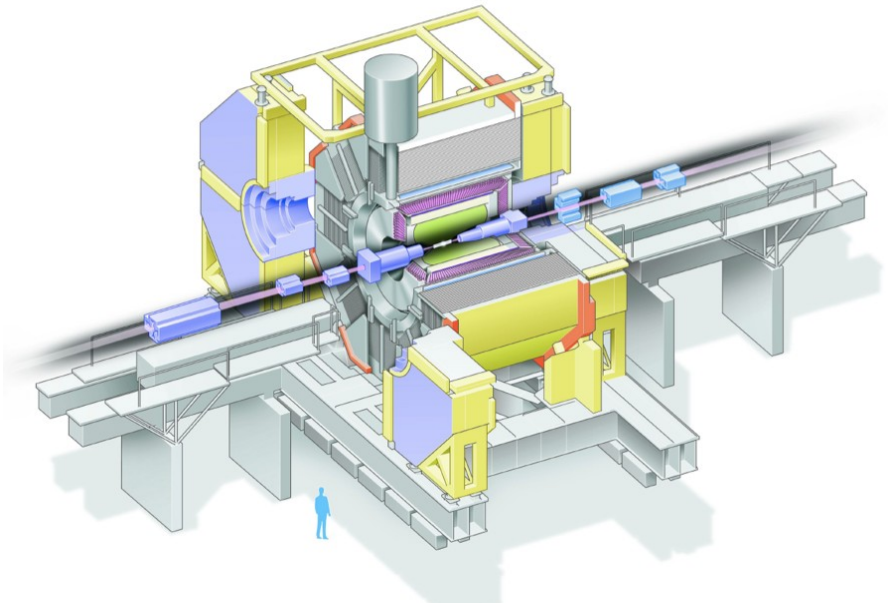
CP asymmetry studies from Belle for the CKM angle Φ_3

Minakshi Nayak (IIT Madras)

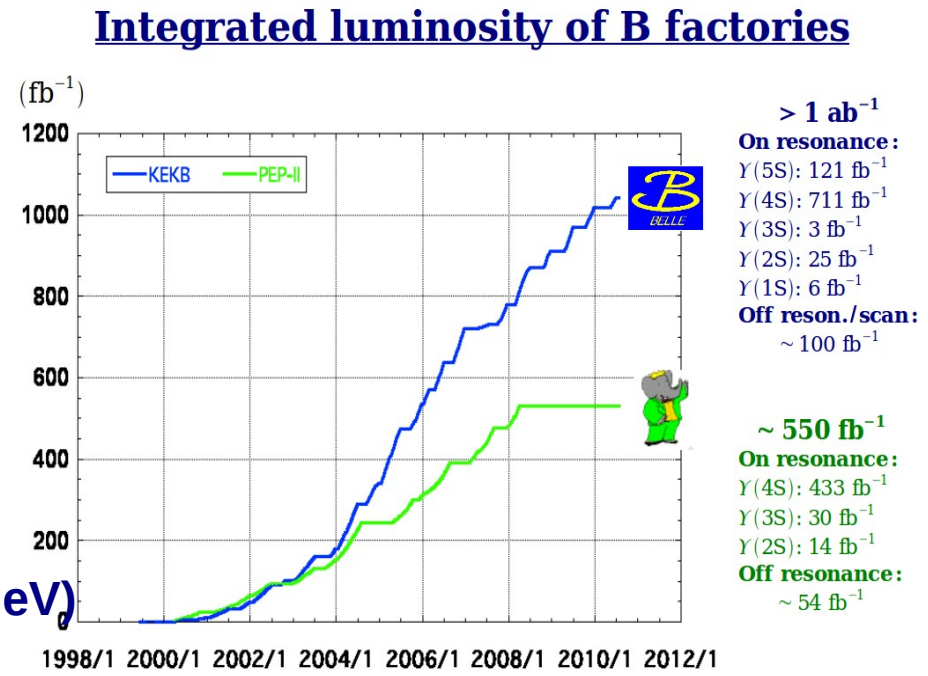
On behalf of Belle Collaboration

19th International Symposium on Particles, Strings and Cosmology (PASCOS 2013)

KEKB contributing to φ_3 determination.



KEKB asymmetric e^+e^- collider (3.5 on 8 GeV)



KEK peak luminosity 2.11 x 10^{34} $cm^{-2}s^{-1}$ (world record!)

Belle total data sample: 1000 fb^{-1}

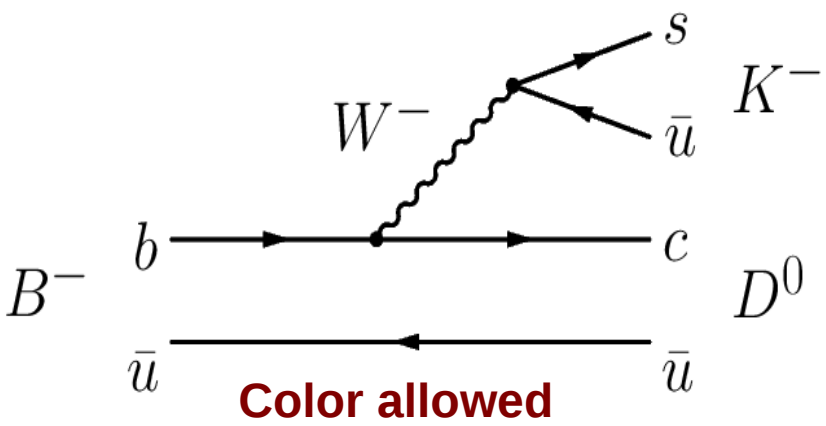
Υ(4S) data sample : 711 fb^{-1} (~772 M $B\bar{B}$ pairs)

Belle data taking period: 1999 - 2010
Aim was to measure sin(2φ_1)!

φ_3 measurements from $B^{\pm} \to DK^{\pm}$ decay

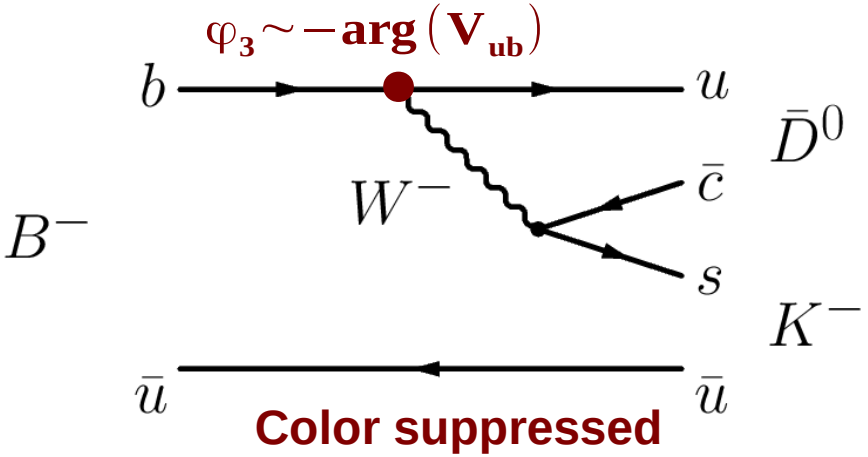
$$\varphi_3 \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{-V_{cd}V_{cb}^*}\right) \sim -\arg\left(V_{ub}\right)$$

Determination of Φ_3 via interference between $B^- \to D^0K^-$ and $B^- \to \bar{D}^0K^-$ using tree level B decay



Color allowed

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



Color suppressed

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

No loop contribution to $B \to DK$ decay.
Theoretically clean way to determine φ_3

Methods for φ_3 measurements from $B^{\pm} \to DK^{\pm}$ decay

Reconstruction of $D\,(D^0/\bar{D}^0)$ final states using

- CP eigenstates such as K^+K^- , $\pi^+\pi^-$, $K_S\pi^0$
  GLW method (Gronau - London - Wyler)
  PLB 253, 483 (1991), PLB 265, 172 (1991)

- Doubly - Cabbibo suppressed D decays such as $K\pi$, $K\pi\pi^0$
  ADS method (Atwood - Dunietz - Soni)
  PRD 63, 036005 (2001)

- Three- body decays such as $D \to K_S\pi^+\pi^-$, $K_SK^+K^-$
  GGSZ (Dalitz) method (Giri - Grossman - Soffer - Zupan)
  GGSZ is the most accurate

