Paper Reading Seminar
“ Observation of CP violation in $B^{\pm} \to DK^{\pm}$ decays”

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Introduction

$$\phi_3 \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{-V_{cd}V_{cb}^*}\right) \cong -\arg\left(V_{ub}^*\right)$$

- $B \to D^0 K$ amplitude : proportional to V_{cb}
- $B \to \overline{D}^0 K$ amplitude : depends on V_{ub}
- $D^0 \to f$, $\overline{D}^0 \to f$

→ interference gives sensitivity to $\gamma(\phi_3)$ and may exhibit direct CPV

- f (it can be accessed D^0 and $\overline{D}^0$.)
  - CP mode ($D \to KK$, $\pi\pi$)
  - ADS mode ($D \to \pi K$)
    - $b \to c$ to be followed DCSD
    - $b \to u$ to be followed favored D decay
    - Similar total magnitude

Introduction

- 測定項目

$$R^{f}_{K/\pi}\ \frac{\Gamma\left(B^{-}\to[f]_{D}K^{-}\right)+\Gamma\left(B^{+}\to[f]_{D}K^{+}\right)}{\Gamma\left(B^{-}\to[f]_{D}\pi^{-}\right)+\Gamma\left(B^{+}\to[f]_{D}\pi^{+}\right)}$$

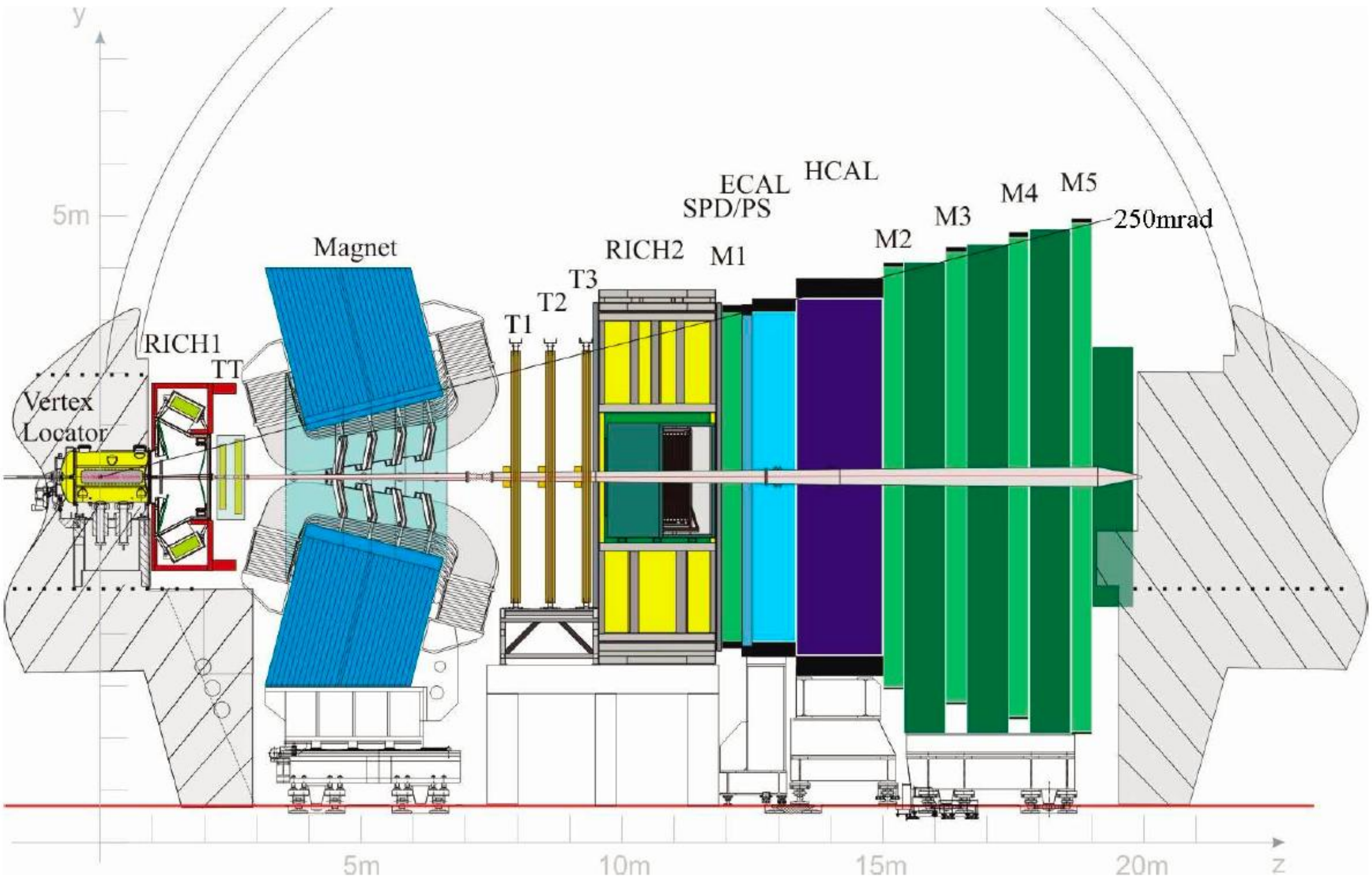
$$A^{f}_{h}=\frac{\Gamma\left(B^{-}\to[f]_{D}h^{-}\right)-\Gamma\left(B^{+}\to[f]_{D}h^{+}\right)}{\Gamma\left(B^{-}\to[f]_{D}h^{-}\right)+\Gamma\left(B^{+}\to[f]_{D}h^{+}\right)}$$

