Measurements of CP violation in charmless two-body B decays at LHCb

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on behalf of the LHCb Collaboration

LHCb

University of Glasgow
VIA VERITAS VITA

Introduction

- In this talk, we will present the LHCb results on charmless two-body B decays
- The talk will consist of the following three topics:
  - Measurements of the branching fractions of $B^0 \to h^+h^-$ and $B_s^0 \to h^+h^-$, where $h = \pi, K$, $\Lambda_b^0 \to p\pi^-$ and $\Lambda_b^0 \to pK^-$
  - Measurements of direct CP violation in $B^0 \to K^+\pi^-$ and $B_s^0 \to K^-\pi^+$ decays
  - Measurement of time-dependent CP violation in two-body charmless decays $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$
- We will follow closely the following publications: arXiv:1206.2794, arXiv:1202.6251, LHCb-CONF-2012-007

Motivation

- Study of time-dependent CP asymmetries in $B \to hh$ can be used to extract the unitarity angle γ from loop-mediated processes:

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

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

- For the decays $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ we have:

$A_{\pi\pi}^{dir}(\gamma,d,\theta)$ $\quad A_{KK}^{dir}(\gamma,d',\theta')$

$A_{\pi\pi}^{mix}(\gamma,\phi_d,d,\theta)$ $\quad A_{KK}^{dir}(\gamma,\phi_s,d',\theta')$

d,d' = strong amplitudes

θ,θ' = strong phases

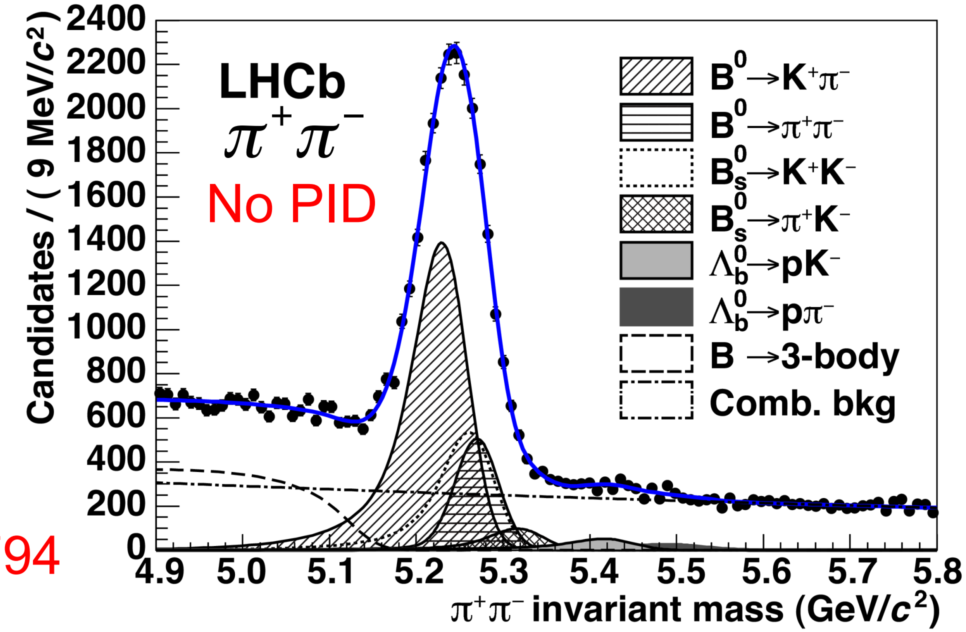
ϕ_d,ϕ_s = B_d and B_s mixing phases

  – U-spin symmetry (Fleischer, PLB 459, 1999, 306): *d=d'* and $\theta=\theta'$
  – Use measured value of ϕ_d to extract γ and ϕ_s
  – Use branching fractions to constrain *d,d'*,θ, θ' and U-spin

Branching fractions

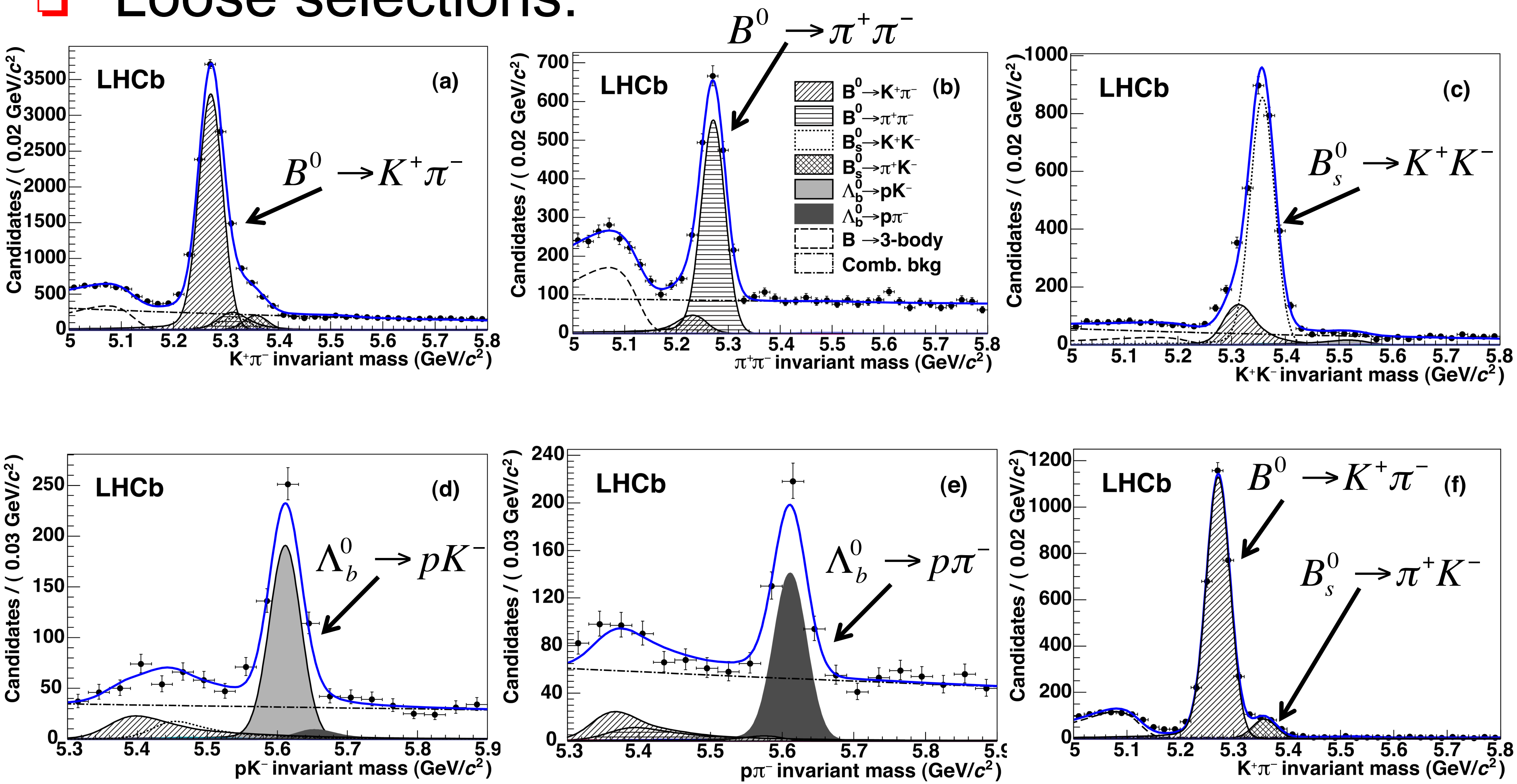
- Branching fractions in charmless two-body decays are all normalised to: $B^0 \to K^+\pi^-$
- Data considered for this analysis: 0.37 fb^{-1} from 2011
- Particle ID used to identify each of the channels
- Three selections, optimised for different channels:
  loose for $B^0 \to K^+\pi^-$, $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$, $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$
  tighter for $B_s^0 \to \pi^+K^-$ and the tightest for $B^0 \to K^+K^-$ and $B_s^0 \to \pi^+\pi^-$

