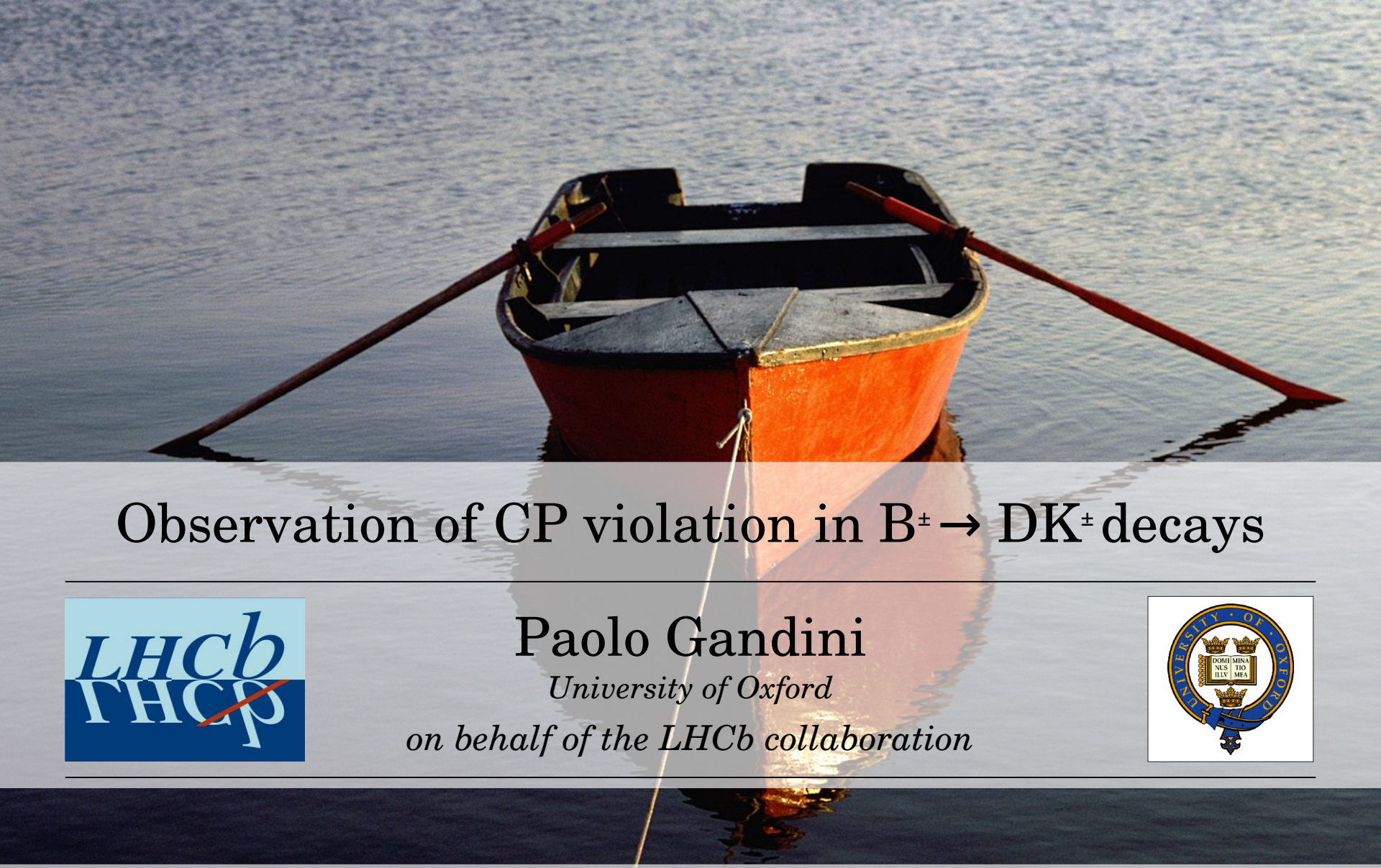


Observation of CP violation in $B^{\pm} \to DK^{\pm}$ decays

Paolo Gandini

University of Oxford

on behalf of the LHCb collaboration

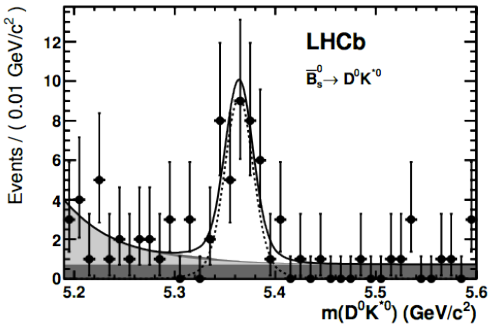
IOP Meeting - Queen Mary, University of London

4th April 2012

γ from B → DK at LHCb

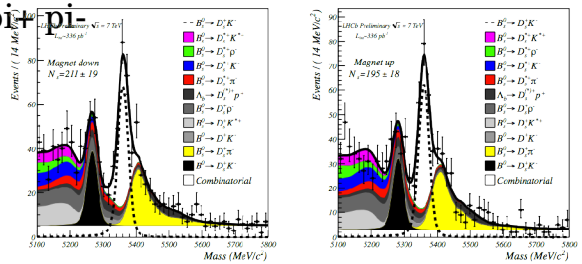
Many analyses for γ in progress. Many milestones passed:

$B \to [hh,hhhh]_D K$ decays { LHCb-CONF-2011-031, LHCb-CONF-2011-044



$\overline{B}{}^0 \to D^0 K^{*0}$ { Phys. Lett. B 706 (2011) 32-39
First observation of $\overline{B}_s \to D^0 K^{*0}$ LHCb
*Cabibbo-allowed background mode for Bd -> D0K**

$B \to DK\pi\pi$ decays { LHCB-PAPER-2011-040 ArXiv:1201.4402
First observation of the decays
B0 → D+ K- pi+ pi- and B- → D0 K- pi+ pi-



$B_s \to D_s K^{\pm}$ { LHCb-CONF-2011-057
first observation by LHCb

THIS TALK: presentation of ***DIRECT CP VIOLATION in B → DK decays***

LHCb-PAPER-2012-001 arXiv:1203.3662 submitted to PLB

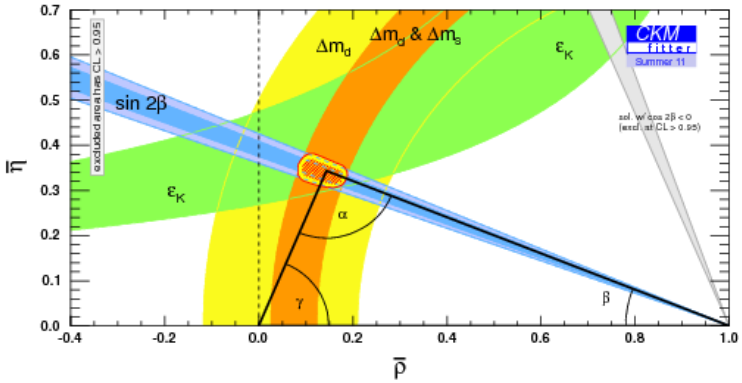
using the full 2011 data set of 1.0 fb^{-1}