$$R^{\pm}_{h}=\frac{\Gamma\left(B^{\pm}\to[\pi^{\pm}K^{\mp}]_{D}h^{\pm}\right)}{\Gamma\left(B^{\pm}\to[K^{\pm}\pi^{\mp}]_{D}h^{\pm}\right)}$$

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

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

Detector

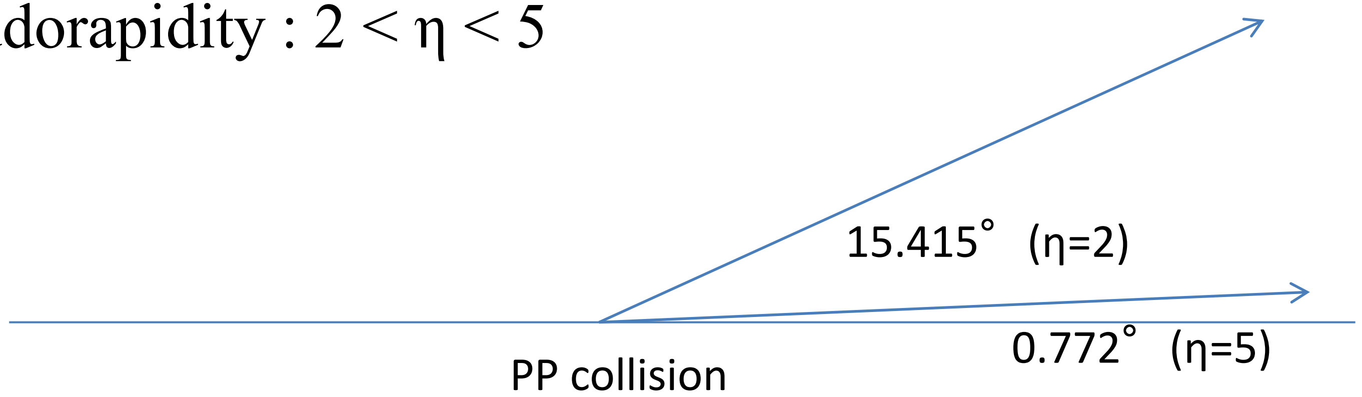


y
5m
Magnet
RICH1
TT
Vertex
Locator
T1
T2
T3
RICH2
M1
SPD/PS
ECAL
HCAL
M2
M3
M4
M5
250mrad
5m
10m
15m
20m
z

- the spectrometer magnet, a warm dipole magnet providing an integrated field of 4 Tm
- the vertex locator system (including a pile-up veto counter), called the VELO
- the tracking system
  - Trigger Tracker (a silicon microstrip detector, TT) in front of the spectrometer magnet
  - three tracking stations behind the magnet, made of silicon microstrips in the inner parts (IT) and of Kapton/Al straws for the outer parts (OT)
- two Ring Imaging Cherencov counters (RICH1 and RICH2) using Aerogel, C4F10 and CF4 as radiators, to achieve excellent π-K separation in the momentum range from 2 to 100 GeV/c, and Hybrid Photon Detectors
- the calorimeter system composed of a Scintillator Pad Detector and Preshower (SPD/PS), an electromagnetic (shashlik type) calorimeter (ECAL) and a hadronic (Fe and scintillator tiles) calorimeter (HCAL)
- the muon detection system composed of MWPC (except in the highest rate region, where triple-GEM's are used)

Introduction

- 1.0 fb^{-1} of $\sqrt{s}$ = 7 TeV
- Pseudorapidity : $2 < \eta < 5$



- Tracking system momentum resolution : 0.4-0.6% in the range 5-100 GeV/c
  - Silicon microstrip vertex detector
- Dipole magnet can be operated in either polarity → reduce systematic error due to detector asymmetries
  - 58%:42%