arXiV:1206.2794



Branching fractions

- Loose selections:



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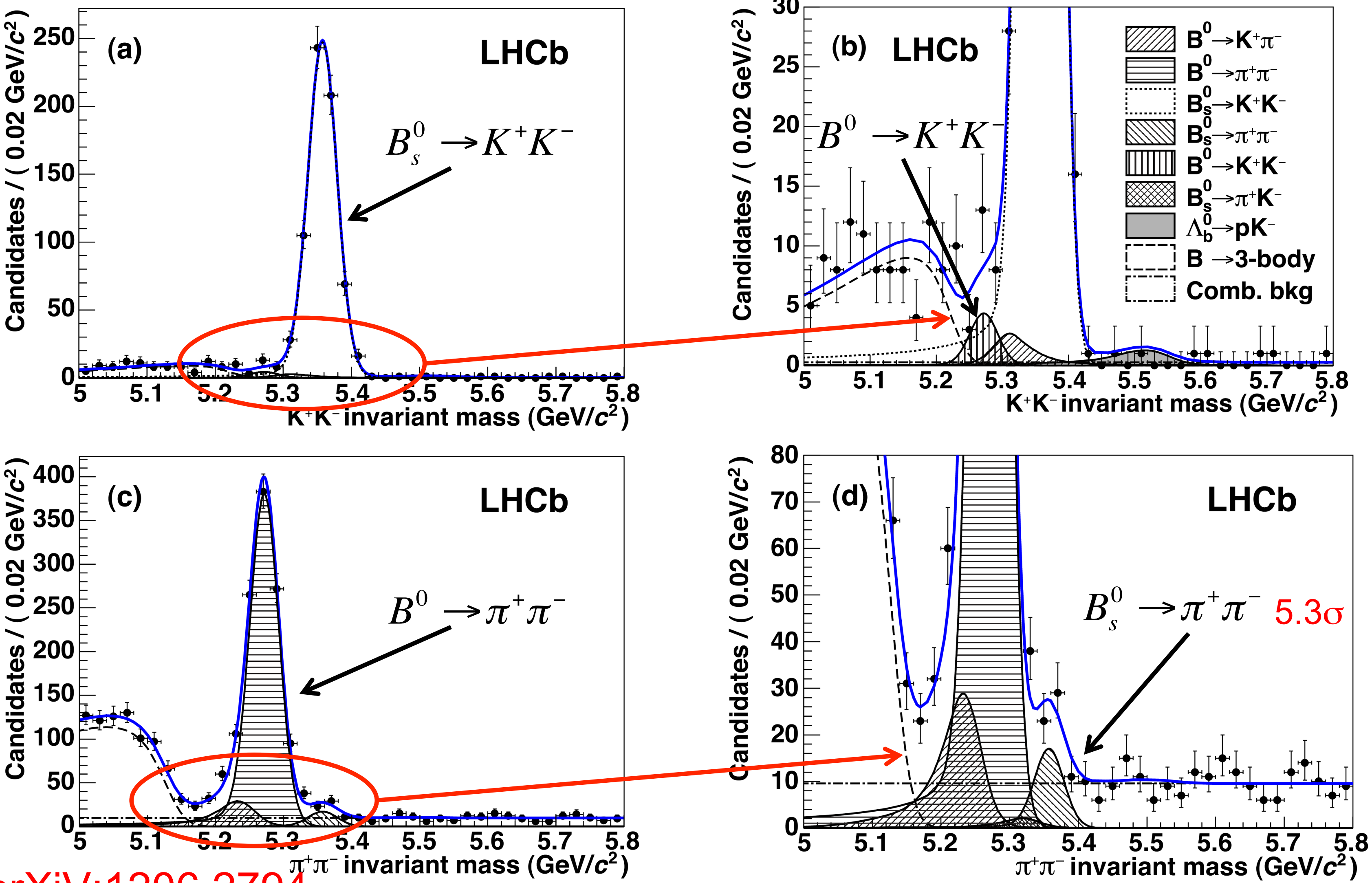
Branching fractions

- Tight selection:



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Branching fractions

- Final results branching fractions: arXiv:1206.2794

$$\mathcal{B}(B^0 \to \pi^+\pi^-)/\mathcal{B}(B^0 \to K^+\pi^-) = 0.262 \pm 0.009 \pm 0.017$$

$$(f_s/f_d) \cdot \mathcal{B}(B_s^0 \to K^+K^-)/\mathcal{B}(B^0 \to K^+\pi^-) = 0.316 \pm 0.009 \pm 0.019$$

$$(f_s/f_d) \cdot \mathcal{B}(B_s^0 \to \pi^+K^-)/\mathcal{B}(B^0 \to K^+\pi^-) = 0.074 \pm 0.006 \pm 0.006$$

$$(f_d/f_s) \cdot \mathcal{B}(B^0 \to K^+K^-)/\mathcal{B}(B_s^0 \to K^+K^-) = 0.018^{+0.008}_{-0.007} \pm 0.009$$

$$(f_s/f_d) \cdot \mathcal{B}(B_s^0 \to \pi^+\pi^-)/\mathcal{B}(B^0 \to \pi^+\pi^-) = 0.050^{+0.011}_{-0.009} \pm 0.004$$

$$\mathcal{B}(\Lambda_b^0 \to p\pi^-)/\mathcal{B}(\Lambda_b^0 \to pK^-) = 0.86 \pm 0.08 \pm 0.05$$ (world's most precise)

