Belle time-integrated γ (ϕ_3) measurements

Y. Horii

(Tohoku University, Japan)

8th September
University of Warwick

1

Introduction

▸ The phase ϕ_3 is included in the transition b➙u.

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

▸ Most popular methods use the decay B⁻➙DK⁻ (and the conjugate).

$B^- \to D^0 K^-$ (No penguin) $B^- \to \bar{D}^0 K^-$
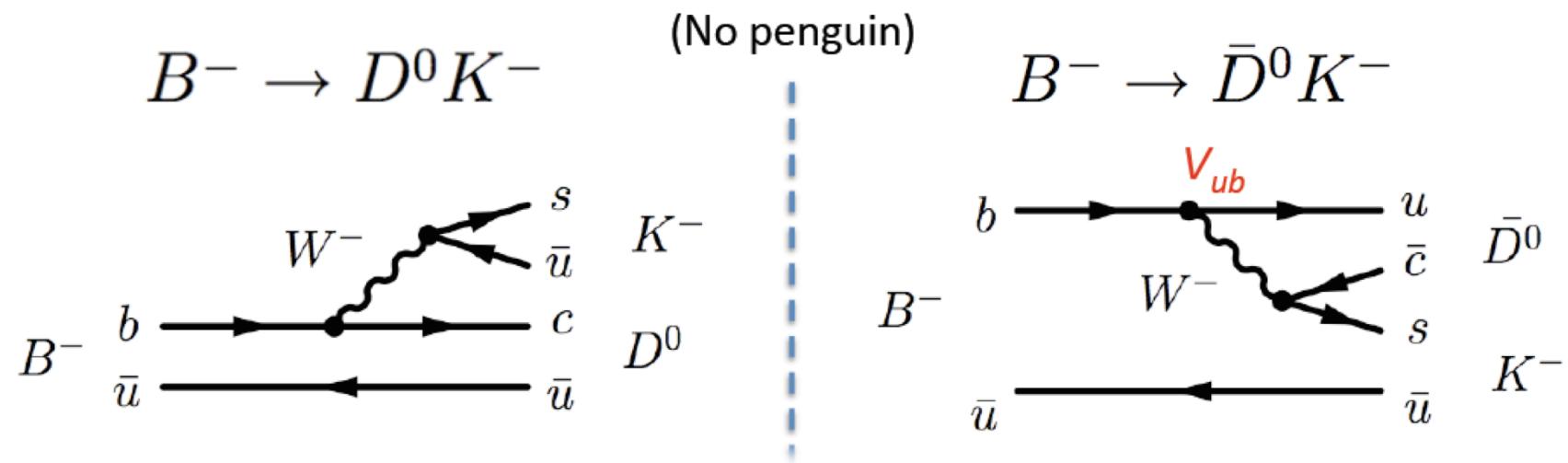
▸ Value of ϕ_3 is extracted through the interference of two paths, which occurs when D^0 and $\bar{D}^0$ decay to the same final state.

Introduction

- ## Dalitz (GGSZ)

  - GGSZ, PRD 68, 054018 (2003).
  - Dalitz analysis on $D \rightarrow K_S \pi^+ \pi^-$, etc.
  - Most sensitive.

- ## GLW+ADS

  - GW, PLB 265, 172 (1991).
    ADS, PRL 78, 3257 (1997).
  - Fit using the observables
    from $D \rightarrow CP$ eigenstates, $K^+ \pi^-$, etc.

- In each case, enough information is obtained to extract
  the ratio of magnitudes of amplitudes (r) and the strong phase (δ).
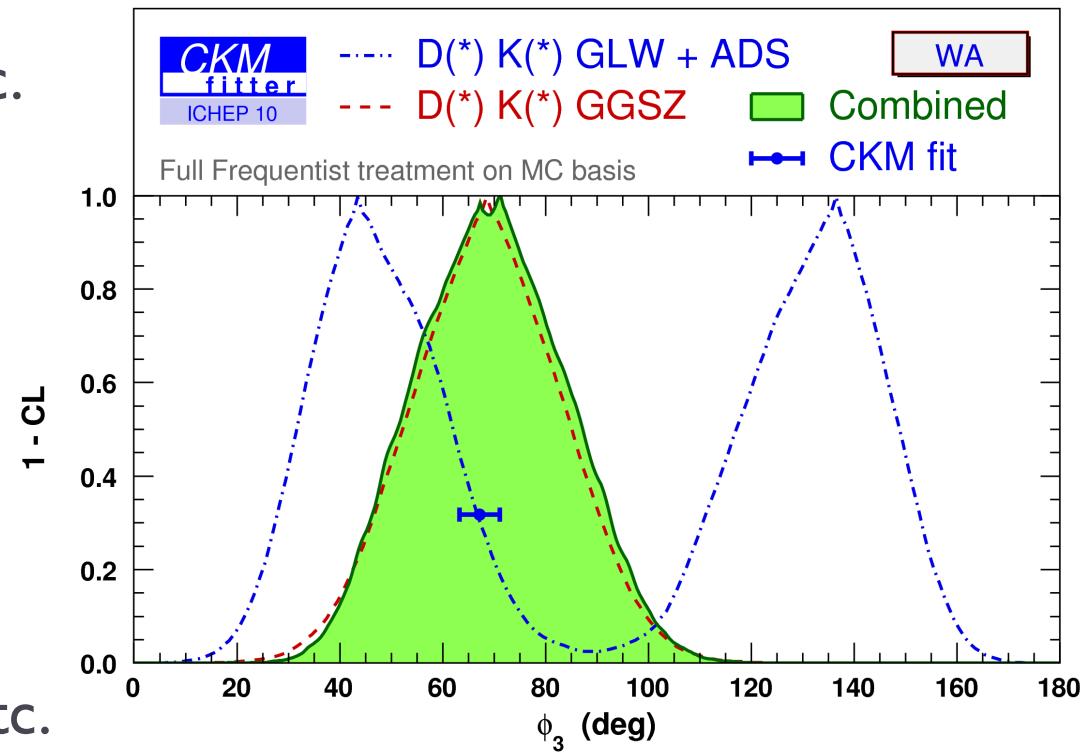
Topics for Today

- **B$^-\to$D$^{(*)}$K$^-$, D$\to$K$_S\pi^+\pi^-$ Dalitz**

  - A. Poluektov et al.,
    PRD 81, 112002 (2010).
  - 657 M BB.

- **B$^-\to$DK$^-$, D$\to$K$^+\pi^-$ ADS**

  - New result (preliminary) shown for the first time.
  - 772 M BB:
    full Y(4S) data for Belle.

