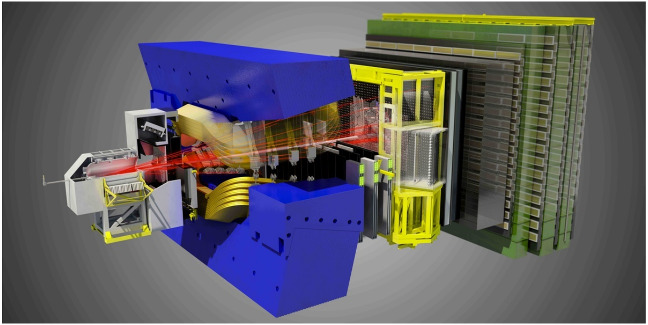
Results from LHCb

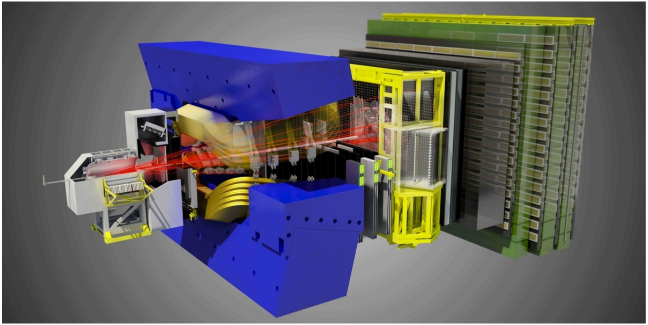


N. Serra

Particle physics in the LHC era 7-9th January 2013

University of Zurich[UZH]

Arbitrary choice of recent resuts from LHCb



N. Serra

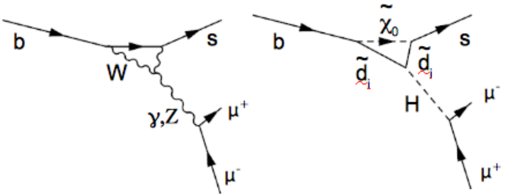
Particle physics in the LHC era 7-9th January 2013

Overview

1. Introduction
2. CP violation in beauty
   - γ measurement
3. CP violation in charm
   - D oscillations
4. Rare decays
   - $B_s \to \mu^+\mu^-$
   - $B_d \to K^*\mu^+\mu^-$
   - Isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$
5. Summary and prospects

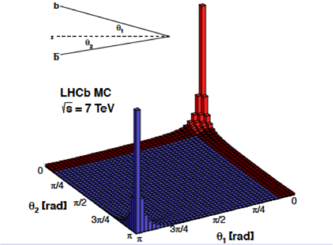
N.B.: No spetroscopy or xsection measurements

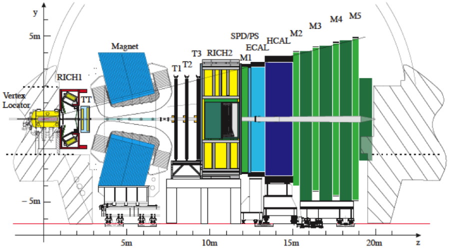
Indirect search for NP with b/c-hadrons



- Allow to test high energies
- Indirect search has often paved the way to important discoveries:
  - RD and mixing in kaons led to the prediction of the charm quark
  - CPV in kaons led to the prediction of a 3rd generation of quarks
- Correlation of different channels allow to “understand” the structure of NP

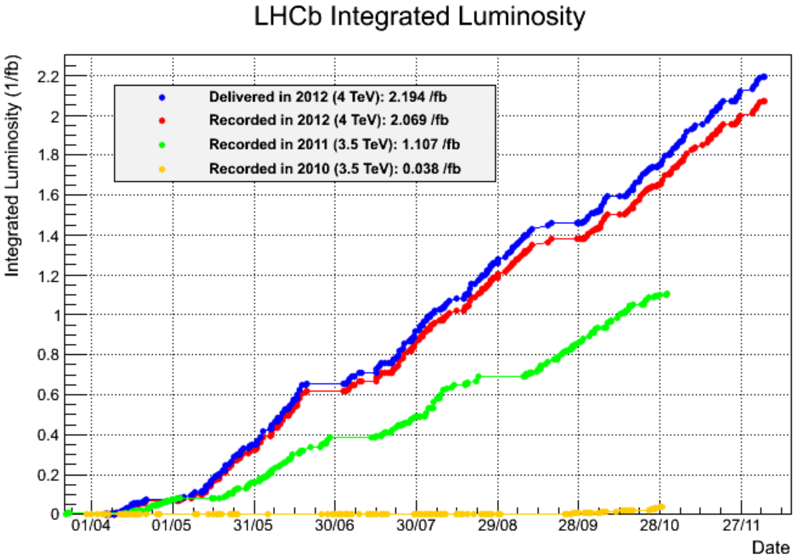
The LHCb detector





- Pseudorapidity range $1.9 < \eta < 4.9$
- Good vertex and momentum resolution:
  - $\Delta p/p = (0.4 - 0.6)\%$ in the range $5 - 100$GeV/c
  - $\sigma_{PV}(x, y) \sim 10\mu m$, $\sigma_{PV}(z) \sim 60\mu$m
- Good particle identification performances:
  - $\epsilon(\mu) \sim 97\%$, mis-ID$(\pi \to \mu) 1 - 3\%$
  - $\epsilon(K) \sim 95\%$, mis-ID$(\pi \to K) \sim 5\%$

Recorded data

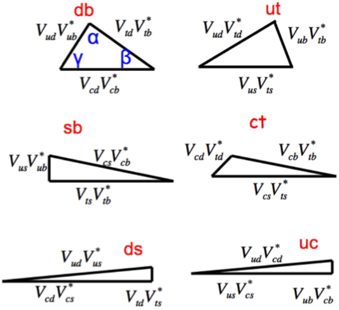


CP violation in beauty

γ measurement

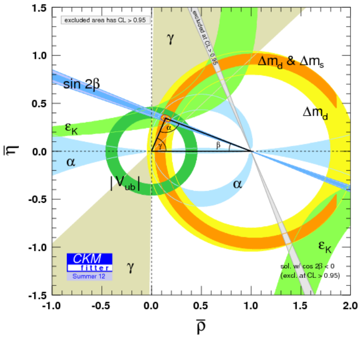
$$V^{CKM} = \text{CKM Matrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

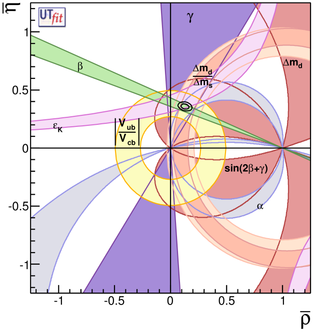
$$\text{where} \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V^{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



- $\gamma = arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$ is the least known of the angles of the UT
- γ can be extracted from Tree level (this talk) or penguin (JHEP 1210 (2012) 037, LHCb-CONF-2012-007) decays
- Difference between tree level and penguin would point to NP

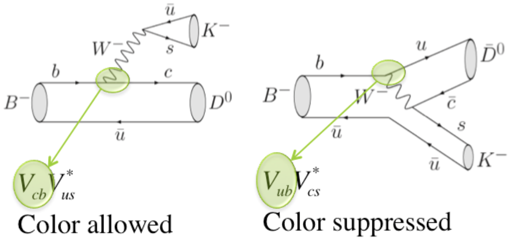
Present knowledge of γ





- Does $\alpha + \beta + \gamma = 180^\circ$?
- Over constraining the UT is a powerful test of the CKM paradigm
- CKM Fitter: $\gamma = (66 \pm 12)^\circ$, UTFit: $\gamma = (76 \pm 10)^\circ$

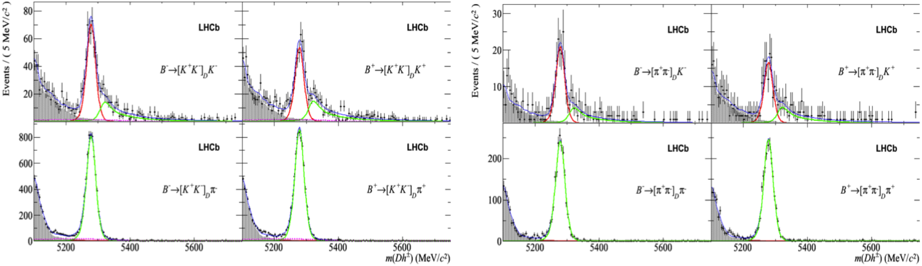
Input of LHCb γ combination



GLW: $D^0 \to K^+K^-, \pi^+\pi^-$
ADS: $D^0 \to \pi^\pm K^\mp$
GGSZ: $D^0 \to K^0_S h^+h^-$

