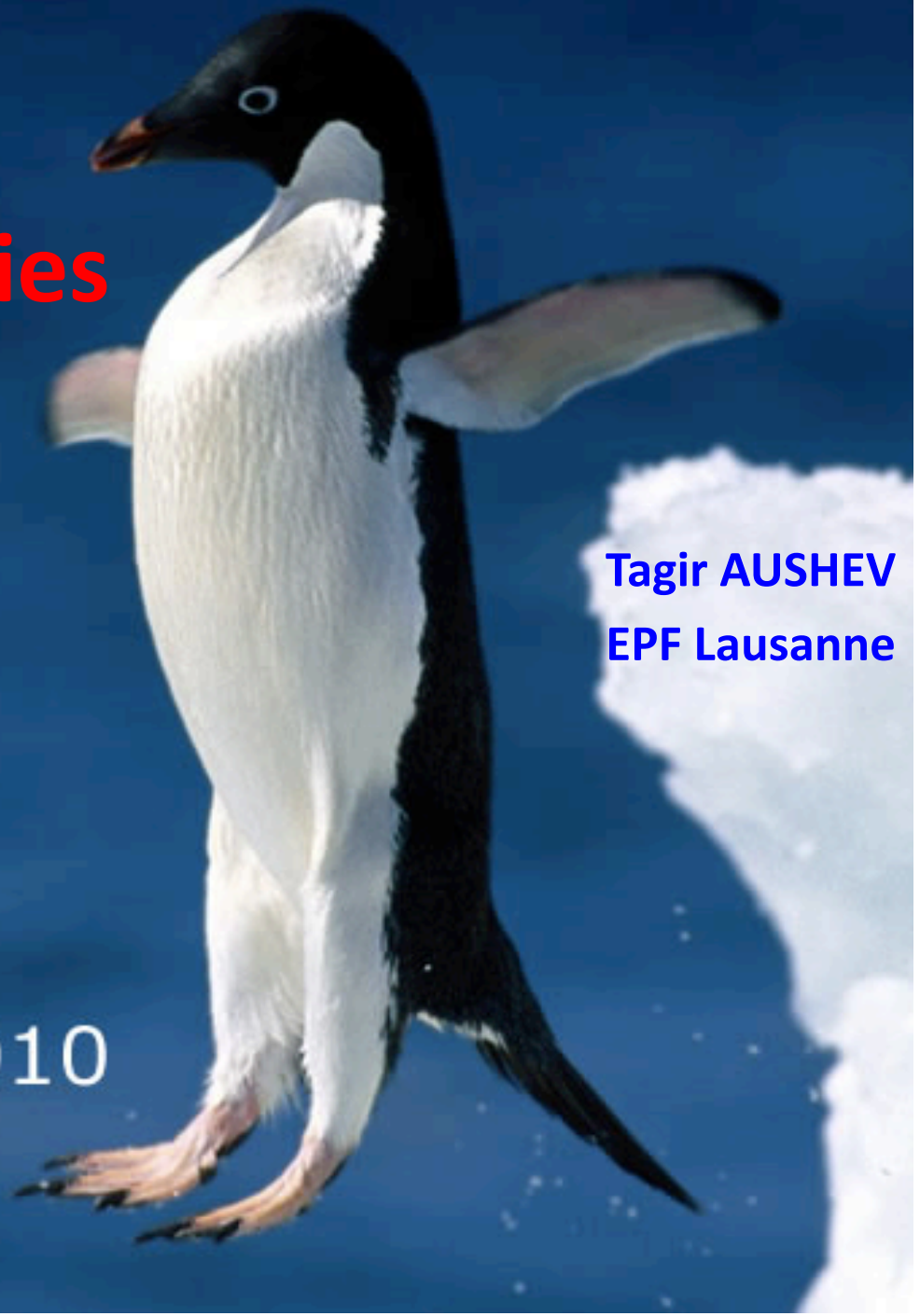
Recent results from B-factories



- Overview of B-physics topics
- New XYZ states
- CKM matrix and ϕ_3/γ angle
- ADS analysis
- GLW analysis
- Dalitz three-body decay analysis
- Summary

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EPF Lausanne

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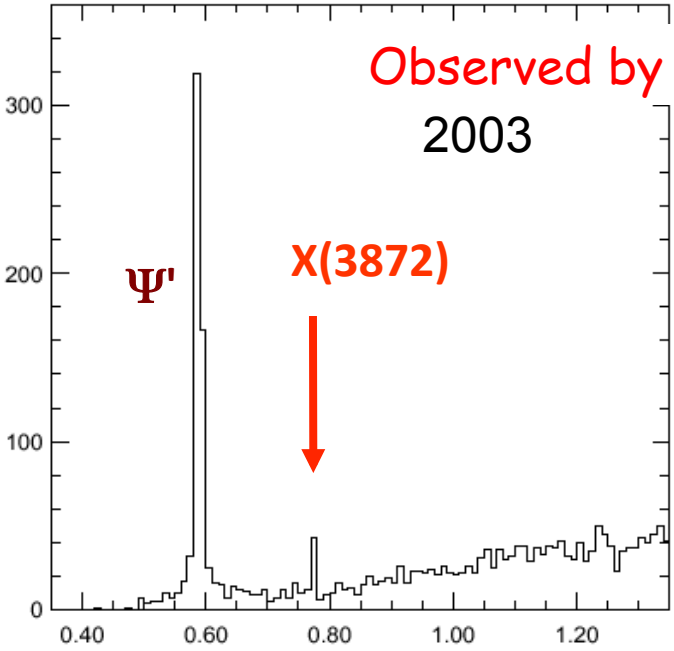
B-physics topics

- There are many interesting results recently published by B-factories:
  - CP violation measurements from Belle and BaBar
  - Charm, charmonium, baryon spectroscopes
  - Rare and radiative decays
  - Tau physics
  - B_s mixing
  - $\Upsilon(5S)$ studies
  - …
- Due to limited time only two topics will be presented in this talk:
  - The most recent results for new XYZ states
  - CKM angle γ measurements

Observation of X(3872)

Many new states are recently observed by Belle/BaBar/CDF:
X(3872), X(3940), Y(3940), X(4160), Y(4008), Y(4260), Y(4350), Y(4660), …

All the story was started from the observation of X(3872):



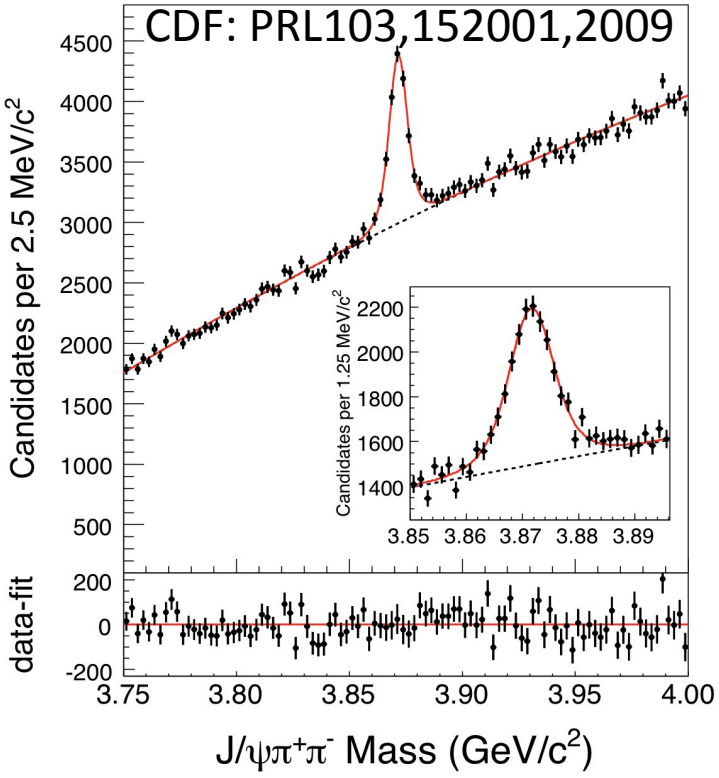
Belle data: 152 M BB events
Mass = 3872.0±0.6±0.5 MeV
Significance = 10 σ

This measurement was confirmed
in 2004 by BaBar and in 2006 by CDF

Not fittable to any known cc-bar states
Mass of X(3872) is close to *DD**
What is it: charmonium, *DD**-molecule, tetraquark...?

X(3872) mass measurements

- Recently CDF published most precise measurement of X(3872) mass;
- Together with CLEO's update on the D^0 mass gives hint on the X(3872) mass to be below the D^0D^{*0} threshold



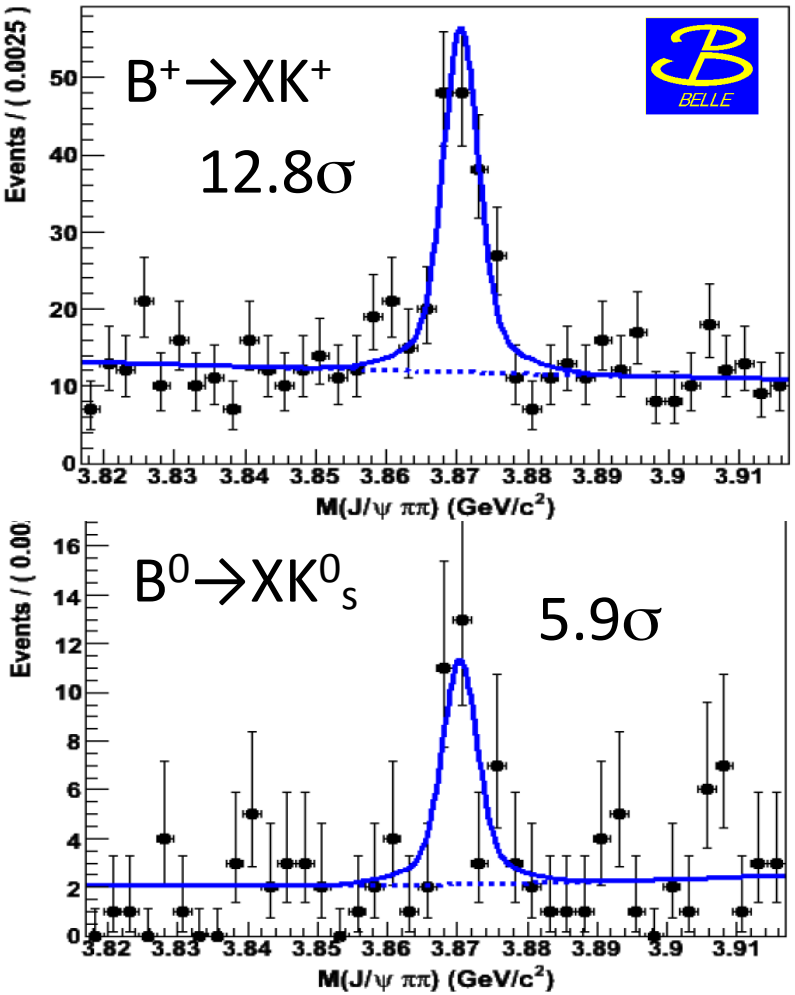
Latest results for X(3872) mass

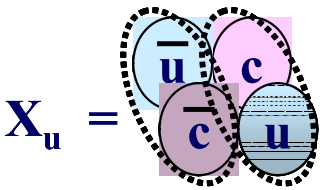
	$M(X(3872))$, MeV/c^2
B→XK	3871.46±0.37±0.07
B→XK	3871.4±0.6±0.1
$X\to J/\psi\pi^+\pi^-$	3871.61±0.16±0.19
Our average	3871.50±0.19
$M(D^0)+M(D^{*0})$	3871.81±0.36