Luminosity at B factories

(fb^{-1})

772 M BB

> 1 ab^{-1}
On resonance:
Y(5S): 121 fb^{-1}
Y(4S): 711 fb^{-1}
Y(3S): 3 fb^{-1}
Y(2S): 24 fb^{-1}
Y(1S): 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
Y(4S): 433 fb^{-1}
Y(3S): 30 fb^{-1}
Y(2S): 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}
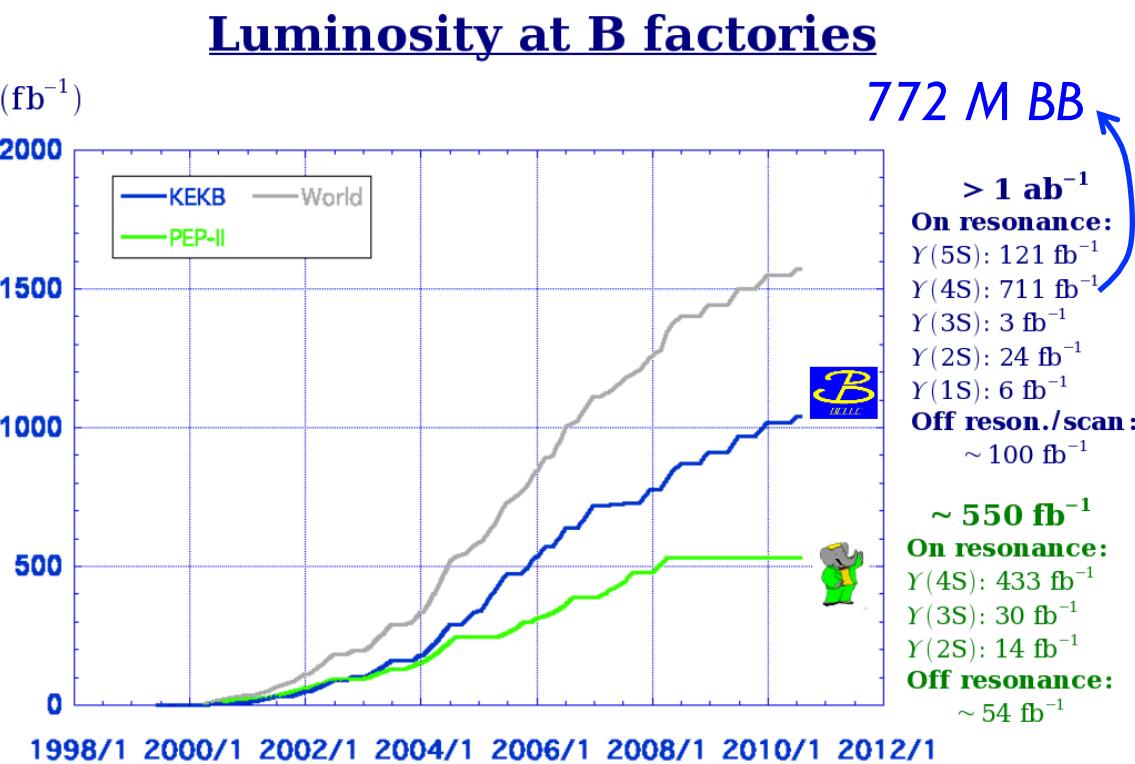
B Meson Reconstruction

▸ Primary particles

  ▸ K/π identification: efficiency ~ 85%, fake rate ~ 10%.

  ▸ K_S: reconstructed from $\pi^+\pi^-$ using $M_{\pi\pi}$ and vertex information.

  ▸ π^0: reconstructed from $\gamma\gamma$ using $M_{\gamma\gamma}$ and E_γ.

▸ Two kinematic variables

  ▸ Energy difference $\Delta E \equiv E_B - E_{\text{beam}}$

  ▸ Beam-energy constrained mass $M_{\text{bc}} \equiv \sqrt{E_{\text{beam}}^2 - |p_B|^2}$

▸ Continuum suppression by

  ▸ Fisher discriminant of SFW moments or

  ▸ Neural Network including more variables.

spherical   jet-like
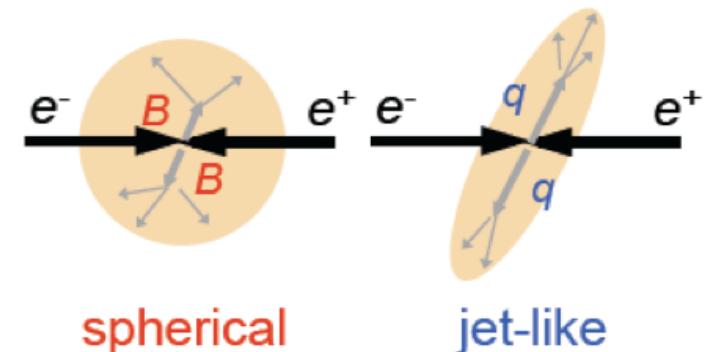
B$^-$→D$^{(*)}$K$^-$, D→K$_S$π$^+$π$^-$ Dalitz

- Amplitude of B$^\pm$→DK$^\pm$ process can be expressed as

$$M_\pm = f(m_\pm^2, m_\mp^2) + re^{\pm i\phi_3 + i\delta} f(m_\mp^2, m_\pm^2)$$

$$\boxed{m_\pm^2 = m_{K_S \pi^\pm}^2}$$

Ratio of magnitudes
of interfering amplitudes.

Amplitude of D→K$_S$π$^+$π$^-$ decay
determined from Dalitz plot of large continuum data
(Flavor is tagged by soft-pion charge in D$^{*\pm}$→Dπ$^\pm_{soft}$).
Isobar-model assumption with BW for resonances.
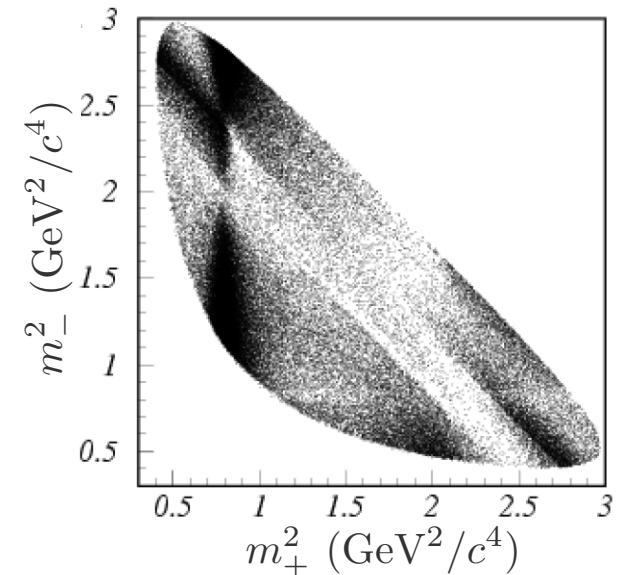
- Procedure of analysis:
  1. Background fractions are determined by 2-D UML fit for ΔE and M$_{bc}$.
 2. Fit is performed to m$_\pm$ (Dalitz plane).