Different B decay modes: DK , D*K . . .
PRD 68, 054018 (2003)

different hadronic factors (r_B, δ_B) for each B decay mode

Extraction of Φ_3 by combining information from all measurements

Latest preliminary and published results from Belle

GLW analysis and results

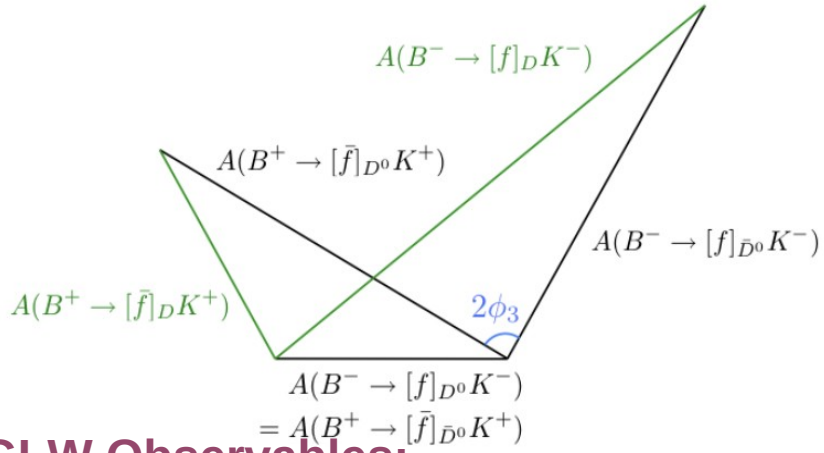
ADS analysis and results

Dalitz analysis and results

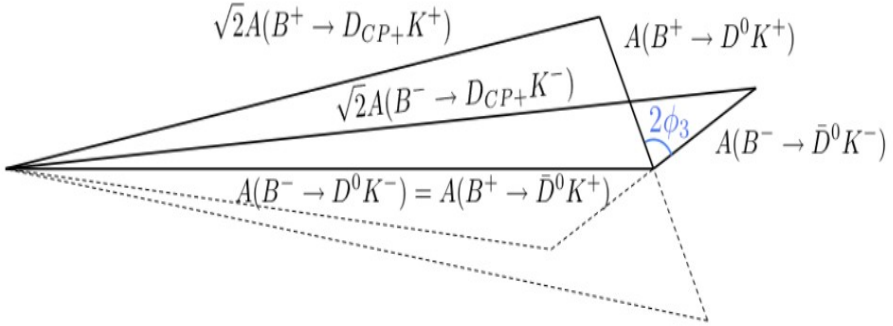
Combined Dalitz, ADS & GLW results

GLW and ADS Observables:

GLW Amplitude Triangles:



ADS Amplitude Triangles:



GLW Observables:

$$\mathcal{R}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D^0 K^-) + \mathcal{B}(B^+ \to \bar{D}^0 K^+)}$$
$$= 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\phi_3,$$
$$\mathcal{A}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}$$
$$= \pm 2 r_B \sin\delta_B \sin\phi_3 / R_{CP\pm},$$

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

$$\delta_B = \text{strong phase}$$

Input parameters

ADS Observables:

$$\mathcal{R}_{\rm ADS} \equiv \frac{\mathcal{B}(B^- \to [f]_D K^-) + \mathcal{B}(B^+ \to [\bar{f}]_D K^+)}{\mathcal{B}(B^- \to [\bar{f}]_D K^-) + \mathcal{B}(B^+ \to [f]_D K^+)}$$
$$= r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\phi_3,$$
$$\mathcal{A}_{\rm ADS} \equiv \frac{\mathcal{B}(B^- \to [f]_D K^-) - \mathcal{B}(B^+ \to [\bar{f}]_D K^+)}{\mathcal{B}(B^- \to [f]_D K^-) + \mathcal{B}(B^+ \to [\bar{f}]_D K^+)}$$
$$= 2 r_B r_D \sin(\delta_B + \delta_D) \sin\phi_3 / R_{\rm ADS},$$

$$r_D = \left|\frac{A(D^0 \to f)}{A(\bar{D}^0 \to f)}\right|$$

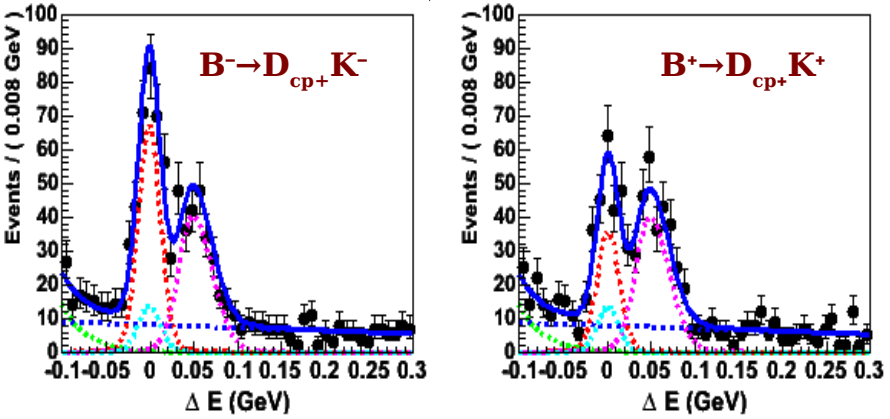
$$\delta_D = \text{strong phase}$$

Additional Input from charm

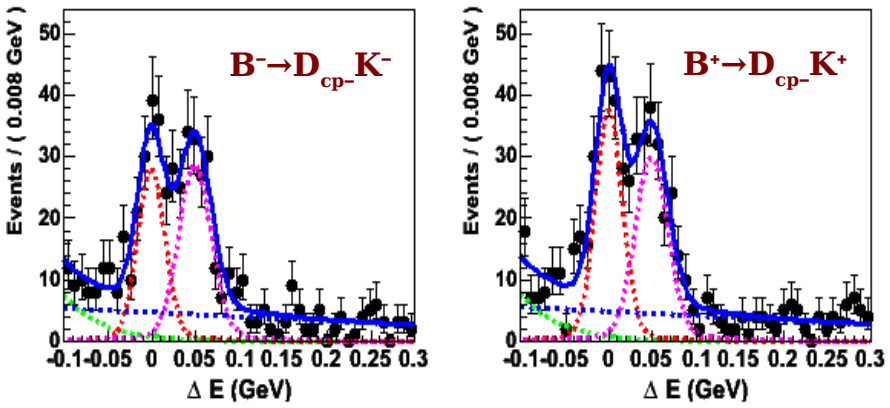
Preliminary GLW results from Belle

Preliminary (LP2011) 772 M BB

B→DK, D→KK, ππ (CP+)



B→DK, D→$K_s\eta$, $K_s\pi^0$ (CP-)



Blue: total
Red: signal peaks at 0
Magenta: Dπ peaks at 0.05
Green: BB
Dotted blue: qq
Cyan: peaking BG (KKK contribution)

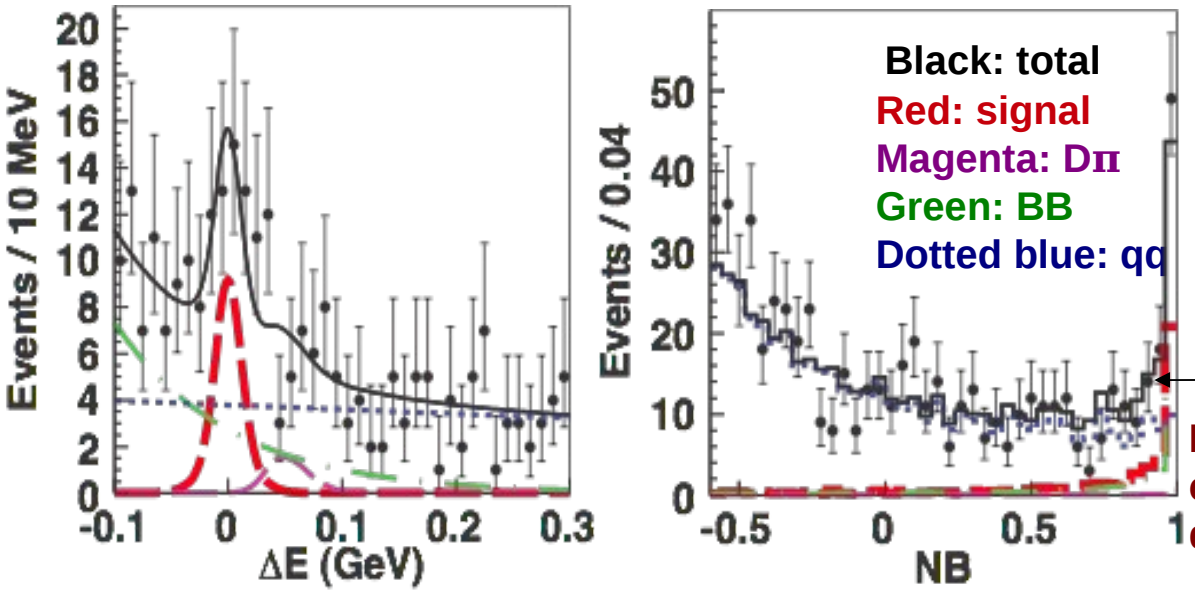
$$R_{CP+} = 1.03 \pm 0.07 \pm 0.03$$
$$R_{CP-} = 1.13 \pm 0.09 \pm 0.05$$

$$A_{CP+} = +0.29 \pm 0.06 \pm 0.02$$
$$A_{CP-} = -0.12 \pm 0.06 \pm 0.01$$

Published ADS results from Belle

Results from $B \to DK$, $D \to K\pi$ mode using 772 M $B\bar{B}$ pair events.

