The study of γ/ϕ_3-sensitive hadronic decays at LHCb

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on behalf of LHCb Collaboration

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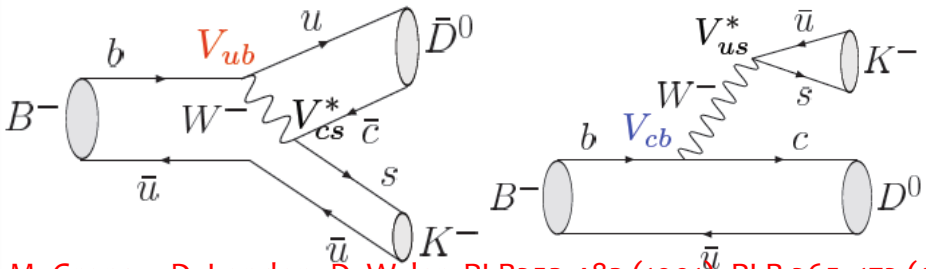
Introduction

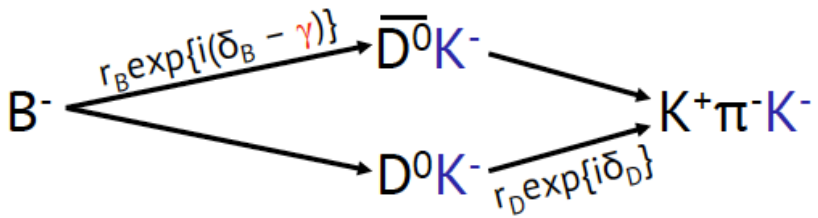
Results from two families of decays related to γ determination

Tree-level determination of γ from $B^{\pm}\to DK^{\pm}$ and $B^{\pm}\to D\pi^{\pm}$



M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991)
D. Atwood, I. Dunietz, A. Soni, PRL 78, 3357 (1997).

✓ $D\to K\pi/K3\pi/KK$: ADS/GLW



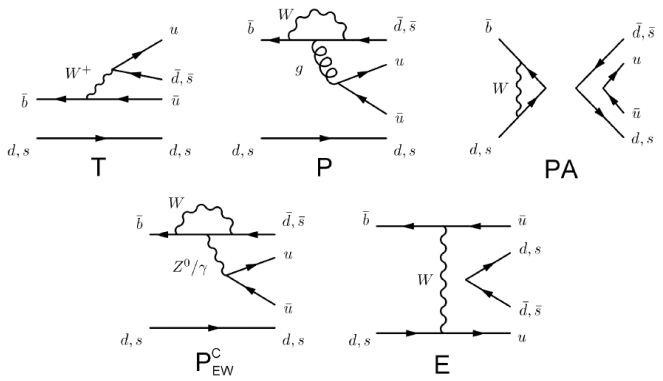
r_B relative magnitude
δ_B strong phase difference

✓ $D\to K_s\pi\pi$: Dalitz plot analysis

Loop-level determination of γ from $B\to h^+h^{-\prime}$ family

The direct and mixing induced CP asymmetries in the $B^0\to\pi\pi$ and $B^0_s\to KK$ modes are related to the angle γ and the B^0 and B_s^0 mixing phase ϕ_d and ϕ_s

R. Fleischer, PLB 459 (1999) 306 R. Fleischer and R. Knegjens EPJ C71 (2011) 1532



Need U-spin symmetry

Today results

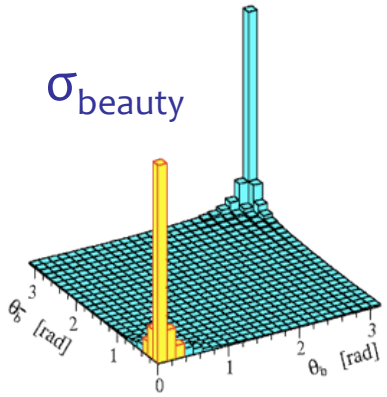
- $B \rightarrow h^+ h^{-\prime}$
  - Analysis with 320 pb^{-1} (2011 data) [LHCb-CONF-2011-042]
    - charge (direct) CP asymmetries in $B^0 \rightarrow K\pi$ and $B^0_s \rightarrow \pi K$
    - first observation of $B^0_s \rightarrow \pi\pi$ and measurement of branching ratio
    - Measurement of the $B^0 \rightarrow KK$ branching ratio
- $B^\pm \rightarrow DK^\pm$ and $B^\pm \rightarrow D\pi^\pm$
  - Analysis with 36.5 pb^{-1} (2010 data) [LHCb-CONF-2011-031]
    - Ratio of branching fraction $BR(B^\pm \rightarrow DK^\pm)/BR(B^\pm \rightarrow D\pi^\pm)$ with $D \rightarrow K\pi$, KK, $K\pi\pi\pi$, $K_s^0\pi\pi$
    - $R_{CP+} = 1 + r_B^2 + 2\, r_B \cos(\delta_B)\cos(\gamma)$
    - $A_{CP+} = 2 r_B \sin(\delta_B)\sin(\gamma)/R_{CP+}$

