ϕ_3/γ measurement at Belle

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Outline

- Introduction
- Overview of ϕ_3/γ measurements
- New result on $B^- \to [K^+\pi^-]_D K^-$

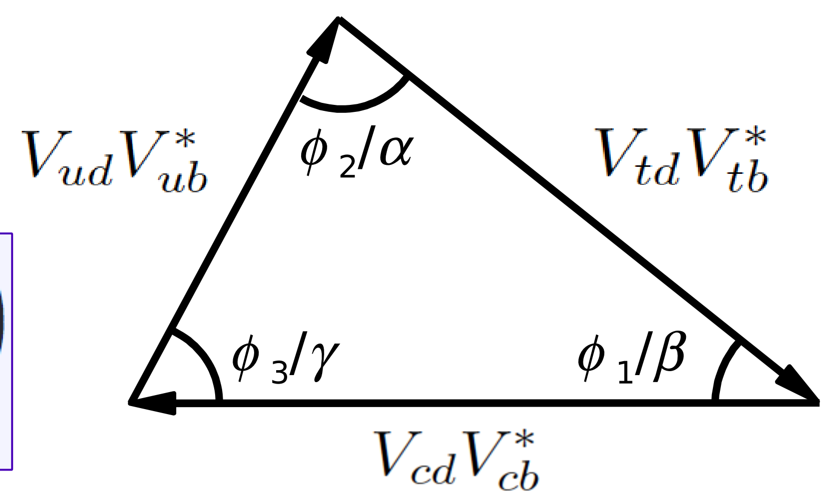
Introduction

- CKM (Cabbibo-Kobayashi-Maskawa) matrix
  - The quark mixing matrix, which is unitary.

$$\boldsymbol{V} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Complex phase

- The Unitarity Triangle $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

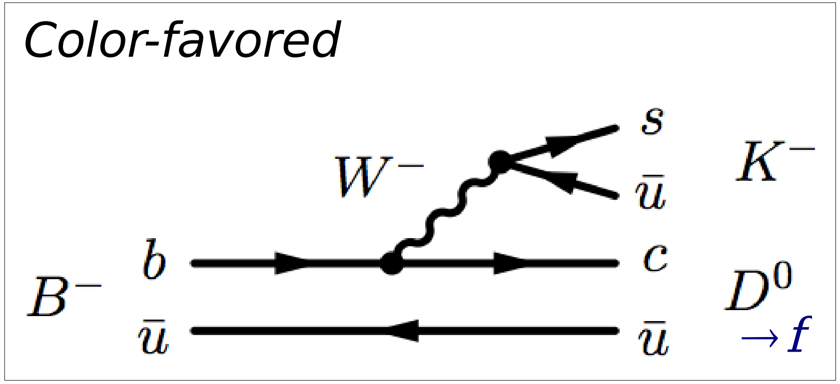


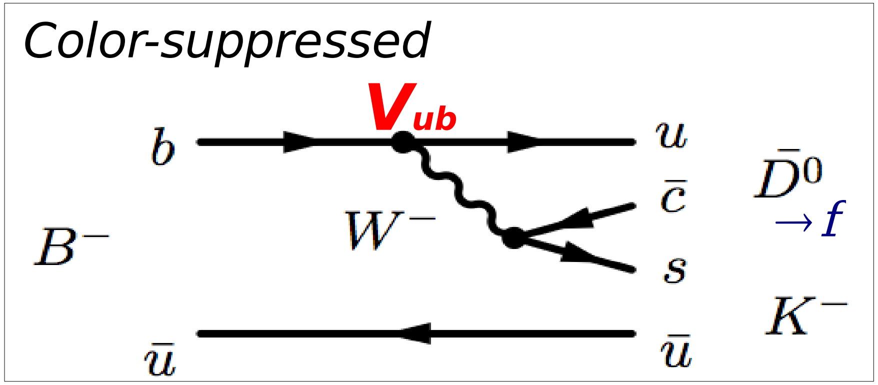
$$\phi_3/\gamma \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{-V_{cd}V_{cb}^*}\right) \sim -\arg(V_{ub})$$

Methods of ϕ_3/γ measurements

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

(No penguin)





  - Access ϕ_3 using the same final state f of D^0 and $\overline{D}^0$ decays.
  - Basically, we extract ϕ_3 with the ratio of the amplitudes

$$r_B \equiv \left| \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)} \right|$$