- $B^\pm \to [h^+h^-]_D h^\pm$ with $(h = \pi, K)$ (PLB 712(2012), 203)
- $B^\pm \to [K\pi]_D h$ with $(h = \pi, K)$ (Phys. Lett. B 712 (2012) 203-212)
- $B^\pm \to [K\pi\pi\pi]_D h$ with $(h = \pi, K)$ (LHCb-CONF-2012-030)
- $B^\pm \to DK^\pm$ with $D \to K^0_{\rm S} h^+h^-$ $(h = \pi, K)$ (Phys. Lett. B 718 (2012) 43-55)

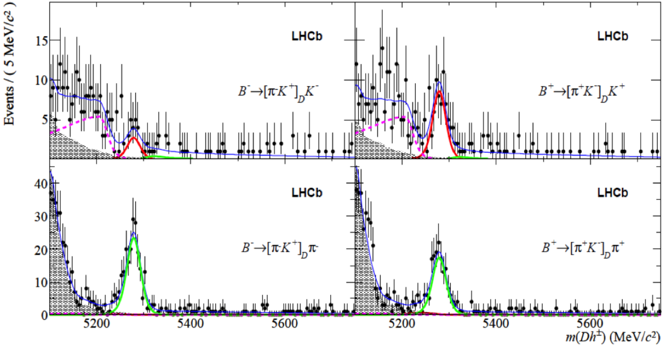
GLW with $B \to [h^+h^-]_D K$



- $R_{CP+} = 2\frac{\Gamma(B^-\to D_{CP+}K^-)+\Gamma(B^+\to D_{CP+}K^+)}{\Gamma(B^-\to D^0K^-)+\Gamma(B^+\to \overline{D}^0K^+)} = 1 + r_B^2 + 2r_B\cos\delta_B\cos\gamma$
- $A_{CP+} = \frac{\Gamma(B^-\to D_{CP+}K^-)-\Gamma(B^+\to D_{CP+}K^+)}{\Gamma(B^-\to D_{CP+}K^-)+\Gamma(B^+\to D_{CP+}K^+)} = \frac{2r_B\sin\delta_B\sin\gamma}{1+r_B^2\cos\delta_B\cos\gamma}$
- Evidence of non-zero A_{CP+} in $B^\pm \to DK^\pm$ at 4.5σ
- $A_{CP+}(KK) = (-14.8 \pm 3.7 \pm 1.0)\%$ $A_{CP+}(\pi\pi) = (-13.5 \pm 6.6 \pm 1.0)\%$

ADS with $B^+ \to [K\pi]_D K^+$

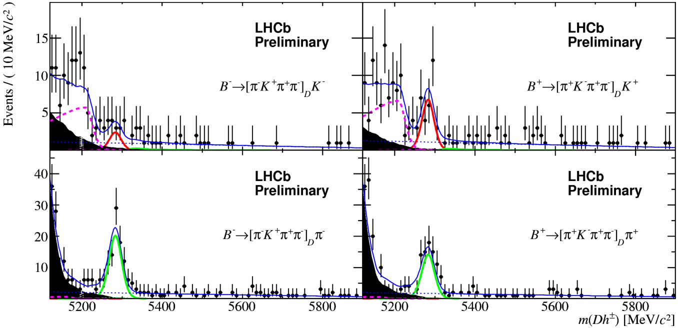
First observation of rare ADS $B^+ \to D(K^-\pi^+)K^+$ at $\sim 10\sigma$



- $R_h^{\pm} = \frac{\Gamma(B^{\pm} \to [\pi^{\pm} K^{\mp}]_D h^{\pm})}{\Gamma(B^{\pm} \to [\pi^{\mp} K^{\pm}]_D h^{\pm})}$
- $R_K^{ADS} = \frac{(R_K^- + R_K^+)}{2} = 0.0152 \pm 0.0020, \; A_K^{ADS} = \frac{(R_K^- - R_K^+)}{(R_K^- + R_K^+)} = -0.52 \pm 0.15$
- $R_\pi^{ADS} = \frac{(R_\pi^- + R_\pi^+)}{2} = 0.00410 \pm 0.00025, \; A_\pi^{ADS} = \frac{(R_\pi^- - R_\pi^+)}{(R_\pi^- + R_\pi^+)} = 0.143 \pm 0.063$

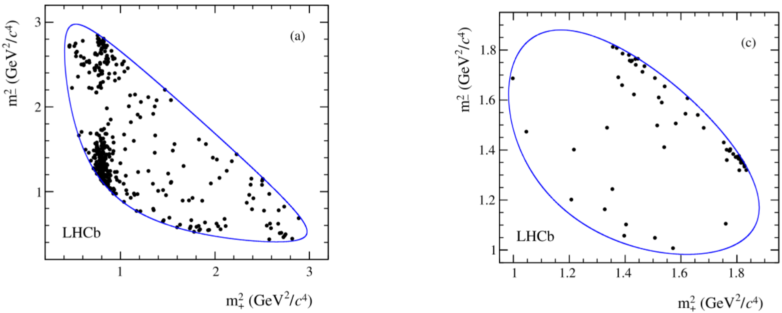
ADS with $B^{\pm} \to [K\pi\pi\pi]_D h$

We have the first observation of the modes $B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{+}\pi^{-}]_D\pi^{\pm}$ ($\sim 10\sigma$) and $B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{+}\pi^{-}]_D K^{\pm}$ ($\sim 5\sigma$).



- $R_h^{\pm} = \frac{\Gamma(B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{+}\pi^{-}]_D h^{\pm})}{\Gamma(B^{\pm} \to [\pi^{\mp}K^{\pm}\pi^{+}\pi^{-}]_D h^{\pm})}$
- $R_K^{ADS} = \frac{(R_K^{-} + R_K^{+})}{2} = 0.0124 \pm 0.0027,\ A_K^{ADS} = \frac{(R_K^{-} - R_K^{+})}{(R_K^{-} + R_K^{+})} = -0.417 \pm 0.222$
- $R_\pi^{ADS} = \frac{(R_\pi^{-} + R_\pi^{+})}{2} = 0.00369 \pm 0.00036,\ A_\pi^{ADS} = \frac{(R_\pi^{-} - R_\pi^{+})}{(R_\pi^{-} + R_\pi^{+})} = 0.130 \pm 0.097$

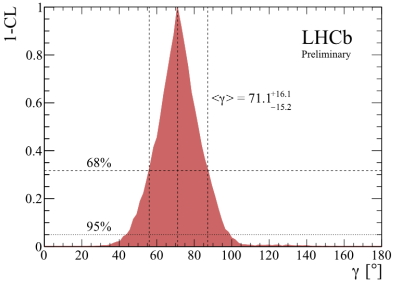
GGSZ method



- Comparing the distribution of events in the $D^0 \to K^0_S h^+ h^-$ Dalitz plot for $B^+ \to DK^+$ and $B^- \to DK^-$ decays
- Necessary to know how the strong phase of the D decay varies over the Dalitz plot
- Use CLEO measurements for the D strong-phase
- Results: $\gamma = (44^{+43}_{-38})^\circ$, $\delta_B = (137^{+35}_{-46})^\circ$, $r_B = 0.07 \pm 0.04$

LHCb γ combination

- Combination of $B^{\pm} \to DK^{\pm}$ analyses
- Parameters of Interest: $\vec{\alpha} = (\gamma, r_B\ , \delta_B, \ldots)$
- The likelihood $\mathcal{L}(\vec{\alpha}) = \sum_i f_i(\vec{A}_{i\ obs}|\vec{A}_i(\vec{\alpha}_i))$ is used
- where $f_i \propto exp\left(-(\vec{A}_i(\vec{\alpha}_i) - \vec{A}_{i\ obs})V_i^{-1}(\vec{A}_i(\vec{\alpha}_i) - \vec{A}_{i\ obs})\right)$



γ	$71.1°$
68%CL	[55.4, 87.7]
95%CL	[41.4, 101.3]

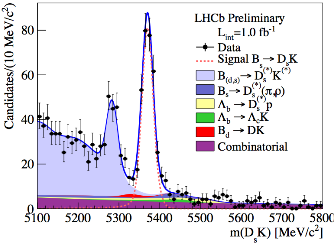
$B^{-} \to DK^{-}$ from LHCb

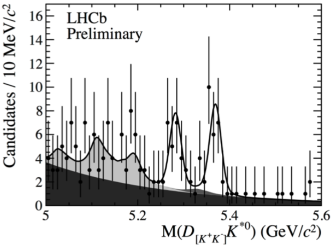
D-system from CLEO

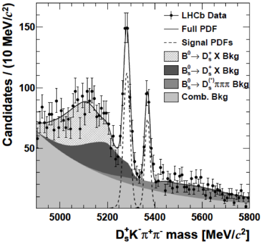
LHCb-CONF-2012-032

Other modes to be added

There are several other modes that can be added to extract γ, eg.:



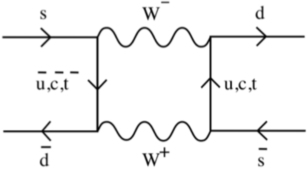


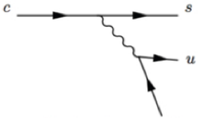


- Time dependent analysis of $B_s \to D_s K$
- Time integrated analysis of $B \to DK^{*0}$
- LHCb made the world's first observation of $B_s \to D_s K\pi\pi$ (time dependent analysis similar to $B_s \to D_s K$)
- ...