PRL 106, 231803 (2011)



Signal peaks at 1

More detail on continuum supression is discussed in later slides

This was the first evidence of suppressed DK signal obtained with a significance of 4.2 σ

$$R_{DK} = [1.63^{+0.44}_{-0.41}(\text{stat})^{+0.07}_{-0.13}(\text{syst})] \times 10^{-2}$$

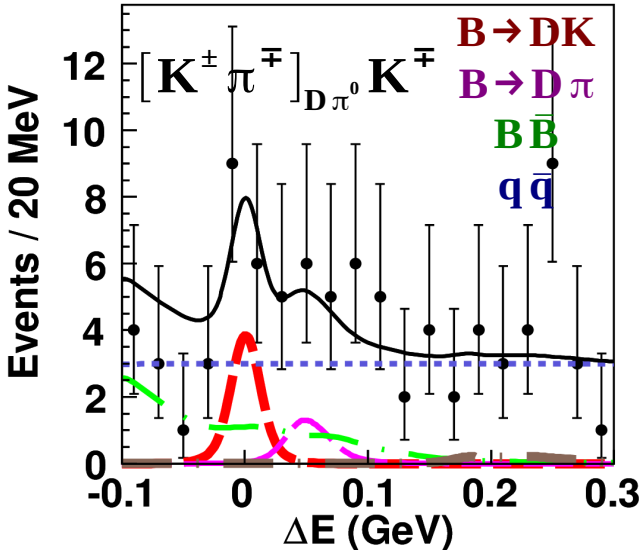
$$A_{DK} = [-0.39^{+0.26}_{-0.28}(\text{stat})^{+0.04}_{-0.03}(\text{syst})]$$

Preliminary ADS results from Belle

Preliminary (LP2011) 772 M $B\bar{B}$

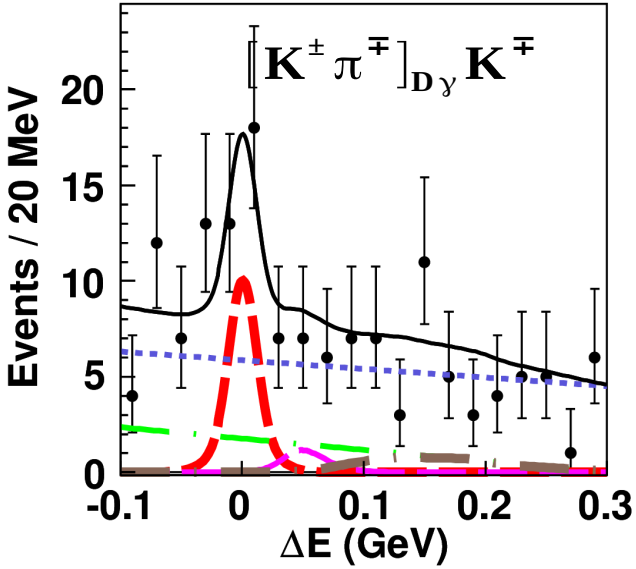
Results from $B \to [K\pi]_{D\pi^0}, D^* \to D\pi^0/D\gamma$ mode using 772 M $B\bar{B}$ events

$D^* \to D\gamma$ signal seen at 3.5σ



Ratio to favored mode :

$$R_{D\pi^0} = \left(1.0^{+0.8}_{-0.7}(\text{stat})^{+0.1}_{-0.2}(\text{syst})\right) \times 10^{-2}$$
$$R_{D\gamma} = \left(3.6^{+1.4}_{-1.2}(\text{stat}) \pm 0.2(\text{syst})\right) \times 10^{-2}$$



Asymmetry :

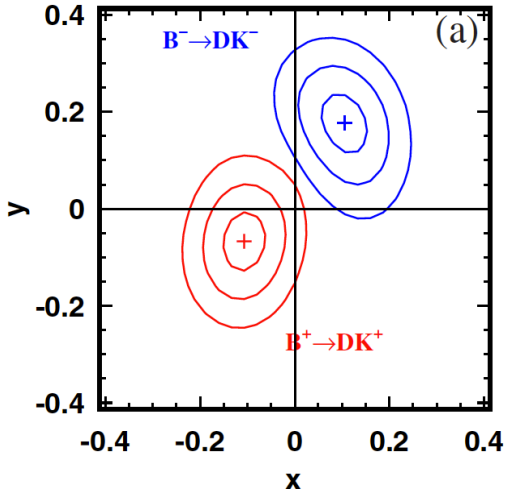
$$A_{D\pi^0} = \left(0.4^{+1.1}_{-0.7}(\text{stat})^{+0.2}_{-0.3}(\text{syst})\right)$$
$$A_{D\gamma} = \left(-0.51^{+0.33}_{-0.29}(\text{stat}) \pm 0.8(\text{syst})\right)$$

Review of GGSZ results from Belle:

Model dependent analysis

PRD81, 112002 (2010), 657M BB

$$x_{\pm} = r_B \cos(\delta_B \pm \gamma), \quad y_{\pm} = r_B \sin(\delta_B \pm \gamma)$$

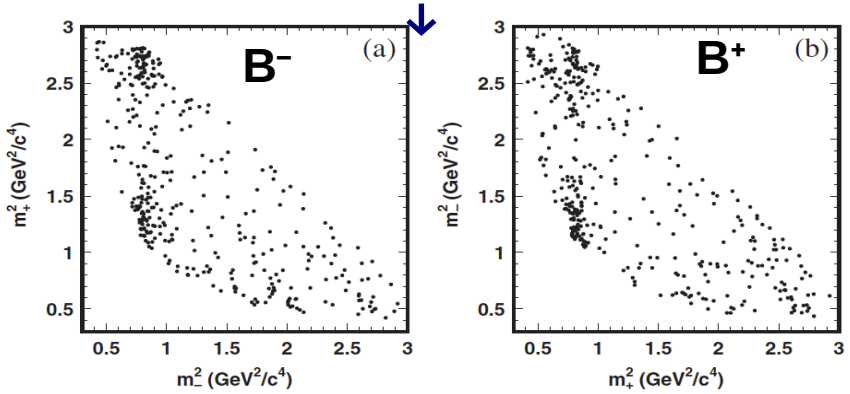


Parameter	$B^+ \to DK^+$ mode	$B^+ \to D^*K^+$ mode
ϕ_3	$(80.8^{+13.1}_{-14.8} \pm 5.0 \pm 8.9)^\circ$	$(73.9^{+18.9}_{-20.2} \pm 4.2 \pm 8.9)^\circ$
r	$0.161^{+0.040}_{-0.038} \pm 0.011^{+0.050}_{-0.010}$	$0.196^{+0.073}_{-0.072} \pm 0.013^{+0.062}_{-0.012}$
δ	$(137.4^{+13.0}_{-15.7} \pm 4.0 \pm 22.9)^\circ$	$(341.7^{+18.6}_{-20.9} \pm 3.2 \pm 22.9)^\circ$

combining both B modes :

$$\varphi_3 = \left(78.4^{+10.8}_{-11.6} \pm 3.6\,(\text{syst.}) \pm 8.9\,(\text{model})\right)^\circ$$

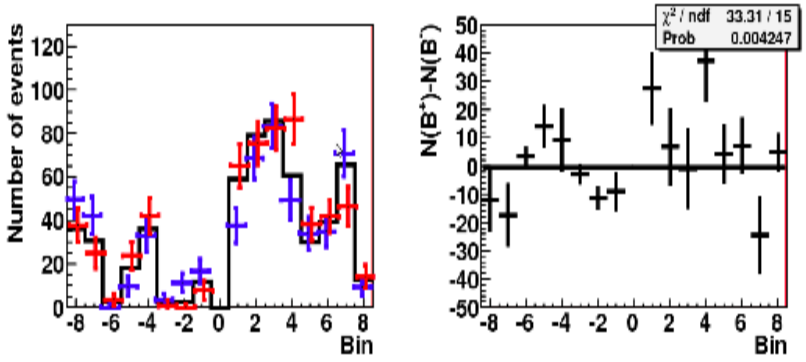
Dalitz plot for $B^{\pm} \to [K_s \pi\pi]_D K^{\pm}$