Introduction

- Two-ring imaging cherenkov (rich) with three radiators
  - PID (K,π) : momentum range from 2 to 100 GeV/c
- Two-stage trigger
  - Hardware-based decision : 40MHz以内
    - It accepts high transverse energy clusters in calorimeters(e or h) or muon of high transverse momentum
  - Software trigger
    - Receive 1 MHz of events
    - Retains ~0.3%
    - Required track with large Pt and large impact parameter
      - Part of secondary vertex
        - » Displaced from the PV
  - 2.5x10^5 events

Introduction

- Outline of the analysis
- Analysis is based on **full 2011 dataset: 1.0 fb^{-1}**
- Every mass hypothesis combination $B \rightarrow [hh]_D h$ were reconstructed.
  h=π,K
- Extract Ratios & Asymmetries with simultaneous fit

Event selection

- Event reconstruction

D mass	$1765 < M_D < 1965$ MeV/c^2
D daughter tracks	$0.5 < p_T < 10$ GeV/c^2
Bachelor tracks	$5 < p < 100$ GeV/c^2
Mass vertex fit	

- Reconstructed candidates are selected using a boosted decision tree (BTD) discriminator.

Event selection:BDT

- Train
  - $B \to [K^{\pm}\pi^{\mp}]_D K^{\pm}$
  - D sideband BG

From	
The tracks, the D and B	p_T
	χ^2 with respect to the PV
The B and D	Decay time
	Vertex quality
The B	The angle between momentum vector and line connecting the PV to its decay vertex

- Optimal cut chosen by
  - ADS, favored : > 0.92
  - CP : > 0.8

Event selection:PID

- PID
  - Quantified as difference between $\ln L_\mathrm{h}$: DLL
  - Daughter K of the D : $\mathrm{DLL}_{\mathrm{K}\pi} = \ln L_\mathrm{K} - \ln L_\pi > 2$
  - Daughter π of the D : $\mathrm{DLL}_{\mathrm{K}\pi} < -2$

Event selection:Fake D

- Flight distance significance : D from B vertex > 2
    - KKK, $K\pi\pi$, $KK\pi$
    - Cross feed
        - bachelor is confused with a D daughter at low decay time
- B invariant mass is J/ψ or $\psi(2S)$ mass $\pm$ 22 MeV $\rightarrow$ veto
    - the combination of bachelor and opposite-sign D^0 is made under hypothesis that they are muon.

Event selection:cross feed

- It is reduced by vetoing any ADS candidate whose D candidate mass under the exchange of its daughter track mass hypotheses, lies within ±15 MeV/c^2 of PDG D^0 mass.

Event selection:Partially reconstructed events

- Partially reconstructed events
  - $B \to XD\pi \xrightarrow{\text{misidentify}} B \to XDK$
  - Used to model : $B_{u,d,s} \to DX$

  $\to$Non-parametric PDFs are defined for DK and $D\pi$.