B⁻→D^(*)K⁻ Dalitz, ΔE and M_bc Projections
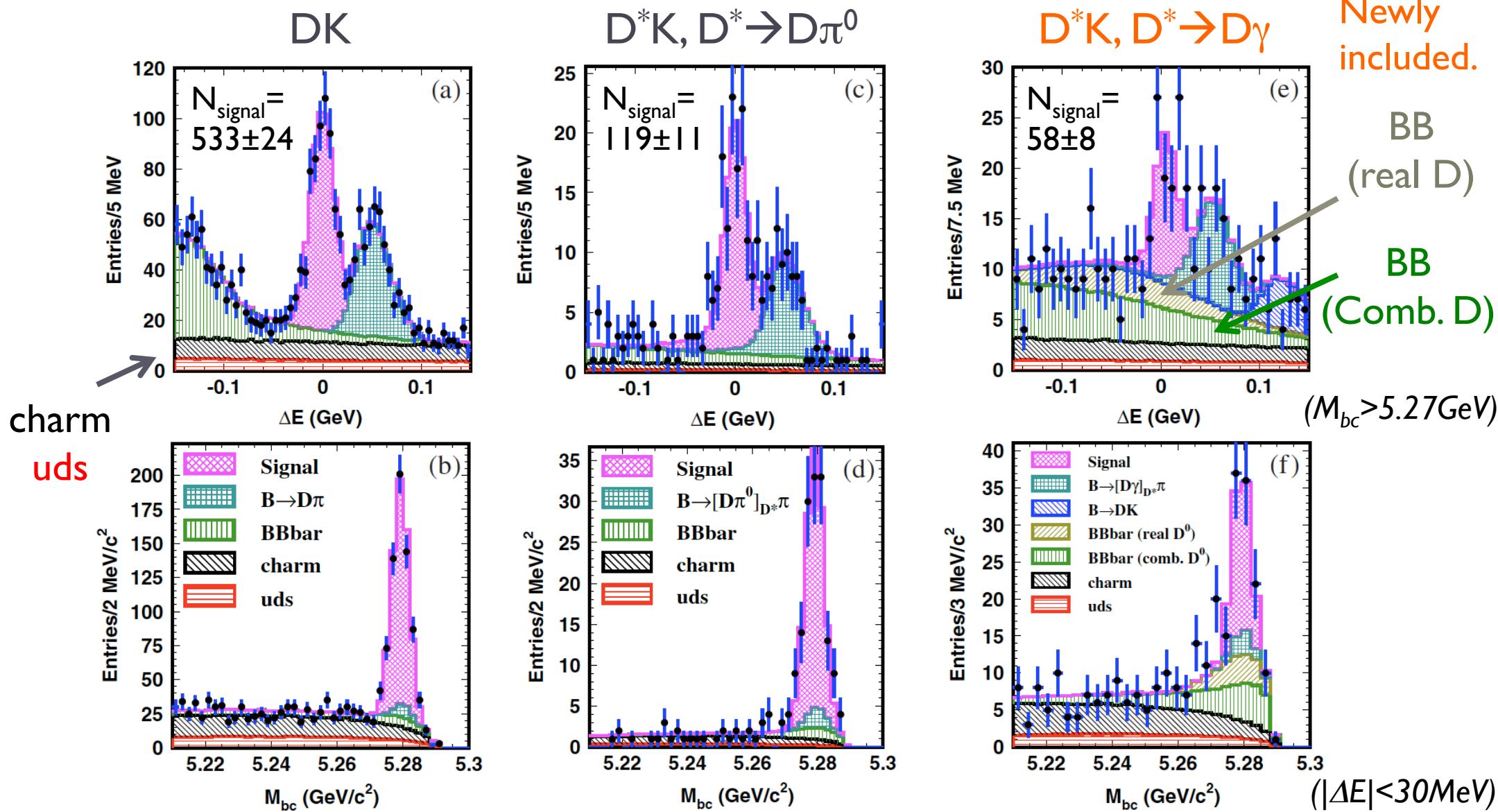
B⁻→D$^{(*)}$K⁻ Dalitz, Result

▸ Using the background fractions, Dalitz plane is fitted with the parameters $x_\pm = r_\pm \cos(\pm\phi_3+\delta)$ and $y_\pm = r_\pm \sin(\pm\phi_3+\delta)$.
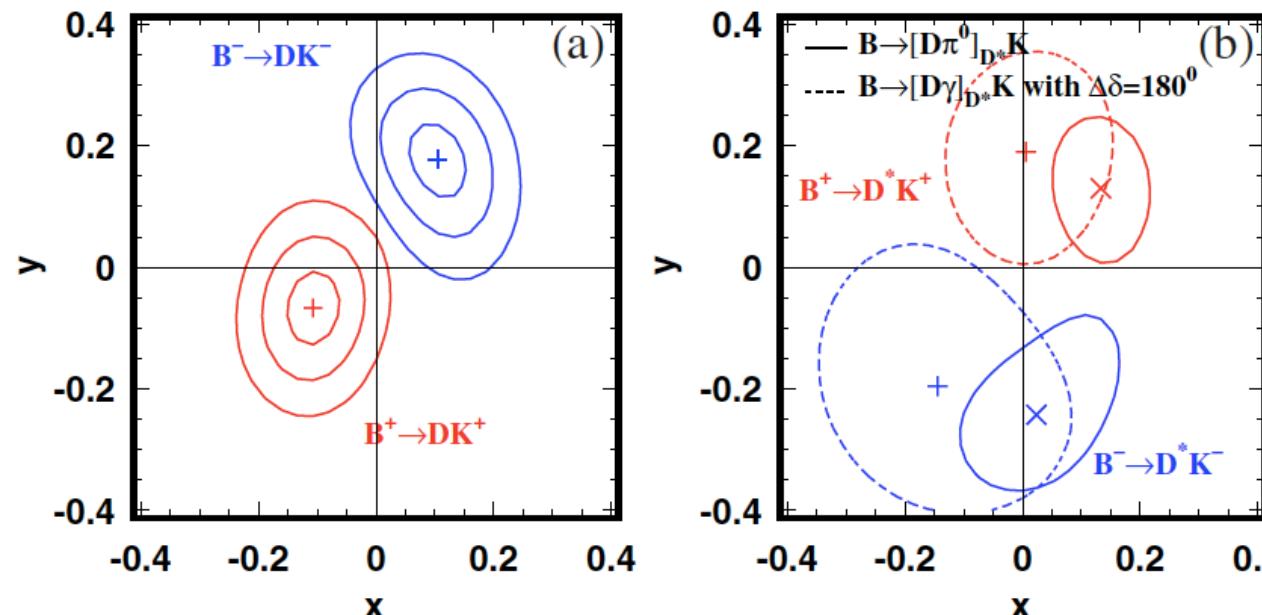
▸ Combining the results for B→D$^{(*)}$K, we obtain

