$\phi_3(\gamma)$ measurements

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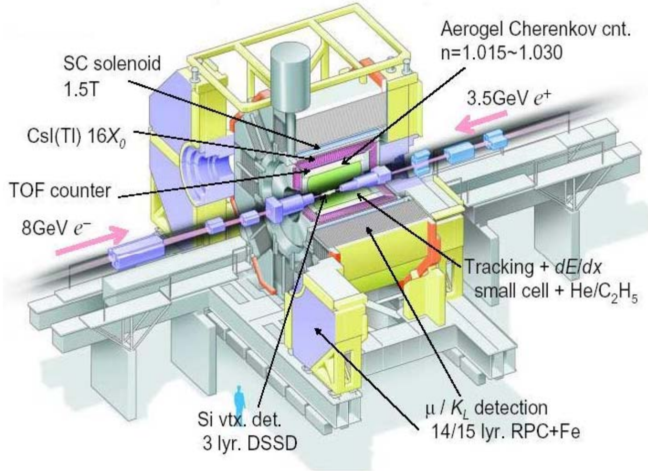
KEK



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- Methods
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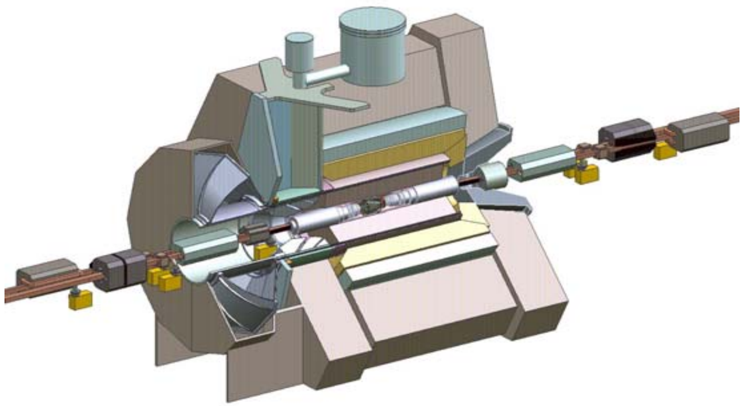
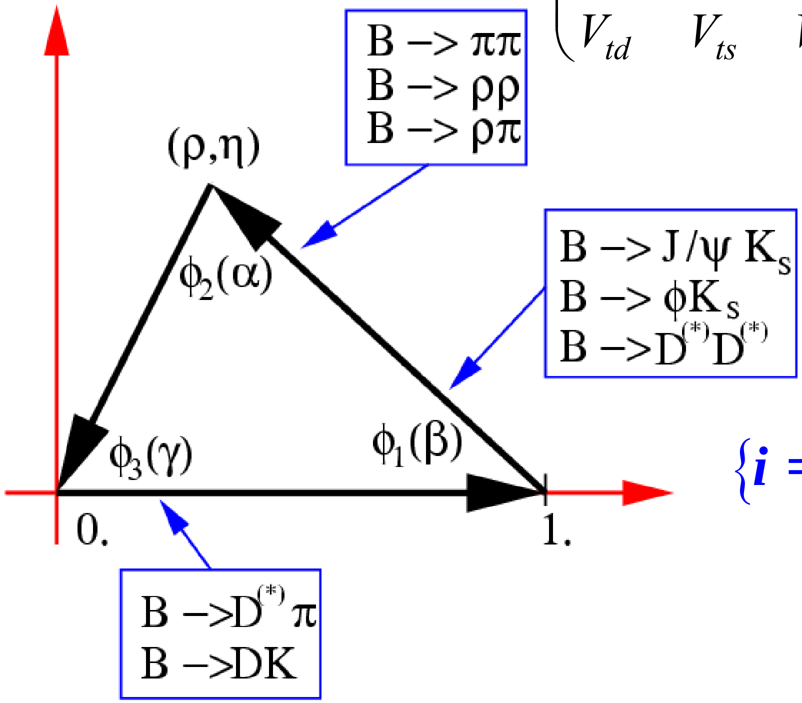
- Summary



Unitarity triangle

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



Using unitarity requirement:

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

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

$\sin 2\varphi_1(\beta)$ is measured with a good accuracy at B-factories.

Measurement of all the angles needed to test SM.

Constraints on CKM parameters

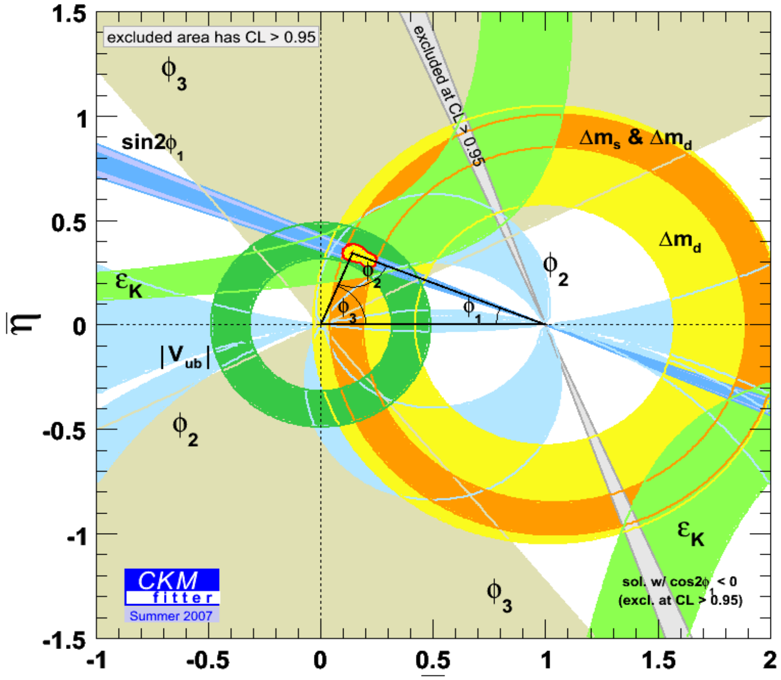
Direct angle measurements

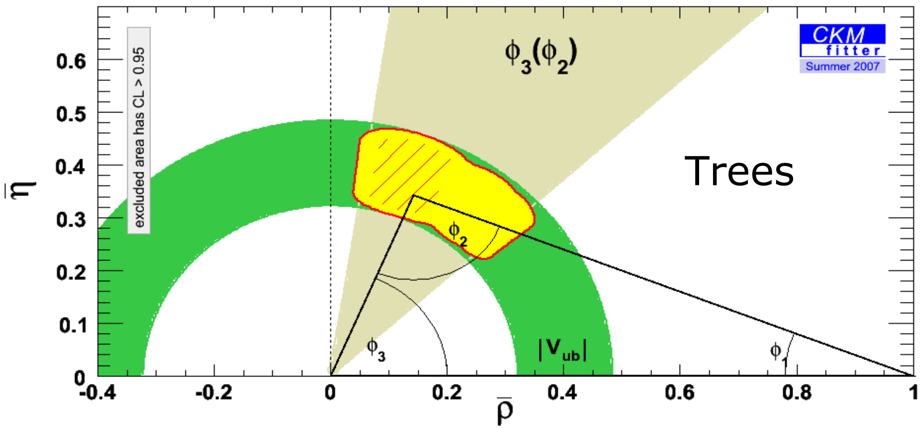
(CKMfitter world averages, 2007):

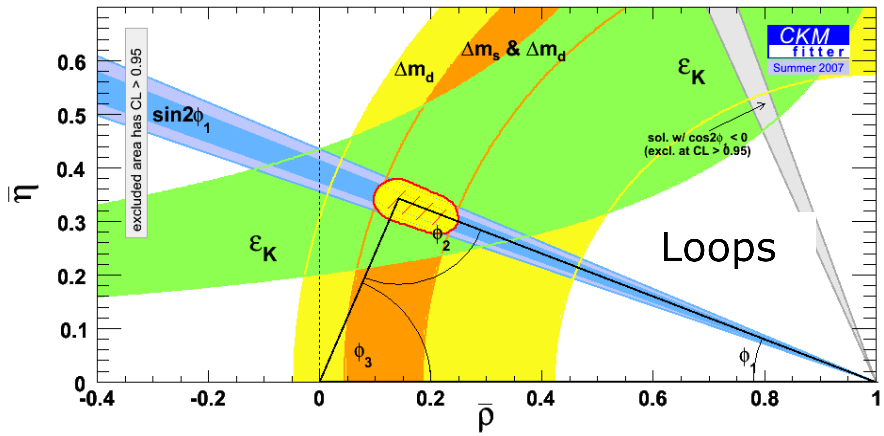
- $\varphi_1/\beta = 21.5 \pm 1.0^o$ ($B \to J/\psi K^0$)
- $\varphi_2/\alpha = 88 \pm 6^o$ ($B \to \rho\rho,\ \pi\pi$)
- $\varphi_3/\gamma = 77 \pm 30^o$ ($B \to DK$)

[BaBar (SLAC) , Belle (KEK)]