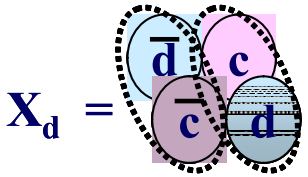
Note that the current mass is below the DD* threshold

Charged and neutral partners of X(3872)

$X(3872)\to J/\psi\pi^+\pi^-$







diquark-antidiquark models

Xu and Xd from B^0 and B^+ decays

$\Delta M_X = 8\pm3$ MeV

Maiani et al PRD71, 014028

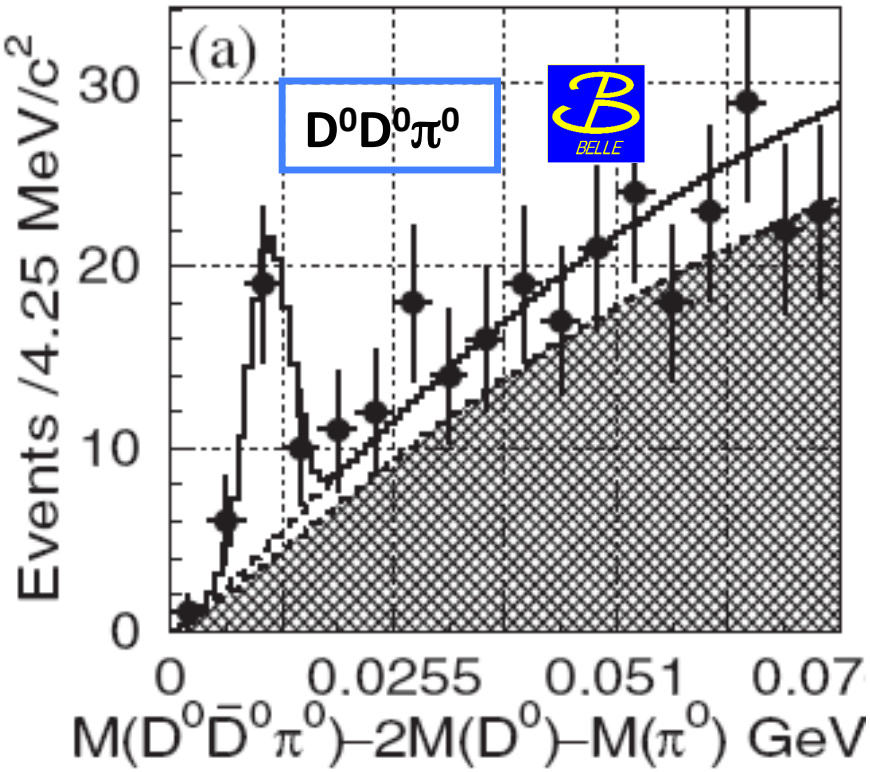
$\Delta M_X = (+0.18\pm0.89\pm0.26)$ MeV/c^2

$Br(B^0\to XK^0) / Br(B^+\to XK^+) = 0.82 \pm 0.22 \pm 0.05$

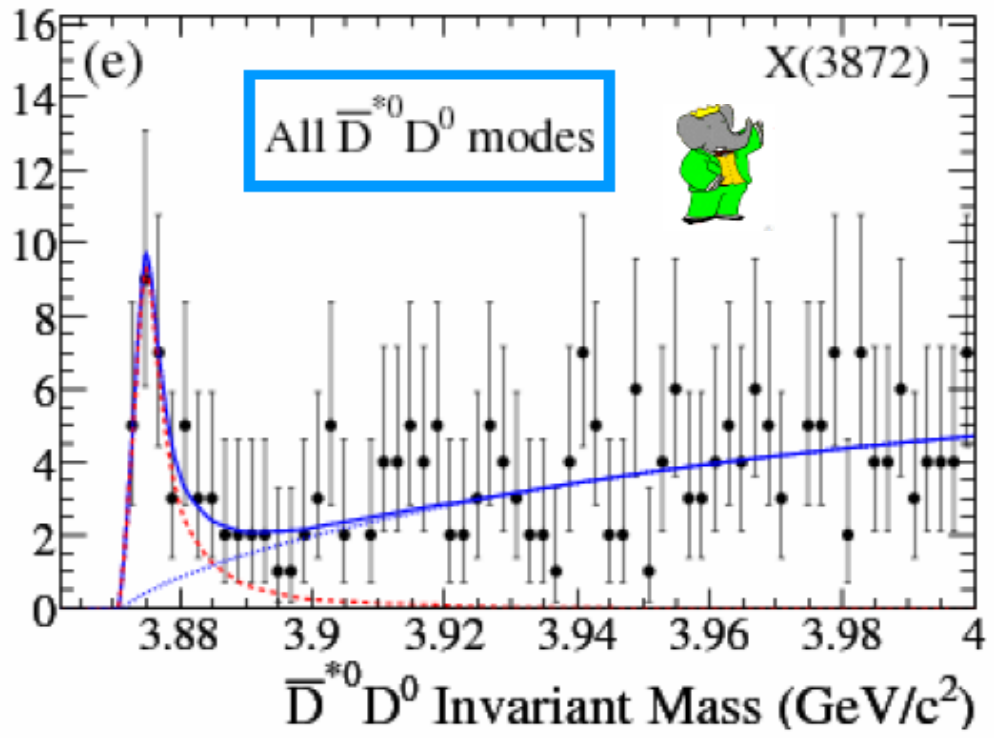
$Br(B^0\to XK^0)\, Br(J/\psi\pi^-\pi^+) = (6.65 \pm 1.63 \pm 1.00)\times10^{-6}$

$Br(B^+\to XK^+)\, Br(J/\psi\pi^-\pi^+) = (8.10 \pm 0.92 \pm 0.66)\times10^{-6}$

DD* threshold enhancement in B→KDD*



PRL 97, 162002 (2006)

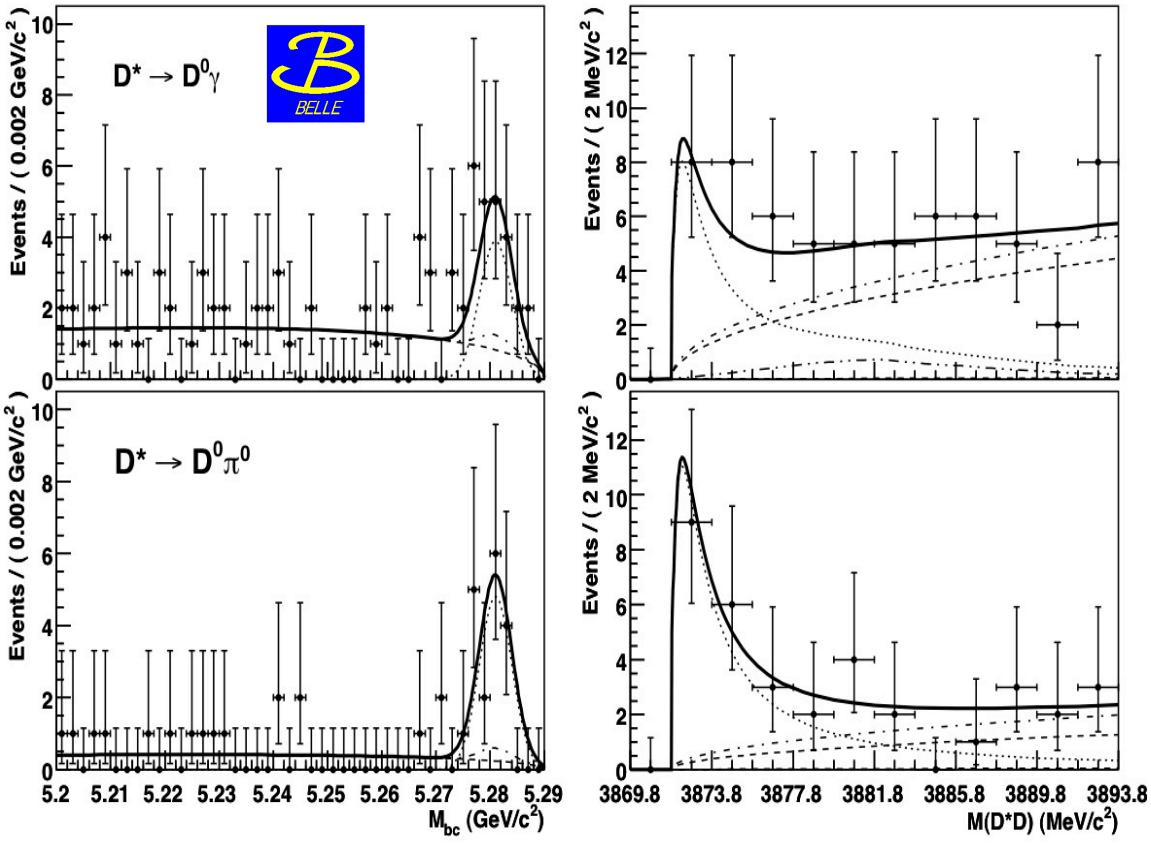


PRD 77, 011102 (2008)

Both saw higher mass & BR(DD*) ≈ 10x BR($\pi^+\pi^-$J/ψ)

	Mass, MeV	Width, MeV	B^+ BR x 10^4
Belle	$3875.4\pm0.7^{+1.2}_{-2.0}$		$1.25\pm0.31\pm0.30$
BaBar	$3875.1^{+0.7}_{-0.5}\pm0.5$	$3.0^{+1.9}_{-1.4}\pm0.9$	$1.67\pm0.36\pm0.47$

B→X(3872) K; X(3872)→$\underline{D}^{*0}D^0$; $\underline{D}^{*0}\to D^0(\gamma,\pi^0)$



hep-ex:0810.0358

$M_{D^*D} = (3872.9^{+0.6}_{-0.4}{}^{+0.4}_{-0.5})$ MeV
BaBar: $(3875.1^{+0.7}_{-0.5}\pm 0.5)$ MeV

Γ(Belle) $=(3.9^{+2.8}_{-1.4}{}^{+0.2}_{-1.1})$ MeV
Γ(BaBar)$=(3.0^{+2.5}_{-1.3}{}^{+0.5}_{-0.3})$ MeV

Nsig $= 50.1^{+14.8}_{-11.1}$
Significance = 6.4 σ

NEW

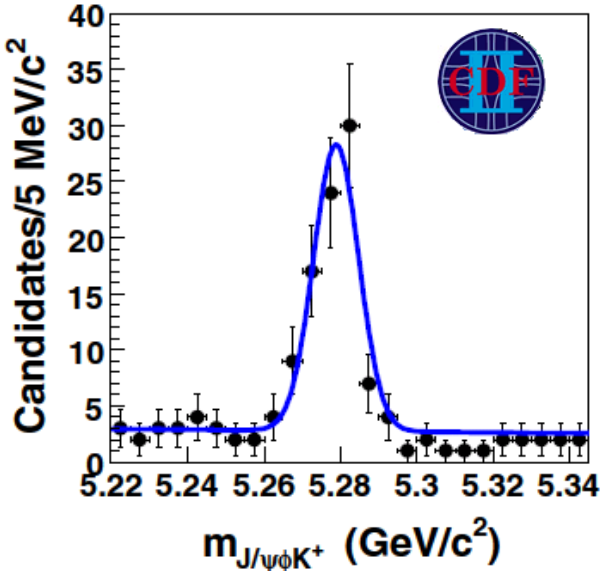
X(3872) mass shape is also well fittable by Flatte function

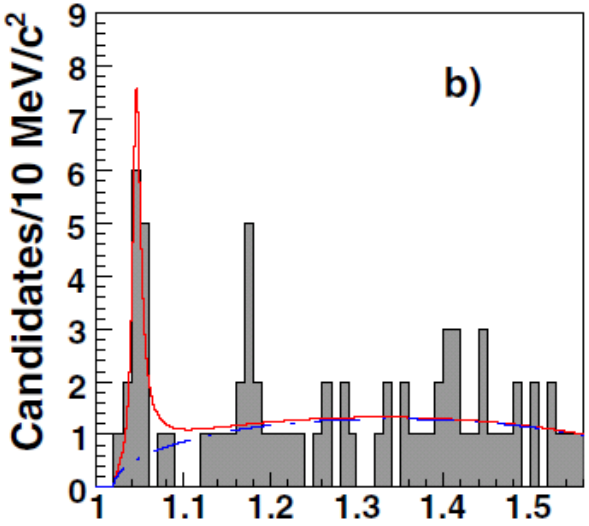
BR(B→X(3872)($D^{*0}D^0$)K) = $(0.73\pm0.17\pm0.13)\times10^{-4}$
BR(B→Y(3940)($D^{*0}D^0$)K) < 0.67×10^{-4} @ 90% C.L.