Model-independent analysis will be applied for 772M BB.

$$\phi_3 = 78.4°\ ^{+10.8°}_{-11.6°} \pm 3.6°(\text{syst}) \pm 8.9°(\text{model})$$

$$\left(\begin{array}{l} r_{DK} = 0.160^{+0.040}_{-0.038} \pm 0.011^{+0.050}_{-0.010},\ \delta_{DK} = 136.7°\ ^{+13.0°}_{-15.8°} \pm 4.0° \pm 22.9° \\ r_{D*K} = 0.196^{+0.072}_{-0.069} \pm 0.012^{+0.062}_{-0.012},\ \delta_{D*K} = 341.9°\ ^{+18.0°}_{-19.6°} \pm 3.0° \pm 22.9° \end{array} \right)$$

B⁻→DK⁻, D→K⁺π⁻ ADS

- Large effect of ϕ_3 appears in the branching fraction due to similar magnitudes of interfering amplitudes.

- We also analyze B→Dπ as a reference.

- We measure

  Calibration Mode

  - Partial rate

  $$\mathcal{R}_{Dh} \equiv \frac{\mathcal{B}(B^- \to [K^+\pi^-]_D h^-) + \mathcal{B}(B^+ \to [K^-\pi^+]_D h^+)}{\mathcal{B}(B^- \to [K^-\pi^+]_D h^-) + \mathcal{B}(B^+ \to [K^+\pi^-]_D h^+)}$$
  $$= r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos\phi_3,$$

  - Asymmetry

  $$\mathcal{A}_{Dh} \equiv \frac{\mathcal{B}(B^- \to [K^+\pi^-]_D h^-) - \mathcal{B}(B^+ \to [K^-\pi^+]_D h^+)}{\mathcal{B}(B^- \to [K^+\pi^-]_D h^-) + \mathcal{B}(B^+ \to [K^-\pi^+]_D h^+)}$$
  $$= 2r_B r_D \sin(\delta_B + \delta_D)\sin\phi_3/\mathcal{R}_{Dh},$$

  $$h = K \text{ or } \pi$$

$r_{B(D)}$: ratio of magnitudes of amplitudes for B (D) decays.
$\delta_{B(D)}$: strong-interaction phase for B (D) decays.
HFAG and CLEO-c inputs for r_D and δ_D.

Continuum Suppression

▸ Main background is $e^+e^- \to q\bar{q}$ (q=u, d, s, c) continuum process.

▸ To discriminate this background,
new technique employs NeuroBayes (NB) neural network.

NB inputs (10 in total):
• LR for Fisher of SFW moments
• Vertex separation between
  reconstructed B and the other B (Δz)
• Decay angle for $D \to K\pi$
• ...

histogram: signal on MC
dots: Calib. mode ($D\pi$) on data
histogram: qq on MC
dots: ΔE sideband on data

Fit region: NB > -0.6.
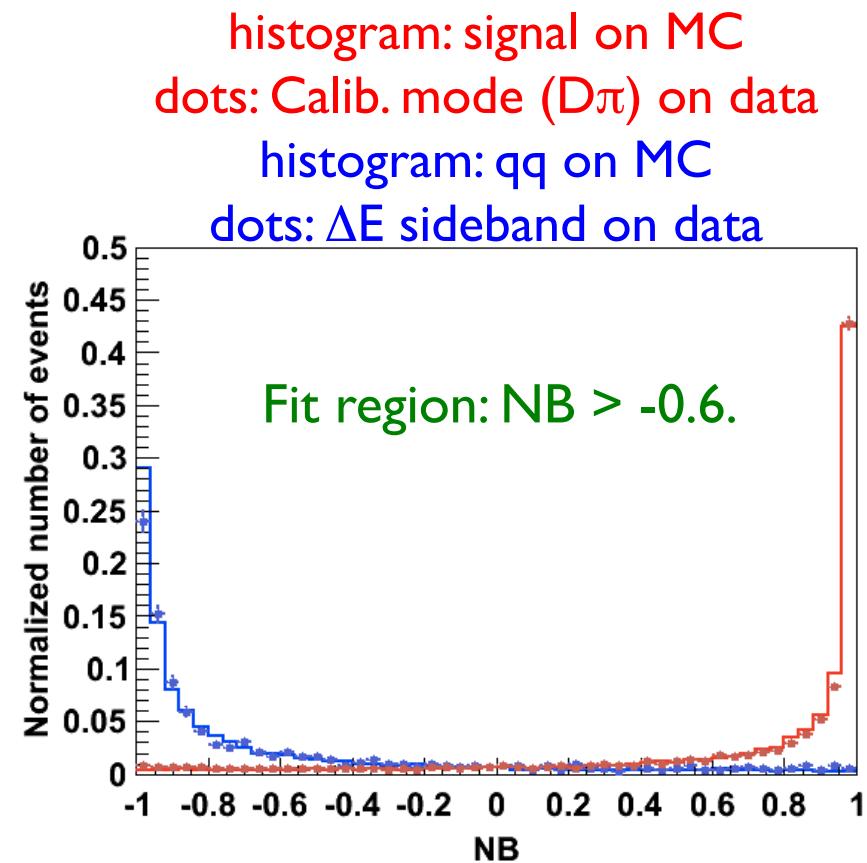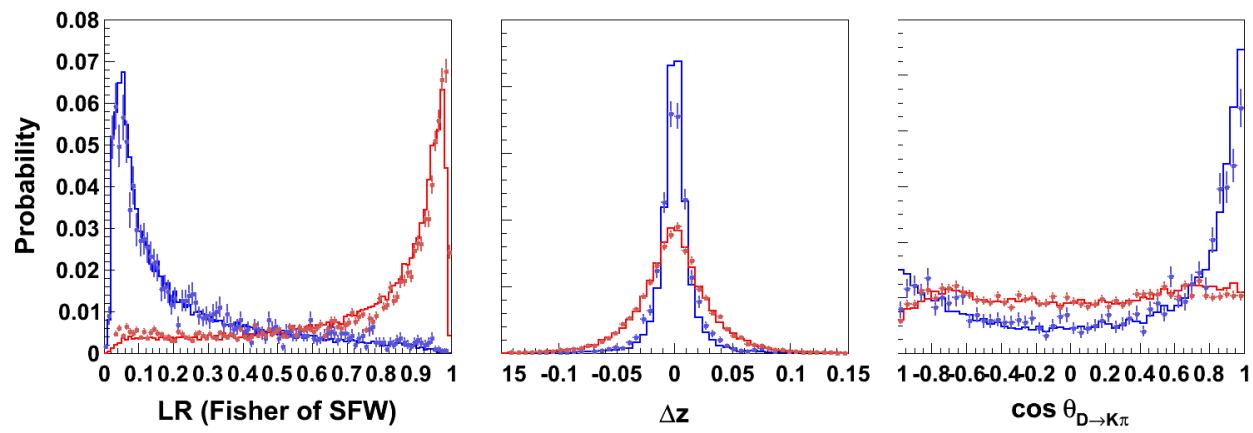
Peaking Background

