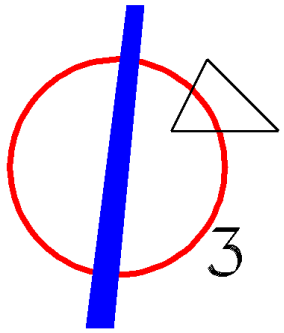
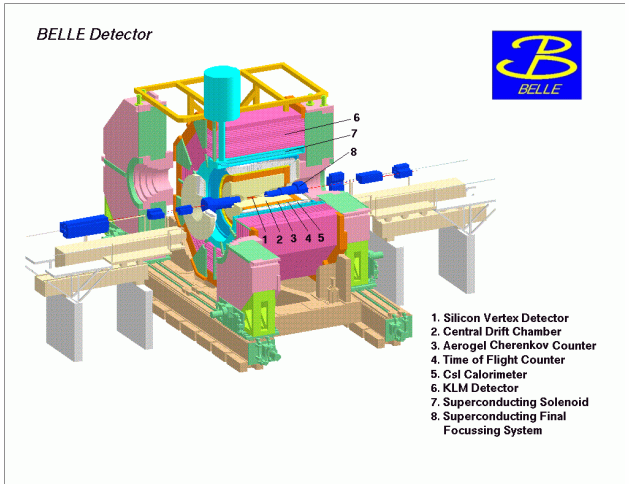


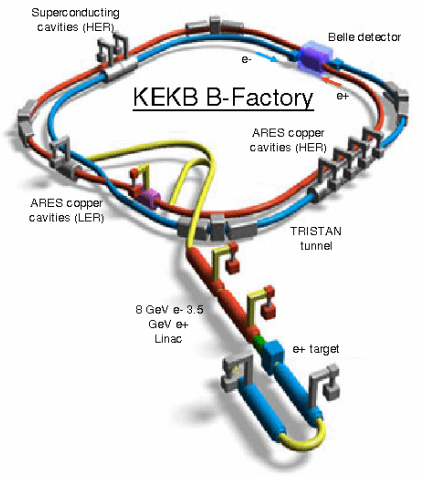
Measurements of ϕ_3 at Belle

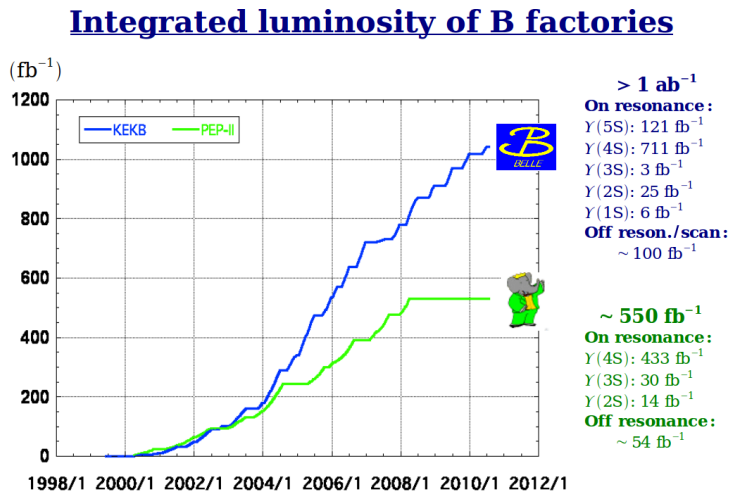
Kentaro Negishi (Tohoku Univ.)
on behalf of the Belle collaboration

EPS-HEP 2013 @ Stockholm

KEKB and Belle







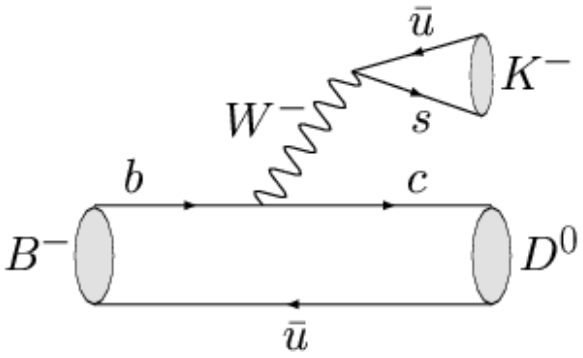
KEKB peak luminosity has world record in e^+e^- collider 2.11×10^{34} cm^{-2} s^{-1}