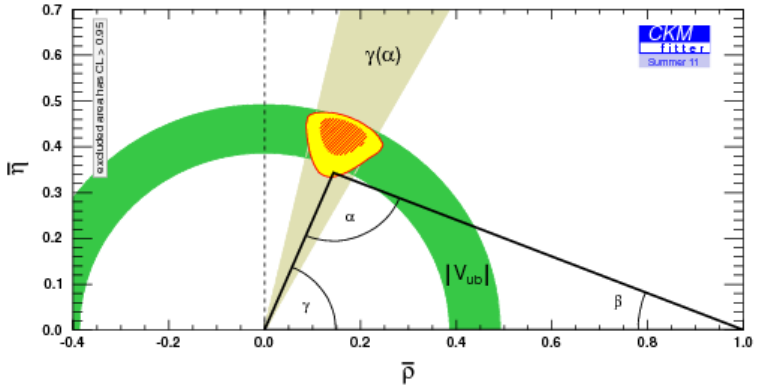
Introduction

Loop Only

Courtesy of CKMfitter

Tree Only

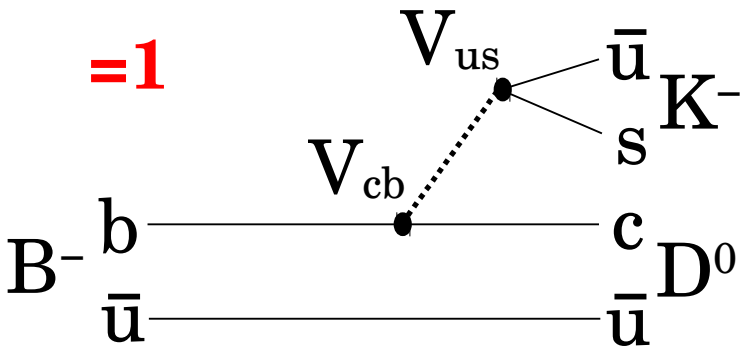


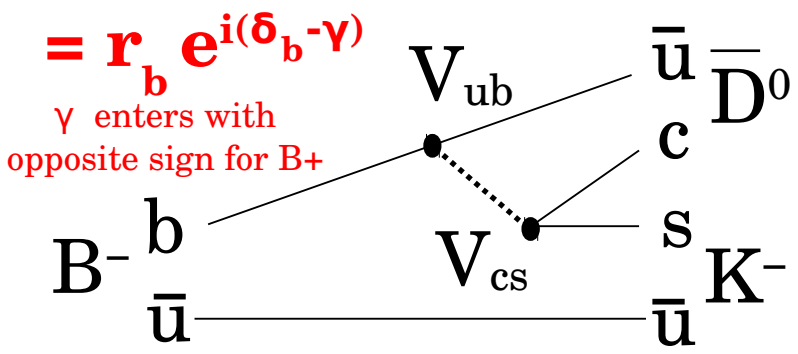


Idea: tree level determination of γ using $B^{\pm} \to DK^{\pm}$ decays

No contribution from penguins → Theoretically clean

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





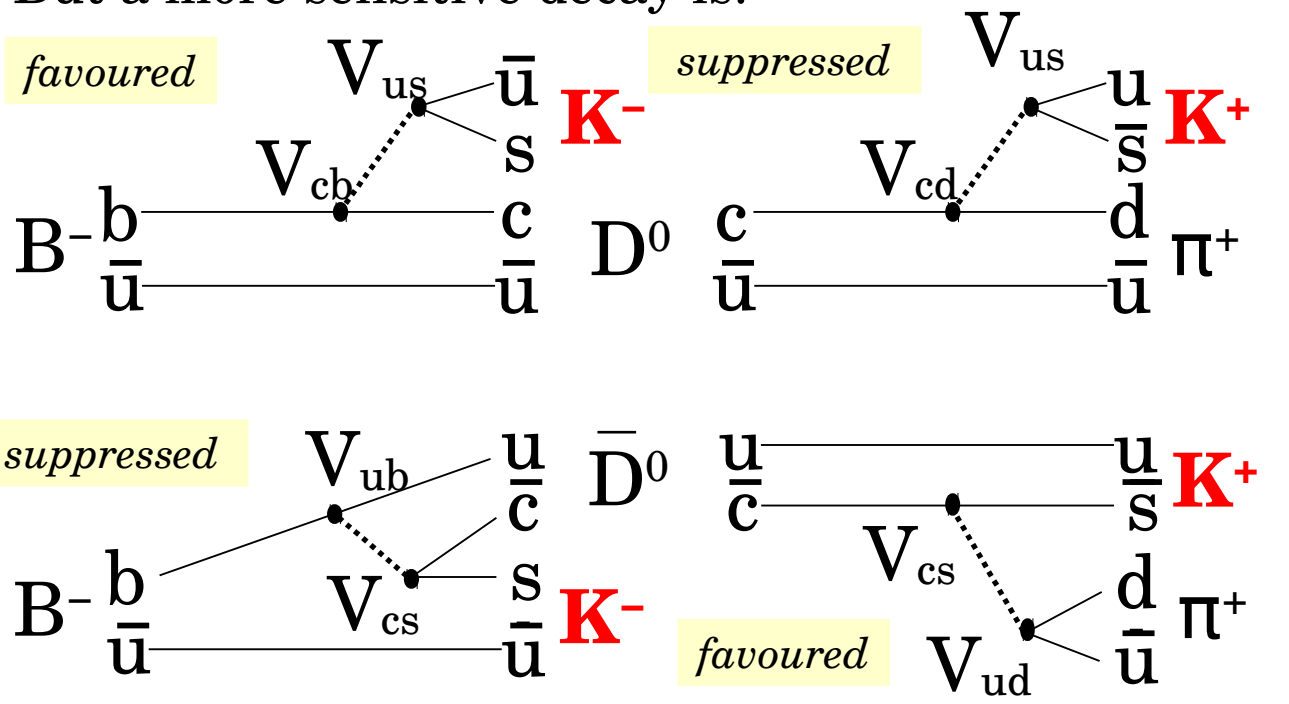
Easiest way → look at D^0 final states with only two charged tracks

Introduction

- Exploit interference: D^0 and $\overline{D}^0$ must decay to the same final state
- Obvious choice is CP eigenstates like K^+K^- and $\pi^+\pi^-$ Phys. Lett. B 265 17 (1991) referred to as "GLW"

