CP violation in $B \to h\, h$

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Standard Model @ LHC - Copenhagen, 13 April 2012

Introduction

Direct CP asymmetry in Bd,s$\rightarrow K\pi$: LHCb-PAPER-2011-029

- Interference of tree and loop diagrams.
- Potentially sensitive to new physics.

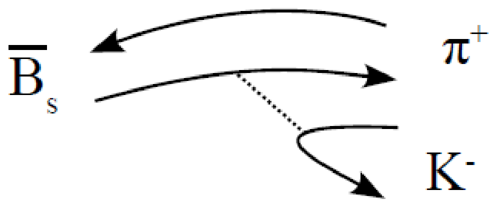
Time dependent CP violation in B $\rightarrow$ hh: LHCb-CONF-2012-007

- Sensitive to β, β_s and γ
- First measurement for B $\rightarrow$ KK

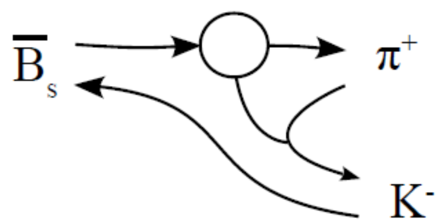
Bs $\rightarrow$ K K effective lifetime: LHCb [PLB 707 (2012)] , LHCb-CONF-2012-001

- Sensitive to $\Delta\Gamma$s and ϕs
- Two measurements: 2010 and 2011 datasets

Direct CP asymmetry in Bd,s→Kπ



Vub Vcs ~ $A\lambda^3(\rho - i\eta)$



Vtb Vtd ~ $A\lambda^3(1 - \rho - i\eta)$

Interference of tree and loop diagrams.

- Potentially sensitive to new physics.
- CP asymmetry in Bd →Kπ is established.
- Consider Bs system
  - 14 times lower decay rate, 4 times lower production rate

The direct CP asymmetry is defined:

$$A_{CP} = \frac{\Gamma\left(\overline{B^0_{(s)}} \to \overline{f_{(s)}}\right) - \Gamma\left(B^0_{(s)} \to f_{(s)}\right)}{\Gamma\left(\overline{B^0_{(s)}} \to \overline{f_{(s)}}\right) + \Gamma\left(B^0_{(s)} \to f_{(s)}\right)}$$

The raw A_{CP} measured in data need correction factors: $A_{CP} = A_{CP}^{RAW} - A_D(K\pi) - \kappa A_P$

- $A_D(K\pi)$ = instrumental charge asymmetry
- A_P = Production asymmetry
- κ is a selection dependent factor

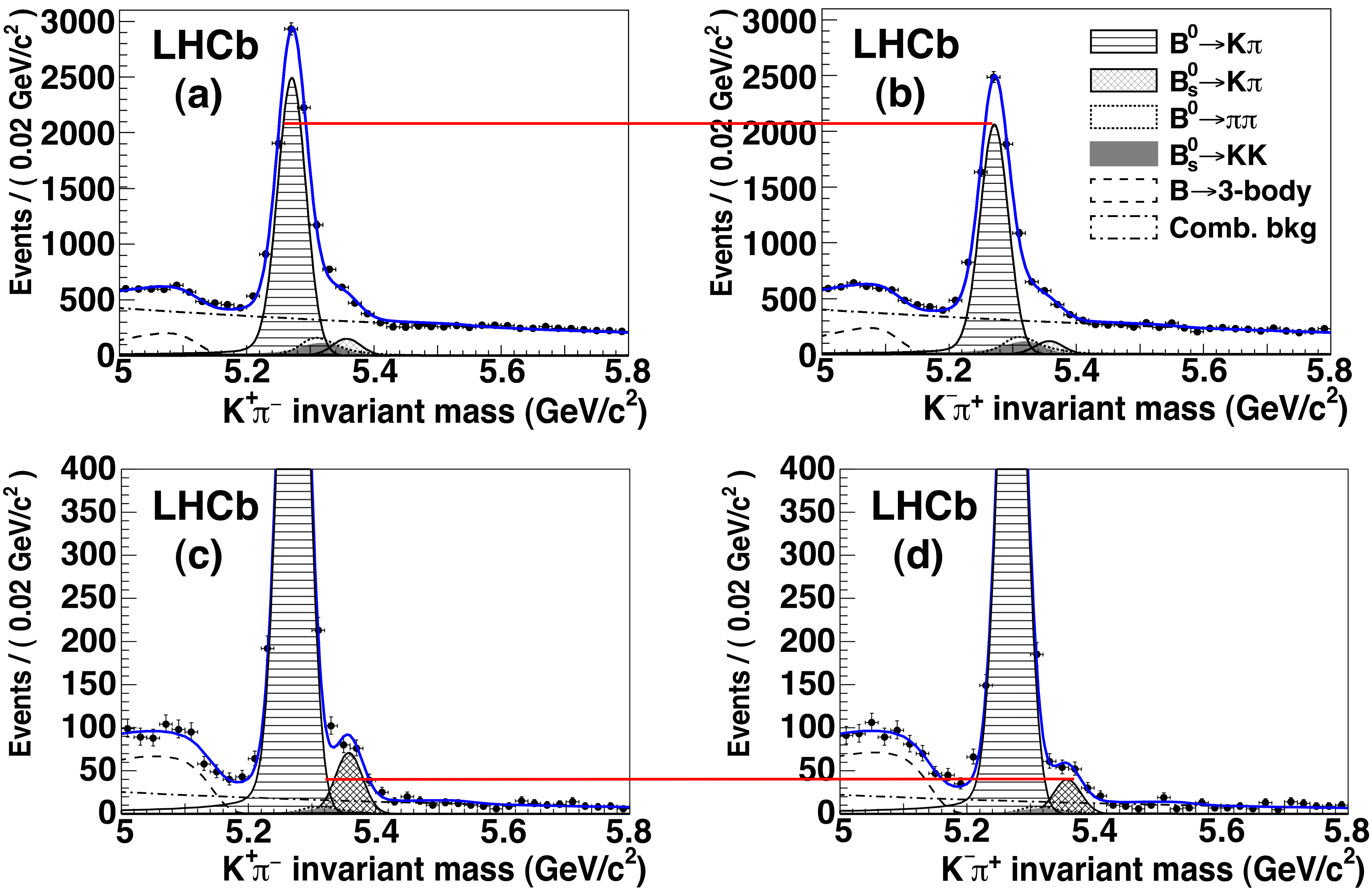
- Instrumental asymmetry studied with $D^* \to D^0(K\pi)\,\pi$, $D^* \to D^0(KK)\,\pi$ and untagged $D^0 \to K\pi$.
- B^0 production asymmetry has been studied using ~25400 $B^0 \to J/\psi(\mu\mu)K^*(K\pi)$.

$$\kappa = \frac{\int \left(e^{-\Gamma t'} \cos \Delta m t'\right) \varepsilon(t) dt}{\int \left(e^{-\Gamma t'} \cosh \frac{\Delta\Gamma}{2} t'\right) \varepsilon(t) dt}$$

- $\varepsilon(t)$ = acceptance as a function of the proper decay time

B mass distributions

LHCb-PAPER-2011-029



Results

LHCb-PAPER-2011-029

The results in 0.35 fb^{-1}

$A_{CP}(B_d \to K\pi) = -0.088 \pm 0.011$ (*stat*) ± 0.008 (*syst*)