- Belle started in 1999
  - Experiment designed for sin2ϕ_1 measurement
  - Data taking is finished in 2010
- Belle recorded ~772 M $B\bar{B}$ pairs as the final sample

1. Introduction

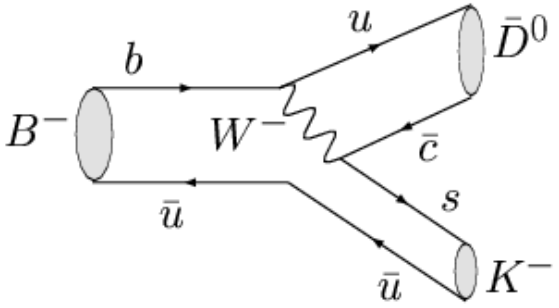
ϕ_3 measurements from B→DK

- Access ϕ_3 via interference between B→DK and B→$\bar{D}$K



Color allowed

$B^- \to D^0 K^-$ $\sim V_{cb}V_{us}^*$ $\sim A\lambda^3$



Color suppressed

$B^- \to \bar{D}^0 K^-$ $\sim V_{ub}V_{cs}^*$ $\sim A\lambda^3(\rho+i\eta)$

- Relative weak phase is ϕ_3
- Relative strong phase is δ_B
- $r_B = \dfrac{|A_{\text{supp.}}|}{|A_{\text{allowed}}|} \sim \dfrac{V_{ub}V_{cs}^*}{V_{cb}V_{us}^*} \times [\text{color supp.}]$
  $= 0.1 \ - \ 0.2$

3 unknowns,
2 observables per mode

ϕ_3 measurements from B→DK

- Reconstruct D in final states accessible to both D^0 and $\bar{D}^0$
  - D = D_{CP}, CP eigenstates such as K^+K^-, $\pi^+\pi^-$, $K_S\pi^0$
    - GLW method (Gronau-London-Wyler)
  - D = D_{sup}, Doubly-Cabibbo-suppressed decay such as $D^0 \to K^+\pi^-$
    - ADS method (Atwood-Dunietz-Soni)
  - Three-body decay such as $D \to K_S\pi^+\pi^-$, $K_SK^+K^-$
    - GGSZ (Dalitz) method (Giri-Grossman-Soffer-Zupan)

- No penguin, no other significant contamination to ϕ_3
  - Charm mixing and charm CPV are both negligible [Grossman, Soffer, Zupan, PRD 72, 031501 (2005)]

- Different B decay modes (DK, D*K, DK*)
  - ϕ_3 is common, (r_B, δ_B) are mode dependent
  - Resolve ϕ_3 from multiple measurements

