pm)$
    - $\mathcal{A}_{\text{CP}}(B^\pm \rightarrow K^\pm K^+ K^-) = -0.046 \pm 0.009 \pm 0.005 \pm 0.007 (J/\psi K^\pm)$
- first evidence of inclusive CPV in charmless three-body  $B$  decays



# Evidence for CPV in $D \rightarrow h^+ h^-$ decays

[PRL 108 (2012) 111602]

- Using  $D^{*+} \rightarrow D^0 \pi_s^+$  tagged sample, with  $D^0 \rightarrow \pi^+ \pi^-, K^+ K^-$   
 $\mathcal{A}_{\text{raw}}(f) = \mathcal{A}_{\text{CP}}(f) + \mathcal{A}_D(f) + \mathcal{A}_D(\pi_s) + \mathcal{A}_P(D^{*+})$ 
  - $\mathcal{A}_D(f)$ , final state detection asymmetry vanishes
  - $\mathcal{A}_D(\pi_s)$  and  $\mathcal{A}_P(D^{*+})$  the same for both  $D$  final states, so cancel in difference to first order

$$\Delta \mathcal{A}_{\text{CP}} \equiv \mathcal{A}_{\text{raw}}(K^- K^+) - \mathcal{A}_{\text{raw}}(\pi^- \pi^+) = \mathcal{A}_{\text{CP}}(K^- K^+) - \mathcal{A}_{\text{CP}}(\pi^- \pi^+)$$

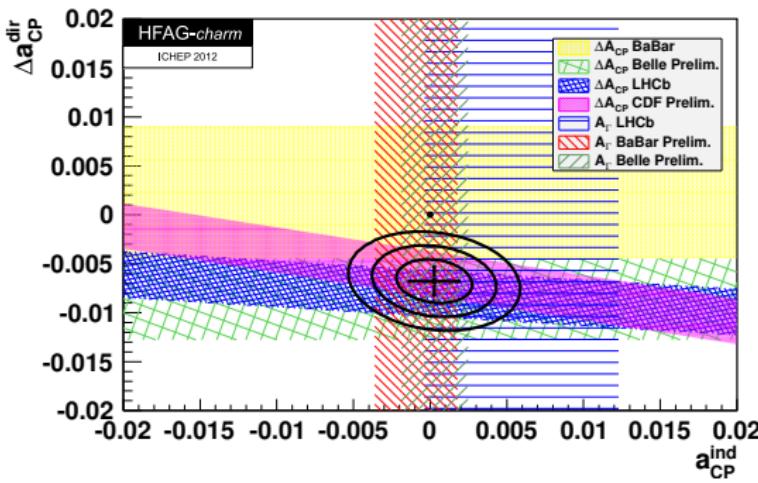
- $\Delta \mathcal{A}_{\text{CP}} = (-0.82 \pm 0.21 \pm 0.11)\%$ ,  $3.5\sigma$  effects.  
First evidence of CPV in charm sector! Also seen by other experiments:

- CDF:  $(-0.62 \pm 0.21 \pm 0.11)\%$  [CDF note 10784]
- Belle:  $(-0.87 \pm 0.41 \pm 0.06)\%$  [Belle, ichep 2012]

# CPV in $D \rightarrow h^+ h^-$ decays, latest combination

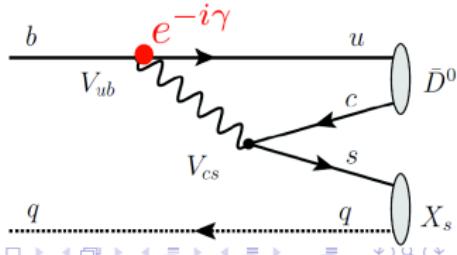
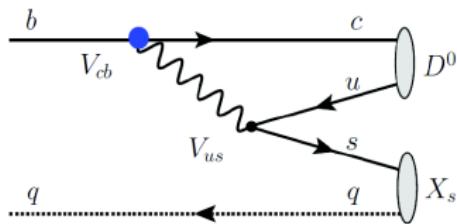
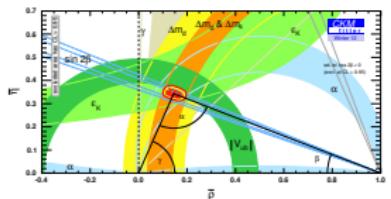
- Latest combination [Gersabeck, arXiv:1207.2195]

