Recent results from LHCb

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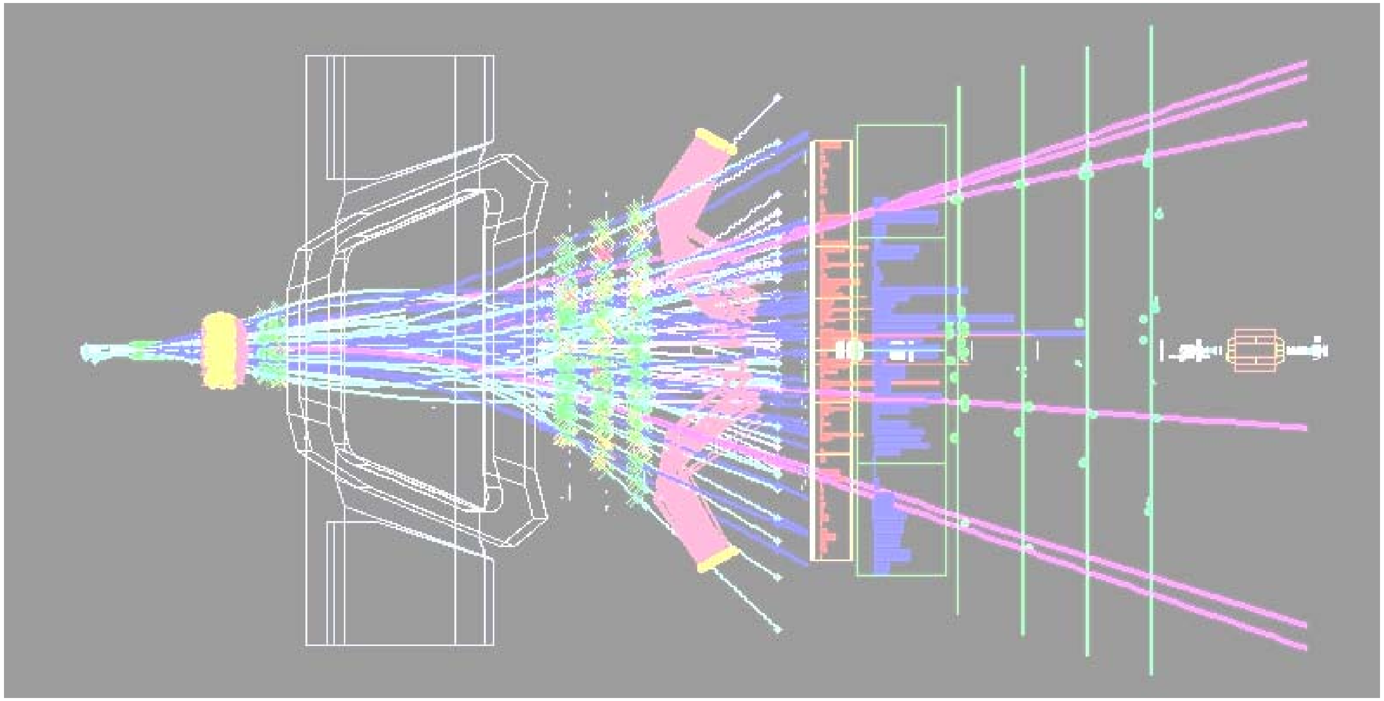
On behalf of the LHCb collaboration



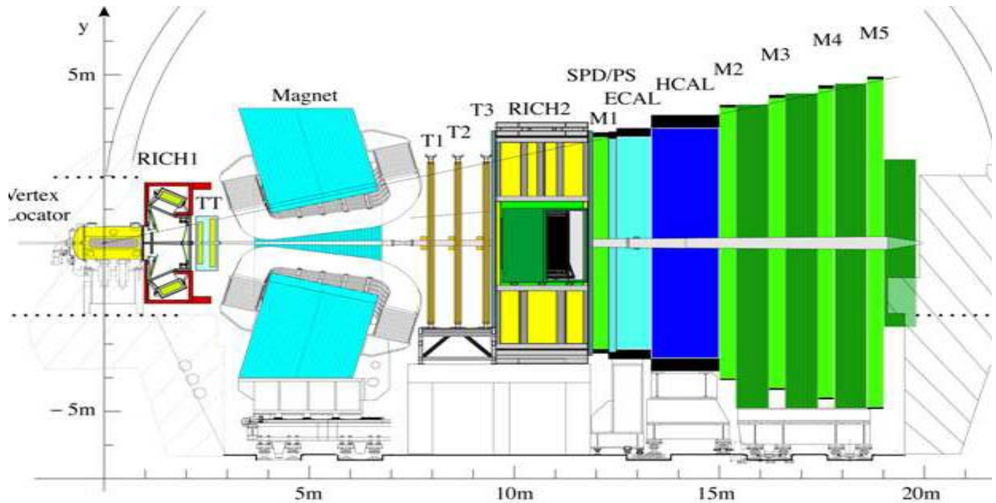
Lattice, June 28th 2012, Cairns

Outline

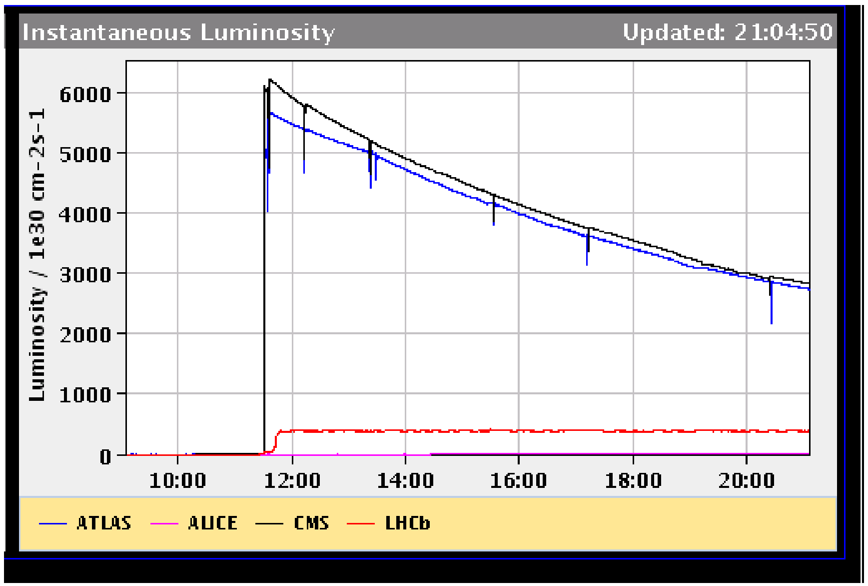
- LHCb
- Rare B decays
  - $B_{(s)} \to \mu\mu$
  - $b \to sll$
  - $b \to s\,\gamma$
- Mixing and CPV
  - B_s mixing
  - ϕ_s
  - CVP in charm
  - γ angle
- Spectroscopy
- Semileptonic decays
- Future

LHCb

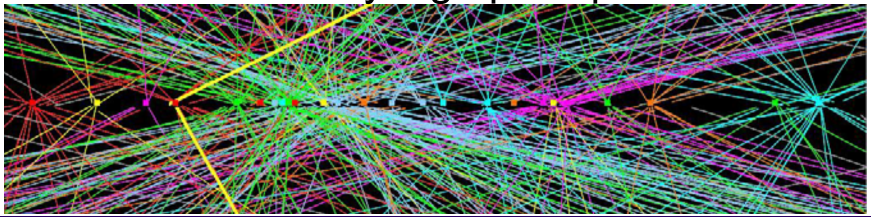
- Forward spectrometer optimised for heavy flavour physics at the LHC
  - Large acceptance 2<η<5
  - Low trigger thresholds
  - Precise vertexing
  - Efficient particle identification
  - Large boost (B mesons flight ~1cm)



- Running at a constant luminosity of 4.10^{32} cm^{-2} s^{-1} thanks to the luminosity leveling (design 2.10^{32})
- Precision physics easier in a low pile-up environment: interactions per bunch crossing ~1.5

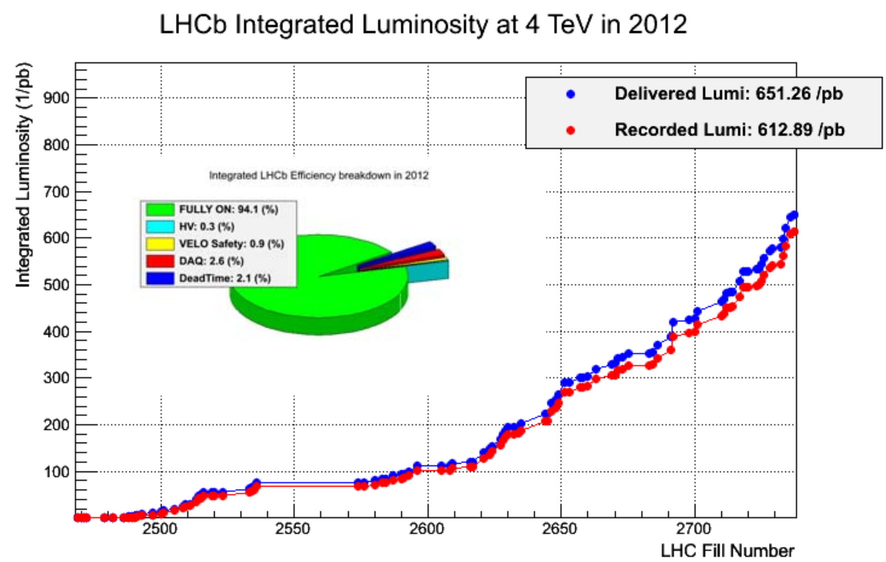


ATLAS 2012: very high pile up!



Statistics

	LHCb	ATLAS/CMS
2010 (7TeV)	37 pb^{-1}	45 pb^{-1}
2011 (7TeV)	1 fb^{-1}	5.2 fb^{-1}
2012 (8TeV)	0.61 fb^{-1}	6.2 fb^{-1}
Expected end 2012	1.5 fb^{-1}	15 fb^{-1}



- Large cross section: σ(pp → bbX) @ 7TeV = 284±53 μb (LHCb, PLB 694 209)

  ⇒ 100,000 bb pairs produced/second (10^4 x B factories)

  ⇒ Huge sample of B mesons and baryons (and charm as well!)

- But :

  Hadronic environment: ~100 tracks/event → large background

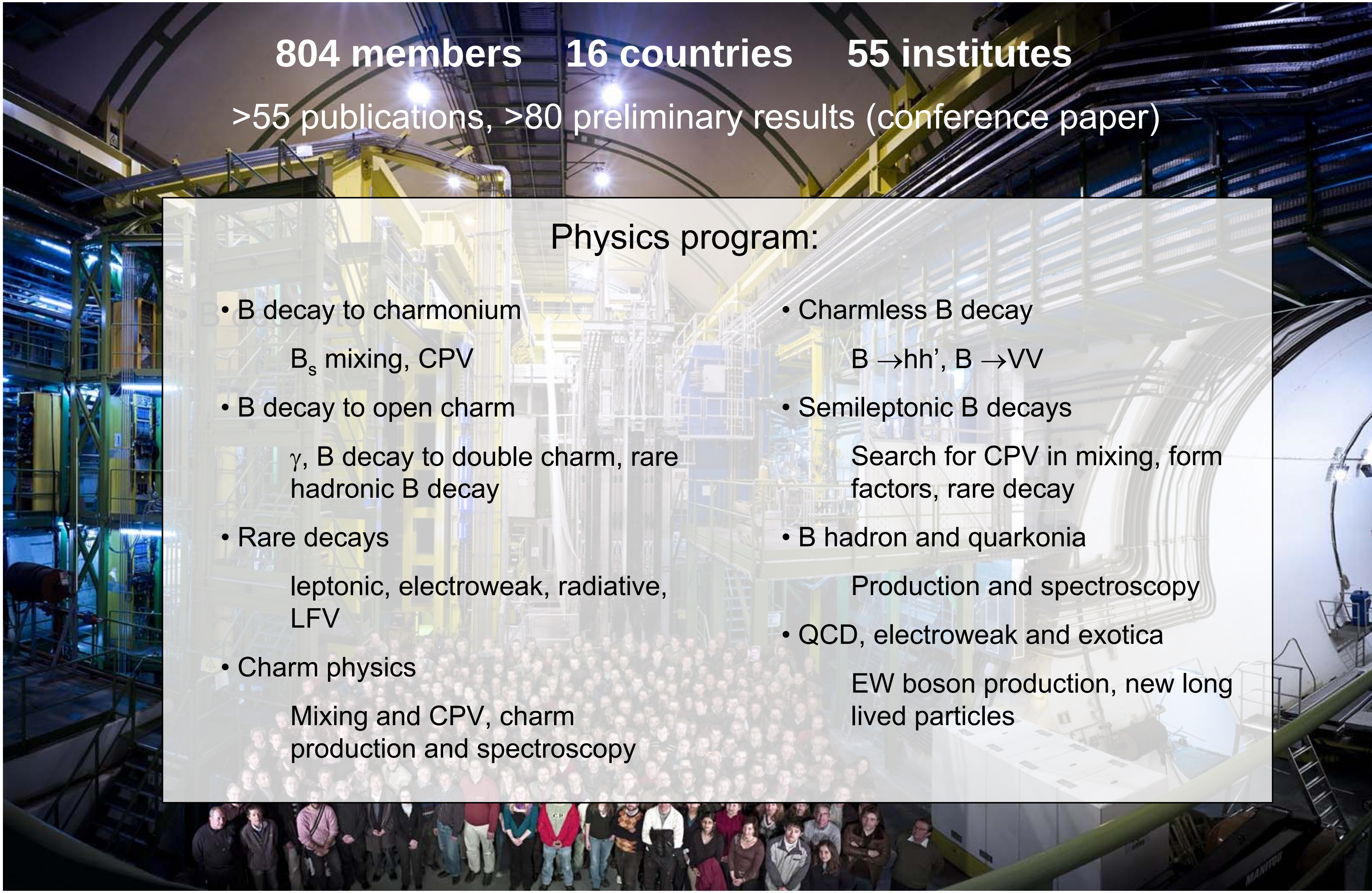
  LHCb does not have a full angular coverage → difficult to reconstruct channels with missing particles

Collaboration

804 members 16 countries 55 institutes

>55 publications, >80 preliminary results (conference paper)

Collaboration



804 members **16 countries** **55 institutes**

>55 publications, >80 preliminary results (conference paper)

Physics program:

- B decay to charmonium

  B_s mixing, CPV

- B decay to open charm

  γ, B decay to double charm, rare hadronic B decay

- Rare decays

  leptonic, electroweak, radiative, LFV

- Charm physics

  Mixing and CPV, charm production and spectroscopy

- Charmless B decay

  $B \rightarrow hh'$, $B \rightarrow VV$

- Semileptonic B decays

  Search for CPV in mixing, form factors, rare decay

- B hadron and quarkonia

  Production and spectroscopy

- QCD, electroweak and exotica

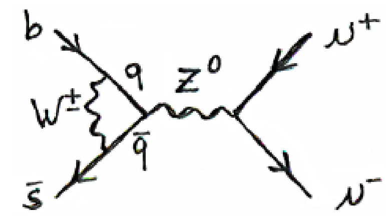
  EW boson production, new long lived particles