Y(4140)→J/ψ φ

CDF, PRL 102, 242002 (2009)

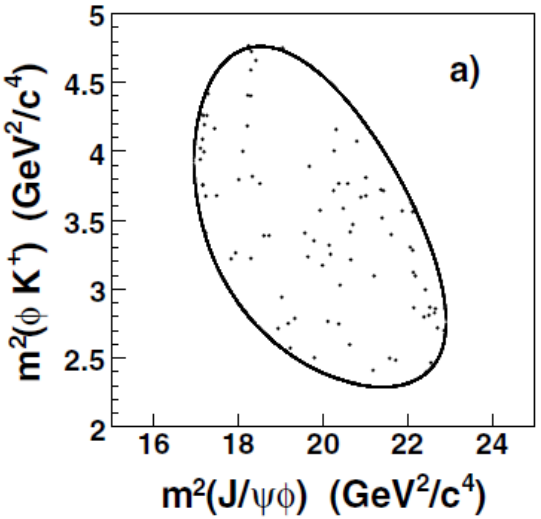
CDF observed new charmonium-like particle





$B^+ \rightarrow J/\psi\ \phi\ K^+$

14 ± 5 events (3.8σ)
from 2.7 fb^{-1}



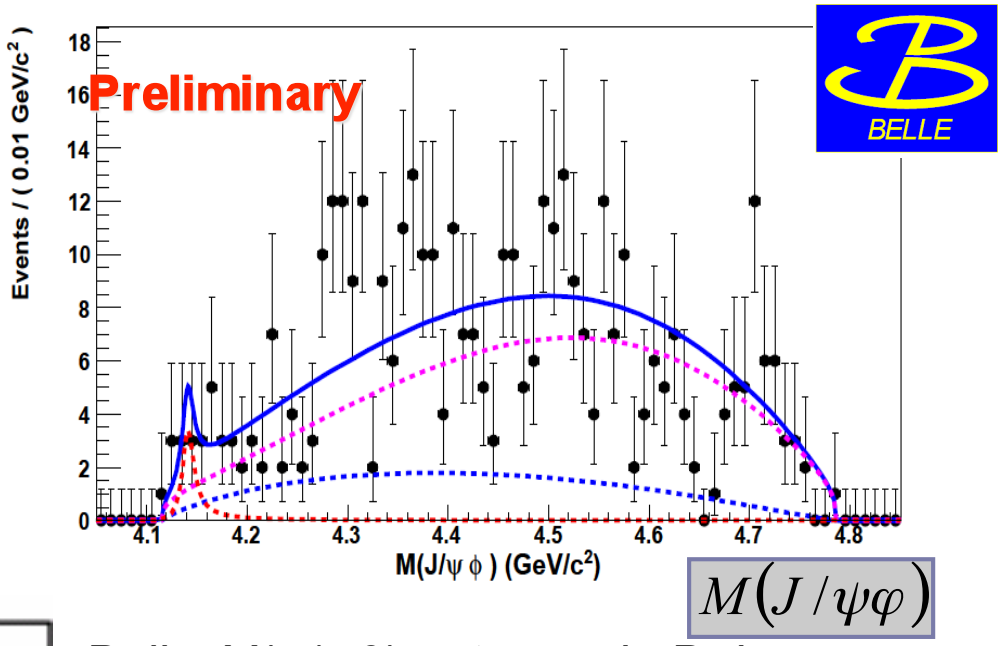
M = 4143.0 ±2.9 ±1.2 MeV/c^2

$\Gamma = 11.7\ ^{+\ 8.3}_{-5.0} \pm 3.7$ MeV

Ds* $\overline{\text{Ds*}}$ molecule or tetraquark ?

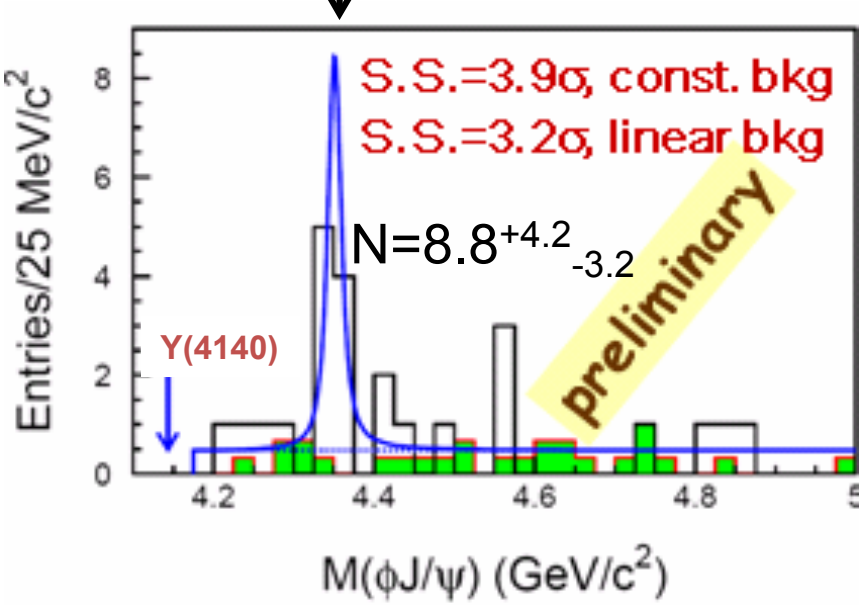
Searches at Belle

$B^+ \to J/\psi\, \phi\, K^+$



$BF(B \to YK)BF(Y \to J/\psi\phi) < 6 \times 10^{-6}$ (@90%CL)

$\gamma\gamma \to J/\psi\, \phi$



Belle: Y(4140) not seen in B decays or in two-photon

Instead, a new peak is seen at around 4.35 GeV in $\gamma\gamma \to J/\psi\phi$

$M = 4350.6\ ^{+4.6}_{-5.1} \pm 0.7$ MeV/c²

$\Gamma = 13.3\ ^{+17.9}_{-9.1} \pm 4.1$ MeV

XYZ Summary

- More and more new states since 2003 observed by Belle, BaBar, CDF, …

- **Recent updates** on XYZ resonances
  - X(3872) : Mass splitting is not found in decays from B mesons
  - Updated analysis for X(3872)→$D^{*0}D^{0}$ has been submitted to PRD

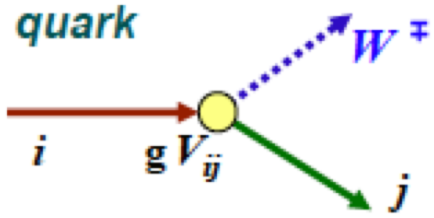
- **Very New Topics**:
  - CDF's found new particle Y(4140) → $J/\psi\phi$
  - It is not seen by Belle
  - Instead new structure seen by Belle at a bit higher mass in $J/\psi\phi$

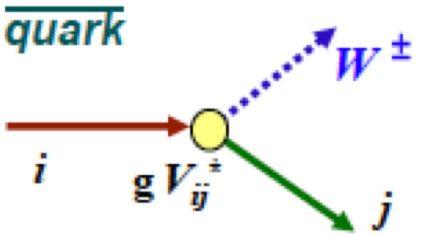
CKM matrix & ϕ_3/γ

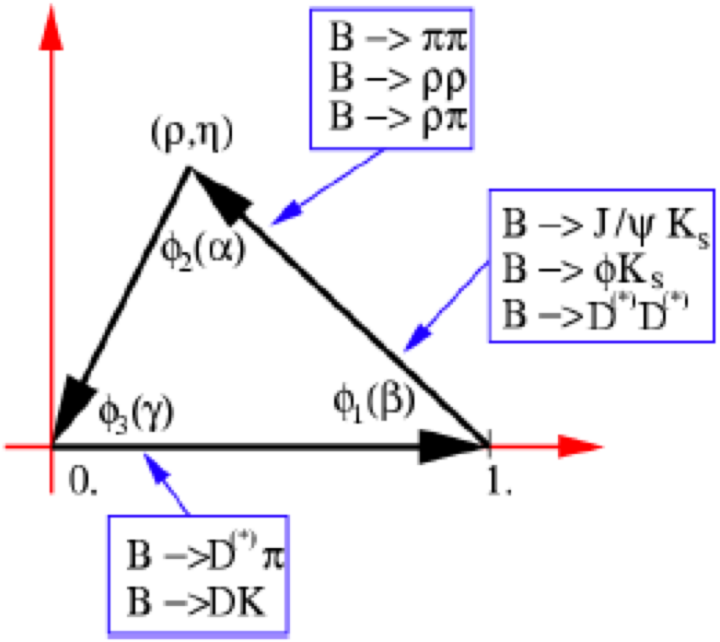
Cabibbo-Kobayashi-Maskawa quark mixing matrix (CKM):

$$V=\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$\sim e^{i\varphi_3}$







CKM unitarity leads to triangle in complex plane:

$$\{i=1, j=3\}: V_{ud}V_{ub}^{*}+V_{cd}V_{cb}^{*}+V_{td}V_{tb}^{*}=0$$

$$\Rightarrow \frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}+1+\frac{V_{td}V_{tb}^{*}}{V_{cd}V_{cb}^{*}}=0$$

Constraints on CKM parameters

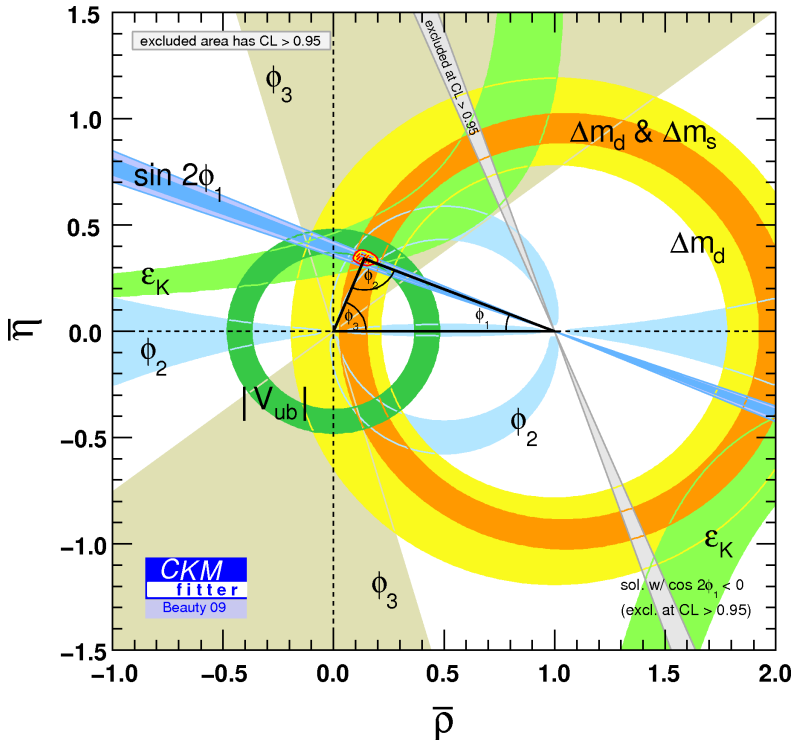
Direct angle measurements
[CKMfitter world average, 2009]:

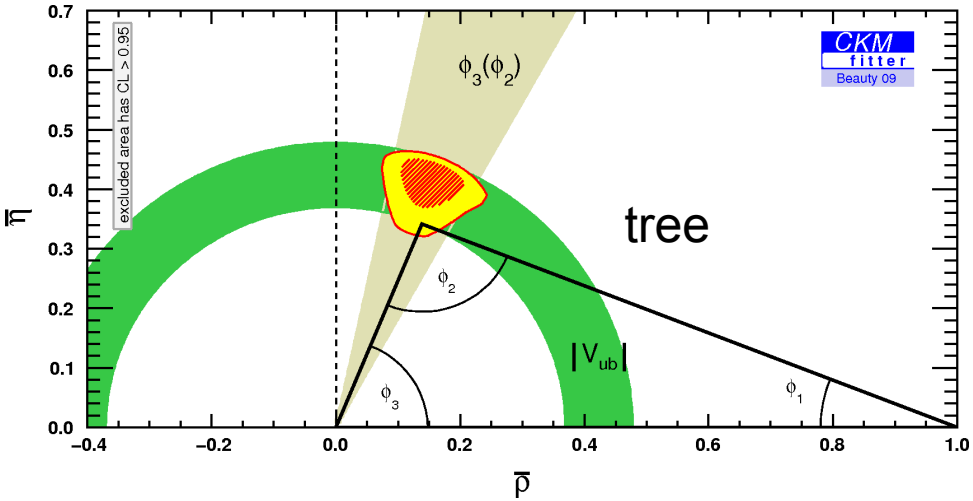
$\phi_1/\beta = 21.15\ ^{+0.90}_{-0.88}$

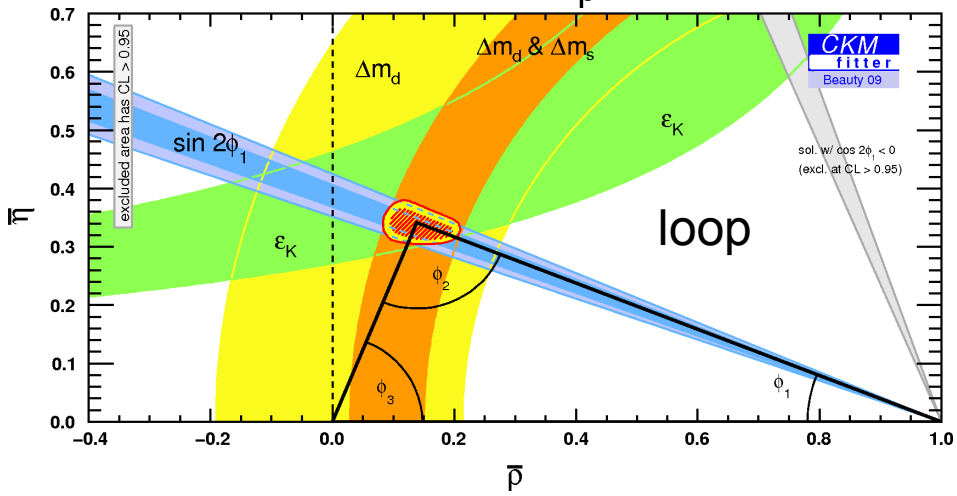
$\phi_2/\alpha = 89.0\ ^{+4.4}_{-4.2}$

$\phi_3/\gamma = 73\ ^{+22}_{-25}$

ϕ_3/γ is measured in tree decays. Together with $|V_{ub}|$ provides a SM reference for new physics searches.







Methods of ϕ_3/γ measurement

- Based on $B \rightarrow DK$ decay with D^0-$\overline{D^0}$ interference:
  - GLW (CP eigenstates: $D^0 \rightarrow \pi\pi$, KK, $K_S\phi$, $K_S\omega$)
  - ADS (CF and DCS states: $D^0 \rightarrow K\pi$, $K\pi\pi^0$)
  - Dalitz (multibody states: $D^0 \rightarrow K_S\pi\pi$, K_SKK, $\pi\pi\pi^0$)

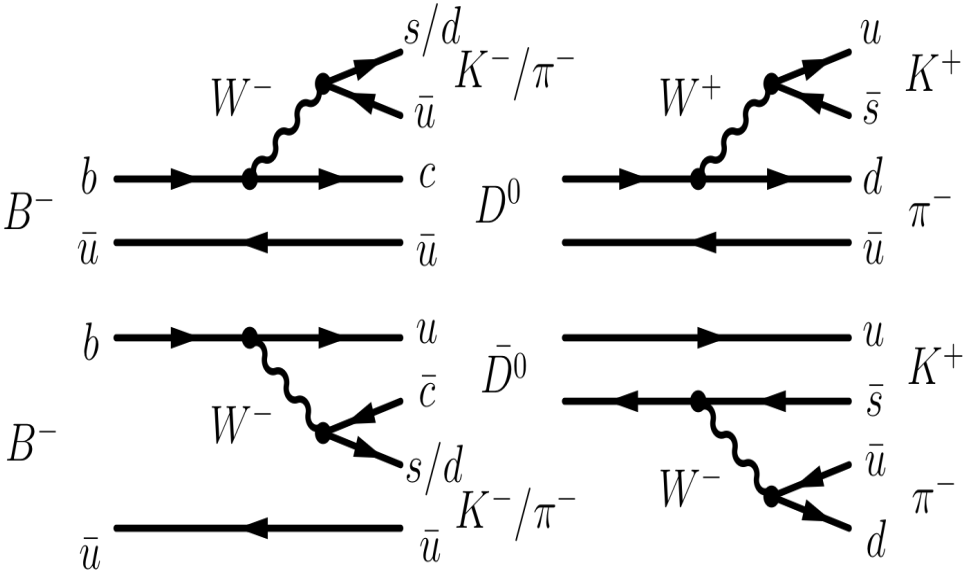
- Based on B^0 decays (measurement of $2\phi_1+\phi_3$)
  - $B^0 \rightarrow D^{(*)-}\pi^+$, $D\rho$ full rec.
  - $B^0 \rightarrow D^{*-}\pi^+$ partial rec.

- Results for the first item will be presented

ADS method: $B^- \to DK^-$ with $D \to K^+\pi^-$

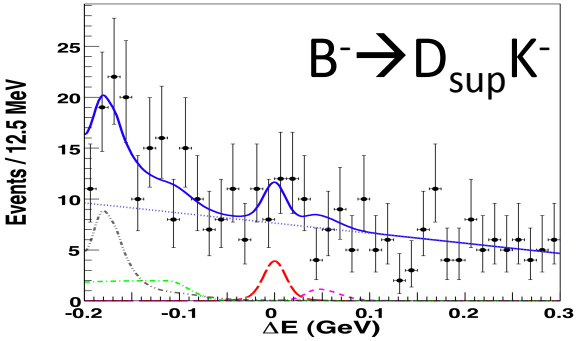
D. Atwood, I. Dunietz and A. Soni, PRL **78, 3357 (1997)**

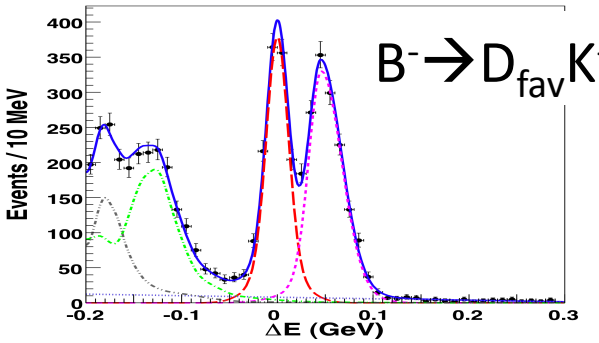
Enhance magnitude of CP violation by using Doubly Cabibbo-suppressed *D* decays



$$R_{ADS} = \frac{Br(B \to D_{\text{sup}}K)}{Br(B \to D_{fav}K)} = r_B^2 + r_D^2 + 2r_B r_D \cos\delta\cos\varphi_3$$

$$\delta = \delta_B + \delta_D, r_D = \left|\frac{A(D^0 \to K^-\pi^+)}{A(D^0 \to K^+\pi^-)}\right| = 0.0578 \pm 0.0008$$





657M BB

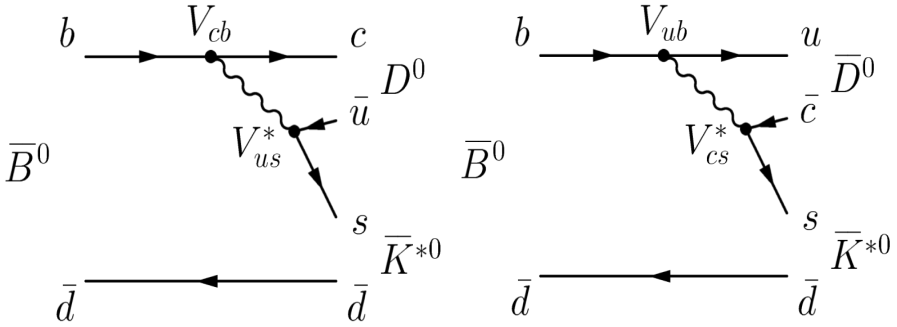
In the absence of the signal:

$R_{DK} < 1.8 \times 10^{-2}$ @ 90% C.L.