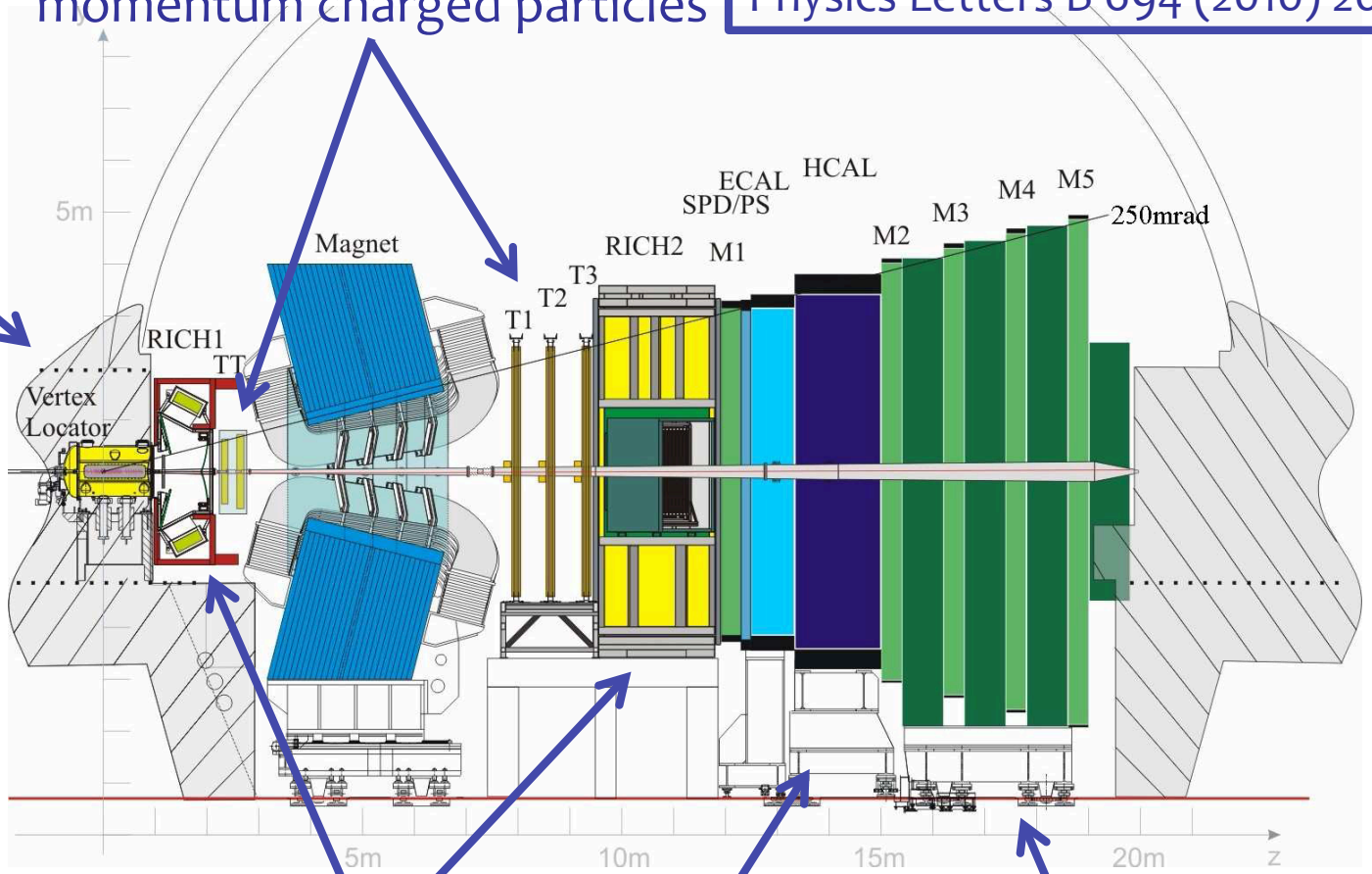
LHCb detector

σ_{beauty} = (284 ± 20 ± 49) μb @ 7TeV
Physics Letters B 694 (2010) 209

Vertex Locator:
Primary Vertex
Impact parameters

Tracking Stations:
momentum charged particles





For more details on detector performances see
Martin Van Beuzekom's talk

Rich I & II
PID: π,K,p

Calorimeters
PID: γ,e,π⁰

Muon System
PID: μ

Results from $B \rightarrow h^{+}h^{-'}$ decays

Direct CP asymmetries

- Direct CP asymmetries:

$$A_{CP}(B^0 \to K\pi) = \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)} \qquad A_{CP}(B_s^0 \to \pi K) = \frac{\Gamma(\bar{B}_s^0 \to \pi^-K^+) - \Gamma(B_s^0 \to \pi^+K^-)}{\Gamma(\bar{B}_s^0 \to \pi^-K^+) + \Gamma(B_s^0 \to \pi^+K^-)}$$

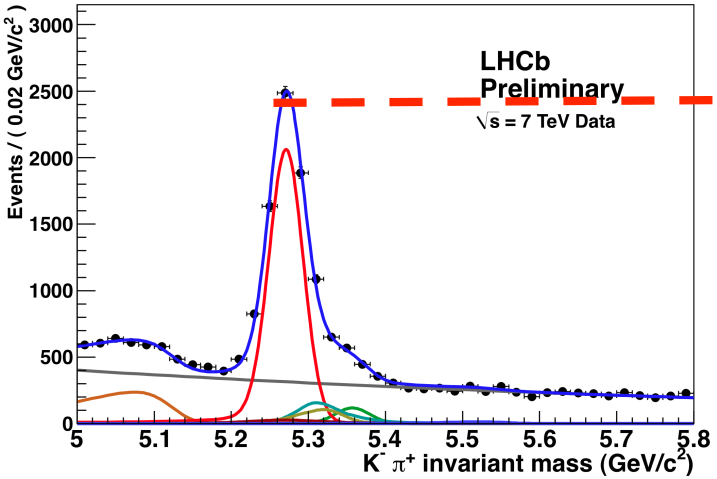
- The asymmetries measured in data must be corrected for:
  - detector-induced $K^+\pi^-/\pi^-K^+$ charge asymmetries
  - B production asymmetry
- The physical CP asymmetries are then related to the "Raw" asymmetries:

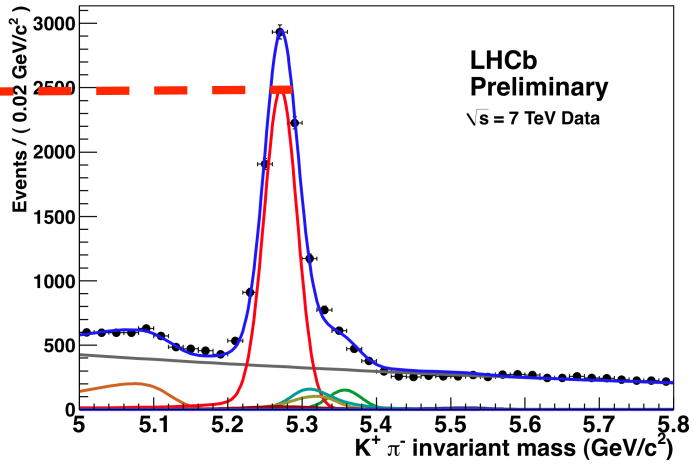
$$A_{CP}(B^0 \to K\pi) = A_{CP}^{RAW}(B^0 \to K\pi) - A_\Delta(B^0 \to K\pi)$$