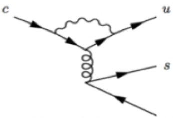
CP violation in charm

Introduction





(a) *Tree diagram.*



(b) *Penguin diagram.*

In the SM:

- Indirect CPV is process independent and quite small $O(10^{-3})$
- Direct CPV in the decay is process dependent:
  - Negligibly small for Cabibbo favoured
  - Expected at the level of 10^{-3} for Cabibbo suppressed

LHCb has an extensive program of charm physics:

- First evidence of CPV in charm PRL 108, 111602 (2012)
- Search for CPV in mixing JHEP 04 (2012) 129
- Search for CPV in decays: CONF-2012-019, PRD 84 2011 112008, ...

D Oscillations

- Neutral mesons oscillates between matter and anti-matter

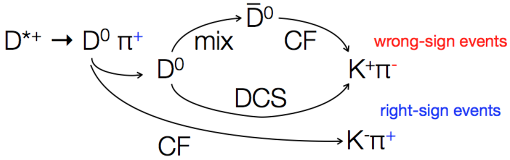
$$i\frac{d}{dt}\begin{bmatrix}|D^0\rangle\\ |\overline{D}^0\rangle\end{bmatrix} = \left(\begin{bmatrix}M_{11} & M_{12}\\ M_{12}^* & M_{22}\end{bmatrix} - \frac{i}{2}\begin{bmatrix}\Gamma_{11} & \Gamma_{12}\\ \Gamma_{12}^* & \Gamma_{22}\end{bmatrix}\right)\begin{bmatrix}|D^0\rangle\\ |\overline{D}^0\rangle\end{bmatrix}$$

$$|D_{L,H}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle \text{ where } \frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$

The charm mixing parameters are $x = \frac{\Delta m}{\Gamma}$ and $y = \frac{\Delta\Gamma}{2\Gamma}$

- Oscillations of neutral kaons and B-mesons are well established
- Charm mixing predicted to be small in the SM (x,$y \lesssim O(10^{-2})$)
- Sensitive to NP contributions
- Strong evidence of charm mixing only by combining the different experiments

Strategy



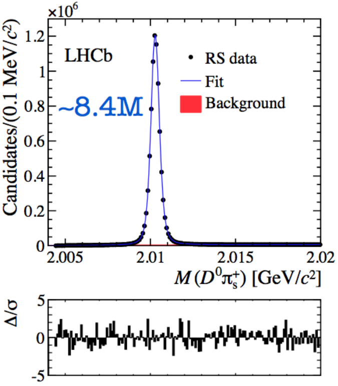
- Prompt $D^{*0} \to D^0\pi^+$ are used
- The wrong sign decays occurs either due to $D^0 - \overline{D}^0$ oscillations or via doubly-Cabibbo-suppressed decays

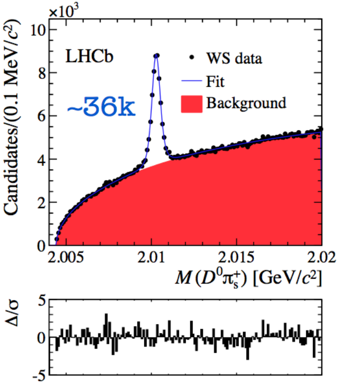
The time-dependent ratio between right-sign and wrong-sign is:

$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} \approx R_D + \sqrt{R_D}y't + \frac{x'^{\,2} + y'^{\,2}}{4}t^2$$

where $x' = x\cos\delta + y\sin\delta$ and $y' = y\cos\delta - x\sin\delta$

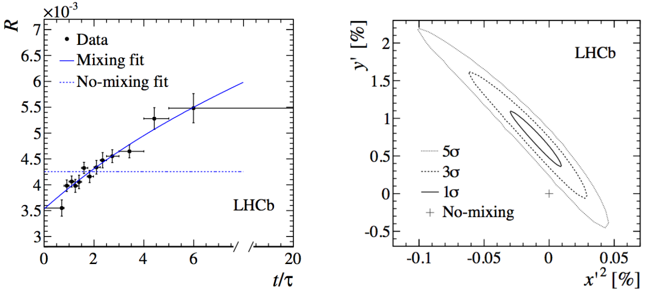
Signal Selection





- Excellent resolution and PID important for this analysis
- Data are divided in into 13 decay-time bins
- $\frac{t}{\tau} = m_{D^0}\frac{L}{p\tau}$, where L is the distance $PV - SV$

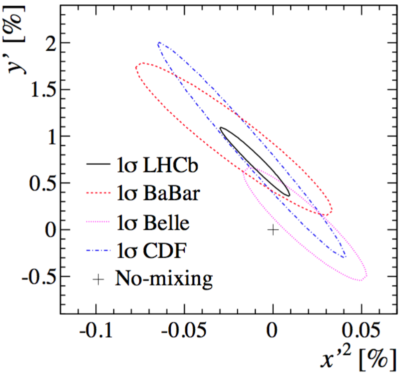
Results



Fit type	Parameter	Result (10^{-3})
Mixing $\chi^2/nDoF = (9.5/10)$	R_D y' x'^2	3.52 ± 0.15 7.2 ± 2.4 -0.09 ± 0.13
No Mixing $\chi^2/nDoF = (98.1/12)$	R_D	4.25 ± 0.04

No-mixing hypothesis excluded at 9.1 standard deviations
First single experiment observation above 5 sigma!

Comparison with other experiments



BaBar: Phys. Rev. Lett. 98 (2007) 211802

Belle: Phys. Rev. Lett. 96 (2006) 151801

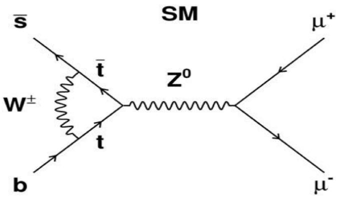
CDF: Phys. Rev. Lett. 100 (2008) 121802

Experiment	R_D (10^{-3})	y' (10^{-3})	x'^2 (10^{-4})
LHCb	3.52 ± 0.15	7.2 ± 2.4	-0.9 ± 1.3
BaBar	3.03 ± 0.19	9.7 ± 5.4	-2.2 ± 3.7
Belle	3.64 ± 0.17	$0.6^{+4.0}_{-3.9}$	$1.8^{+2.1}_{-2.3}$
CDF	3.04 ± 0.55	8.5 ± 7.6	-1.2 ± 3.5

- Measured parameters nicely agree with other experiments
- Results dominated by statistical uncertainties

Rare decays

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



Mode	SM prediction
$B_s \to \mu^+\mu^-$	$(3.54 \pm 0.30) \times 10^{-9}$
$B^0 \to \mu^+\mu^-$	$(0.11 \pm 0.01) \times 10^{-9}$

A. Buras et al., arXiv:1208.0934

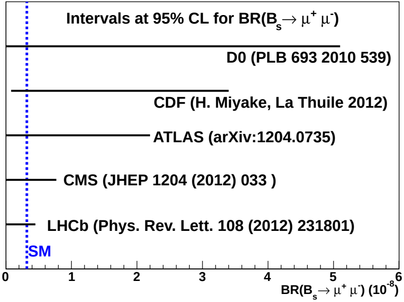
DeBruyn et al., arXiv:1204.1737

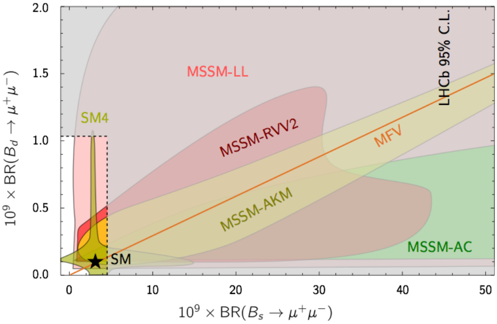
C. Davies, arXiv:1203.3862 (and ref. therein)

$$\mathcal{B}(B_s \to \mu^+\mu^-) \propto |\mathcal{C}_S - \mathcal{C}'_S|^2 \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) + \left|(\mathcal{C}_P - \mathcal{C}'_P) + \frac{2m_\mu}{m_{B_s}}(\mathcal{C}_{10} - \mathcal{C}'_{10})\right|^2$$