- No CPV hypothesis,  $2 \times 10^{-5}$
- $\Delta a_{\text{CP}}^{\text{dir}} = (-0.678 \pm 0.147)\%$
- $a_{\text{CP}}^{\text{dir}} = (0.027 \pm 0.163)\%$



# Towards $\gamma$

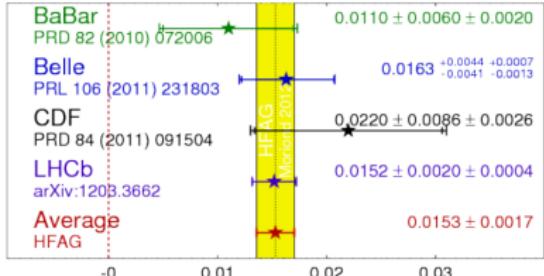
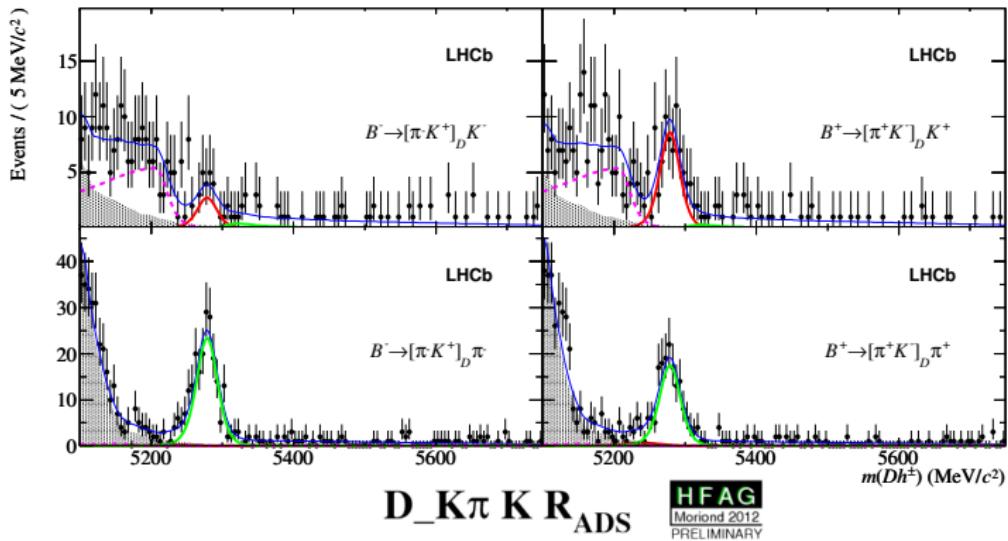
- $\gamma$  is the least well measured CKM angle, the only CKM parameter that can be measured **through tree decays**
- Access CKM phase  $\gamma$  through interference of  $b \rightarrow u$  and  $b \rightarrow c$  transitions in decays with a common final state.
  - ▶ For  $q = u$ ,  $B^+ \rightarrow DX_s$ , where  $X_s = K^+, K^+\pi\pi, K^{*+}, \dots$
  - ▶ For  $q = d$ ,  $B^0 \rightarrow DX_s$ , where  $X_s = K^{*0}$
- Interference if  $D/\bar{D}$  decay to common final states
  - ▶  $D^0, \bar{D}^0 \rightarrow \pi^+\pi^-$  or  $K^+K^-$  (GLW),
  - ▶  $D^0, \bar{D}^0 \rightarrow K^+\pi^-$  (ADS)
- CP observables (function of  $\gamma$ ) measured



$B \rightarrow DK$

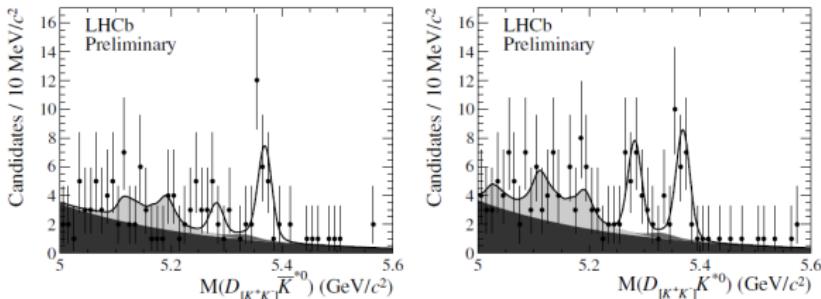
- First observation of ADS suppressed mode