Rare B decays

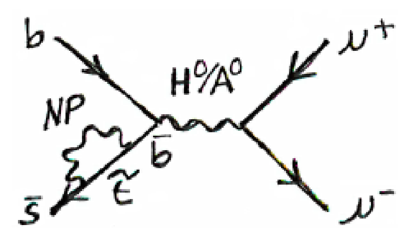
- FCNC and helicity suppressed decays

- Precise SM prediction:
  - $BR(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$
  - $BR(B_d \to \mu^+\mu^-) = (1.1 \pm 0.1) \times 10^{-10}$

  A.J.Buras: arXiv:1012.1447,
  E. Gamiz et al: Phys.Rev.D 80 (2009) 014503



- Very sensitive to new physics, especially models with extended Higgs sector
  - Ex: in the MSSM, BR scales as $\tan^6\beta / M^4_A$

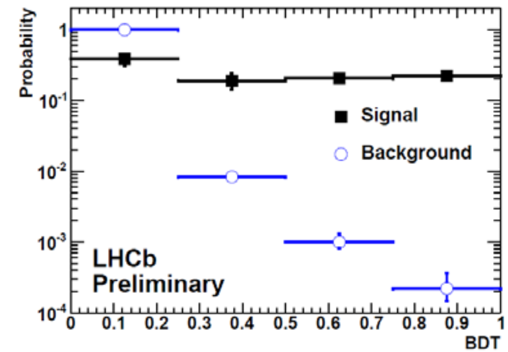


- More generally:

$$\mathrm{BR}(B_s \to \mu^+\mu^-) \propto |C_S - C'_S|^2 \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) + |(C_P - C'_P) + \frac{2m_\mu}{m_{B_s}^2}(C_{10} - C'_{10})|^2$$

Scalars operators

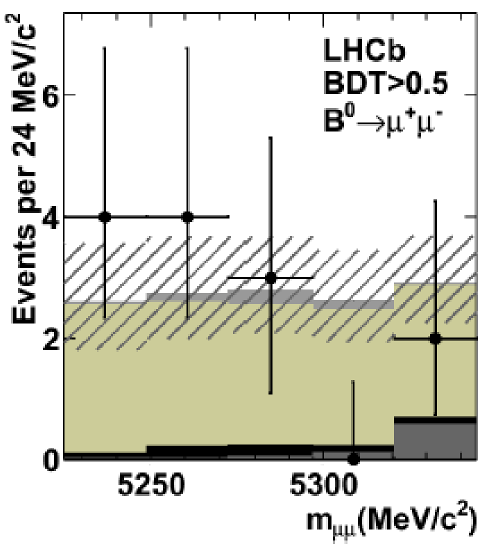
semileptonic operators

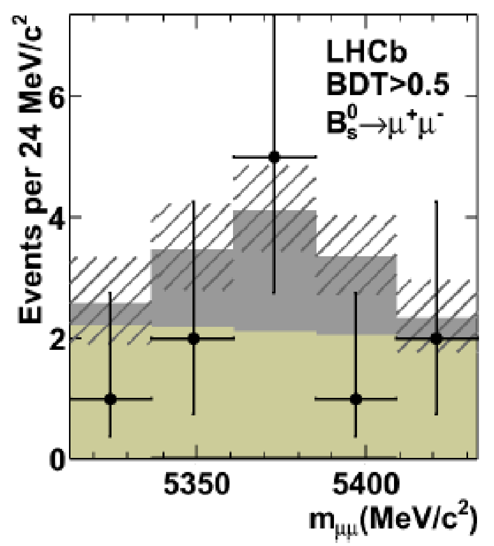


- Limit extracted with the CLs method in bins of
  - $\mu\mu$ invariant mass
  - Output of a Boosted Decision Tree combining geometrical and kinematical informations
- Distributions calibrated on data using $B\to hh'$, and dimuon resonances (J/ψ, $\psi(2s)$, Υ's)
- Analysis blind

- Open the box:

PRL 108, 231801 (2012)





Signal SM
Background
Cross feed
$B\to hh'$

f_s/f_d

- To compute the BR we need to normalize to decay channels with known BR:

$B^+ \to J/\psi K^+$ $B_s \to J/\psi \phi$ $B^0 \to \pi^- K^+$

$$\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = \mathrm{BR}(B_q \to X) \frac{f_q}{f_s} \frac{\epsilon_X}{\epsilon_{\mu\mu}} \frac{N_{\mu\mu}}{N_X}$$

- f_s/f_d is measured at LHCb with hadronic decays using $B^0 \to D^- K^+/\pi^+$ and $B_s \to D_s^- \pi^+$ (method from R. Fleischer et al, PRD 82, 034038)

$$\frac{f_s}{f_d} = 0.0743 \times \frac{\tau_{B^0}}{\tau_{B_s^0}} \times \left[\frac{\epsilon_{DK}}{\epsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{DK}}\right] \times \frac{1}{\mathcal{N}_a \mathcal{N}_F}$$

Result with $B^0 \to D^- K^+$:

$$f_s / f_d = 0.250 \pm 0.024_{stat} \pm 0.017_{syst} \pm 0.017_{theo}$$

PRL 107 21(2011)

Dominant systematics from form factors ratio

$$\mathcal{N}_F = \left[\frac{f_0^{(s)}(M_\pi^2)}{f_0^{(d)}(M_K^2)}\right]^2 .$$

LHCb result use LCSR, new lattice calculation by Fermilab/MILC arXiv:1202.6346

- And semileptonic decays: $B_s \to D_s X\mu$ and $B \to D^+ X\mu$

PRD 85, 032008 (2011)

- We compute the average:

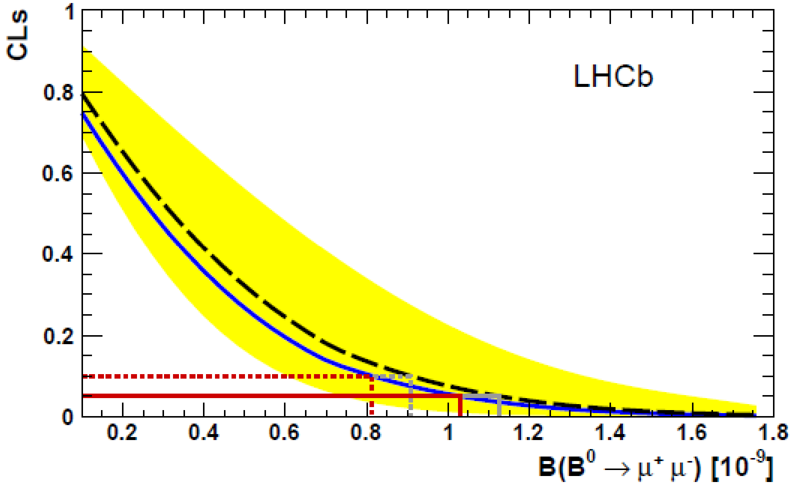
$$\boxed{f_s / f_d = 0.267^{+0.021}_{-0.020}}$$

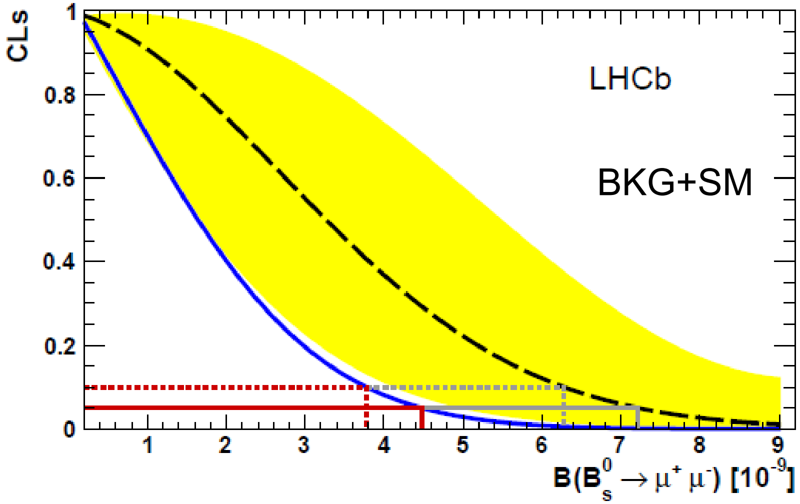
LHCb-CONF-2011-034

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

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

PRL 108, 231801 (2012)





Limit at 95% CL	$B_d \to \mu^+\mu^-$	$B_s \to \mu^+\mu^-$
Expected bkg only	1.1 x10^{-9}	3.4 x10^{-9}
Expected bkg+SM		7.2 x10^{-9}
Observed	1.0 x10^{-9}	4.5 x10^{-9}

- CMS (5 fb^{-1}): BR($B_s \to \mu^+\mu^-$) < 7.7 x10^{-9} @ 95% CL (Expected: 8.4 x10^{-9}) *arXiv:1204.0735*
- ATLAS (2.4 fb^{-1}): BR($B_s \to \mu^+\mu^-$) < 22 x10^{-9} @ 95% CL *arXiv:1203.3976*

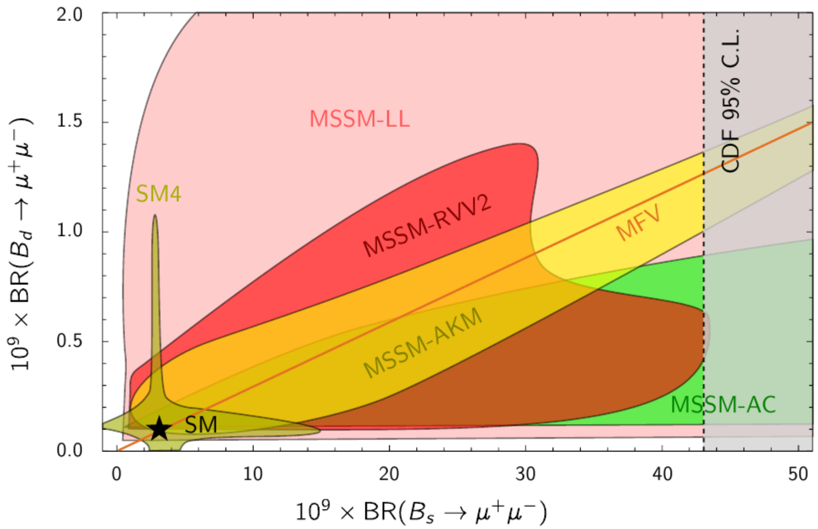
NEW! LHCb+CMS+ATLAS: $\boxed{\text{BR}(B_s \to \mu^+\mu^-) < 4.2 \times 10^{-9} \text{ @ 95\% CL}}$ *LHCb-CONF-2012-017*

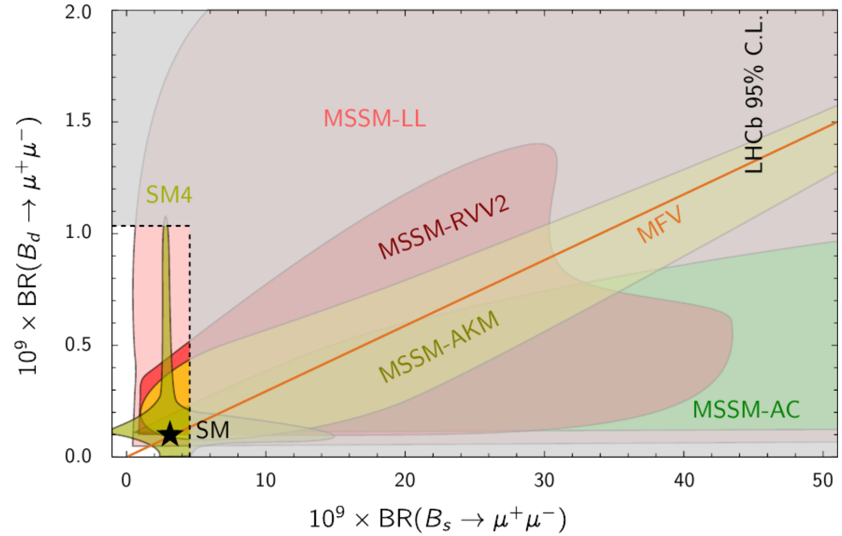
$B_{s/d} \to \mu^+\mu^-$ implications

2010

Straub, Moriond 2012, arXiv:1205.6094

Moriond 2012

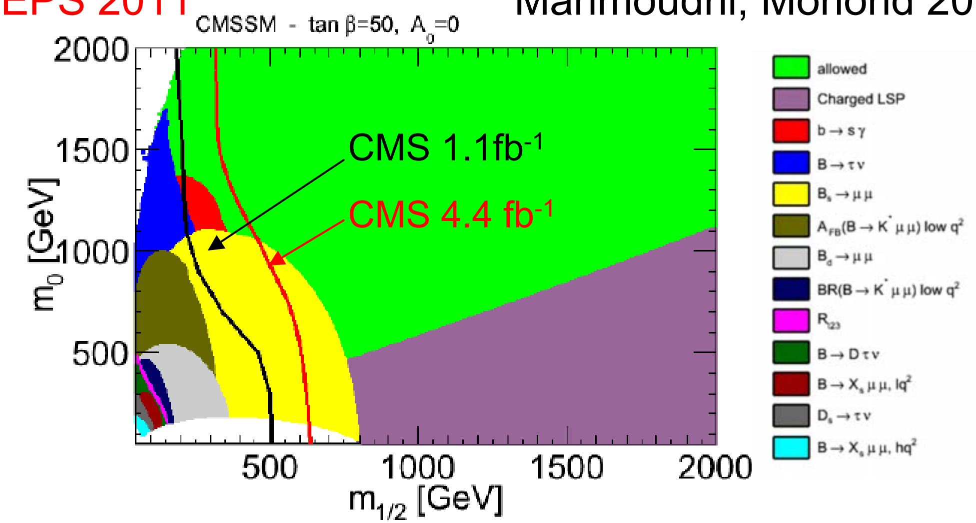


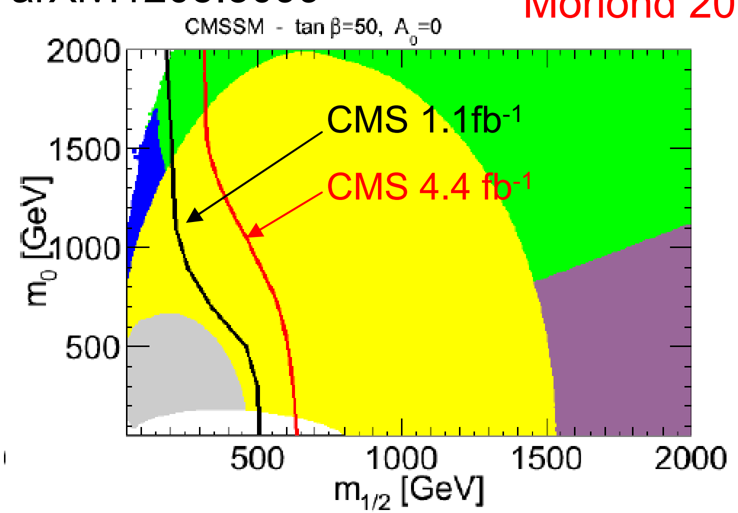


EPS 2011

Mahmoudhi, Moriond 2012, arXiv:1205.3099

Moriond 2012





$B_s \to \mu^+\mu^-$: Experimental limit and SM prediction

- 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

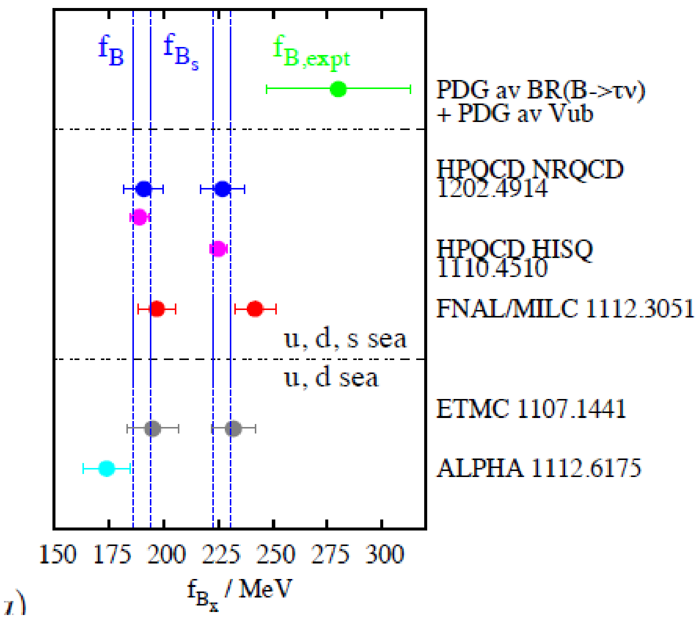
- So far we used Buras prediction BR($B_s \to \mu^+\mu^-$)= $(3.2\pm0.2)\times10^{-9}$