- B$^-$→Dπ^-, D→K$^+$K$^-$ (same final state)
  - Veto on K$^+$K$^-$ mass.
- B$^-$→Dh$^-$, D→K$^-\pi^+$ (double mis-ID)
  - Veto on K$^-\pi^+$ mass, where ID is exchanged.
- Charmless B$^-$→K$^+$K$^-\pi^-$ (same final state)

~Flat K$^+\pi^-$-mass distribution.

- We estimate the total contribution using K$^+\pi^-$-mass sideband of data.
  - 0.020 < |M$_{K\pi}$−1.865| < 0.050 (in GeV).
  - Estimated number = 0.4 ± 5.5.

Fit for K$^+\pi^-$-mass sideband. Projection for ΔE (NB>0.5).
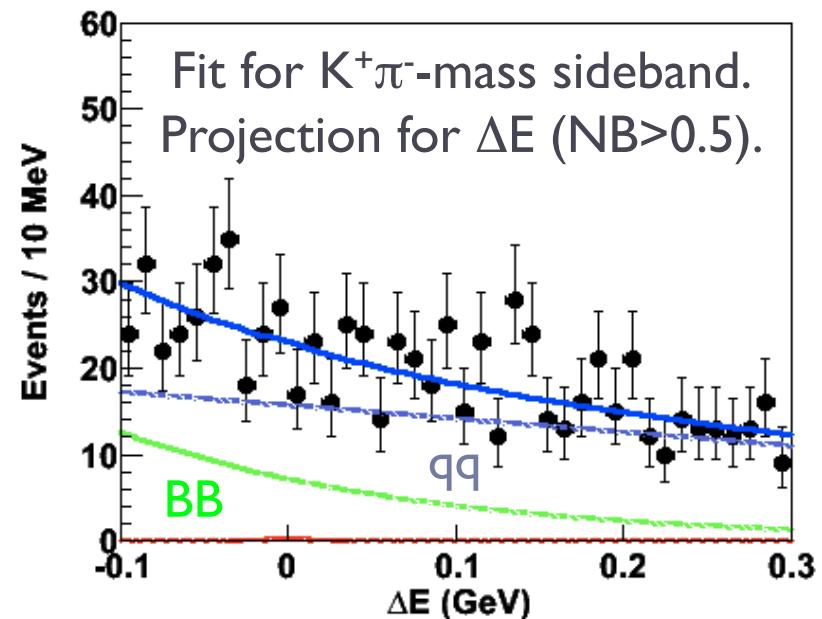
Simultaneous Fit for B⁻→[K⁻π⁺]$_D$h⁻ (Calib. Modes)
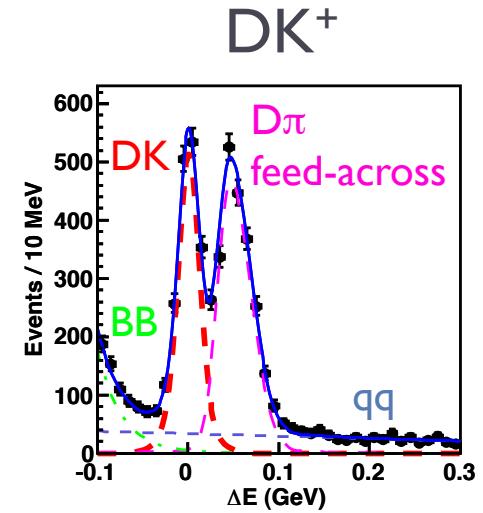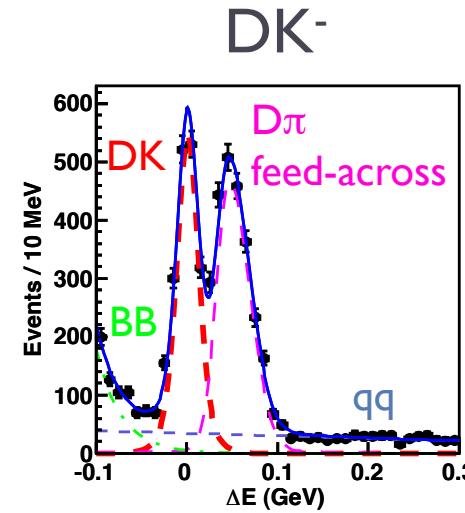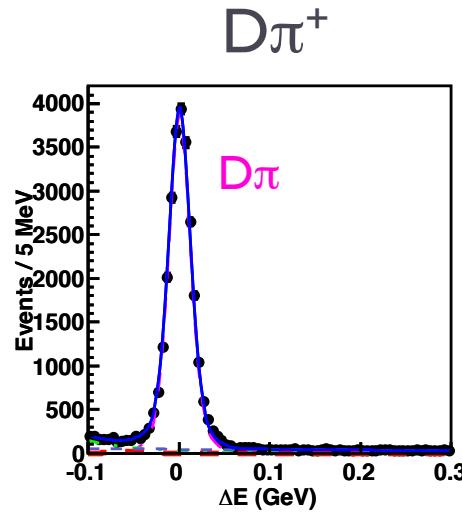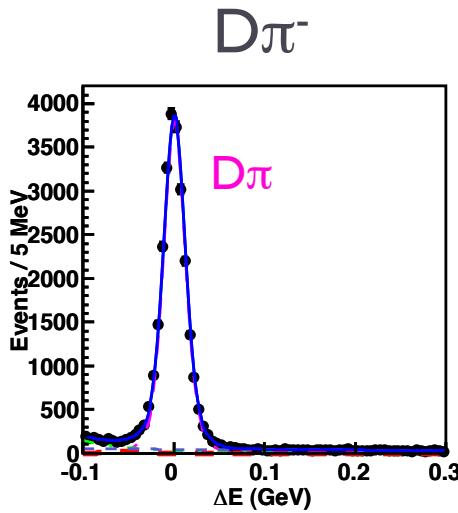
(Projections for all fitted regions are shown.)
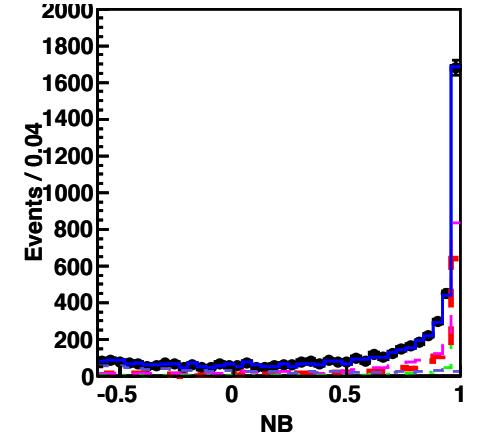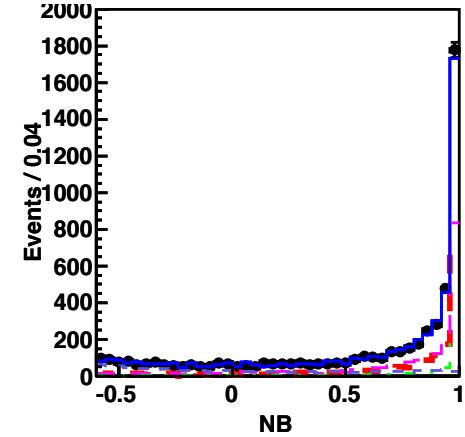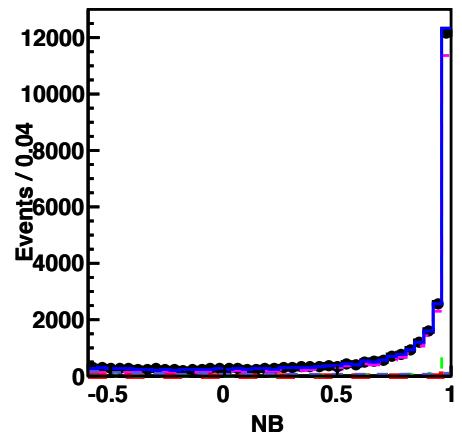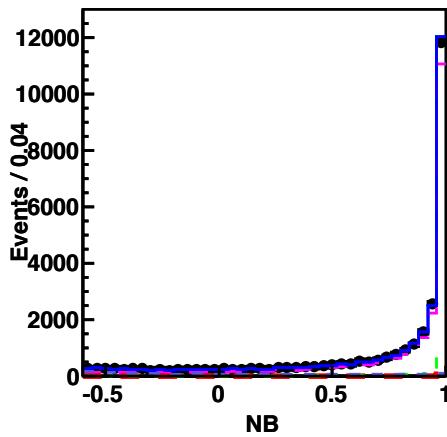
ΔE: Dh: 2 Gaussians (the same free shape for π/K).
Dπ feed-across: 2 Asym. Gaussians (μ, $\sigma_{l,right}$ free).
BB: free exponential. qq: free linear.

