Belle time-integrated γ (ϕ_3) measurements

Y. Horii
(Tohoku University, Japan)

8th September
University of Warwick

CKM2010

Introduction

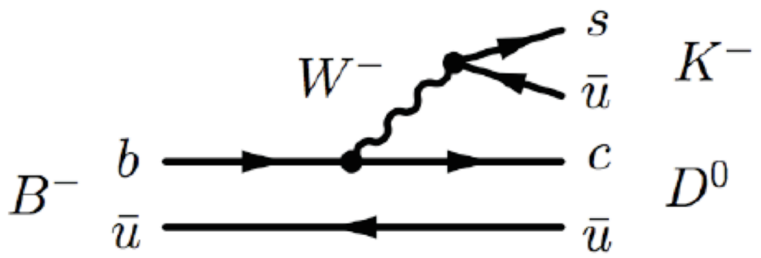
- The phase ϕ_3 is included in the transition b→u.

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

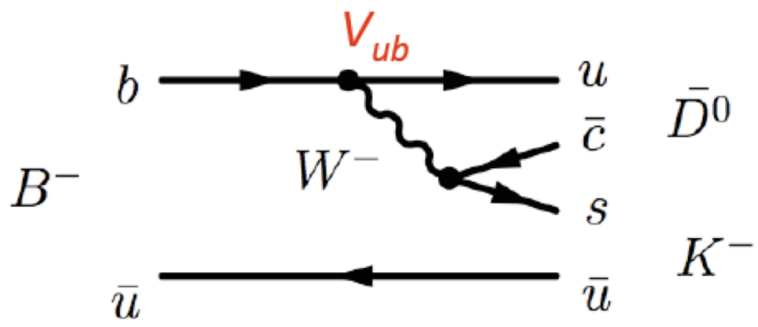
- Most popular methods use the decay $B^- \to DK^-$ (and the conjugate).

(No penguin)

$$B^- \to D^0 K^-$$



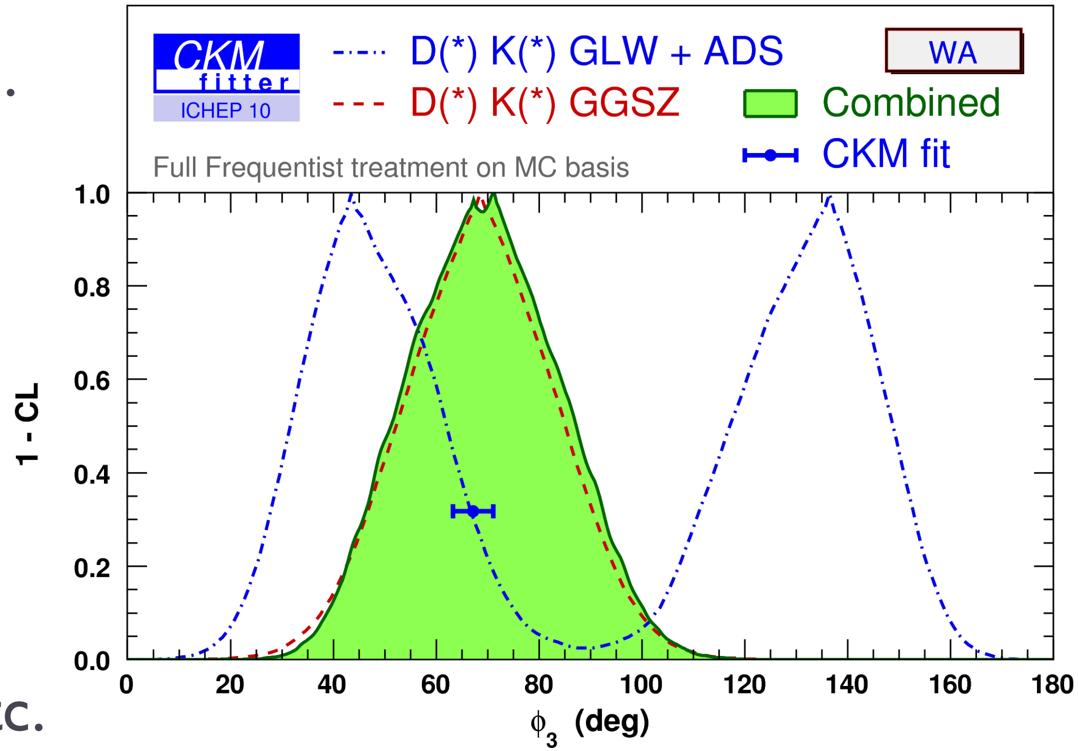
$$B^- \to \bar{D}^0 K^-$$



- 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.