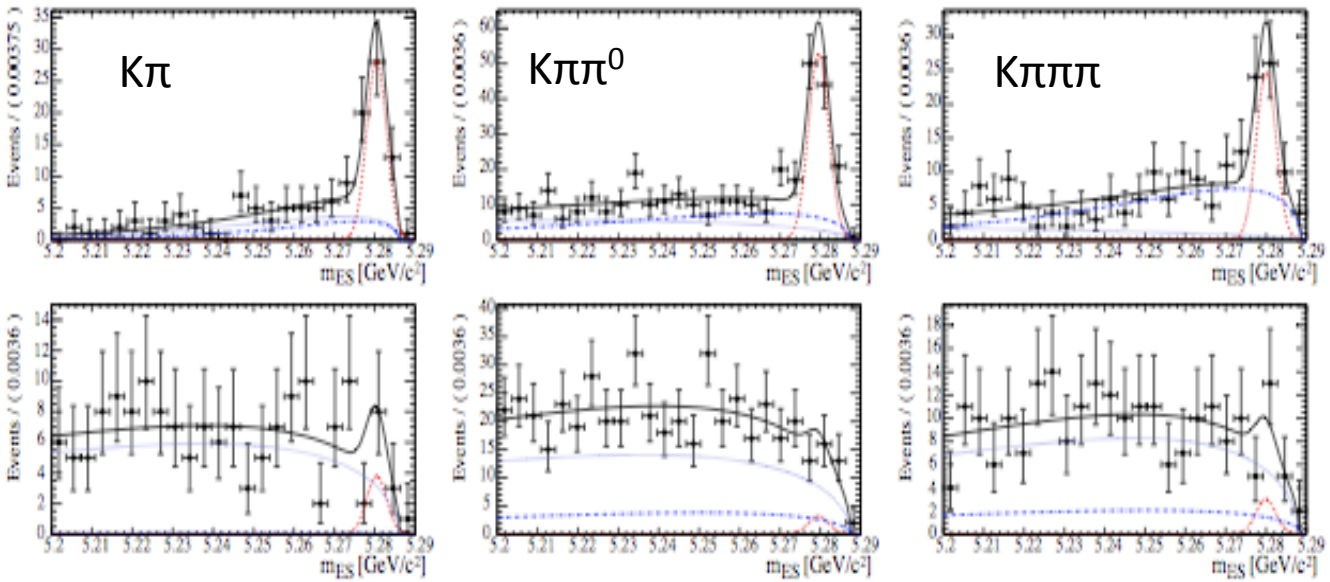
which corresponds to: $r_B < 0.19$

PRD 78, 071901 (2008)

ADS method: $B^0 \to D^0 K^{*0}$



$$R_{ADS} \equiv \frac{\Gamma(\bar{B}^0 \to [f]_D \bar{K}^{*0}) + \Gamma(B^0 \to [\bar{f}]_D K^{*0})}{\Gamma(\bar{B}^0 \to [\bar{f}]_D \bar{K}^{*0}) + \Gamma(B^0 \to [f]_D K^{*0})}$$

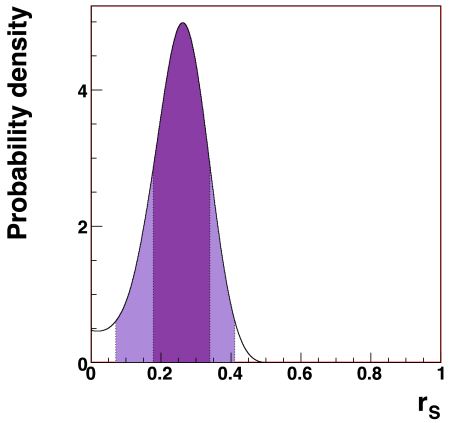


465M BB

arXiv: 0904.2112

Neglecting K^{*0} final states interference the combined result for three modes is:

$$R_{ADS} \sim r_S^2 = \frac{\Gamma(B^0 \to D^0 K^+ \pi^-)}{\Gamma(B^0 \to \bar{D}^0 K^+ \pi^-)} = 0.26$$



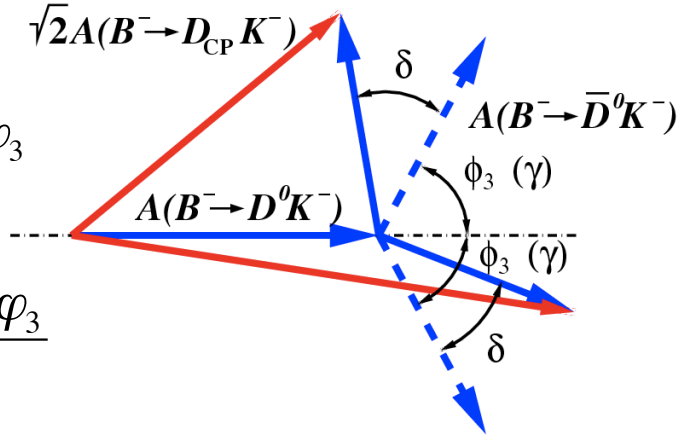
GLW method

M. Gronau, D. London, D. Wyler, **PLB 253, 483 (1991); PLB 265, 172 (1991)**

CP eigenstate of D-meson is used (D_{CP})
CP-even: $D_1 \rightarrow K^+K^-, \pi^+\pi^-$, CP-odd: $D_2 \rightarrow K_S\pi^0, K_S\omega, K_S\phi, K_S\eta, \ldots$

$$R_{1,2} = \frac{Br(B \rightarrow D_{1,2}K)/Br(B \rightarrow D_{1,2}\pi)}{Br(B \rightarrow D^0K)/Br(B \rightarrow D^0\pi)} = 1 + r_B^2 + 2r_B \cos\delta'\cos\varphi_3$$

$$A_{1,2} = \frac{Br(B^+ \rightarrow D_{1,2}K^+) - Br(B^- \rightarrow D_{1,2}K^-)}{Br(B^+ \rightarrow D_{1,2}K^+) + Br(B^- \rightarrow D_{1,2}K^-)} = \frac{2r_B \sin\delta'\sin\varphi_3}{R_{1,2}}$$



Sensitivity depends on hadronic parameters
$r_B = |A(b \rightarrow u)|/|A(b \rightarrow c)|$ and $\delta = \arg(A(b \rightarrow u)/A(b \rightarrow c))$

Alternative set of variables: $x_\pm = r_B \cos(\delta \pm \varphi_3) = \frac{R_1(1 \mp A_1) - R_2(1 \mp A_2)}{4}$ $\quad r_B^2 = \frac{R_1 + R_2 - 2}{2}$

Does not provide direct measurement of ϕ_3/γ, but helps in combination with other methods
Sensitivity depends on strong phase (δ=0 or 180 give no sensitivity)

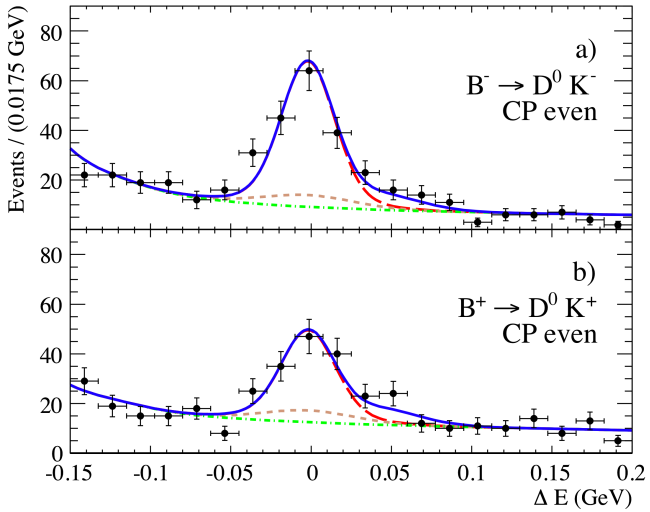
GLW: BaBar, Belle & CDF results

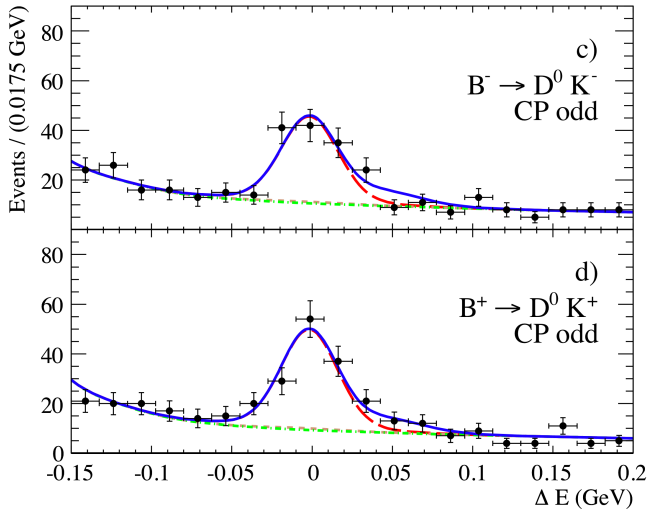
$B^- \to D_{CP} K^-$

BaBar: 382M BB pairs [PRD 77, 111102 (2008)]

$D^0 \to \pi^+\pi^-, K^+K^-$

$D^0 \to K_S\pi^0, K_S\omega$



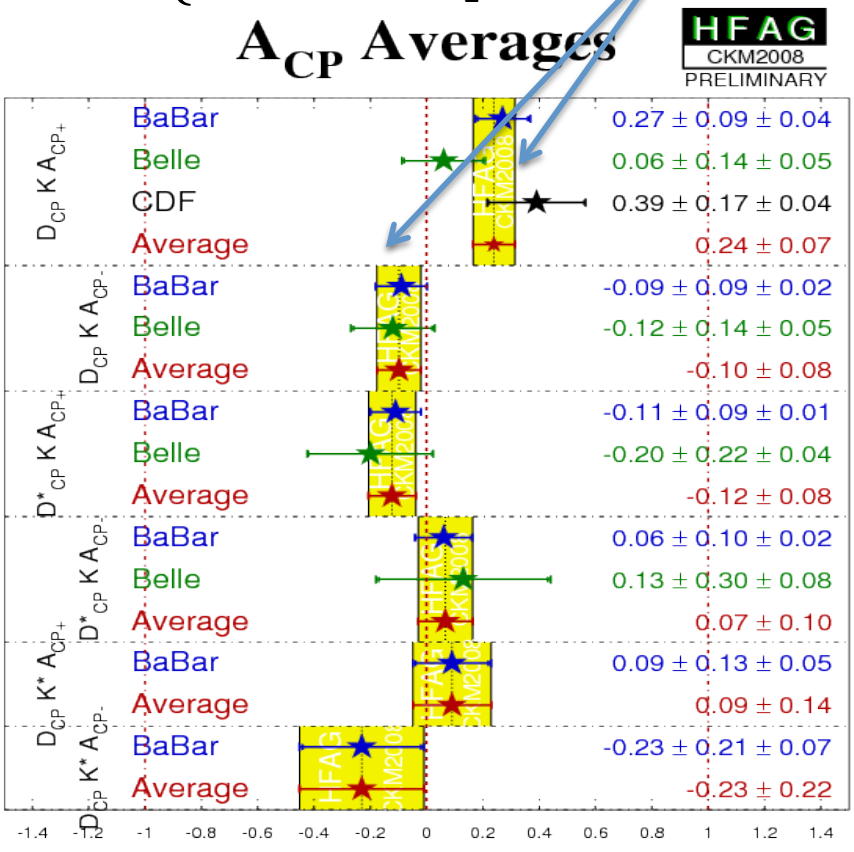


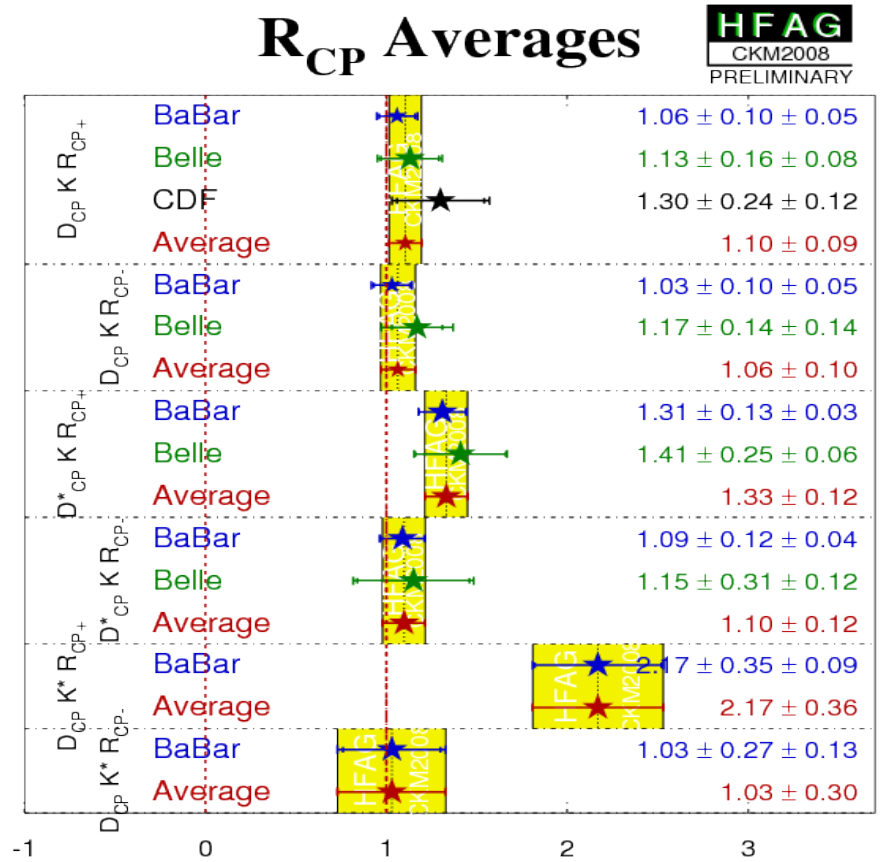
	R_{CP+}	A_{CP+}	R_{CP-}	A_{CP-}	x_+	x_-	r^2
BaBar	1.06±0.10±0.05	+0.27±0.09±0.04	1.03±0.10±0.05	-0.09±0.09±0.02	-0.09±0.05±0.02	+0.10±0.05±0.03	+0.05±0.07±0.03
Belle	1.13±0.16±0.05	+0.06±0.14±0.05	1.17±0.14±0.14	-0.12±0.14±0.05	-0.06±0.08±0.05	+0.04±0.08±0.04	+0.15±0.11±0.08
CDF	1.30±0.24±0.12	+0.39±0.17±0.04	-	-			