NB: Dh: Hist. from |ΔE|<10 MeV. ← Subtract qq.
Dπ feed-across: Hist. from |ΔE-50 MeV|<10 MeV.
BB: Hist. from MC. qq: Hist. from M$_{bc}$ sideband.

▶ 12

Simultaneous Fit for $B^- \to [K^+\pi^-]_D h^-$

- ▸ Projections for h=π in signal regions are shown.
  - ▸ NB > 0.5
  - ▸ |ΔE| < 0.04 GeV

- ▸ The results ($R_{D\pi}$ in 10^{-3}) are

$$\mathcal{R}_{D\pi} = 3.28 \pm 0.37(\text{stat})^{+0.22}_{-0.23}(\text{syst})$$

$$\mathcal{A}_{D\pi} = -0.04 \pm 0.11(\text{stat})^{+0.01}_{-0.02}(\text{syst})$$

- ▸ Most precise measurements to date with a significance 8.4σ (including syst).

$D\pi^-$

Dπ: shape from Calib. mode (data).

$D\pi^+$

BB: free exponential. qq: free linear.

Dπ: shape from Calib. mode (data).

BB: shape from MC. qq: shape from sideband (data).
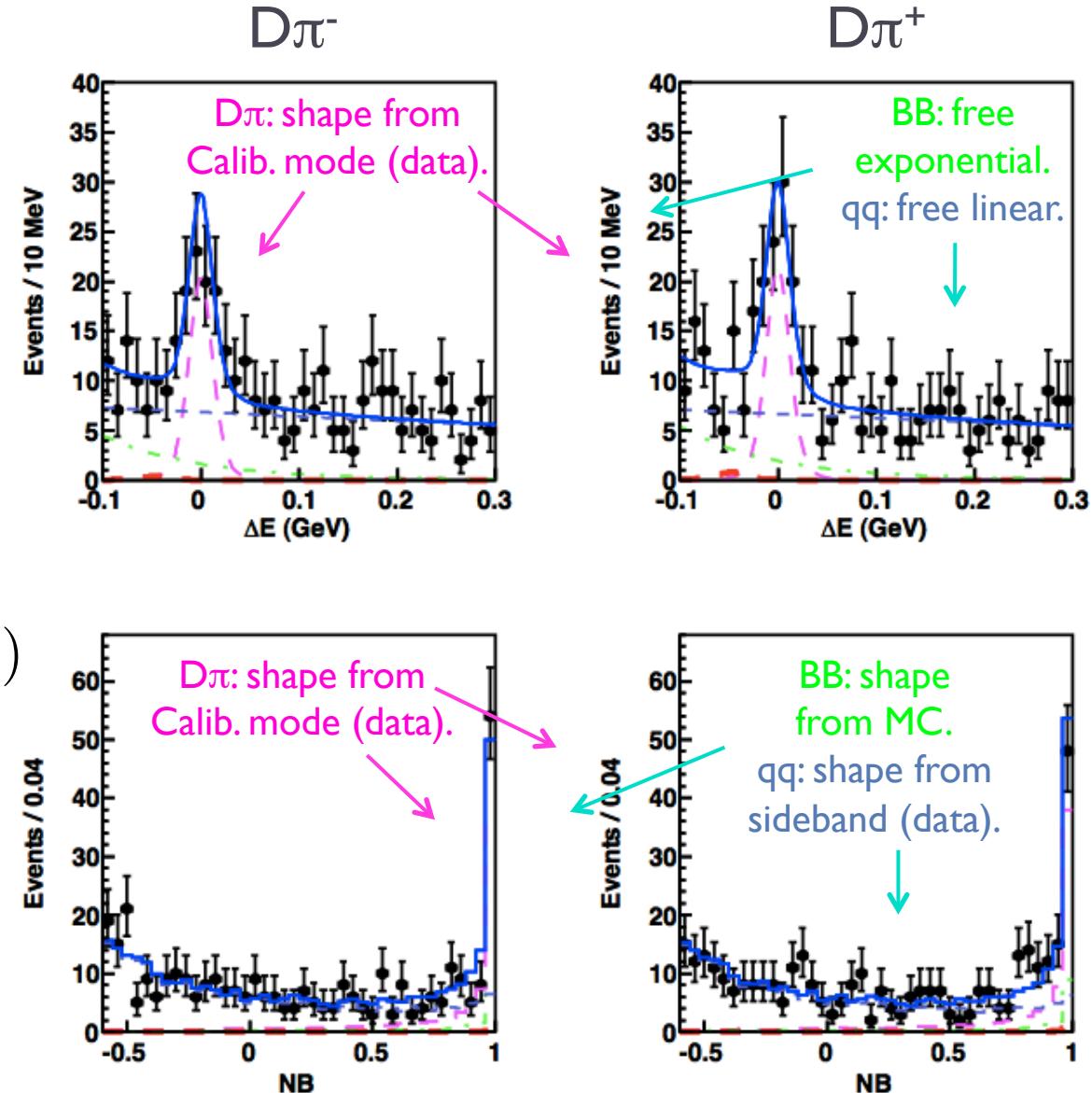
Simultaneous Fit for B$^-$→[K$^+$π$^-$]$_D$h$^-$ 772 M BB