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

Raw asymmetries

Raw CP asymmetry in $B^0 \to K\pi$: -0.095 ± 0.011

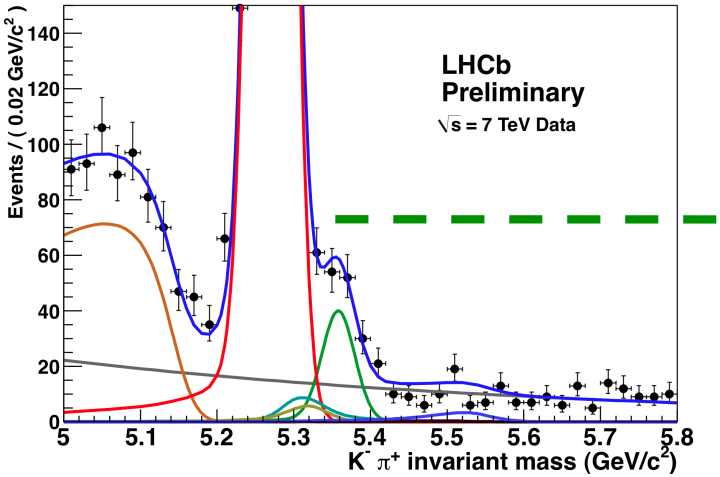


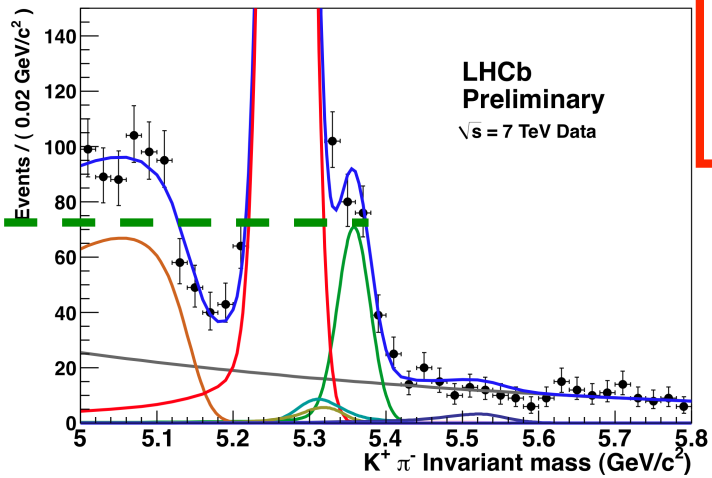


2011 data
$L=320\ pb^{-1}$

Selection optimized for $A_{CP}(B^0 \to K\pi)$

Raw CP asymmetry in $B^0_s \to \pi K$: 0.28 ±0.08





Raw CP asymmetry clearly visible from the plots

Selection optimized for $A_{CP}(B^0_s \to \pi K)$

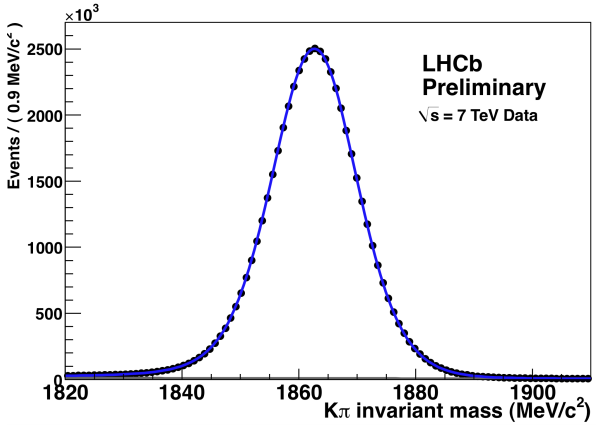
From raw to physical asymmetries

2011 data L=320 pb^{-1}

- Instrumental $K^+\pi^-/\pi^-K^+$ charge asymmetry extracted from control channels: $D^* \rightarrow D^0(K\pi)\pi_s$, $D^* \rightarrow D^0(KK)\pi_s$ and untagged $D^0 \rightarrow K\pi$
- B production asymmetry measured from the decay $B^0 \rightarrow J/\psi(\mu\mu)K^{*0}(K\pi)$