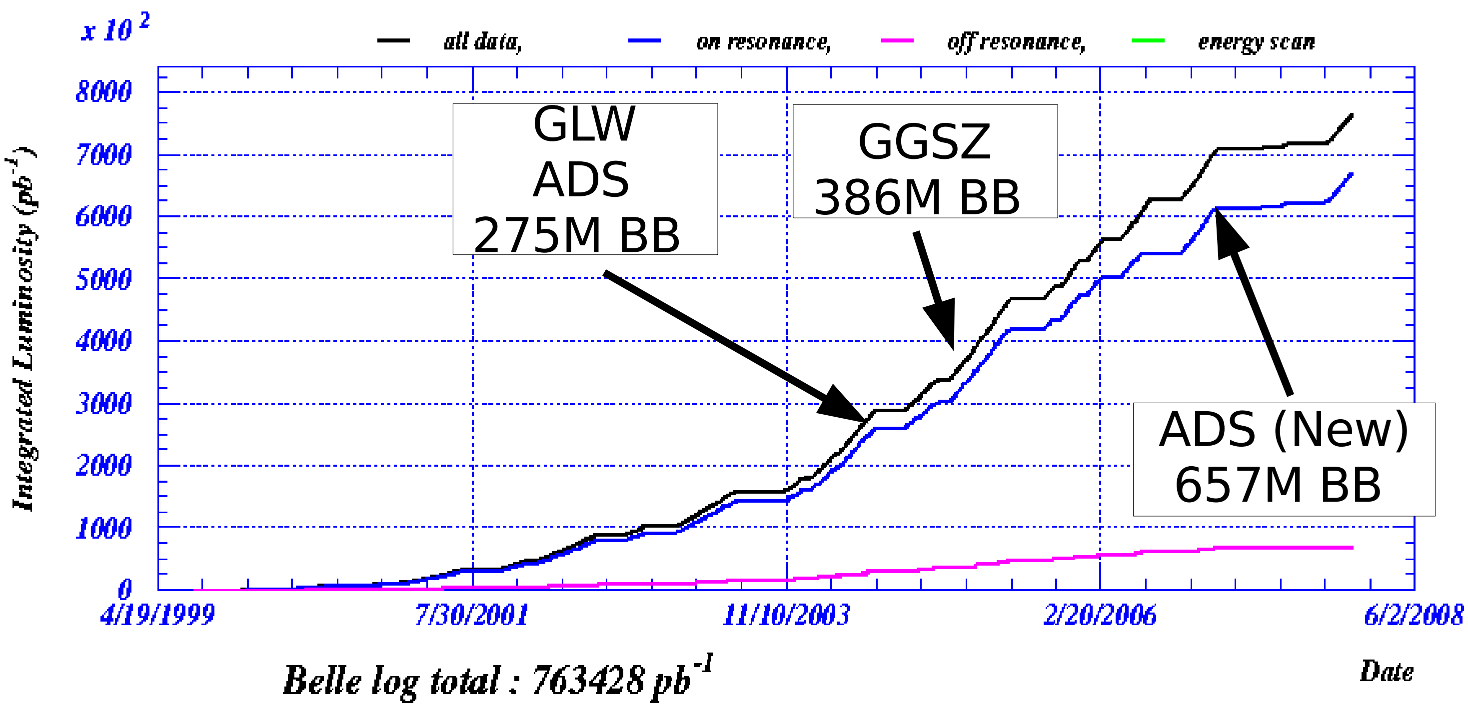
r_B is a crucial parameter in ϕ_3 measurement.

(Expected to be 0.1-0.2.)

- $B \to D^{(*)\pm} \pi^{\mp}$, $D^{\pm} \rho^{\mp}$
  - Extract $\sin(2\phi_1+\phi_3)$ by the studies of $B^0-\overline{B}^0$ transitions.

Methods of ϕ_3/γ measurements

- $B^- \to D^{(*)} K^{(*)-}$
  - Three types of final state f of D^0 and $\overline{D}^0$ decays
    - GLW (Gronau-London-Wyler) : $f = K^+K^-, \pi^+\pi^-, K_S\pi^0, \ldots$
    - ADS (Atwood-Dunietz-Soni) : $f = K^+\pi^-, K^+\pi^-\pi^0, \ldots$
    - GGSZ (Giri-Grosman-Soffer-Zupan) : $f = K_S\pi^+\pi^-$
- The Luminosity of KEKB/Belle with corresponding analyses

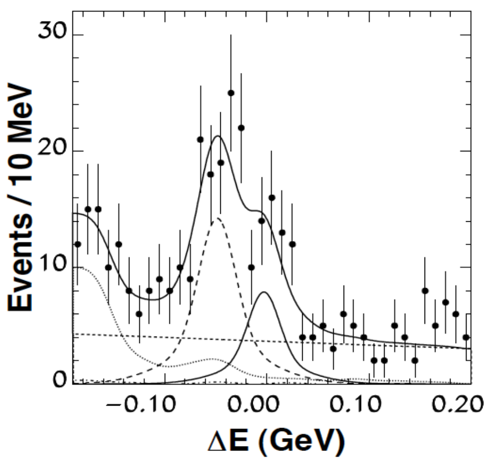


GLW

PRD(RC)73, 051106 (2006)
Belle: 275M BB

f = CP eigenstates
$(K^+K^-, \pi^+\pi^-, K_S\pi^0, \ldots)$

Signals are observed.