- ▸ Projections for h=K in signal regions are shown.
  - ▸ NB > 0.5
  - ▸ |ΔE| < 0.04 GeV

- ▸ The results (R$_{DK}$ in 10^{-2}) are

$$\mathcal{R}_{DK} = 1.62 \pm 0.42(\text{stat})^{+0.16}_{-0.19}(\text{syst})$$

$$\mathcal{A}_{DK} = -0.39 \pm 0.26(\text{stat})^{+0.06}_{-0.04}(\text{syst})$$

- ▸ First evidence is obtained with a significance 3.8σ (including syst).

DK$^-$ DK$^+$

Dh: shape from Calib. mode (data).

BB: free exponential. qq: free linear.

Dπ: fake rate fixed to result on Calib. mode.

Dh: shape from Calib. mode (data).

BB: shape from MC. qq: shape from sideband (data).
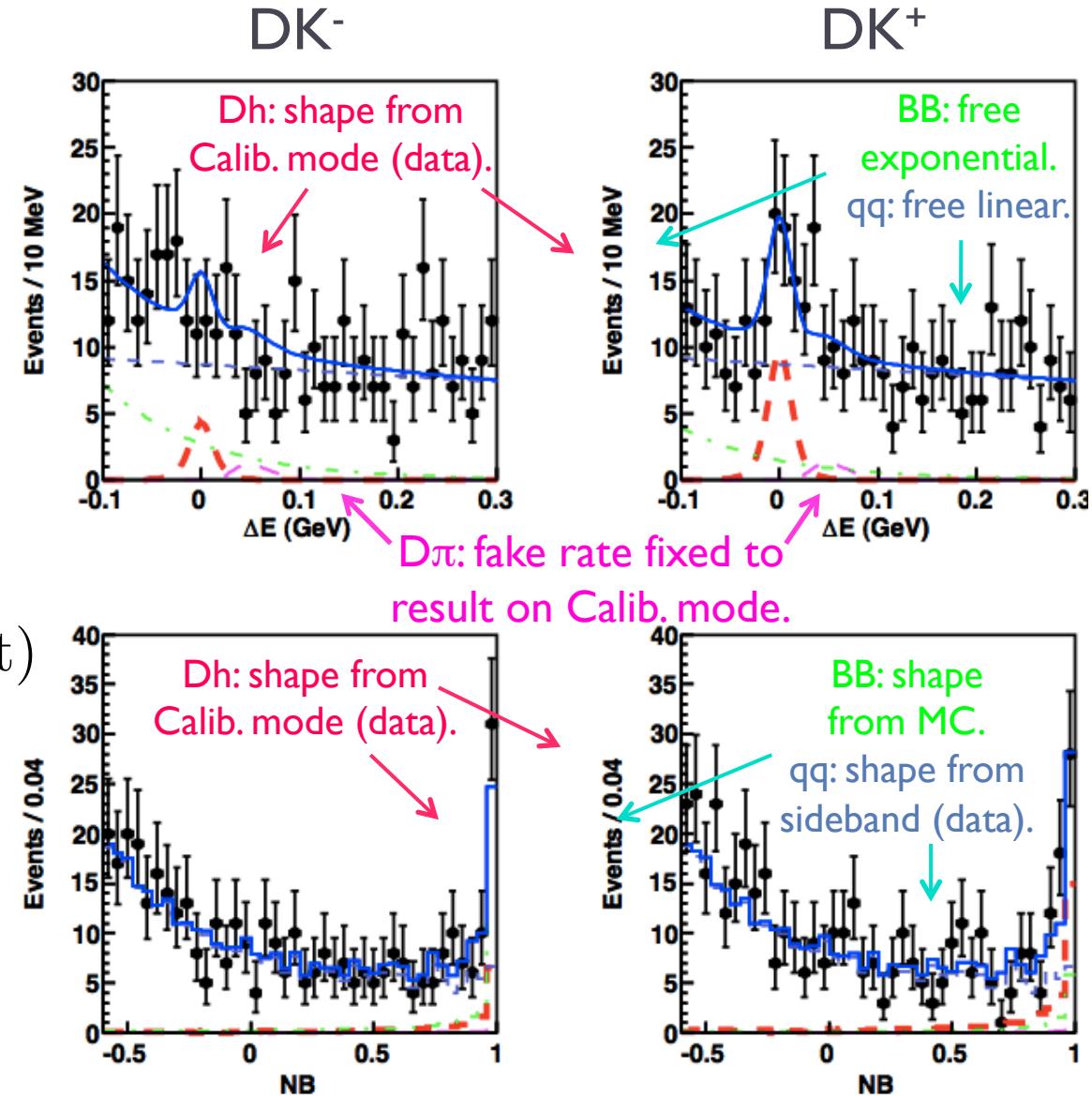
Systematic Uncertainties