- With $\mathcal{B}(B^0 \to K^+\pi^-) = (19.4 \pm 0.6) \times 10^{-6}$ (HFAG) and $f_s/f_d = 0.267^{+0.021}_{-0.020}$ PRD 85 (2012), 032008

$$\mathcal{B}(B^0 \to \pi^+\pi^-) = (5.08 \pm 0.17 \pm 0.37) \times 10^{-6}$$

$$\mathcal{B}(B_s^0 \to K^+K^-) = (23.0 \pm 0.7 \pm 2.3) \times 10^{-6}$$ (world's most precise)

$$\mathcal{B}(B_s^0 \to \pi^+K^-) = (5.4 \pm 0.4 \pm 0.6) \times 10^{-6}$$ (world's most precise)

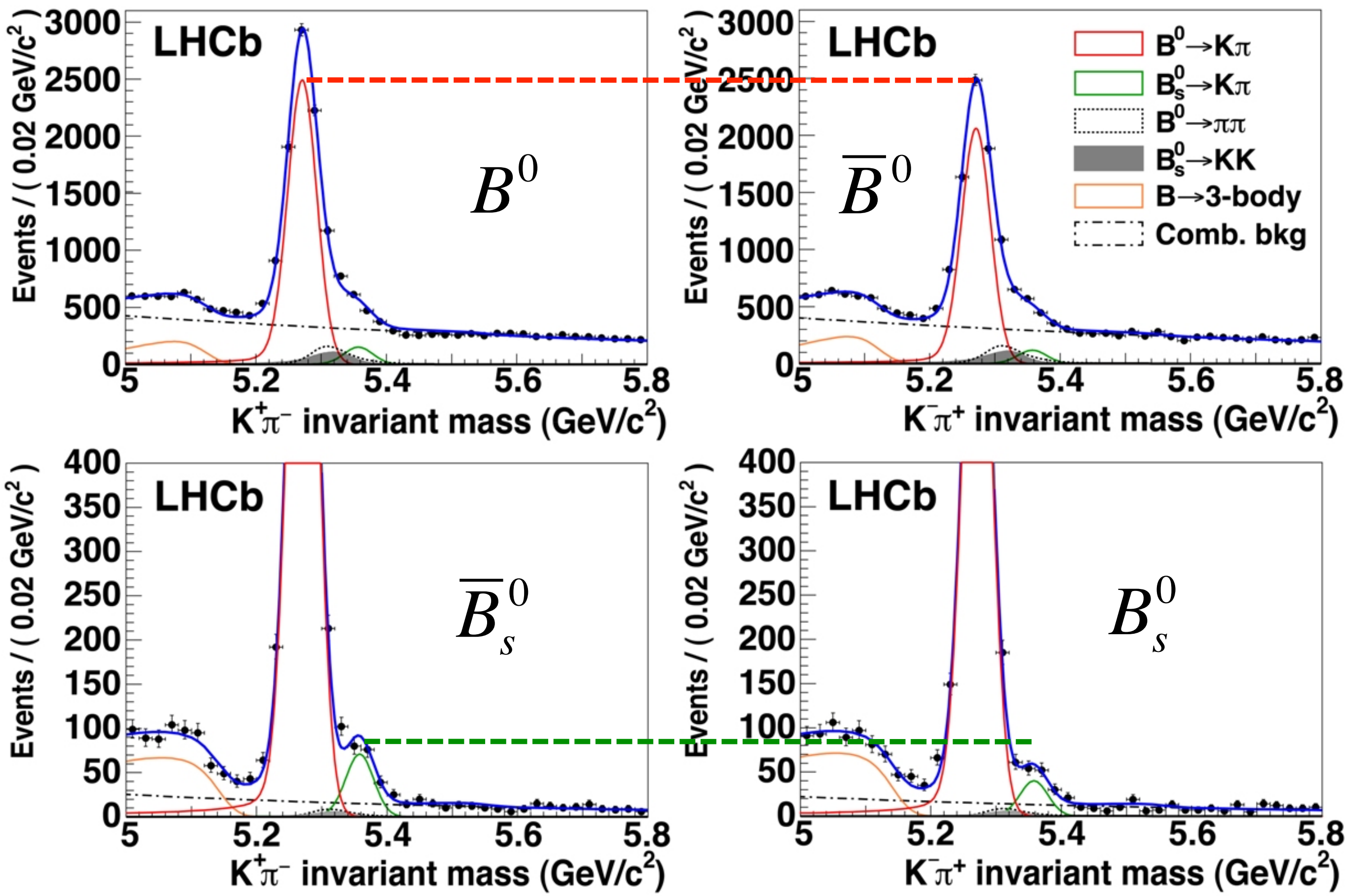
$$\mathcal{B}(B^0 \to K^+K^-) = (0.11^{+0.05}_{-0.04} \pm 0.06) \times 10^{-6}$$ (world's most precise)

$$\mathcal{B}(B_s^0 \to \pi^+\pi^-) = (0.95^{+0.21}_{-0.17} \pm 0.13) \times 10^{-6}$$ (5.3σ, first observation)

$B^0, B_s \rightarrow K\pi$: direct CPV

- Direct CP violation in time integrated decays: PRL 108 (2012), 201601

$$B^0, B_s^0 \rightarrow K^{\pm}\pi^{\mp}$$



$$\mathcal{A}_{CP} \equiv \frac{\Gamma_{\overline{B} \rightarrow \bar{f}} - \Gamma_{B \rightarrow f}}{\Gamma_{\overline{B} \rightarrow \bar{f}} - \Gamma_{B \rightarrow f}}$$