[PLB 712 (2012), 203]

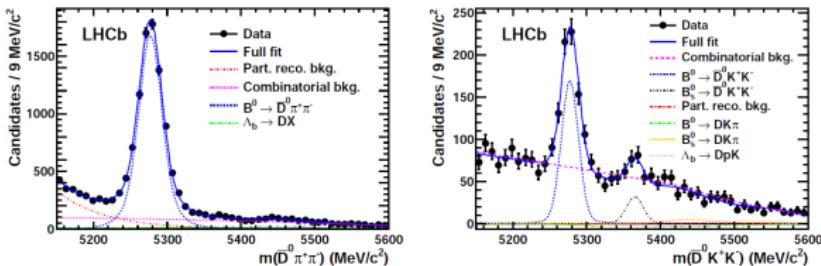


# New analysis presented at ICHEP

- $B \rightarrow D^0 K^{*0}$  [LHCb-CONF-2012-024]



- $B_{(s)}^0 \rightarrow \bar{D}^0 K^+ K^-$  [LHCb-PAPER-2012-018]

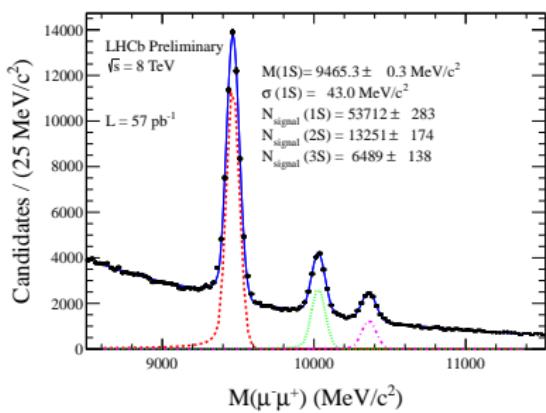
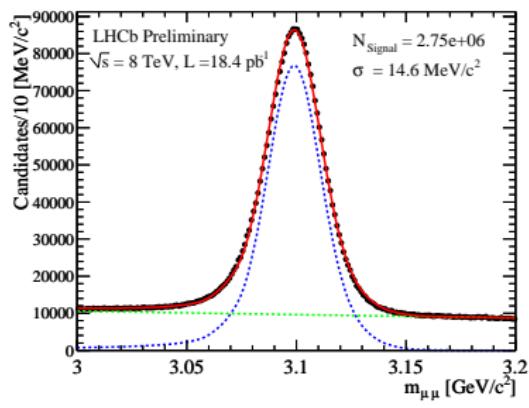


- First observation of  $B^+ \rightarrow \bar{D}^0 K^+ \pi^+ \pi^-$  decays to CP-even states [LHCb-CONF-2012-021]

# Analysis of 2012 data

[LHCb-CONF-2012-025]

- LHCb is performing extremely well @  $\sqrt{s} = 8$  TeV. E.g., Mass resolutions,
  - $\sigma_m(J/\psi) \sim 14.6 \text{ MeV}/c^2$ ,  $\sigma_m(\Upsilon) \sim 43 \text{ MeV}/c^2$



- More analysis based on 2012 data will be out soon

# Summary

- The LHC(b) is the new Flavour Factory, and has the power to do precision measurements at a hadron collider
- Exploring rare decays and CPV in the  $b$  and  $c$  sectors
- Putting strong constraints on New Physics models
  - ▶  $\mathcal{B}(B_{(s)} \rightarrow \mu^+ \mu^-)$ ,  $\phi_s$
- Earlier hints for possible deviations from SM not confirmed
  - ▶  $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ ,  $a_{\text{sl}}$
- Some observations awaiting theory explanations
  - ▶  $\Delta \mathcal{A}_{\text{CP}}$  in charm, Isospin asymmetry in  $B \rightarrow K \mu^+ \mu^-$
- Most measurements dominated by statistical uncertainties
- Many other results can be found on LHCb website [\[link\]](#)
  - ▶ EW, QCD physics, searches for exotics...