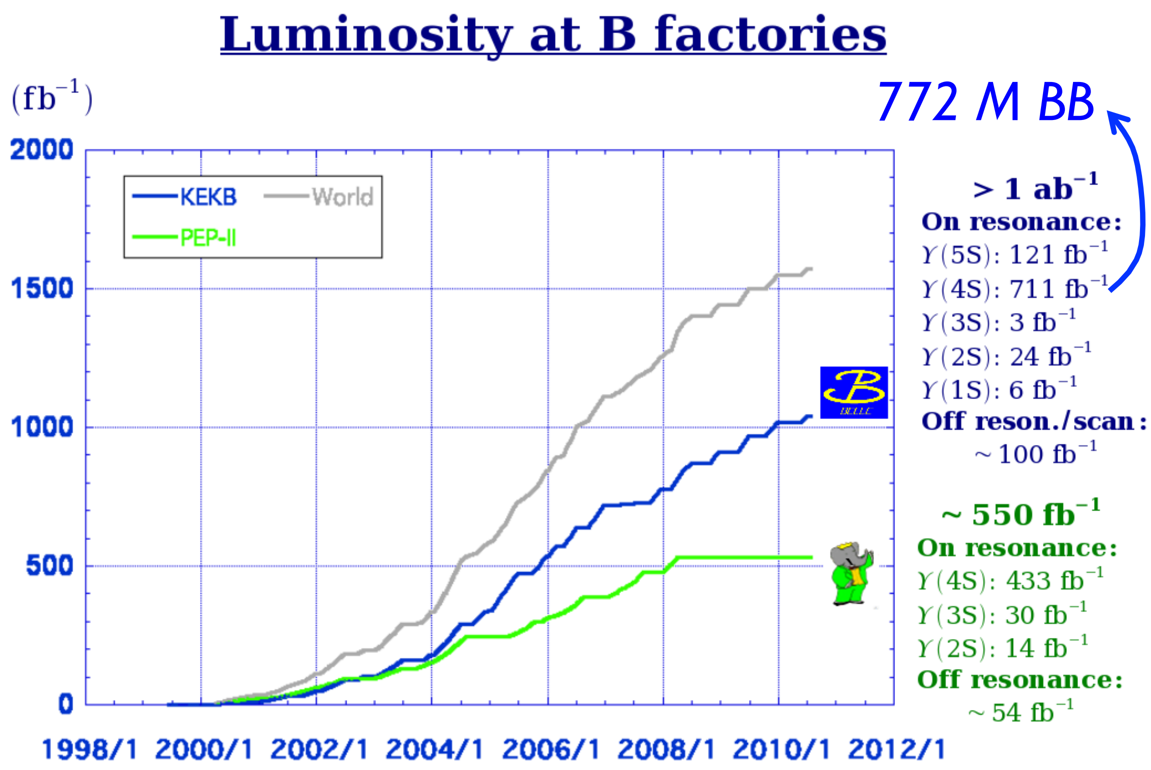


- GLW+ADS
  - GW, PLB 265, 172 (1991).
    ADS, PRL 78, 3257 (1997).
  - Fit using the observables
    from $D \rightarrow CP$ eigenstates, $K^+\pi^-$, etc.

- 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.
- $B^- \to D K^-$, $D \to K^+ \pi^-$ ADS
  - New result (preliminary) shown for the first time.
  - 772 M BB: full $\Upsilon(4S)$ data for Belle.

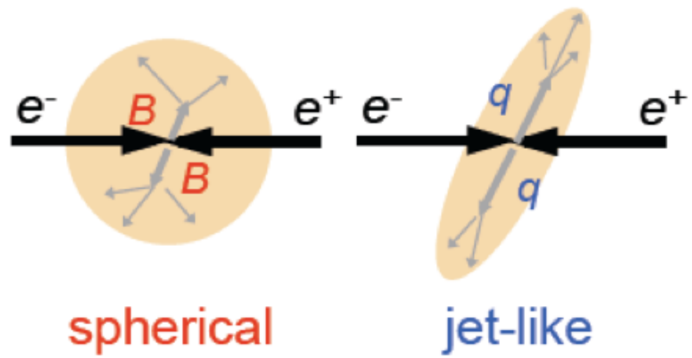


B Meson Reconstruction

- 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 $\Delta E \equiv E_B - E_{\mathrm{beam}}$
  - Beam-energy constrained mass $M_{\mathrm{bc}} \equiv \sqrt{E_{\mathrm{beam}}^2 - |p_B|^2}$

- Continuum suppression by
  - Fisher discriminant of SFW moments or
  - Neural Network including more variables.