Belle: 275M BB pairs [PRD 73, 051106 (2006)]

GLW Summary

$$\delta' = \begin{cases} \delta & \text{for } D_1 \\ \delta + \pi & \text{for } D_2 \end{cases} \Rightarrow$$ $A_{1,2}$ have opposite signs





ϕ_3 can be extracted using input value of r_B from Dalitz analysis or using $B^+ \to D^{*0} K^+$ with both $D^{*0} \to D^0\pi^0$ and $D^0\gamma$

Dalitz analysis: three-body decays

A.Giri, Yu.Grossman, A.Soffer, J.Zupan, PRD 68, 054018 (2003)
A.Bondar, Proc. of Belle Dalitz analisis meeting, 24-26 Sep 2002

$\left|D^0\right\rangle + re^{i\theta}\left|\overline{D}^0\right\rangle$ Using 3-body final state, identical for D^0 and anti-D^0: $K_S\pi^+\pi^-$

Dalitz distribution density:

$$dp(m^2_{K_S\pi^+}, m^2_{K_S\pi^-}) \sim \left|f_D\right|^2 dm^2_{K_S\pi^+} dm^2_{K_S\pi^-}$$

$$\left|f_B(m^2_{K_S\pi^+}, m^2_{K_S\pi^-})\right|^2 =$$

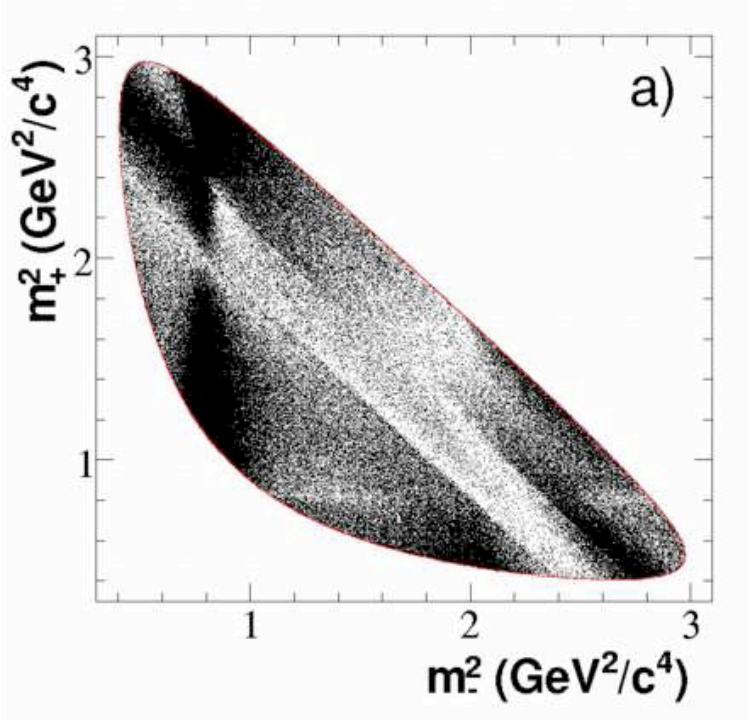
(Assuming CP-conservation in D^0 decays)

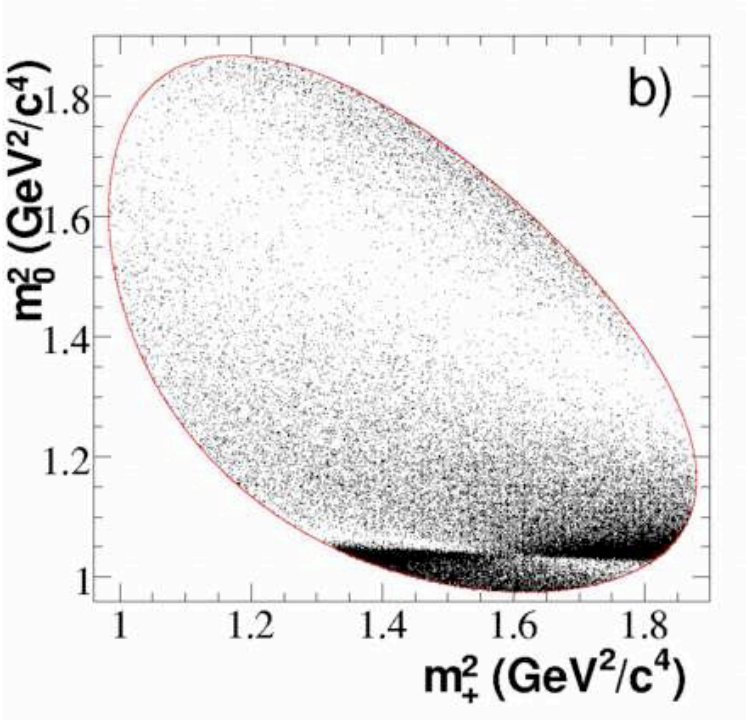
$$= \left| \quad + re^{i\delta \pm i\phi_3} \quad \right|^2$$

If $f_B(m^2_{K_S\pi^+}, m^2_{K_S\pi^-})$ is known, parameters ($\phi_3/\gamma, r_B, \delta$) are obtained from the fit to Dalitz distributions of $D \rightarrow K_S\pi^+\pi^-$ from $B^\pm \rightarrow DK^\pm$ decays.
Need to know a complex form of the D^0 decay amplitude, but only $|f_D|^2$ is obtained from $D^* \rightarrow D\pi$: Need to use model description, model uncertainty as a result.

$D^0 \to K_S\pi^+\pi^-$ and $K_SK^+K^-$ amplitudes

Amplitudes extracted from $D^* \to D^0\pi^+$ produced in continuum ($e^+e^- \to c\bar{c}$)





$K^*(892)^\pm$, $K_0^*(1430)^\pm$, $K_2^*(1430)^\pm$,
$K^*(1680)^\pm$, $\rho(770)$, $\omega(782)$, $f_2(1270)$,

$a_0(980)^0$, $\phi(1020)$, $f_0(1370)$, $f_2(1270)$,
$a_0(1450)^0$, $a_0(980)^\pm$, $a_0(1450)^\pm$

S-wave: K-matrix (BaBar) Scalar resonances σ,f_0, K^*_0 (Belle)
CLEO data can provide model independent Dalitz

Dalitz: results

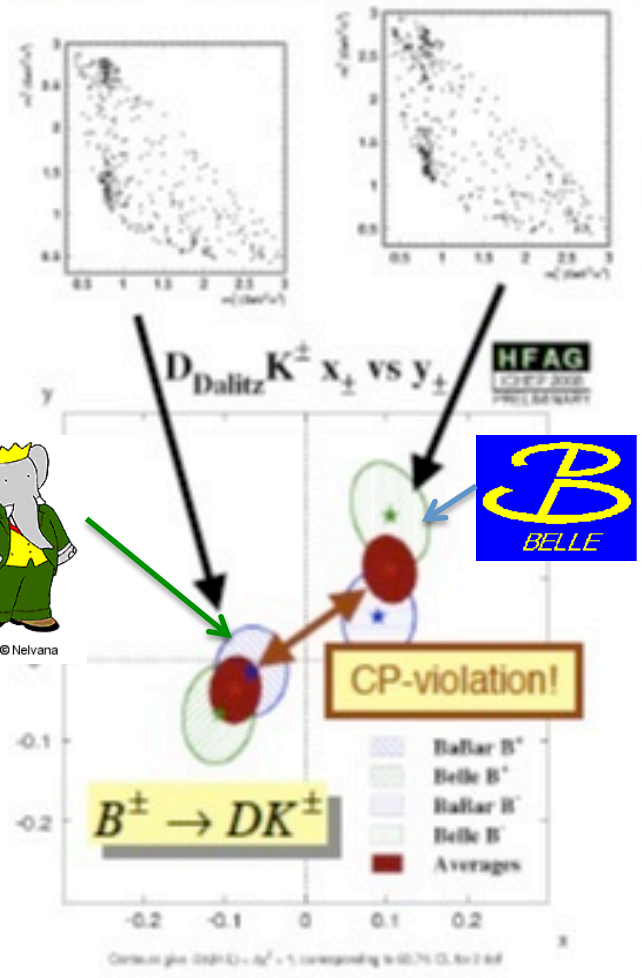
Fit results expressed in Cartesian coordinates $x_\pm = r_B \cos(\pm\gamma+\delta)$, $y_\pm = r_B \sin(\pm\gamma+\delta)$

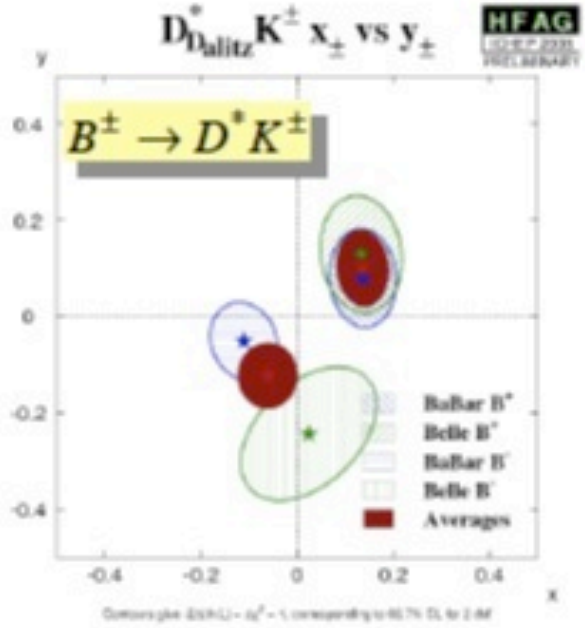
$$|\tilde{D}\rangle = |D^0\rangle + (x+iy)|\overline{D}^0\rangle$$