Model independent analysis

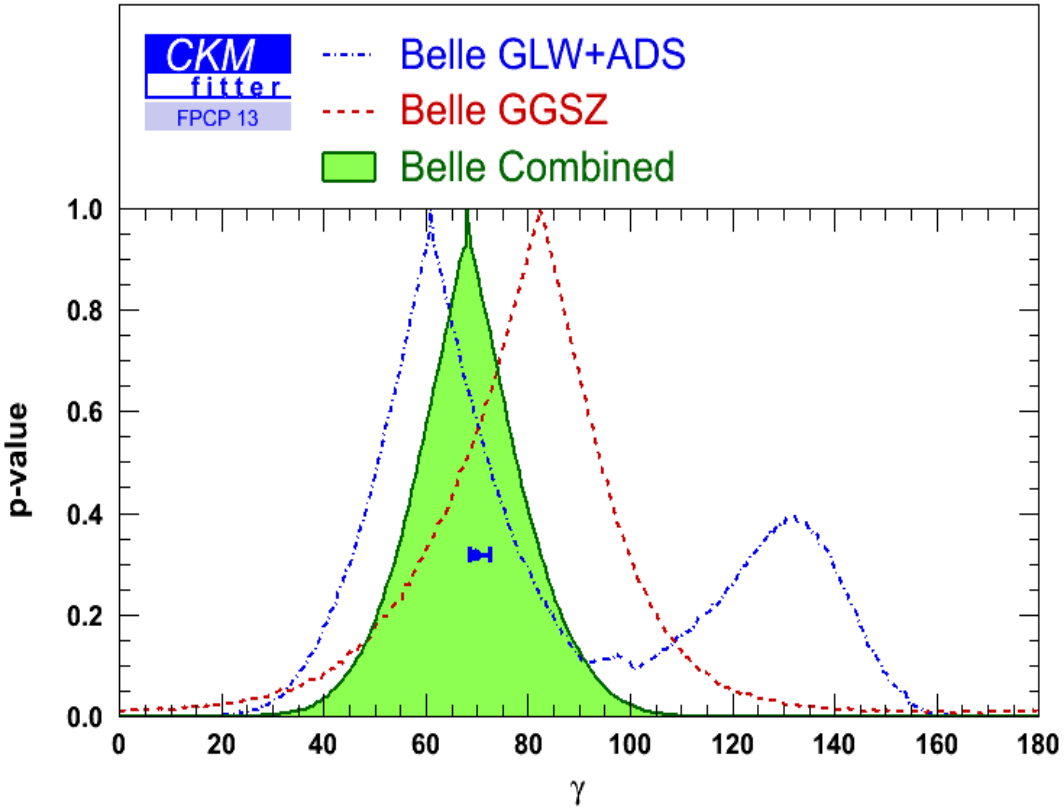
(Dividing Dalitz plot in to several bins)

PRD85, 112014 (2012), 772M BB



$$\varphi_3 = \left(77.3^{+15.1}_{-14.9} \pm 4.1 \pm 4.3\right)^\circ$$

Determination of φ_3 via GGSZ , ADS and GLW methods using Belle $D^0 K$ and $D^{*0} K$ results



combined result from Belle

$\varphi_3 = (68 \pm 14)^o$

New results from Belle

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

PRD 88, 091104(R) 2013

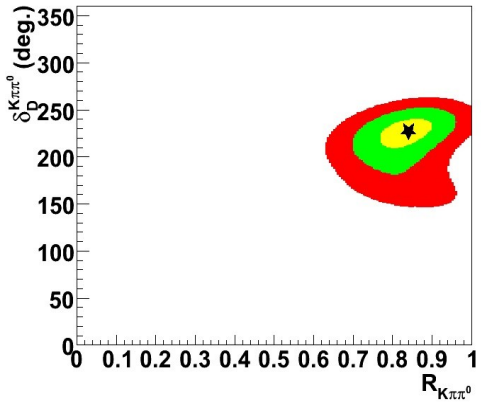
ADS $B^{\pm} \to [K\pi\pi^0]_D K^{\pm}$ analysis by Belle

observables measured:

$$R_{ADS} = \frac{B(B^- \to [K^+\pi^-\pi^0]_D K^-) + B(B^+ \to [K^-\pi^+\pi^0]_D K^+)}{B(B^- \to [K^-\pi^+\pi^0]_D K^-) + B(B^+ \to [K^+\pi^-\pi^0]_D K^+)}$$
$$= r_B^2 + r_D^2 + 2 r_B r_D R_{K\pi\pi^0} \cos\phi_3 \cos(\delta_B + \delta_D^{K\pi\pi^0}),$$

$$A_{ADS} = \frac{B(B^- \to [K^+\pi^-\pi^0]_D K^-) - B(B^+ \to [K^-\pi^+\pi^0]_D K^+)}{B(B^- \to [K^+\pi^-\pi^0]_D K^-) + B(B^+ \to [K^-\pi^+\pi^0]_D K^+)}$$
$$= \frac{2 r_B r_D R_{K\pi\pi^0} \sin\phi_3 \sin(\delta_B + \delta_D^{K\pi\pi^0})}{r_B^2 + r_D^2 + 2 r_B r_D R_{K\pi\pi^0} \cos\phi_3 \cos(\delta_B + \delta_D^{K\pi\pi^0})}$$

Here $R_{K\pi\pi^0}$ and $\delta_D^{K\pi\pi^0}$ are the coherence factor and average strong − phase difference for $D^0 \to K\pi\pi^0$ decay



CLEO measurements:

$$R_{K\pi\pi^0} = 0.84 \pm 0.07, \quad \delta_D^{K\pi\pi^0} = \left(227^{+14}_{-17}\right)^{o}.$$

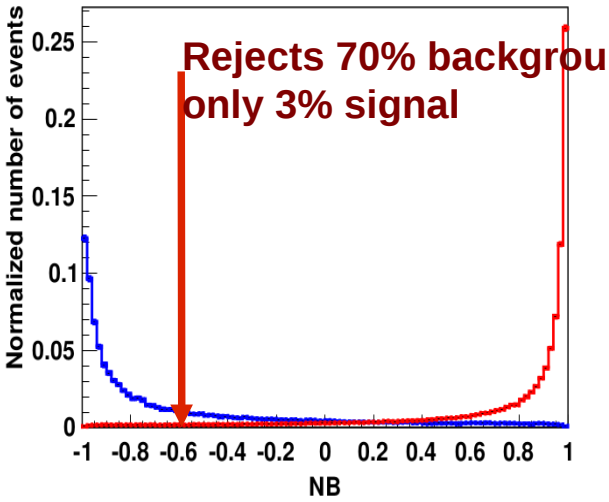
Phys. Rev. D 80, 031105(R) (2009)

Main challenge of selection is Continuum Suppression

Continuum supression via neural network output (combining event topology parameters as inputs):

Nine topological variables used.

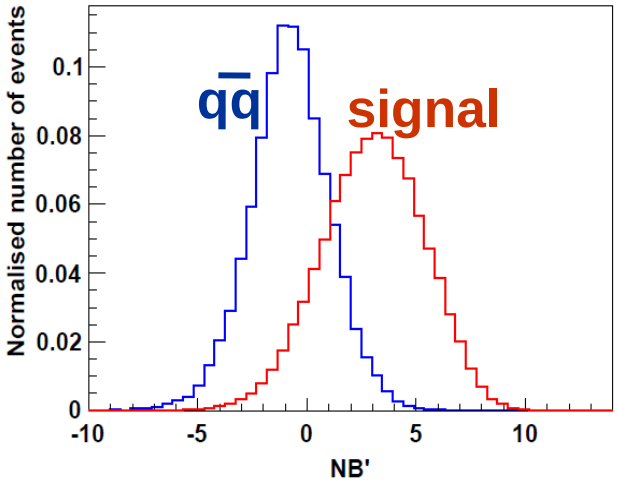
Network Output ↓



Transformed using ↓

$$C'_{NB} = \log\left(\frac{C_{NB} - C_{NB,min}}{C_{NB,max} - C_{NB}}\right)$$

Transformed Output (To simplify fit using PDFs) ↓



Signal extraction via 2D fit between ΔE and C'_{NB}

Fit parameters :

– N_{sup}, N_{fav}, A_{ADS}

– N_{peak} $N_{B\bar{B}}$, $N_{q\bar{q}}$

– PDF shape parameters ...

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

PRD 88, 091104(R) 2013

R_{DK}

ΔE and C'_{NB} distributions : →

Blue : total

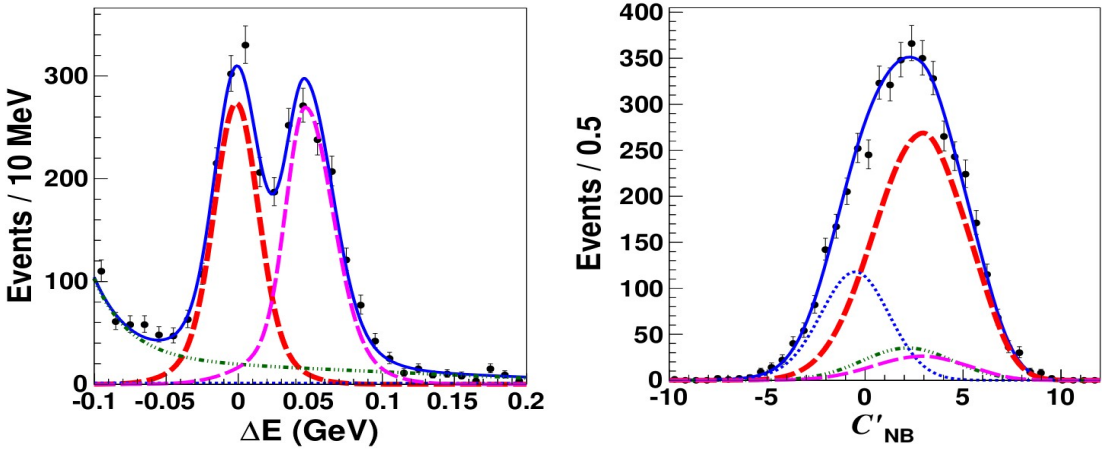
Red : DK signal

Magenta : $D\pi$

Green : $B\bar{B}$

Dotted blue : $q\bar{q}$

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



Belle Result using 772 M $B\bar{B}$ pairs :