φ_3/γ remains the worst known element



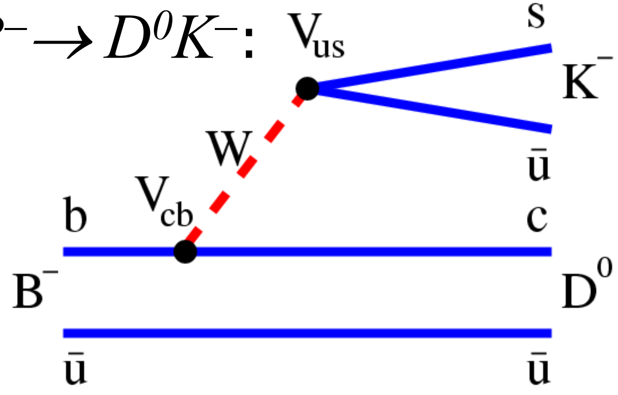




$B^+ \to D^0 K^+$ decay

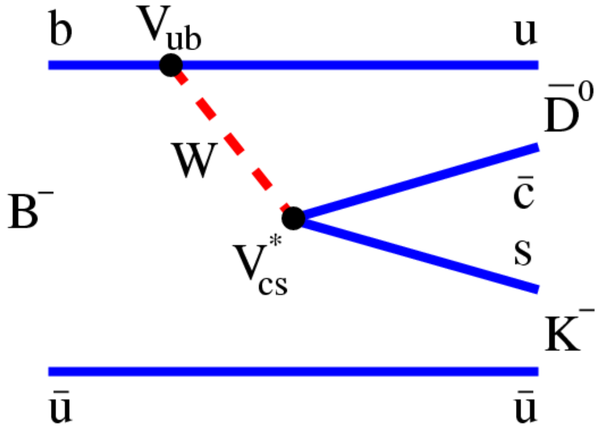
Need to use the decay where V_{ub} contribution interferes with another weak vertex.

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



$\mathbf{A}_1 \sim V_{cb} V_{us}^* \sim A\lambda^3$

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



$\mathbf{A}_2 \sim V_{ub} V_{cs}^* \sim A\lambda^3(\rho - i\eta) \sim e^{-i\gamma}$

If D^0 and $\bar{D}^0$ decay into the same final state, $\left|\tilde{D}^0\right\rangle = \left|D^0\right\rangle + re^{i\theta}\left|\bar{D}^0\right\rangle$

Relative phase: $\theta = -\gamma + \delta \;\; (B^- \to DK^-)$, $\theta = +\gamma + \delta \;\; (B^+ \to DK^+)$

includes weak (γ/φ_3) and strong (δ) phase.

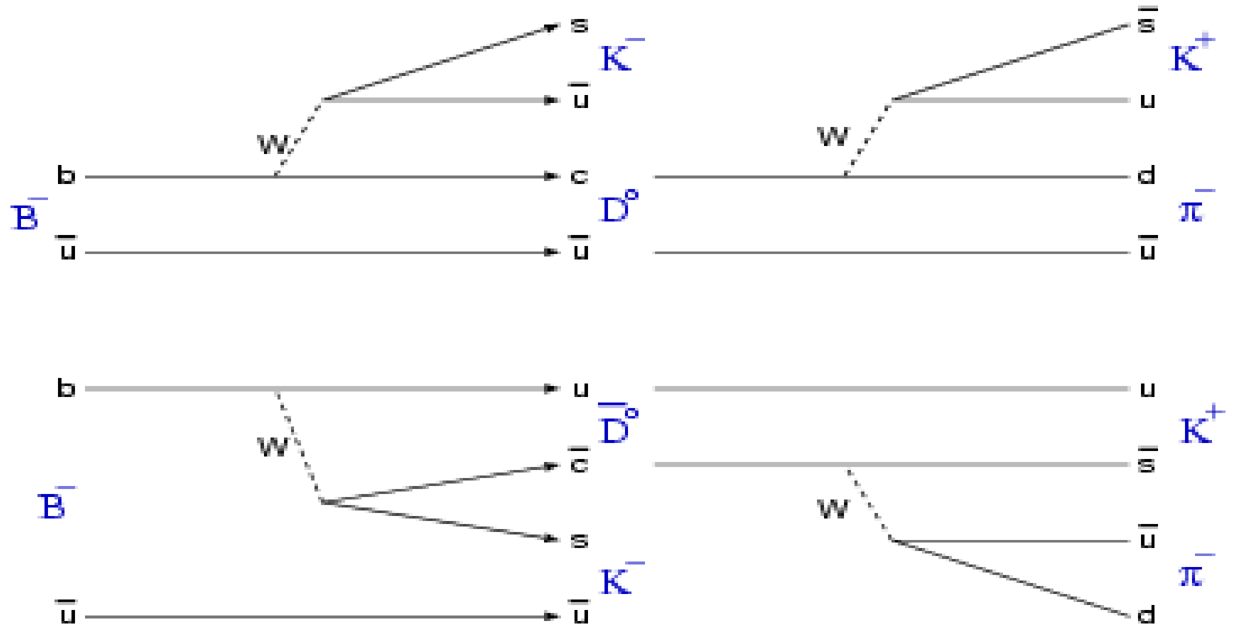
Amplitude ratio:

$$r_B = \left|\mathbf{A}(B^- \to \bar{D}^0 K^-) / \mathbf{A}(B^- \to D^0 K^-)\right| \approx \frac{\left|V_{ub}^* V_{cs}\right|}{\left|V_{cb}^* V_{us}\right|} \times [\text{color supp}] \approx 0.1$$

Atwood-Dunietz-Soni method

D. Atwood, I. Dunietz and A. Soni, PRL **78**, 3357 (1997);
PRD **63**, 036005 (2001)

Enhancement of CP-violation due to use of Cabibbo-suppressed D decays



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

$D^0 \to K^+ \pi^-$ - doubly Cabibbo-suppressed

$B^- \to \overline{D}^0 K^-$ - color suppressed

$\overline{D}^0 \to K^+ \pi^-$ - Cabibbo-allowed

$\Rightarrow$ Interfering amplitudes are comparable

ADS method (Belle)

Belle collaboration, 657M BB pairs [arXiv: 0804:2063, submitted to PRD(RC)]

$B^-\to[K^+\pi^-]_D K^-$ (suppressed) and $B^-\to[K^-\pi^+]_D K^-$ (favored) modes are selected.

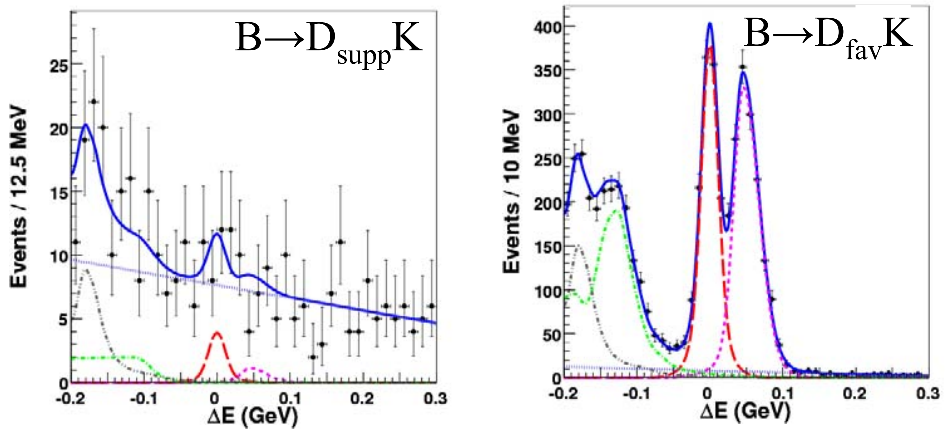
$$R_{ADS} = \left(8.0^{+6.3+2.0}_{-5.7-2.8}\right)\times 10^{-3}$$

CP asymmetry:

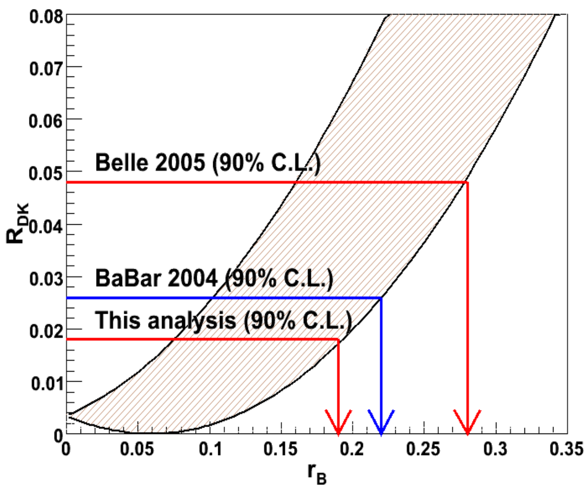
$$A_{ADS} = -0.13^{+0.98}_{-0.88} \pm 0.26$$

r_B<0.19 at 90% CL

(with the conservative assumption $\cos\varphi_3 \cos\delta = -1$)



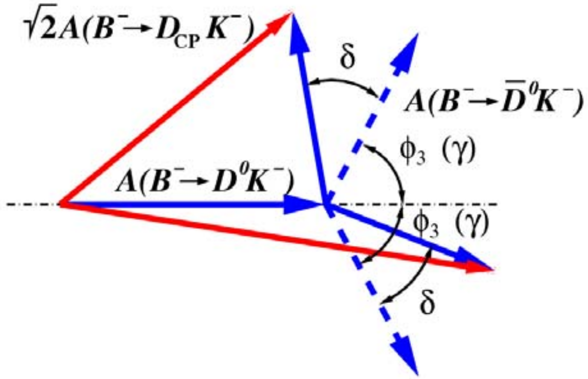
Using CLEO measurement $\delta = \left(22\,^{+11}_{-12}\,^{+9}_{-11}\right)^\circ$ [arXiv: 0802:2268] and φ_3,δ_B measurements from Dalitz analysis, tighter r_B constraint can be obtained.