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

with $B_s = 1.33 \pm 0.06$ E. Gamiz et al, Phys.Rev.D 80 (2009) 014503

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

C.Davies,arXiv:1203.3862



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

- N. Mahmoudi et al (arXiv:1205.1845): $(3.53\pm0.38)\times10^{-9}$ using $f_{Bs} = (234\pm10)$MeV
- C. Davies (arXiv:1203.3862): $(3.32\pm0.25)\times10^{-9}$ using $f_{Bs} = (227\pm4)$MeV

Which value of f_{Bs} should we use?

$B_{s/d} \to \mu^+\mu^-$: Experimental limit and SM prediction

- 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

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

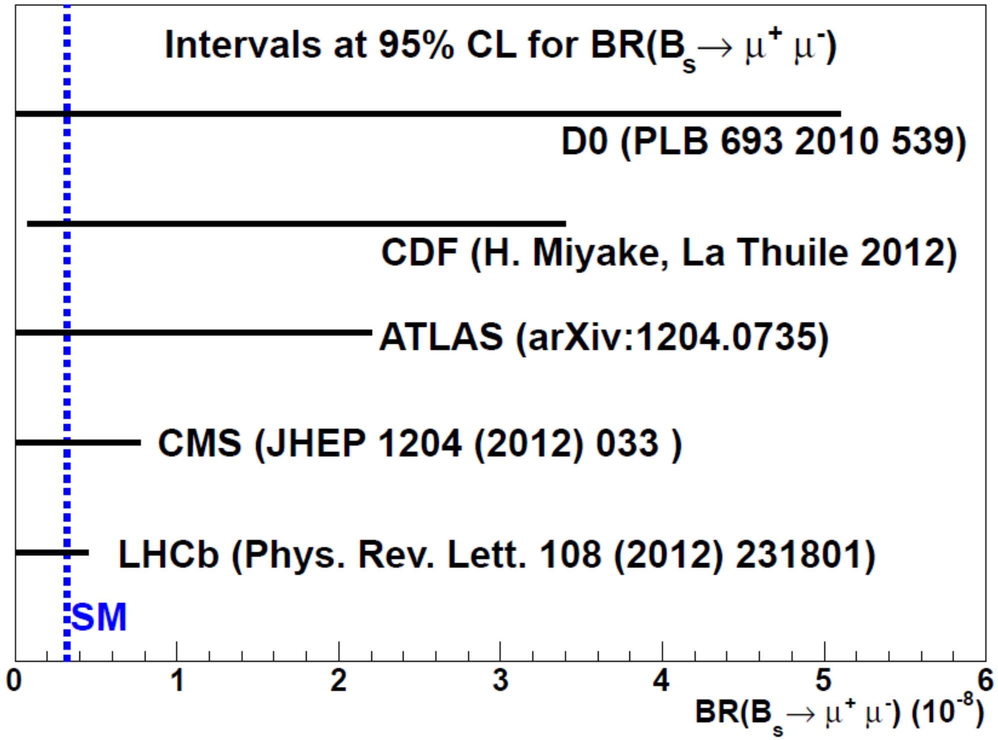
$\downarrow$

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

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

$B_{s/d} \to \mu^+\mu^-$: what's next?

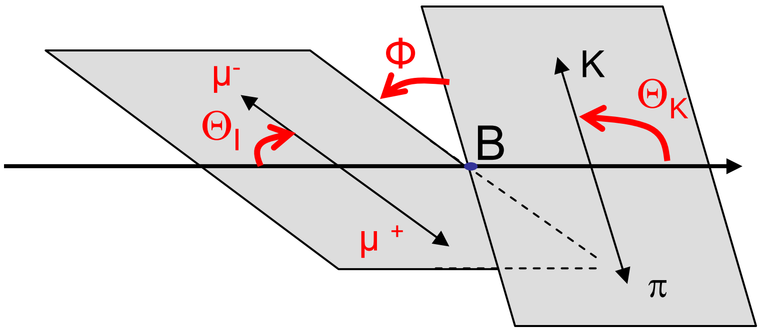
- Lot of activity in the last 2 years!



- CMS/ATLAS expect 15 fb^{-1} at the end of 2012
- LHCb expect 1.5 fb^{-1} at the end of 2012
- A first observation may come soon, stay tuned!

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

- Give access to $c^{(')}_7$, $c^{(')}_9$, $c^{(')}_{10}$
- Sensitivity through branching fraction measurement and angular observables
- Decay described by 3 angles and di-muon invariant mass squared q^2



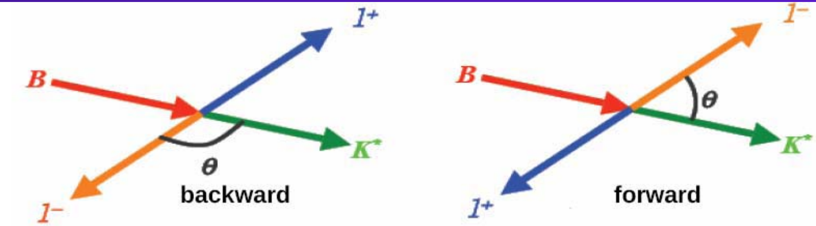
- Folding the ϕ angle (if $\phi<0$, $\phi=\phi+\pi$), we can reduce the number of free parameters:

$$
\begin{aligned}
\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}\,\mathrm{d}q^2} = \frac{9}{16\pi}\Big[& F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) \; - \\
& F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) \; + \\
& \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) \; + \\
& S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} \; + \\
& \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell \; + \\
& S_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi} \; \Big]
\end{aligned}
$$

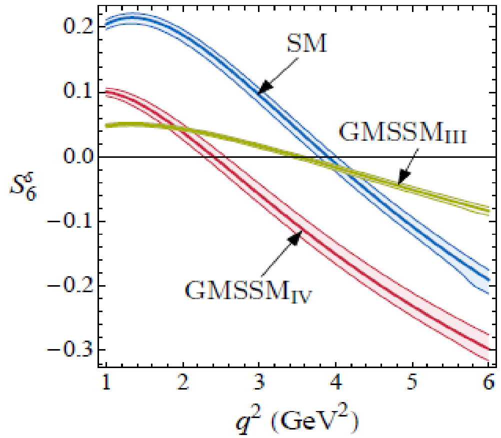
Angular observables

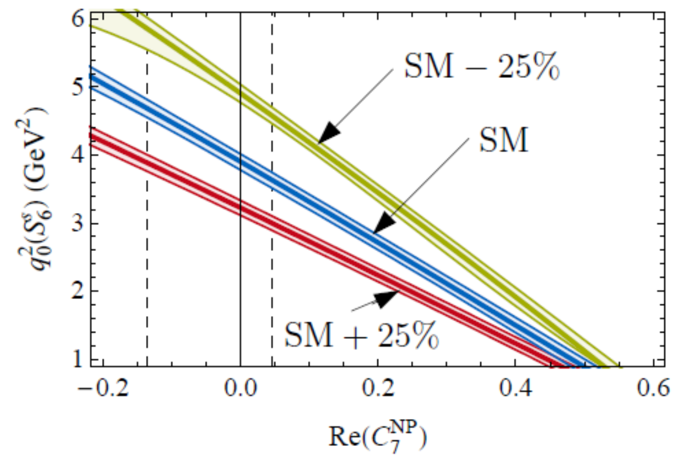
$$\boxed{A_{FB}(q^2) = \frac{N_F - N_B}{N_F + N_B}}$$

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



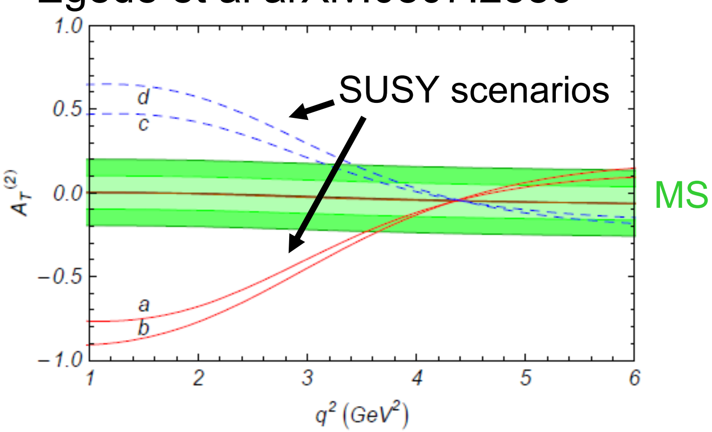
Altmannshofer et al arXiv:0811.1214v5

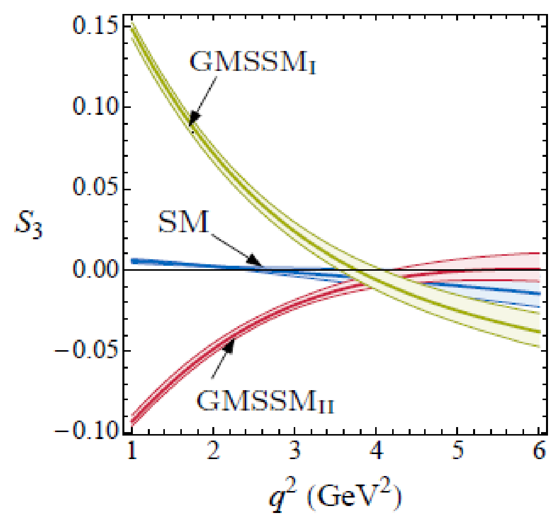




25% change in C_9

Egede et al arXiv:0807.2589



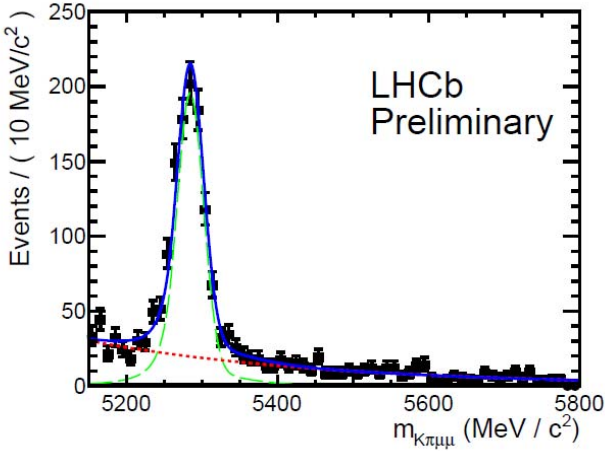


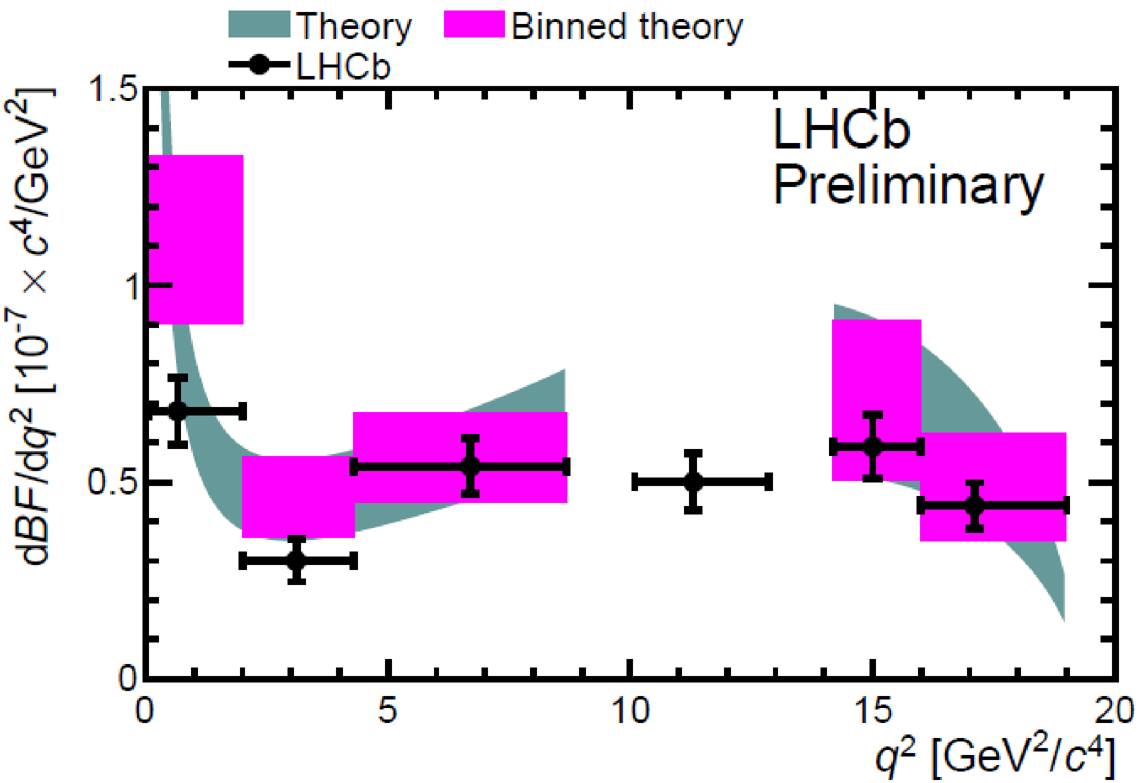
$$\boxed{A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}}$$