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

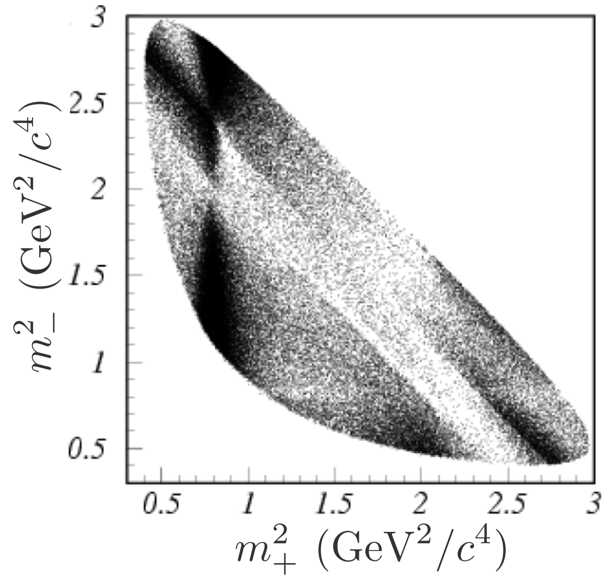
- Amplitude of $B^\pm \to DK^\pm$ process can be expressed as

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

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

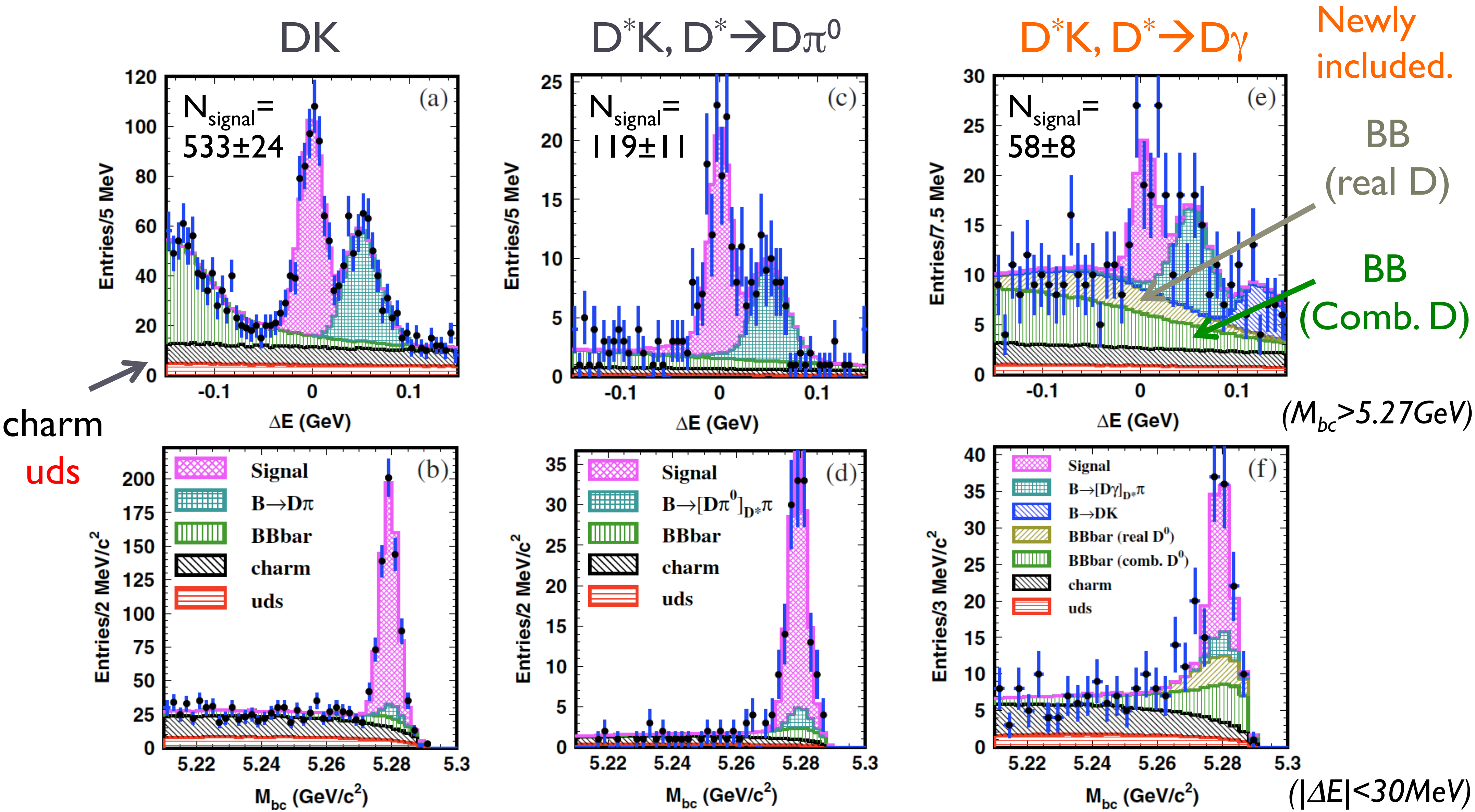
Ratio of magnitudes
of interfering amplitudes.