    - Apply all four D models

  ☆Specific cases

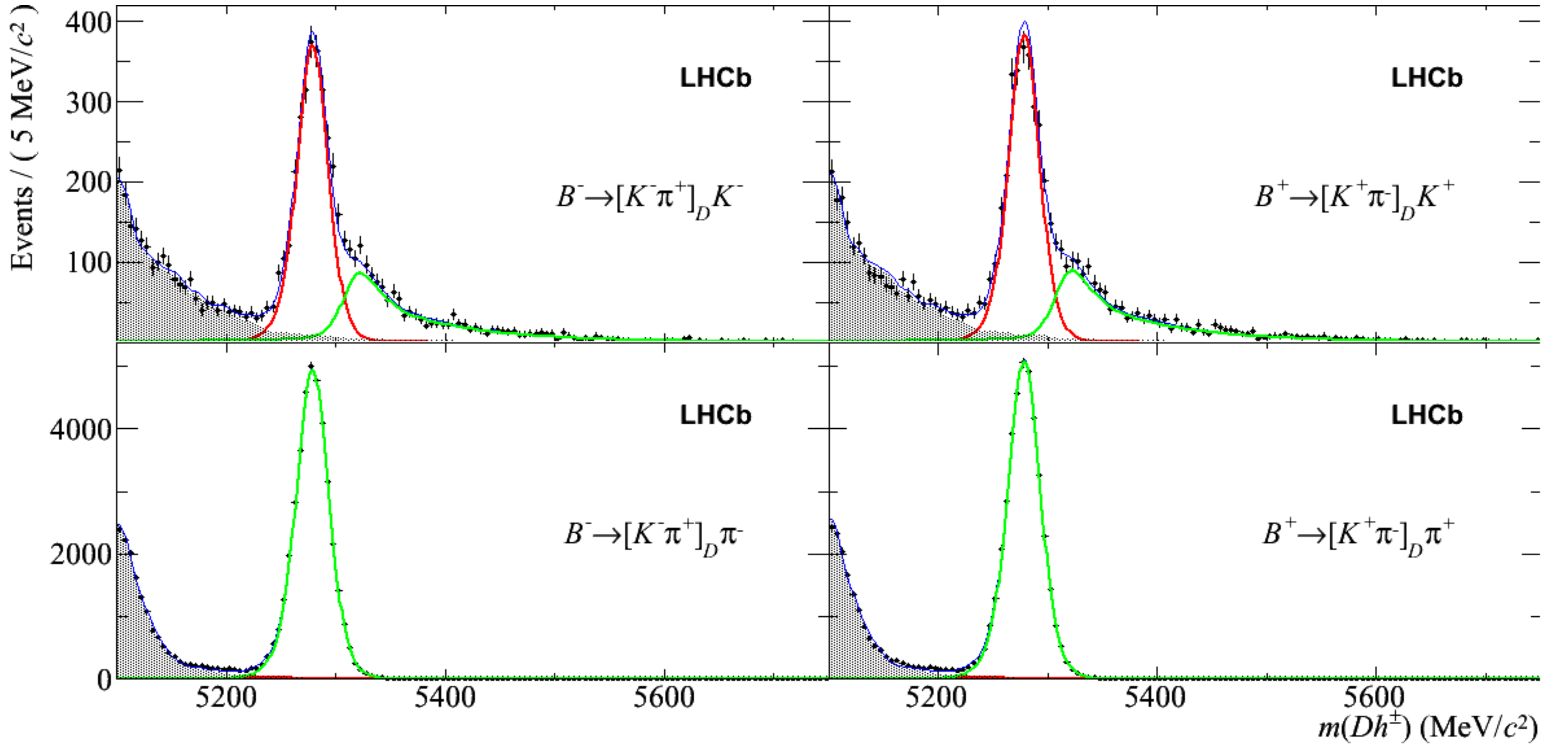
  - $D \to KK$
    - $\Lambda^0_b \to [pK\pi]_\Lambda h$: pion miss, proton $\to$ K
  - $B \to D_{ADS}K$
    - $B_s^0 \to D^0 K\pi$: partially reconstructed. Cabibbo-favoured BG
  - Both from sim, smeared by the modest degradation in resolution observed data.

Signal yield determination

- 観測量はinvariant mass distributions のbinned maximum-likelihood fit で決定
- Sensitivity to CP asymmetry : B^-B^+ separation
- PID cut for bachelor track : DLL > 4
  - Pass : $B \to DK$
  - Not : $B \to D\pi$
- Fit comprise four subsamples
  - (plus, minus)x(K, π)