- Suppressed being a FCNC and also helicity suppressed
- Sensitive to "scalar" and "pseudo-scalar" contributions beyond the SM, e.g. MSSM with high $\tan\beta$

Present situation and new analysis





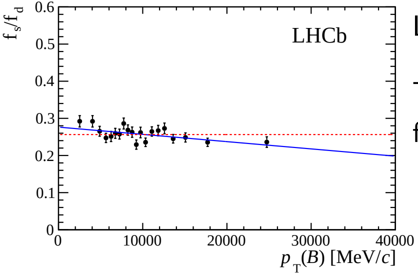
D. Straub arXiv:1205.6094

- LHC combination: $\mathcal{B}(B_s \to \mu^+\mu^-) < 4.2 \cdot 10^{-9}$ at 95% CL
- For the new analysis two datasets are combined
  - 1.0 fb^{-1} at $\sqrt{s} = 7$TeV (2011)
  - 1.1 fb^{-1} at $\sqrt{s} = 8$TeV (2012)
- The present analysis supersedes the previous 2011 publication

Analysis strategy

- The selection consist of a soft cut-based “pre-selection” to reduce the size of data followed by a BDT

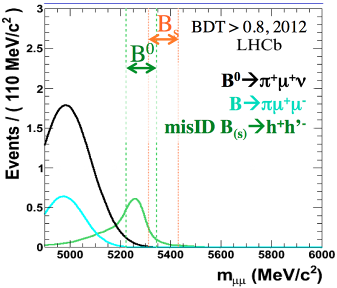
- The normalisation uses the decays $B^\pm \to J/\psi K^\pm$ and $B \to h^+h'^-$
- $\frac{f_s}{f_d} = 0.256 \pm 0.020$ has been measured combining:
  - Ratio of $B_s \to D_s\mu X$ and $B \to D^+\mu X$
  - Ratio of $B_s \to D_s\pi$ and $B^0 \to DK$

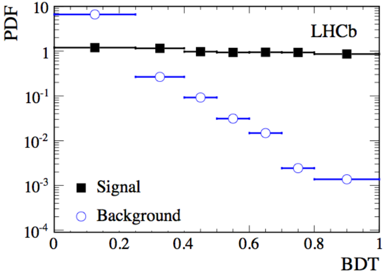


LHCb-Paper-2012-037, to appear shortly

The dependence of P_T is negligible for $B_s \to \mu^+\mu^-$ normalisation

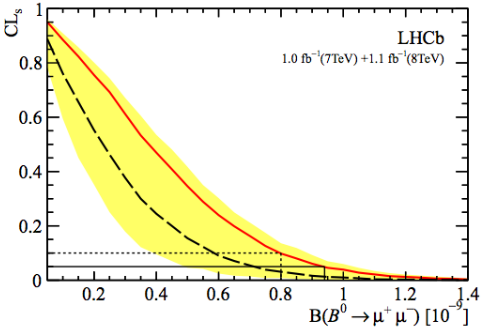
Analysis strategy II





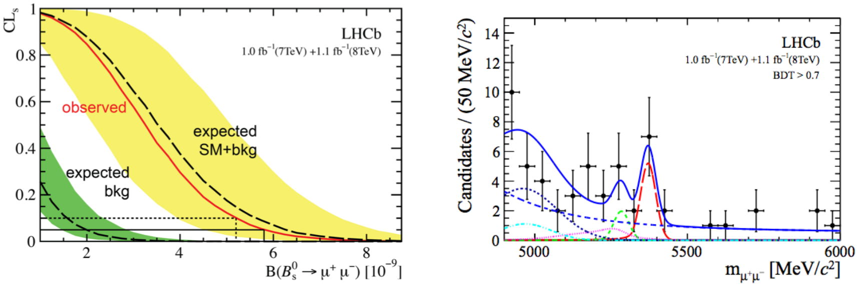
- The fit is performed in 8 (for 2011) + 7 (for 2012) BDT bins
- Combinatorial background modelled with an exponential
- Better treatment of exclusive backgrounds wrt previous analysis
    - $B^0 \to \pi^+\mu^-\nu$, $B_d \to \pi^0\mu^+\mu^-$
    - $B^+ \to \pi^+\mu^-\mu^+$
    - $B_{(s)} \to h^+h^{-\prime}$ with MisID

$B^0 \to \mu^+\mu^-$ Result



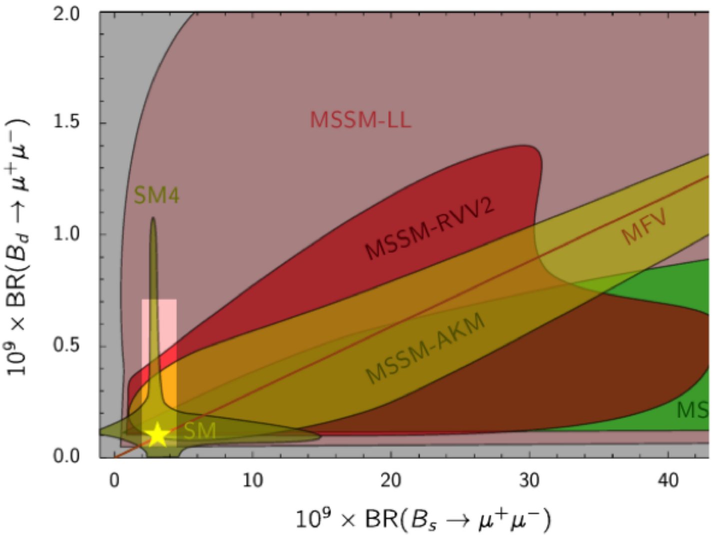
- Combining 2011 and 2012 dataset
- Background only p-value is 11%
- Upper limit $\mathcal{B}(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}$ at 95% CL
- World's best single experiment UL

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



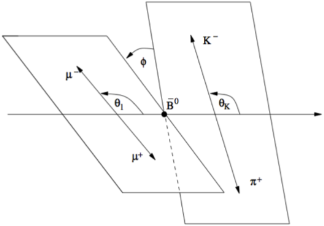
- Combining 2011+2012 data
- Bkg only hypothesis p-value is 5×10^{-4} corresponding to 3.5 σ
- $\mathcal{B}(B_s \to \mu^+\mu^-) = 3.2^{+1.4}_{-1.2}(stat)^{+0.5}_{-0.3}(syst) \times 10^{-9}$
- First evidence of the decay $B_s \to \mu^+\mu^-$
- Consistent with the SM!
- Submitted to PRL arXiv:1211.2674

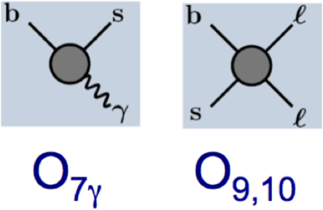
Implications of $B_s \to \mu^+\mu^-$ result



Adapted from D. Straub arXiv:1205.6094

$B_d \to K^* \mu^+ \mu^-$





- Angular observables in the decay $B_d \to K^* \mu^+ \mu^-$ are sensitive probe of NP
- Several observables where the hadronic uncertainty are under control can be built
- These observables are sensitive to the effective operators $O_{7,9,10}$ and their right-handed counterparts

Angular observables

- The total angular distribution of the decay $B_d \to K^* \mu^+ \mu^-$ is

$$\frac{1}{\Gamma}\frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell \, d\cos\theta_K \, d\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + \frac{3}{4}A_{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + A_{Im}\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

- $F_L = \frac{A_0^2}{A_\parallel^2 + A_\perp^2 + A_0^2}$, longitudinal polarization of the K^*
- $S_3 = \frac{A_\parallel^2 - A_\perp^2}{A_\parallel^2 + A_\perp^2 + A_0^2}$, related to the transverse asymmetry
- $A_{FB} = \frac{3}{4}\frac{\Re(A_\parallel^* A_\perp)}{A_\parallel^2 + A_\perp^2 + A_0^2}$, the forward-backward asymmetry
- $A_{Im} = \frac{\Im(A_0^* A_\parallel)}{A_\parallel^2 + A_\perp^2 + A_0^2}$