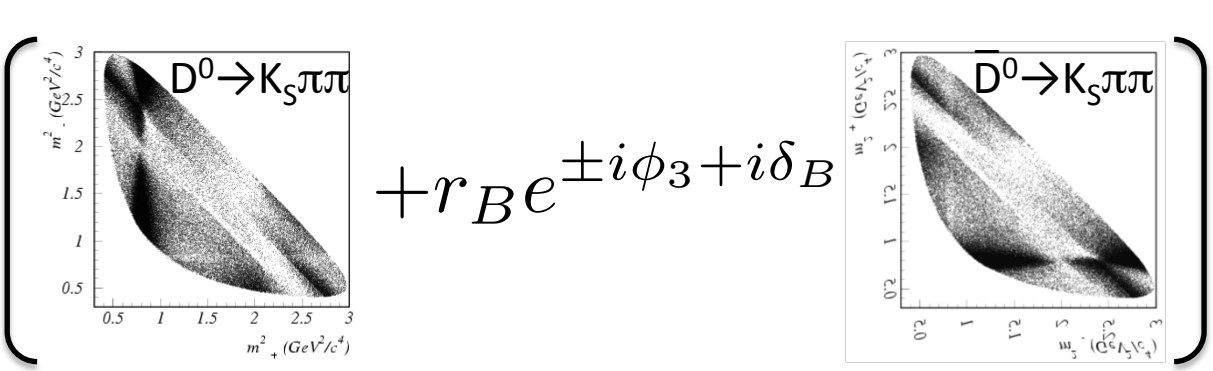
2. Previous Belle Result

Review of Dalitz analysis

Review of GLW and ADS

Combine Dalitz ADS & GLW result

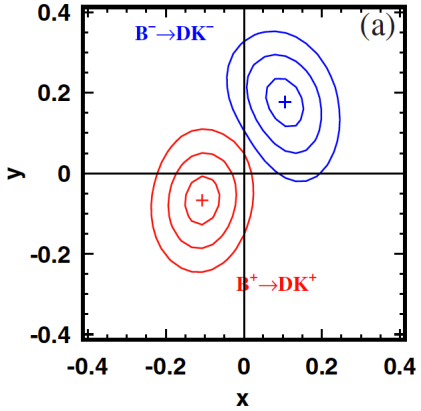
Review of Dalitz ($B^- \to [K_S\pi\pi]_D K^-$)



PRD 81, 112002 (2010)
657 M BB

PRD 85 112014 (2012)
772M BB

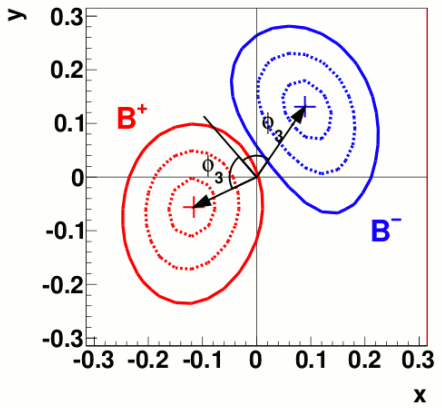
Model dependent analysis

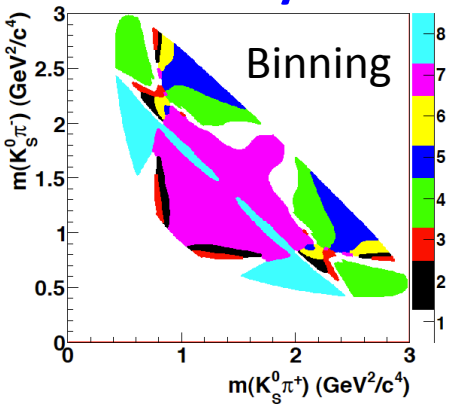


$x_\pm = r_B \cos(\delta_B \pm \phi_3)$
$y_\pm = r_B \sin(\delta_B \pm \phi_3)$

$\phi_3 = (80.8\ ^{+13.1}_{-14.8} \pm 5.0 \pm 8.9)^\circ$
$r_B = 0.161\ ^{+0.040}_{-0.038} \pm 0.011\ ^{+0.050}_{-0.010}$
$\delta_B = (137.4\ ^{+13.0}_{-15.7} \pm 4.0 \pm 22.9)^\circ$