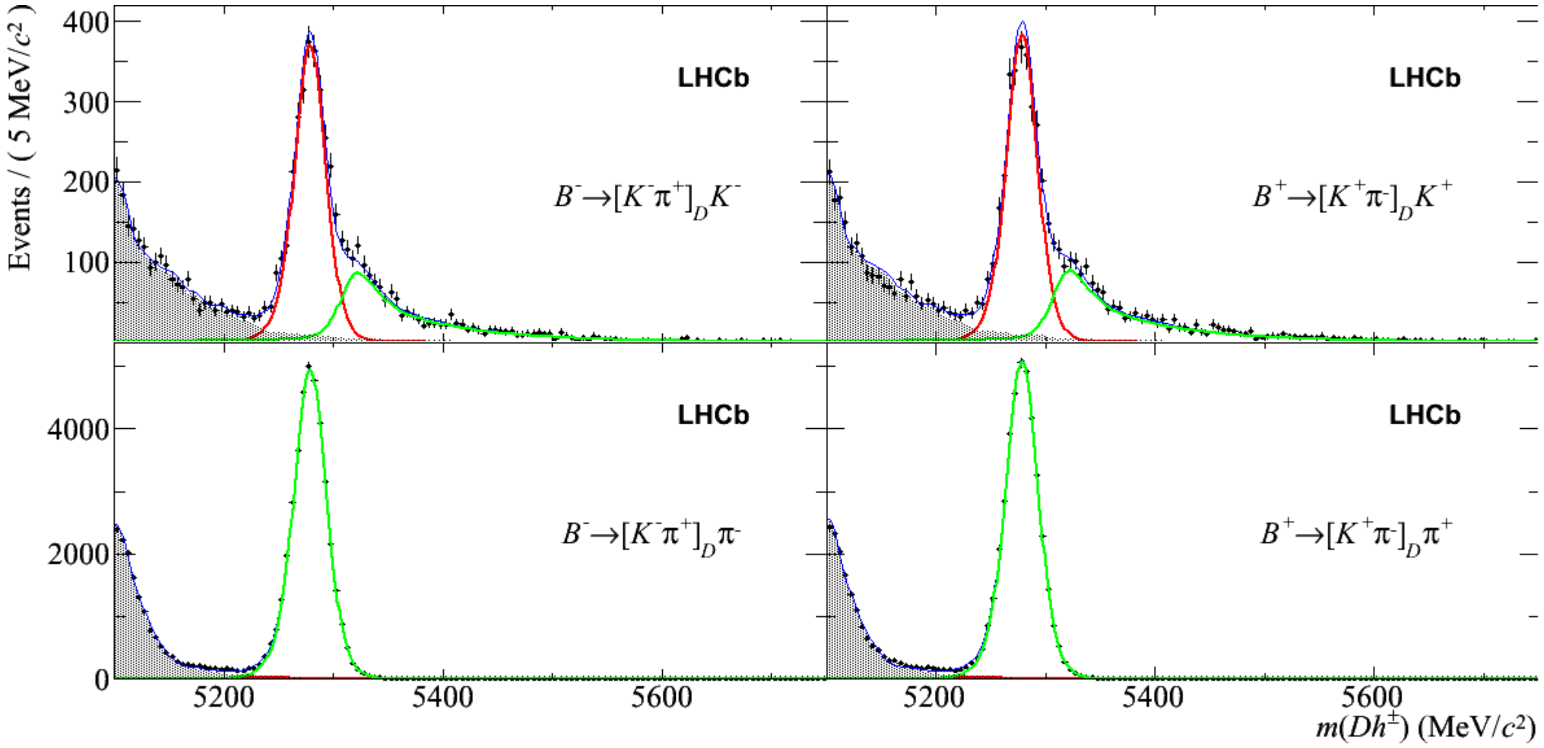
Signal yield determination

- PDF
- B→Dπ
  - Modified gaussian : $f(x) \propto \exp(-(x-\mu)^2/2\sigma^2+(x-\mu)^2\alpha_{L,R})$
  - B→Dπ pssing DLL cut (reconstruct as DK): sum of 2 gaussian



Signal yield determination

- PDF
- B→DK
  - Same modified gaussian
  - Width : 0.95±0.02 times Dπ
  - B→DK reconstructed as Dπ: fix