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

First 5σ observation of CPV at hadron machine

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

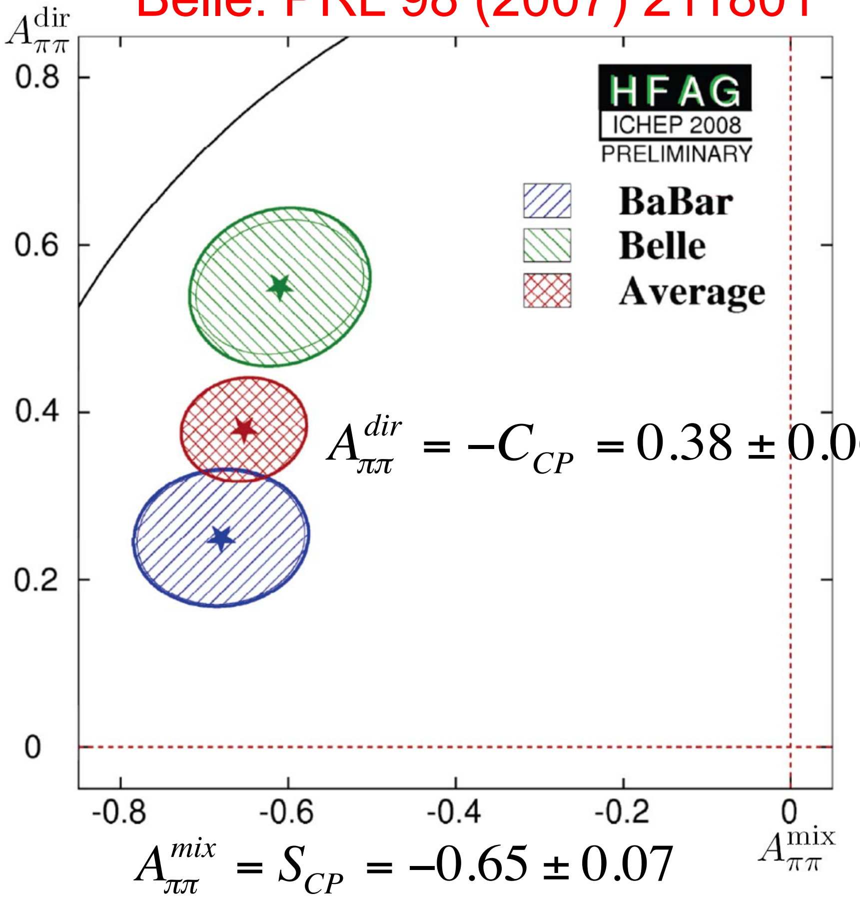
First evidence for CPV in B_s decays (3.3σ)

Experimental situation

- Time-dependent CP asymmetry in $B^0 \to \pi^+\pi^-$
  - Tension in Belle and Babar results on direct CP asymmetry

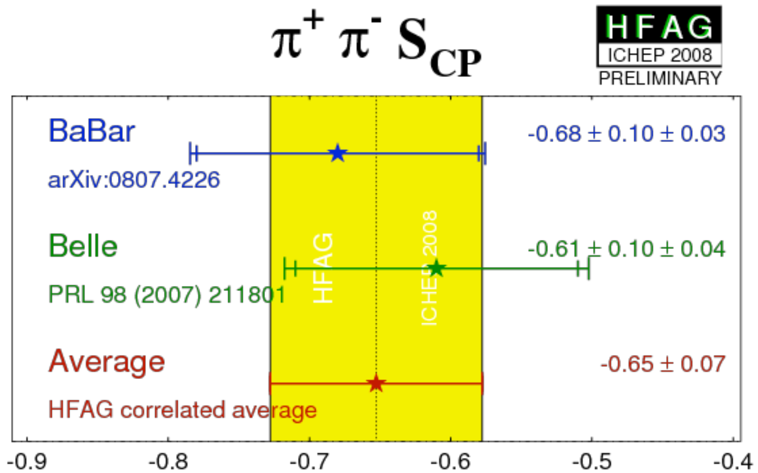
Babar: arXiv:0807.4226

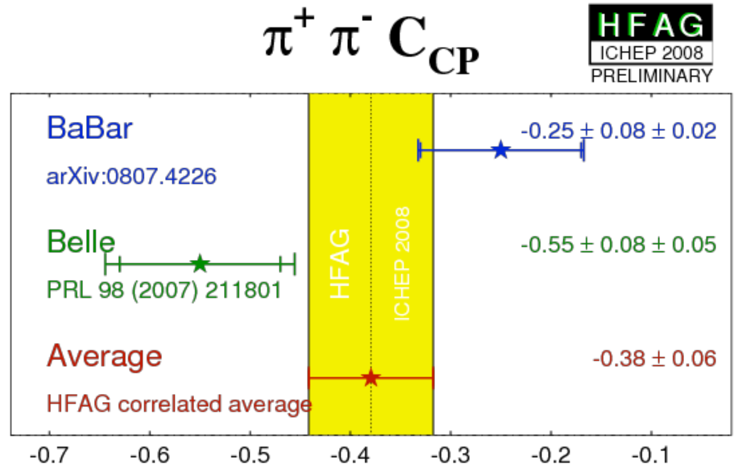
Belle: PRL 98 (2007) 211801



$A_{\pi\pi}^{dir} = -C_{CP} = 0.38 \pm 0.06$

$A_{\pi\pi}^{mix} = S_{CP} = -0.65 \pm 0.07$

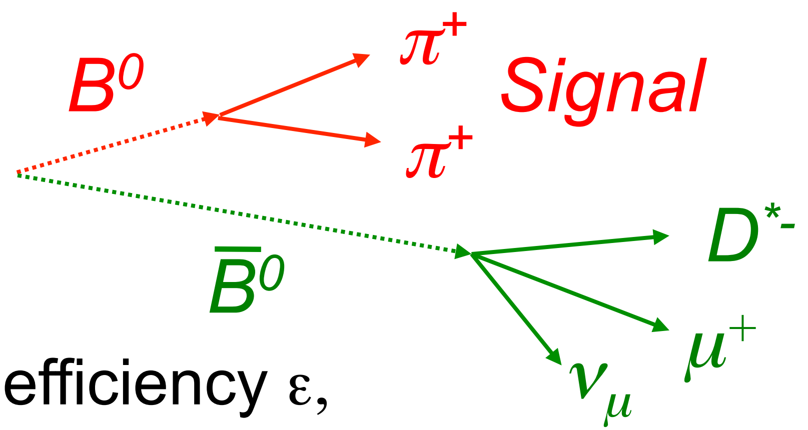




Time-dependent analysis

- LHCb measurement on time-dependent asymmetries
  - Data sample: integrated luminosity 0.69 fb^{-1} from 2011
  - Common event selection: $B \to K\pi$, $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$
  - PID cuts identify each of the final states
  - Parameterisation decay time resolution $\sigma_t = 50\ fs$, from $B \to J/\psi\ X$
  - Acceptance from MC
  - Flavour tagging:
    - Opposite side tagging: arXiv:1202.4979
    - Use $B \to K\pi$ to calibrate efficiency ε, mistag rate ω and tagging power ε_{eff}