$A_{CP}(B_s \to K\pi) = 0.27 \pm 0.08$ (*stat*) ± 0.02 (*syst*)

- The result of $A_{CP}(B_d \to K\pi)$ constitutes the most precise measurement available to date
- It is in good agreement with the current world average from HFAG: $-0.098^{+0.012}_{-0.011}$
- Deviation from 0 exceeds 6 σ (sum in quadrature stat + syst)
- Systematic uncertainty most important contribution from instrumental and production asymmetry

- The significance of $A_{CP}(B_s \to K\pi)$ is 3.3 σ
- It is the first evidence of CP violation in the decays of B_s mesons
- It is in agreement with CDF result: 0.39 ± 0.15 (*stat*) ± 0.08 (*syst*) PRL 106, 181802 (2011)
- Systematic uncertainty most important contribution from modelling of the signal and background components in the maximum likelihood fit

Time dependent CPV in B → hh

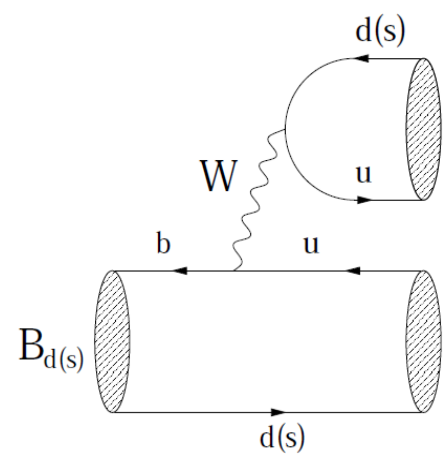
R. Fleischer PLB459 (1999) 306

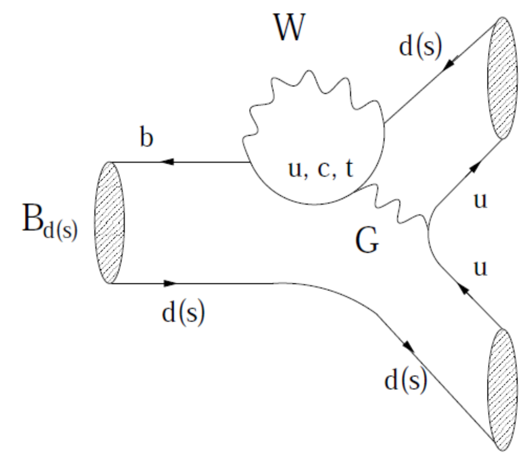
Time dependent CP asymmetry

$$\mathcal{A}_{CP}(t) = \frac{\Gamma_{\bar{B}\to f}(t) - \Gamma_{B\to f}(t)}{\Gamma_{\bar{B}\to f}(t) + \Gamma_{B\to f}(t)} = \frac{\mathcal{A}^{dir}\cos(\Delta M t) + \mathcal{A}^{mix}\sin(\Delta M t)}{\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \mathcal{A}^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma}{2}t\right)}$$

With the constraint

$$\left(A_f^{\rm dir}\right)^2 + \left(A_f^{\rm mix}\right)^2 + \left(A_f^{\Delta\Gamma}\right)^2 = 1$$





For $\pi\pi$ and KK the amplitudes:

$$A_{\pi\pi}^{dir}(\gamma, d, \theta) \qquad A_{\pi\pi}^{mix}(\gamma, 2\beta, d, \theta)$$

$$A_{KK}^{dir}(\gamma, d', \theta') \qquad A_{KK}^{mix}(\gamma, 2\beta_s, d', \theta')$$

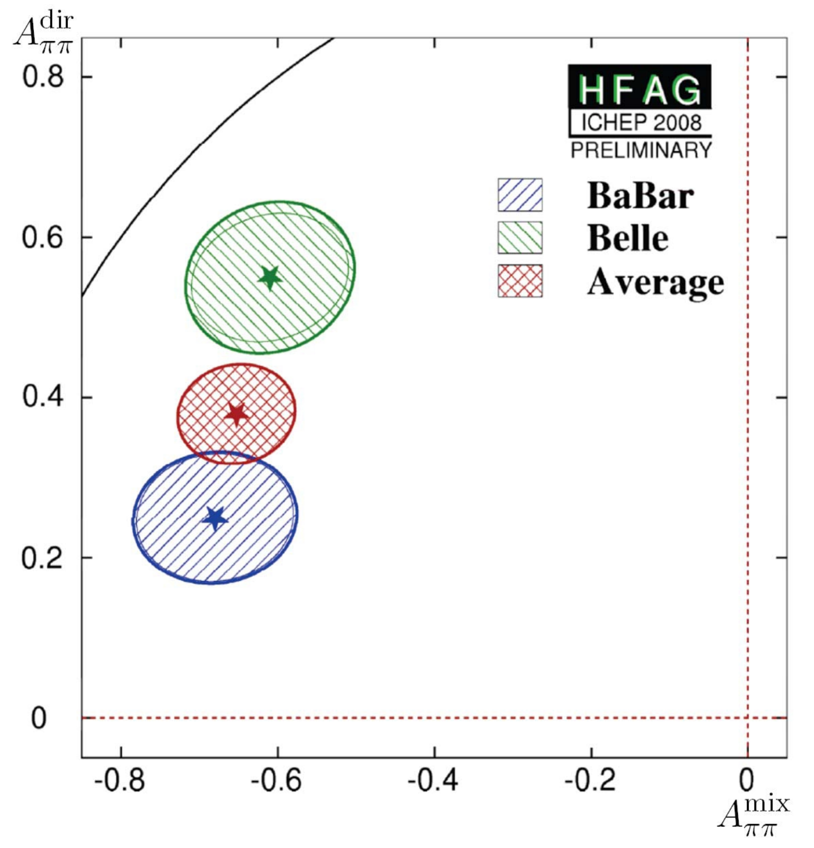
$$d\, e^{i\theta} \equiv \frac{1}{(1-\lambda^2/2)R_b}\left(\frac{A_{\rm pen}^{ct}}{A_{\rm cc}^{u} + A_{\rm pen}^{ut}}\right)$$

- Assuming U-symmetry: d=d', $\theta=\theta'$
- Input β_s from Bs → j/ψ ϕ: extract β and γ

Results form the B-factories

- Only the measurement Bd $\rightarrow \pi\pi$ available
- Not in good agreement
  - A 3rd measurement is necessary