Signal yield determination

- PDF

  Partially reconstructed

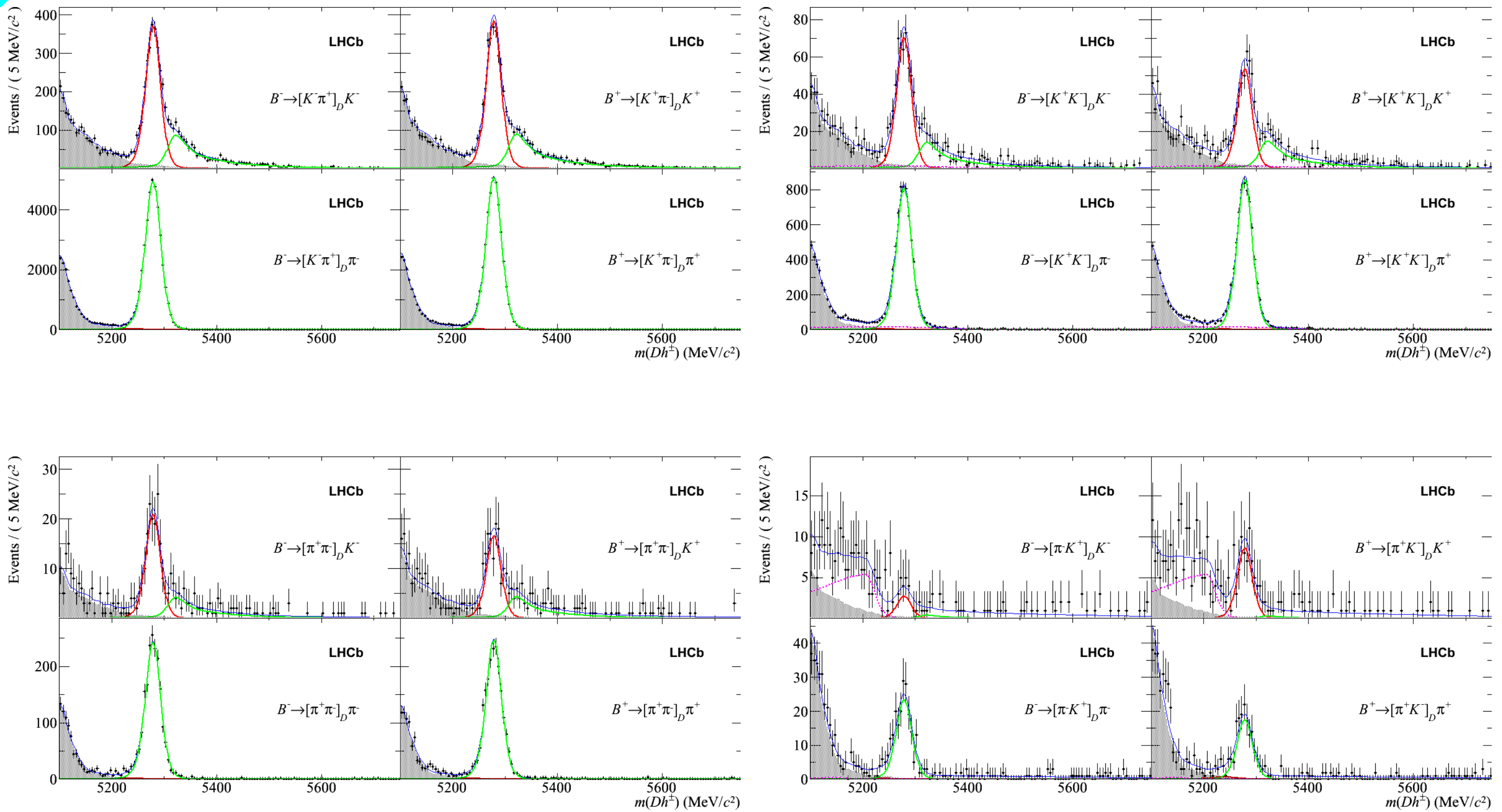
  – Non-parametric PDF from simulation

  Combinatoric BG

  – line

  Mode specific BG

Signal yield determination



First observation

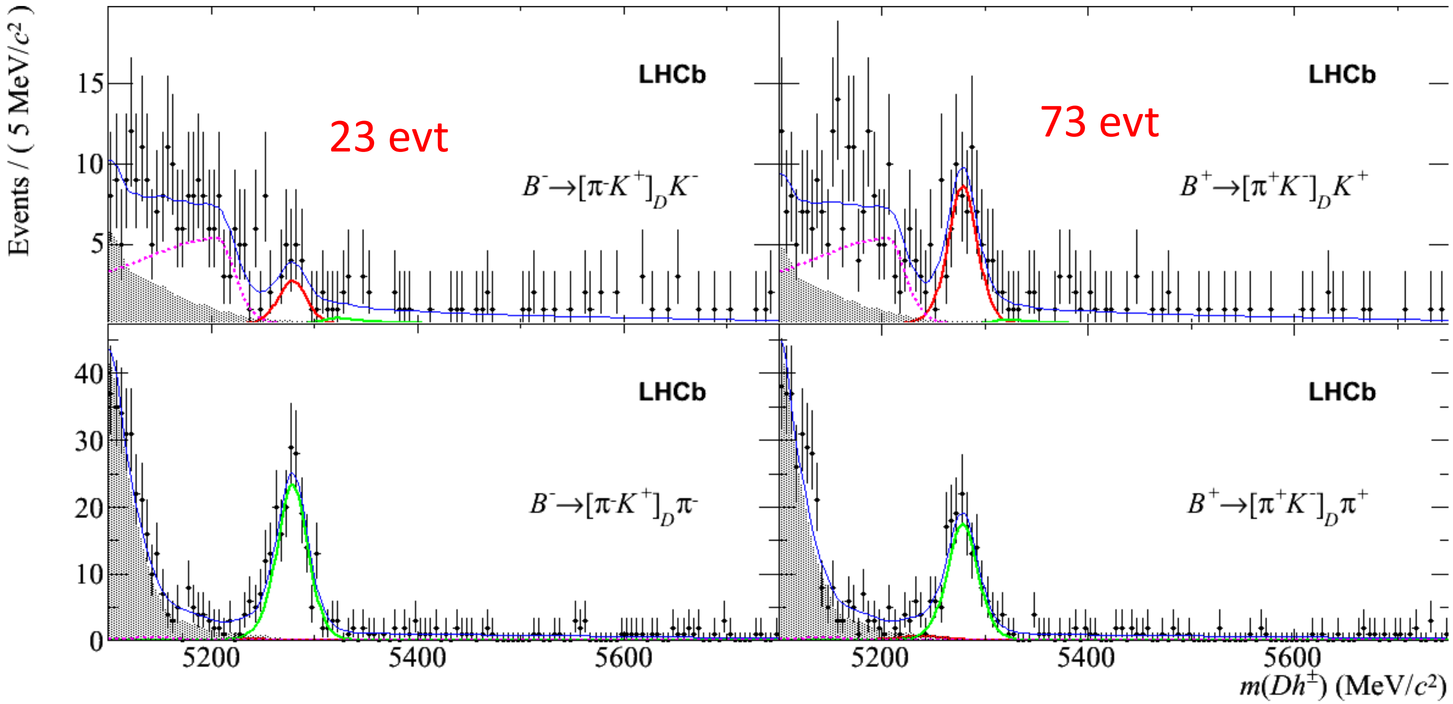


Table 1: Corrected event yields.