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

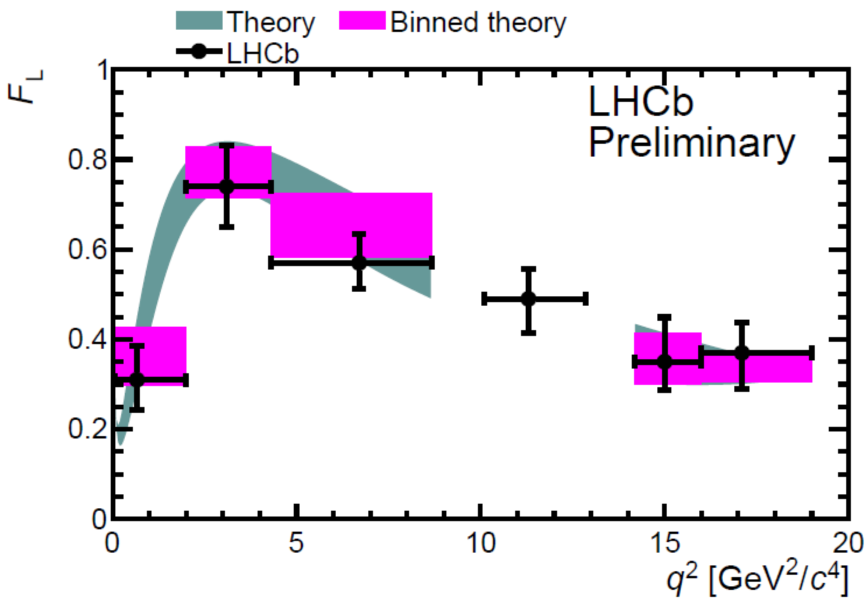
$B_d \to K^{*0}\mu^+\mu^-$

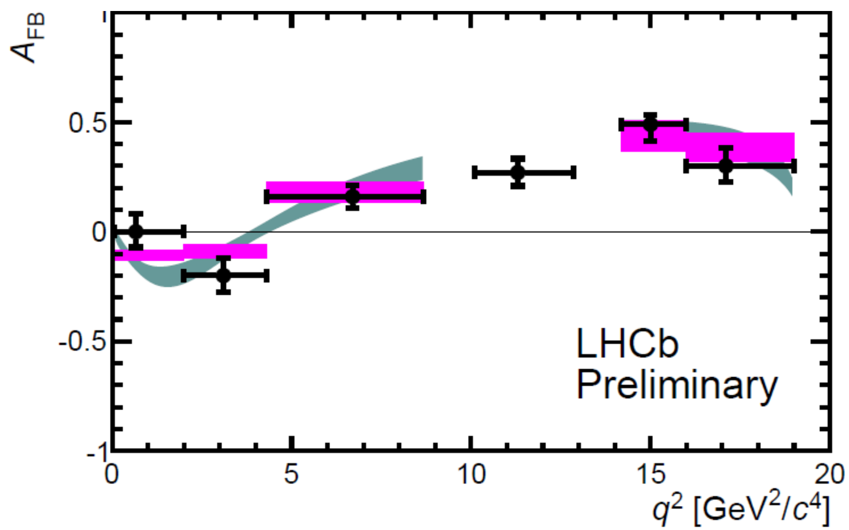
- Analysis performed on $1fb^{-1}$ *LHCb-CONF-2012-008*
- Observe 900±34 events (Babar+Belle+CDF~600)
- Differential BR obtained with mass fits in 6 q^2 bins





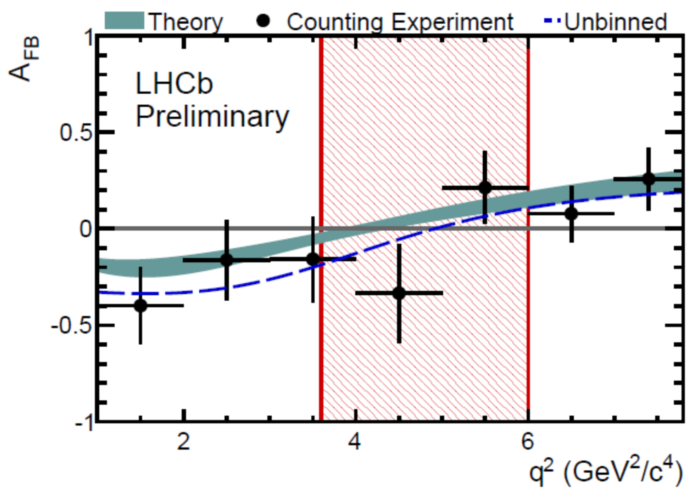
Theory predictions from C. Bobeth et al arXiv:11105.0376





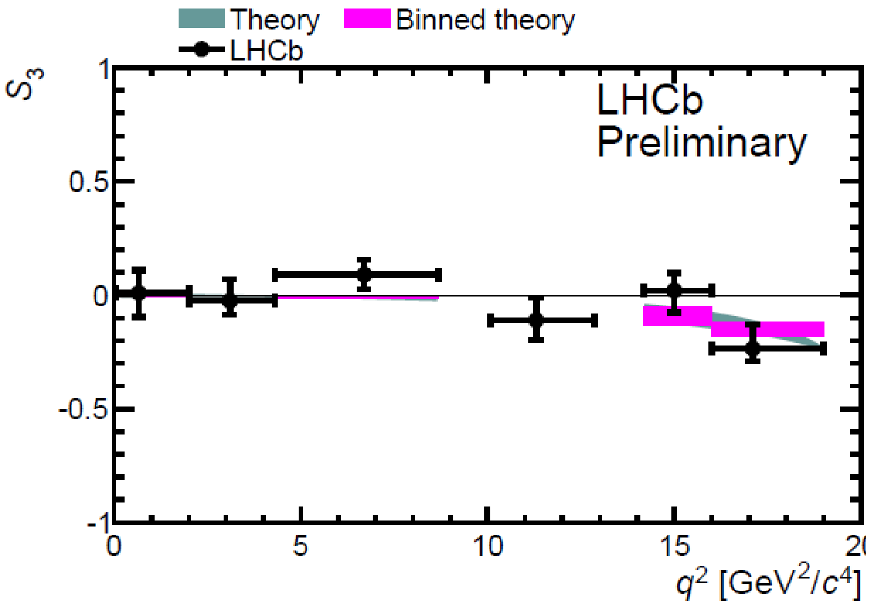
- In the SM A_{FB} changes sign at a well defined point where leading uncertainties from B→K* form factors cancel
- SM predictions 3.9-4.3 GeV^2
- Estimate the zero crossing point fitting separately q^2 and invariant mass distributions for forward and backward going events

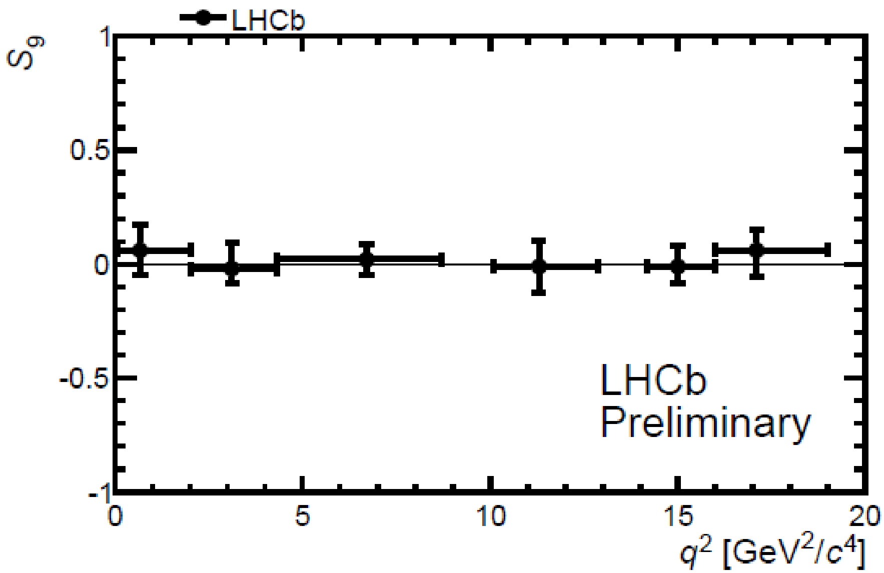
$$\boxed{q_0^2 = 4.9^{+1.1}_{-1.3} GeV^2/c^4}$$ (preliminary)



S_3 and S_9

LHCb-CONF-2012-008



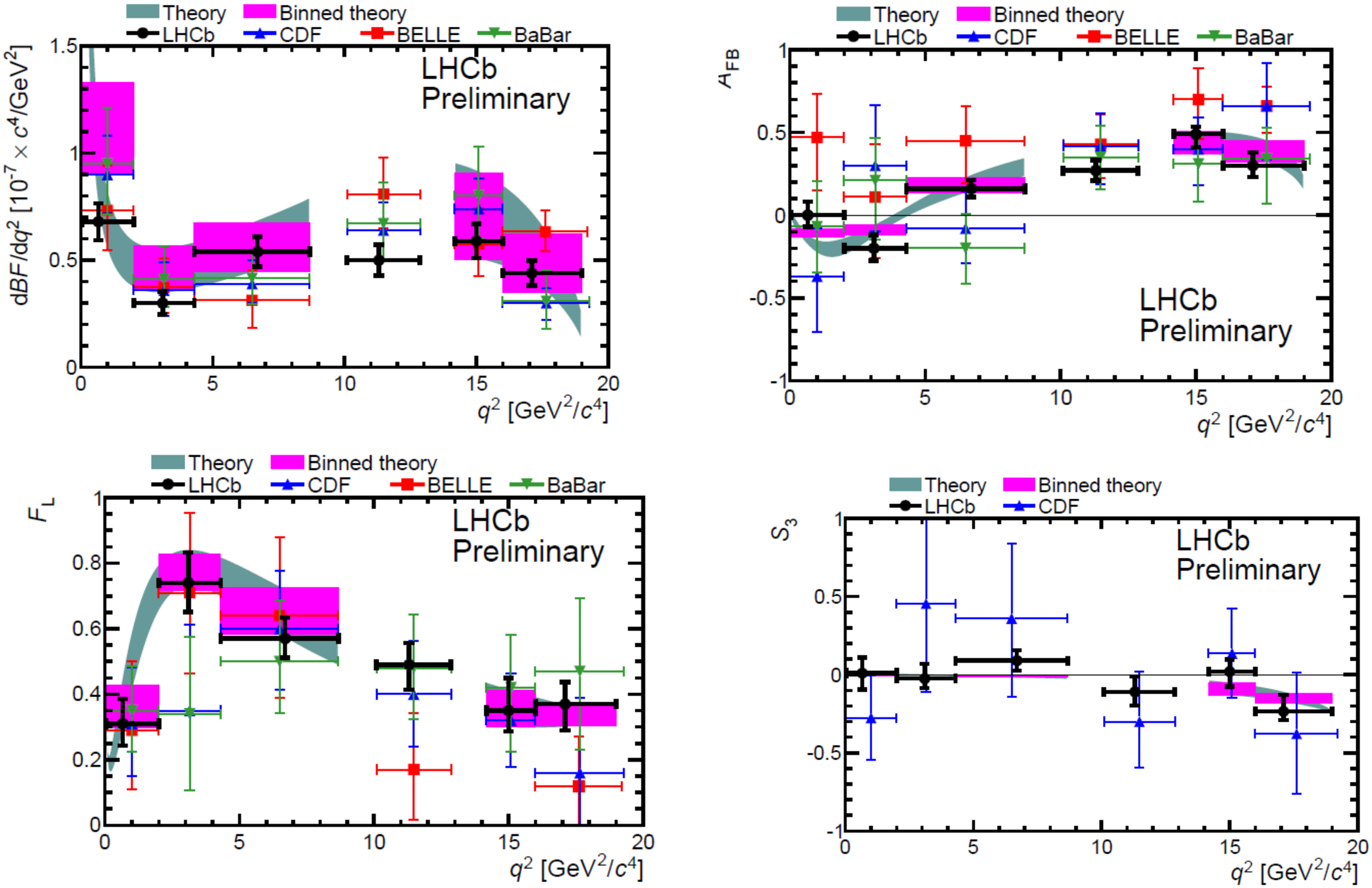


S_9 expected to be ~10^{-3} in SM

All compatible with standard model…

Comparison with other experiments

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



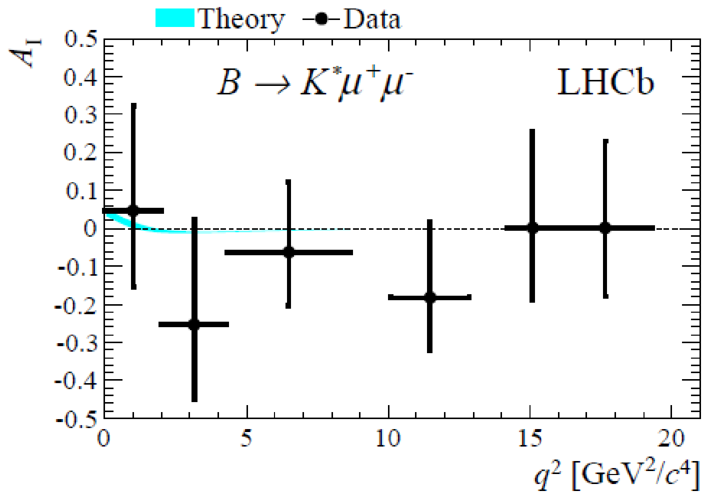
Isospin asymmetry in B→K$^{(*)}\mu^+\mu^-$

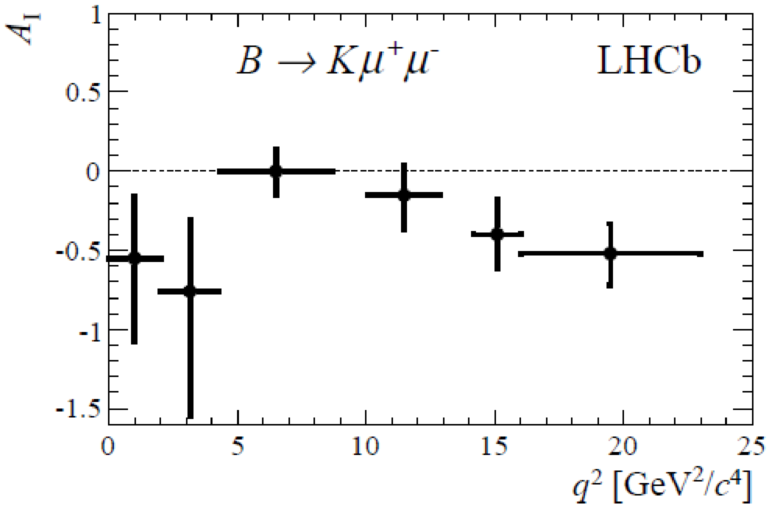
- Reconstruct B→K$^{(*)}\mu^+\mu^-$ with $K^0 \to K^0_s \to \pi\ \pi$ *arXiv:1205.3422*

$$\mathcal{B}(B_d \to K^0 \mu^+ \mu^-) = (0.31^{+0.07}_{-0.06}) \times 10^{-6}$$
$$\mathcal{B}(B_u \to K^{*+} \mu^+ \mu^-) = (1.16 \pm 0.19) \times 10^{-6}$$

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

Expected to be very close to 0 in SM





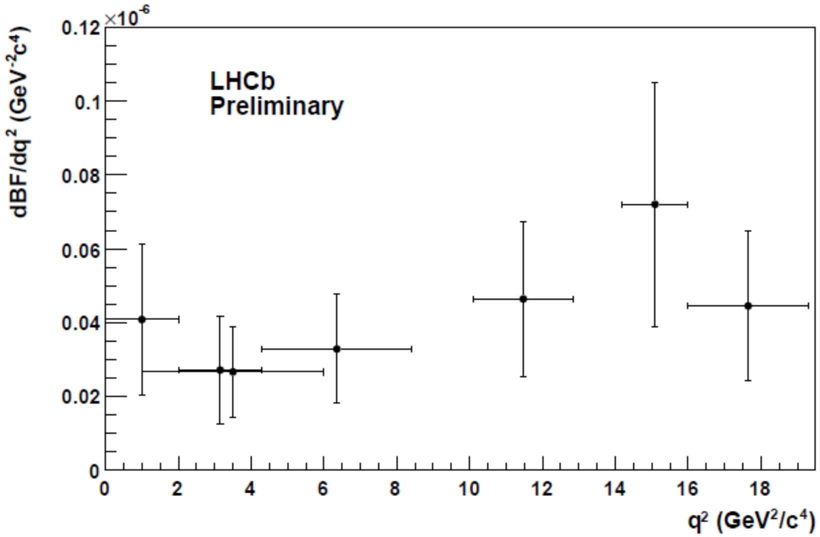
Consistent with Belle and Babar measurement but <0 for B→K$\mu^+\mu^-$ (naïve average over q^2 bins gives 4.4σ effect), unexpected! Need more statistics.