Colour FAVOURED
Colour SUPPRESSED } *Interference O(10%)*

- But a more sensitive decay is:



- Favoured & Suppressed combination → referred as "ADS" Phys.Rev.Lett. 78 (1997) 3257-3260

Outline of the analysis

- Analysis is based on **full 2011 dataset**: **1.0 fb^{-1}**
- We reconstruct every mass hypothesis combination $B \to [hh]_D h$
  $h = \pi, K$
- Extract Ratios & Asymmetries with simultaneous fit
- Most systematic uncertainties cancel

$$A_{CP\pm} \equiv \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}$$

CP+ = KK,ππ

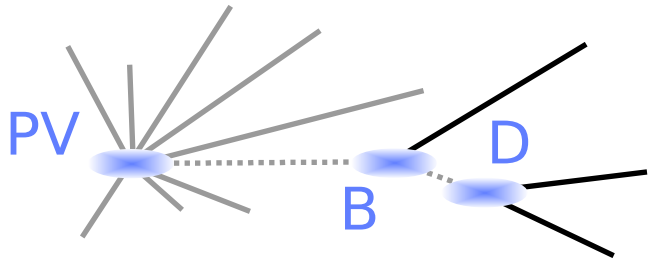
$$R_{CP\pm} \equiv 2\,\frac{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \overline{D}^0K^+)}$$

and others using similar combinations

$$\begin{aligned}\mathcal{R}^{\pm}_{DK} &\equiv \frac{\Gamma([K^{\mp}\pi^{\pm}]_D K^{\pm})}{\Gamma([K^{\pm}\pi^{\mp}]_D K^{\pm})} \\ &= r_B^2 + r_D^2 + 2\,r_B r_D \cos(\pm\gamma + \delta)\end{aligned}$$

$$\begin{aligned}\mathcal{A}_{DK} &\equiv \frac{\mathcal{R}^-_{DK} - \mathcal{R}^+_{DK}}{\mathcal{R}^-_{DK} + \mathcal{R}^+_{DK}} \\ &= 2\,r_B r_D \sin\gamma \sin\delta / \mathcal{R}_{DK}\end{aligned}$$

Selection



- Most background from combinatoric
- Use MVA method: **BDT with 20 variables**
- Train on **Signal MC** *vs* **2010 Sidebands**
  (35 pb^{-1} independent sample)

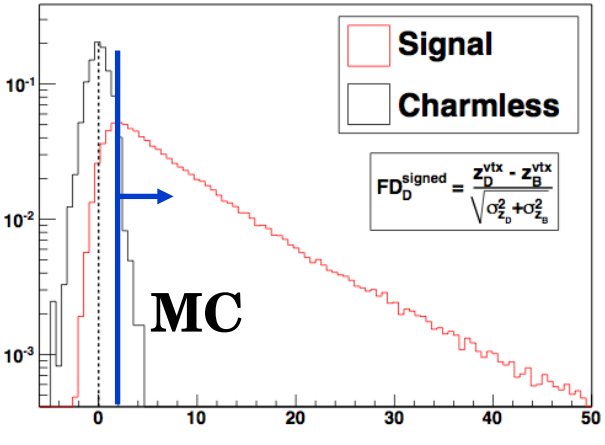
- Partially reconstructed background
- Peaking backgrounds (from charmless B decays & internal **cross feed btw modes)**
- Exploit forward boost in LHCb and cut on D flight distance

e.g. $B^{\pm}\to[\pi\pi]_D K^{\pm}$ suffers from:

$B^{\pm}\to K\pi\pi^{\pm}$ Charmless

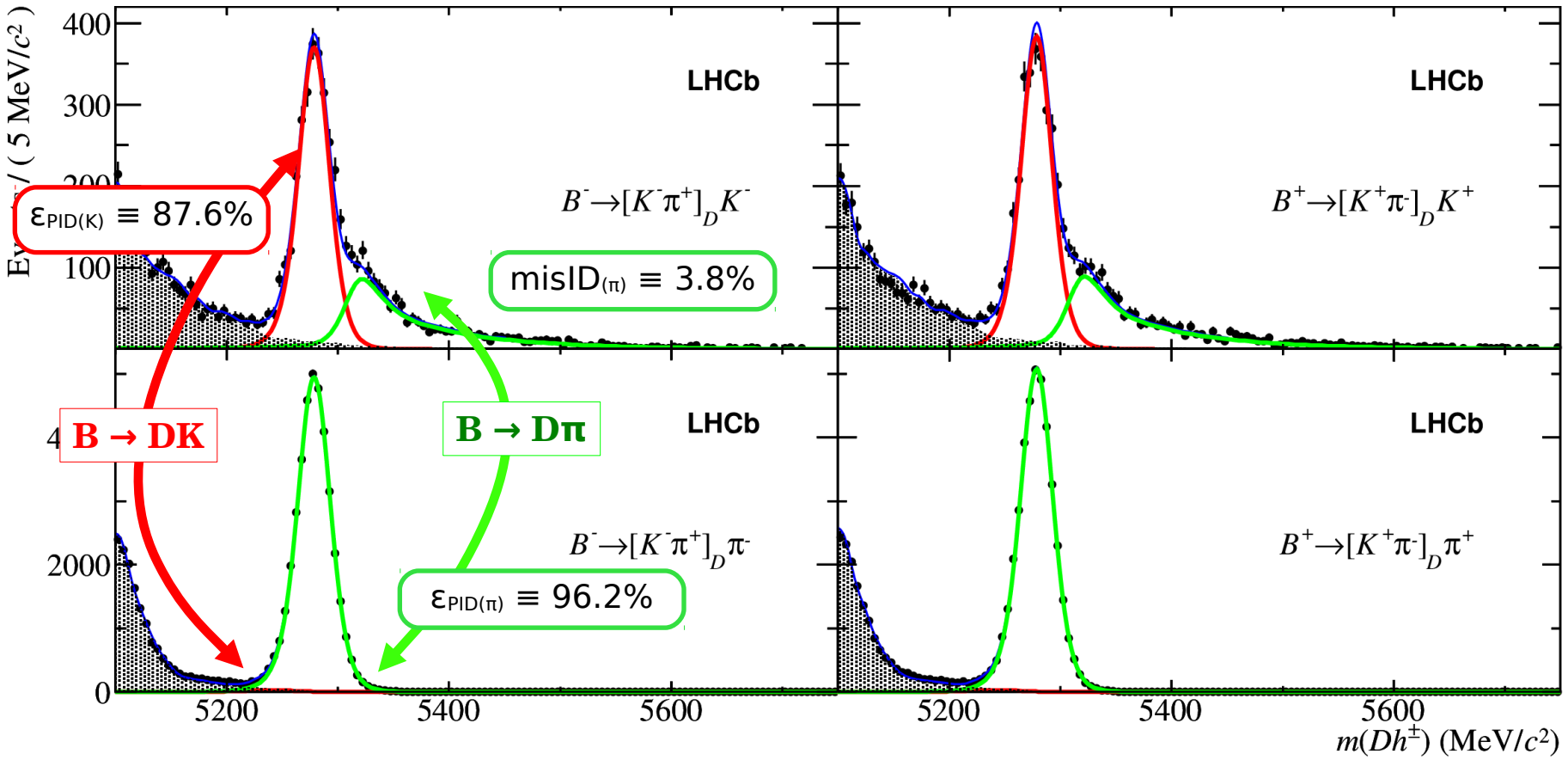
$B^{\pm}\to[K\pi]_D\pi^{\pm}$ Cross feed