Amplitude of $D \to K_S\pi^+\pi^-$ decay
determined from Dalitz plot of large continuum data
(Flavor is tagged by soft-pion charge in $D^{*\pm} \to D\pi^\pm_{soft}$).
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).

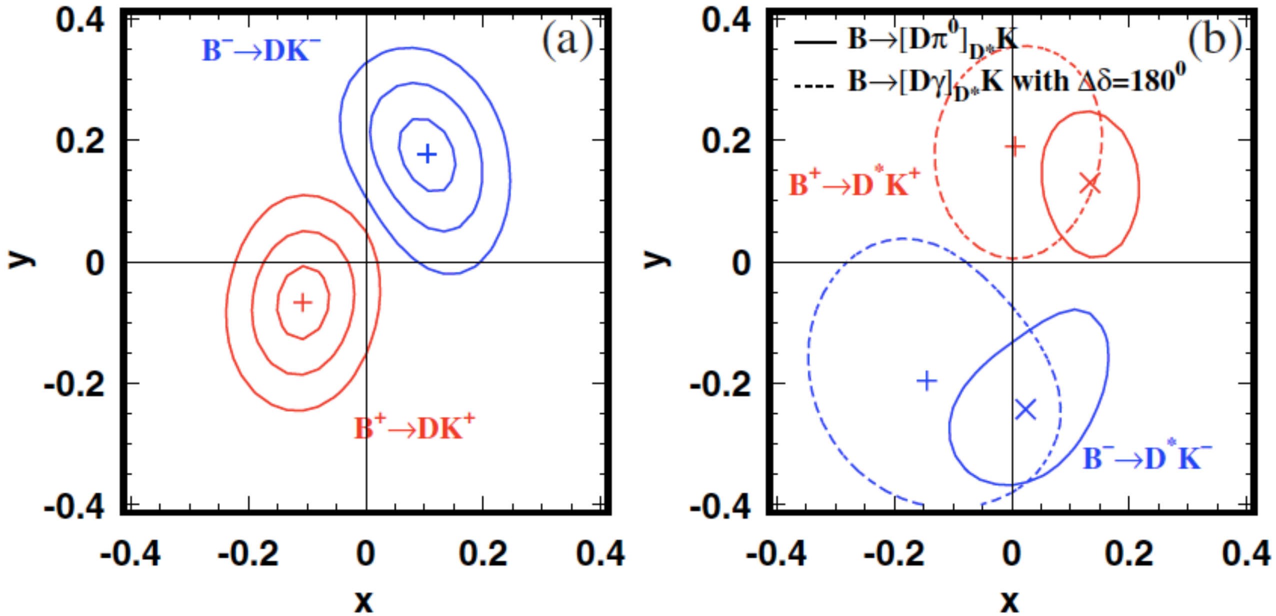
$B^- \rightarrow D^{(*)}K^-$ Dalitz, ΔE and M_{bc} Projections



$B^- \to D^{(*)} K^-$ Dalitz, Result

657 M BB

- Using the background fractions, Dalitz plane is fitted with the parameters $x_\pm = r_\pm \cos(\pm\phi_3+\delta)$ and $y_\pm = r_\pm \sin(\pm\phi_3+\delta)$.



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

- Combining the results for $B \to D^{(*)}K$, we obtain

$$\phi_3 = 78.4^\circ \,{}^{+10.8^\circ}_{-11.6^\circ} \pm 3.6^\circ(\mathrm{syst}) \underline{\pm 8.9^\circ(\mathrm{model})}$$

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

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

- Large effect of ϕ_3 appears in the branching fraction due to similar magnitudes of interfering amplitudes.
- We also analyze $B \to D\pi$ as a reference.
- We measure
  - Partial rate

Calibration Mode

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

  - Asymmetry

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

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

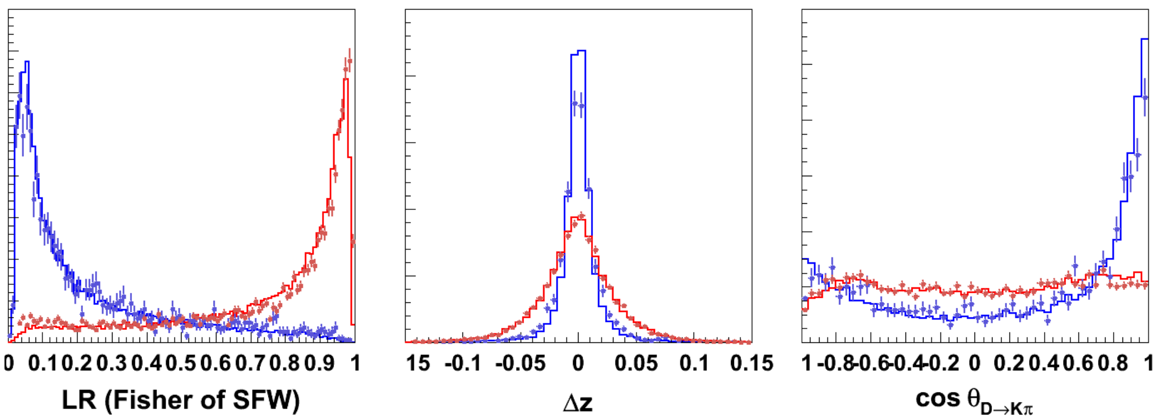
$r_{B(D)}$: ratio of magnitudes of amplitudes for B (D) decays.
$\delta_{B(D)}$: strong-interaction phase for B (D) decays.
HFAG and CLEO-c inputs for r_D and δ_D.