Gronau-London-Wyler method

[Phys. Lett. B 253 (1991) 483]
[Phys. Lett. B 265 (1991) 172]

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



CP-asymmetry:

$$\mathcal{A}_{1,2} = \frac{Br(B^- \to D_{1,2}K^-) - Br(B^+ \to D_{1,2}K^+)}{Br(B^- \to D_{1,2}K^-) + Br(B^+ \to D_{1,2}K^+)} = \frac{2r_B \sin\delta' \sin\gamma}{1 + r_B^2 + 2r_B \cos\delta' \cos\gamma}$$

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

Additional constraint:

$$\mathcal{R}_{1,2} = \frac{Br(B \to D_{1,2}K)/Br(B \to D_{1,2}\pi)}{Br(B \to D^0K)/Br(B \to D^0\pi)} = 1 + r_B^2 + 2r_B \cos\delta' \cos\gamma$$

4 equations (3 independent: $\mathcal{A}_1\mathcal{R}_1 = -\mathcal{A}_2\mathcal{R}_2$), 3 unknowns (r_B, δ, γ)

GLW method (BaBar)

BaBar collaboration, 382M BB pairs [arXiv: 0802:4052]

CP-even modes: $D_{CP+} \to K^+K^-, \pi^+\pi^-$

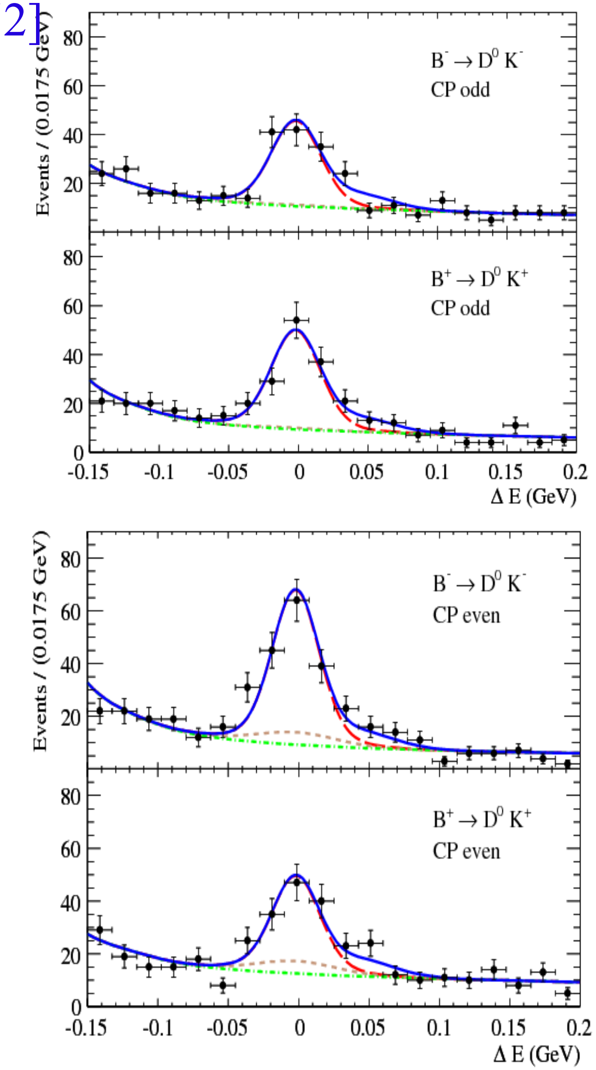
CP-odd modes : $D_{CP-} \to K_S\pi^0, K_S\omega$

A_{CP+}	$+0.27 \pm 0.09 \pm 0.04$
A_{CP-}	$-0.09 \pm 0.09 \pm 0.02$
R_{CP+}	$1.06 \pm 0.10 \pm 0.05$
R_{CP-}	$1.03 \pm 0.10 \pm 0.05$

The same result expressed in Cartesian variables:

x_+	$-0.09 \pm 0.05 \pm 0.02$
x_-	$+0.10 \pm 0.05 \pm 0.03$
r^2	$0.05 \pm 0.07 \pm 0.03$

$x_\pm$ precision comparable to Dalitz analysis



GLW method (BaBar)

BaBar collaboration, 382M BB pairs, $B\to D^*K$ with $D^*\to D\pi$ and $D^*\to D\gamma$

CP-even modes: $D_{CP+}\to K^+K^-, \pi^+\pi^-$

CP-odd modes : $D_{CP-}\to K_S\pi^0, K_S\omega, K_S\varphi$

- $D^*\to D\pi$ and $D^*\to D\gamma$ have strong phase difference exactly 180° ⇒ Can combine both

A_{CP+}	$-0.11 \pm 0.09 \pm 0.01$
A_{CP-}	$+0.06 \pm 0.10 \pm 0.02$
R_{CP+}	$1.31 \pm 0.13 \pm 0.03$
R_{CP-}	$1.10 \pm 0.12 \pm 0.04$

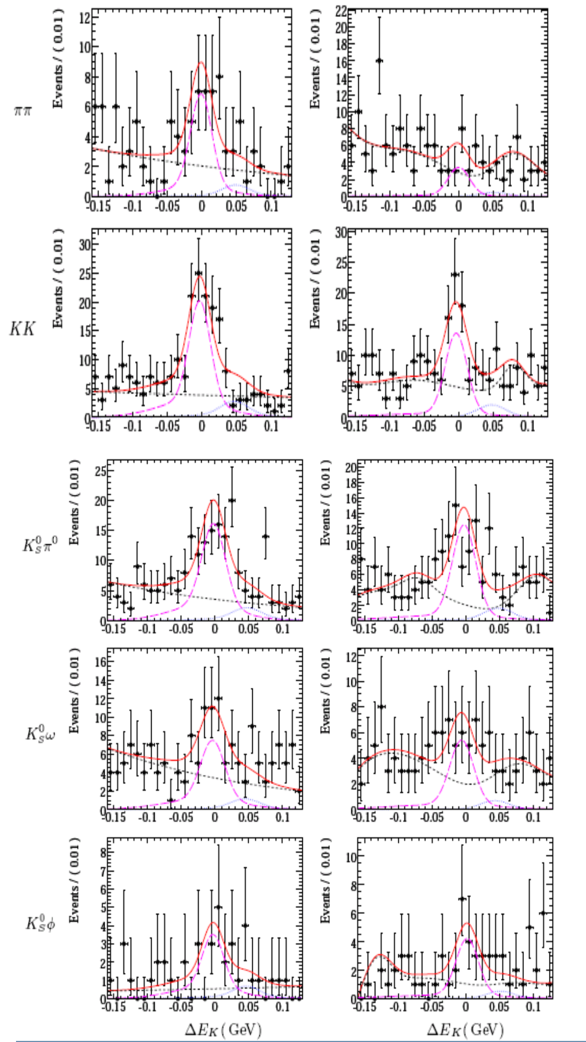
The same result expressed in Cartesian variables:

x_+^*	$+0.09 \pm 0.07 \pm 0.01$
x_-^*	$-0.02 \pm 0.06 \pm 0.01$
r^{*2}	$0.22 \pm 0.10 \pm 0.03$

($K_S\varphi$ excluded to allow comparison with Dalitz)

Preliminary

New!



Dalitz analysis method

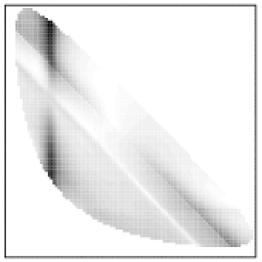
A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD **68**, 054018 (2003)
A. Bondar, Proc. of Belle Dalitz analysis meeting, 24-26 Sep 2002.

$$\left|\tilde{D}^0\right\rangle = \left|D^0\right\rangle + re^{i\theta}\left|\overline{D}^0\right\rangle$$

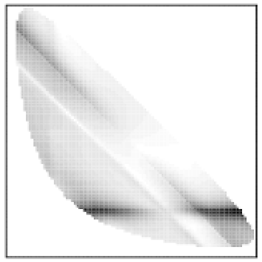
Using 3-body final state, identical for D^0 and $\bar{D}^0$: $K_s\pi^+\pi^-$.