$B^- \to D_{CP(+)} K^-$

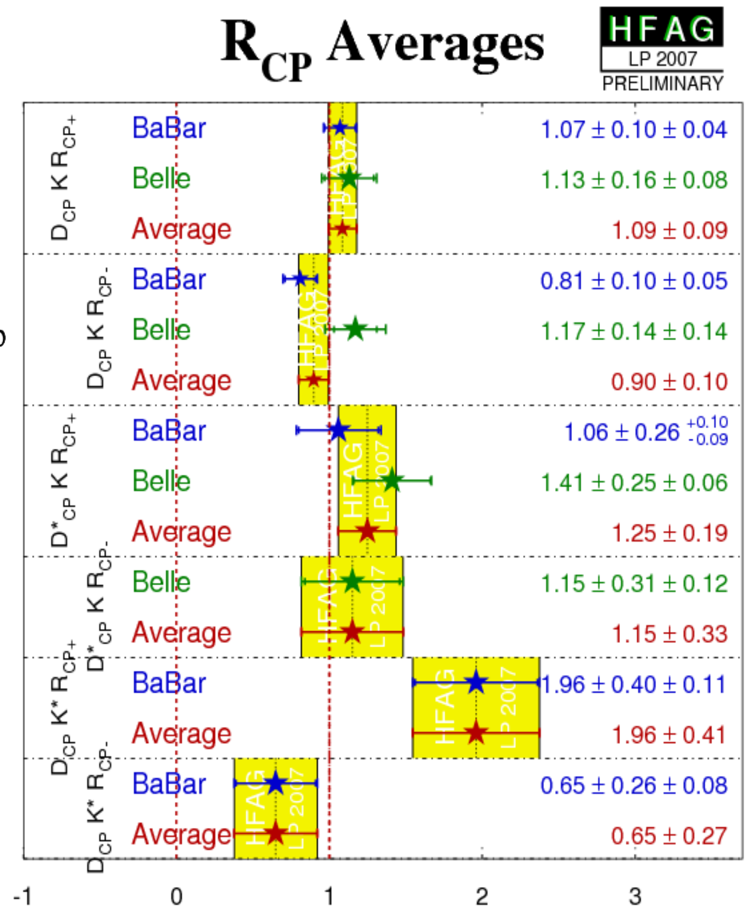
$D_{CP(+)} = K^+K^-$ and $\pi^+\pi^-$

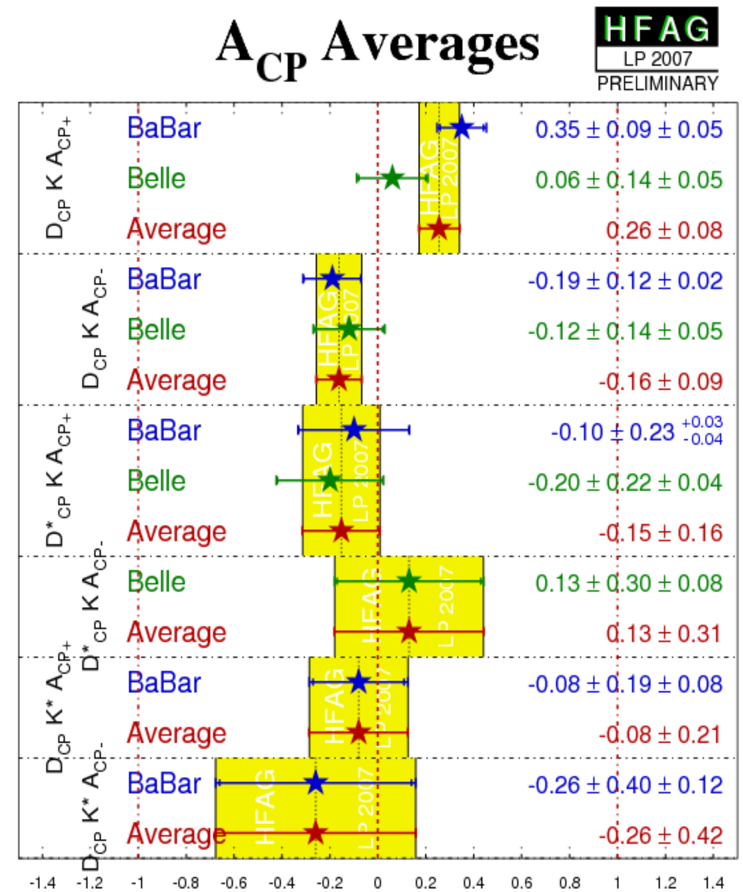
R_{CP}: Ratio to $B^- \to D^0 K^-$

$$R_{CP(\pm)} = 1 + r_B^2 \pm 2r_B \cos\delta_{CP} \cos\phi_3$$

$\mathcal{A}_{CP}$: Charge asymmetry

$$\mathcal{A}_{CP\pm} = \frac{\pm 2r_B \sin\delta \sin\phi_3}{1 + r_B^2 \pm 2r_B \cos\delta \cos\phi_3}$$





Can be used to improve the constraint by GGSZ at present.