$$\varepsilon_{eff} = \varepsilon(1-2\omega)^2$$



Sign of muon tags B^0 flavour at production

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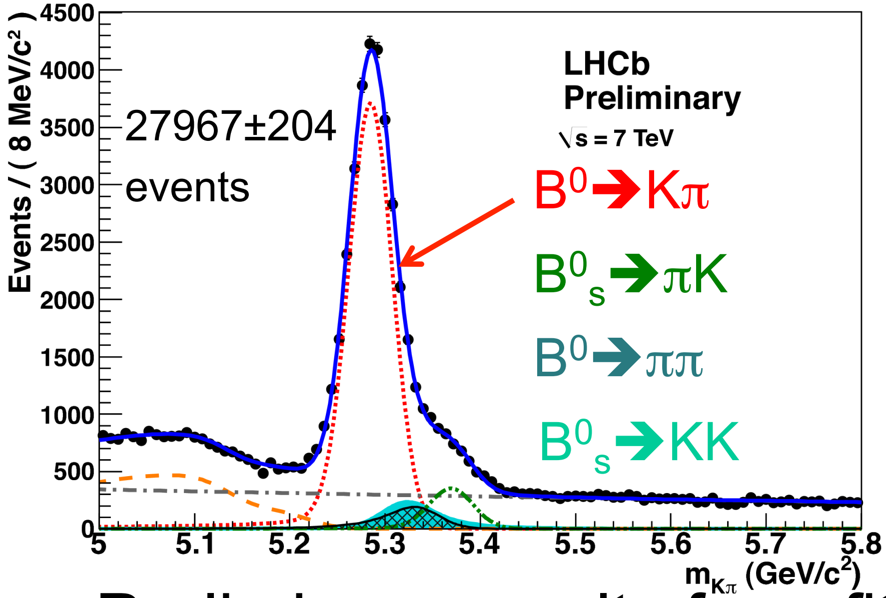
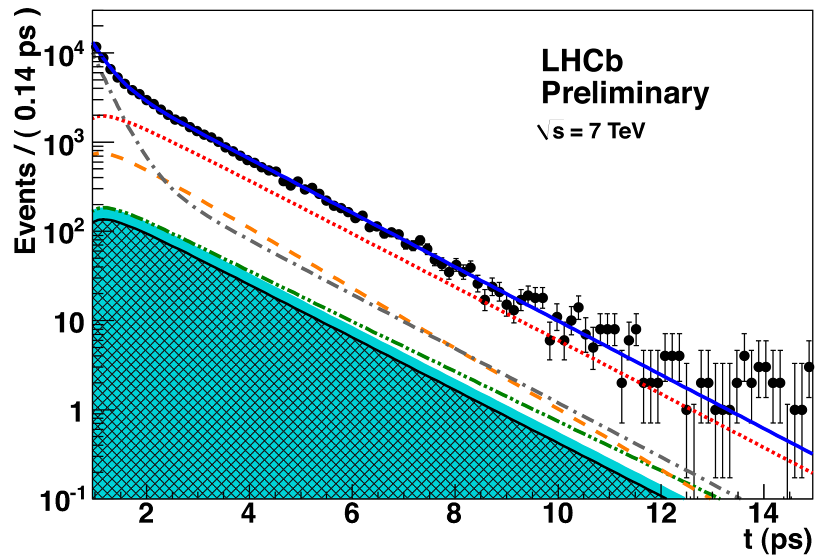
Time-dependent fits $B^0, B^0_s \rightarrow K\pi$

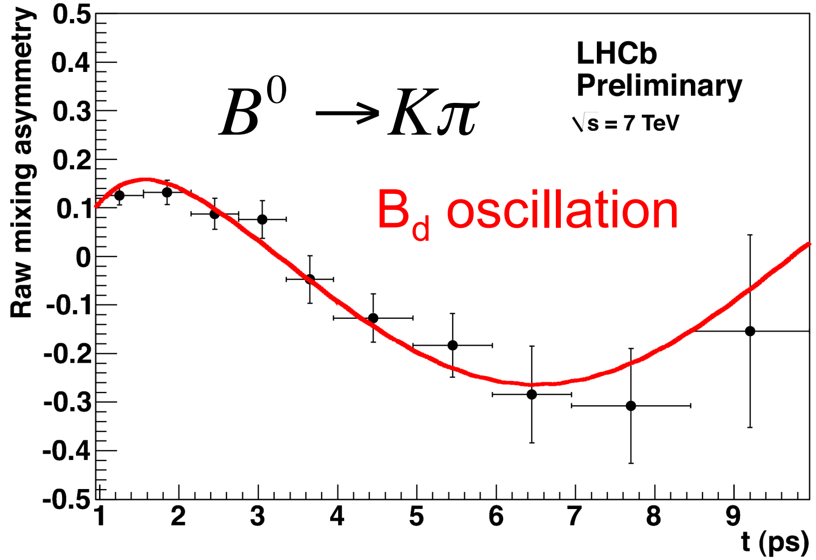




- Preliminary results from fit:
  - Used as control channel
  - Extract Δm_d and $\tau(B^0)$, which agree with world average
  - Tagging power: ε_{eff} = (2.3±0.1)%
  - Production asymmetry:

    $A_p(B)$=(-1.5±1.3)%

    $A_p(B_s)$=(-3±6)% $\sigma_m = 22.4$ MeV/c



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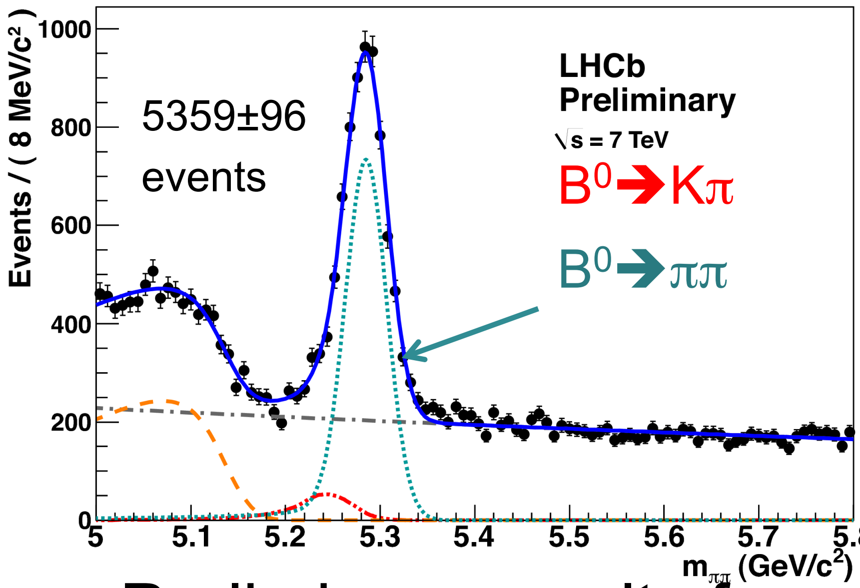
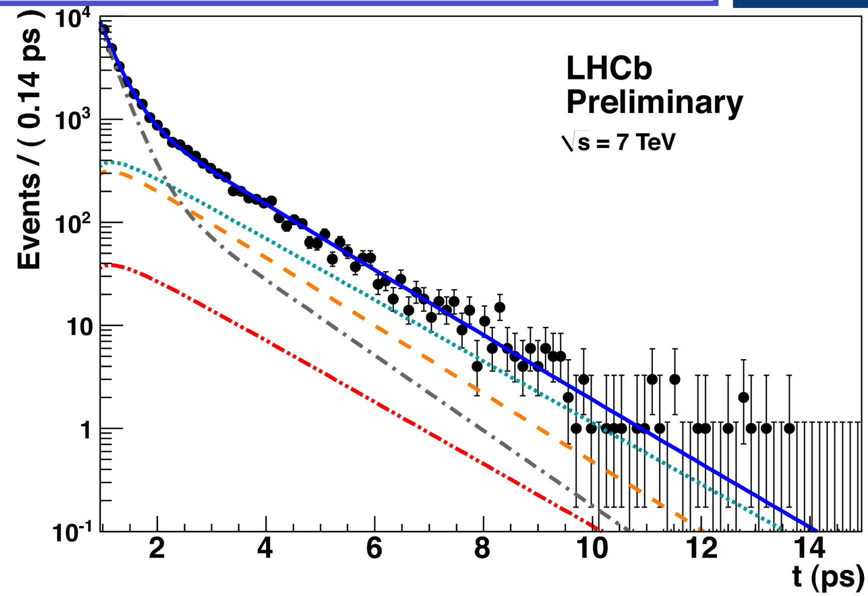
Time-dependent fits $B^0 \rightarrow \pi\pi$





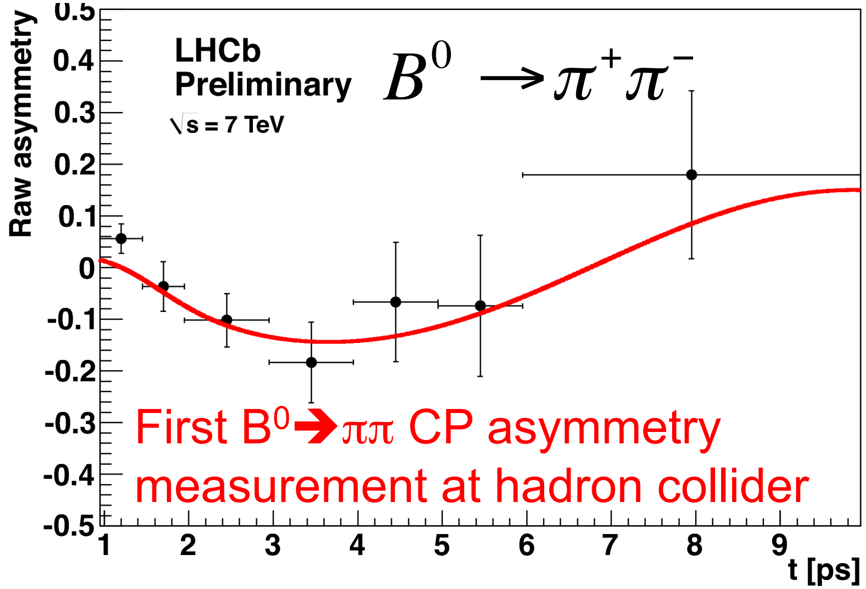
- Preliminary results from fit:

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

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

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

  - Input Δm_d from LHCb, extract $\tau(B^0)$, agrees with world average



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Results $B^0 \rightarrow \pi\pi$

- Preliminary $B^0 \to \pi^+\pi^-$ results from LHCb

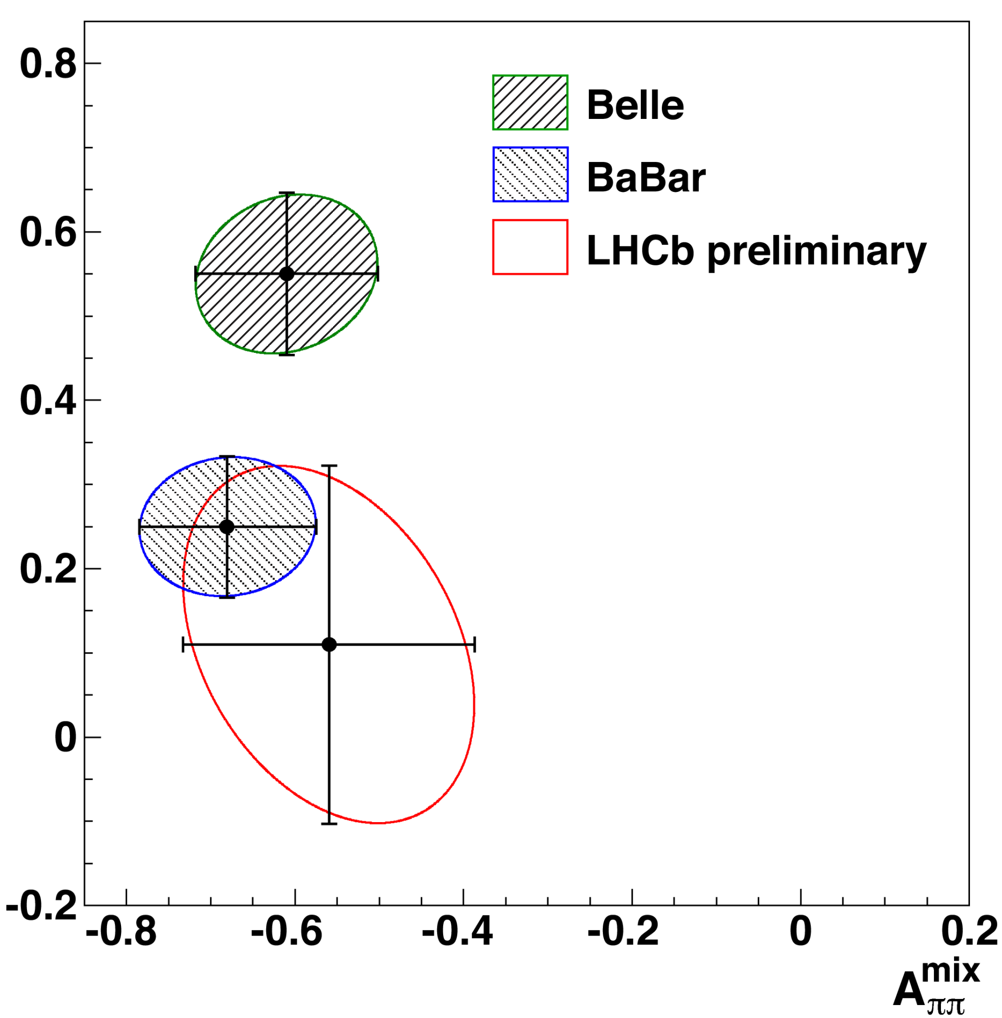
$$A_{\pi\pi}^{dir} = 0.11 \pm 0.21 \pm 0.03$$