Dalitz distribution density: $d\sigma(m^2_{K_s\pi^+}, m^2_{K_s\pi^-}) \propto |\mathbf{A}|^2\, dm^2_{K_s\pi^+} dm^2_{K_s\pi^-}$

$$|\mathbf{A}(m^2_{K_s\pi^+}, m^2_{K_s\pi^-})|^2 = \Bigg|$$



$$+\, re^{i\delta\pm i\phi_3}$$



$$\Bigg|^2$$

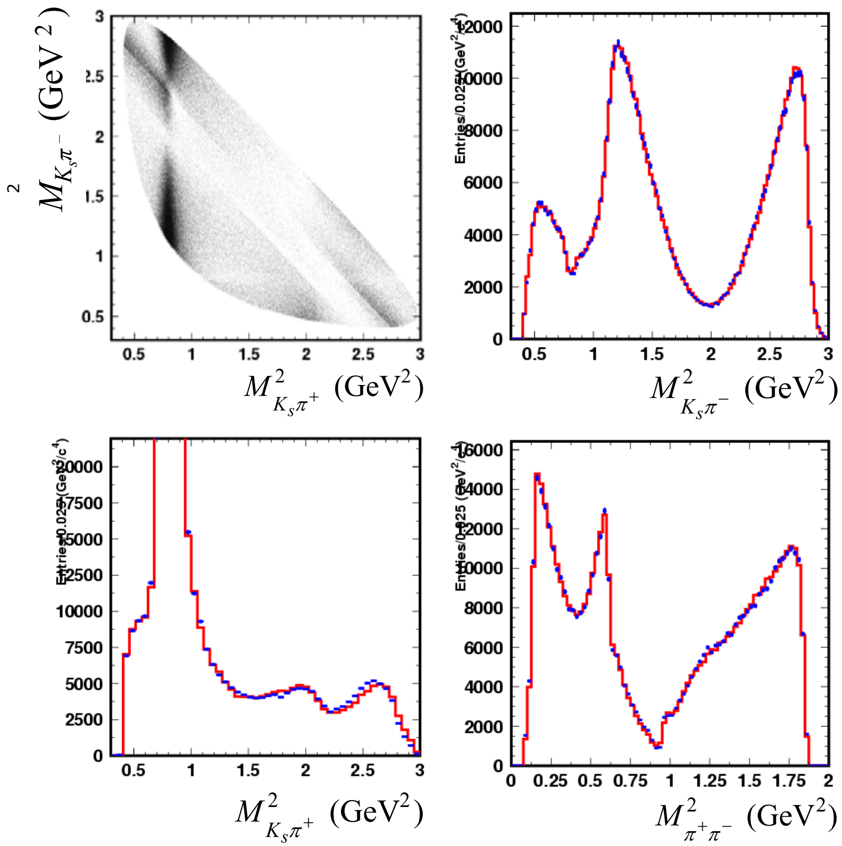
(assuming CP-conservation in D^0 decays)

If $f(m^2_{K_s\pi^+}, m^2_{K_s\pi^-})$ is known, parameters (r_B, δ, γ) are obtained from the fit to Dalitz distributions of $D\rightarrow K_s\pi^+\pi^-$ from $B^\pm\rightarrow DK^\pm$ decays

Belle Dalitz: $D^0 \to K_S\pi^+\pi^-$ amplitude

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

Isobar model is used as a baseline. *K*-matrix for systematics test.



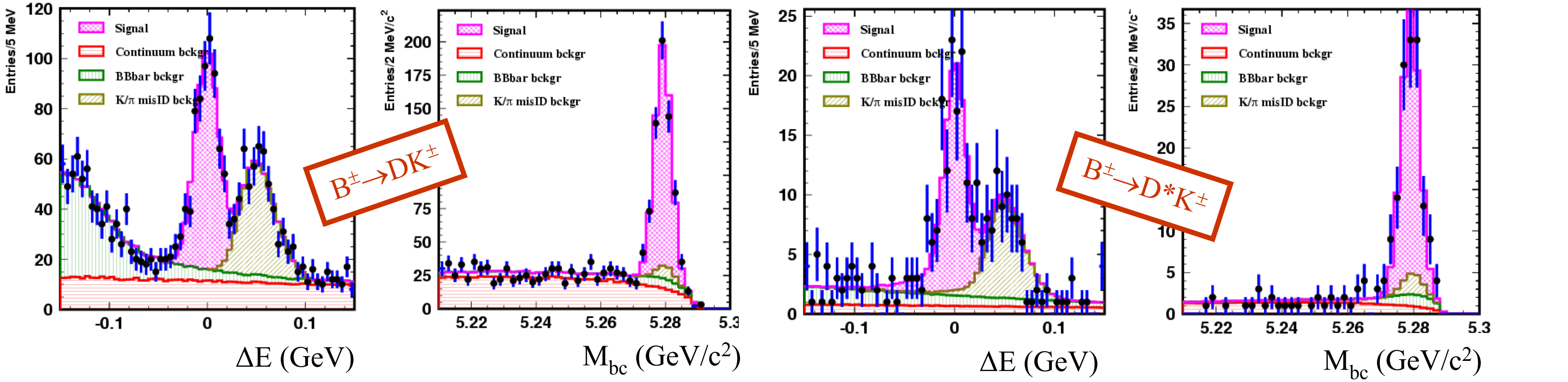
Intermediate state	Amplitude	Phase, °
$K_S\ \sigma_1$	1.56±0.06	214±3
$K_S\ \rho(770)$	1 (fixed)	0 (fixed)
$K_S\ \omega$	0.0343±0.0008	112.0±1.3
$K_S\ f_0(980)$	0.385±0.006	207.3±2.3
$K_S\ \sigma_2$	0.20±0.02	212±12
$K_S\ f_2(1270)$	1.44±0.04	342.9±1.7
$K_S\ f_0(1370)$	1.56±0.12	110±4
$K_S\ \rho(1450)$	0.49±0.08	64±11
$K^*(892)^+\pi^-$	1.638±0.010	133.2±0.4
$K^*(892)^-\pi^+$	0.149±0.004	325.4±1.3
$K^*(1410)^+\pi^-$	0.65±0.05	120±4
$K^*(1410)^-\pi^+$	0.42±0.04	253±5
$K^*_0(1430)^+\pi^-$	2.21±0.04	358.9±1.1
$K^*_0(1430)^-\pi^+$	0.36±0.03	87±4
$K^*_2(1430)^+\pi^-$	0.89±0.03	314.8±1.1
$K^*_2(1430)^-\pi^+$	0.23±0.02	275±6
$K^*(1680)^+\pi^-$	0.88±0.27	82±17
$K^*(1680)^-\pi^+$	2.1±0.2	130±6
Nonresonant	2.7±0.3	160±5

σ_1(M=522±6 MeV, Γ=453±10 MeV)

σ_2(M=1033±7 MeV, Γ=88±7 MeV)

Belle Dalitz: signal selection

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



- $|\Delta E|<30$ MeV
- $M_{bc}>5.27$ GeV/c²
- $|M_{ks\pi\pi}-M_D| < 11$ MeV/c²
- $144.9 < \Delta M < 145.9$ MeV/c² ($B\rightarrow D^*K$ only)
- Continuum rejection variables $\cos\theta_{thr}$, "virtual calorimeter" Fisher discriminant:

  $|\cos\theta_{thr}| < 0.8$, $F > -0.7$ in (M_{bc}, ΔE) fit to determine background composition.

  Whole range is used in Dalitz fit, included into likelihood.