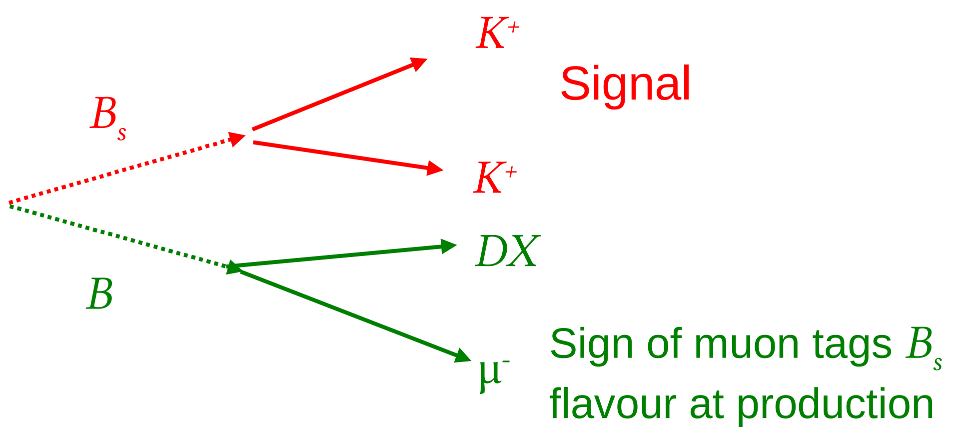
No measurement of Bs $\rightarrow$ KK available



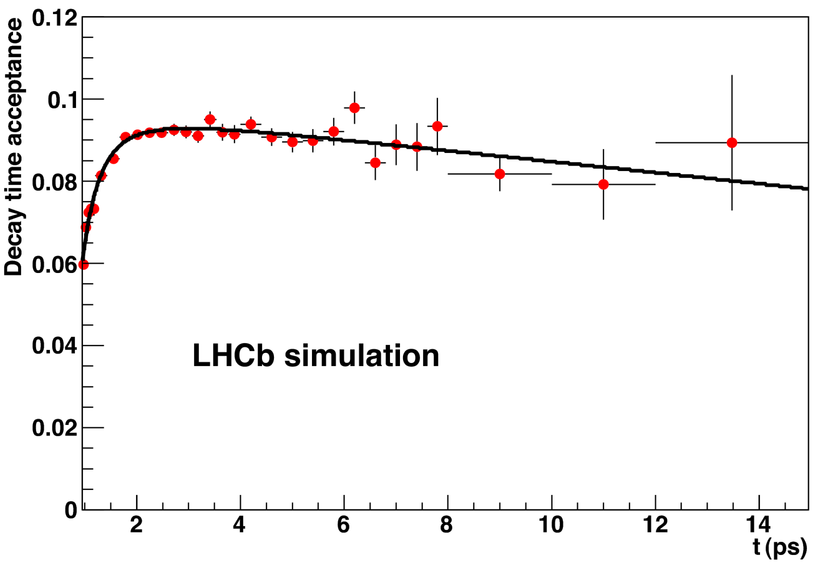
Experiment	$A^{dir}_{\pi\pi}$	$A^{mix}_{\pi\pi}$	$\rho(A^{dir}_{\pi\pi}, A^{mix}_{\pi\pi})$
BABAR	$0.25 \pm 0.08 \pm 0.02$	$-0.68 \pm 0.10 \pm 0.03$	0.06
Belle	$0.55 \pm 0.08 \pm 0.05$	$-0.61 \pm 0.10 \pm 0.04$	0.15
HFAG average	0.38 ± 0.06	-0.65 ± 0.07	0.08

Analysis strategy

- Integrated luminosity : 0.69 fb^{-1}
- Events selection:
  - Common kinematic cuts for $B \to K\pi$, $B \to \pi\pi$, $Bs \to KK$
  - PID cuts to distinguish the different final states
- Decay time resolution:
  - Form $B \to j/\psi$ X: 50 fs
- Decay time acceptance from MC
- Flavour tagging:
  - Use Opposite side (OS) tagging
  - Use $B \to K\pi$ to calibrate efficiency and mistag rate



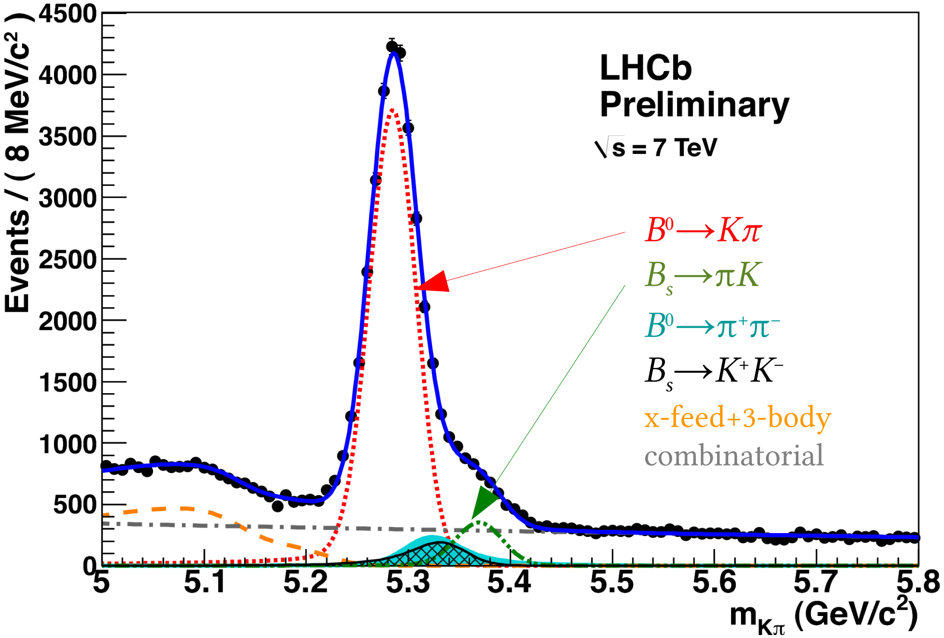
Example of flavour tagging

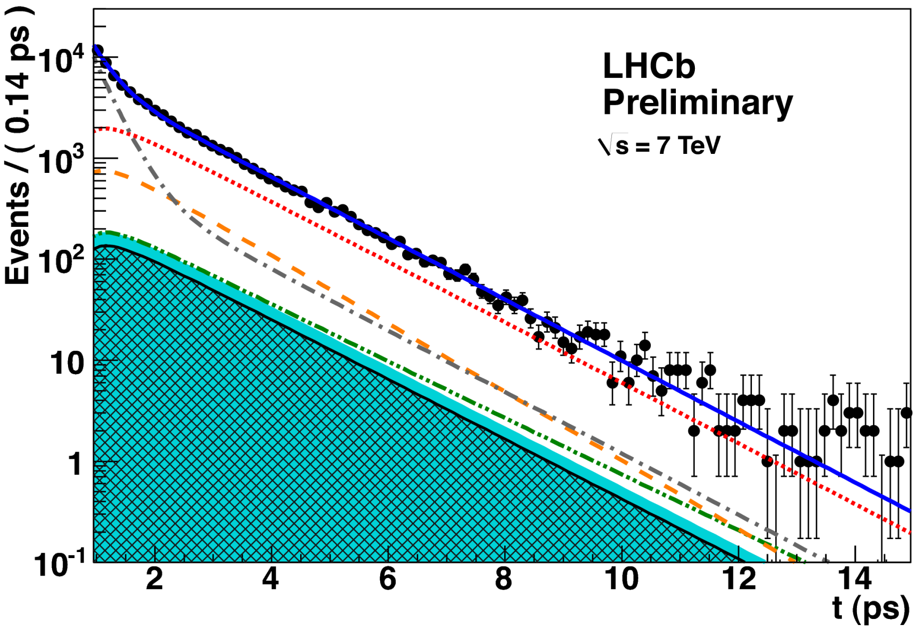


$Bs \to KK$ acceptance determined from MC

Time dependent B → K π fit (I)