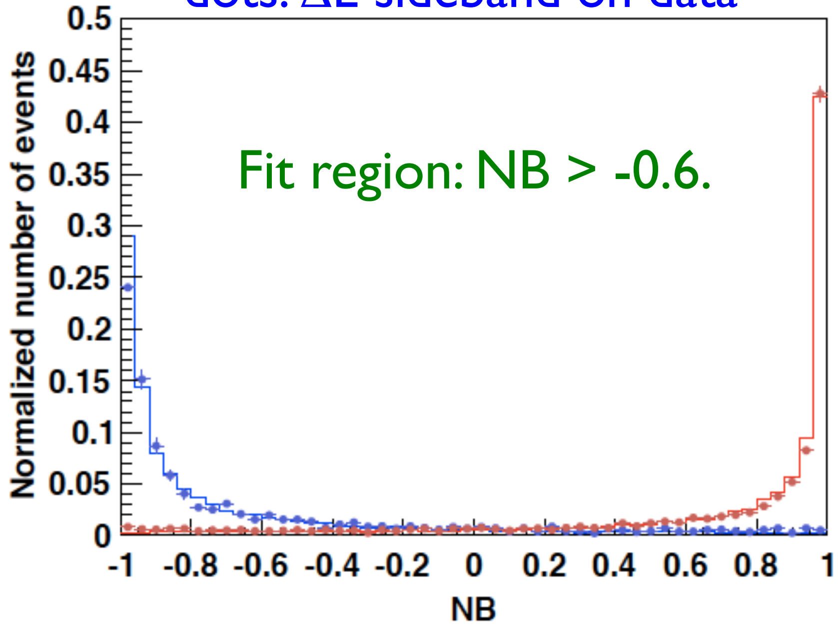
Continuum Suppression

- Main background is $e^+e^- \rightarrow q\bar{q}$ (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 $D \rightarrow K\pi$
- ...