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

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

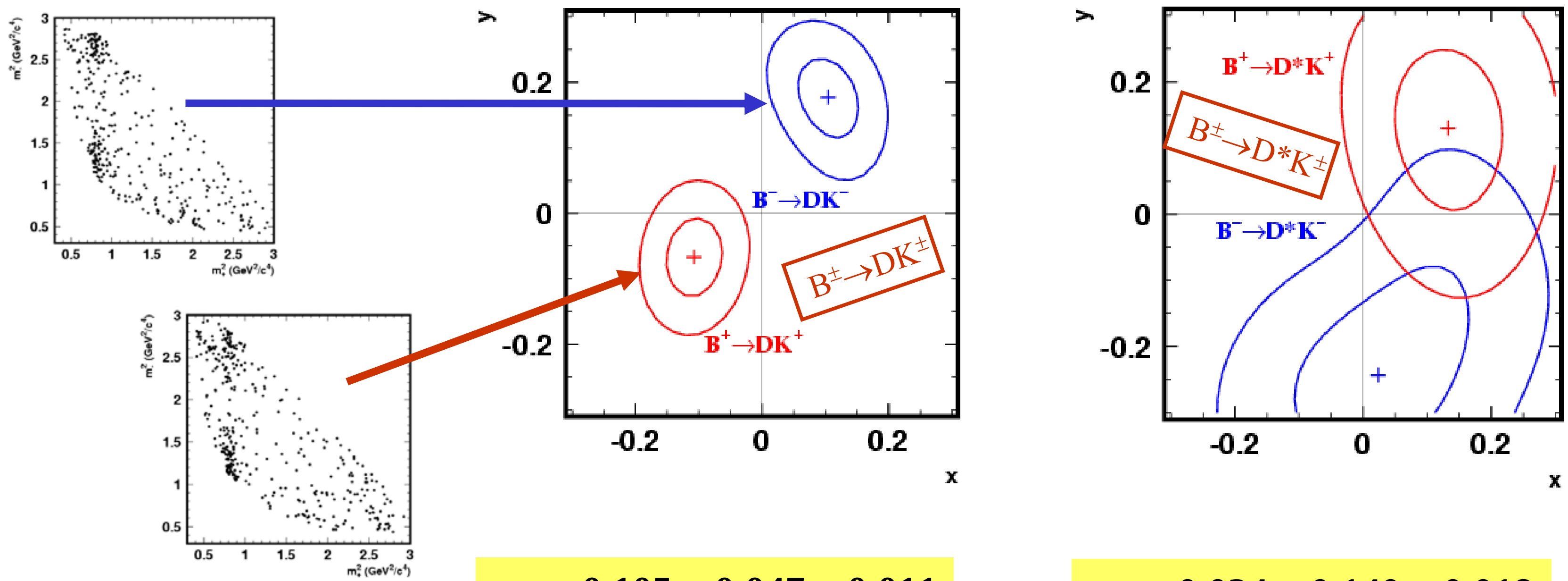
Belle Dalitz: fit results

[preliminary]

Fit parameters are $x_{\pm} = r_B \cos(\pm\varphi_3+\delta)$ and $y_{\pm} = r_B \sin(\pm\varphi_3+\delta)$

Unbinned maximum likelihood fit with event-by-event background treatment

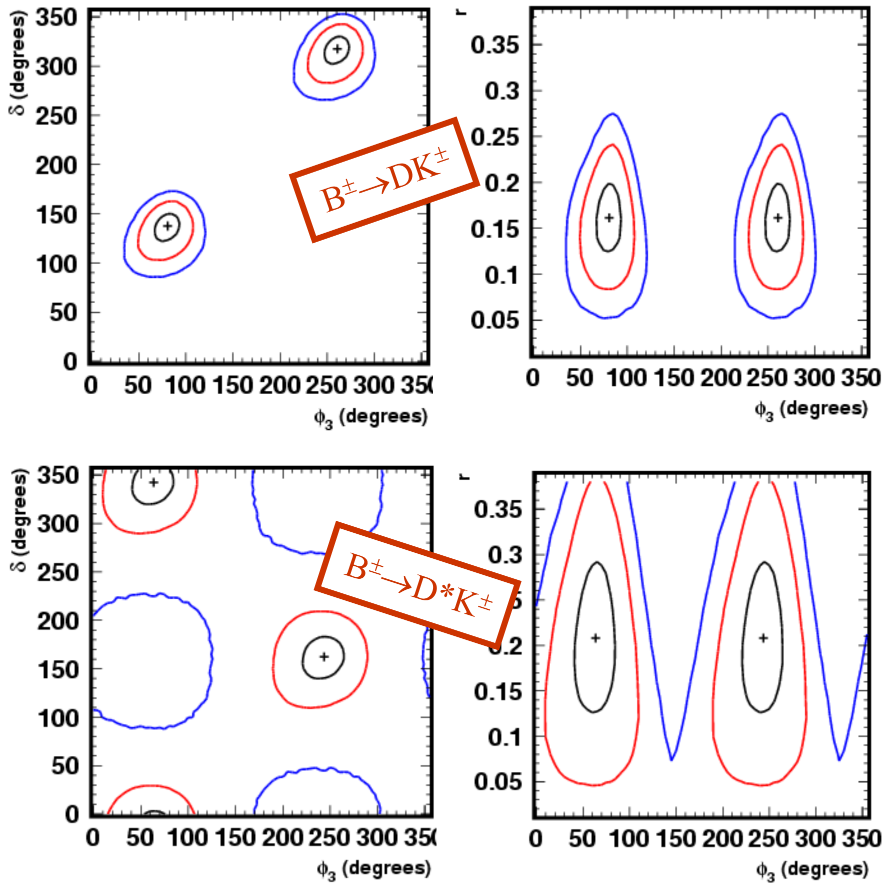
(ΔE, M_{bc}, $|\cos\theta_{thr}|$, F included into likelihood)



$B^{\pm} \to DK^{\pm}$	$B^{\pm} \to D^*K^{\pm}$
$x_- = +0.105 \pm 0.047 \pm 0.011$	$x_- = +0.024 \pm 0.140 \pm 0.018$
$y_- = +0.177 \pm 0.060 \pm 0.018$	$y_- = -0.243 \pm 0.137 \pm 0.022$
$x_+ = -0.107 \pm 0.043 \pm 0.011$	$x_+ = +0.133 \pm 0.083 \pm 0.018$
$y_+ = -0.067 \pm 0.059 \pm 0.018$	$y_+ = +0.130 \pm 0.120 \pm 0.022$

Errors are statistical and experimental systematic. Model error not included.

Belle Dalitz: fit results



[preliminary]

$B^{\pm}\to DK^{\pm}$ only:

$\varphi_3 = 81\,^{+13}_{-15}\,^{\circ} \pm 5^{\circ}(\text{syst}) \pm 9^{\circ}(\text{model})$

$B^{\pm}\to D^{*}K^{\pm}$ only:

$\varphi_3 = 64\,^{+21}_{-23}\,^{\circ} \pm 4^{\circ}(\text{syst}) \pm 9^{\circ}(\text{model})$

$B^{\pm}\to DK^{\pm}$, $B^{\pm}\to D^{*}K^{\pm}$ combined:

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

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

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

$\delta_{DK} = 136\,^{+14}_{-16}\,^{\circ} \pm 4^{\circ}(\text{syst}) \pm 23^{\circ}(\text{model})$

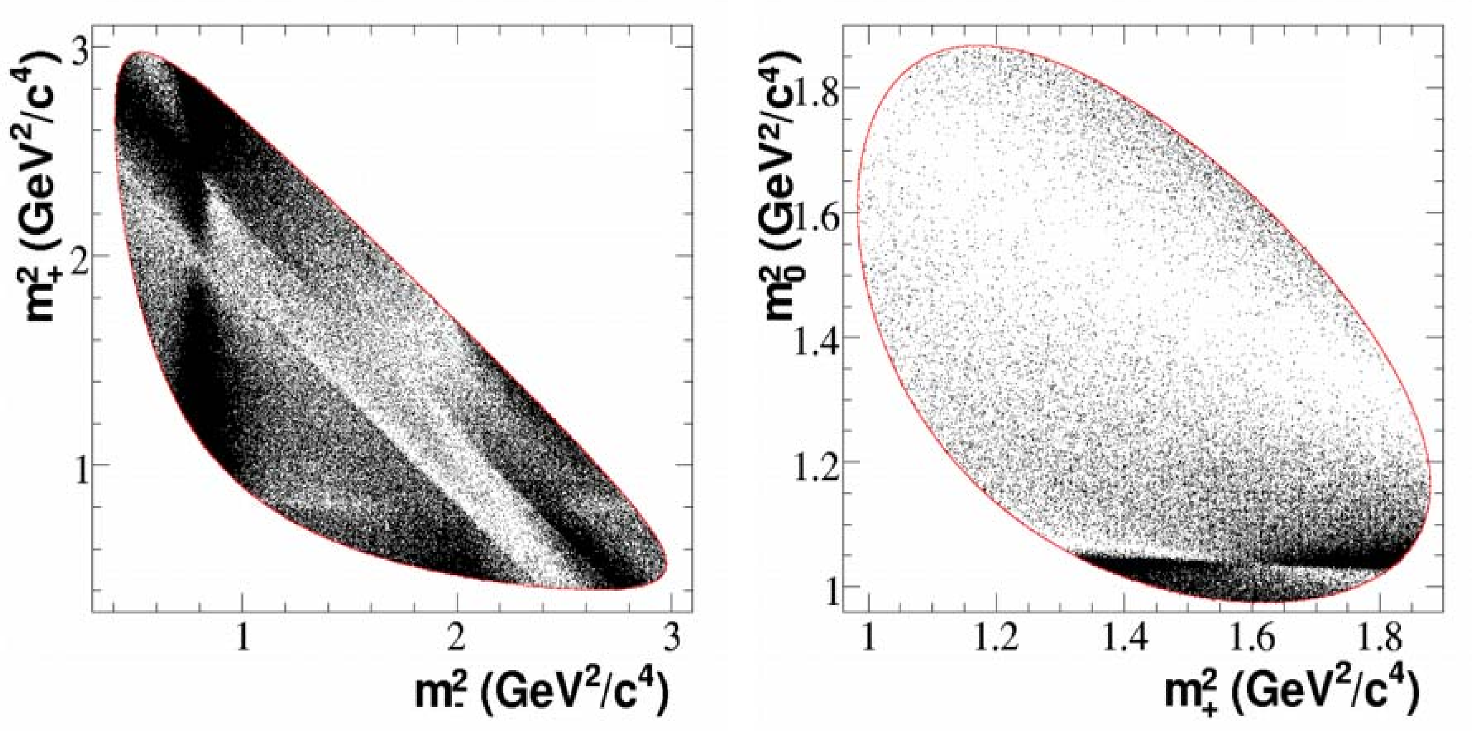
$\delta_{D^*K} = 343\,^{+20}_{-22}\,^{\circ} \pm 4^{\circ}(\text{syst}) \pm 23^{\circ}(\text{model})$

Model error estimate is the same as in previous analysis.