$B^{\pm}\to[\pi\pi\pi^0]_D\pi^{\pm}$ Part. reco. cross feed



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

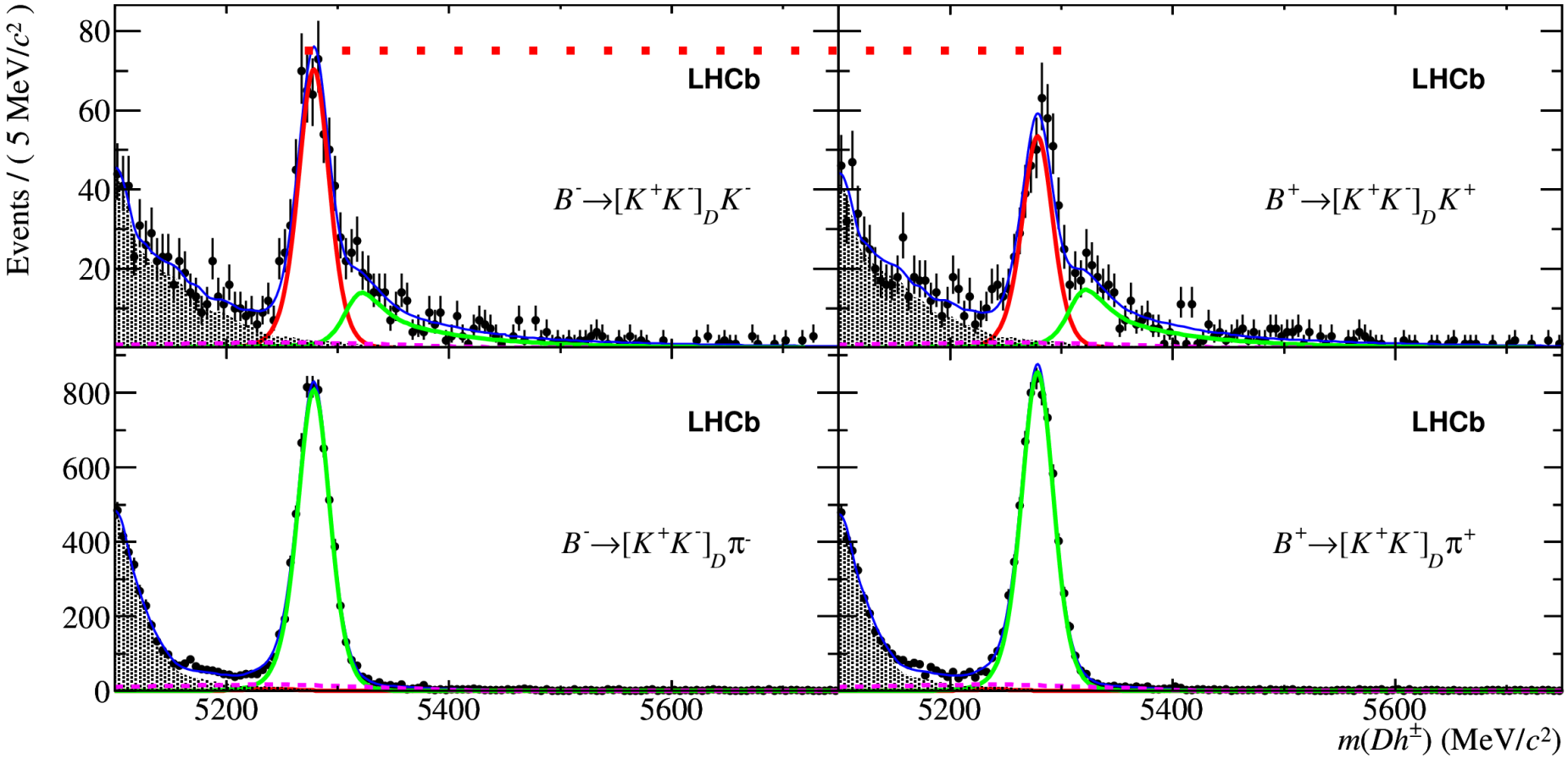
arXiv:1203.3662



- Simultaneous fit over all modes → Data divided in PASS & FAIL slices
- Favoured decay modes dominate statistics and constrain all the shapes
- Little asymmetry expected in these most abundant modes