$$A_{\pi\pi}^{mix} = -0.56 \pm 0.17 \pm 0.03 \text{ (3.2}\sigma\text{)}$$

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

Preliminary LHCb result favours Babar

Statistically limited
Main systematic: input Δm_d



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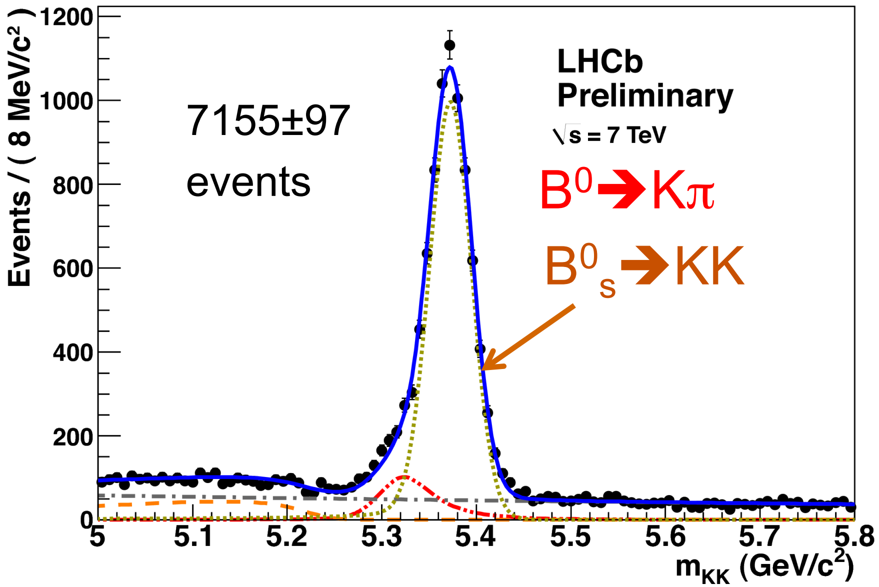
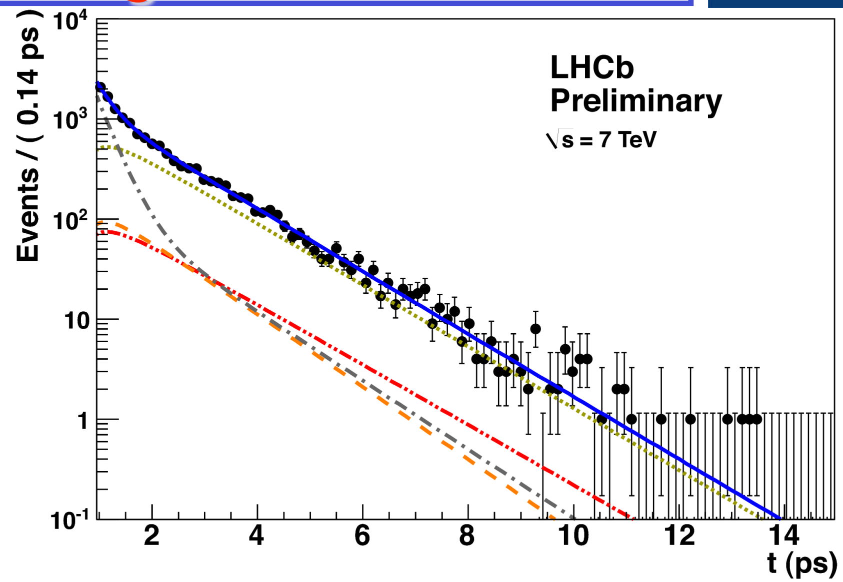
Time-dependent fits $B_s \rightarrow KK$





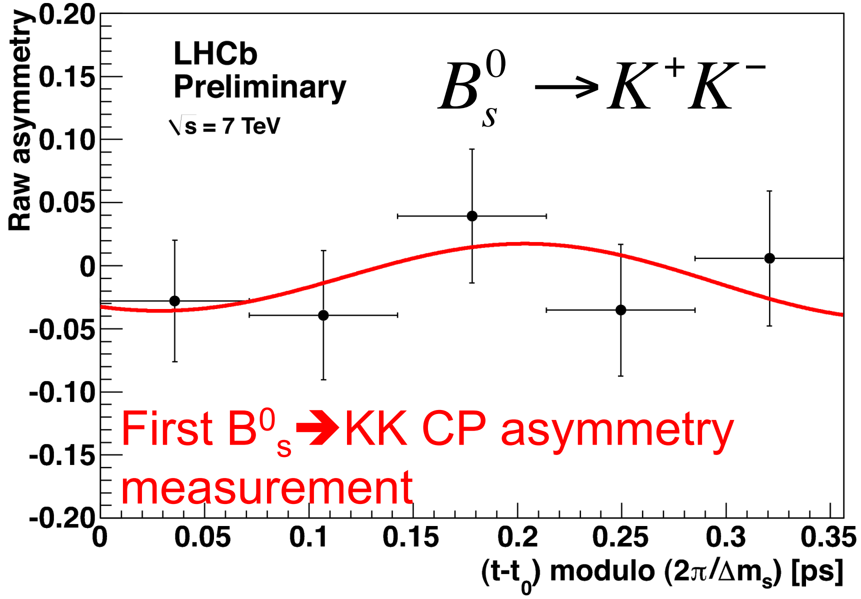
- Preliminary results from fit:

$$A_{KK}^{dir} = 0.02 \pm 0.18 \pm 0.04$$

$$A_{KK}^{mix} = 0.17 \pm 0.18 \pm 0.05$$

$$\rho\left(A_{KK}^{dir}, A_{KK}^{mix}\right) = -0.10$$

  - Input: Δm_s, Γ_s from LHCb
  - Extract $\Delta\Gamma_s$, agrees world average



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Results $B_s \rightarrow KK$