GGSZ

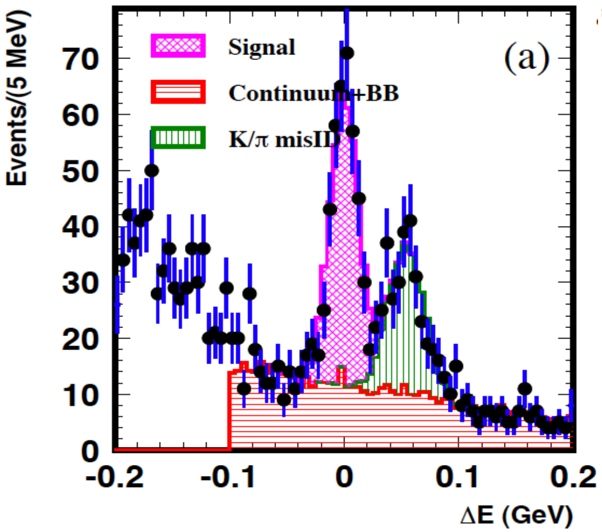
PRD73, 112009 (2006)

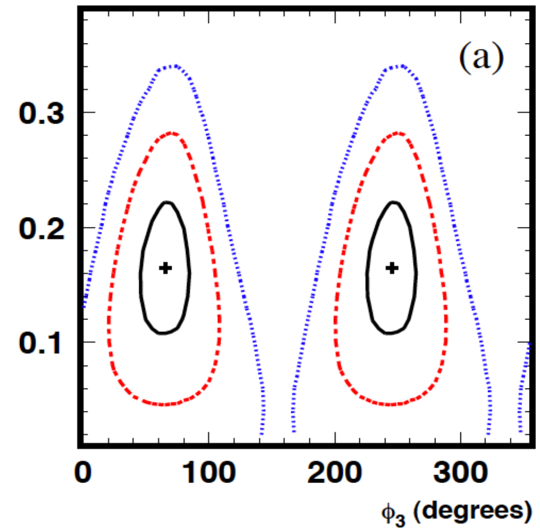
Belle: 386M BB

$f = K_S \pi^+ \pi^-$

The most precise determination of ϕ_3 comes from this method.

- $B^- \to DK^-$





$$\phi_3 = 66^{\circ}{}^{+19^{\circ}}_{-20^{\circ}}(\text{stat})$$

- Combining $B^- \to DK^-$, $B^- \to D^* K^-$, and $B^- \to DK^{*-}$,

$$\phi_3 = 53^{\circ}{}^{+15^{\circ}}_{-18^{\circ}}(\text{stat}) \pm 3^{\circ}(\text{syst}) \pm 9^{\circ}(\text{model})$$

$$r_B(DK) = 0.157^{+0.054}_{-0.050}$$
$$r_B(D^*K) = 0.175^{+0.108}_{-0.099}$$
$$r_B(DK^*) = 0.564^{+0.216}_{-0.155}$$

Analysis of $B^- \to [K^+\pi^-]_D K^-$

ADS $f = K^+\pi^-$

- Main decays
  - $B^- \to [K^+\pi^-]_D K^- : B^- \to D_{sup} K^-$
  - $B^- \to [K^-\pi^+]_D K^- : B^- \to D_{fav} K^-$

$$R_{DK} \equiv \frac{\mathcal{B}(B^- \to D_{sup}K^-) + \mathcal{B}(B^+ \to D_{sup}K^+)}{\mathcal{B}(B^- \to D_{fav}K^-) + \mathcal{B}(B^+ \to D_{fav}K^+)} = r_B^2 + r_D^2 + 2r_B r_D \cos\phi_3 \cos\delta$$

$$r_D \equiv \left| \frac{A(D^0 \to K^+\pi^-)}{A(D^0 \to K^-\pi^+)} \right|$$

$$\delta = \delta_B + \delta_D$$

(Strong phase difference)

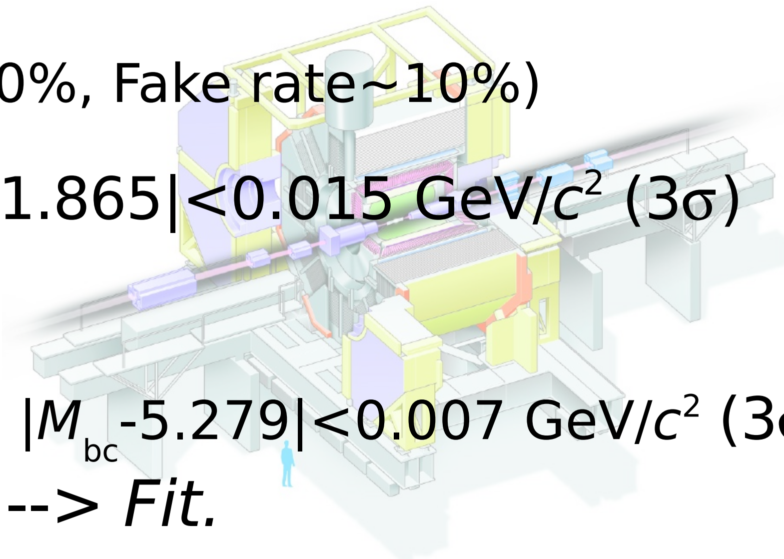
- Reference decays: (parameterize PDF)

  The charge asymmetry is expected to be very small.
  - $B^- \to [K^+\pi^-]_D \pi^- : B^- \to D_{sup} \pi^-$
  - $B^- \to [K^-\pi^+]_D \pi^- : B^- \to D_{fav} \pi^-$

Large statistics

We imply that the charge conjugate decay is included.
We use the same selection criteria whenever possible.