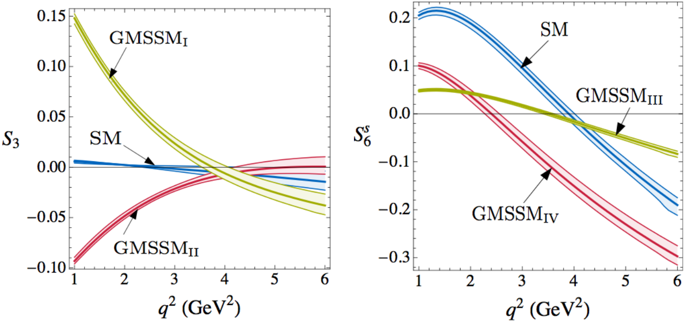
Angular Observables

- We don't have yet enough statistics to measure the full angular distribution
- By applying the transformation $\phi \to \phi + \pi$ for $\phi < 0$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + \frac{3}{4}A_{FB}\sin^2\theta_K\cos\theta_\ell + A_{Im}\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

- This allow to extract the physics parameters F_L, S_3, A_{FB}, A_{Im} with a three-dimentional angular fit
- This procedure allows to improve the sensitivity wrt angular projection fits used by other experiments

$B_d \to K^*\mu^+\mu^-$ in BSM scenarios



Plots from

W. Altmannshofer et al.

See also:

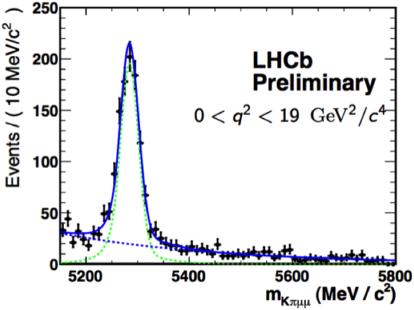
J. Mattias et al.

C. Bobeth et al.

and references therein

- Many observables sensitive to different NP scenarios
- S_3 sensitive to right-handed currents, i.e. $C_7' \neq 0$
- Early measurements by B-factories showed tention at low q^2 for $A_{FB} = \frac{4}{3} S_6$
- Important to measure the zcp (where FF uncertainties cancel out)

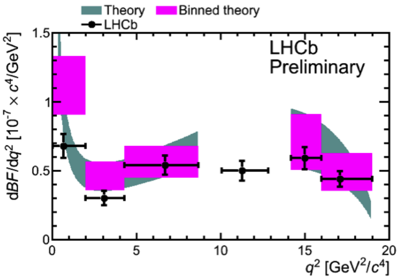
Analysis strategy

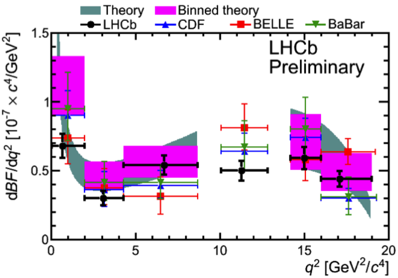


World's largest reconstructed sample of this decay

- Events are selected with a BDT
- Acceptance effects are corrected in a model independent way on an event-by-event basis
- The physics parameters are extracted with a fit to the invariant mass and the three angles in six q^2 bin

Results: Differential branching ratio





BaBar: S.Akar Lake Louise (2012)

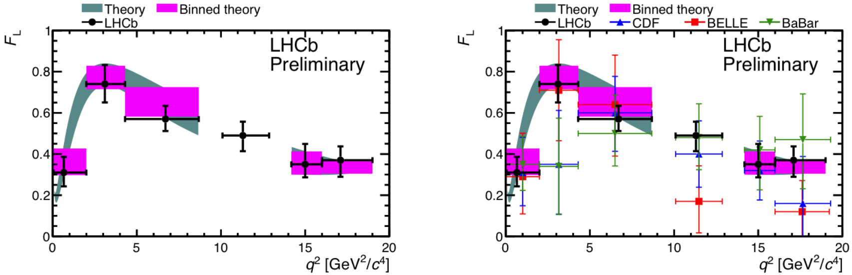
Belle: Phys.Rev.Lett. 103, 171801 (2009)

CDF :Phys. Rev. Lett. 108, 081807 (2012)

Theory prediction from C. Bobeth, G. Hiller, D. van Dyk, JHEP 07, 067 (2011)

- Most precise measurement to date
- Consistent with SM prediction

Results: F_L



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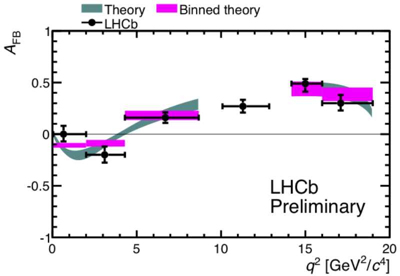
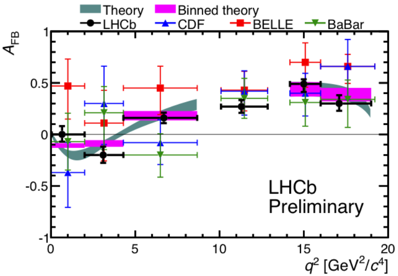
Theory prediction from C. Bobeth, G. Hiller, D. van Dyk, JHEP 07, 067 (2011)

- Most precise measurement to date
- Consistent with SM prediction

Results: A_{FB}





BaBar: S.Akar Lake Louise (2012)

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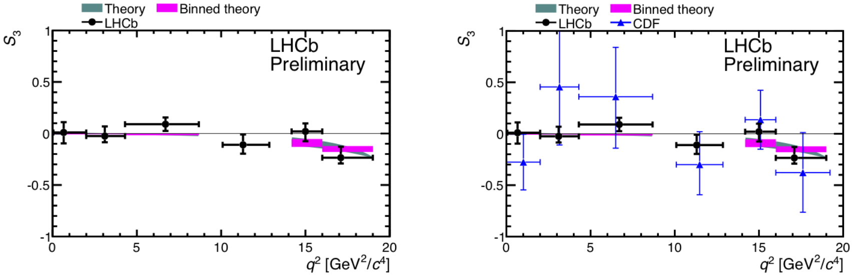
CDF :Phys. Rev. Lett. 108, 081807 (2012)

Theory prediction from C. Bobeth, G. Hiller, D. van Dyk, JHEP 07, 067 (2011)

- Most precise measurement to date
- Consistent with SM prediction

Results: S_3

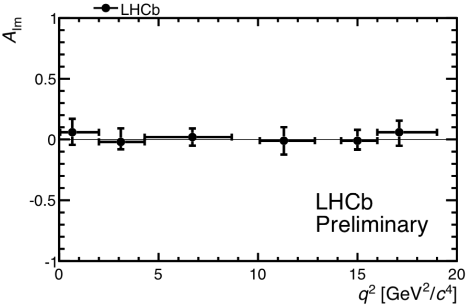


CDF :Phys. Rev. Lett. 108, 081807 (2012)

Theory prediction from C. Bobeth, G. Hiller, D. van Dyk, JHEP 07, 067 (2011)

- Most precise measurement to date
- Consistent with SM prediction

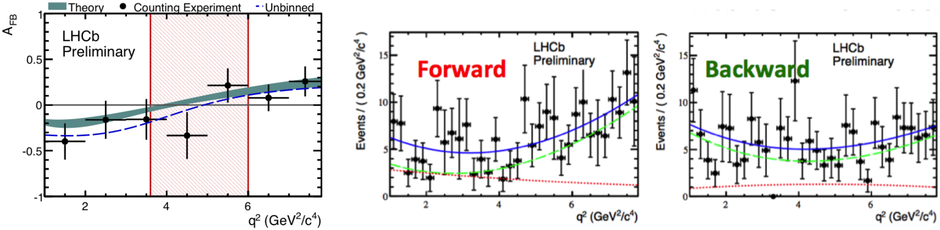
Results: A_{Im}



- Most precise measurement to date
- Consistent with SM prediction

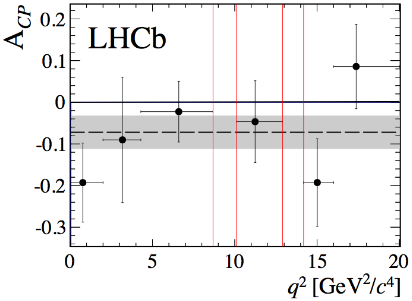
Zero-crossing point

- The ZCP is measured by doing an unbinned likelihood fit of the q^2 distribution and the invariant mass