Source	$\mathcal{R}_{DK}$	$\mathcal{R}_{D\pi}$	$\mathcal{A}_{DK}$	$\mathcal{A}_{D\pi}$
Fit	$^{+9.7}_{-6.3}\%$	$^{+6.5}_{-5.3}\%$	$^{+0.05}_{-0.04}$	$^{+0.009}_{-0.018}$
(ΔE-PDF	$^{+4.4}_{-3.6}\%$	$^{+2.4}_{-2.3}\%$	±0.02	±0.003)
($\mathcal{NB}$-PDF	$^{+4.2}_{-1.6}\%$	$^{+4.0}_{-2.8}\%$	$^{+0.02}_{-0.01}$	$^{+0.001}_{-0.010}$)
(Yield and asymmetry	$\pm1.1\%$	$\pm0.1\%$	±0.01	±0.005)
Peaking backgrounds	$^{+0.7}_{-9.9}\%$	$^{+0.0}_{-4.1}\%$	$^{+0.03}_{-0.00}$	$^{+0.002}_{-0.000}$
Efficiency	$\pm1.7\%$	$\pm1.5\%$	$\cdots$	$\cdots$
Detector asymmetry	$\cdots$	$\cdots$	±0.02	±0.005

▸ The uncertainties due to the fit are dominant components.

   ▸ Conservatively take a linear sum of all uncertainties in the fit.

▸ Detector asymmetry is obtained by the calibration mode.

▸ The total systematic error is the sum in quadrature.

Summary

- $B^- \rightarrow D^{(*)}K^-$, $D \rightarrow K_S\pi^+\pi^-$ Dalitz
  - 657 M BB.
  - Mode $D^* \rightarrow D\gamma$ is included.
  - Most precise measurement of ϕ_3 is obtained.

$$\phi_3 = 78.4° \; {}^{+10.8°}_{-11.6°} \pm 3.6°\,(\text{syst}) \pm 8.9°\,(\text{model})$$

- $B^- \rightarrow DK^-$, $D \rightarrow K^+\pi^-$ ADS (PRELIMINARY)
  - 772 M BB: full $\Upsilon(4S)$ data.
  - New approach on continuum suppression is employed.
  - First evidence of signal is obtained with a significance 3.8σ.

# Backup

A Check for NeuroBayes Performance

NB training is performed with 7 variables (removing Δz, $\cos\theta_{D\to K\pi}$, and distance_{Dh}).
By using the result of this training, we obtain the NB-output distributions for
    qq MC shown with a histogram and
    data ($\Delta E > 150$ MeV: qq-dominated region) shown with dots.

some data/MC differences

MC: histogram
Data: dots

Good agreement obtained.
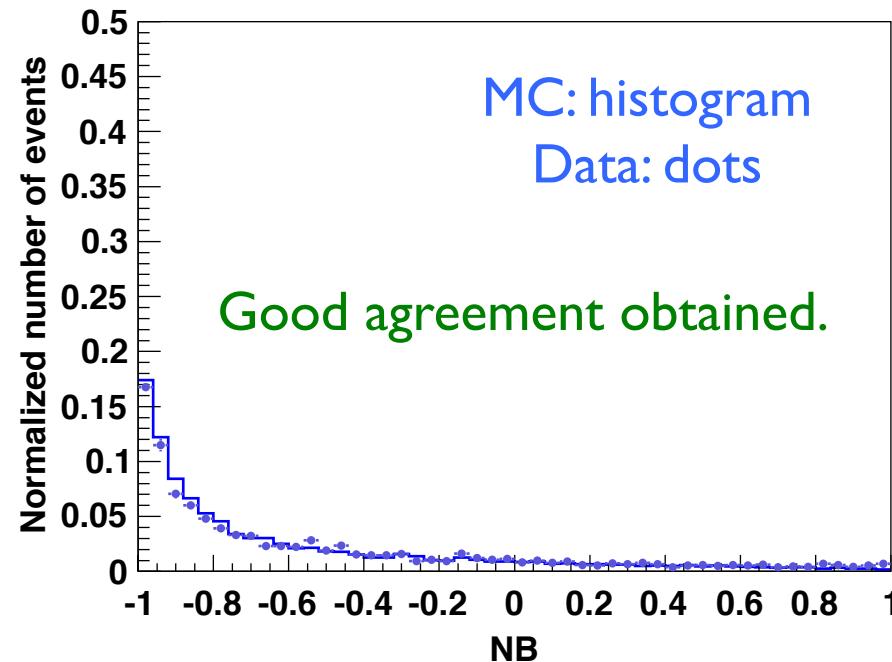
Note: we obtain the PDF used for the fit from M_{bc} sideband (5.20 GeV$<M_{bc}<$5.26 GeV) of data; the result will not be effected by a discrepancy between data and MC.

Comparison between Different Results

	This Analysis	Previous Result by Belle	Latest Result by BaBar
$\mathcal{R}_{DK}\ [\times 10^{-2}]$	$1.62 \pm 0.42\ ^{+0.16}_{-0.19}$	$0.78\ ^{+0.62}_{-0.57}\ ^{+0.20}_{-0.28}$	$1.1 \pm 0.6 \pm 0.2$
$\mathcal{R}_{D\pi}\ [\times 10^{-3}]$	$3.28 \pm 0.37\ ^{+0.22}_{-0.23}$	$3.40\ ^{+0.55}_{-0.53}\ ^{+0.15}_{-0.22}$	$3.3 \pm 0.6 \pm 0.4$
$\mathcal{A}_{DK}$	$-0.39 \pm 0.26\ ^{+0.06}_{-0.04}$	$-0.1\ ^{+0.8}_{-1.0} \pm 0.4$	$-0.86 \pm 0.47\ ^{+0.12}_{-0.16}$
$\mathcal{A}_{D\pi}$	$-0.04 \pm 0.11\ ^{+0.01}_{-0.02}$	$-0.02\ ^{+0.15}_{-0.16} \pm 0.04$	$0.03 \pm 0.17 \pm 0.04$

N(BB) =	772 M	657 M	467 M

▸ The consistencies for Dπ results strongly encourage us to be confident with our new method.

▸ The value of R_{DK} is ∼1σ higher than the previous value by Belle, for which the reason can be statistical since more than 60 % events are independent of the ones in the previous analysis.
(In the previous analysis, tight cut was applied for qq suppression.)

Significance

▸ The significance is estimated by convoluting the likelihood in the fit and an asymmetric Gaussian whose widths are the systematic errors.