$B^{\pm} \to [KK]_D h^{\pm}$

arXiv:1203.3662

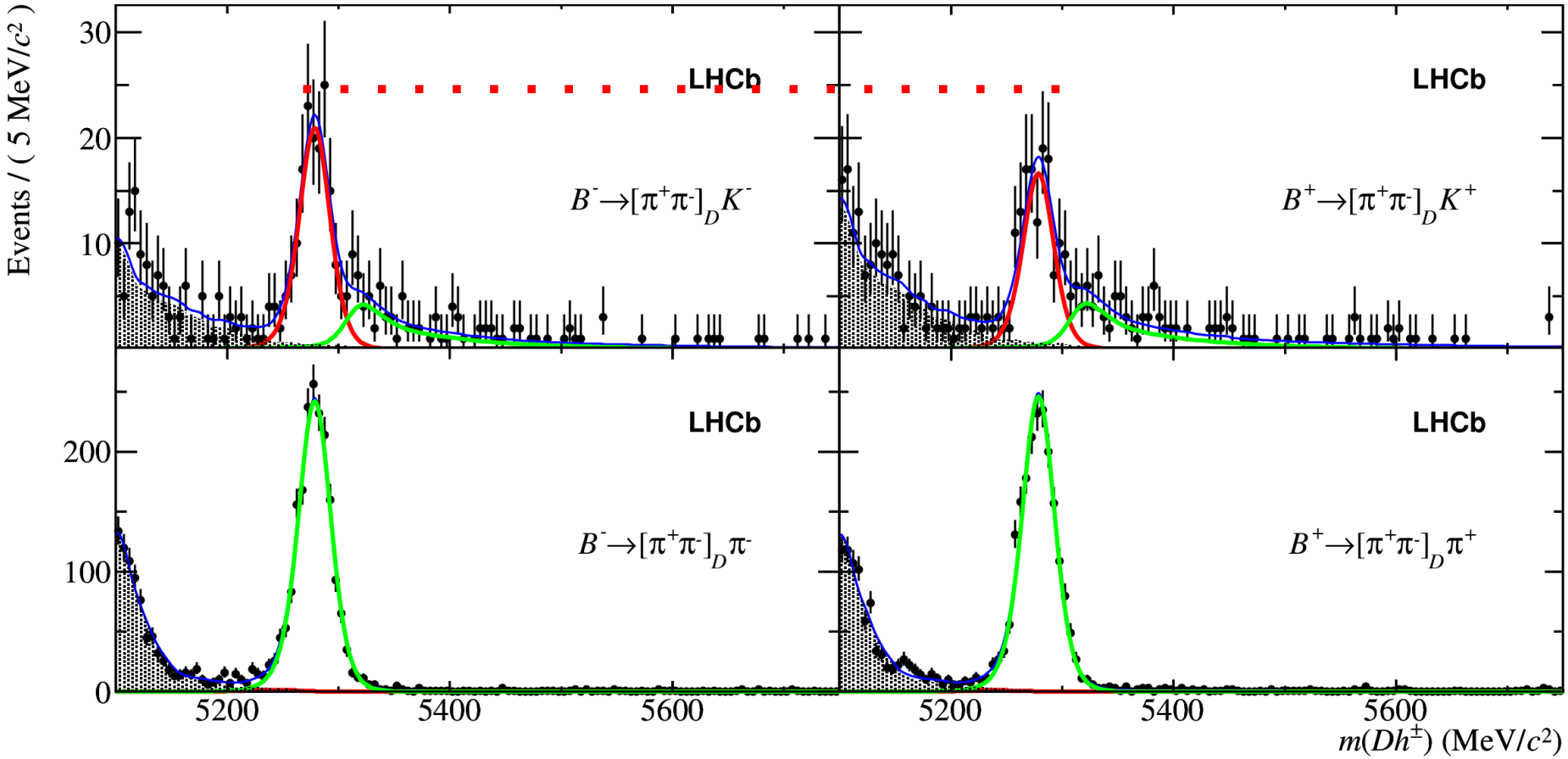


Clear asymmetry seen in **B → DK**

No asymmetry seen in **B → Dπ** (as expected)

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

arXiv:1203.3662



Clear asymmetry seen in **B → DK**

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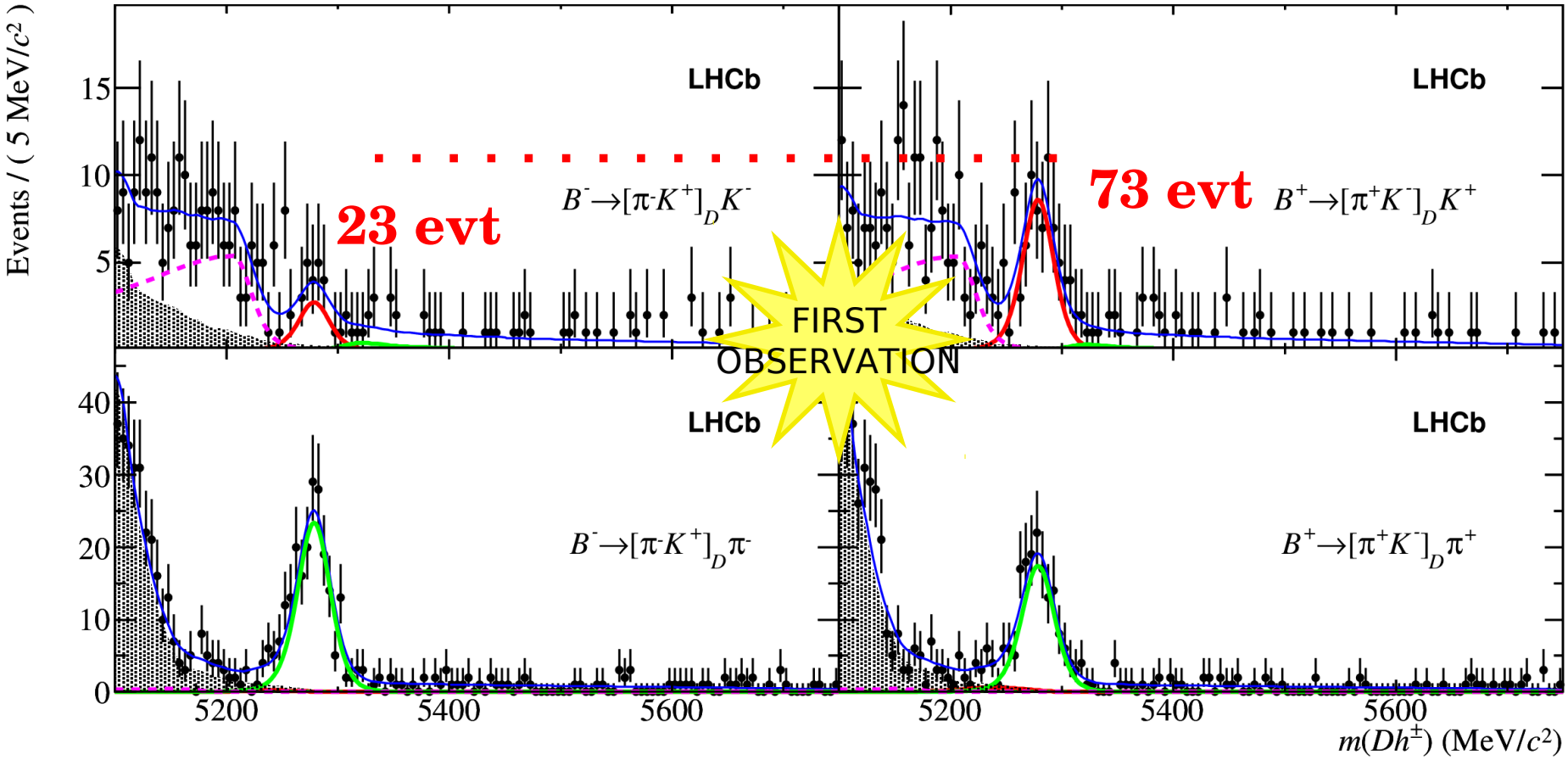
arXiv:1203.3662



Suppressed ADS modes (Kaons with wrong sign)

Results

arXiv:1203.3662

- Ratios and Asymmetries for all modes [Kπ,KK,ππ,πK]