Reconstruction and $q\bar{q}$ suppression



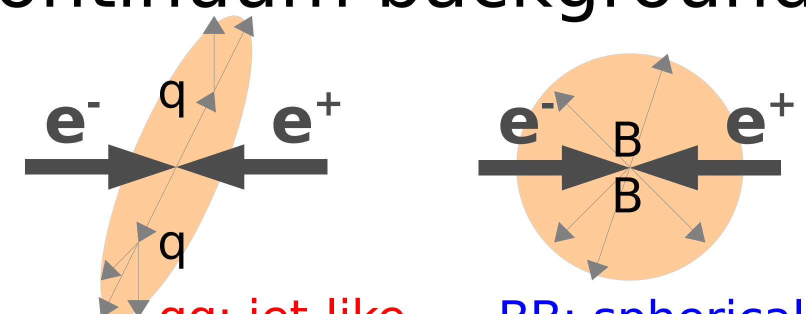
- K/π identifications (Efficiency~90%, Fake rate~10%)
- D mass requirement: $|M(K^+\pi^-)-1.865|<0.015$ GeV/c^2 (3σ)
- For B reconstruction, we use

$$M_{\rm bc} \equiv \sqrt{E_{\rm beam}^2 - |\vec{p}_{K^+} + \vec{p}_{\pi^-} + \vec{p}_{K^-}|^2}$$: $|M_{bc}-5.279|<0.007$ GeV/c^2 (3σ)

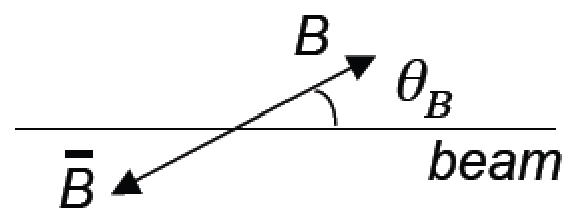
$$\Delta E \equiv E_{K^+} + E_{\pi^-} + E_{K^-} - E_{\rm beam}$$ --> *Fit.*

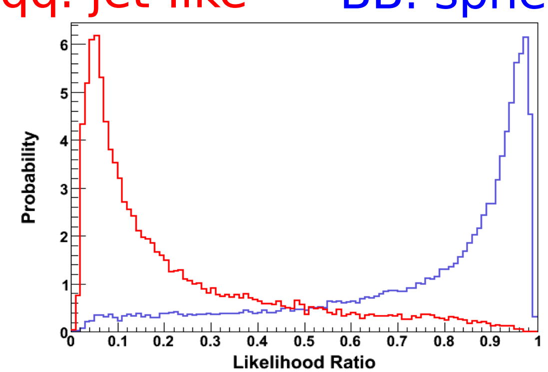
- Continuum background ($e^+e^- \rightarrow q\bar{q}$) suppression

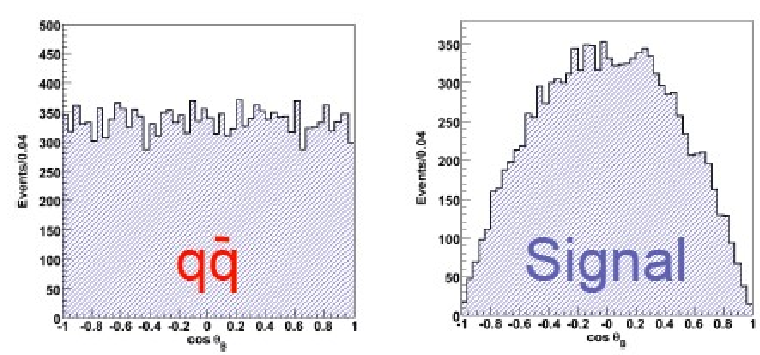
q=u,d,s,c



qq: jet-like BB: spherical







$\cos\theta_B$

Background peaking in ΔE

- **$B^- \to [K^+ K^-]_D \pi^-$ background**
  - Caused by the unfortunate condition: $M(K^+\pi^-) \sim M_D$
  - We veto events with $M(K^+K^-) \sim M_D$
  - After the veto, (0.22 ± 0.19) events will contribute *Subtract.*
- **$B^- \to [K^- \pi^+]_D K^-$ (favored) background**
  - Caused by double misidentifications for candidates from D
  - We veto events with $M(K^+\pi^-) \sim M_D$ when IDs are swapped
  - After the veto, (0.17 ± 0.13) events will contribute *Subtract.*
- **$B^- \to K^+ K^- \pi^-$ background**
  - We fit the data sample of $M(K^+\pi^-)$ sideband, and estimate the yield contribute to the signal as (-2.3 ± 2.4) events