Model independent analysis

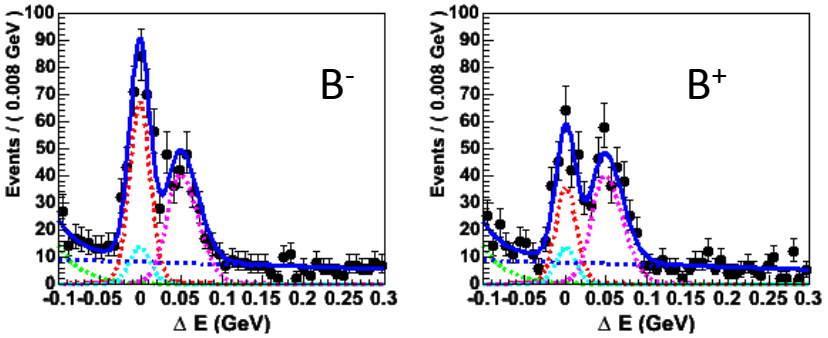




$\phi_3 = (77.3\ ^{+15.1}_{-14.9} \pm 4.1 \pm 4.3)^\circ$
$r_B = 0.145 \pm 0.030 \pm 0.010 \pm 0.011$
$\delta_B = (129.9 \pm 15.0 \pm 3.8 \pm 4.7)^\circ$

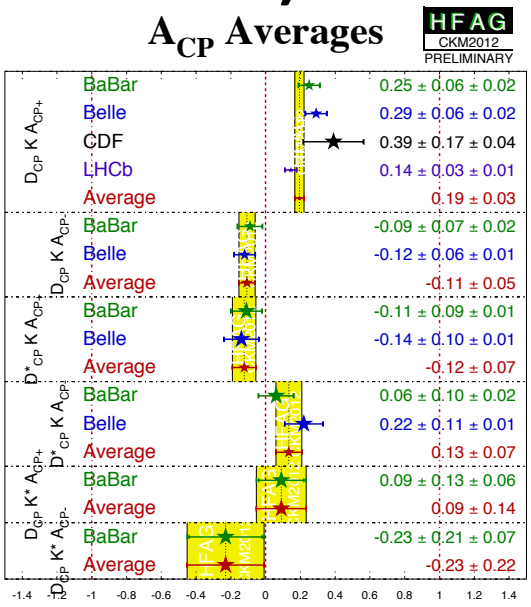
Review of GLW and ADS ($B^- \to DK^-$)

$B \to DK$, $D \to KK, \pi\pi$ (CP+)

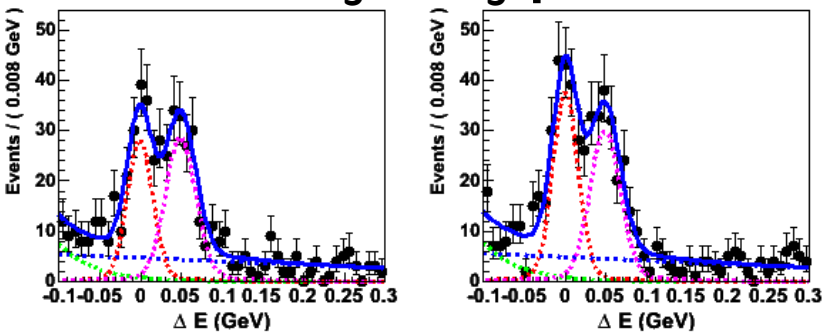


Preliminary (LP2011)
772 M BB

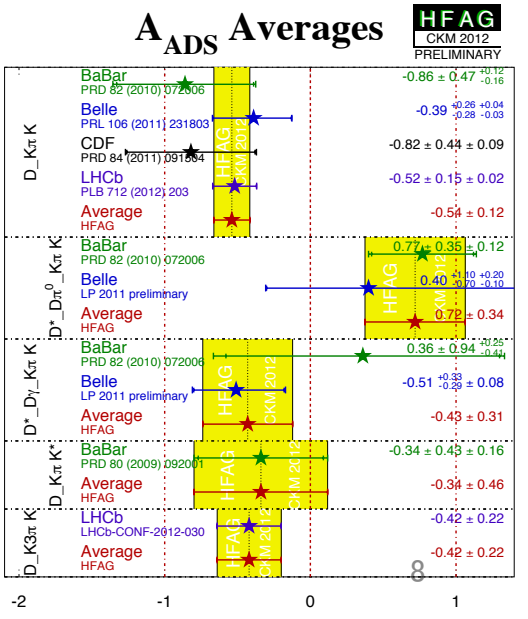
$R_{CP+} = 1.03 \pm 0.07 \pm 0.03$
$A_{CP+} = +0.29 \pm 0.06 \pm 0.02$