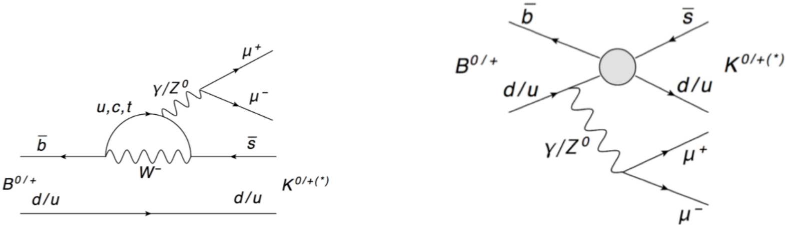
- LHCb made the world's first measurement of the ZCP $q_0^2 = 4.9^{+1.1}_{-1.3}\mathrm{GeV}^2/\mathrm{c}^4$
- This measurement is consistent with the SM
- Strongly disfavours models with flipped C_7 sign wrt to the SM

A_{CP} in the decay $B_d \to K^* \mu^+ \mu^-$



- Direct CP asymmetry in $B_d \to K^* \mu^+ \mu^-$ (arXiv:1210.4492)
- $\mathcal{A}_{CP}(B_d \to K^* \mu^+ \mu^-) = (-7.2 \pm 4.0(stat) \pm 0.5(syst))\%$
- World's best measurement of this observable
- Good agreement with Belle and BaBar measurements

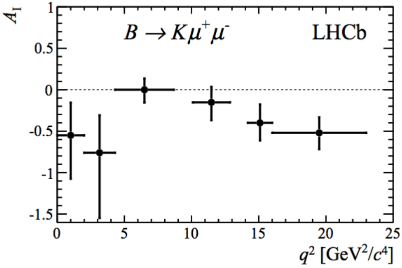
Isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$

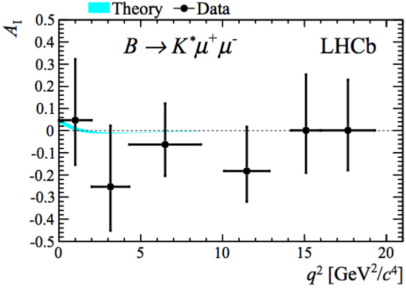


- The isospin asymmetry is defined as
$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}$$
- It is expected to be negligibly small in the SM
- beyond the SM contribution can enhance it (wilson coefficients O_{1-6} and O_8)

Results

JHEP 07 (2012) 133



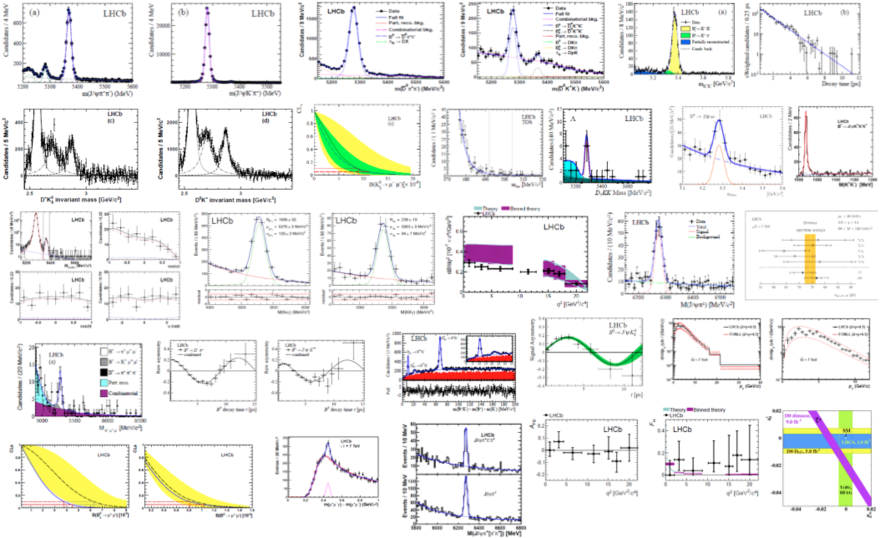


- Both measurements are in agreement with previous experiments: CDF, BaBar, Belle
- The isospin asymmetry for the $B \to K^*\mu^+\mu^-$ is in agreement with expectation
- The isospin asymmetry for $B \to K\mu^+\mu^-$ (when combining all q^2 bins) is about 4σ from zero (näive SM expectation)

Summary and prospects

- γ measurement:
  - We have the first γ combination from LHCb
  - Results for γ competitive with B-factories
  - More data to analyse and more modes to be added!
- Charm physics
  - Performing well in charm physics
  - First single observation of $D^0 - \overline{D}^0$ mixing ($\sim 9\sigma$)
  - I also remind you the evidence of CP violation in charm
  - More CPV measurements in the charm will come soon
- Rare decays
  - First evidence of the decay $B_s \to \mu^+\mu^-$
  - Measured several observables in $B_d \to K^*\mu^+\mu^-$
  - Interesting and puzzeling results for A_I in $B \to K\mu^+\mu^-$
- No big tention wrt SM prediction is observed
- Most of the result statistically limited
- Several other observables yet to measure

Other results...



... many other interesting results could not fit in this talk

Thank you for the attention

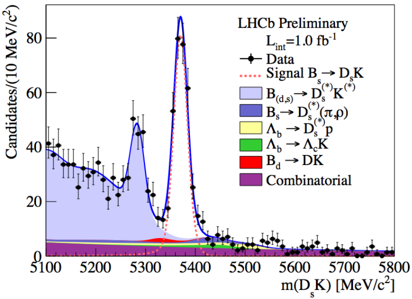
Backup Slides

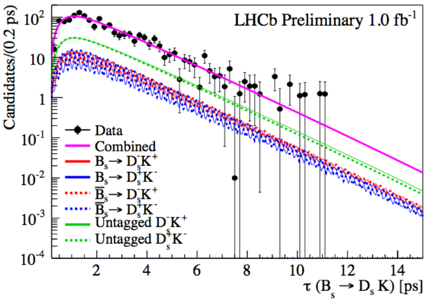
Upgrade Physics

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B^0_s mixing	$2\beta_s$ ($B^0_s \to J/\psi\,\phi$)	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B^0_s \to J/\psi\, f_0(980)$)	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B^0_s)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta^{\mathrm{eff}}_s(B^0_s \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta^{\mathrm{eff}}_s(B^0_s \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K^0_S)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta^{\mathrm{eff}}_s(B^0_s \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B^0_s \to \phi\gamma)/\tau_{B^0_s}$	–	5 %	1 %	0.2 %
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]	6 %	2 %	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	$\mathcal{B}(B^0_s \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B^0_s \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–$12°$ [19, 20]	4°	0.9°	negligible
	γ ($B^0_s \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\, K^0_S$)	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}	–

Implications of LHCb measurements and future prospects:
arXiv:1208.3355

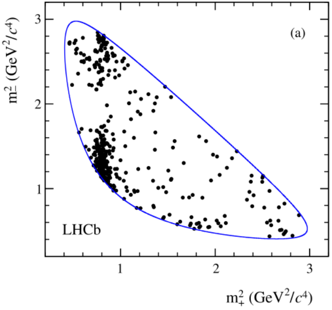
$B_s \to D_s K$

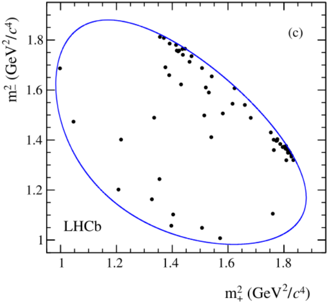




- Presented at CKM 2012 LHCb-CONF-2012-029
- Two possible decay paths:
  - Direct $b \to c$ decay
  - B_s mixing and $b \to u$ decay
- A time dependent analysis is required
- We do not have a γ extraction from this channel yet, more studies on systematics are required

GGSZ method

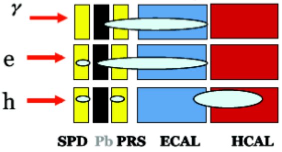


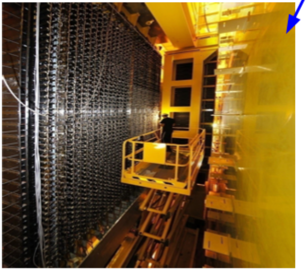


- Comparing the distribution of events in the $D^0 \to K_S^0 h^+ h^-$ Dalitz plot for $B^+ \to DK^+$ and $B^- \to DK^-$ decays
- Determine the yield of B^+ and B^- in each bins of the Dalitz plot
- $N^+_{+i} = n_{B^+}\left(K_{-i} + (x_+^2 + y_+^2)K_{+i} + 2\sqrt{K_{+i}K_{-i}}(x_+ c_{+i} - y_+ s_{+i})\right)$
  $x_\pm = r_B \cos(\delta_B \pm \gamma)$, $y_\pm = r_B \sin(\delta_B \pm \gamma)$
- K_i flavour tagged yield in bin i, c_i,s_i - CLEO inputs

Calorimeter system

PID with Calo system





Scitillating Pad Detector and Preshower detector

~6000 plastic scintillator pads 15 mm thick interlayed with 2.5 X_0 lead converter;