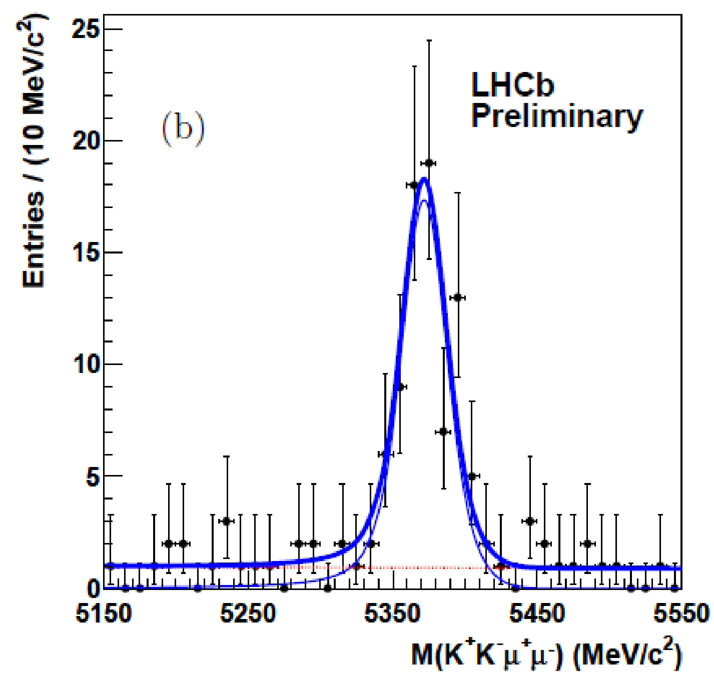
LHCb-CONF-2012-003

- Measure $B_s \to \phi\mu^+\mu^-$ normalized to $B_s \to J/\psi\phi$ with 1 fb^{-1}
- Observe 77±10 signal candidates

$$BR(B_s \to \phi\mu^+\mu^-) = (0.78 \pm 0.10(stat) \pm 0.06(syst) \pm 0.28(BR))\ 10^{-6}$$

- Lower than but still compatible with CDF result (PRL,107(2011) 201802)
- Also obtain the partial BR as function of q^2

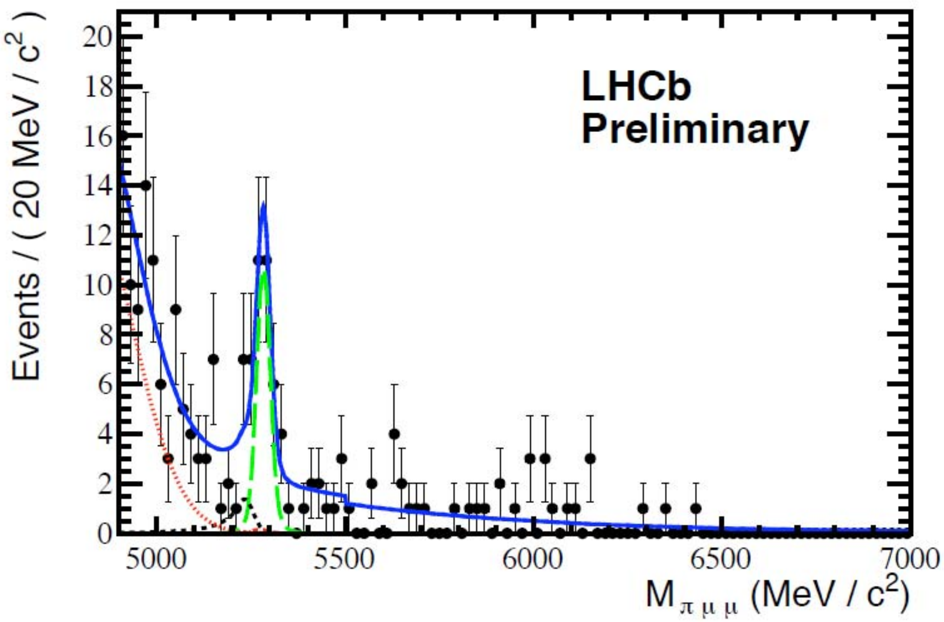




$B^+ \rightarrow \pi^+ \mu^+ \mu^-$

LHCb-CONF-2012-006

- Very rare decay in SM: BR=$(2\pm0.2)\times10^{-8}$ Hai-Zhen et al, Commun. Theor. Phys. **50** 696
- Previous best limit from Belle BR<6.9×10^{-8} PRD 78 (2008)
- LHCb observe $25.3^{+6.7}_{-6.4}$ candidates in $1\,fb^{-1}$



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

First observation at 5.2 σ (rarest B decay observed!!)

CP asymmetry in B → K*γ

- Precise SM prediction

  Y. Keun et al PRD 72,014013 $A_{CP}^{SM}(B^0 \to K^{*0}\gamma) = -0.0061 \pm 0.0043$

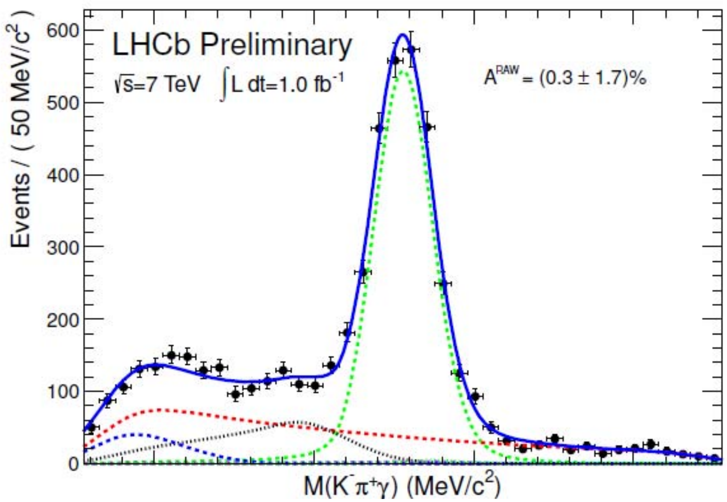
- Previous best measurement by Babar

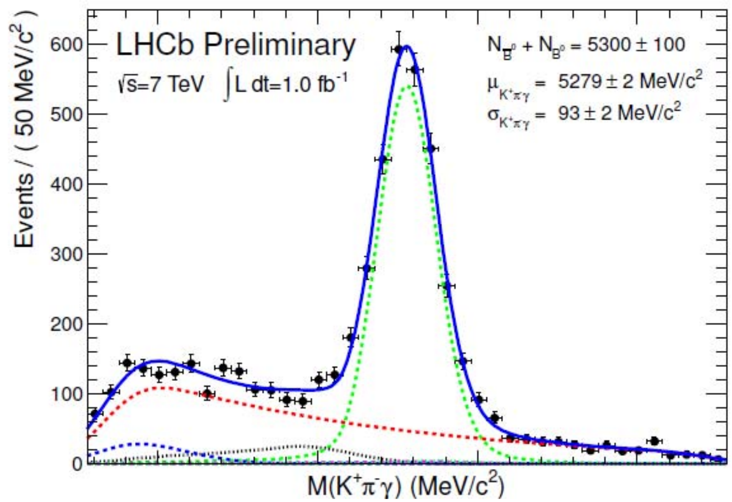
  $A_{CP}^{Exp}(B^0 \to K^{*0}\gamma) = -0.016 \pm 0.022 \pm 0.007$ PRL 103, 211802

- LHCb has the most precise measurement, in agreement with SM

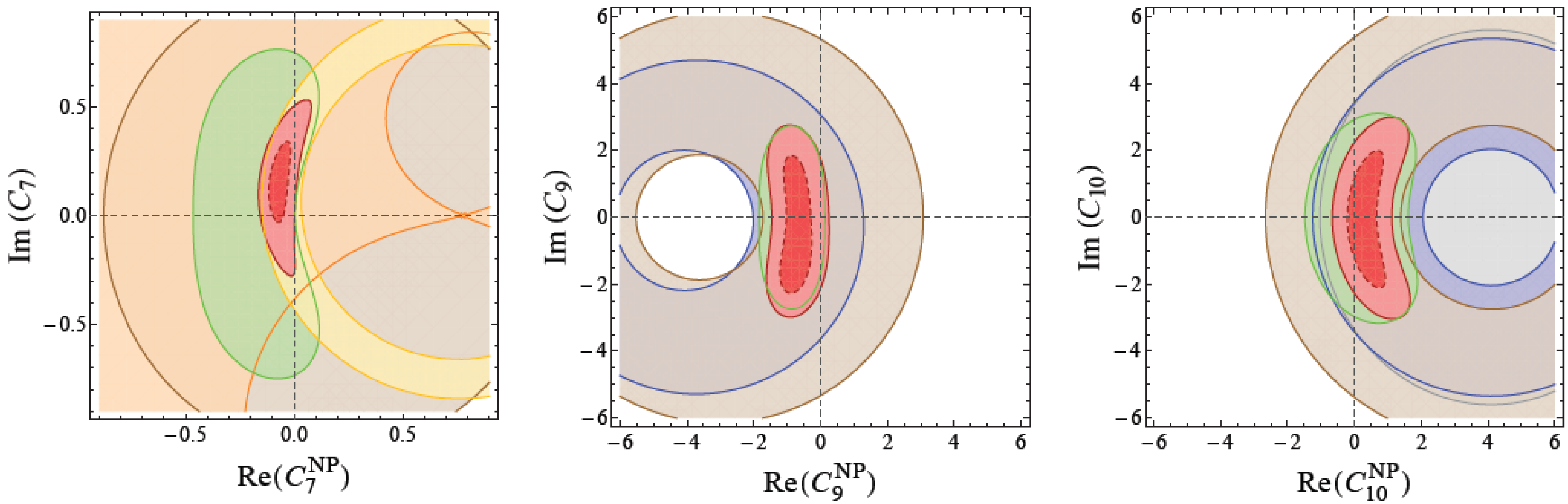
$$\boxed{A_{CP}(B^0 \to K^{*0}\gamma) = 0.008 \pm 0.017 \pm 0.009}$$

LHCb-CONF-2012-004





- Several studies, ex: Straub et al, arXiv:1206.0273
- Model independent constraint $C_i = C_i^{SM} + C_i^{NP}$
- Over constraint Wilson coefficients with many measurements 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

CP violation and B_s mixing

Δm_s

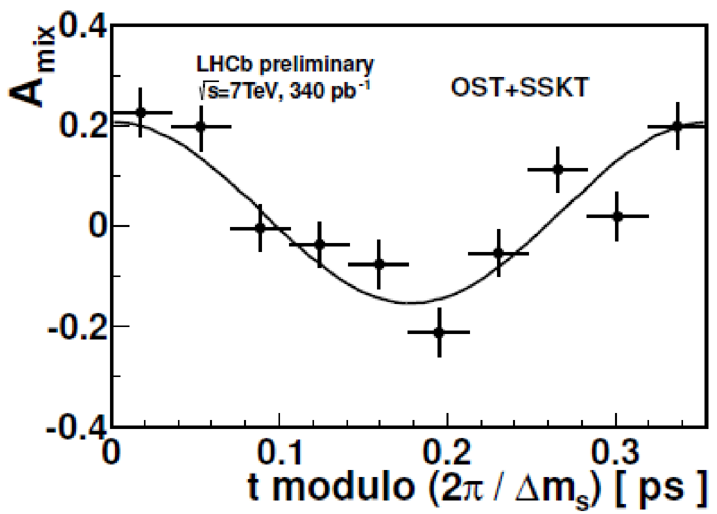
LHCb-CONF-2011-050

- Measure Δm_s in flavour-tagged analysis of $B_s \to D_s^- \pi^+$ events
- Signal decay time probability:

$$\mathcal{P}_t(t, q|\sigma_t, \eta) \;\propto\; \left\{\Gamma_s e^{-\Gamma_s t}\,\frac{1}{2}\left[\cosh\left(\frac{\Delta\Gamma_s}{2}t\right) + q\,[1-2\omega(\eta)]\cos(\Delta m_s t)\right]\,\theta(t)\right\}$$
$$\otimes\, G(t, S_{\sigma_t}\,\sigma_t)\,\epsilon(t)\,\epsilon_s.$$

q: tagging decision
ω: mistag probablity

- Use same side and opposite side tagging
  - SS: use the kaon associated to the B_s production, $\varepsilon(SS) = 1.3\pm0.4\%$
  - OS: look at the flavour of the other B, $\varepsilon(OS) = 2.1\pm0.2\%$



- In 0.34 fb^{-1}:

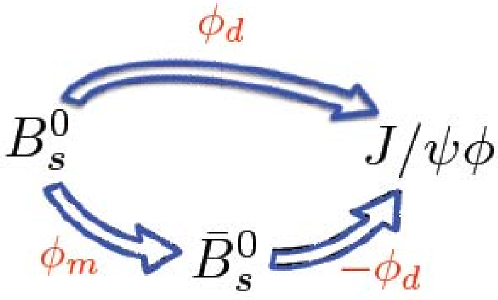
$$\boxed{\Delta m_s = 17.725 \pm 0.041 \pm 0.026\ \text{ps}^{-1}}$$

(preliminary)