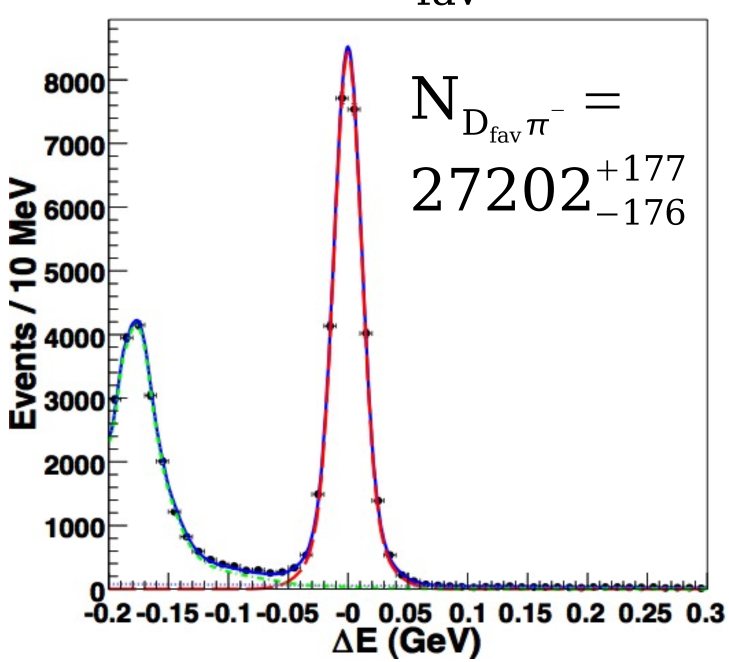
-->*Syst. Err.*

ΔE fit for Favored modes

$(657\text{M } B\bar{B})$

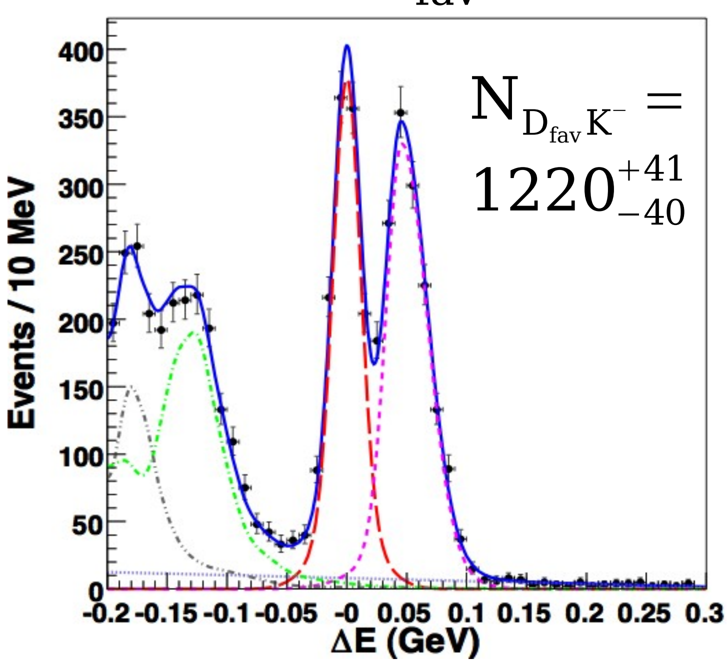
- Signal: Sum of two Gaussians
- $B^- \to X\pi^-$ BG (as $B^- \to D^* \pi^-$): Smoothed function
- $B^- \to XK^-$ BG (as $B^- \to D^* K^-$): Smoothed function
- $q\bar{q}$ BG: Linear function
- $B^- \to D\pi^-$ BG: A sum of asymmetric Gaussians

$B^- \to D_{fav}\pi^-$



pion mass assigned

$B^- \to D_{fav}K^-$



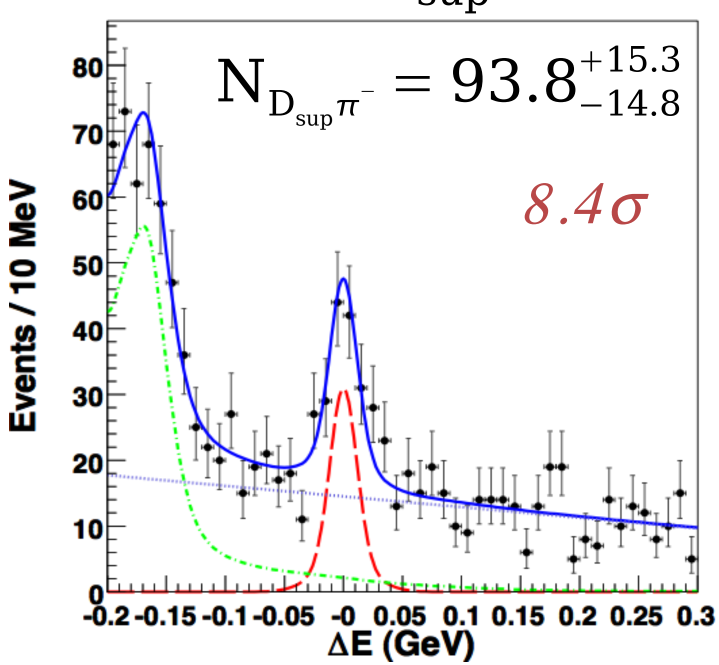
kaon mass assigned

ΔE fit for Suppressed modes

(657M $B\bar{B}$)