$N_{sup} = 77 \pm 24$

$N_{fav} = 3871 \pm 90$

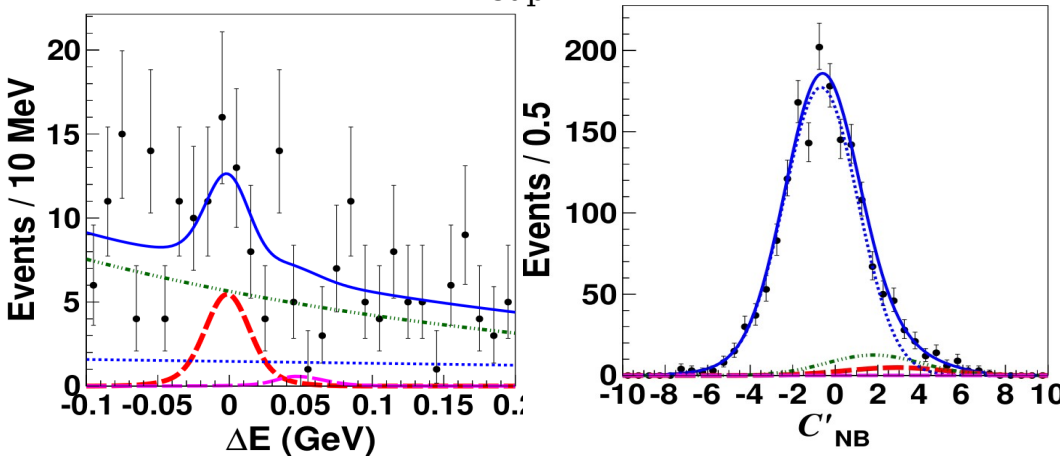
Ratio to favored mode :

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

Babar Result using 474 M $B\bar{B}$ pairs :

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

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

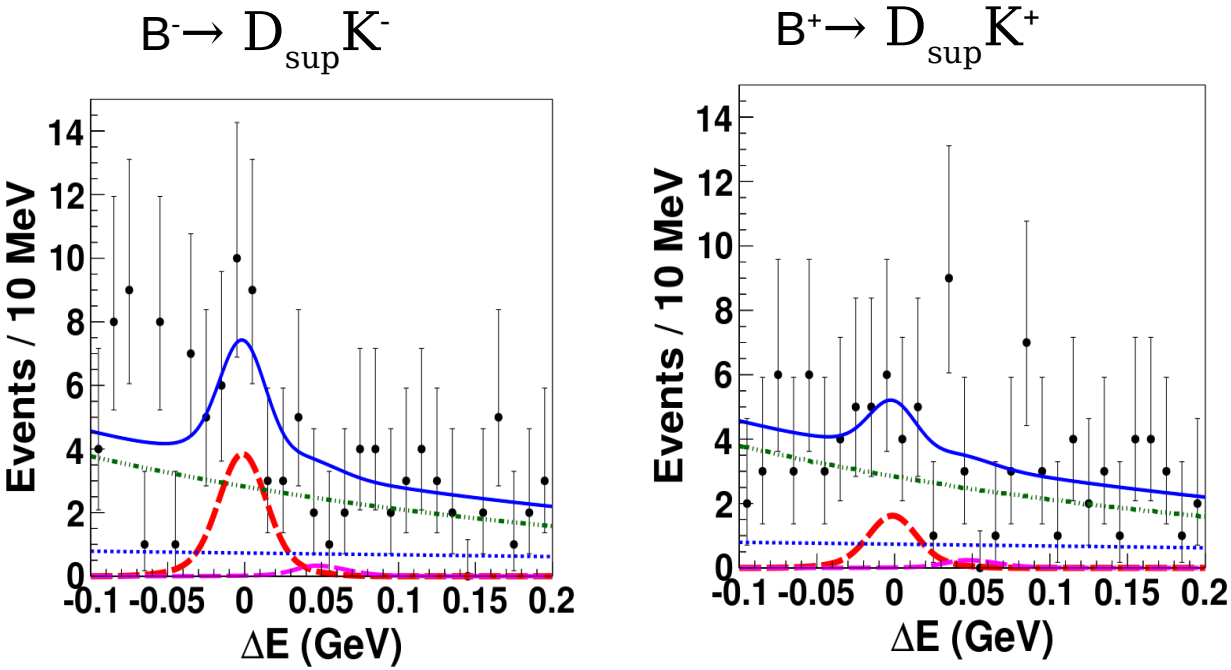


Suppressed DK signal significance 3.2 σ

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

PRD 88, 091104(R) 2013

A_{DK}



Belle Result using 772 million $B\bar{B}$ pairs :

$$R_{DK} = (1.98 \pm 0.62(\text{stat}) \pm 0.23(\text{syst})) \times 10^{-2}$$

$$A_{DK} = (0.41 \pm 0.30(\text{stat}) \pm 0.05(\text{syst}))$$

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

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

PRD 88, 091104(R) 2013

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

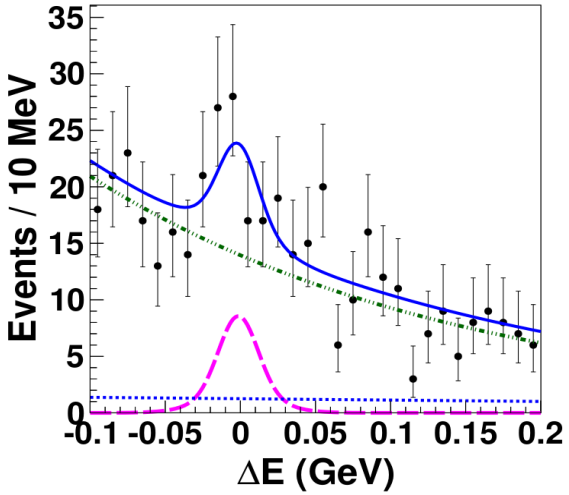
ΔE and C′ distributions : →

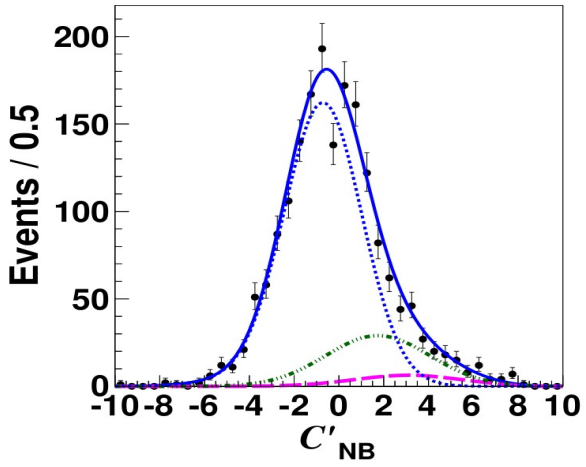
Blue : total

Magenta : Dπ signal

Green : $B\bar{B}$

Dotted blue : $q\bar{q}$





Suppressed Dπ signal significance 3.3 σ

Small r_B. So, less sensitive to ϕ_3

Dπ Results :

$$R_{D\pi} = \left(1.89 \pm 0.54\,(\text{stat})^{+0.22}_{-0.25}\,(\text{syst})\right) \times 10^{-3}$$

$$A_{D\pi} = \left(0.16 \pm 0.27\,(\text{stat})^{+0.03}_{-0.04}\,(\text{syst})\right)$$

First measurements !

D mixing corrections need to be taken in to account if above results are used to measure ϕ_3 (arXiv:1307.4384)

Conclusion:

* Combined value of φ_3 measured by Belle : $(68 \pm 14)^o$

* New $[K \pi \pi^0]_D K$ results :

Suppressed signal seen with a significance of $3.2\,\sigma$ (including systematics)