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



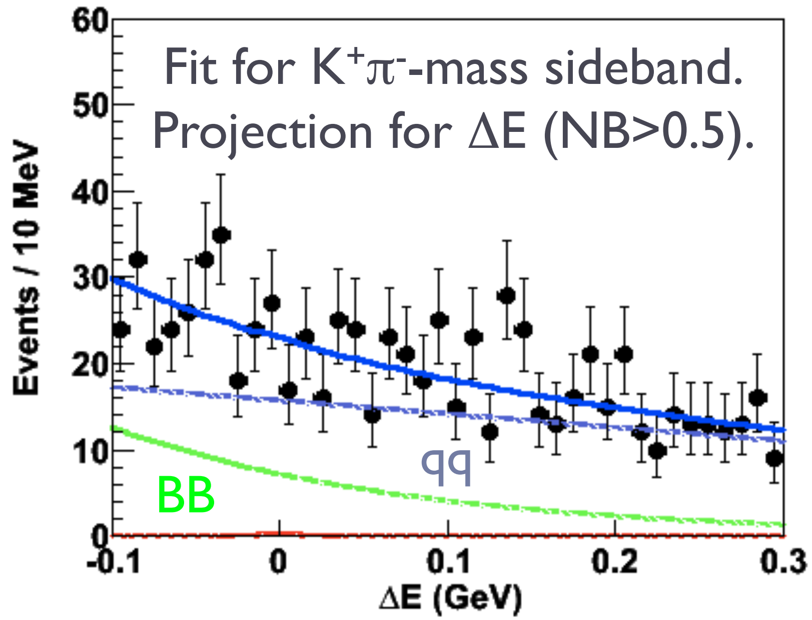


Peaking Background

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

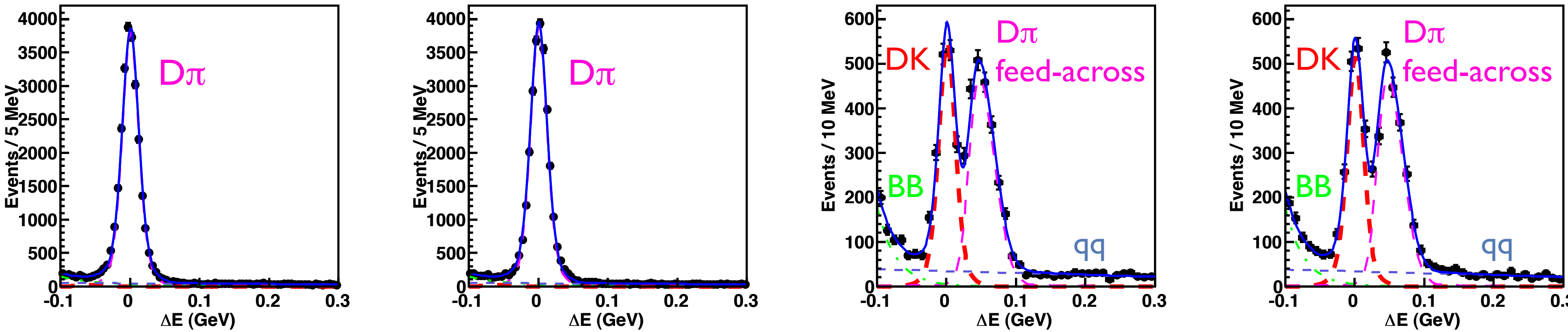
~Flat $K^+\pi^-$-mass distribution.

- 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.

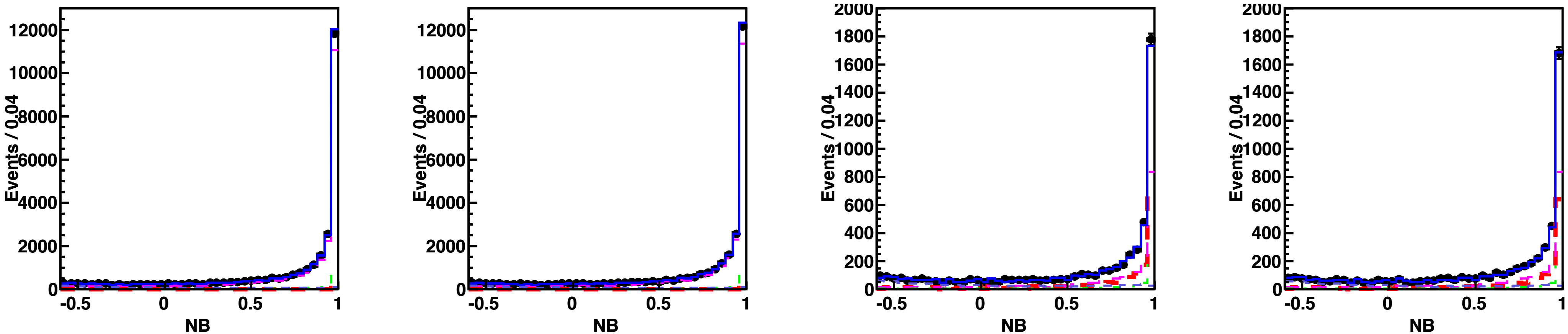


Simultaneous Fit for $B^- \to [K^-\pi^+]_D h^-$ (Calib. Modes)

$D\pi^-$ | $D\pi^+$ | DK^- | DK^+



(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 $|\Delta E|<10$ MeV. *Subtract qq.*
Dπ feed-across: Hist. from $|\Delta E-50\ \text{MeV}|<10$ MeV.
BB: Hist. from MC. qq: Hist. from M_{bc} sideband.