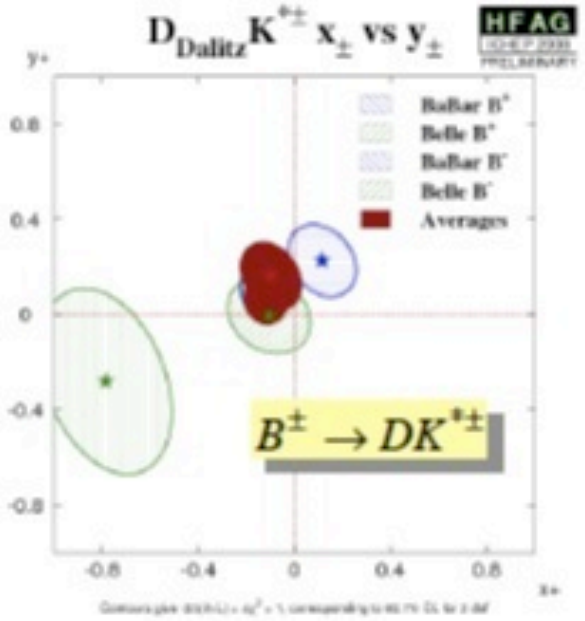
$x_\pm$ is the same as in GLW

Belle collaboration, 657M BB pairs [arXiv: 0803:3375]

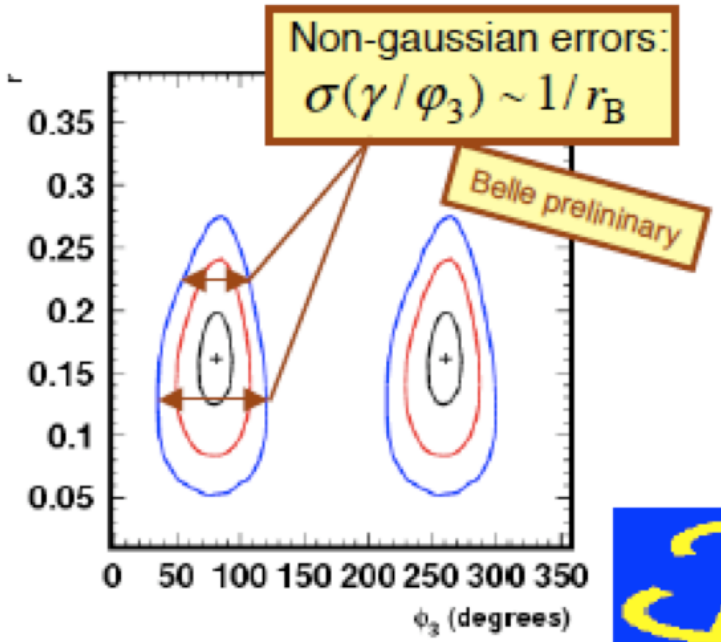
BaBar collaboration, 383M BB pairs **PRD 78, 034023 (2008)**

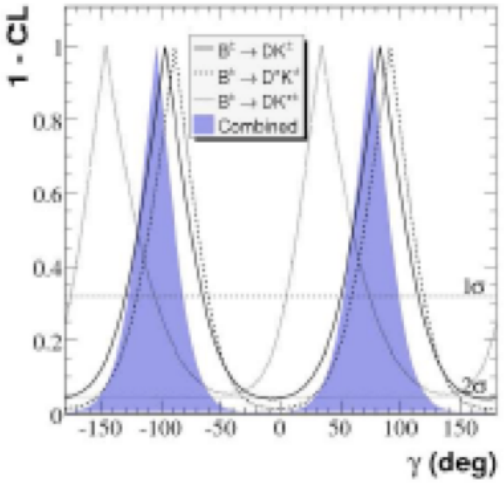


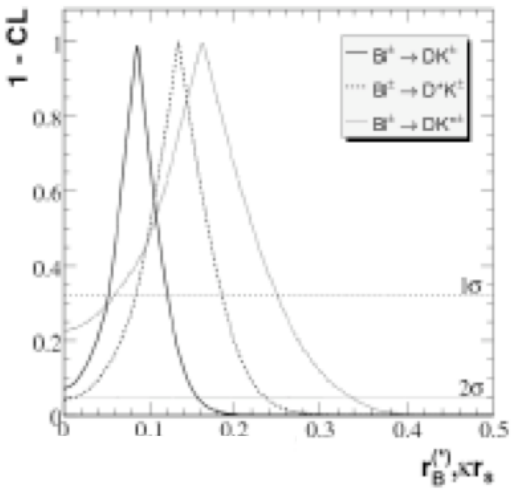




Dalitz: Summary







$\varphi_3 = 76^{+12}_{-13}{}^{\circ} \pm 4^{\circ}\,(\text{syst}) \pm 9^{\circ}\,(\text{model})$ 3.5σ CPV

$r_{DK} = 0.16 \pm 0.04 \pm 0.01(\text{syst}) \pm 0.05(\text{model})$

$r_{D^*K} = 0.21 \pm 0.08 \pm 0.01(\text{syst}) \pm 0.05(\text{model})$

$\gamma = 76^{+23}_{-24}{}^{\circ} \pm 5^{\circ} \pm 5^{\circ}$ 3.0σ CPV

$r_B = 0.086 \pm 0.035 \pm 0.010 \pm 0.011$

$r_B^* = 0.135 \pm 0.051 \pm 0.011 \pm 0.005$

$\kappa r_s = 0.163^{+0.088}_{-0.105} \pm 0.037 \pm 0.021$

Note $(\varphi_3,\delta) \rightarrow (\varphi_3+180^{\circ},\delta+180^{\circ})$ ambiguity. Solution consistent with SM is shown

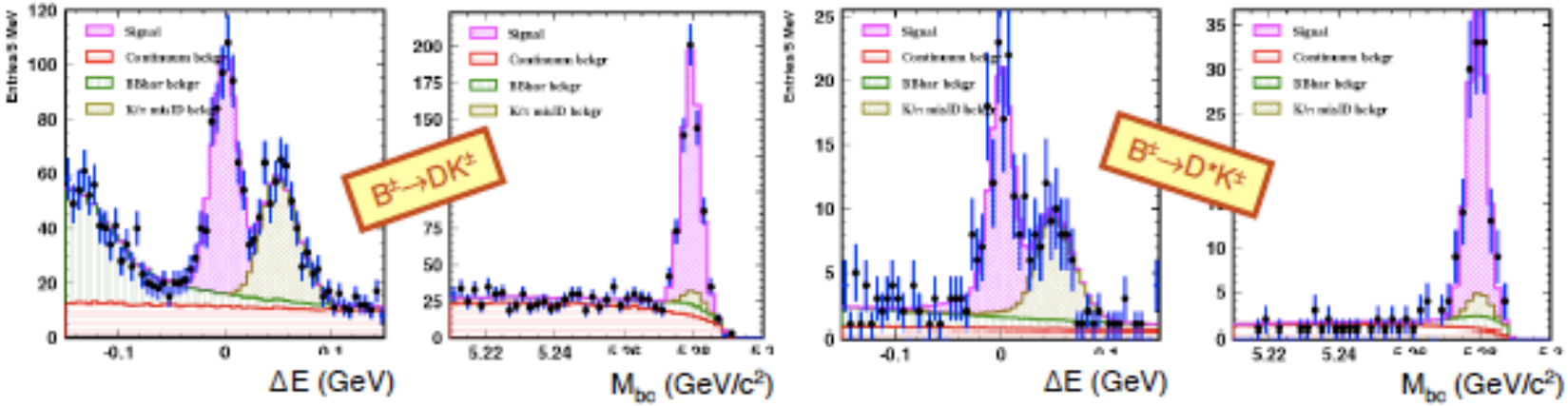
Summary

- Many results are provided by B-factories in last year:
  - BaBar GLW, Belle ADS
  - Belle Dalitz update with $D^0 \to K_S\pi^+\pi^-$
  - BaBar Dalitz update with $D^0 \to K_S\pi^+\pi^-$ and new $D^0 \to K_S K^+ K^-$
- Good agreement between different measurements, both in r_B and ϕ_3/γ:
  - **BaBar: $\gamma = (76 \pm 22 \pm 5 \pm 5)°$**
  - **Belle: $\phi_3 = (76\ ^{+12}_{-13} \pm 4 \pm 9)°$**
- Each method has his advantages/disadvantages
  - Combined result from all methods will give the best measurement

Backup

Dalitz: signal selection (Belle)

Belle collaboration, 657M BB pairs [arXiv: 0803:3375] [preliminary]



- $|\Delta E|<30$ MeV
- $M_{bc}>5.27$ GeV/c^2
- $|M_{K_S\pi\pi\pi}-M_D| < 11$ MeV/c^2
- $144.9 < \Delta M < 145.9$ MeV/c^2 ($B\to D^*K$ only)
- Continuum rejection variables: cuts to determine background composition.
  Whole range is used in Dalitz fit, included into likelihood.

756 events, 29% background ($B\to DK$).
149 events, 20% background ($B\to D^*K$, $D^*\to D\pi^0$).

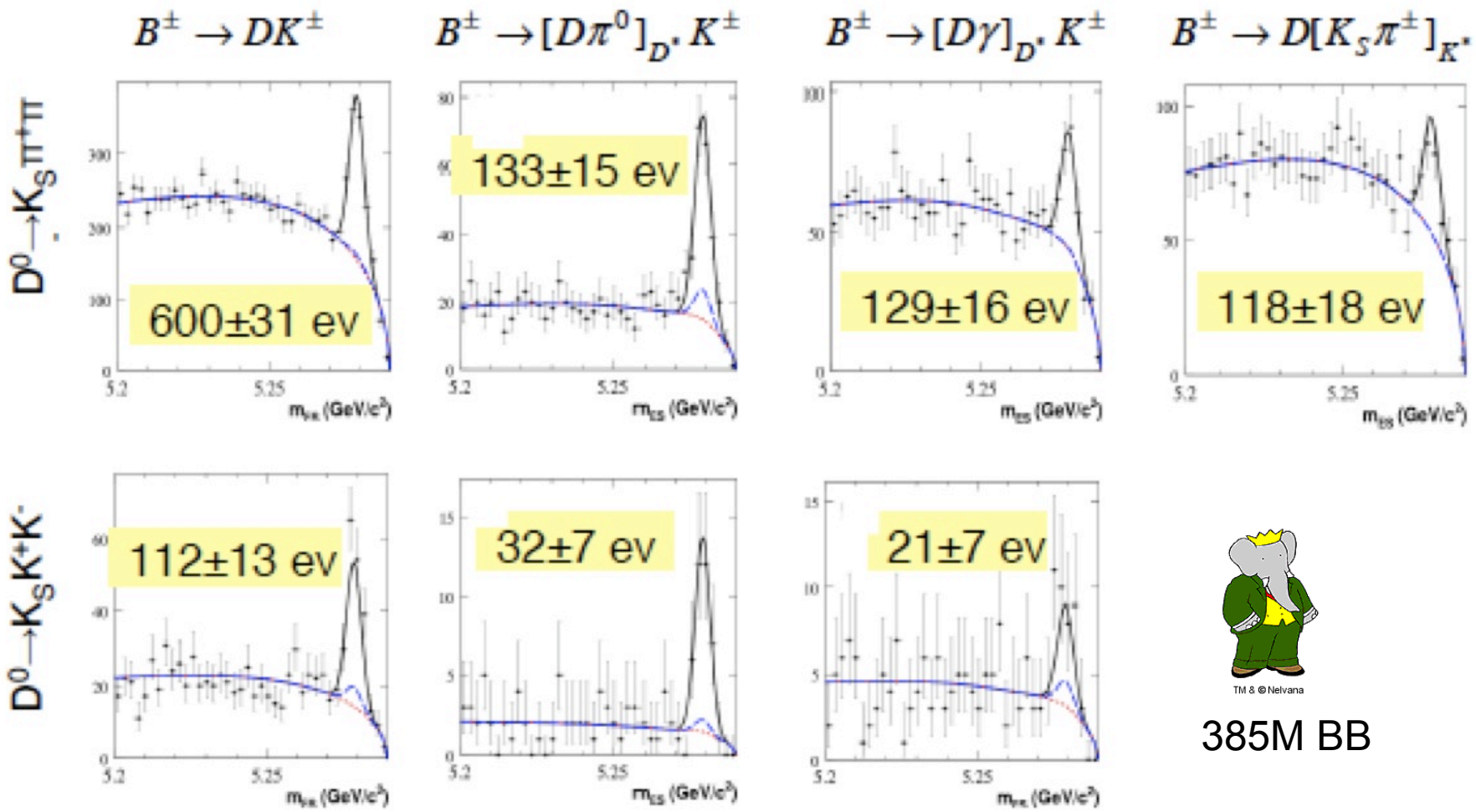
In "clean" signal region
($|\cos\theta_{thr}| < 0.8$, $\mathcal{F} > -0.7$)