Electromagnetic calorimeter (ECAL)

Shashlik sampling technology

Alternating scintillator (4 mm)/lead (2mm) tiles

42mm thick = $25X_0$

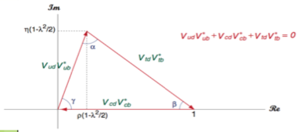
Hadron calorimeter (HCAL)

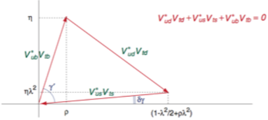
Iron plates interspaced with scintillating tiles

5.6 λ_I thick

11

Unitarity Triangle





Sides:

V_{ud}	β-decay	$(A,Z) \rightarrow (A,Z+1) + e^- + \bar{\nu}_e$	$\cos\vartheta_C$
V_{us}	K-decay	$K^+ \rightarrow \pi^0 + \ell^+ + \nu_\ell$ $K^0 \rightarrow \pi^- + \ell^+ + \nu_\ell$	$\sin\vartheta_C$
V_{cd}	ν-production of c's	$\nu_\ell + d \rightarrow \ell^- + c$	$\cos\vartheta_C$
V_{cs}		$D^\pm \rightarrow K^0 + \ell^\pm + \nu_\ell$	$\sin\vartheta_C$
V_{ub}	B-decay	$b \rightarrow u + \ell^- + \bar{\nu}_\ell$	
V_{cb}		$b \rightarrow c + \ell^- + \bar{\nu}_\ell$	
V_{td}	Δm in B^0-$\bar{B}^0$		

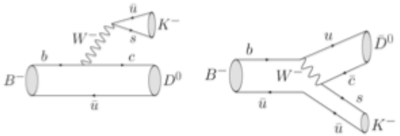
Measurement of the angles:

$$\alpha \Rightarrow \quad B \rightarrow \pi\pi, \quad B \rightarrow \rho\rho, \quad B \rightarrow \rho\pi$$

$$\beta \Rightarrow \quad B \rightarrow J/\psi K_s, \quad B \rightarrow \phi K_s, \quad B \rightarrow D^{(*)}D^{(*)}$$

$$\gamma \Rightarrow \quad B \rightarrow D^{(*)}\pi, \quad B \rightarrow DK$$

Gamma with Trees



$A(B^- \to D^0 K^-) = A_c e^{i\delta_c}$, $A(B^- \to \overline{D}^0 K^-) = A_u e^{i(\delta_u - \gamma)}$

$A(D^0 \to f) = A_f e^{i\delta_f}$ and $A(\overline{D}^0 \to f) = A_{\bar{f}} e^{i\delta_{\bar{f}}}$ f being a generic final state of D-meson.

The δs are strong phases and γ is the week phase, while A are real and positive

$$A(B^- \to (f)_D K^-) = A_C A_f e^{i(\delta_c + \delta_f)} + A_u A_{\bar{f}} e^{i(\delta_u + \delta_{\bar{f}} - \gamma)}$$

$$\Gamma(B^- \to (f)_D K^-) = A_C^2 A_{\bar{f}}^2 \left(A_f^2 / A_{\bar{f}}^2 + r_B^2 + 2 r_B \, A_f / A_{\bar{f}} \, \mathrm{Re}(e^{i(\delta_B + \delta_D - \gamma)}) \right)$$

where $r_B = A_u / A_C$, $\delta_B = \delta_u - \delta_C$, $\delta_D = \delta_{\bar{f}} - \delta_f$

GLW method

In the GLW method the D meson is reconstructed when it decays into a CP eigenstate (e.g. K K), therefore the $A_f / A_{\bar{f}} = 1$, $\delta_D = 0, \pi$ and CP=+1,-1 $\Rightarrow$

$$\Rightarrow \Gamma(B^- \to [f_{CP\pm}]_D K^-) = A_C^2 A_{f_{CP\pm}}^2 (1 + r_B^2 \pm 2 r_B \cos(\delta_B - \gamma))$$

We have:

$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm} K^-) - \Gamma(B^+ \to D^0_{CP\pm} K^+)}{\Gamma(B^- \to D^0_{CP\pm} K^-) + \Gamma(B^+ \to D^0_{CP\pm} K^+)} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma}$$

$$R_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm} K^-) + \Gamma(B^+ \to D^0_{CP\pm} K^+)}{2\Gamma(B^- \to D^0 K^-)} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma$$

ADS method

In the ADS method it used the interference of

$B^- \to D^0 K^-$ followed by doubly Cabibbo-suppressed $D^0 \to K^+\pi^-$

and the suppressed $B^- \to \overline{D}^0 K^-$ followed by the Cabibbo-allowed $\overline{D}^0 \to K^+\pi^-$.

$$r_D = A/A = \frac{\left\| A(D^0 \to K^+\pi^-) \right\|}{\left\| A(D^0 \to K^-\pi^+) \right\|}$$

Since $r_D \sim 5\%$ and r~10% the interference can be quite large!

$$R_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^-\pi^+]_D K^-) + \Gamma(B^+ \to [K^+\pi^-]_D K^+)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\gamma \cos(\delta_B + \delta_D)$$

$$A_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) - \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)} = 2 r_B r_D \sin\gamma \sin(\delta_B + \delta_D) \Big/ R_{ADS}$$

Other ways of extracting Υ

GGSZ:

In this method the D^0 is reconstructed when it decays in 3bodies (e.g. $K_s^0 \pi\pi$).

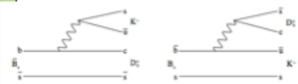
$$A_f e^{i\delta_f} = f(m_-^2, m_+^2)$$

$$A_{\bar f} e^{i\delta_{\bar f}} = f(m_+^2, m_-^2)$$

$$\Gamma(B^\mp \to [K_s^0\pi\pi]_D K^\mp) \propto \left\| f(m_\mp^2, m_\pm^2)\right\|^2 + r_B^2 \left\| f(m_\pm^2, m_\mp^2)\right\|^2 + 2r_B \left\| f(m_\mp^2, m_\pm^2)\right\| \left\| f(m_\pm^2, m_\mp^2)\right\| \cos(\delta_B + \delta_D(m_\mp^2, m_\pm^2) \mp \gamma)$$

Bs→DsK (Time dependent CP asymmetry):

The interference between the direct decay and the decay after mixing allows to access Υ. The non-zero $\Delta\Gamma_s$ allows to include non tagged events in the analysis.



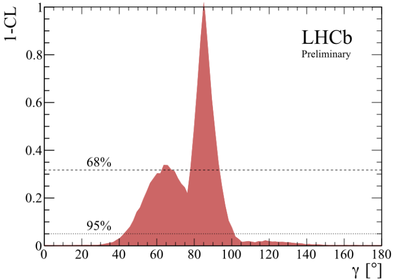
$$\Gamma_{B_s^0/B_s^0 \to f}(t) = 2 \cdot |A_f|^2 (1 + |\lambda_f|^2) \frac{e^{-\Gamma_s t}}{2} \cdot \left(\cosh\frac{\Delta\Gamma_s t}{2} + D_f \sinh\frac{\Delta\Gamma_s t}{2}\right)$$

$$\Gamma_{B_s^0/B_s^0 \to f}(t) = 2 \cdot |\bar A_f|^2 (1 + |\bar\lambda_f|^2) \frac{e^{-\Gamma_s t}}{2} \cdot \left(\cosh\frac{\Delta\Gamma_s t}{2} + D_f \sinh\frac{\Delta\Gamma_s t}{2}\right)$$

$$\gamma + \phi_s = \frac{1}{2}[arg(\bar\lambda_{\bar f}) - arg(\lambda_f)]$$

LHCb γ combination

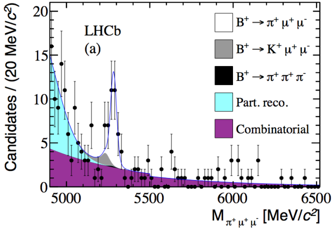
- Combination of $B^{\pm} \to Dh^{\pm}$ analyses
- Parameters of Interest: $\vec{\alpha} = (\gamma, r_B\ , \delta_B, \ldots)$
- The likelihood $\mathcal{L}(\vec{\alpha}) = \sum_i f_i(\vec{A}_{i\ obs}|\vec{A}_i(\vec{\alpha}_i))$ is used
- where $f_i \propto exp\left(-(\vec{A}_i(\vec{\alpha}_i) - \vec{A}_{i\ obs})V_i^{-1}(\vec{A}_i(\vec{\alpha}_i) - \vec{A}_{i\ obs})\right)$



γ	$63.7°$	$85.1°$
68%CL 95%CL	$[61.8, 67.8]°$	$[77.9, 92.4]°$ $[43.8, 101.5]°$

$B^- \to DK^- + B^- \to D\pi^-$ from LHCb
D-system from CLEO

Other physics results..