PDG 0.076 ± 0.006

$$R^{K\pi}_{K/\pi} = 0.0774 \pm 0.0012 \pm 0.0018$$

$$R^{KK}_{K/\pi} = 0.0773 \pm 0.0030 \pm 0.0018$$

$$R^{\pi\pi}_{K/\pi} = 0.0803 \pm 0.0056 \pm 0.0017$$

$$R_{CP+} \approx < R^{KK}_{K/\pi}, R^{\pi\pi}_{K/\pi} > / R^{K\pi}_{K/\pi} = 1.01 \pm 0.04 \pm 0.01$$

$$A^{K\pi}_{\pi} = -0.0001 \pm 0.0036 \pm 0.0095$$

$$A^{K\pi}_{K} = 0.0044 \pm 0.0144 \pm 0.0174$$

4.5σ

$$A^{KK}_{K} = 0.1480 \pm 0.0369 \pm 0.0097$$

$$A^{\pi\pi}_{K} = 0.1351 \pm 0.0661 \pm 0.0095$$

$$A_{CP+} = < A^{KK}_{K}, A^{\pi\pi}_{K} > = 0.15 \pm 0.03 \pm 0.01$$

$$A^{KK}_{\pi} = -0.0199 \pm 0.0091 \pm 0.0116$$

$$A^{\pi\pi}_{\pi} = -0.0009 \pm 0.0165 \pm 0.0099$$

- Asymmetries of most abundant B → DK and B → Dπ ~ 0
- Asymmetries of B → $[KK,\pi\pi]_D$ π consistent with 0
- **Evidence of A_{CP+} with 4.5 sigma significance!**

Results

arXiv:1203.3662

10σ

4.0σ

$$
\begin{aligned}
R_{ADS(K)} &= (R_K^- + R_K^+)/2 \\
&= 0.015 \pm 0.002 \pm 0.000 \\
A_{ADS(K)} &= (R_K^- - R_K^+)/(R_K^- + R_K^+) \\
&= -0.52 \pm 0.15 \pm 0.02
\end{aligned}
$$

$$
\begin{aligned}
R_{ADS(\pi)} &= (R_\pi^- + R_\pi^+)/2 \\
&= 0.0041 \pm 0.0003 \pm 0.0001 \\
A_{ADS(\pi)} &= (R_\pi^- - R_\pi^+)/(R_\pi^- + R_\pi^+) \\
&= 0.143 \pm 0.062 \pm 0.011
\end{aligned}
$$

2.4σ

Combining all together...

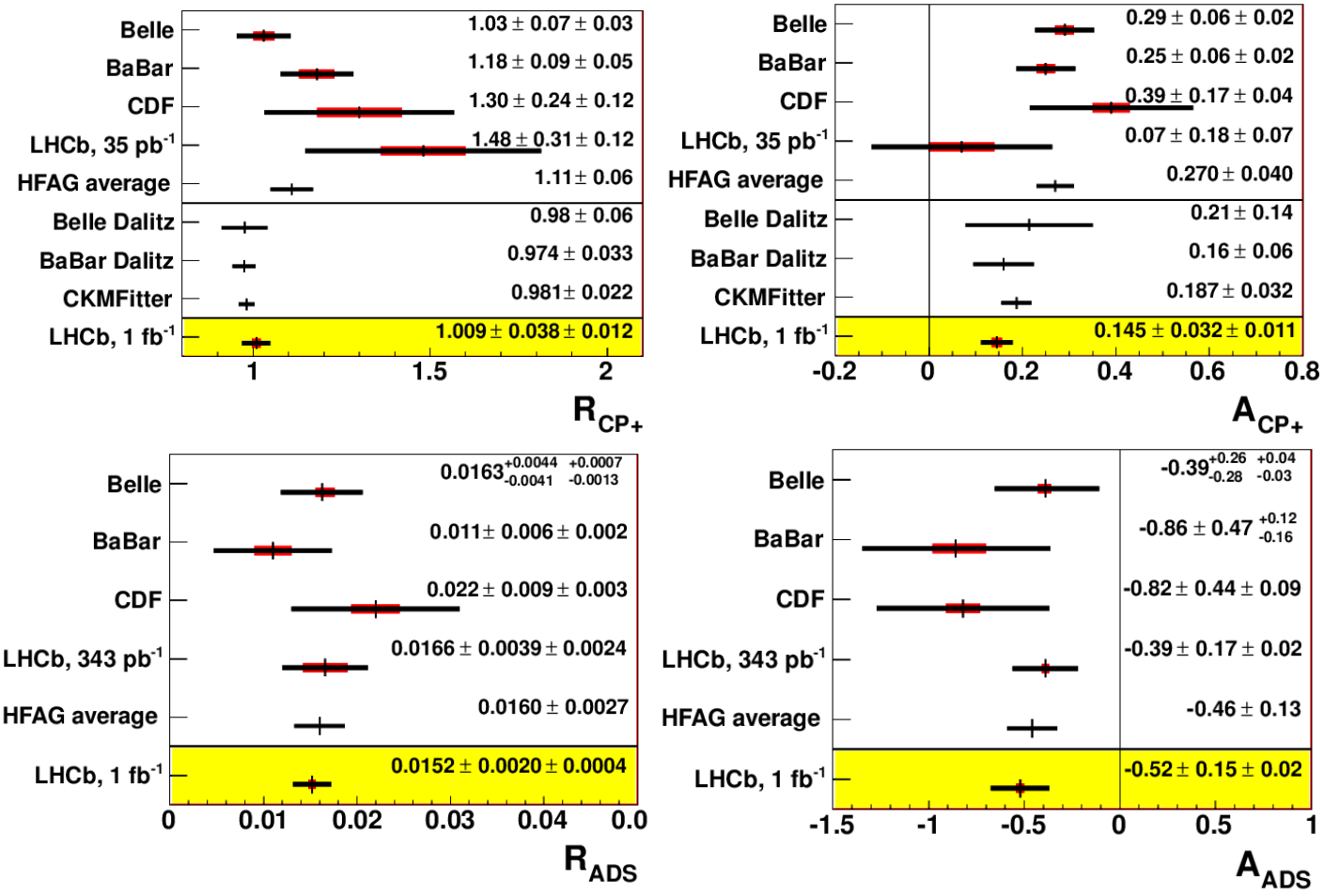
CP violation is observed in B→DK with a significance of 5.8σ

FIRST OBSERVATION of direct CP violation in $B^\pm$!