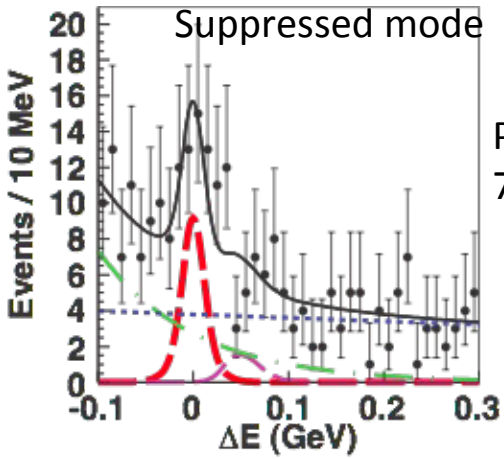
$B \to DK$, $D \to K_S\pi^0, K_S\eta$ (CP-)



$R_{CP-} = 1.13 \pm 0.09 \pm 0.05$
$A_{CP-} = -0.12 \pm 0.06 \pm 0.01$



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

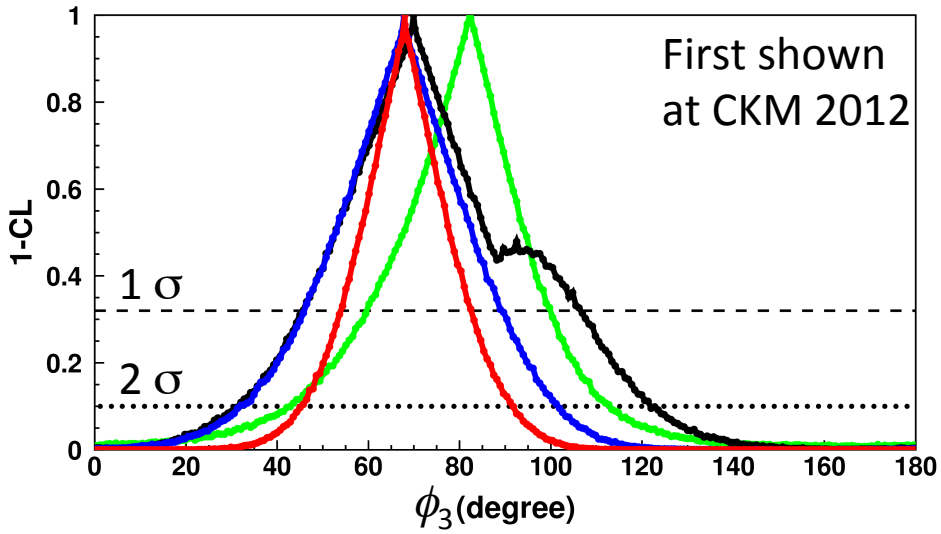


PRL 106 231803 (2011)
772 M BB

$R_{DK} = (1.63^{+0.44}_{-0.41} {}^{+0.07}_{-0.13}) \times 10^{-2}$
$A_{DK} = -0.39^{+0.26}_{-0.28} {}^{+0.04}_{-0.03}$

Determination of ϕ_3 with Belle D^0K, $D^{*0}K$ result

GGSZ + ADS + GLW = (8+6+8)
= 22 observables, 5 parameters



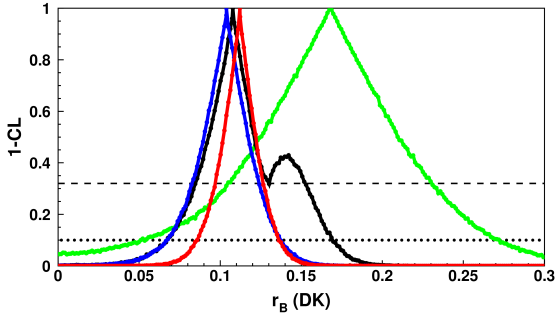
GGSZ only
$\phi_3 = (82^{+18}_{-23})^\circ$