$B^{\pm}$ mode	D mode	B^-	B^+
$DK^{\pm}$	$K^{\pm}\pi^{\mp}$	3170 ± 83	3142 ± 83
	$K^{\pm}K^{\mp}$	592 ± 40	439 ± 30
	$\pi^{\pm}\pi^{\mp}$	180 ± 22	137 ± 16
	$\pi^{\pm}K^{\mp}$	23 ± 7	73 ± 11
$D\pi^{\pm}$	$K^{\pm}\pi^{\mp}$	40767 ± 310	40774 ± 310
	$K^{\pm}K^{\mp}$	6539 ± 129	6804 ± 135
	$\pi^{\pm}\pi^{\mp}$	1969 ± 69	1973 ± 69
	$\pi^{\pm}K^{\mp}$	191 ± 16	143 ± 14

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

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

Results

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

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

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

$$R^{-}_{K} = 0.0073 \pm 0.0023 \pm 0.0004$$

$$R^{+}_{K} = 0.0232 \pm 0.0034 \pm 0.0007$$

$$R^{-}_{\pi} = 0.00469 \pm 0.00038 \pm 0.00008$$

$$R^{+}_{\pi} = 0.00352 \pm 0.00033 \pm 0.00007$$

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

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

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

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

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

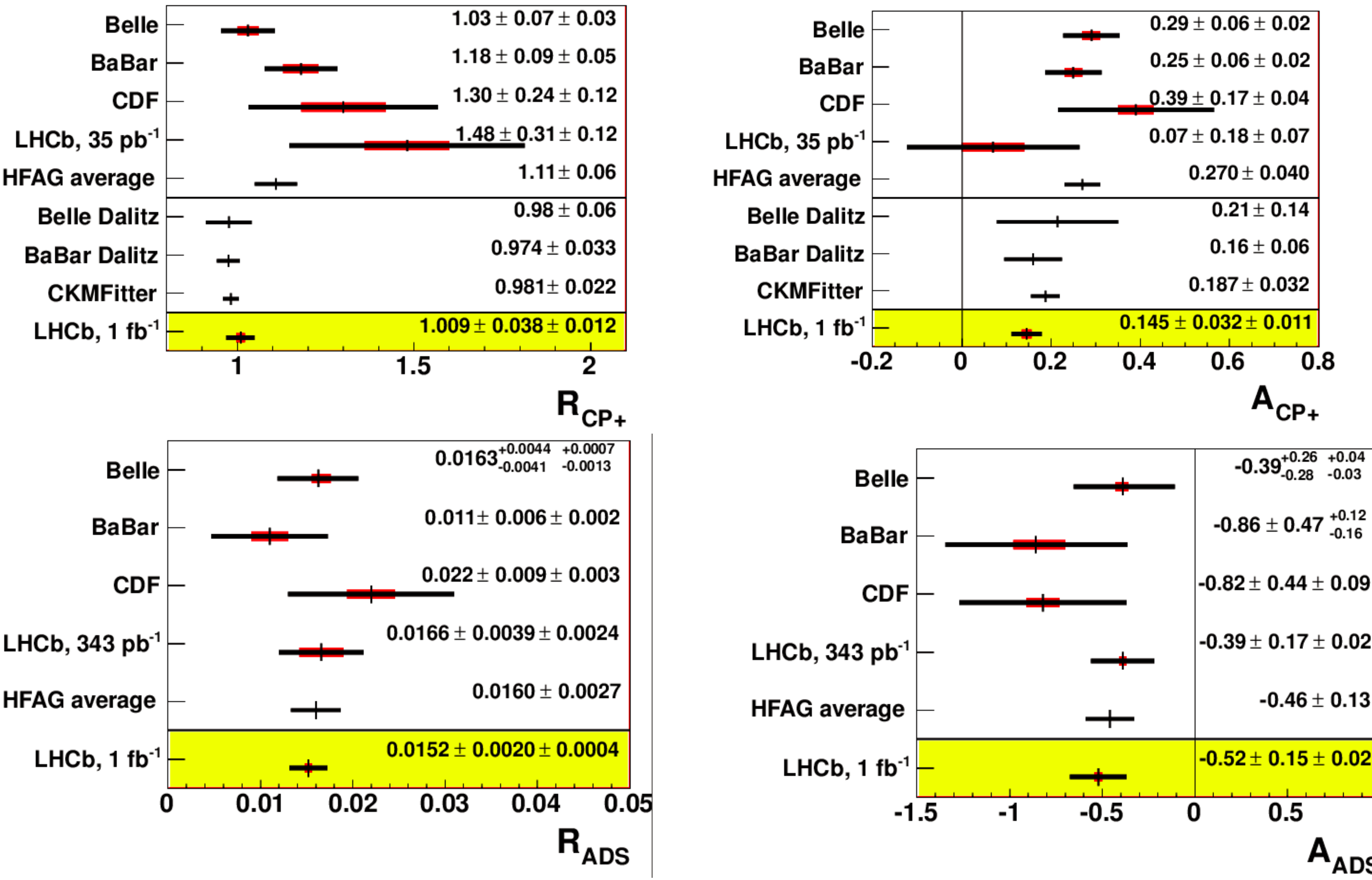
$$A^{\pi\pi}_{\pi} = -0.0009 \pm 0.0165 \pm 0.0099$$