Summary

arXiv:1203.3662

Paper submitted to PLB
Expect impact on determination of γ



Backup Slides

Ratios & Asymmetries

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

$$\frac{\Gamma(B^- \to [K^-\pi^+]_D K^-) + \Gamma(B^+ \to [K^+\pi^-]_D K^+)}{\Gamma(B^- \to [K^-\pi^+]_D \pi^-) + \Gamma(B^+ \to [K^+\pi^-]_D \pi^+)} = R^{K\pi}_{K/\pi}$$

$$\frac{\Gamma(B^- \to [K^-\pi^+]_D K^-) - \Gamma(B^+ \to [K^+\pi^-]_D K^+)}{\Gamma(B^- \to [K^-\pi^+]_D K^-) + \Gamma(B^+ \to [K^+\pi^-]_D K^+)} = A^{K\pi}_K$$

$$\frac{\Gamma(B^- \to [K^-\pi^+]_D \pi^-) - \Gamma(B^+ \to [K^+\pi^-]_D \pi^+)}{\Gamma(B^- \to [K^-\pi^+]_D \pi^-) + \Gamma(B^+ \to [K^+\pi^-]_D \pi^+)} = A^{K\pi}_\pi$$

$\sim R_{CP+}$

$B^{\pm} \to [KK]_D h^{\pm}$

$$\frac{\Gamma(B^- \to [K^-K^+]_D K^-) + \Gamma(B^+ \to [K^+K^-]_D K^+)}{\Gamma(B^- \to [K^-K^+]_D \pi^-) + \Gamma(B^+ \to [K^+K^-]_D \pi^+)} = R^{KK}_{K/\pi}$$

$$\frac{\Gamma(B^- \to [K^-K^+]_D K^-) - \Gamma(B^+ \to [K^+K^-]_D K^+)}{\Gamma(B^- \to [K^-K^+]_D K^-) + \Gamma(B^+ \to [K^+K^-]_D K^+)} = A^{KK}_K$$

$$\frac{\Gamma(B^- \to [K^-K^+]_D \pi^-) - \Gamma(B^+ \to [K^+K^-]_D \pi^+)}{\Gamma(B^- \to [K^-K^+]_D \pi^-) + \Gamma(B^+ \to [K^+K^-]_D \pi^+)} = A^{KK}_\pi$$

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

$$\frac{\Gamma(B^- \to [\pi^-\pi^+]_D K^-) + \Gamma(B^+ \to [\pi^+\pi^-]_D K^+)}{\Gamma(B^- \to [\pi^-\pi^+]_D \pi^-) + \Gamma(B^+ \to [\pi^+\pi^-]_D \pi^+)} = R^{\pi\pi}_{K/\pi}$$

$$\frac{\Gamma(B^- \to [\pi^-\pi^+]_D K^-) - \Gamma(B^+ \to [\pi^+\pi^-]_D K^+)}{\Gamma(B^- \to [\pi^-\pi^+]_D K^-) + \Gamma(B^+ \to [\pi^+\pi^-]_D K^+)} = A^{\pi\pi}_K$$

$$\frac{\Gamma(B^- \to [\pi^-\pi^+]_D \pi^-) - \Gamma(B^+ \to [\pi^+\pi^-]_D \pi^+)}{\Gamma(B^- \to [\pi^-\pi^+]_D \pi^-) + \Gamma(B^+ \to [\pi^+\pi^-]_D \pi^+)} = A^{\pi\pi}_\pi$$

A_{CP+}

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

$$\frac{\Gamma(B^- \to [\pi^-K^+]_D K^-)}{\Gamma(B^- \to [K^-\pi^+]_D K^-)} = R^-_K$$

$$\frac{\Gamma(B^+ \to [\pi^+K^-]_D K^+)}{\Gamma(B^+ \to [K^+\pi^-]_D K^+)} = R^+_K$$

$$\frac{\Gamma(B^- \to [\pi^-K^+]_D \pi^-)}{\Gamma(B^- \to [K^-\pi^+]_D \pi^-)} = R^-_\pi$$

$$\frac{\Gamma(B^+ \to [\pi^+K^-]_D \pi^+)}{\Gamma(B^+ \to [K^+\pi^-]_D \pi^+)} = R^+_\pi$$

$R_{ADS(K)}$ $A_{ADS(K)}$

$R_{ADS(\pi)}$ $A_{ADS(\pi)}$

A_{CP+} and R_{CP+} from global fit

- From the HFAG page → BaBar & Belle estimations of $[r_b, \delta_b, \gamma]$

Constraining $\gamma \equiv \phi_3$:

The measurements of $x_{+,-}$ and $y_{+,-}$ in the various $D^{(*)}K^{(*)}$ decay modes can be used to place bounds on $\gamma \equiv \phi_3$. Both experiments have done so using frequentist techniques.

BaBar obtain		Belle obtain	
$\gamma = (68\ ^{+15}_{-14} \pm 4 \pm 3)°$ (from DK^-, D^*K^- & DK^{*-})		$\phi_3 = (78\ ^{+11}_{-12} \pm 4 \pm 9)°$ (from DK^- & D^*K^-)	
The experiments also obtain values for the hadronic parameters			
$r_B(DK^-) = 0.096 \pm 0.029 \pm 0.005 \pm 0.004$	$\delta_B(DK^-) = (119\ ^{+19}_{-20} \pm 3 \pm 3)°$	$r_B(DK^-) = 0.160\ ^{+0.040}_{-0.038} \pm 0.011\ ^{+0.05}_{-0.010}$	$\delta_B(DK^-) = (138\ ^{+13}_{-16} \pm 4 \pm 23)°$
$r_B(D^*K^-) = 0.133\ ^{+0.042}_{-0.039} \pm 0.014 \pm 0.003$	$\delta_B(D^*K^-) = (-82 \pm 21 \pm 5 \pm 3)°$	$r_B(D^*K^-) = 0.196\ ^{+0.072}_{-0.069} \pm 0.012\ ^{+0.062}_{-0.012}$	$\delta_B(D^*K^-) = (342\ ^{+19}_{-21} \pm 3 \pm 23)°$
$\kappa r_s = 0.149\ ^{+0.066}_{-0.062} \pm 0.026 \pm 0.006$	$\delta_s = (111 \pm 32 \pm 11 \pm 3)°$	($r_B(DK^{*-}) = 0.56\ ^{+0.22}_{-0.16} \pm 0.04 \pm 0.08$ *)	($\delta_B(DK^{*-}) = (243^{+20}_{-23} \pm 3 \pm 50)°$ *)

For attempts to extract $\gamma \equiv \phi_3$ from the combined BaBar and Belle results, visit the CKMfitter and UTfit sites.

Note that the above results suffer an ambiguity: $\gamma \to \gamma + \pi \equiv \phi_3 \to \phi_3 + \pi$, $\delta \to \delta + \pi$. We quote the result which is consistent with the Standard Model fit.