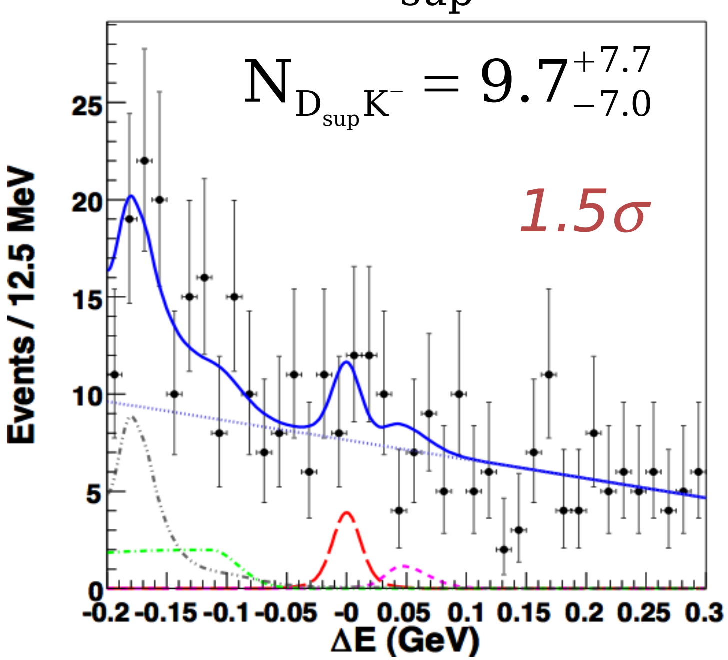
- Signal: Sum of two Gaussians
- $B^- \to X\pi^-$ BG (as $B^- \to D^* \pi^-$): Smoothed function
- $B^- \to XK^-$ BG (as $B^- \to D^* K^-$): Smoothed function
- $q\bar{q}$ BG: Linear function
- $B^- \to D\pi^-$ BG: A sum of asymmetric Gaussians

$B^- \to D_{sup}\pi^-$



pion mass assigned

$B^- \to D_{sup}K^-$



kaon mass assigned

(657M $B\bar{B}$)

- We obtain the ratio of the branching fractions.

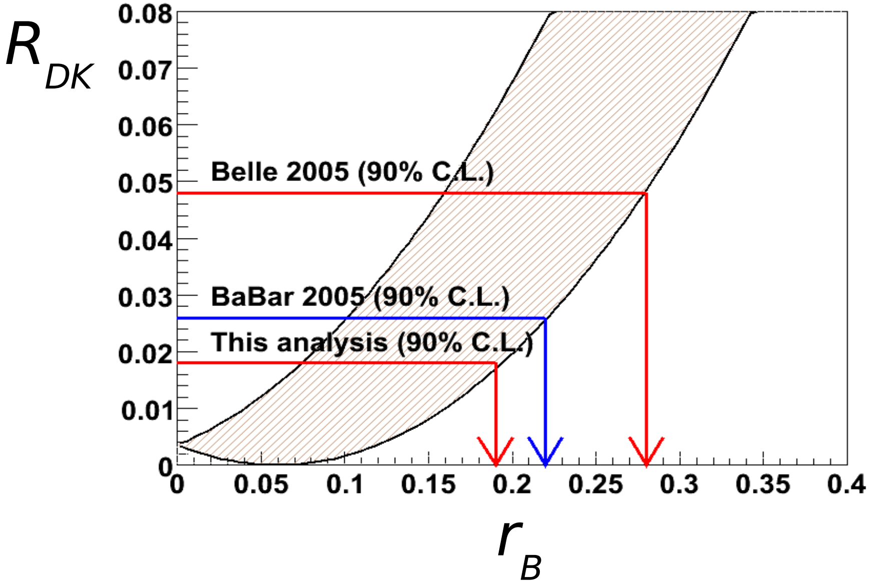
$$R_{Dh} \equiv \frac{\mathcal{B}(B^- \to D_{\rm sup} h^-)}{\mathcal{B}(B^- \to D_{\rm fav} h^-)} = \frac{N_{D_{\rm sup}h^-}/\epsilon_{D_{\rm sup}h^-}}{N_{D_{\rm fav}h^-}/\epsilon_{D_{\rm fav}h^-}} \quad (h = \pi, K)$$

ε: Detection efficiency

$$R_{D\pi} = [3.40^{+0.56}_{-0.54}(stat)^{+0.13}_{-0.21}(sys)] \times 10^{-3}$$
$$R_{DK} = [8.0^{+6.3}_{-5.7}(stat)^{+2.0}_{-2.8}(sys)] \times 10^{-3}$$

Signal is not significant for DK--> $R_{DK} < 1.8 \times 10^{-2}$ (90% C.L.)