LHCb-CONF-2012-007





- Very small contribution from Λ_b negected
- Input form other LHCb measurements

Input parameters		LHCb results
parameter	value	reference
Δm_s	$17.63 \pm 0.11 \pm 0.02$ ps^{-1}	arXiv:1112.4311
Γ_s	$0.657 \pm 0.009 \pm 0.008$ ps^{-1}	arXiv:1112.3183
$\Delta\Gamma_s$	$0.123 \pm 0.029 \pm 0.011$ ps^{-1}	arXiv:1112.3183

Time dependent B → K π fit (II)

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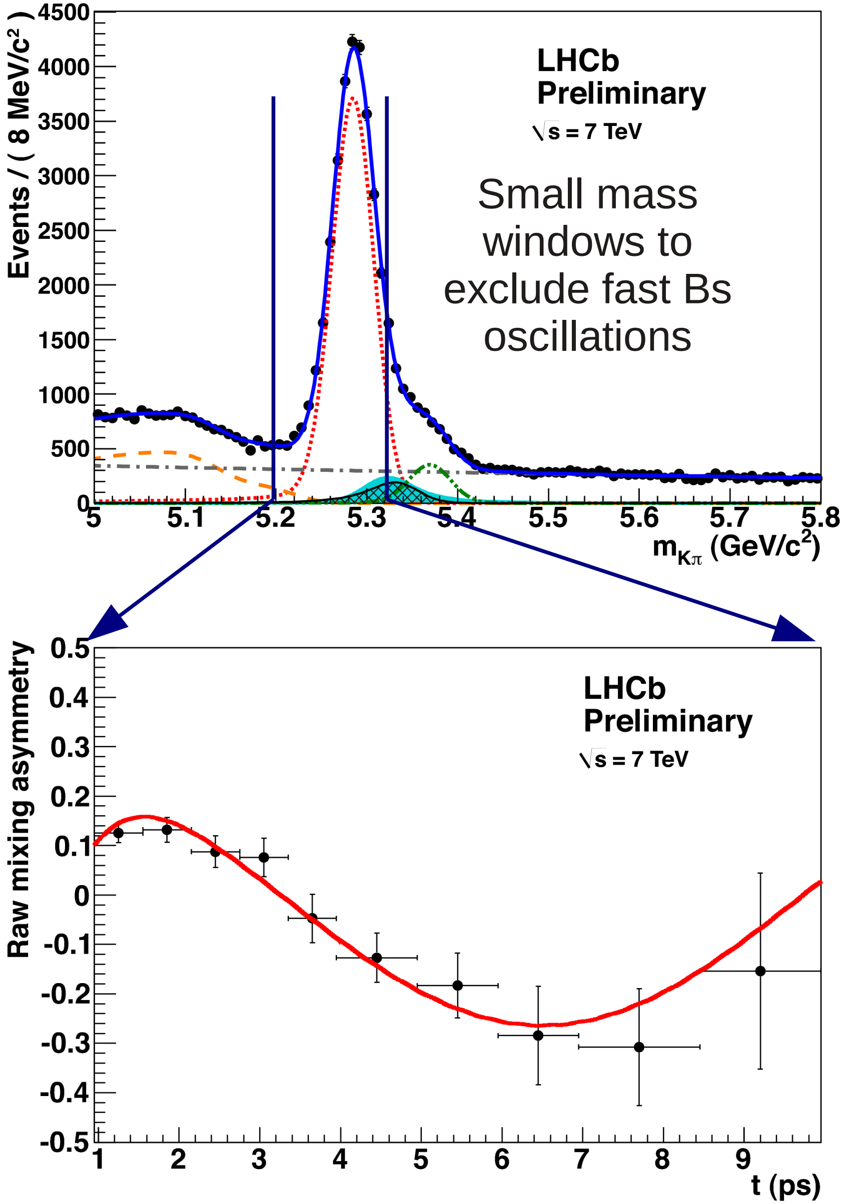


- 5 tagging categories
- ~4.5% efficiency
- No large difference between B and $\overline{B}$ observed

Production asymmetry

- AP(Bd) = -0.015 ± 0.013
- AP (Bs) = -0.03 ± 0.06

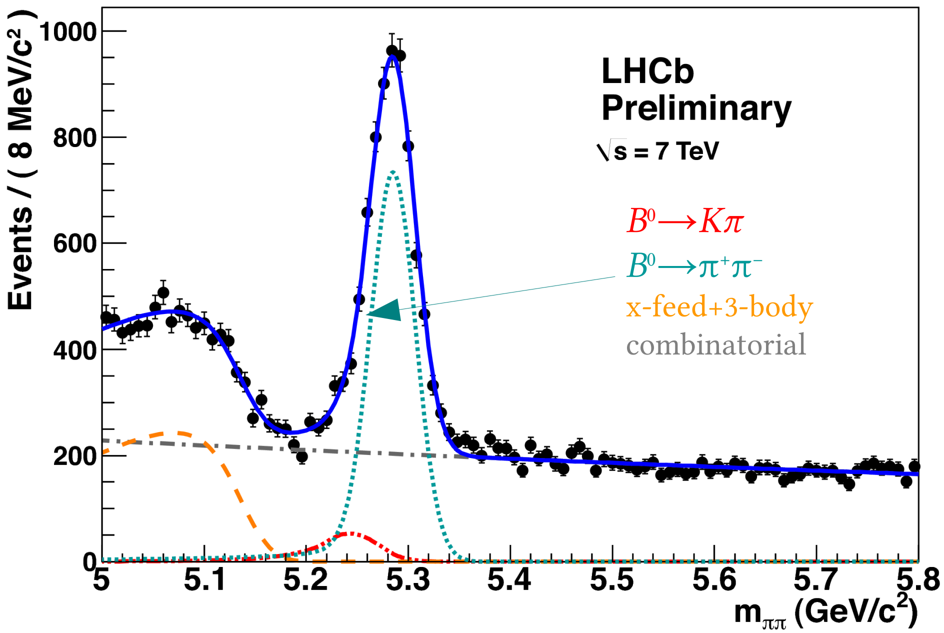
Propagated Gaussian term in ππ and KK

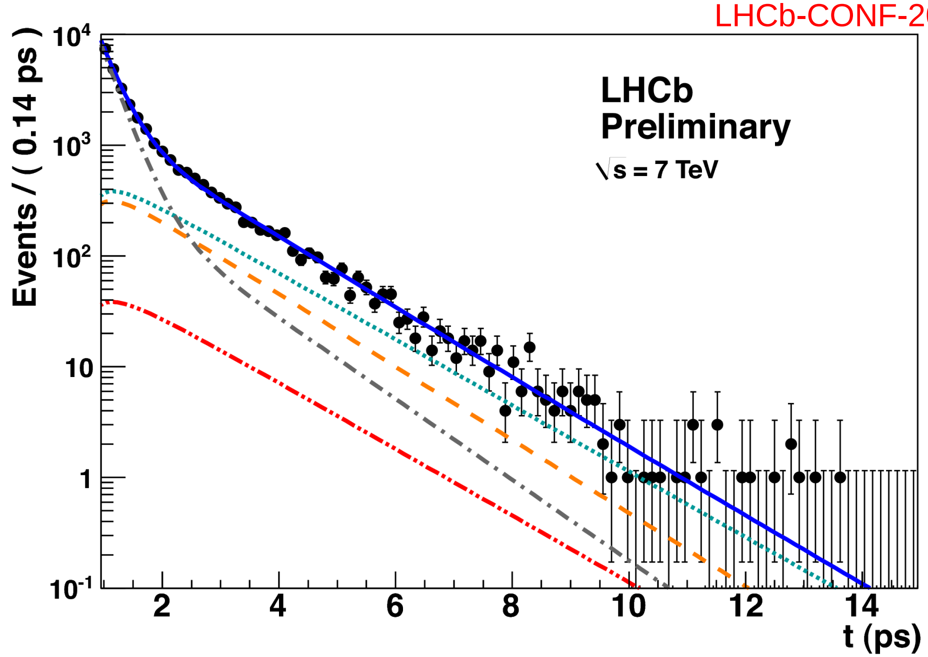
Bd parameters:

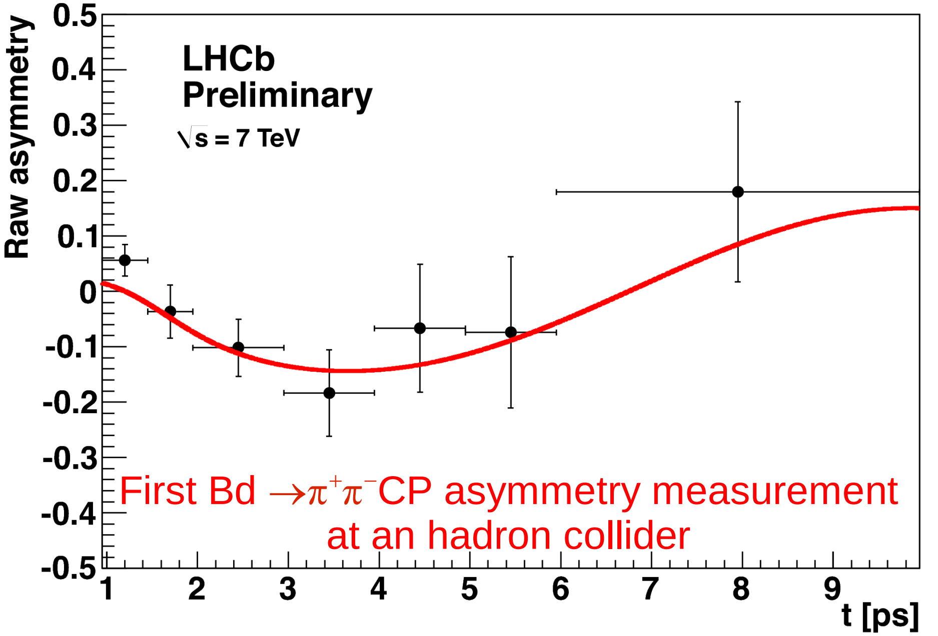
- Δm_d=(0.484 ± 0.019) ps^{-1}
- $\tau(B_d)$=(1.509 ± 0.011) ps

Time dependent Bd → π π fit

LHCb-CONF-2012-007







Input parameters		LHCb results
parameter	value	reference
Δm_d	$0.499 \pm 0.032 \pm 0.003\ \mathrm{ps}^{-1}$	LHCb-CONF-2011-010

$$A_{\pi\pi}^{\mathrm{dir}} = 0.11 \pm 0.21 \pm 0.03$$

$$A_{\pi\pi}^{\mathrm{mix}} = -0.56 \pm 0.17 \pm 0.03$$

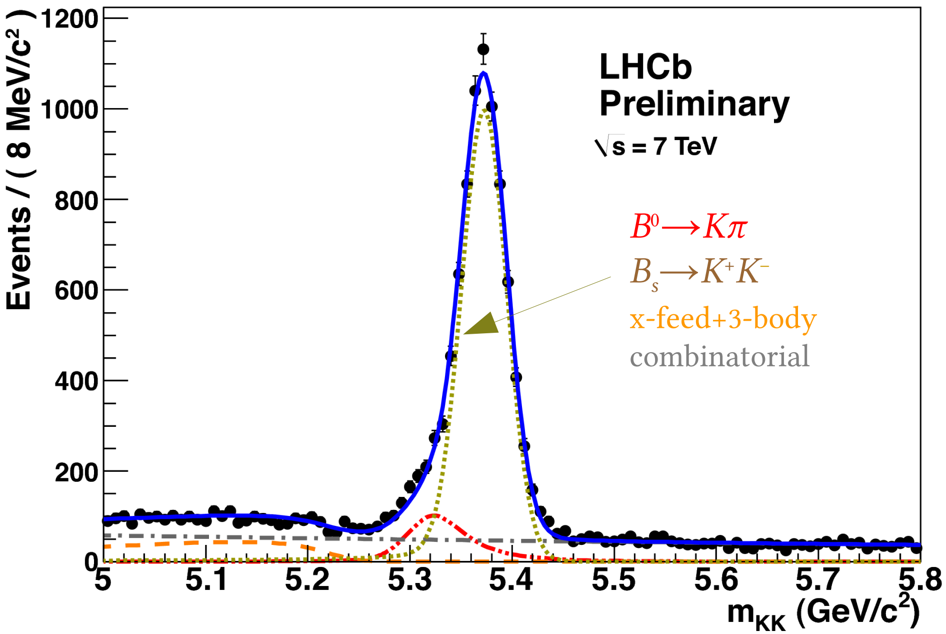
$$\rho(A_{\pi\pi}^{\mathrm{dir}},\ A_{\pi\pi}^{\mathrm{mix}}) = -0.34$$