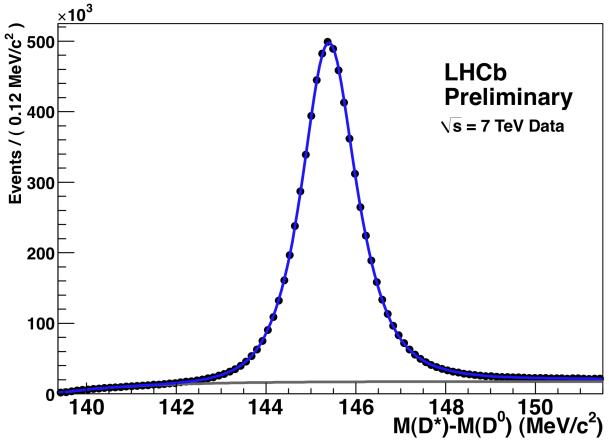
$D^0 \rightarrow K\pi$

N_{sig}=54M



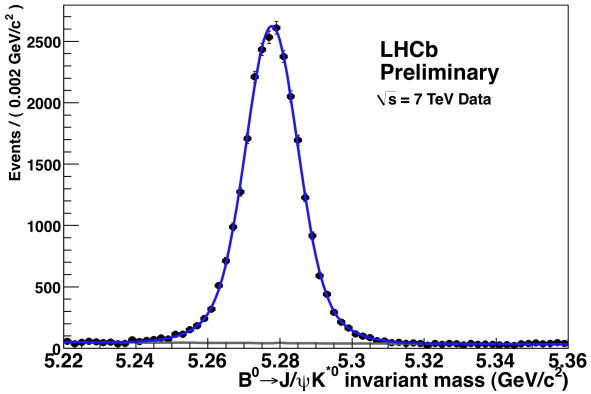
$D^* \rightarrow D^0(K\pi)\pi_s$

N_{sig}=7M



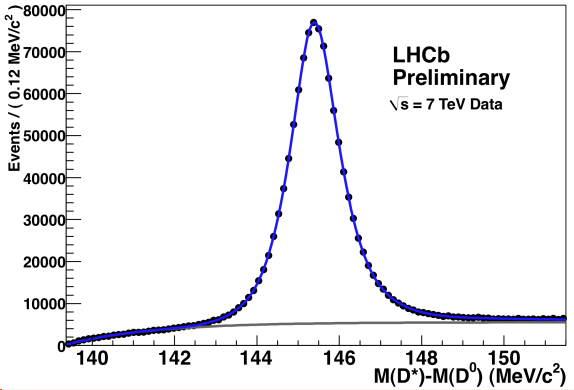
$B^0 \rightarrow J/\psi K^{*0}$

N_{sig}=25k



$D^* \rightarrow D^0(KK)\pi_s$

N_{sig}=1M

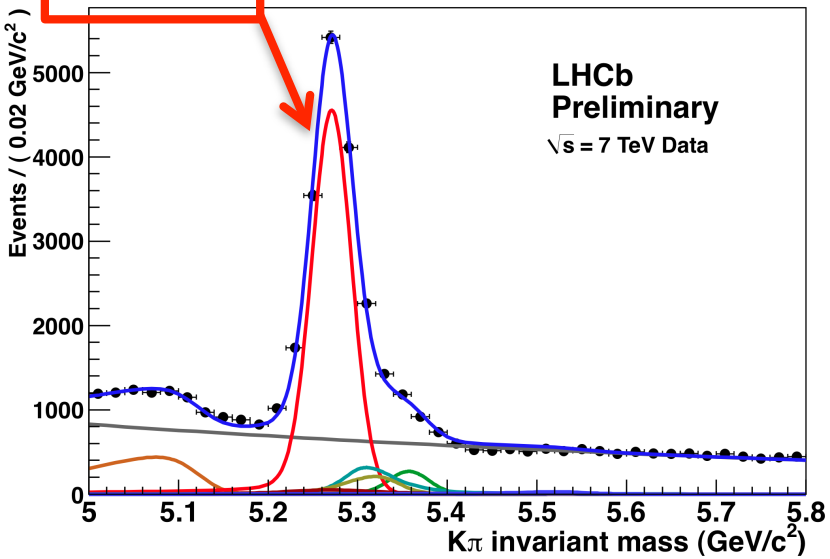


Direct CP asymmetries results

Kπ mass spectra

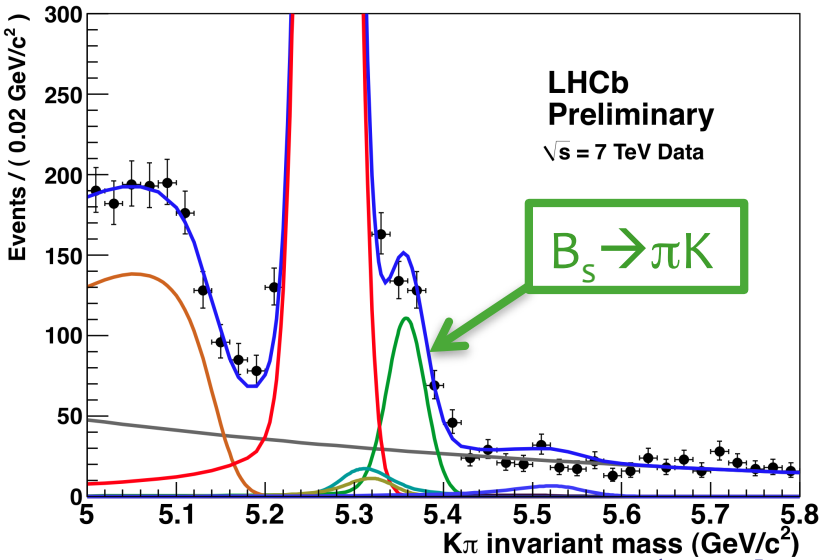
2011 data L=320 pb^{-1}

$B^0 \to K\pi$



Selection optimized for $A_{CP}(B^0 \to K\pi)$

$N(B^0 \to K\pi) = 13244 \pm 151$



Selection optimized for $A_{CP}(B^0_s \to \pi K)$

$N(B^0_s \to \pi K) = 313 \pm 26$

$$A_{CP}(B^0 \to K^+\pi^-) = -0.088 \pm 0.011(\text{stat}) \pm 0.008(\text{syst})$$

World's first 5σ measurement of CP violation in the B system in a hadron collider

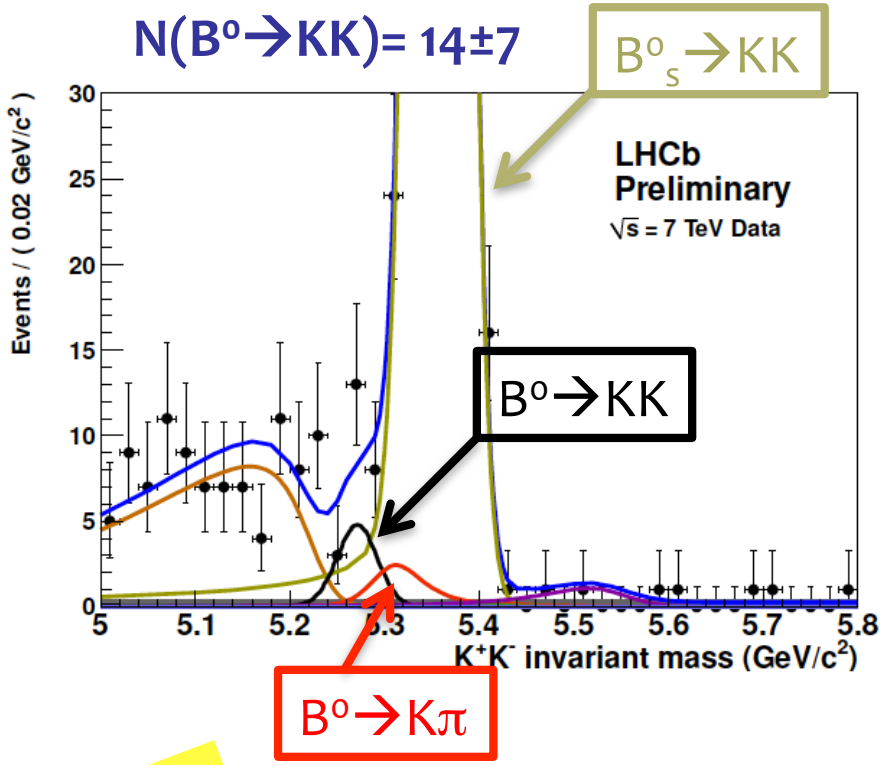
$$A_{CP}(B^0_s \to \pi^+ K^-) = 0.27 \pm 0.08(\text{stat}) \pm 0.02(\text{syst})$$

Preliminary

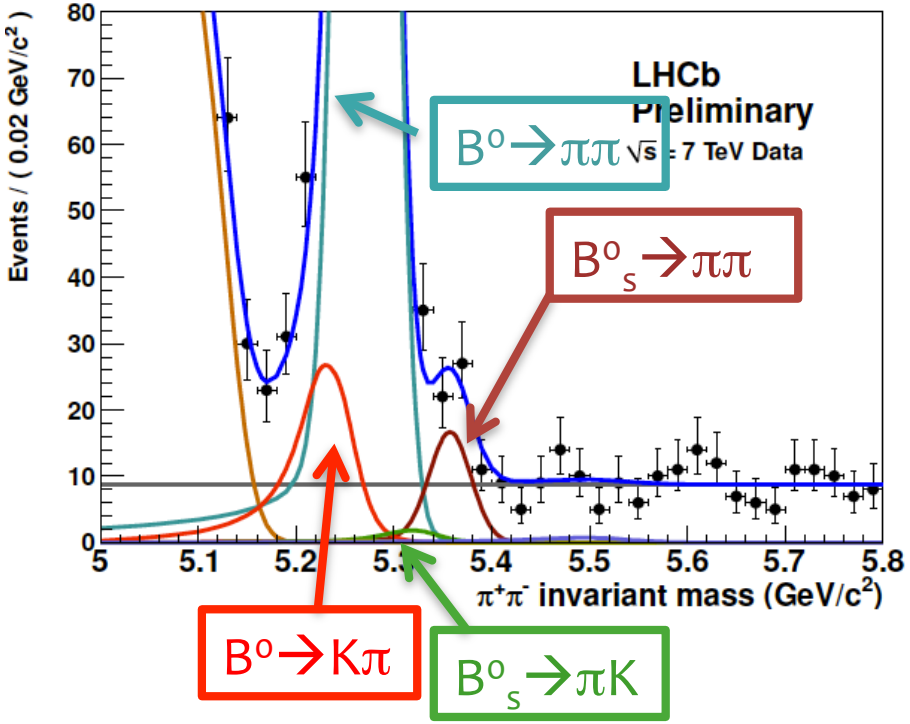
First evidence of CP violation in $B_s \to \pi K$