- We can then derive a limit on r_B.



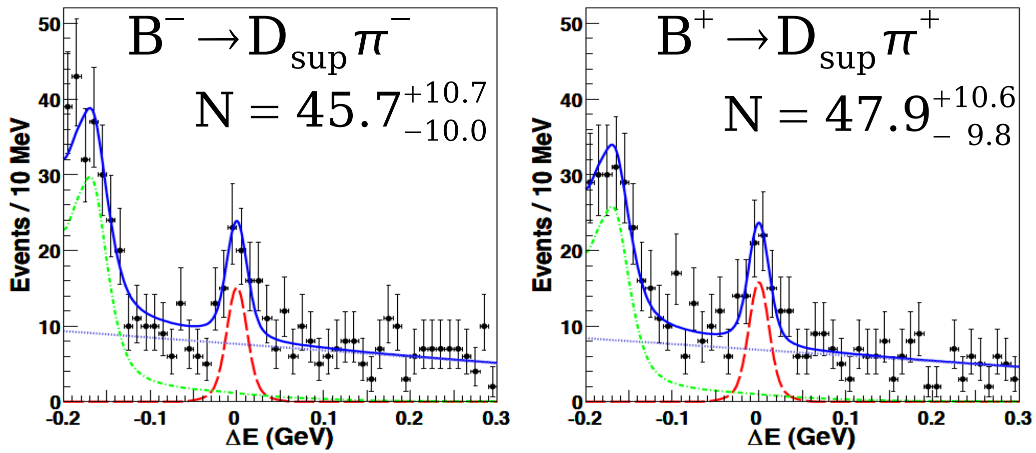
$$R_{DK} = r_B^2 + r_D^2 + 2 r_B r_D \cos\phi_3 \cos\delta$$
$$r_D = 0.0574^{+0.0012}_{-0.0010} \text{ [HFAG'07]}$$

***r*$_B$ < 0.19** (90% C.L.)

(657M $B\bar{B}$)

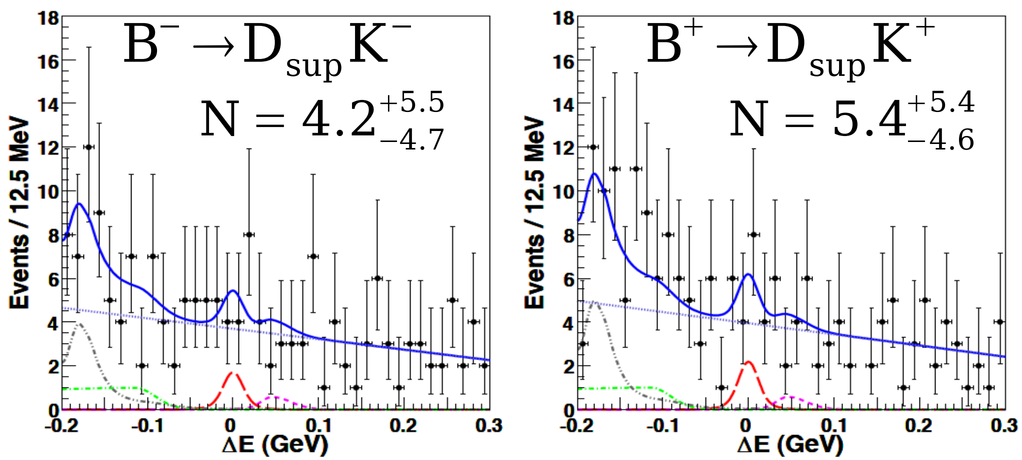
- We obtain the charge asymmetry.

$$\mathcal{A}_{Dh} \equiv \frac{\mathcal{B}(B^- \to Dh^-) - \mathcal{B}(B^+ \to Dh^+)}{\mathcal{B}(B^- \to Dh^-) + \mathcal{B}(B^+ \to Dh^+)} \qquad (h = \pi, K)$$



$$\mathcal{A}_{D\pi} = -0.023 \pm 0.218(stat) \pm 0.071(sys)$$

- *$A_{D\pi}$ is consistent with the expectation.*



$$\mathcal{A}_{DK} = -0.13^{+0.97}_{-0.88}(stat) \pm 0.26(sys)$$

- *Will need much more statistics to measure ϕ_3 with ADS method.*

Summary

- The methods for extracting ϕ_3 are overviewed.
- New result on $B^- \to [K^+\pi^-]_D h^-$ is reported.
  - For $D_{sup}\pi^-$, the asymmetry is measured to be consistent with zero as expected.
  - No significant signal is observed for $D_{sup}K^-$, and we set an upper limit of $\boldsymbol{r_B<0.19}$ at 90% C.L.