Stat. confidence level of CPV is $(1-5.5\cdot 10^{-4})$ or 3.5σ !

BaBar Dalitz: $D^0 \to K_S\pi^+\pi^-$ and $K_SK^+K^-$ modes

BaBar collaboration, 383M BB pairs [arXiv: 0804:2089]



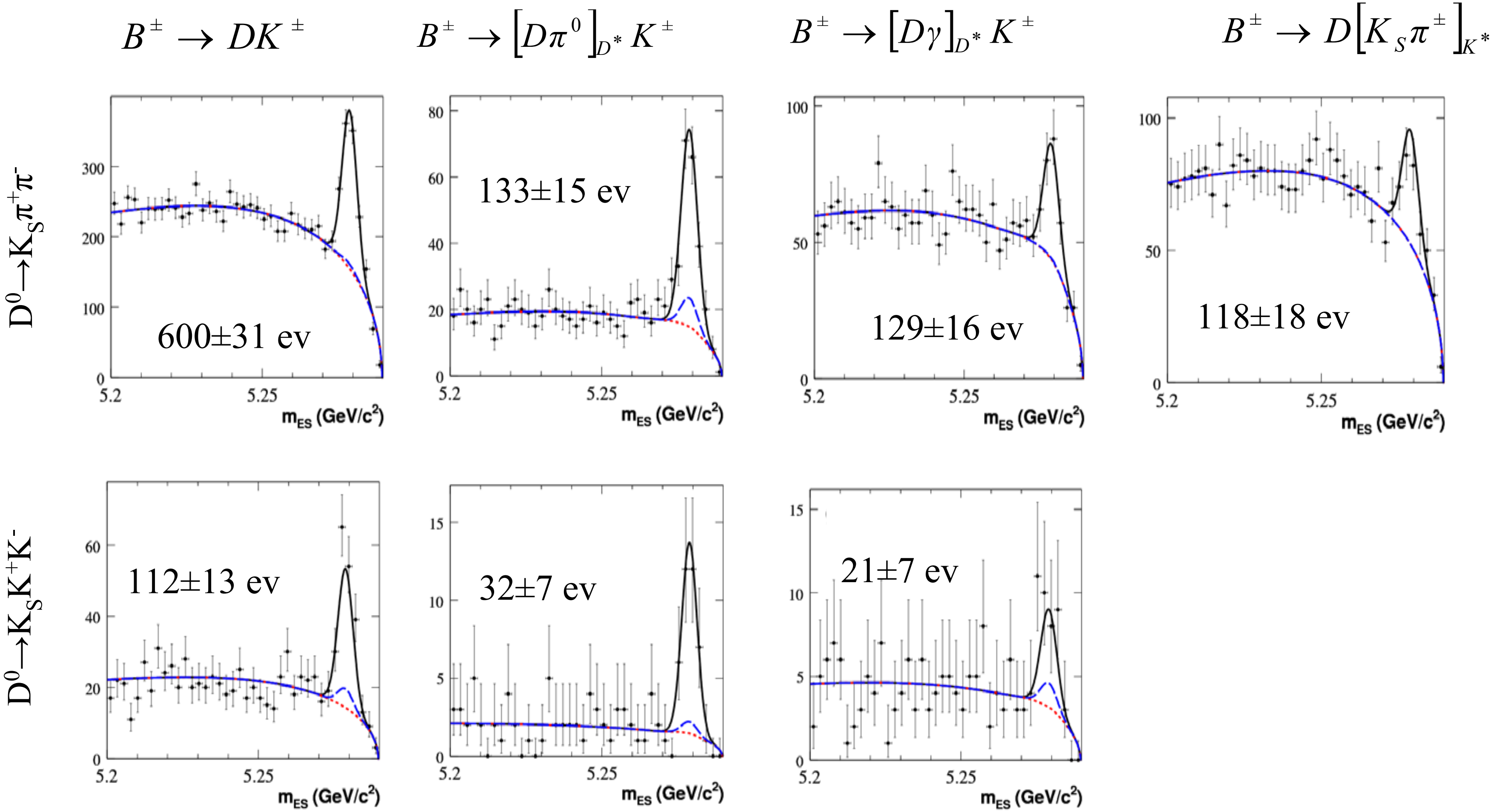
$K^*(892)^{\pm}, K_0^*(1430)^{\pm}, K_2^*(1430)^{\pm},$
$K^*(1680)^{-}, \rho(770), \omega(782), f_2(1270),$
K-matrix for $\pi\pi$ S-wave and running phase
non-resonant for $K\pi$ S-wave.

$a_0(980)^0, \varphi(1020), f_0(1370), f_2(1270),$
$a_0(1450)^0, a_0(980)^{\pm}, a_0(1450)^{+}$

BaBar Dalitz: signal selection

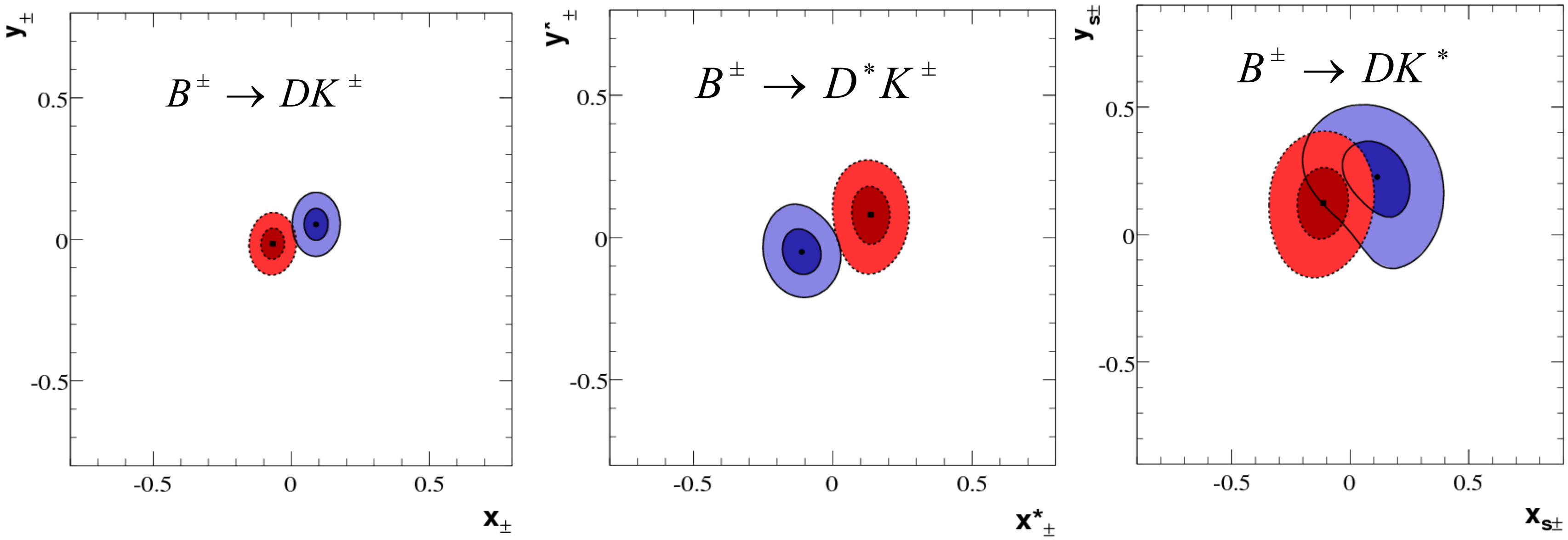
7 modes used: $B\to DK$, $B\to D^{*}K$ with $D^{*}\to D\pi^{0}$ and $D\gamma$, $B\to DK^{*}$

$D^{0}\to K_{S}\pi^{+}\pi^{-}$ and $K_{S}K^{+}K^{-}$ (except for $B\to DK^{*}$)