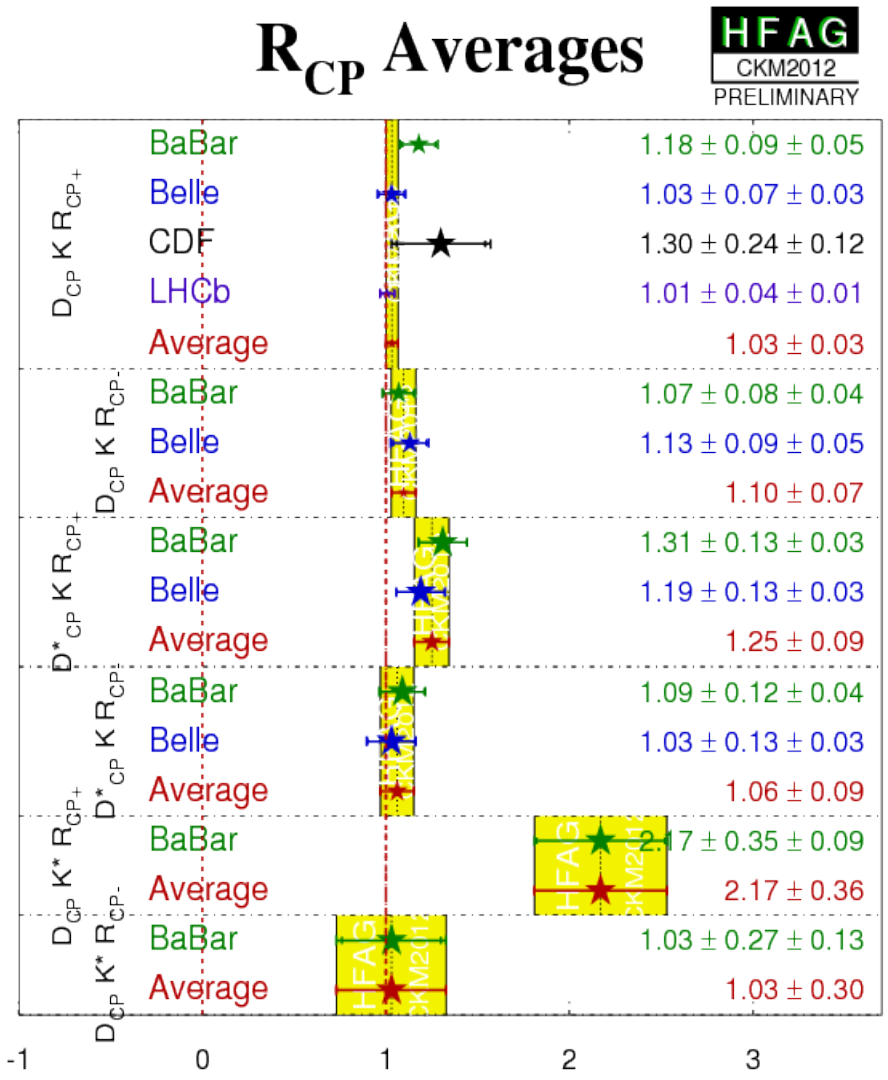
$$R_{DK} = (1.98 \pm 0.62(\text{stat}) \pm 0.23(\text{syst})) \times 10^{-2}$$

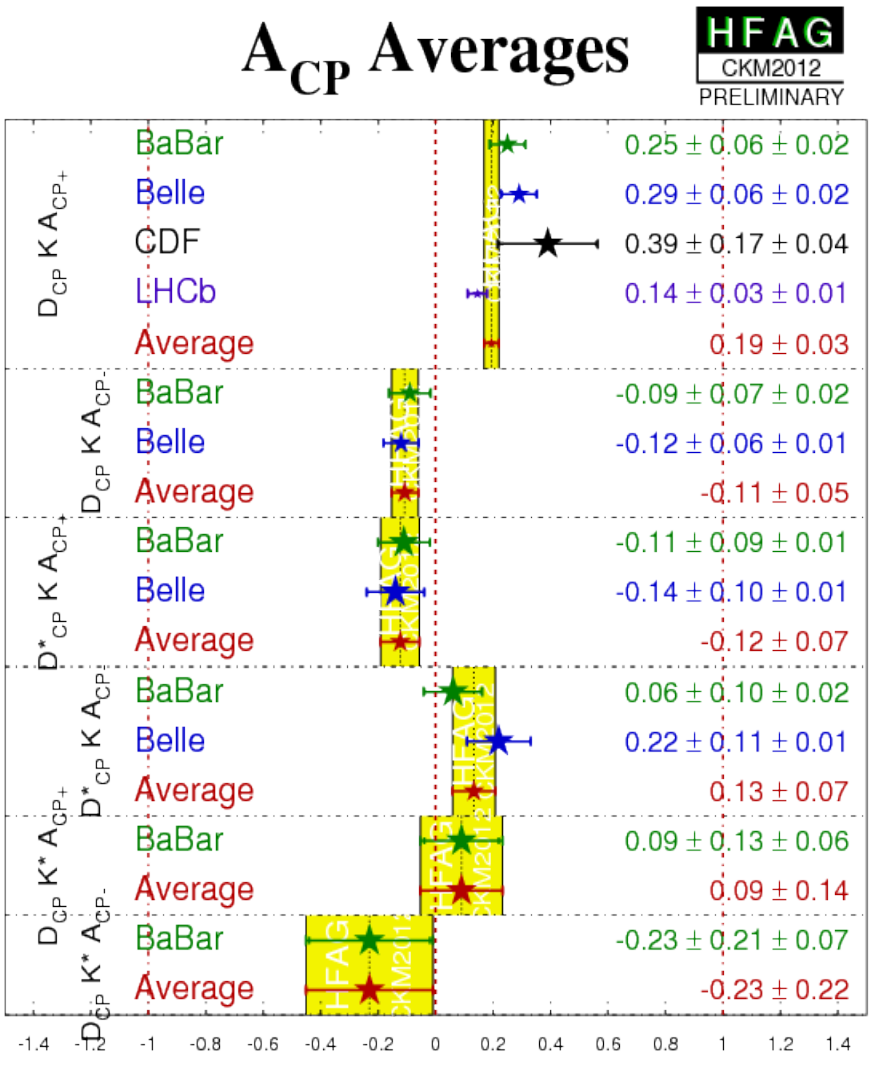
$$A_{DK} = (0.41 \pm 0.30(\text{stat}) \pm 0.05(\text{syst}))$$

* Several other analysis for measuring φ_3 using Belle full data sample are ongoing.

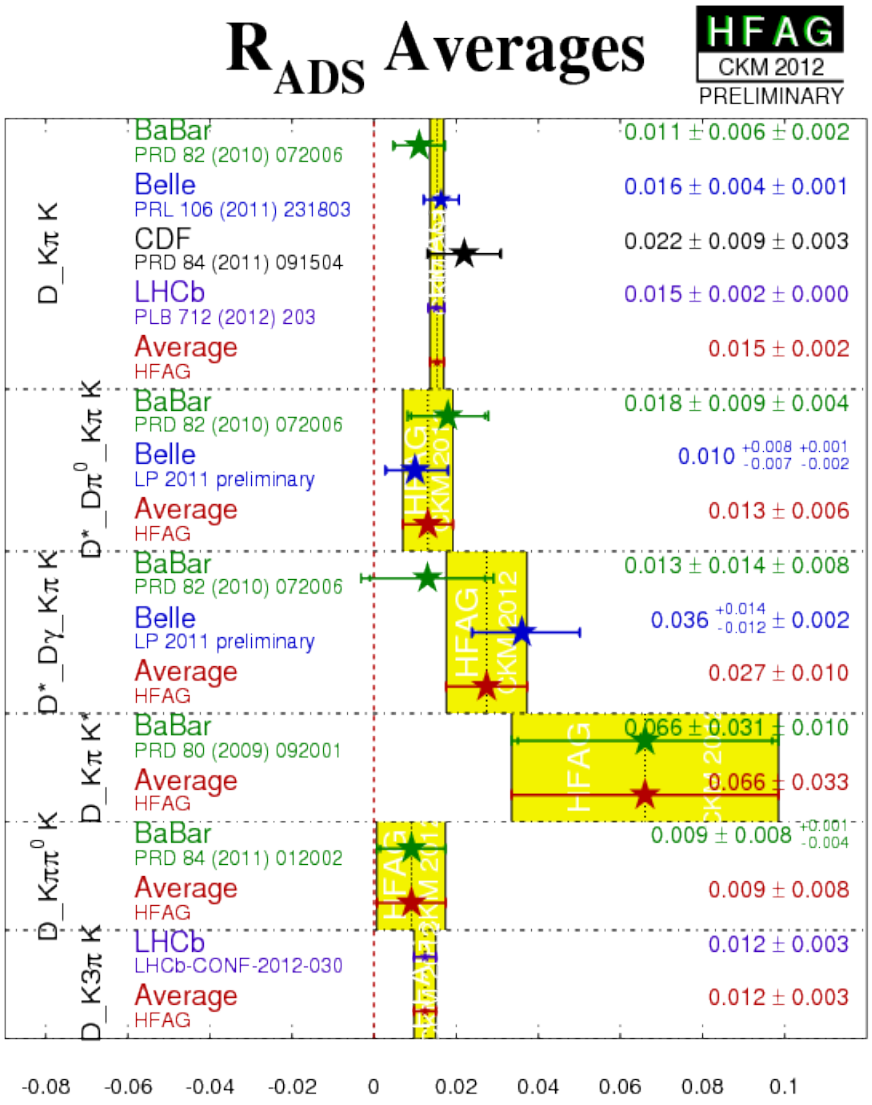
THANK YOU!