- r_b, δ_b dominated by Dalitz analysis → using these as inputs

$$R_{CP\pm} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma\,,$$

$$A_{CP\pm} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma}.$$

Belle: ~ 0.29 ± 0.06
preliminary

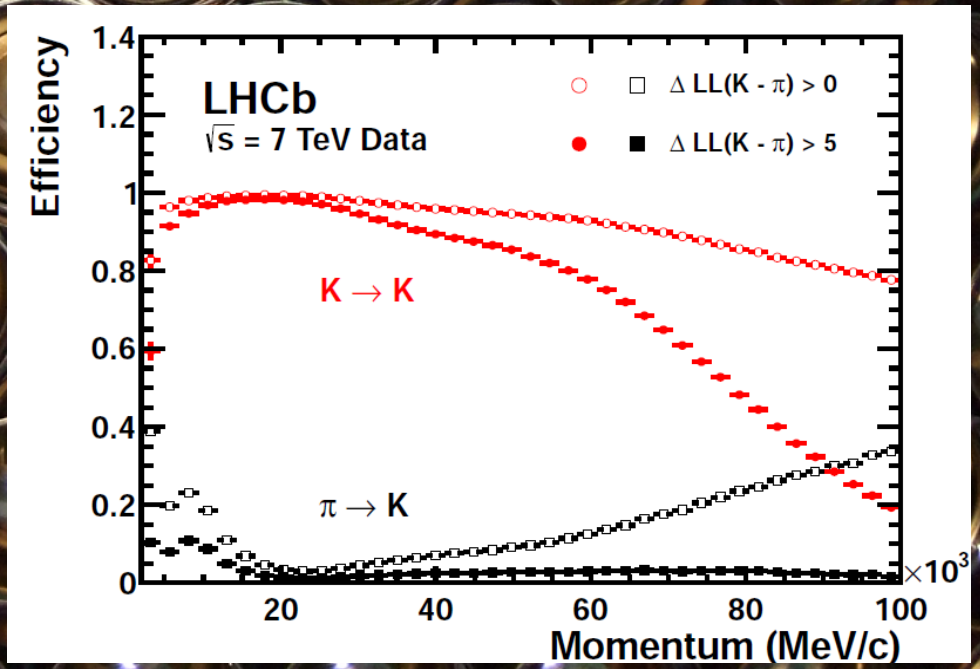
BaBar: ~ 0.25 ± 0.06

LHCb

$$R_{CP+} = \frac{< R^{KK}_{K/\pi}, R^{\pi\pi}_{K/\pi} >}{R^{Kpi}_{K/\pi}} = 1.007 \pm 0.038 \pm 0.012$$

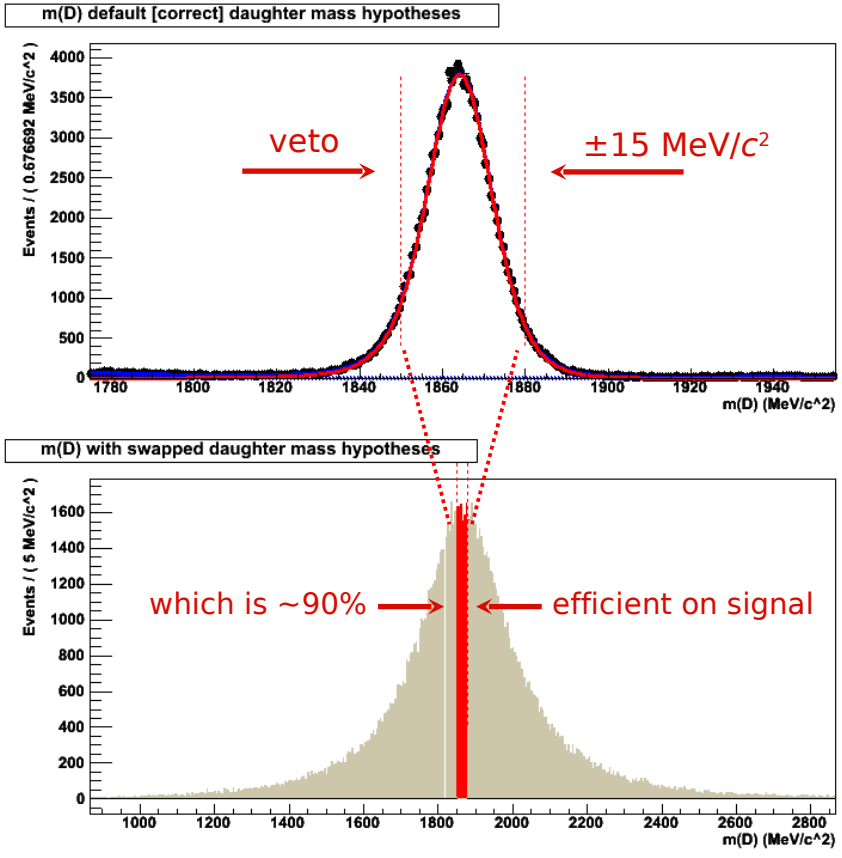
$$A_{CP+} = < A^{KK}_{K}, A^{\pi\pi}_{K} > = 0.145 \pm 0.032 \pm 0.010$$

LHCb detector - RICHes



Favoured → Suppressed cross feed

- Peaking bkg due to truly $D^0 \to K^-\pi^+$ combined as $D^0 \to \pi^-K^+$
- Mis-ID distributions have the same mean but are broader



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

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

check for by swapping mass hypothesis back

Reduce it with PID cuts on the daughters

Veto on the "double swapped" mass hypotesis

Include a PDF in the fit for what remains

Asymmetries

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

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

$B^{\pm} \to [KK]_D h^{\pm}$

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

$$
\begin{aligned}
A_{CP}((K\pi)_D\pi) &= A_{raw}((K\pi)_D\pi) - A_{Prod} - A_K \\
A_{CP}((K\pi)_D K) &= A_{raw}((K\pi)_D K) - A_{Prod} - 2 \times A_K \\
A_{CP}((\pi K)_D\pi) &= A_{raw}((\pi K)_D\pi) - A_{Prod} + A_K \\
A_{CP}((\pi K)_D K) &= A_{raw}((\pi K)_D K) - A_{Prod} \\
A_{CP}((KK)_D\pi) &= A_{raw}((KK)_D\pi) - A_{Prod} \\
A_{CP}((KK)_D K) &= A_{raw}((KK)_D K) - A_{Prod} - A_K \\
A_{CP}((\pi\pi)_D\pi) &= A_{raw}((\pi\pi)_D\pi) - A_{Prod} \\
A_{CP}((\pi\pi)_D K) &= A_{raw}((\pi\pi)_D K) - A_{Prod} - A_K
\end{aligned}
$$

FIXED (%)

$A_{Prod} = -0.7 \pm 0.7$

$A_K = -0.5 \pm 0.7$

$A_\pi = 0.0 \pm 0.7$