PRELIMINARY

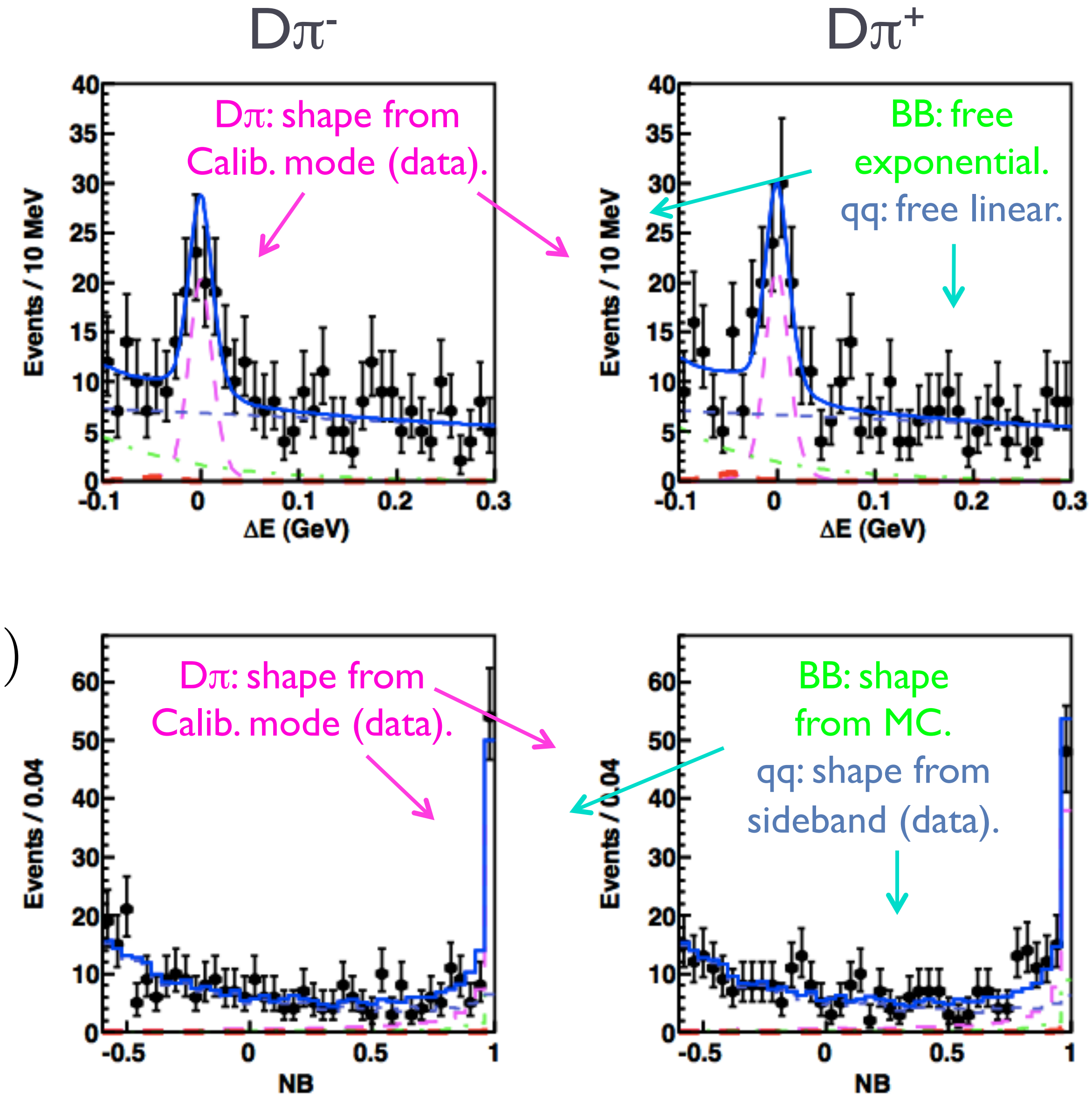
Simultaneous Fit for $B^- \rightarrow [K^+\pi^-]_D h^-$

772 M BB

- 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

$$\mathcal{R}_{D\pi} = 3.28 \pm 0.37(\mathrm{stat})^{+0.22}_{-0.23}(\mathrm{syst})$$
$$\mathcal{A}_{D\pi} = -0.04 \pm 0.11(\mathrm{stat})^{+0.01}_{-0.02}(\mathrm{syst})$$