BaBar Dalitz: fit results

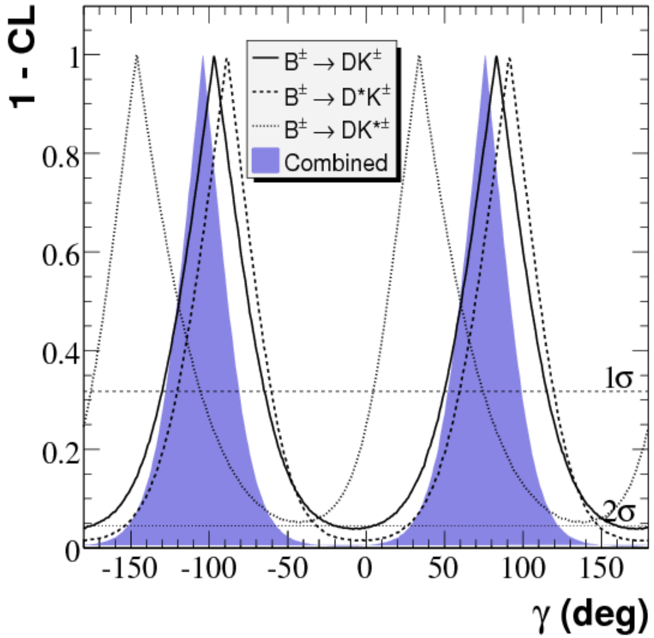
Fit results expressed in Cartesian coordinates $x_{\pm} = r_B \cos(\pm\gamma+\delta)$, $y_{\pm} = r_B \sin(\pm\gamma+\delta)$

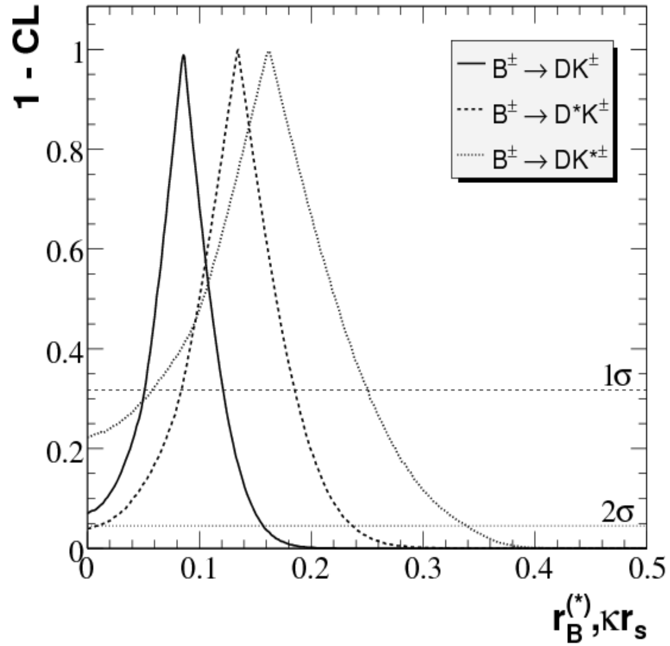


	$B \to D^0K$	$B \to D^{*0}K$	$B \to D^0K^*$
x_-	$+0.090 \pm 0.043 \pm 0.015 \pm 0.011$	$-0.111 \pm 0.069 \pm 0.014 \pm 0.004$	$+0.115 \pm 0.138 \pm 0.039 \pm 0.014$
y_-	$+0.053 \pm 0.056 \pm 0.007 \pm 0.015$	$-0.051 \pm 0.080 \pm 0.009 \pm 0.010$	$+0.226 \pm 0.142 \pm 0.058 \pm 0.011$
x_+	$-0.067 \pm 0.043 \pm 0.014 \pm 0.011$	$+0.137 \pm 0.068 \pm 0.014 \pm 0.005$	$-0.113 \pm 0.107 \pm 0.028 \pm 0.018$
y_+	$-0.015 \pm 0.055 \pm 0.006 \pm 0.008$	$+0.080 \pm 0.102 \pm 0.010 \pm 0.012$	$+0.125 \pm 0.139 \pm 0.051 \pm 0.010$

Statistical Systematic D^0 model

BaBar Dalitz: combined result





$\gamma = \left(76^{+23}_{-24} \pm 5 \pm 5\right)^{\circ}$

$\gamma = \left(63^{+30}_{-28} \pm 8 \pm 7\right)^{\circ}$

($D^0 \to K_S \pi^+ \pi^-$ modes only)

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

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

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

$\delta_B = \left(109^{+28}_{-31} \pm 4 \pm 7\right)^{\circ}$

$\delta_B^* = \left(-63^{+28}_{-30} \pm 5 \pm 4\right)^{\circ}$

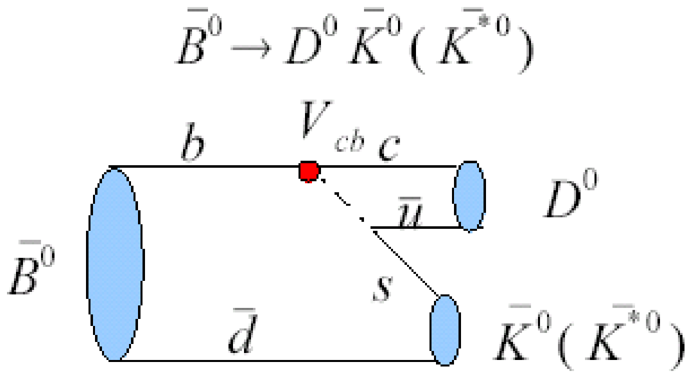
$\delta_s = \left(104^{+43}_{-41} \pm 17 \pm 5\right)^{\circ}$

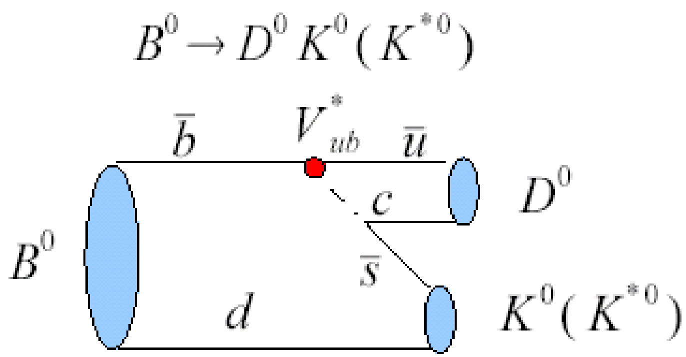
CPV significicne is 3.0σ

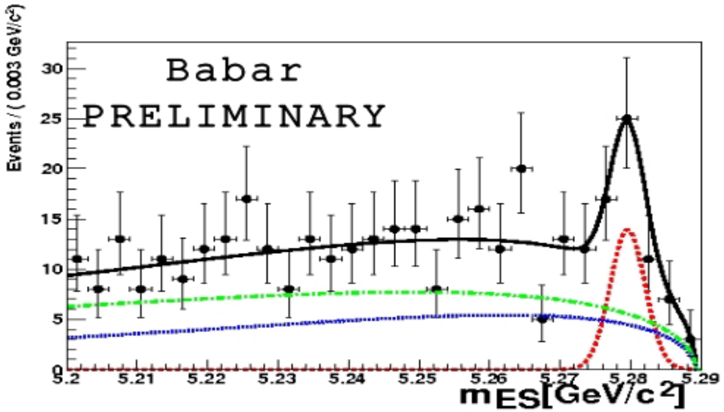
Accounts for possible non-resonant B→DKπ

Techniques using neutral B decays (BaBar)

Decay $B^0 \to D^0 K^{*0}$: Both amplitudes are color-suppressed, r_B ~0.4







$\gamma/\varphi_3 = 162 \pm 56^\circ, r(D^0 K^{*0}) < 0.55(90\%)$

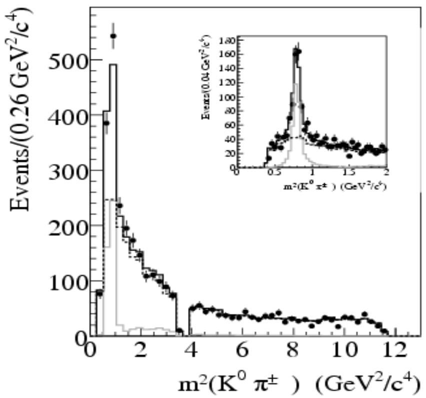
Techniques using neutral B decays (BaBar)

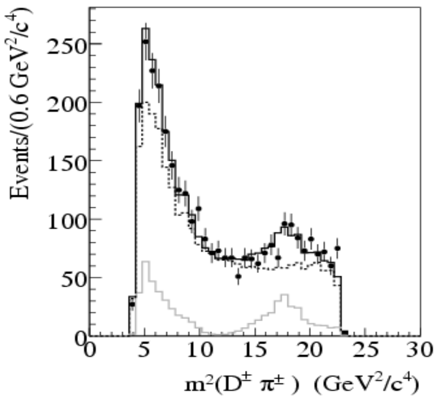
BaBar collaboration, 347M BB pairs [arXiv: 0712:3469]