GGSZ + ADS
$\phi_3 = (70^{+37}_{-24})^\circ$

GGSZ + ADS + δ_D
$\phi_3 = (68 \pm 22)^\circ$

GGSZ + ADS + GLW + δ_D
$\phi_3 = (68^{+15}_{-14})^\circ$

cf. CKM fitter WA : $\phi_3 = (66 \pm 12)^\circ$, from indirect CKM fit $(67.2^{+4.4}_{-4.6})^\circ$



for B→DK
$r_B = 0.168^{+0.063}_{-0.064}$
$r_B = 0.108^{+0.045}_{-0.023}$
$r_B = 0.104^{+0.020}_{-0.021}$
$r_B = 0.112^{+0.014}_{-0.015}$

Here, δ_D is obtained from D^0-$\bar{D}^0$ mixing at Belle, BaBar, CLEO and so on.

3. New Belle Results

$B^{\pm} \to [K\pi\pi^0]_D K^{\pm}$ ADS

$B^{\pm} \to DK^{\pm}$, $D \to K\pi\pi^0$ ADS

2 observables

$$R_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-\pi^0]_D K^-) + \Gamma(B^+ \to [K^-\pi^+\pi^0]_D K^+)}{\Gamma(B^- \to [K^-\pi^+\pi^0]_D K^-) + \Gamma(B^+ \to [K^+\pi^-\pi^0]_D K^+)}$$

Doubly Cabibbo Suppressed

Cabibbo Favored

$$= r_B^2 + r_D^2 + 2 r_B r_D R_{K\pi\pi^0} \cos\phi_3 \cos(\delta_B + \delta_D^{K\pi\pi^0})$$

$$A_{ADS} = \frac{\Gamma(B^- \to [K^+\pi^-\pi^0]_D K^-) - \Gamma(B^+ \to [K^-\pi^+\pi^0]_D K^+)}{\Gamma(B^- \to [K^+\pi^-\pi^0]_D K^-) + \Gamma(B^+ \to [K^-\pi^+\pi^0]_D K^+)}$$

CP Asymmetry of signal (suppressed mode)

$$= \frac{2 r_B r_D R_{K\pi\pi^0} \sin\phi_3 \sin(\delta_B + \delta_D^{K\pi\pi^0})}{R_{ADS}}$$

- Integrated over $D \to K\pi\pi^0$ Dalitz space

$$R_{K\pi\pi^0} e^{i\delta_{K\pi\pi^0}} \equiv \frac{\int d\vec{\mathbf{m}} A_{\rm DCS}(\vec{\mathbf{m}}) A_{\rm CF}(\vec{\mathbf{m}}) e^{i\delta(\vec{\mathbf{m}})}}{\sqrt{\int d\vec{\mathbf{m}} A_{\rm DCS}^2 \int d\vec{\mathbf{m}} A_{\rm CF}^2}}$$

$$R_{K\pi\pi^0} = 0.84 \pm 0.07$$

$$\delta_{K\pi\pi^0} = (227^{+14}_{-17})^\circ$$

from CLEO

- r_B, δ_B are common in $B^{\pm} \to DK^{\pm}$
- $r_D \equiv \frac{\Gamma(D^0 \to K^+\pi^-\pi^0)}{\Gamma(D^0 \to K^-\pi^+\pi^0)} = (2.20 \pm 0.10) \times 10^{-3}$ from PDG