World best measurement, still statistically limited

ϕ_s in $B_s \to J/\psi\phi$

- Interference between mixing and decay gives rise to a CP violating phase

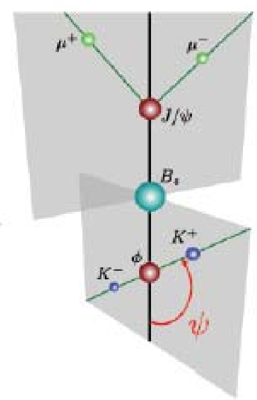


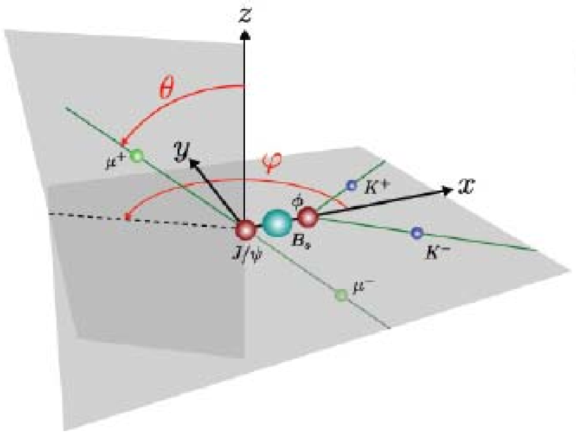
- Very precisely predicted in SM

$$\phi_s^{SM} \approx -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cs}^*}\right) = 0.036 \pm 0.002\ \ rad$$

Charles et al, PRD84 (2011) 033005

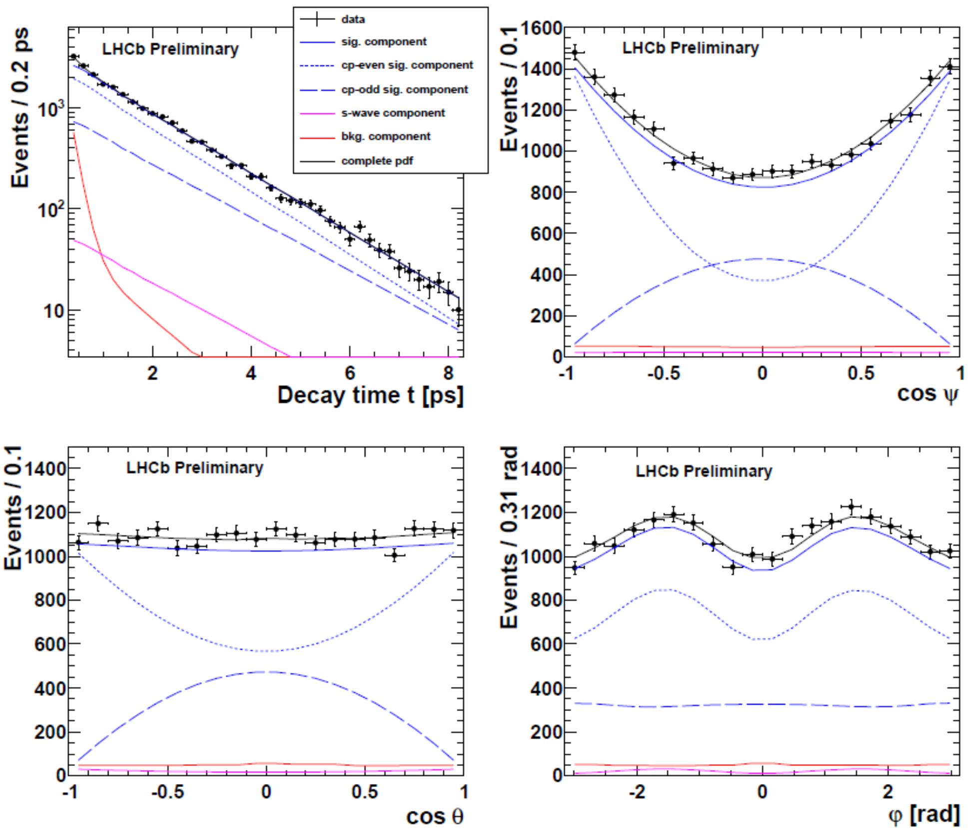
- $B_s \to J/\psi\phi$ is a mixing of CP odd and even final state. Need an analysis
  - Time dependent
  - Tagged
  - Full angular
  - Should measure also $\Delta\Gamma_s$

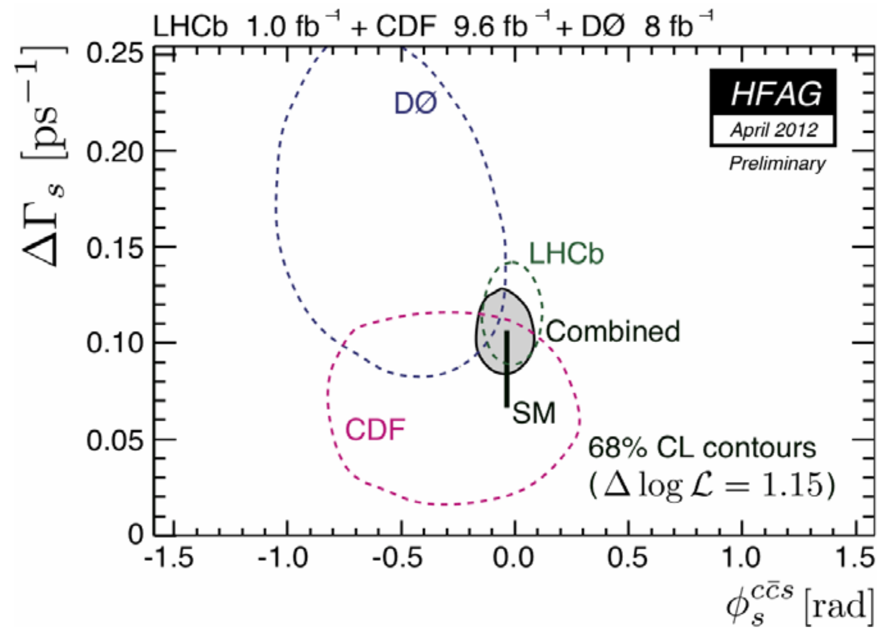




ϕ_s in $B_s \to J/\psi\phi$

LHCb-CONF-2012-002



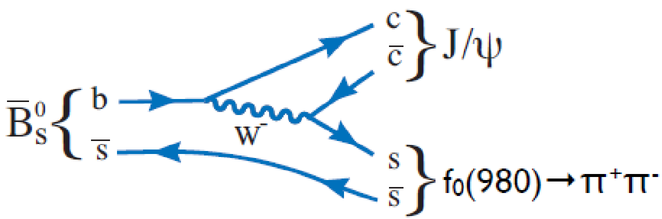


Ambiguous solution eliminated by LHCb study, *arXiv:1202.4717*

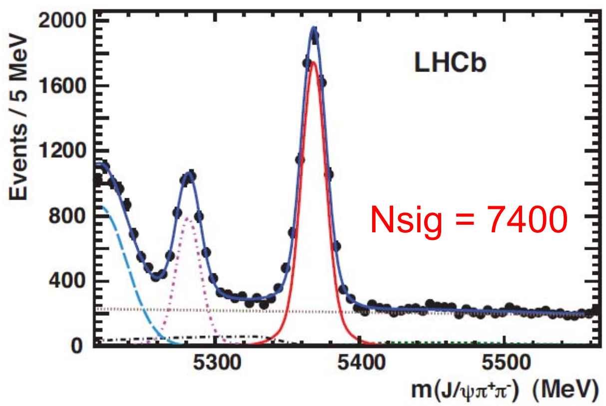
Using 1 fb^{-1}: $\boxed{\phi_s = 0.00 \pm 0.10 \pm 0.03 \text{ rad}}$ (preliminary)

ϕ_s in $B_s \to J/\psi\ \pi\pi$

- Region of mass around f_0 gives a CP-odd final state, no need to do an angular analysis.



LHCb-PAPER-2012-006



Using 1fb^{-1}: ϕ_s = -0.02±0.17±0.02 rad

- Preliminary combination of $B_s \to J/\psi\phi$ and $B_s \to J/\psi\ \pi\pi$:

$\boxed{\phi_s = -0.002 \pm 0.083 \pm 0.027 \text{ rad}}$

LHCb-CONF-2012-006

No big non-SM effect in ϕ_s, but still worth to improve the precision

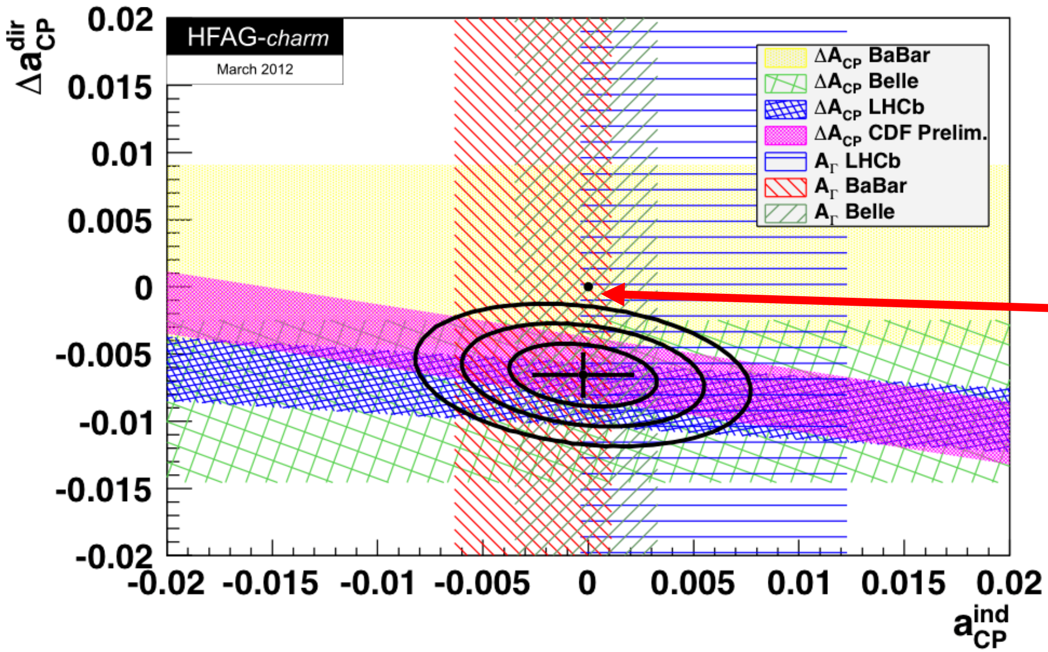
$\Rightarrow$ Need to evaluate the penguins pollution (Fleisher et al, arXiv:0810.4248)

CPV in charm

- Measure the difference of CP asymmetry

$$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$$

$$\Delta A_{CP} = \underbrace{(a_{CP}^{dir}(K^-K^+) - a_{CP}^{dir}(\pi^-\pi^+))}_{\text{direct CP asymmetry}} + \underbrace{\frac{\Delta\langle t\rangle}{\tau_{D^0}} a_{CP}^{ind}}_{\text{indirect CP asymmetry}}$$



HFAG average:

$$\Delta A_{CP}^{dir} = (-0.656 \pm 0.154)\%$$

CL of (0,0) is 6.1×10^{-5}

Results dominated by LHCb *PRL 108,111602(2012),* and CDF *Public note 10784, 2012*

SM hadronic effect or new physics ?? Theoretical work ongoing…

UT angle γ

Status of UT

- Overall consistency at ~2σ level
- Some discrepancy at 2-3 σ level between sin(2β) and B → τυ

- γ obtained from interference between b →c and b→u transitions

$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

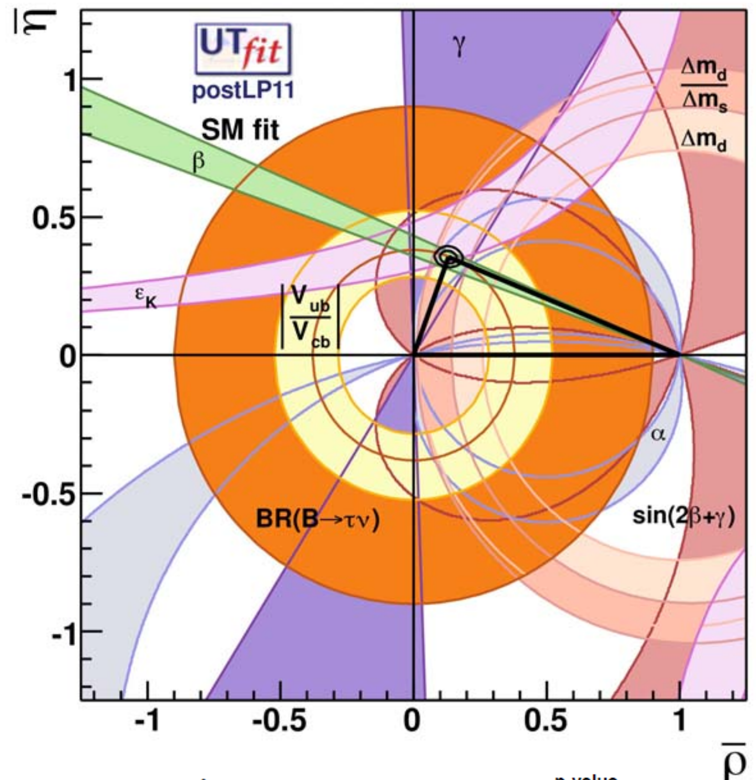
- γ is the least well know of the UT angles

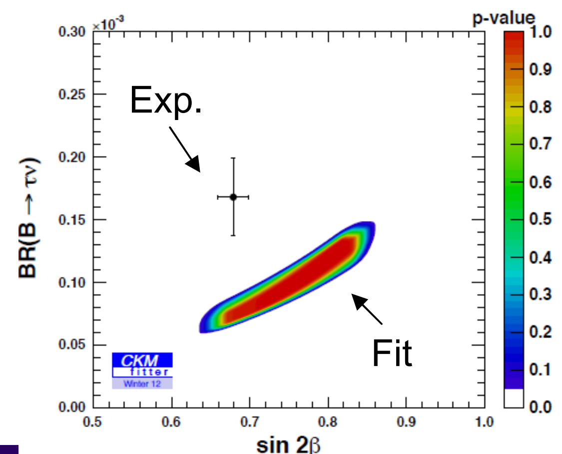
  γ = (75.5±10.5)° average from UTfit

- Indirect contraints :