- Preliminary $B_s^0 \to K^+K^-$ results from LHCb

$$A_{KK}^{dir} = 0.02 \pm 0.18 \pm 0.04$$

$$A_{KK}^{mix} = 0.17 \pm 0.18 \pm 0.05$$

$$\rho\left(A_{KK}^{dir}, A_{KK}^{mix}\right) = -0.10$$

Expect:

$$A_{KK}^{dir} \approx A_{CP}(B^0 \to K^+\pi^-) =$$

$$-0.088 \pm 0.011 \pm 0.008$$

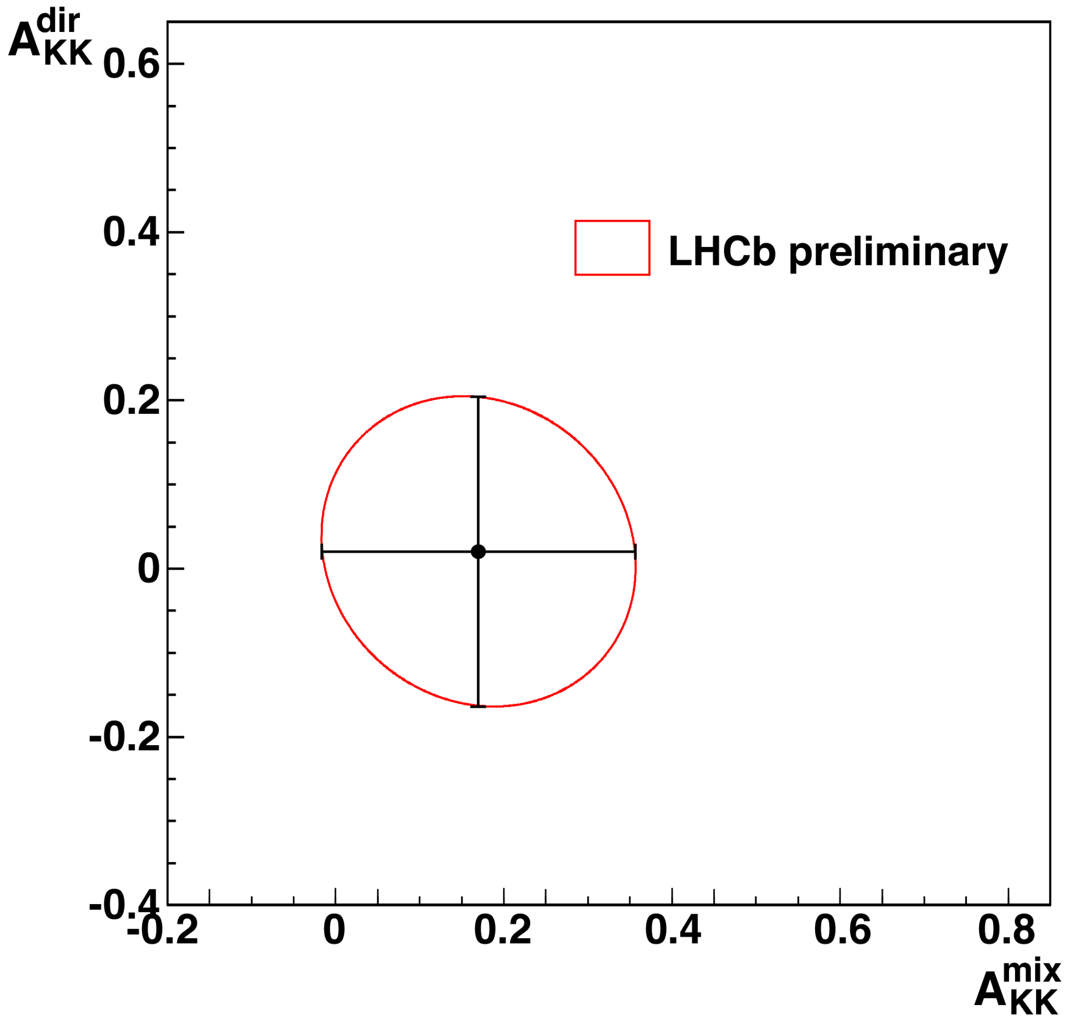
(LHCb measurement)

under U-spin symmetry

SM prediction: $A_{KK}^{mix} \approx 0.15$

Statistically limited

Main systematics: decay time acceptance and resolution, and input Δm_s



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Conclusions

- Branching fractions of two-body charmless B decays established: three channels world's most precise and $B_s^0 \to \pi^+\pi^-$ observed for the first time at 5.3σ
- Direct CPV: first 5σ observation of CPV at hadron collider and first evidence of CPV in B_s decays
- Time-dependent CP violation in two body charmless B decays using 0.69 fb^{-1} data from 2011:
  - $B_d^0 \to \pi^+\pi^-$ CP asymmetries agree with world average
  - First evidence (3.2σ) time-dependent CPV at hadron collider
  - CP asymmetry in $B_s^0 \to K^+K^-$ measured for the first time
- Outlook:
  - Analyses still statistically limited: 1.0 fb^{-1} collected in 2011 and 0.6 fb^{-1} collected in 2012 (expect ~1.5 fb^{-1} by end of the year)

Backup Slides

Branching fractions

- Signal yields from fits to selections A, B and C:

Selection	Decay	Signal yield
A	$B^0 \to K^+\pi^-$	9822 ± 122
	$B^0 \to \pi^+\pi^-$	1667 ± 51
	$B_s^0 \to K^+K^-$	2523 ± 59
	$\Lambda_b^0 \to pK^-$	372 ± 22
	$\Lambda_b^0 \to p\pi^-$	279 ± 22
B	$B^0 \to K^+\pi^-$	3295 ± 59
	$B_s^0 \to \pi^+K^-$	249 ± 20
C	$B^0 \to \pi^+\pi^-$	1076 ± 36
	$B_s^0 \to K^+K^-$	682 ± 27
	$B^0 \to K^+K^-$	$13\,^{+6}_{-5}$
	$B_s^0 \to \pi^+\pi^-$	$49\,^{+11}_{-9}$

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