$B^{\pm} \to DK^{\pm}$, $D \to K\pi\pi^0$ ADS analytical strategy

- Selection criteria
  - Particle ID : efficiency ~ 90 %, fake rate ~ 10 %
  - π^0 reconstruction
    - each γ : E_γ > 50 MeV at calorimeter
    - $P_{\pi 0}$ > 0.4 GeV/c in CM
  - D mass < 3 σ
  - m_{bc} < 3 σ : $m_{\rm bc} \equiv \sqrt{E^2_{\rm beam} - |\vec{p}_B|^2}$
  - BCS : χ^2_{min}(D mass, m_{bc})
  - Veto D* event and double-miss PID
  - qq BG suppression, using neural network
- Detection efficiency = (10.9 ± 0.1) %

E_{beam} : Beam energy at CM
($\vec{p}_B$, E_B) : 4-momentum of reconstructed B at CM

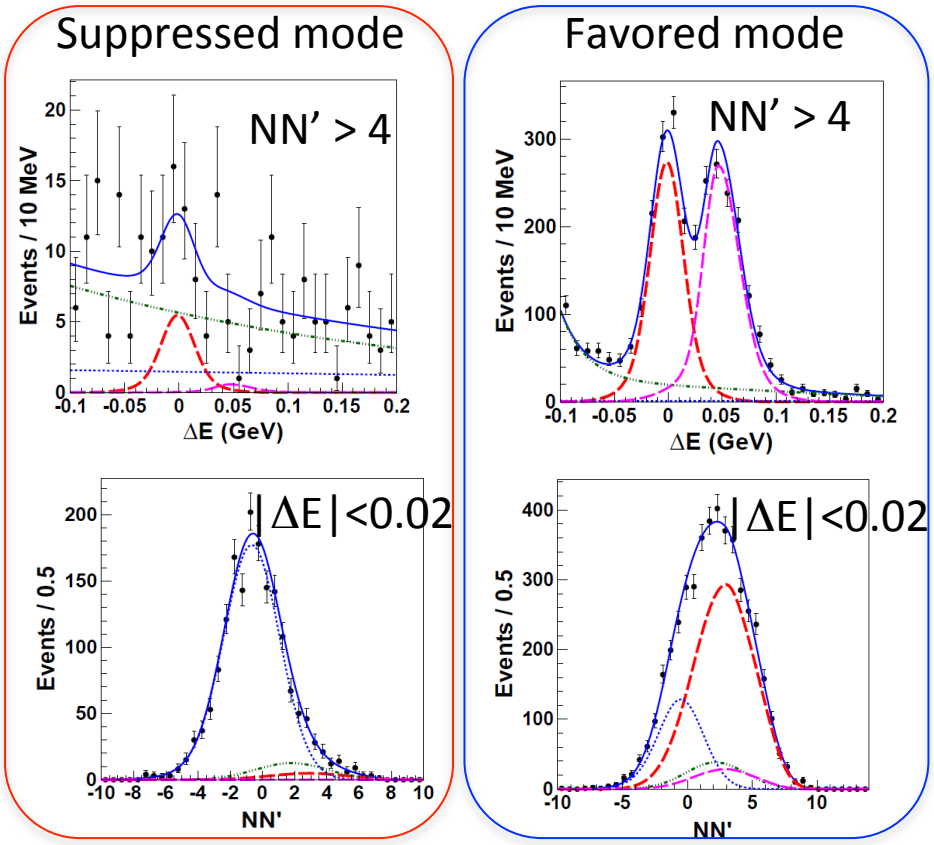
$B^{\pm} \to DK^{\pm}$, $D \to K\pi\pi^0$ ADS analytical strategy 2

- Signal are extracted from 2D fit of ΔE and qq BG suppression neural net output NN'
  - $\Delta E \equiv E_B - E_{\rm beam}$
    Energy difference : Signal ~ 0 GeV
  - NN' is obtained from event topology parameters
  - Fit parameters
    - $N_{sup.}$, A_{ADS}, $N_{fav.}$
      $N_{D\pi}$
      BB BG shape on ΔE, N_{BB}
      qq BG shape on ΔE, $N_{qq, \ldots}$

$$R_{ADS} = \frac{N_{\rm sup.}/{\rm eff}_{\rm sup.}}{N_{\rm fav.}/{\rm eff}_{\rm fav.}}$$

BB BG (e.g. $D^*\pi$, $D\rho$, D^*K …)

$B^{\pm} \to DK^{\pm}$, $D \to K\pi\pi^0$ ADS result R_{ADS}



Suppressed mode signal is seen at 3.5 σ.