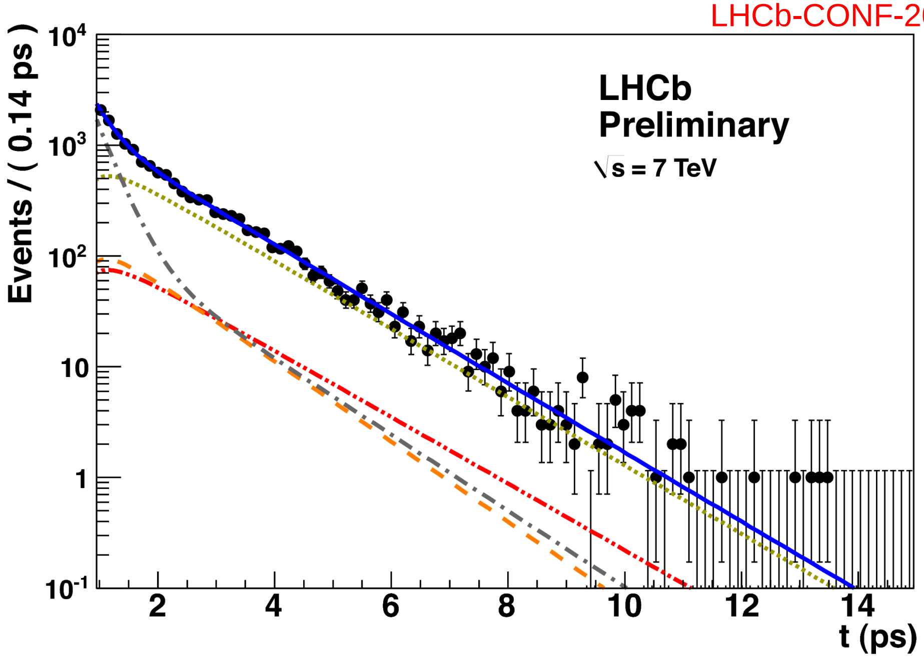
τ(Bd)=(1.497 ± 0.025) ps

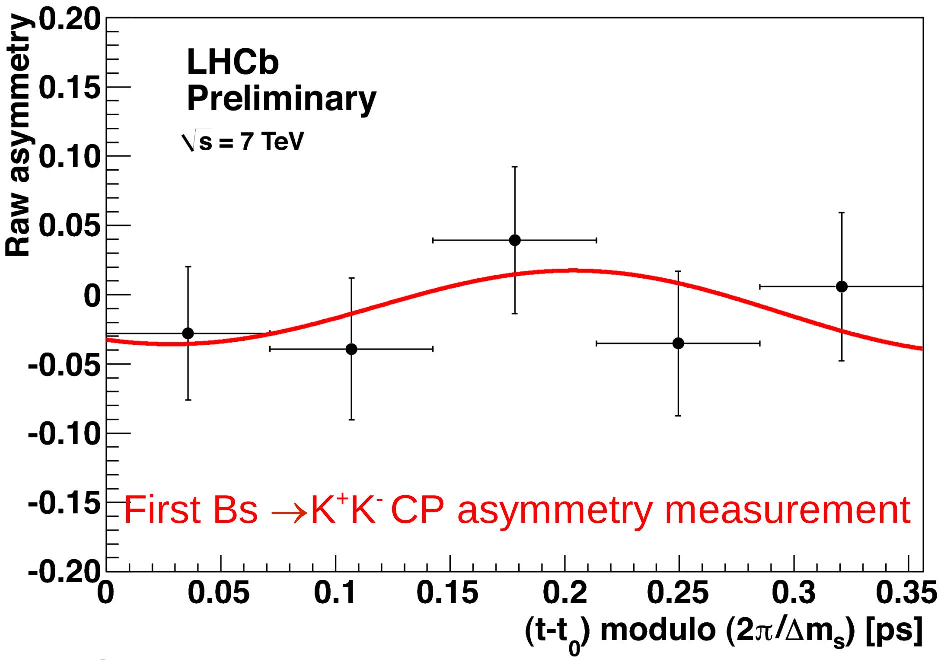
In agreement with World Awarage

Time dependent Bs → K K fit

LHCb-CONF-2012-007







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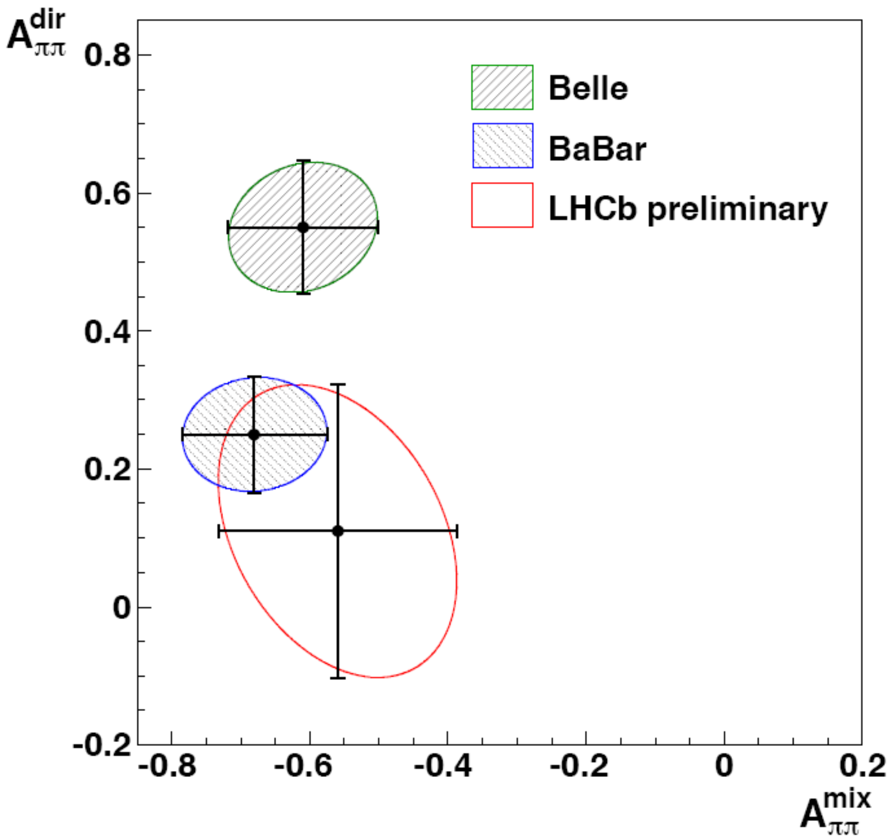
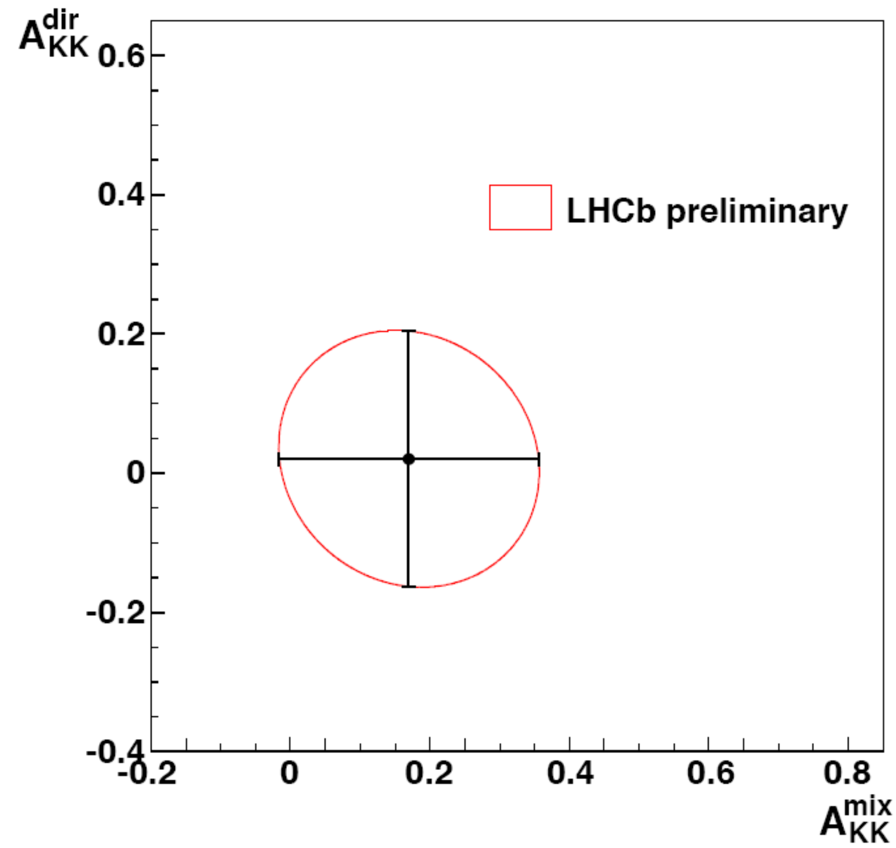
$$\boxed{\begin{aligned} A^{\mathrm{dir}}_{KK} &= 0.02 \pm 0.18 \pm 0.04 \\ A^{\mathrm{mix}}_{KK} &= 0.17 \pm 0.18 \pm 0.05 \\ \rho(A^{\mathrm{dir}}_{KK},\, A^{\mathrm{mix}}_{KK}) &= -0.10 \end{aligned}}$$