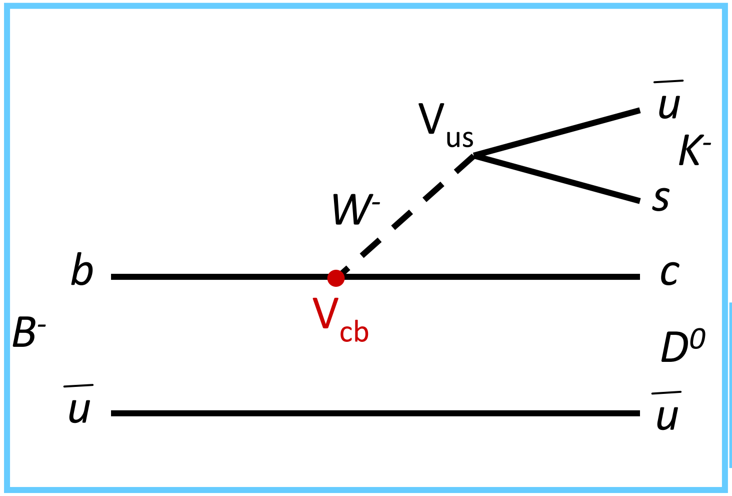
  γ = (68.5±3.2)° UTfit

  γ = (67.1±4.3)° CKMFitter

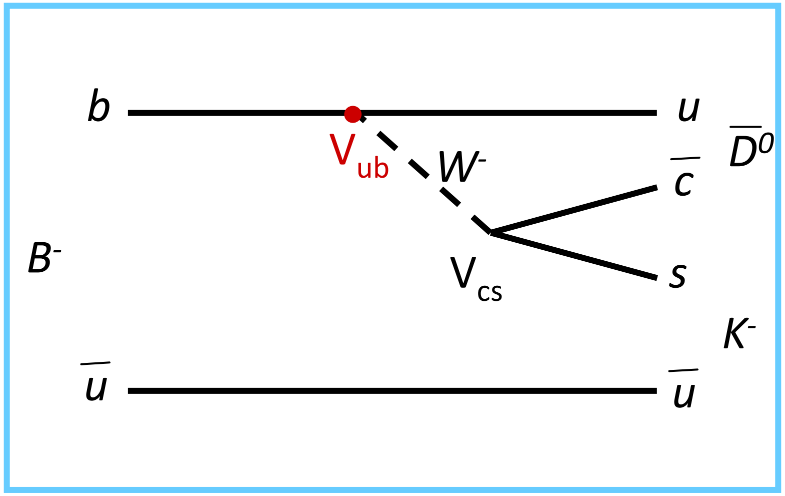




How to measure γ



Relative magnitude
r_B
relative phase δ_B-γ



- Same final state, 3 techniques :
  - GLW (*PLB 265(1-2),172*): use a CP mode for the D^0 decay

$$
\begin{aligned}
R_{GLW} &= 1 + r_{\mathrm{B}}^2 + 2 r_{\mathrm{B}} \cos\delta_{\mathrm{B}} \cos\gamma \\
A_{GLW} &= 2 r_{\mathrm{B}} \sin\delta_{\mathrm{B}} \sin\gamma / R_{GLW}
\end{aligned}
$$

  - ADS (*PRL 78(17), 3257*): use D^0 CA ($K^-\pi^+$) mode for the V_{ub} decay and D^0 DCS ($K^+\pi^-$) for the V_{cb} decay

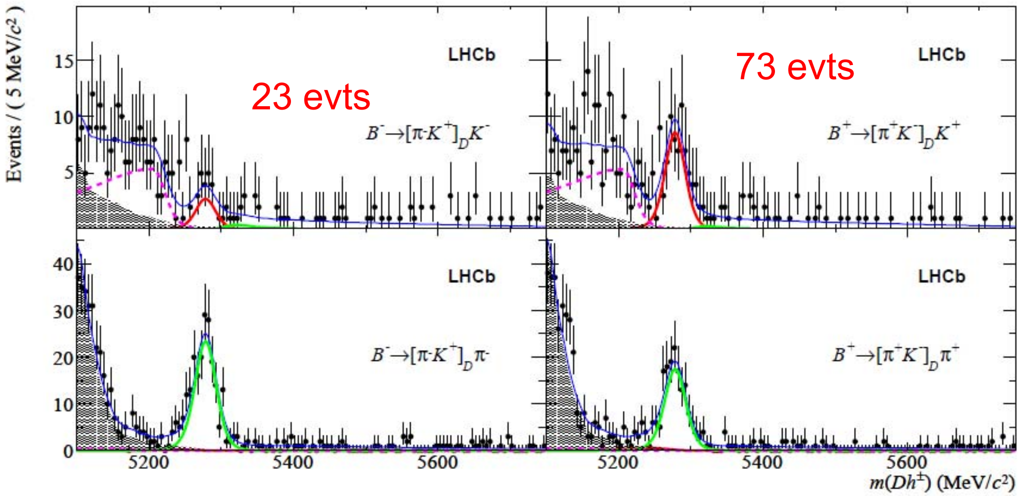
$$
\begin{aligned}
R_{ADS} &= r_{\mathrm{B}}^2 + r_{\mathrm{D}}^2 + 2 r_{\mathrm{B}} r_{\mathrm{D}} \cos(\delta_{\mathrm{B}} + \delta_{\mathrm{D}}) \cos\gamma \\
A_{ADS} &= 2 r_{\mathrm{B}} r_{\mathrm{D}} \sin(\delta_{\mathrm{B}} + \delta_{\mathrm{D}}) \sin\gamma / R_{ADS}
\end{aligned}
$$

  - Dalitz GGSZ (*PRD 68(5), 054018*) : use the $D^0 \rightarrow K_S\pi\pi$ or K_SKK decays
- Also time dependent analysis with eg $B_s \rightarrow D_sK$

CP violation in B → Dh

PLB, 712(2012) 203

$B \to [K\pi]_D h$



World most precise ADS/GLW of $B \to DK$:

- First observation of $B \to DK$ ADS mode with ~10σ
- Evidence of a large asymmetry in DK : -0.52±0.15±0.02 (4σ)
- With KK, ππ, CPV in $B \to DK$ observed at 5.8 σ

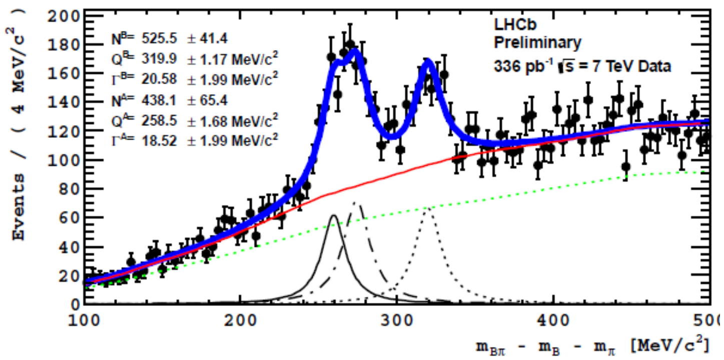
Prospects for γ :

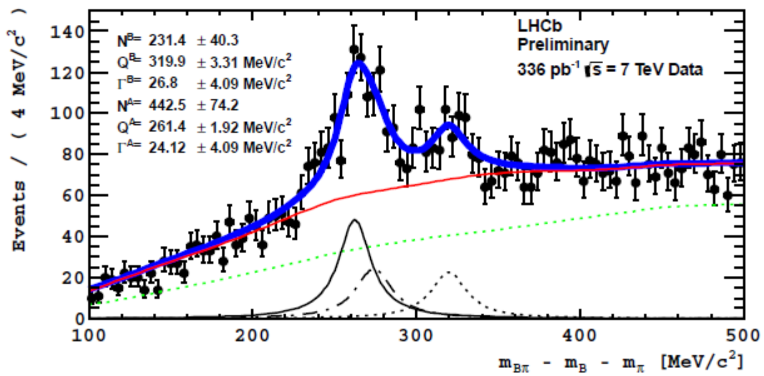
- Many more LHCb results: $B^0 \to D^0K^{*0}$, $\Lambda_b \to DpK$, $B_s \to D_sK$, $B^0 \to Dhhh$
- LHCb is competitive with B factories and Tevatron
- B_s modes are entering the game

Some spectroscopy

LHCb-CONF-2011-053

- Search in final states B^+K^- $B^+\pi^-$ $B^0\pi^+$ in 0.33 fb^{-1}





- No measurement of quantum numbers, matching to expected HQET states

$$
\begin{aligned}
M_{B_{s1}^0} &= (5828.99 \pm 0.08_{\text{stat}} \pm 0.13_{\text{syst}} \pm 0.45_{\text{syst}}^{B\,\text{mass}})\ \text{MeV}/c^2\,, \\
M_{B_{s2}^{*0}} &= (5839.67 \pm 0.13_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.29_{\text{syst}}^{B\,\text{mass}})\ \text{MeV}/c^2\,, \\
M_{B_1^0} &= (5724.1 \pm 1.7_{\text{stat}} \pm 2.0_{\text{syst}} \pm 0.5_{\text{syst}}^{B\,\text{mass}})\ \text{MeV}/c^2\,, \\
M_{B_1^+} &= (5726.3 \pm 1.9_{\text{stat}} \pm 3.0_{\text{syst}} \pm 0.5_{\text{syst}}^{B\,\text{mass}})\ \text{MeV}/c^2\,, \\
M_{B_2^{*0}} &= (5738.6 \pm 1.2_{\text{stat}} \pm 1.2_{\text{syst}} \pm 0.3_{\text{syst}}^{B\,\text{mass}})\ \text{MeV}/c^2\,, \\
M_{B_2^{*+}} &= (5739.0 \pm 3.3_{\text{stat}} \pm 1.6_{\text{syst}} \pm 0.3_{\text{syst}}^{B\,\text{mass}})\ \text{MeV}/c^2\,,
\end{aligned}
$$

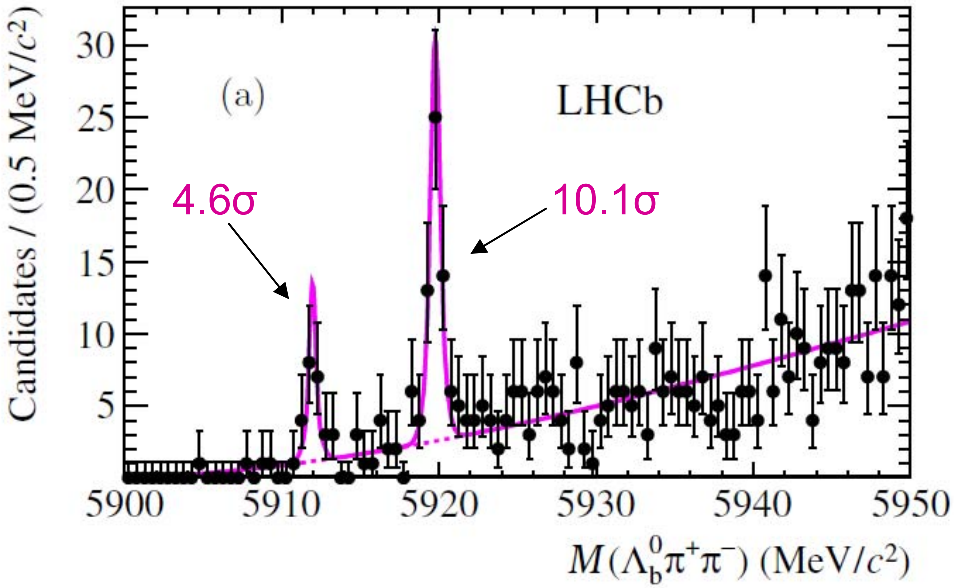
(preliminary)

First measurement of B_1^+ and B_2^{*+} mass, consistent with isospin partner

Λ_b^{0*} first observation

arXiv:1205.3652

- Quark model predicts the existence of 2 orbitally excited Λ_b^0 states with $J^p = 1/2^-$ and $3/2^-$
- 2 narrow states are observed in the $\Lambda_b^0\pi^+\pi^-$ spectra



$$M_{\Lambda_b^{0*}(5912)} = 5911.95 \pm 0.12 \pm 0.03 \pm 0.66 \;\; MeV/c^2$$

$$M_{\Lambda_b^{0*}(5920)} = 5919.76 \pm 0.107 \pm 0.02 \pm 0.66 \;\; MeV/c^2$$

Due to Λ_b^0 mass

And more…

- B_c mass (preliminary): $M(B_c^+) = 6268.0 \pm 4.0 \pm 0.6\,\mathrm{MeV}/c^2$ *LHCb-CONF-2011-027*
- World best measurement of B^+, B_d, B_s and Λ_b masses *LHCb-PAPER-2011-035*

Quantity	LHCb measurement	Best previous measurement	PDG fit
$M(B^+)$	5279.38 ± 0.35	5279.10 ± 0.55 [4]	5279.17 ± 0.29
$M(B^0)$	5279.58 ± 0.32	5279.63 ± 0.62 [4]	5279.50 ± 0.30
$M(B_s^0)$	5366.90 ± 0.36	5366.01 ± 0.80 [4]	5366.3 ± 0.6
$M(\Lambda_b^0)$	5619.19 ± 0.76	5619.7 ± 1.7 [4]	–
$M(B^0) - M(B^+)$	0.20 ± 0.20	0.33 ± 0.06 [15]	0.33 ± 0.06
$M(B_s^0) - M(B^+)$	87.52 ± 0.32	–	–
$M(\Lambda_b^0) - M(B^+)$	339.81 ± 0.72	–	–

[4] CDF, [PRL 96 (2006)] , [15] BaBar, [PRD 78 (2008)]

- Baryons:

$$M_{\Xi_b^-} = 5796.5 \pm 1.2 \pm 1.2\,\mathrm{MeV}/c^2$$

$$M_{\Omega_b^-} = 6050.3 \pm 4.5 \pm 2.2\,\mathrm{MeV}/c^2$$

LHCb-CONF-2011-060

$$M_{\Xi_b^0} = 5802.0 \pm 5.5 \pm 1.7\,\mathrm{MeV}/c^2$$

LHCb-CONF-2011-036

- Exotic onia: X(3872), X(4140), X(4274) *EPJC 72 (2012) 1972, PRD 85 (2012) 091103(R)*

Semileptonic decays

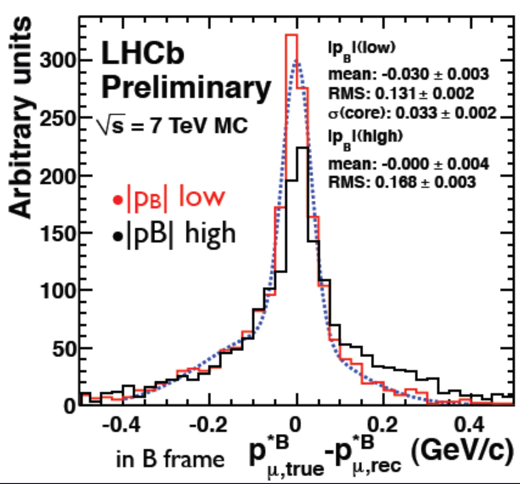
Semileptonic decays

- Semileptonic B^0,B^+,B_s and Λ_b decays have been used to study bb production and hadronization fractions in LHCb