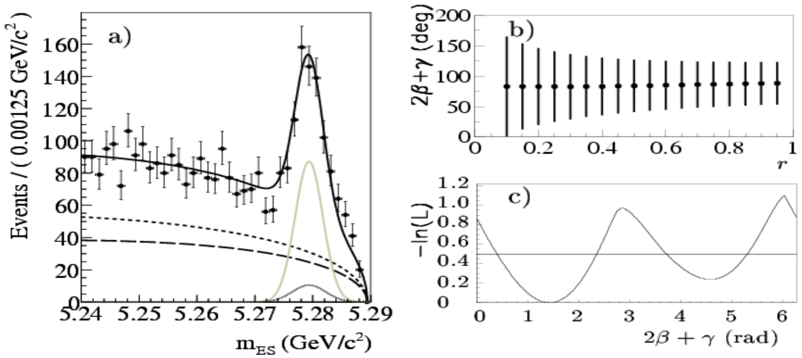
Decay $B^0 \to D^{\mp} K^0 \pi^{\pm}$

Use B flavor tag, perform time-dependent Dalitz plot analysis. Sensitive to $2\beta+\gamma$

Interference between $B^0 \to D^{**0} K_S^0$ (b→u and b→c) and $B^0 \to D^- K^{*+}$ (b→c)

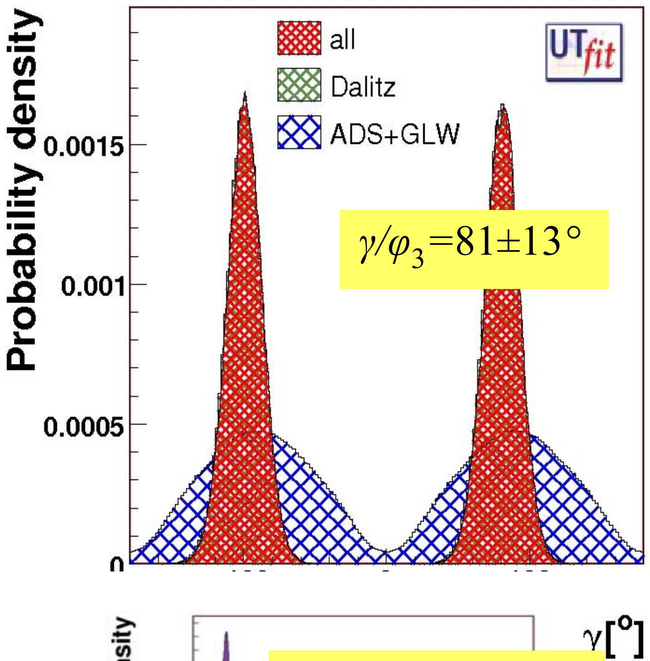


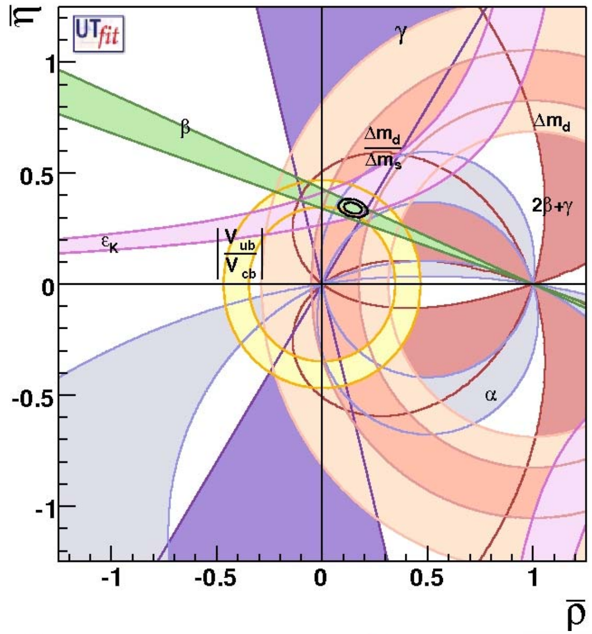




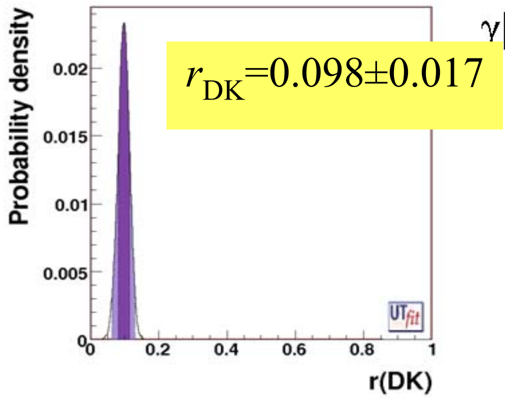
$$2\beta+\gamma / 2\varphi_1+\varphi_3 = (83 \pm 53 \pm 20)^{\circ}$$

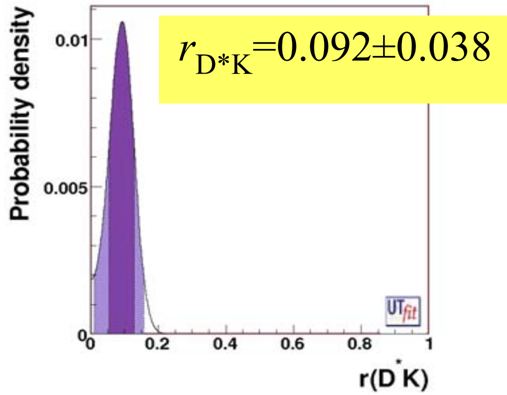
World average (UTfit)

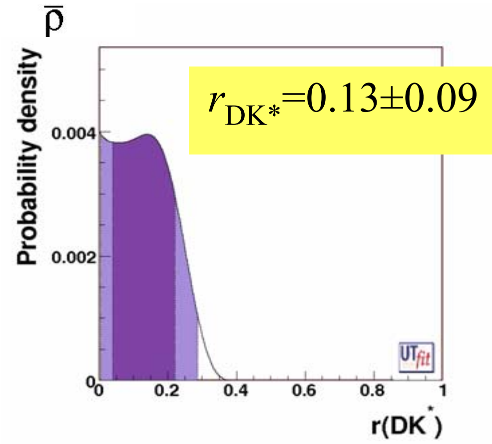




UTfit averages including all results available today







Summary

- New φ_3/γ measurements appeared in 2008:
  - BaBar GLW, Belle ADS updates,
  - Belle Dalitz update with $D^0 \to K_S\pi+\pi-$
  - BaBar Dalitz update with $D^0 \to K_S\pi+\pi-$ and new $D^0 \to K_S K+K-$

- O(10°) Precision in direct measurements of φ_3/γ is achieved. However φ_3/γ remains the worst known angle of the Unitarity Triangle.

- The precision is statistically limited for ADS and GLW methods → good perspectives for improving the result with larger data set.
- The model uncertainty is comparable to statistical error for the Dalitz analysis. Model-independent method using charm data (CLEOc/BES3) will be used to obtain a more reliable result.

Dalitz analisys: model-independent way

Model-independent way: obtain D^0 decay strong phase from $\psi(3770)\to D\overline{D}$ data

$$P_{B^\pm}(m_+^2,m_-^2)=|f_D+(x+iy)\bar{f}_D|^2=P_D+r_B^2\overline{P}_D+2\sqrt{P_D\overline{P}_D}[x_\pm C+y_\pm S]$$

$$P_D(m_+^2,m_-^2)=|f_D(m_+^2,m_-^2)|^2$$

$$\overline{P}_D(m_+^2,m_-^2)=|f_D(m_-^2,m_+^2)|^2$$

$$x_\pm=r_B\cos(\delta\pm\varphi_3)$$

$$y_\pm=r_B\sin(\delta\pm\varphi_3)$$

Free parameters

$$C(m_+^2,m_-^2)=\cos(\delta_D(m_+^2,m_-^2)-\delta_D(m_-^2,m_+^2))$$

$$S(m_+^2,m_-^2)=\sin(\delta_D(m_+^2,m_-^2)-\delta_D(m_-^2,m_+^2))$$

Unknown, can be obtained from charm data at $\psi(3770)$:

$D_{CP}\to K_S\pi^+\pi^-$:

$$P_{CP\pm}(m_+^2,m_-^2)=|f_D\pm\bar{f}_D|^2=P_D+\overline{P}_D\pm2\sqrt{P_D\overline{P}_D}C$$

$\psi(3770)\to(K_S\pi^+\pi^-)_D\,(K_S\pi^+\pi^-)_D$:

$$P_{Corr}(m_+^2,m_-^2,m_+'^2,m_-'^2)=|f_D\bar{f}_D'-\bar{f}_D f_D'|^2=$$
$$=P_D\overline{P}_D'+\overline{P}_D P_D'-2\sqrt{P_D\overline{P}_D P_D'\overline{P}_D'}(CC'+SS')$$

Contribution to φ_3/γ error: ~5° with CLEO data

(but this is stat. error, more reliable than current model uncertainty)

~1° with BES data (20 fb^{-1})