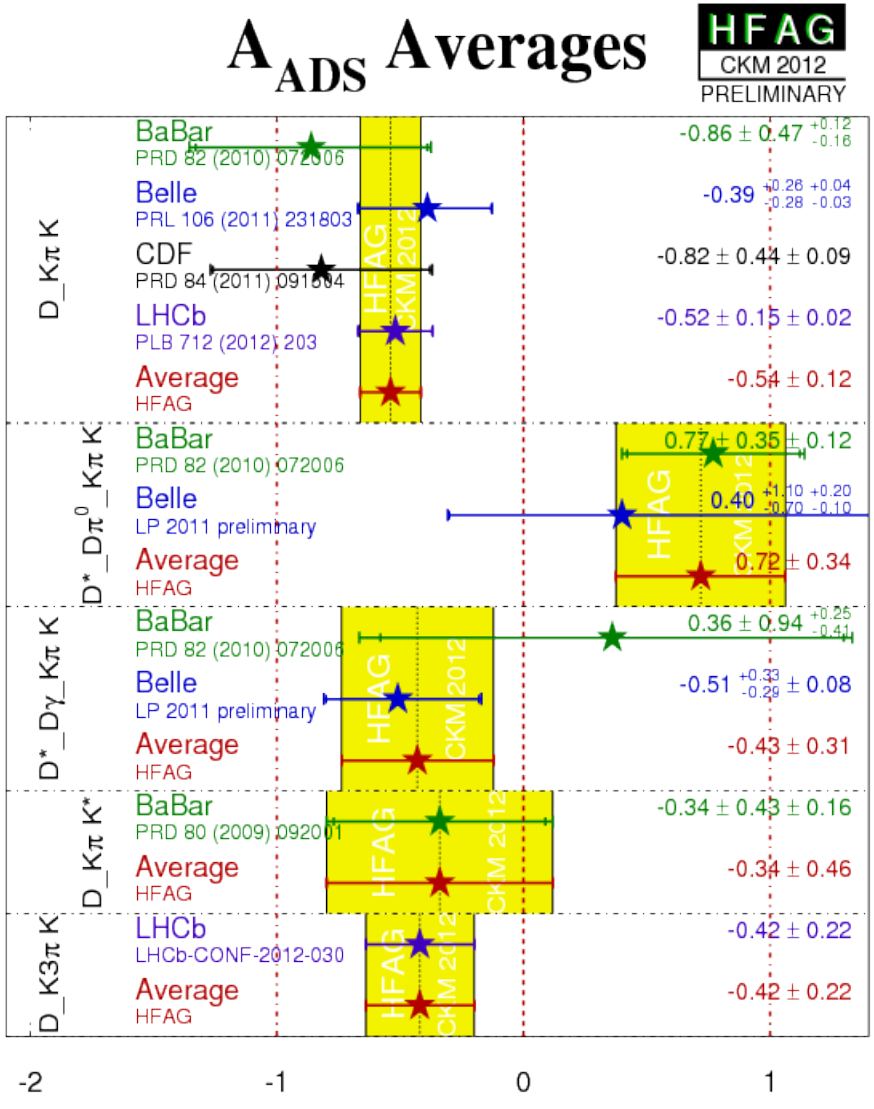
GLW summary


R_CP Averages
HFAG
CKM2012
PRELIMINARY
D_CP K R_CP+
BaBar 1.18 ± 0.09 ± 0.05
Belle 1.03 ± 0.07 ± 0.03
CDF 1.30 ± 0.24 ± 0.12
LHCb 1.01 ± 0.04 ± 0.01
Average 1.03 ± 0.03
D_CP K R_CP-
BaBar 1.07 ± 0.08 ± 0.04
Belle 1.13 ± 0.09 ± 0.05
Average 1.10 ± 0.07
D*_CP K R_CP+
BaBar 1.31 ± 0.13 ± 0.03
Belle 1.19 ± 0.13 ± 0.03
Average 1.25 ± 0.09
D*_CP K R_CP-
BaBar 1.09 ± 0.12 ± 0.04
Belle 1.03 ± 0.13 ± 0.03
Average 1.06 ± 0.09
D_CP K* R_CP+
BaBar 2.17 ± 0.35 ± 0.09
Average 2.17 ± 0.36
D_CP K* R_CP-
BaBar 1.03 ± 0.27 ± 0.13
Average 1.03 ± 0.30
-1
0
1
2
3


A_CP Averages
HFAG
CKM2012
PRELIMINARY
D_CP K A_CP+
BaBar 0.25 ± 0.06 ± 0.02
Belle 0.29 ± 0.06 ± 0.02
CDF 0.39 ± 0.17 ± 0.04
LHCb 0.14 ± 0.03 ± 0.01
Average 0.19 ± 0.03
D_CP K A_CP-
BaBar -0.09 ± 0.07 ± 0.02
Belle -0.12 ± 0.06 ± 0.01
Average -0.11 ± 0.05
D*_CP K A_CP+
BaBar -0.11 ± 0.09 ± 0.01
Belle -0.14 ± 0.10 ± 0.01
Average -0.12 ± 0.07
D*_CP K A_CP-
BaBar 0.06 ± 0.10 ± 0.02
Belle 0.22 ± 0.11 ± 0.01
Average 0.13 ± 0.07
D_CP K* A_CP+
BaBar 0.09 ± 0.13 ± 0.06
Average 0.09 ± 0.14
D_CP K* A_CP-
BaBar -0.23 ± 0.21 ± 0.07
Average -0.23 ± 0.22
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4

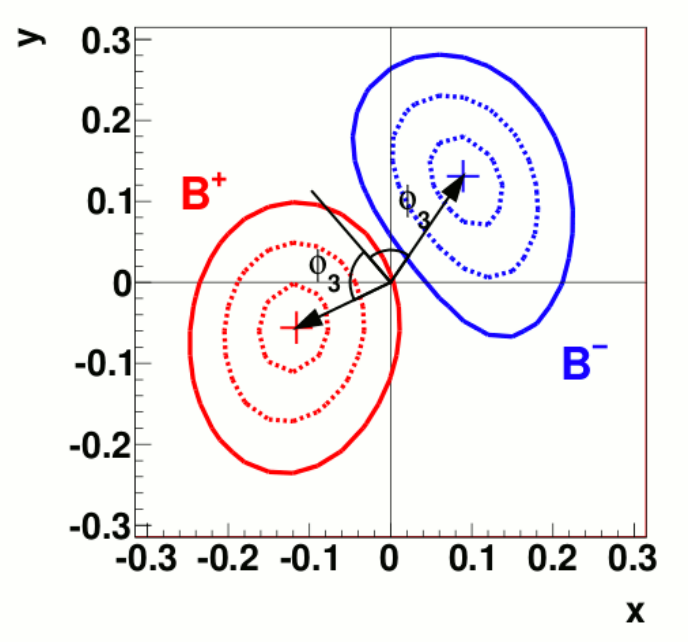
ADS summary

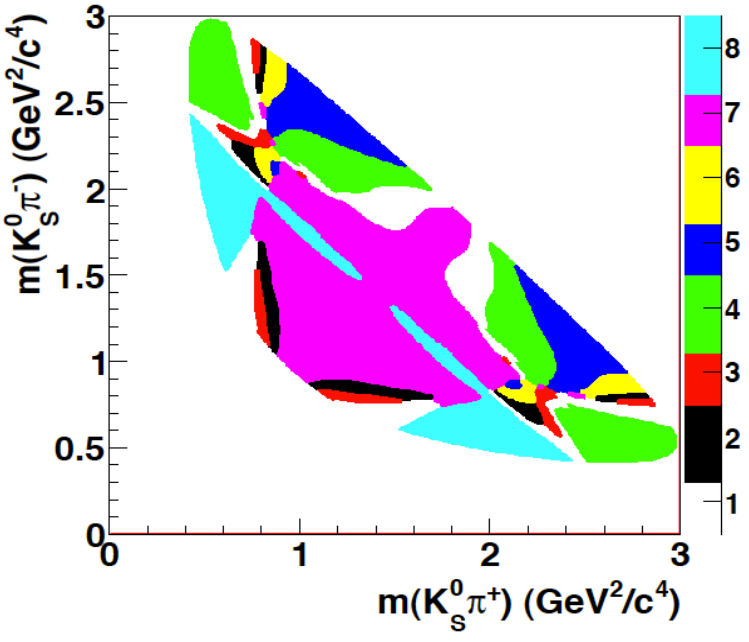

R_ADS Averages
HFAG
CKM 2012
PRELIMINARY
D_Kπ K
BaBar PRD 82 (2010) 072006 0.011 ± 0.006 ± 0.002
Belle PRL 106 (2011) 231803 0.016 ± 0.004 ± 0.001
CDF PRD 84 (2011) 091504 0.022 ± 0.009 ± 0.003
LHCb PLB 712 (2012) 203 0.015 ± 0.002 ± 0.000
Average HFAG 0.015 ± 0.002
D* Dπ0 Kπ K
BaBar PRD 82 (2010) 072006 0.018 ± 0.009 ± 0.004
Belle LP 2011 preliminary 0.010 +0.008 -0.007 +0.001 -0.002
Average HFAG 0.013 ± 0.006
D* Dγ Kπ K
BaBar PRD 82 (2010) 072006 0.013 ± 0.014 ± 0.008
Belle LP 2011 preliminary 0.036 +0.014 -0.012 ± 0.002
Average HFAG 0.027 ± 0.010
D Kπ K*
BaBar PRD 80 (2009) 092001 0.066 ± 0.031 ± 0.010
Average HFAG 0.066 ± 0.033
D Kππ0 K
BaBar PRD 84 (2011) 012002 0.009 ± 0.008 +0.001 -0.004
Average HFAG 0.009 ± 0.008
D K3π K
LHCb LHCb-CONF-2012-030 0.012 ± 0.003
Average HFAG 0.012 ± 0.003
-0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1