$\Delta\Gamma s = 0.076 \pm 0.019$ ps-1 In agreement with LHCb-PAPER-2011-021

Results

LHCb-CONF-2012-007





- A^{dir} favours BaBar result
- A^{mix} compatible with world avarage

Assuming U-symmetry and neglecting penguin contributions (small):

$$\mathcal{A}^{dir}_{K^+K^-} \approx A_{CP}(B^0 \to K^+\pi^-) = -0.088 \pm 0.011 \pm 0.008$$

LHCb-PAPER-2011-029

SM prediction assuming U-symmetry: $A^{\rm mix}_{KK} \simeq 0.15$

Largest systematic contribution is due to the errors on the input parameters in all results

Bs → K K effective lifetime

The untagged decay time distribution:

$$\Gamma(t) \;\propto\; (1-\mathcal{A}_{\Delta\Gamma_s})\, e^{-\Gamma_L t} + (1+\mathcal{A}_{\Delta\Gamma_s})\, e^{-\Gamma_H t}$$

$\mathcal{A}_{\Delta\Gamma_s} = -2\,\mathrm{Re}(\lambda)/(1+|\lambda|^2)$ $\qquad \lambda = (q/p)(\bar{A}/A)$ $\qquad$ No PCV $\rightarrow \lambda = 1$

Bs → K K effective lifetime: $\qquad$ Expand in: $y_s = \Delta\Gamma_s/2\Gamma_s$

$$\tau_{KK} = \tau_{B_s^0} \frac{1}{1-y_s^2}\left[\frac{1+2\mathcal{A}_{\Delta\Gamma_s} y_s + y_s^2}{1+\mathcal{A}_{\Delta\Gamma_s} y_s}\right] \qquad \tau_{B_s^0} = 2/(\Gamma_H+\Gamma_L) = \Gamma_s^{-1}$$

Alternative way to extract $\Delta\Gamma$s and ϕs

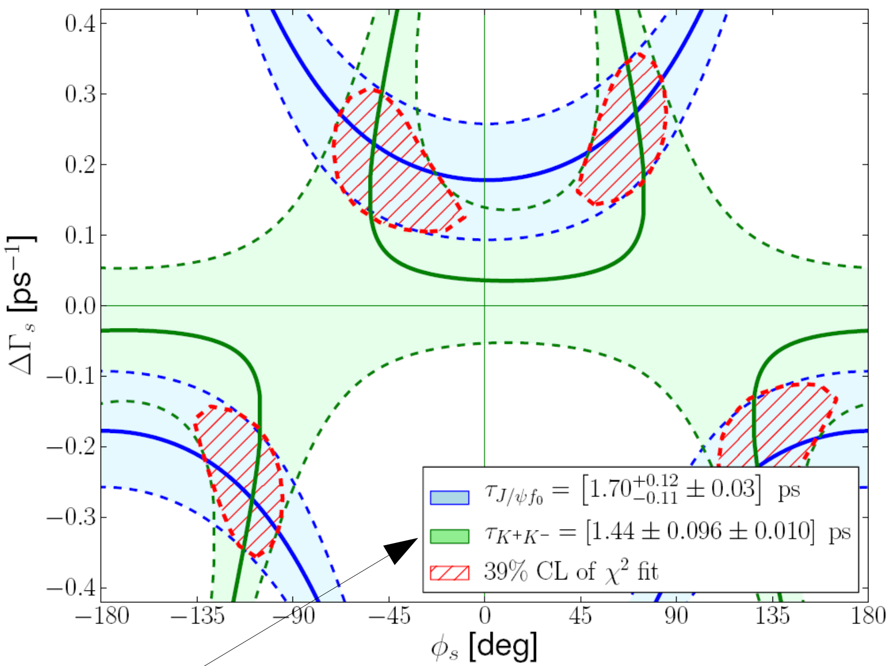
Two measurements:

- 2010 data (37 pb^{-1}): $\tau_{K^+K^-} = [1.44 \pm 0.096(\mathrm{stat}) \pm 0.010(\mathrm{syst})]\,\mathrm{ps}$ $\qquad$ LHCb [PLB 707 (2012)]
- 2011 data (1.0 fb^{-1}): $\qquad$ LHCb-CONF-2012-001

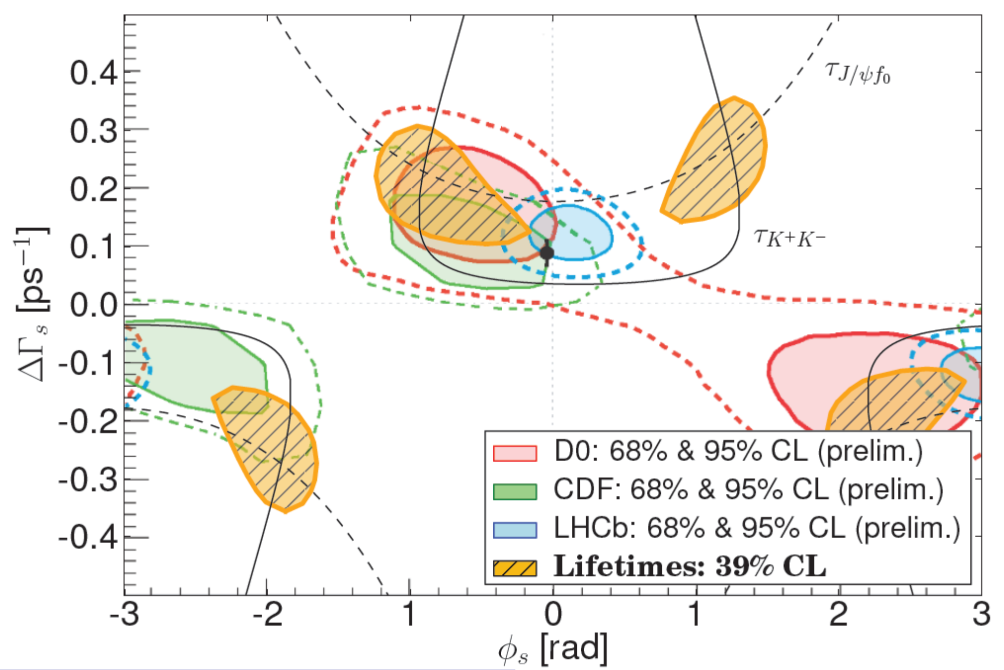
Constrain of ΔΓs and ϕs

Fleischer, Knegjens, [arXiv:1109.5115]