Searching rare decays

$N(B^0 \to KK) = 14 \pm 7$



$N(B_s \to \pi\pi) = 47 \pm 10$



Preliminary

2011 data L=320 pb^{-1}

$$\mathcal{BR}(B^0 \to K^+K^-) = (0.13^{+0.06}_{-0.05}(\text{stat}) \pm 0.07(\text{syst})) \times 10^{-6}$$

$$\mathcal{BR}(B^0_s \to \pi^+\pi^-) = (0.98^{+0.23}_{-0.19}(\text{stat}) \pm 0.11(\text{syst})) \times 10^{-6}$$

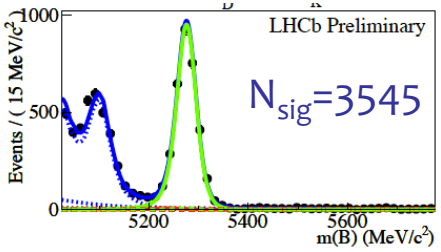
first observation of $B^0_s \to \pi\pi$ with a significance of 5.3 σ

Results from $B^{\pm} \rightarrow DK^{\pm}$ and $B^{\pm} \rightarrow D\pi^{\pm}$ decays

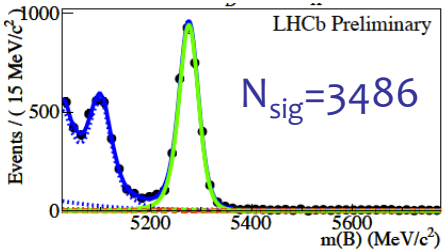
$B^{\pm}\to DK^{\pm}$, $B^{\pm}\to D\pi^{\pm}$: $D\to K\pi, K\pi\pi\pi, K_s^0\pi\pi$

2010 data L=35.6 pb^{-1}

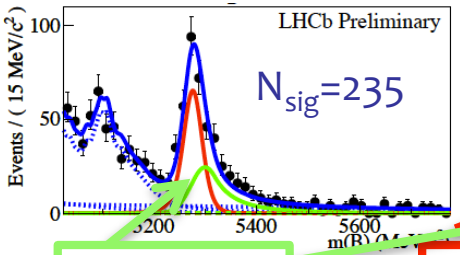
$B^-\to(K\pi)_D\pi^-$



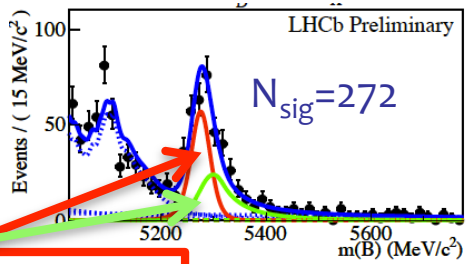
$B^+\to(K\pi)_D\pi^+$



$B^-\to(K\pi)_DK^-$



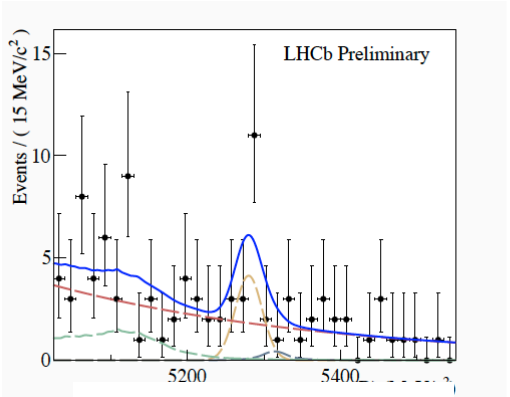
$B^+\to(K\pi)_DK^+$



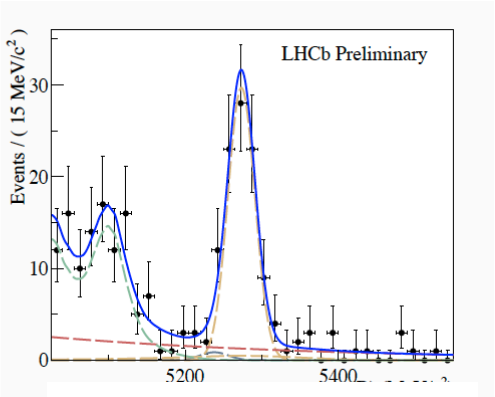
$B^{\pm}\to D\pi^{\pm}$

$B^{\pm}\to DK^{\pm}$

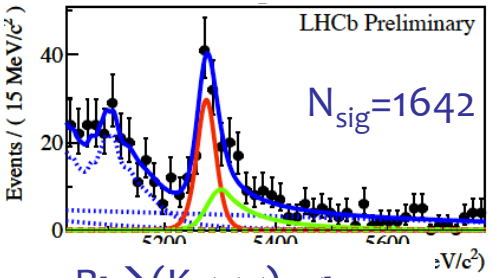
$N(B\to(K_s^0\pi\pi)_DK)= 12^{+6}_{-5}$



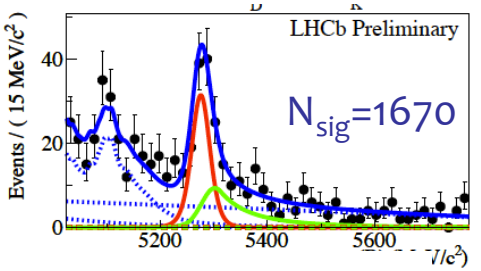
$N(B\to(K_s^0\pi\pi)_D\pi)= 95^{+14}_{-12}$



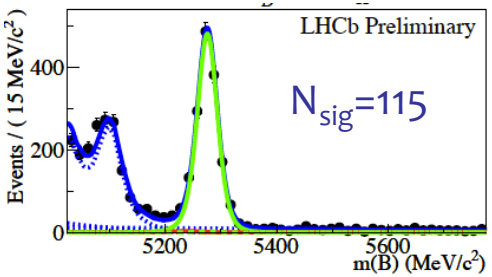
$B^-\to(K\pi\pi\pi)_DK^-$



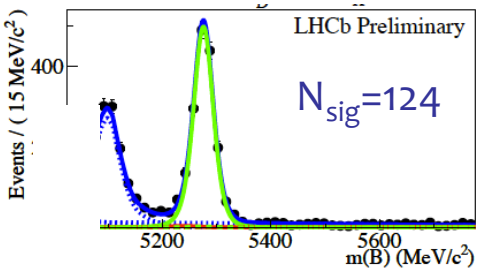
$B^+\to(K\pi\pi\pi)_DK^+$



$B^-\to(K\pi\pi\pi)_D\pi^-$



$B^+\to(K\pi\pi\pi)_D\pi^+$



Ratio of branching fraction

$BR(B^{\pm}\to DK^{\pm})/BR(B^{\pm}\to D\pi^{\pm})$

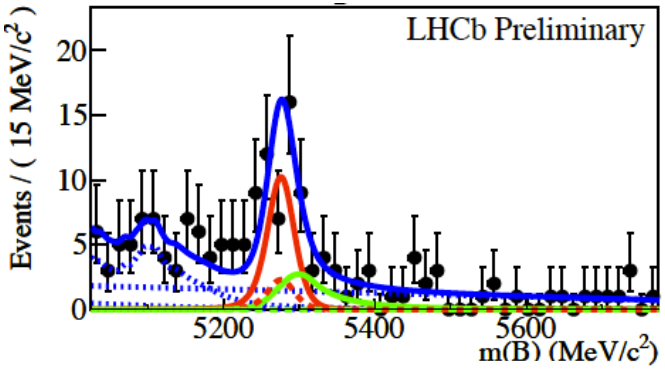
$$\mathcal{R}_{CF}^{k/\pi} = (6.30 \pm 0.38 \pm 0.40)\%$$