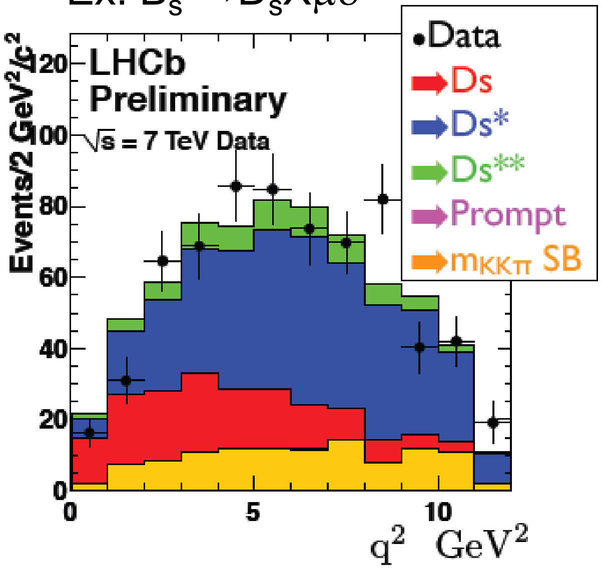
- Ongoing programme to measure:
  - Semileptonic asymmetry A_{sl} using $B_s \rightarrow D_s\mu\upsilon$
  - Exclusive Cabibbo favoured and suppress decays form factors and CKM parameters. Ex: V_{ub} from $B_s \rightarrow K\mu\upsilon$

- Can perform neutrino 'reconstruction' (with 2-fold ambiguity) using B pointing constraint

arXiv:1102.1160



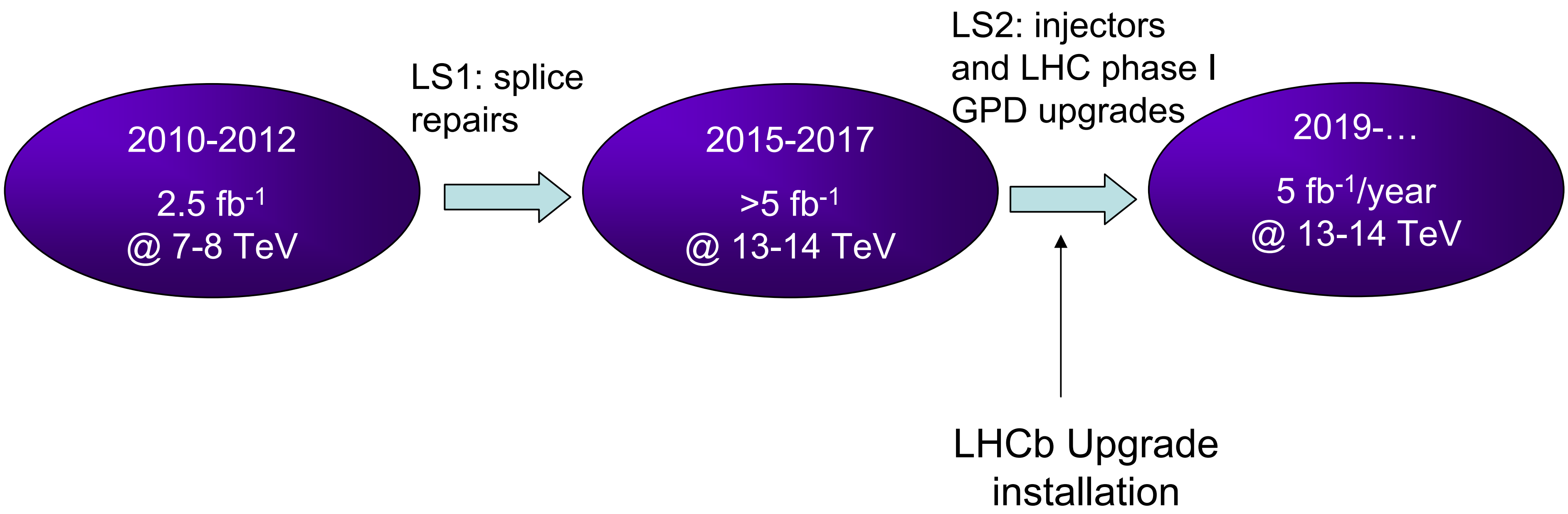
Ex: $B_s \rightarrow D_sX\mu\upsilon$



Future

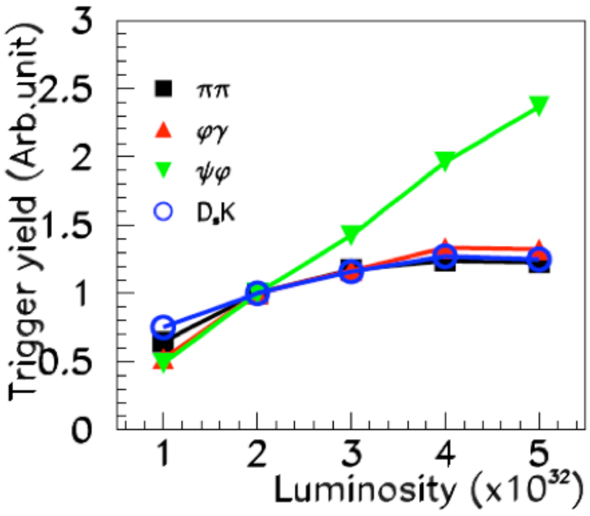
Plans

- New physics has not shown itself clearly at the LHC
- Essential to improve measurements of precisely predicted quantities
- Need more statistics: LHCb upgrade



LHCb upgrade

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



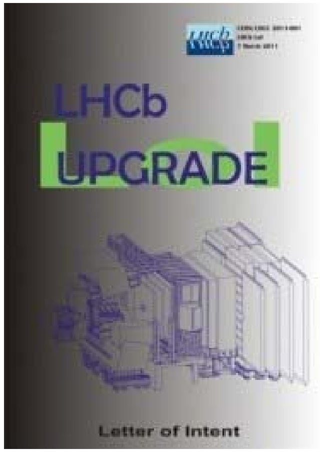
- Propose to remove the hardware trigger and read out LHCb at 40MHz crossing rate

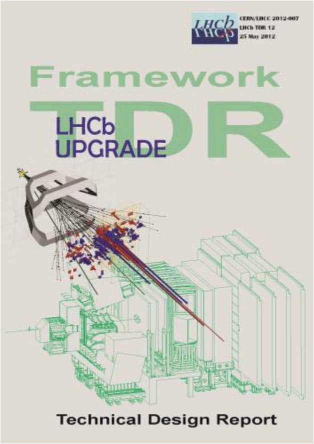
  $\Rightarrow$ increase yields by 10-20 at 1-2 $10^{33}cm^2s^{-1}$

  $\Rightarrow$ aim to collect 50 fb^{-1}

- LOI submitted to LHCC in March 2011, physics case endorsed

- Framework TDR submitted in may 2012





Sensitivity to key chanels

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	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
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.13 %	0.03 %	0.02 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\, A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	8 %	2.5 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	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 ($B \to D^{(*)}K^{(*)}$)	$\sim 20^\circ$ [19]	4°	0.9°	negligible
	γ ($B_s^0 \to D_sK$)	–	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}	–

Conclusion

- Excellent performances of LHC and LHCb in 2011 and 2012
- Large number of new heavy flavour results presented in the last year, more to come at the Summer and Autumn conferences
- Large effect of NP ruled out in flavour physics, but still an important potential for NP discovery
  $\Rightarrow$ What matters is the experimental precision and theoretical cleanliness
- Exciting decade to come for flavour physics, we are just at the beginning!

backup

LFV: search for $\tau \to \mu\mu\mu$

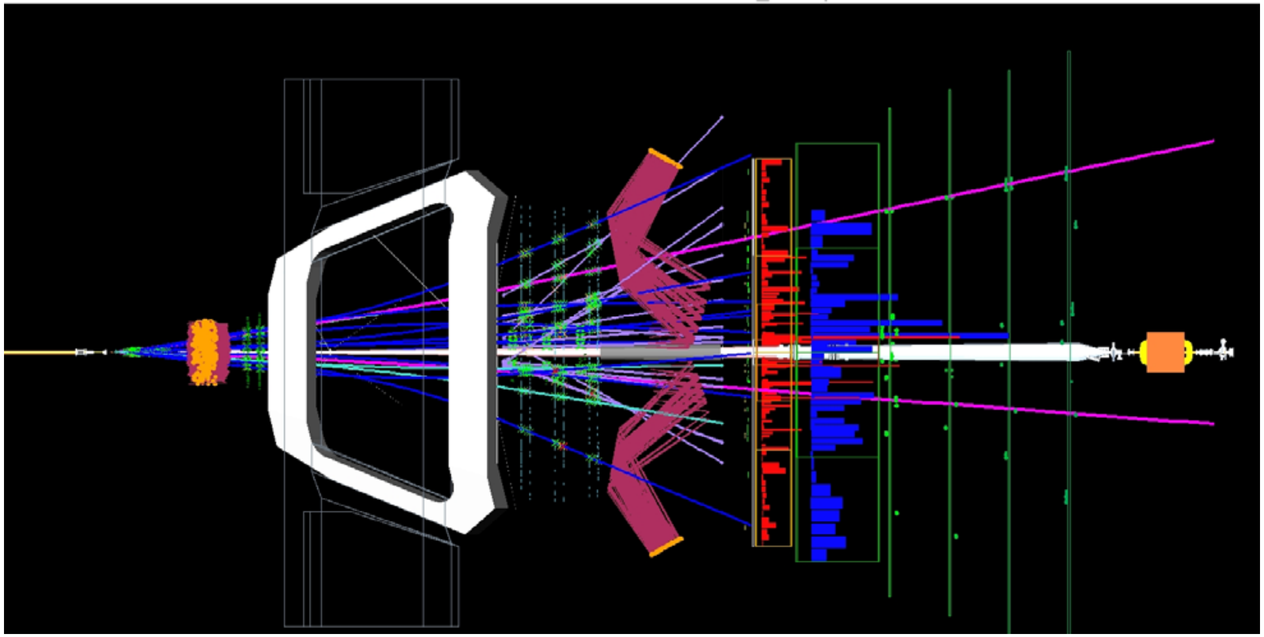
- Lepton flavour violating decay predicted to have BR~10^{-54} in the SM
- Beyond SM predictions
  - Variant of SUSY: BR~10^{-10}
  - Non universal Z': BR~10^{-8}

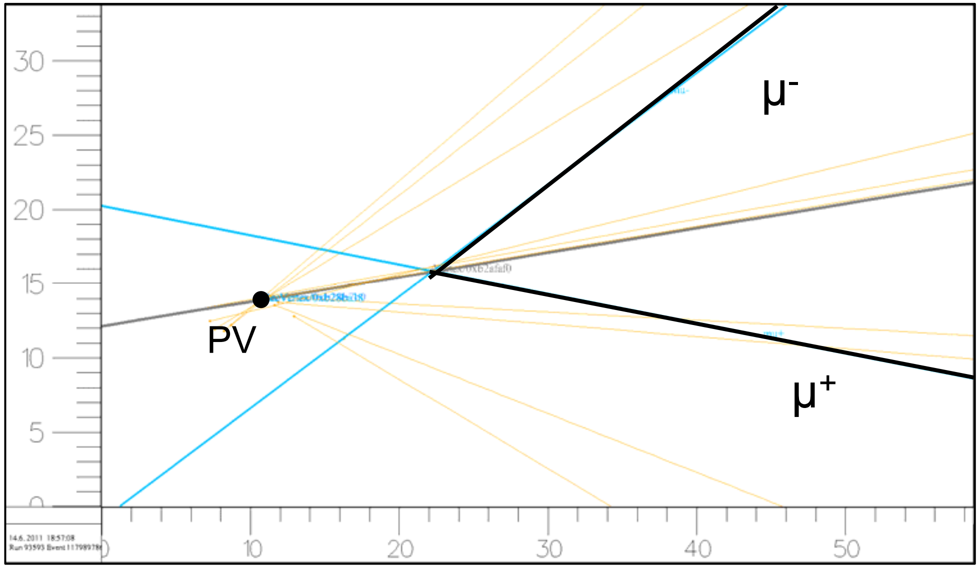
LHCB-CONF-2012-015

- LHCb limit from 1fb^{-1}
- BR< $6.1(7.8)\times10^{-8}$ at 90(95)%CL
  - Babar: BR< 3.3×10^{-8} at 90%CL
  - Belle: BR< 2.1×10^{-8} at 90%CL

- Proof of principle, measurement can be made at hadron collider
- With 1fb^{-1}, LHCb is close to B factory sensitivity, excellent prospects for next year and LHCb Upgrade

A nice signal candidate!

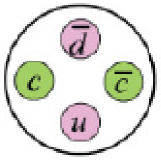




Mμμ = 5.357 GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for *p*T > 0.5 GeV

Exotic onia

- LHCb results on inclusive X(3872) using 2010 data:
  - Measured mass consistent with, but not competitive yet, with the measurements by CDF and Belle.
  - Good efficiency, mass resolution and S/B. Potential to do the best mass measurement with the 2011 data.
  - The measured cross-section somewhat lower than predicted by Artoisenet-Braaten from the Tevatron data.
  - Will determine long-livetime / prompt ratio with the 2011 data
- Worlds best signal statistics for $B^+ \to X(3872)K^+$, $X(3872) \to J/\psi\pi^+\pi^-$ in the 2011 data:
  - J^{PC} determination and BR measurement in progress
- LHCb search for X(4140) in $B^+ \to X(4140)K^+$, $X(4140) \to J/\psi\phi$:
  - The most sensitive measurement to date
  - Don't find evidence for this state in 2.4σ disagreement with the CDF
- Other work in progress:
  - We have the worlds best statistics for $B^0 \to \psi(2S)\pi^+K^-$. Probe for $Z(4430)^+ \to \psi(2S)\pi^+$ (claimed by Belle, but not confirmed by BaBar).



$Z(4430)^+$
?

fs/fd

- R. Fleischer, N. Serra, and N. Tuning, Phys. Rev. D82, 034038 (2010), arXiv:1004.3982:

$$\frac{f_s}{f_d} = 0.0743 \times \frac{\tau_{B^0}}{\tau_{B_s^0}} \times \left[\frac{\epsilon_{DK}}{\epsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{DK}}\right] \times \frac{1}{\mathcal{N}_a \mathcal{N}_F}$$

$$\mathcal{N}_a = \left[\frac{a_1^{(s)}(D_s^+\pi^-)}{a_1^{(d)}(D^+K^-)}\right]^2,$$

$$\mathcal{N}_F = \left[\frac{f_0^{(s)}(M_\pi^2)}{f_0^{(d)}(M_K^2)}\right]^2.$$

a: account for the deviation from the naive factorization

f_0: form factors for the corresponding semileptonic decays

• LHCb measurement with hadronic modes, using N_F=1.24±0.08 from QCD sum rules:

DK: $\left(\frac{f_s}{f_d}\right)_{h1} = 0.250 \pm 0.024(\text{stat}) \pm 0.017(\text{syst}) \pm 0.017(\text{theor}),$

N_F is the largest systematics

Dπ: $\left(\frac{f_s}{f_d}\right)_{h2} = 0.256 \pm 0.014(\text{stat}) \pm 0.019(\text{syst}) \pm 0.026(\text{theor}).$

Using semileptonic $\left(\frac{f_s}{f_d}\right)_{sl} = 0.268 \pm 0.008(\text{stat})^{+0.022}_{-0.020}(\text{syst}),$

• New lattice computation by Fermilab and MILC, http://arxiv.org/abs/1202.6346

N_F=1.094±0.088 ±0.030

But still the dominant systematic for the hadronic determination of fs/fd