ΔE (upper) and NN' (lower) distributions

Blue : total

Red : DK signal

Magenta : Dπ

Green : $B\bar{B}$ BG

Dotted Blue : continuum BG

- Result — Belle 772 M $B\bar{B}$ Preliminary

$N_{sup.} = 77 \pm 24$

$N_{fav.} = 3871 \pm 90$

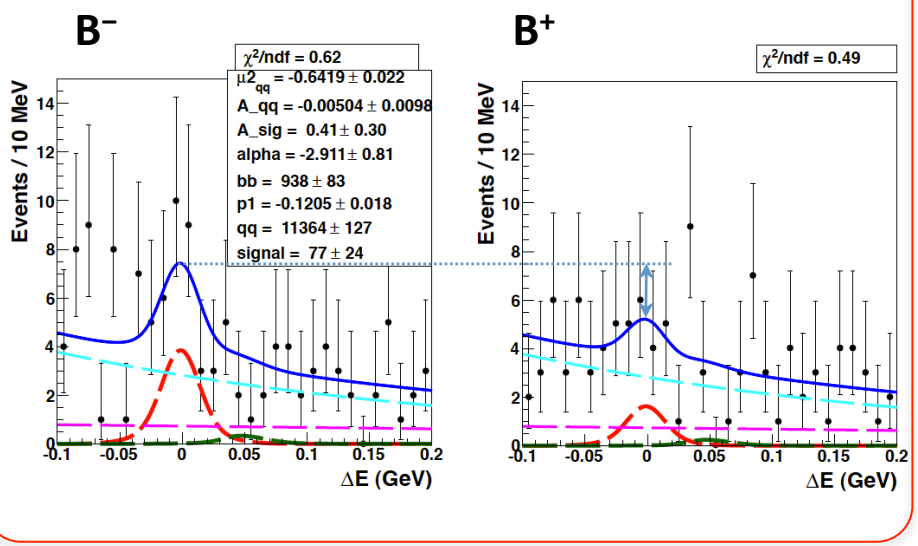
$R_{ADS} = (1.98 \pm 0.62 \pm 0.23) \times 10^{-2}$

cf. BaBar 474 M

$R_{ADS} = (0.91 \,^{+0.82\,+0.14}_{-0.76\,-0.37}) \times 10^{-2}$

$B^{\pm} \to DK^{\pm}$, $D \to K\pi\pi^0$ ADS result A_{ADS}

Suppressed mode



ΔE (upper) and NN' (lower) distributions

Blue	: total
Red	: DK signal
Green	: Dπ
Cyan	: $B\bar{B}$ BG
Magenta	: continuum BG

- Result — Belle 772 M $B\bar{B}$ Preliminary

$R_{ADS} = (1.98 \pm 0.62 \pm 0.23) \times 10^{-2}$

$A_{ADS} = 0.41 \pm 0.30 \pm 0.05$

First $A_{ADS}(D \to K\pi\pi^0)$ measurement!

Summary

- Combined ϕ_3 from Belle before EPS
  - $(68^{+15}_{-14})^\circ$
- New results at EPS
  - $B^\pm \to [K\pi\pi^0]_D K^\pm$ ADS
    - Signal is seen at 3.5 σ.
    - $R_{ADS} = (1.98 \pm 0.62 \pm 0.23) \times 10^{-2}$
    - $A_{ADS} = 0.41 \pm 0.30 \pm 0.05$, **First measurement**
- Many other analysis for ϕ_3 measurement using full data sample are ongoing.