$$\mathcal{R}_{K_S^0\pi\pi}^{k/\pi} = (12.0^{+6.0}_{-5.0} \pm 1.0)\%$$

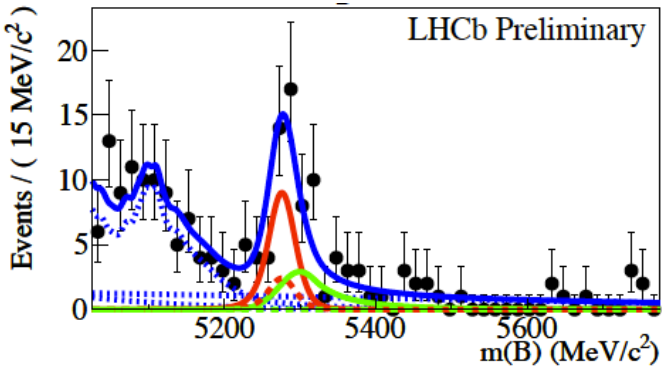
Preliminary

$B^{\pm} \to DK^{\pm}$, $B^{\pm} \to D\pi^{\pm}$: $D \to KK$

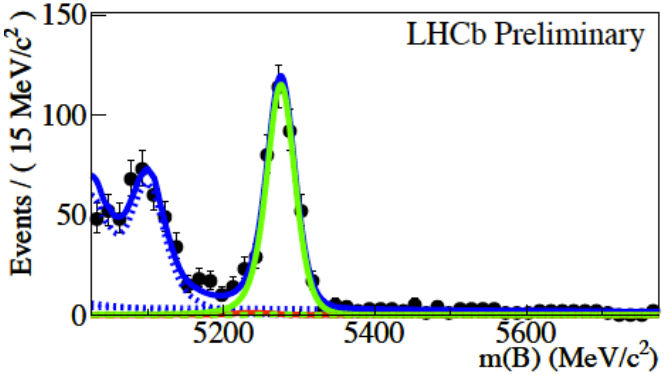
$B^- \to (KK)_D K^-$



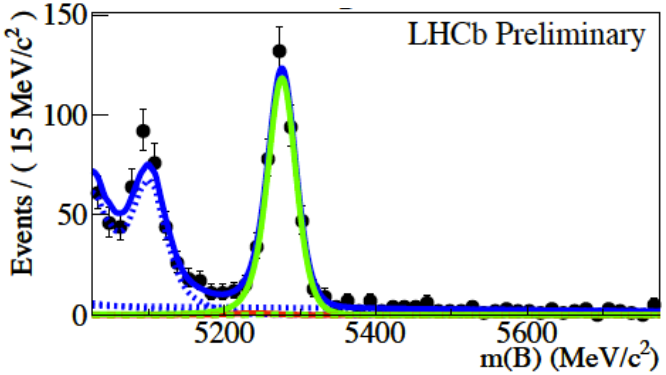
$B^+ \to (KK)_D K^+$



$B^- \to (KK)_D \pi^-$



$B^+ \to (KK)_D \pi^+$



Preliminary

2010 data L=35.6 pb^{-1}

Yields

	$D^0 \to K^+K^-$
$B^- \to DK^-$	44
$B^+ \to DK^+$	40
$B^- \to D\pi^-$	405
$B^+ \to D\pi^+$	419

Ratio of branching fraction

$BR(B^{\pm} \to DK^{\pm})/BR(B^{\pm} \to D\pi^{\pm})$

$$\mathcal{R}^{k/\pi}_{CP+} = (9.31 \pm 1.89 \pm 0.53)\%$$

γ from $B^{\pm} \to D(KK)K^{\pm}/\pi^{\pm}$ decays with GLW method

$r_B \equiv |A(B^- \to \overline{D}^0 K^-)/A(B^- \to D^0 K^-)|$

δ_B difference of strong phases

Observables:

Direct-CP-violating decay rates

$$A_{CP\pm} \equiv \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)} \qquad A_{CP\pm} = \frac{\pm 2 \cdot r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma}$$

2010 data
L=35.6 pb^{-1}

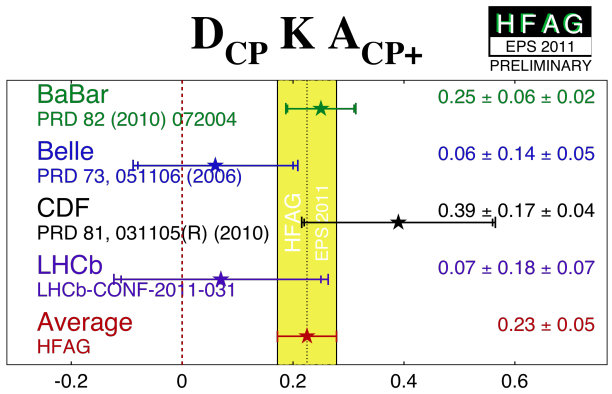
Ratio of charge averaged rates using D decays to CP eingeinstates:

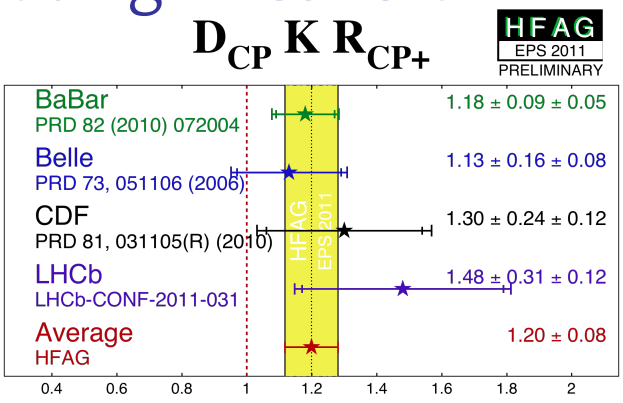
$$R_{CP\pm} \equiv 2\frac{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \overline{D}^0 K^+)} \qquad R_{CP\pm} = 1 + r_B^2 \pm 2 \cdot r_B \cos\delta_B \cos\gamma$$

$$R_{CP+} = 1.48 \pm 0.31(stat.) \pm 0.12(syst.)$$
$$A_{CP+} = 0.07 \pm 0.18(stat.) \pm 0.07(syst.)$$