Results

$$
\begin{aligned}
R_{CP+} &\approx < R_{K/\pi}^{KK}, R_{K/\pi}^{\pi\pi} > / R_{K/\pi}^{K\pi} \\
&= 1.01 \pm 0.04 \pm 0.01
\end{aligned}
$$

$$
\begin{aligned}
A_{CP+} &= < A_K^{KK}, A_K^{\pi\pi} > \\
&= 0.15 \pm 0.03 \pm 0.01
\end{aligned}
$$

$$
\begin{aligned}
R_{ADS(K)} &= (R_K^- + R_K^+)/2 \\
&= 0.015 \pm 0.002 \pm 0.000 \\
A_{ADS(K)} &= (R_K^- - R_K^+)/(R_K^- + R_K^+) \\
&= -0.52 \pm 0.15 \pm 0.02 \\
R_{ADS(\pi)} &= (R_\pi^- + R_\pi^+)/2 \\
&= 0.0041 \pm 0.0003 \pm 0.0001 \\
A_{ADS(\pi)} &= (R_\pi^- - R_\pi^+)/(R_\pi^- + R_\pi^+) \\
&= 0.143 \pm 0.062 \pm 0.011
\end{aligned}
$$



Belle
BaBar
CDF
LHCb, 35 pb^{-1}
HFAG average
Belle Dalitz
BaBar Dalitz
CKMFitter
LHCb, 1 fb^{-1}
1.03 ± 0.07 ± 0.03
1.18 ± 0.09 ± 0.05
1.30 ± 0.24 ± 0.12
1.48 ± 0.31 ± 0.12
1.11 ± 0.06
0.98 ± 0.06
0.974 ± 0.033
0.981 ± 0.022
1.009 ± 0.038 ± 0.012
1
1.5
2
R_{CP+}
Belle
BaBar
CDF
LHCb, 35 pb^{-1}
HFAG average
Belle Dalitz
BaBar Dalitz
CKMFitter
LHCb, 1 fb^{-1}
0.29 ± 0.06 ± 0.02
0.25 ± 0.06 ± 0.02
0.39 ± 0.17 ± 0.04
0.07 ± 0.18 ± 0.07
0.270 ± 0.040
0.21 ± 0.14
0.16 ± 0.06
0.187 ± 0.032
0.145 ± 0.032 ± 0.011
-0.2
0
0.2
0.4
0.6
0.8
A_{CP+}
Belle
BaBar
CDF
LHCb, 343 pb^{-1}
HFAG average
LHCb, 1 fb^{-1}
$0.0163^{+0.0044}_{-0.0041}{}^{+0.0007}_{-0.0013}$
0.011 ± 0.006 ± 0.002
0.022 ± 0.009 ± 0.003
0.0166 ± 0.0039 ± 0.0024
0.0160 ± 0.0027
0.0152 ± 0.0020 ± 0.0004
0
0.01
0.02
0.03
0.04
0.05
R_{ADS}
Belle
BaBar
CDF
LHCb, 343 pb^{-1}
HFAG average
LHCb, 1 fb^{-1}
$-0.39^{+0.26}_{-0.28}{}^{+0.04}_{-0.03}$
$-0.86 \pm 0.47 {}^{+0.12}_{-0.16}$
-0.82 ± 0.44 ± 0.09
-0.39 ± 0.17 ± 0.02
-0.46 ± 0.13
-0.52 ± 0.15 ± 0.02
-1.5
-1
-0.5
0
0.5
1
A_{ADS}