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



PRELIMINARY

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

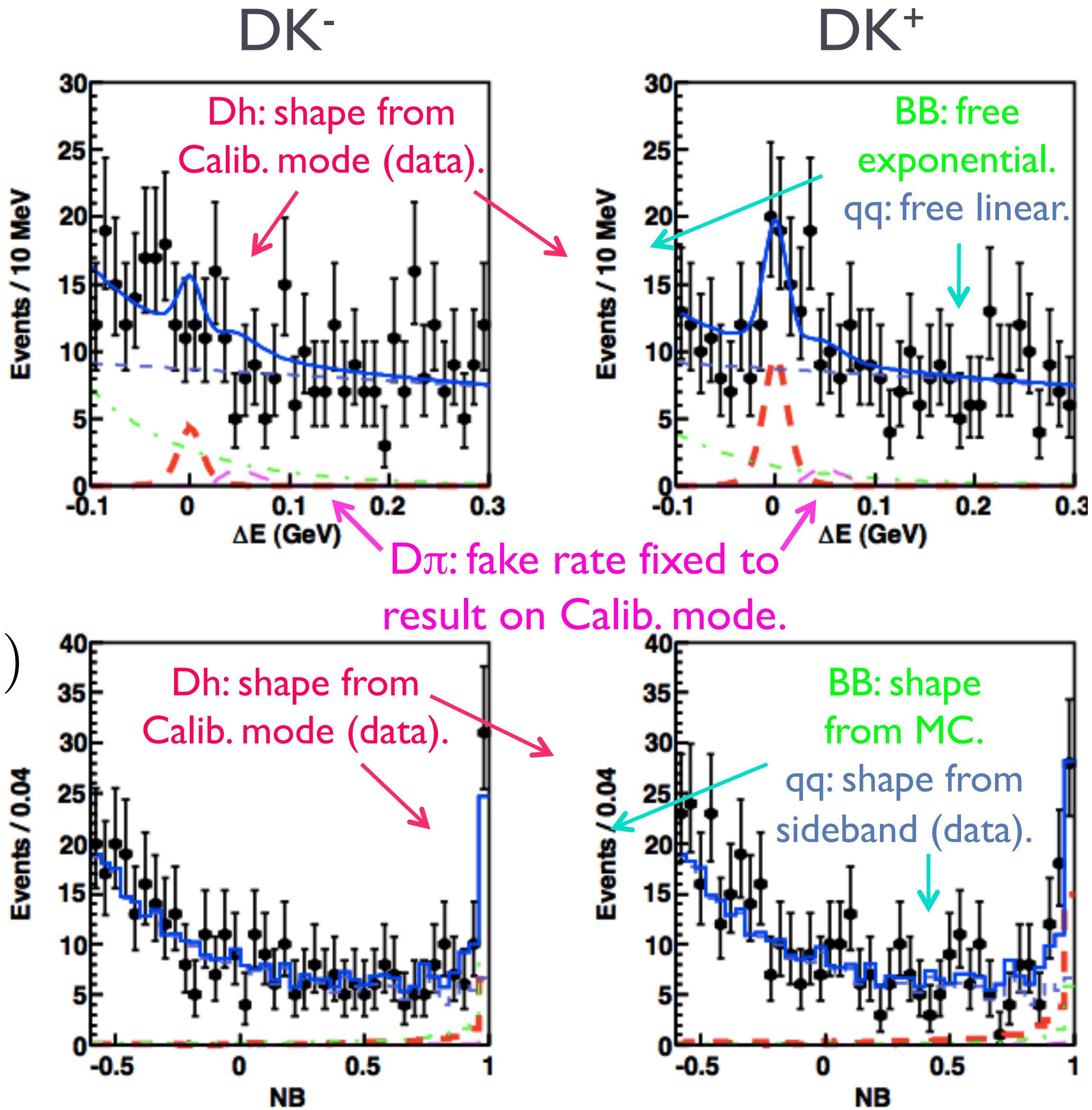
772 M BB

- 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).



PRELIMINARY

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	$\pm 1.1\%$	$\pm 0.1\%$	± 0.01	± 0.005)
Peaking backgrounds	$^{+0.7}_{-9.9}\%$	$^{+0.0}_{-4.1}\%$	$^{+0.03}_{-0.00}$	$^{+0.002}_{-0.000}$
Efficiency	$\pm 1.7\%$	$\pm 1.5\%$	$\cdots$	$\cdots$
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

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

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

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

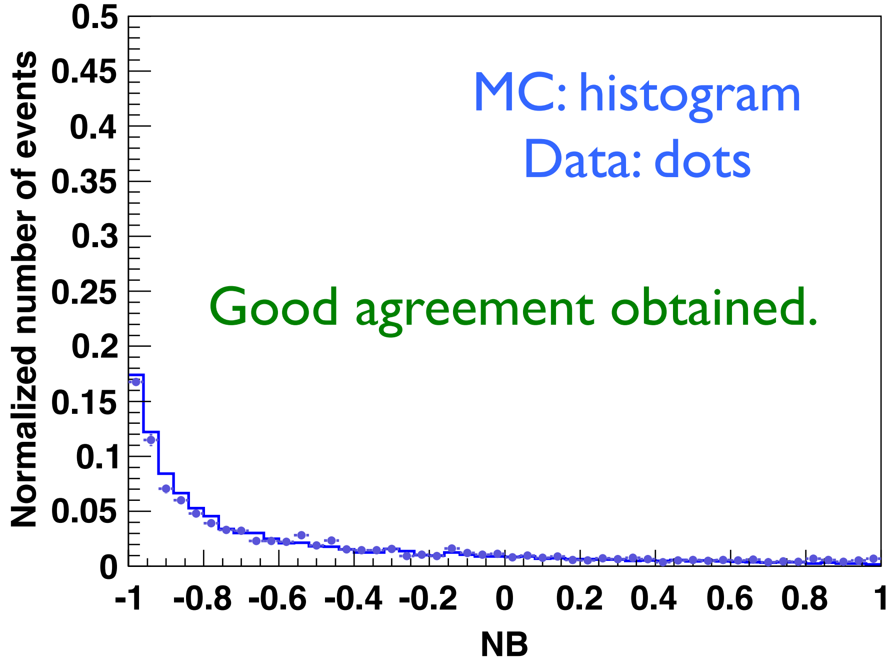
A Check for NeuroBayes Performance

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 (ΔE>150 MeV: qq-dominated region) shown with dots.

some data/MC differences



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 $D\pi$ 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.