Preliminary

New HFAG averages including LHCb results





Conclusions

- $B \rightarrow hh$ ($L=320\ pb^{-1}$, 2011 data)
  - $A_{CP}(B^0 \rightarrow K\pi) = -0.088 \pm 0.011 \pm 0.008$
  - $A_{CP}(B^0_s \rightarrow \pi K) = 0.27 \pm 0.08 \pm 0.02$
  - $BR(B^0_s \rightarrow \pi\pi) = (0.98^{+0.23}_{-0.19} \pm 0.11) \times 10^{-6}$

World's first 5σ measurement of CP violation in the B system in a hadron collider

First evidence CP violation in $B_s \rightarrow \pi K$

First observation with a significance of 5.3 σ

- $B^{\pm} \rightarrow DK^{\pm}/\pi^{\pm}$ ($L=35.6\ pb^{-1}$, 2010 data)
  - $D \rightarrow K\pi, K3\pi$
    - $BR(B^{\pm} \rightarrow DK^{\pm})/BR(B^{\pm} \rightarrow D\pi^{\pm}) = (6.30 \pm 0.38 \pm 0.40)\%$
  - $D \rightarrow KK$:
    - $R_{CP+} = 1.48 \pm 0.31 \pm 0.12$;
    - $A_{CP+} = 0.07 \pm 0.18 \pm 0.07$

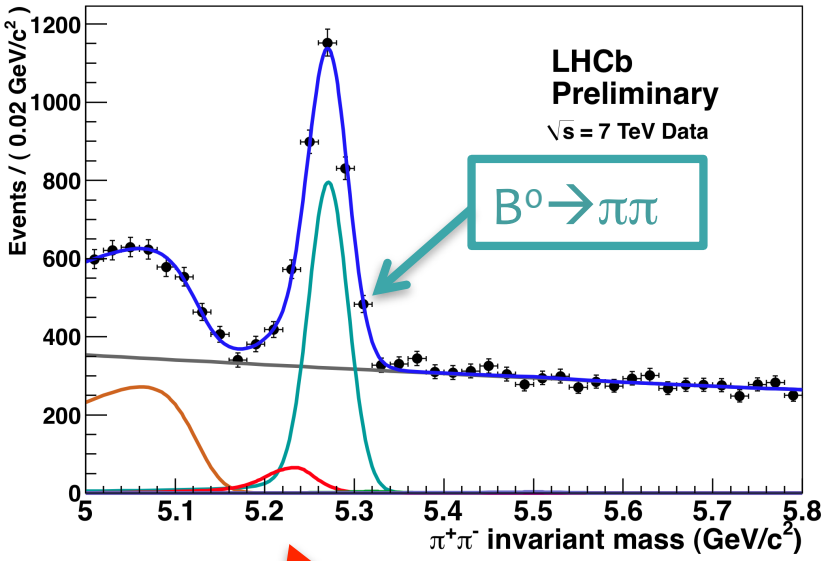
good agreement with existing measurements

Backup

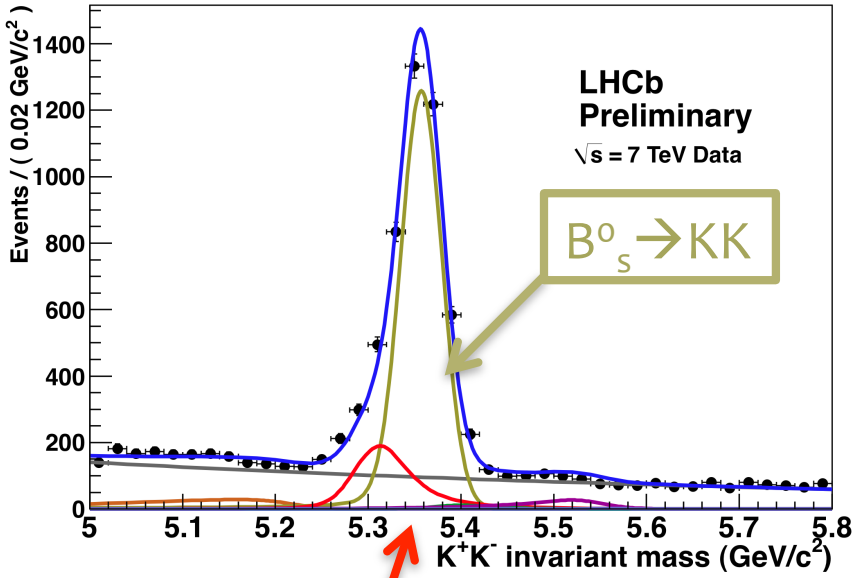
Towards time-dependent asymmetries in $B^0 \to \pi\pi$ and $B^0_s \to KK$

2011 data L=320 pb^{-1}

$N(B^0 \to \pi\pi) = 2347 \pm 71$



$N(B^0_s \to KK) = 3627 \pm 72$



Selection optimized for $A_{CP}(B^0 \to K\pi)$

Cross feed background dominated by $B^0 \to K\pi$ decays

U-spin consistency check

By U-spin symmetry and neglecting penguin annihilation and exchange topologies we expect

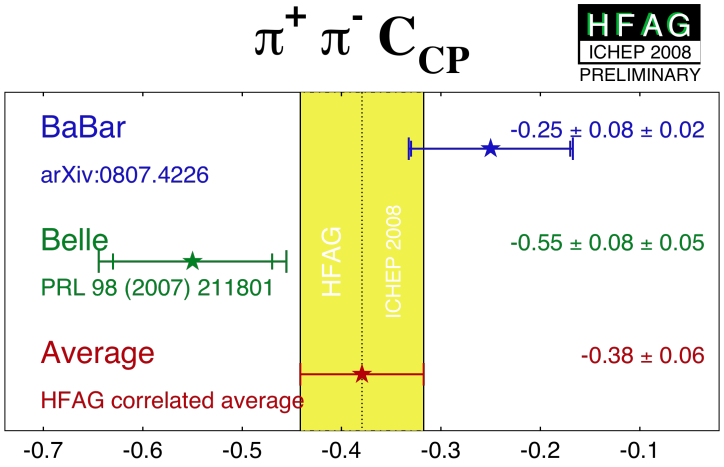
$$A_{CP}(B_s^0 \to \pi^+ K^-) \approx \mathcal{A}^{dir}_{\pi^+\pi^-}$$

$C_{CP} = - A^{dir}_{\pi+\pi-}$

LHCb

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

$$0.27 \pm 0.08(\text{stat}) \pm 0.02(\text{syst})$$



Perfect agreement with Babar
Bare agreement with Belle

Normalizationo of BR($B^0 \to KK$) and BR($B_s^0 \to \pi\pi$)

$$\frac{f_d \cdot \mathcal{BR}(B^0 \to K^+K^-)}{f_s \cdot \mathcal{BR}(B_s^0 \to K^+K^-)} = \frac{N(B^0 \to K^+K^-)}{N(B_s^0 \to K^+K^-)} \cdot \frac{\varepsilon_{rec}(B_s^0 \to K^+K^-)}{\varepsilon_{rec}(B^0 \to K^+K^-)}$$

$$\frac{f_s \cdot \mathcal{BR}(B_s^0 \to \pi^+\pi^-)}{f_d \cdot \mathcal{BR}(B^0 \to \pi^+\pi^-)} = \frac{N(B_s^0 \to \pi^+\pi^-)}{N(B^0 \to \pi^+\pi^-)} \cdot \frac{\varepsilon_{rec}(B^0 \to \pi^+\pi^-)}{\varepsilon_{rec}(B_s^0 \to \pi^+\pi^-)}$$