Using effective lifetimes to constrain of ΔΓs and ϕs



Including direct measurements



$$\tau_{K^+K^-} = [1.44 \pm 0.096(\mathrm{stat}) \pm 0.010(\mathrm{syst})]\ \mathrm{ps}$$

LHCb [PLB 707 (2012)]

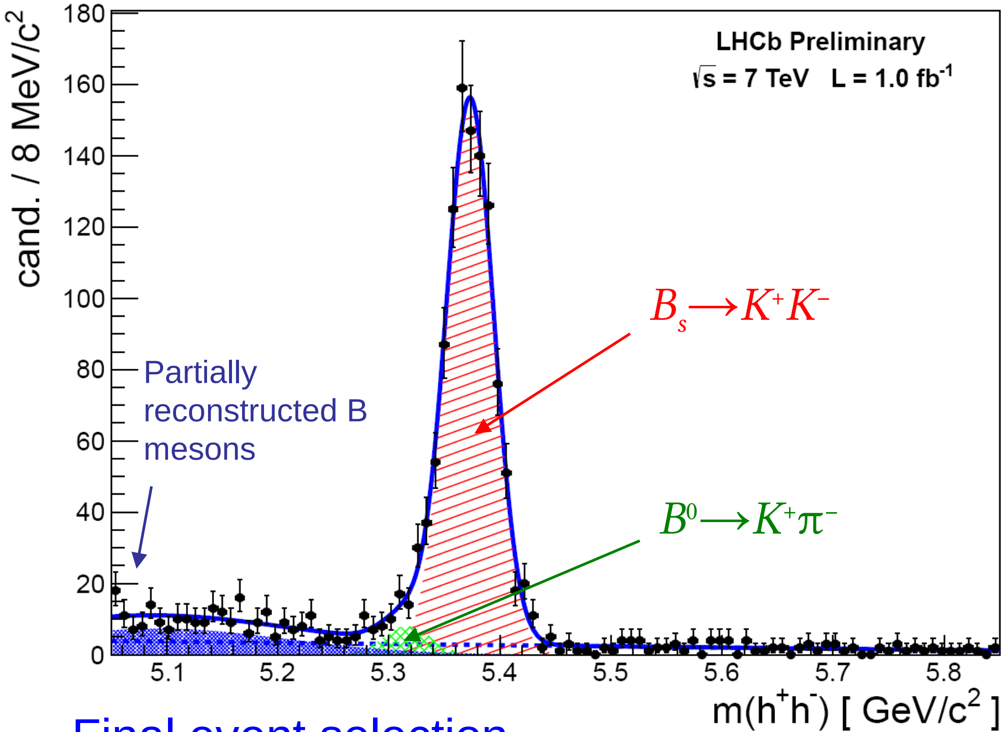
$$\tau_{J/\psi f_0} = [1.70^{+0.12}_{-0.11}(\mathrm{stat}) \pm 0.03(\mathrm{syst})]\ \mathrm{ps}$$

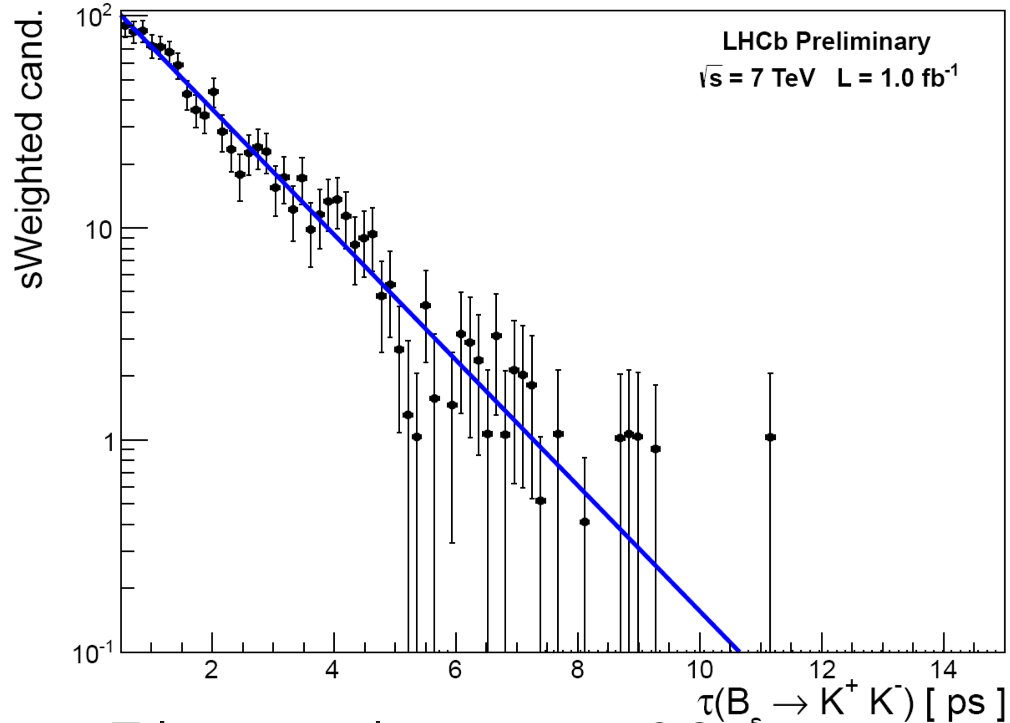
CDF [PRD84:052012, 2011]

2011 dataset analysis

LHCb-CONF-2012-001

New trigger and event selection used in the new analysis to reduce systematic uncertainty





Final event selection

- Use PID to isolate $B_s \to K^+K^-$ vs $B0 \to K^+\pi^-$.
- Cut on proton ID to suppress contribution from Λ.

Trigger needs to cut at t>0.3 ps

→ Fit starts at t=0.5 ps

$$\tau_{KK} = 1.468 \pm 0.046\ (\mathrm{stat.}) \pm 0.006\ (\mathrm{syst.})\ \mathrm{ps}$$

Main systematic uncertainty from reconstruction efficiency

In agreement with 2010 dataset measurement and with standard model prediction

$$\tau_{KK}^{SM} = (1.390 \pm 0.032)\ \mathrm{ps}$$

Fleischer, Knegjens, [EPJC 71 (2011) 1532]

Summary

Direct CP asymmetry in Bd,s$\rightarrow$Kπ: LHCb-PAPER-2011-029

- The result of $A_{CP}(B_d \rightarrow K\,\pi)$ constitutes the most precise measurement available to date
- The deviation from 0 exceeds 6 σ (sum in quadrature stat + syst)
- The significance of $A_{CP}(B_s \rightarrow K\,\pi)$ is 3.3 σ
- It is the first evidence of CP violation in the decays of B_s mesons

Time dependent CP violation in B $\rightarrow$ hh: LHCb-CONF-2012-007

- First measurement of B $\rightarrow$ KK
- For B $\rightarrow \pi\pi$ A^{dir} favours BaBar results

Bs $\rightarrow$ K K effective lifetime: LHCb [PLB 707 (2012)] , LHCb-CONF-2012-001

- Two measurements: 2010 and 2011 datasets
- The new measurement use a new trigger and a new selection to reduce systematic errors
- The two measurements are very compatible

New results expected for CPV analysis using all available data