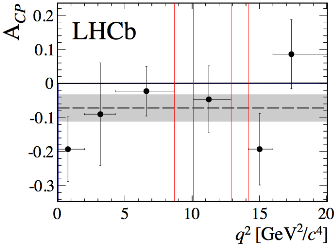


The rarest B-decay ever observed (before $B_s \to \mu^+\mu^-$)

$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-) = (2.3 \pm 0.6(stat) \pm 0.1(syst)) \times 10^{-8}$

Good agreement with SM predictions

arXiv:1210.2645



Direct CP asymmetry in $B_d \to K^*\mu^+\mu^-$

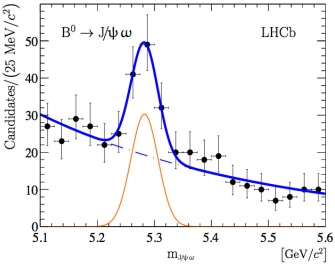
$\mathcal{A}_{CP}(B_d \to K^*\mu^+\mu^-) = (-7.2 \pm 4.0(stat) \pm 0.5(syst))\%$

World's best measurement of this observable

Good agreement with Belle and BaBar measurements

arXiv:1210.4492

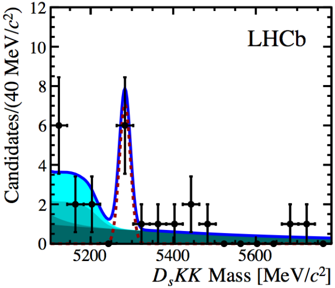
First observation/evidence of ...



First observation of $B^0 \to J/\psi\omega$

$$\frac{B^0 \to J/\psi\omega}{B^0 \to J/\psi\rho} = 0.89 \pm 0.19(stat)^{+0.07}_{-0.13}(syst)$$

arXiv:1210.2631



First evidence of the $B^+ \to D_s^+\phi$ decay

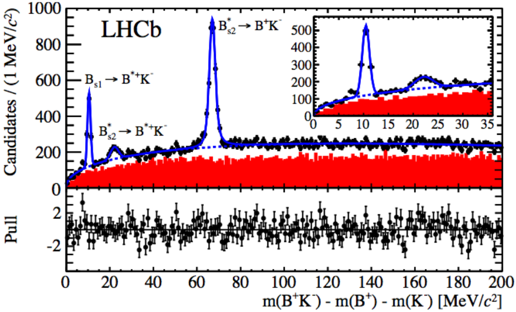
$$\mathcal{B}(B^+ \to D_s^+\phi) = (1.87^{+1.25}_{-0.73}(stat) \pm 0.37(syst)) \times 10^{-6}$$

Also measurement of $\mathcal{A}_{CP}$

$$\mathcal{A}_{CP} = -0.01 \pm 0.41(stat) \pm 0.03(syst)$$

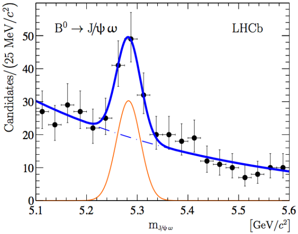
arXiv:1210.1089

First observation/evidence of ...



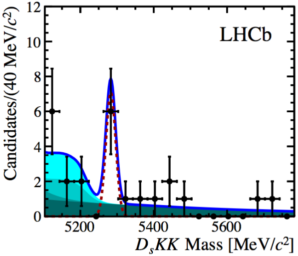
- First observation of the decay $B^*_{s2}(5840)^0 \to B^{*+}K^-$
- World's best measurement of the $B^* - B$ mass difference
- Important for the understanding of Z_b^+ (observed by Belle), which may be a $B - B^*$ molecule
- favours $B^*_{s2}(5840)^0 J^P = 2^+$
- arXiv:1211.5994 submitted to PRL

First observation/evidence of ...



First observation of $B^0 \to J/\psi\omega$

$$\frac{B^0 \to J/\psi\omega}{B^0 \to J/\psi\rho} = 0.89 \pm 0.19(stat)^{+0.07}_{-0.13}(syst)$$



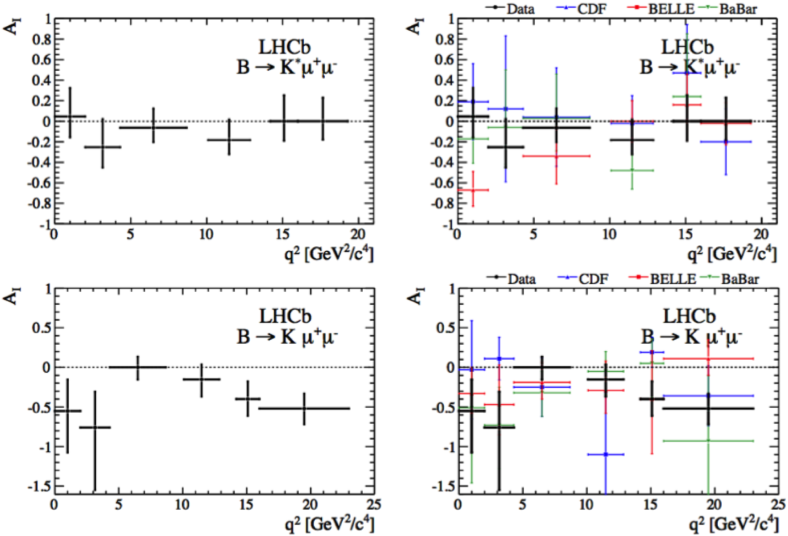
First evidence of the $B^+ \to D_s^+\phi$ decay

$$\mathcal{B}(B^+ \to D_s^+\phi) = (1.87^{+1.25}_{-0.73}(stat) \pm 0.37(syst)) \times 10^{-6}$$

Also measurement of $\mathcal{A}_{CP}$

$$\mathcal{A}_{CP} = -0.01 \pm 0.41(stat) \pm 0.03(syst)$$

Isospin



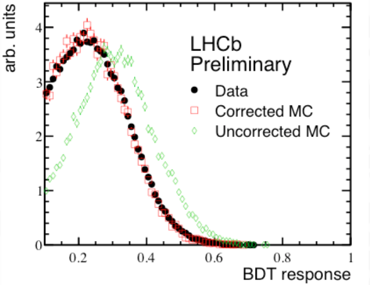
Acceptance effects: LHCb

<u>LHCb Collaboration: LHCb-CONF-2012-008</u>

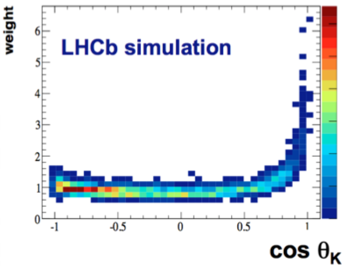
- Tuning of the LHCb simulation for known discrepancy (IP resolution and PID), using data driven techniques

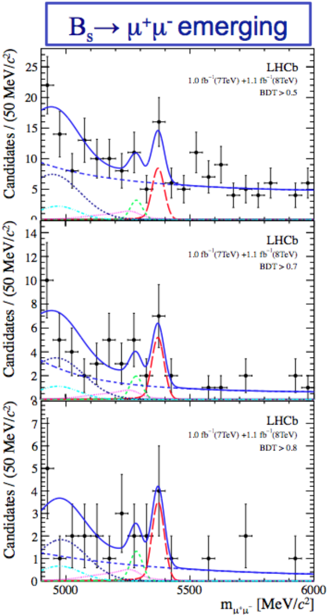
- Quality of the simulation verified by using the control channel $B_d \to K^* J/\psi$

- Using the simulation as a function of the three angles and q^2 to correct on an event-by-event basis



Weights in $B_d \to K^* J/\psi$





$B_s \to \mu^+\mu^-$ emerging
LHCb
1.0 fb^{-1}(7TeV) +1.1 fb^{-1}(8TeV)
BDT > 0.5
BDT > 0.7
BDT > 0.8
Candidates / (50 MeV/c^2)
5000
5500
6000
$m_{\mu^+\mu^-}$ [MeV/c^2]

- Perform simultaneous unbinned likelihood fit to 15 BDT bins of 2011 + 2012
  - Exponential slope+normalization, B_s and B^0 yield fully free
  - Gaussian constraint to
    - Exclusive background parameters
    - B2hh misID
  - Fit result:

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

  - Evaluate systematics with
    - Change bkg model
    - Fix all Gausian constraints

  → BR fully dominated by stat

Likelihood profile vs BR