A_ADS Averages
HFAG
CKM 2012
PRELIMINARY
D_Kπ K
BaBar PRD 82 (2010) 072006 -0.86 ± 0.47 +0.12 -0.16
Belle PRL 106 (2011) 231803 -0.39 +0.26 +0.04 -0.28 -0.03
CDF PRD 84 (2011) 091504 -0.82 ± 0.44 ± 0.09
LHCb PLB 712 (2012) 203 -0.52 ± 0.15 ± 0.02
Average HFAG -0.54 ± 0.12
D* Dπ0 Kπ K
BaBar PRD 82 (2010) 072006 0.77 ± 0.35 ± 0.12
Belle LP 2011 preliminary 0.40 +1.10 +0.20 -0.70 -0.10
Average HFAG 0.72 ± 0.34
D* Dγ Kπ K
BaBar PRD 82 (2010) 072006 0.36 ± 0.94 +0.25 -0.41
Belle LP 2011 preliminary -0.51 +0.33 -0.29 ± 0.08
Average HFAG -0.43 ± 0.31
D Kπ K*
BaBar PRD 80 (2009) 092001 -0.34 ± 0.43 ± 0.16
Average HFAG -0.34 ± 0.46
D K3π K
LHCb LHCb-CONF-2012-030 -0.42 ± 0.22
Average HFAG -0.42 ± 0.22
-2 -1 0 1

GGSZ results from Belle using Model-independent approach

PRD85, 112014 (2012),
772M BB





$$\phi_3 = (77.3^{+15.1}_{-14.9} \pm 4.1 \pm 4.3)^\circ$$

$$r_B = 0.145 \pm 0.030 \pm 0.010 \pm 0.011$$

$$\delta_B = (129.9 \pm 15.0 \pm 3.8 \pm 4.7)^\circ,$$

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

selection Criteria:

- **Primary tracks: $|dr| < 0.2$ cm**
  $|dz| < 1.5$ cm
- **π selection: $L(K/\pi) < 0.4$**
- **K selection: $L(K/\pi) \geq 0.6$**
- **$E\gamma > 50$ MeV in ECL**
- **$P_{\pi 0} > 0.4$ GeV/c**
- **D^0 mass cut: $\pm 3\sigma$**
- **$M_{bc} = \pm 3\sigma$**
- **$\Delta E = E_{beam} - E_B$: [-0.1, 0.2] GeV**

Best candidate selection: $X^2_{min}(M_D, M_{bc})$

BG vetoes:

✓ **$D^{*\pm}$ veto ($D^{*\pm} \to D^0\pi^{\pm}$) :**

$\Delta M (D^{*\pm} - D^0) > 0.15$ GeV/c2

✓ **double- mis-ID veto:**

$(1.804 < M[K\pi\pi^0] < 1.885)$GeV/c²

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

$R_{D\pi}$

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

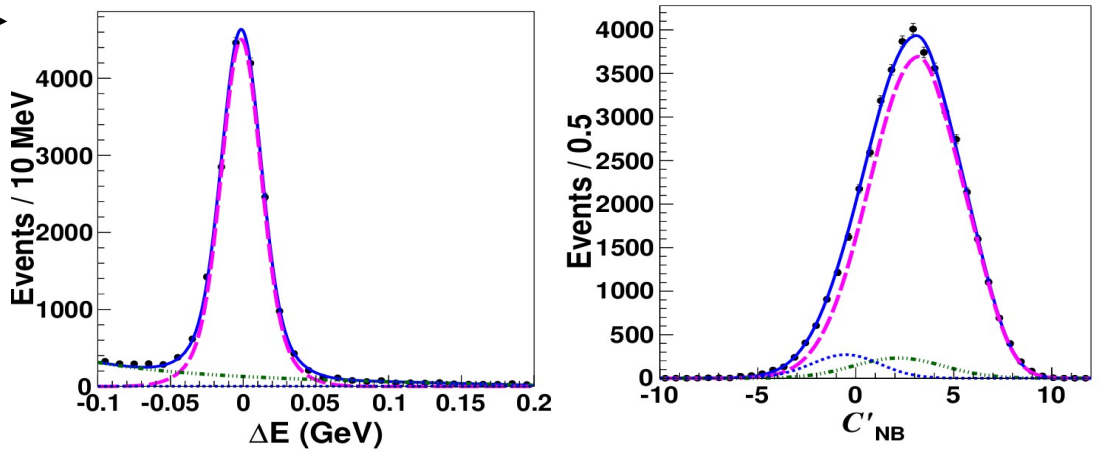
ΔE and C'_{NB} distributions: →

Blue: total

Magenta: Dπ signal

Green: BB

Dotted blue: qq



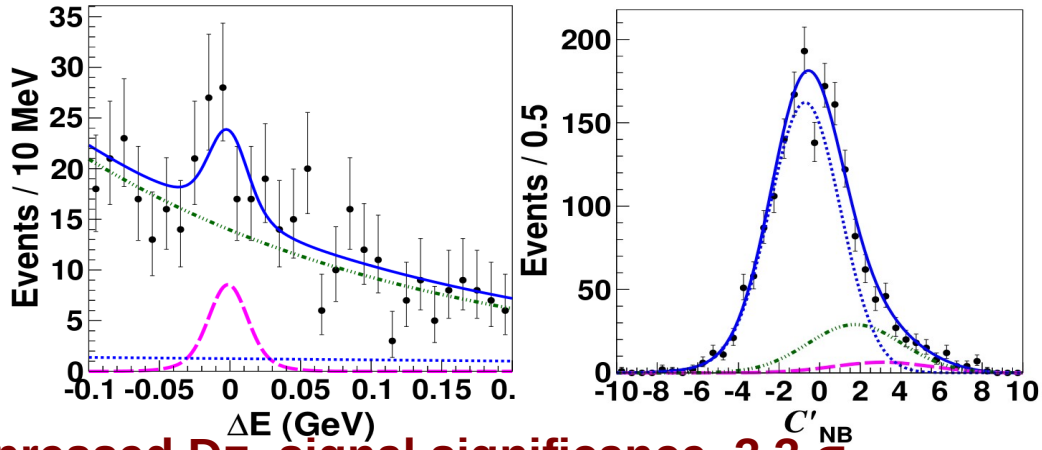
$B^{\pm} \to D_{sup}\pi^{\pm}$

Belle Result using 772 M BB pairs:

$N_{sup} = 94 \pm 27$

$N_{fav} = 49668 \pm 338$

$R_{D\pi} = (1.89 \pm 0.54^{+0.22}_{-0.25}) \times 10^{-3}$

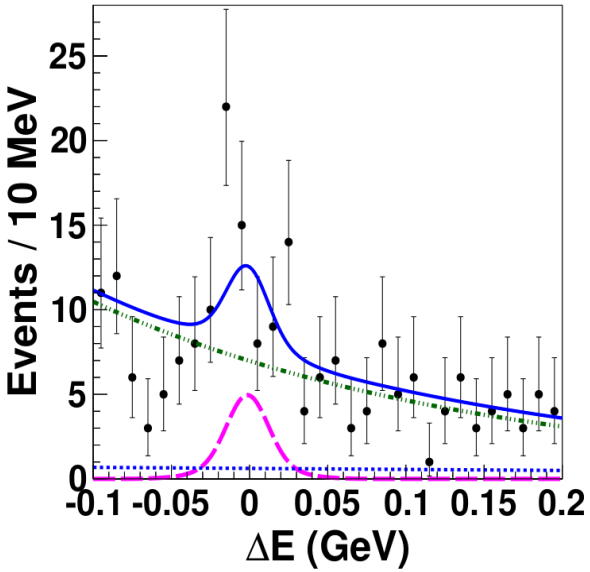


Suppressed Dπ signal significance 3.3 σ

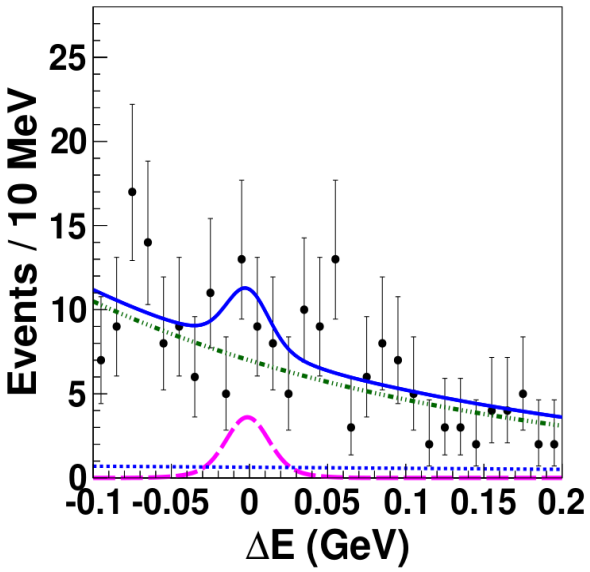
ADS $B^{\pm} \to [K\pi\pi^0]_D K^{\pm}$ result by Belle

$A_{D\pi}$

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



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



Belle Result using 772 M BB pairs:

$R_{D\pi} = (1.89 \pm 0.54\ ^{+0.22}_{-0.25}) \times 10^{-3}$

$A_{D\pi} = (0.16 \pm 0.27\ ^{+0.03}_{-0.04})$

First measurements!