Dalitz: signal selection (BaBar)

PRD 78, 034023 (2008)

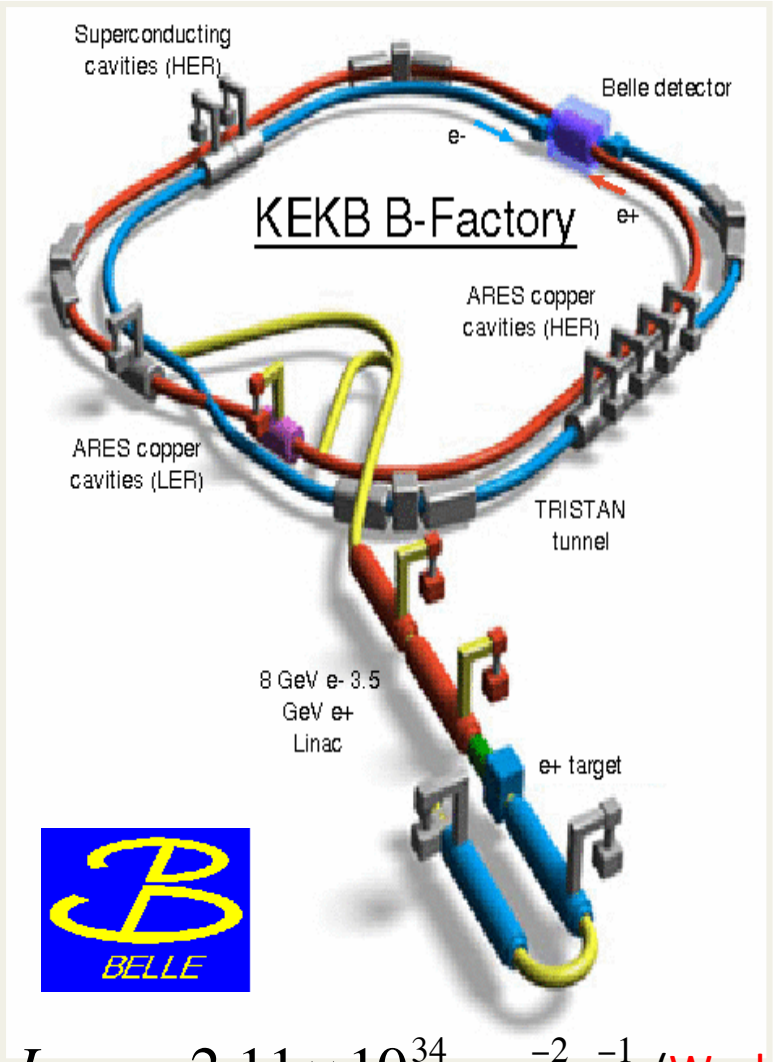
7 modes used: $B \to DK$, $B \to D^*K$ with $D^* \to D\pi^0$ and $D\gamma$, $B \to DK^*$

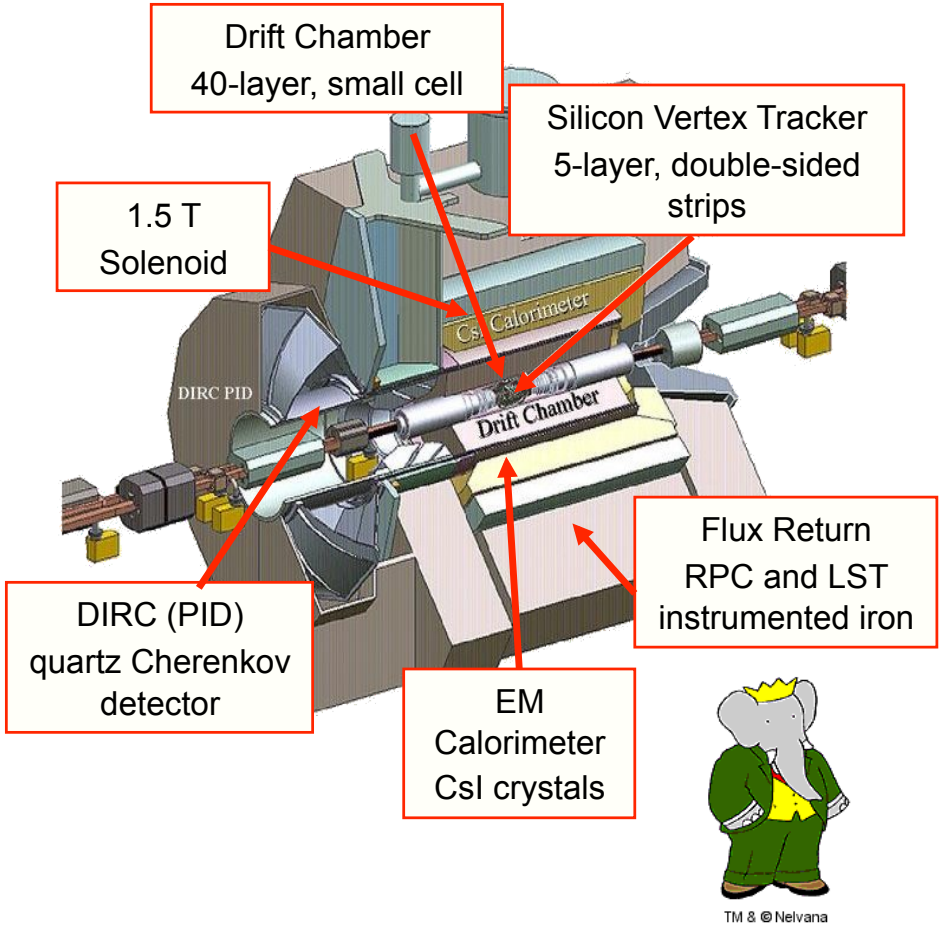
$D^0 \to K_S\pi^+\pi^-$ and $K_SK^+K^-$ (except for $B \to DK^*$)



385M BB

Belle & BaBar B-factories





$L_{peak} = 2.11 \times 10^{34} cm^{-2} s^{-1}$ (World record)

$\int Ldt = (710^{4S} + 300^{+}) fb^{-1}$

$L = 1.2 \times 10^{34} cm^{-2} s^{-1}$

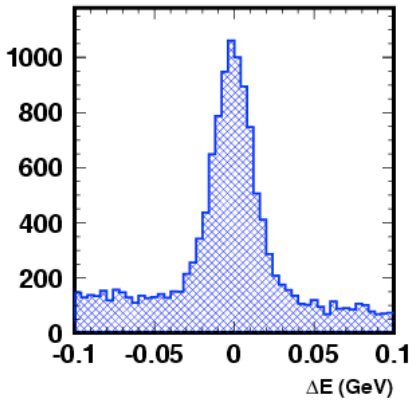
$\int Ldt \sim 433 fb^{-1} @ Y(4S)$

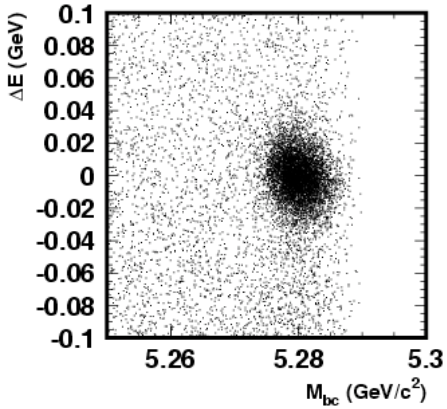
B meson reconstruction

Y(4S) decays to pair of B-mesons, so in CMS energy of B is known:

$$E_B = E_{CM}/2$$

It is used to select B candidates using variables:



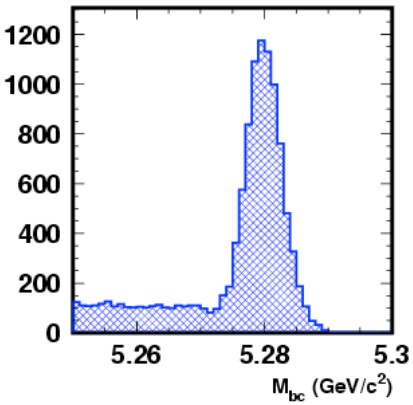


- CM energy difference:

$$\Delta E = \sum E_i - (E_{CM}/2)$$

- B-meson "beam-constrained mass" M_{bc} (Belle) or energy substituted mass" M_{ES} (BaBar):

$$M_{bc} = \sqrt{(E_{CM}/2)^2 - (\sum p_i)^2}$$



Methods of ϕ_3/γ measurement

- Based on $B \to DK$. Different D^0 modes can be used:
  - GLW (CP eigenstates: $D^0 \to \pi\pi$, KK, $K\varphi$, $K\omega$)
    Belle: 275M BB pairs ($B \to D_{CP}K$, $B \to D^*_{CP}K$: PRD 73 051106 (2006))
    BaBar: 382M BB pairs ($B \to D_{CP}K$: arXiv:0802.4052,
    $B \to D^*_{CP}K$: arXiv:0807.2408, $B \to D_{CP}K^*$: PRD 72 071103 (2005))
  - ADS (CF and DCS states: $D^0 \to K\pi$, $K\pi\pi$)
    Belle: 657M BB pairs ($B \to DK$: arXiv:0804:2063)
    BaBar: 232M BB pairs ($B \to DK$, $B \to D^*K$, $B \to DK^*$ with $D \to K\pi$: PRD 72 032004 (2005))
  - Dalitz (multibody states: $D^0 \to K\pi\pi$, KKK, $\pi\pi\pi$)
    Belle: 657M BB pairs ($B \to DK$, $B \to D^*K$ with $D^* \to D\pi^0$, $D^0 \to K_S\pi^+\pi^-$: arXiv:0803.3375)
    BaBar: 382M BB pairs ($B \to DK$, $B \to D^*K$ with $D^* \to D\pi^0, D\gamma$,
    $D^0 \to K_S\pi^+\pi^-, K_SK^+K^-$: arXiv:0804.2089)
    371M BB pairs ($B^0 \to D^0K^{*0}$: Moriond EW 2008)
- Based on B^0 decays (measurement of $2\varphi_1+\varphi_3$)

  Belle: 386M BB pairs ($B \to D^*\pi$ partial, $B \to D^{(*)}\pi$ full rec.: PRD 73 092003 (2006))
  BaBar: 232M BB pairs ($B \to D^*\pi$ partial: PRD 71 112003 (2005),
  $B \to D^{(*)}\pi$, $D\rho$ full rec.: PRD 73 111101 (2006))
  347M BB pairs ($B \to DK\pi$ time-dependent Dalitz: arXiv:0712.3469)