LHCb average

[LHCb-CONF-2011-034]

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

HFAG average

$$\mathcal{BR}(B^0 \to \pi^+\pi^-) = (5.16 \pm 0.22) \times 10^{-6}$$

$$\mathcal{BR}(B_s^0 \to K^+K^-) = (26.5 \pm 4.4) \times 10^{-6}$$

$$\mathcal{BR}(B^0 \to K^+K^-) = (0.14 \pm 0.06(\text{stat}) \pm 0.07(\text{syst})) \times 10^{-6}$$

$$\mathcal{BR}(B_s^0 \to \pi^+\pi^-) = (0.98 \pm 0.21(\text{stat}) \pm 0.11(\text{syst})) \times 10^{-6}$$

B→hh: trigger and event selection

- Hadronic trigger
  - Look for large E_T cluster in the hadronic calorimeter (Level-0) and high p_T track with large impact parameter with respect to the primary vertex (High Level Trigger)
- Then offline we make use of three sets of kinematic selection cuts, optimized to get the best sensitivity for the measurements of $A_{CP}(B^0 \to K\pi)$, $A_{CP}(B^0_s \to \pi K)$ and for observing rare decays $B^0 \to KK$ and $B^0_s \to \pi\pi$

For the measurement of $A_{CP}(B^0 \to K^+\pi^-)$

Cut type	Accepted regions
Track p_T [GeV/c]	> 1.1
Track IP [μm]	> 150
Track χ^2/d.o.f.	< 3
$\max(p_T^{h^+}, p_T^{h'^-})$ [GeV/c]	> 2.8
$\max(IP^h, IP^{h'^-})$ [μm]	> 300
p_T^B [GeV/c]	> 2.2
$t_{\pi\pi}$ [ps]	> 0.9

For the measurement of $A_{CP}(B_s \to \pi^+K^-)$

Cut type	Accepted regions
Track p_T [GeV/c]	> 1.2
Track IP [μm]	> 200
Track χ^2/d.o.f.	< 3
$\max(p_T^{h^+}, p_T^{h'^-})$ [GeV/c]	> 3.0
$\max(IP^h, IP^{h'^-})$ [μm]	> 400
p_T^B [GeV/c]	> 2.4
$t_{\pi\pi}$ [ps]	> 1.5

For the measurement of $BR(B_s \to \pi^+\pi^-)$ and $BR(B^0 \to K^+K^-)$

Cut type	Accepted regions
Track p_T [GeV/c]	> 1.2
Track IP [μm]	> 200
Track χ^2/d.o.f.	< 3
$\max(p_T^{h^+}, p_T^{h'^-})$ [GeV/c]	> 3.0
$\text{amax}(IP^h, IP^{h'^-})$ [μm]	> 400
p_T^B [GeV/c]	> 2.8
$t_{\pi\pi}$ [ps]	> 2.0

B→Dh: event selection

Quantity	$D^0 \to K^+\pi^-$	$D^0 \to K^+K^-$	$D^0 \to K^+\pi^-\pi^+\pi^-$
D^0 p_T		$> 1\,\mathrm{GeV}/c$	$> 2\,\mathrm{GeV}/c$
Daughter $K^\pm$ $\lvert\vec{p}\rvert$		$> 2\,\mathrm{GeV}/c$	$> 3\,\mathrm{GeV}/c$
Number (#) of D daughters		$> 330\,\mathrm{MeV}/c$ (2)	$> 240\,\mathrm{MeV}/c$ (3)
with p_T			$> 400\,\mathrm{MeV}/c$ (2)
Number (#) of D daughters		> 21 (2)	> 16 (3)
with IP significance χ^2		> 40 (1)	> 30 (2)
			> 40 (1)
$B^\pm$ impact parameter (IP) χ^2		< 9	
$B^\pm$ flight distance χ^2		> 76	
$B^\pm$ DOCA		$< 0.1\,\mathrm{mm}$	
$B^\pm$ cos(direction angle)		> 0.99995	
$B^\pm$ lifetime		$> 0.2\,\mathrm{ps}$	
$B^\pm$ vertex χ^2/d.o.f.		< 12	
$B^\pm$ mass window		5025 — $5779\,\mathrm{MeV}/c^2$	
D^0 flight distance χ^2		> 252	
D^0 max(DOCA)		$< 0.3\,\mathrm{mm}$	
D^0 cos(direction angle)		> 0.992	
D^0 vertex χ^2/d.o.f.		< 6	
$\mathrm{m}(D^0) - \mathrm{m}(D^0)_{\mathrm{PDG}}$		$\pm 25\,\mathrm{MeV}/c^2$	
Bachelor p_T		0.5 — 10 GeV/c	
Bachelor $\lvert\vec{p}\rvert$		5 — 100 GeV/c	
Bachelor IP significance χ^2		> 28	
Daughter K DLL_K		> 0	
Daughter π $\lvert\vec{p}\rvert$		$> 2\,\mathrm{GeV}/c$	
All track χ^2/d.o.f.		< 5	
Selection efficiency for $DK(D\pi)$	9.2%(9.3%)	8.8%(9.0%)	2.7%(2.7%)

Particle	Selection criterion
K^0_S daughter π	IP $\chi^2 > 9$ 2 GeV/c < $\lvert\vec{p}\rvert$ < 100 GeV/c track χ^2/d.o.f. < 5
K^0_S	$\lvert$mass - PDG$\rvert$ < 15 MeV/c^2 vertex χ^2/d.o.f. < 16 flight distance χ^2> 4
D daughter π	IP $\chi^2 > 25$ 2 GeV/c < $\lvert\vec{p}\rvert$ < 100 GeV/c $\Delta LL(\pi - K) > -10$ track χ^2/d.o.f. < 5
D	$\lvert$mass - PDG$\rvert$ < 25 MeV/c^2 vertex χ^2/d.o.f. < 4
Bachelor $K^\pm$ or $\pi^\pm$	$\mathrm{DLL}_K > 0$ (for K) or $\mathrm{DLL}_K < 0$ (for π) track χ^2/d.o.f. < 5 2 GeV/c < $\lvert\vec{p}\rvert$ < 100 GeV/c IP $\chi^2 > 16$ $p_T > 1$ GeV/c
$B^\pm$	5025 MeV/c^2 < mass < 5550 MeV/c^2 flight distance $\chi^2 > 169$ vertex χ^2/d.o.f.< 6.25 IP $\chi^2 < 9$ cos(decay angle) > 0.99999
-	Number of tracks in event < 240