PHENO06
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Measurements of the angles of the Unitarity Triangle at *BaBar*

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On behalf of the ***BaBar*** Collaboration

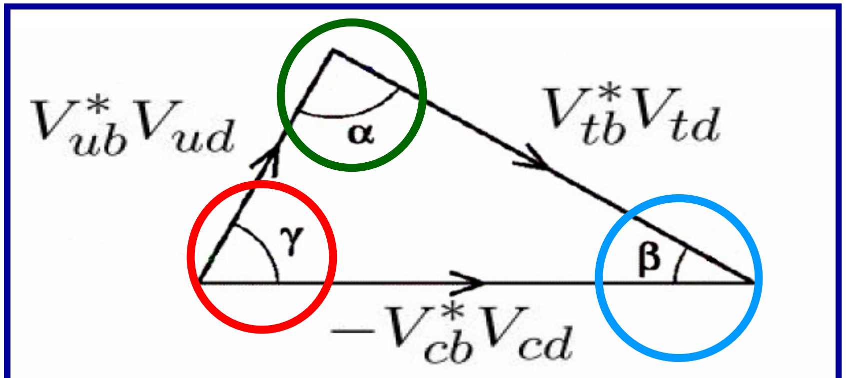
The *CKM* matrix and the *Unitarity Triangle*

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

The Standard Model explains the CP violation through the matrix V_{CKM}

Unitarity of V_{CKM}

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



Unitarity Triangle

$$\alpha \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\beta \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right)$$

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

Improving α measurement

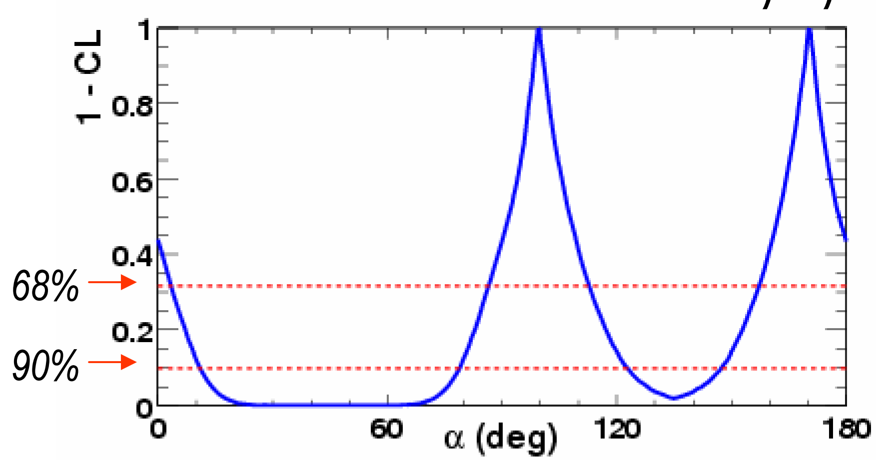
$B^{\pm} \to \rho^{\pm}\rho^{0}$

$B^{0} \to a_1^{\pm}\pi^{\mp}$

$B^{0} \to a_1^{\pm}\rho^{\mp}$

Up to now the best channel

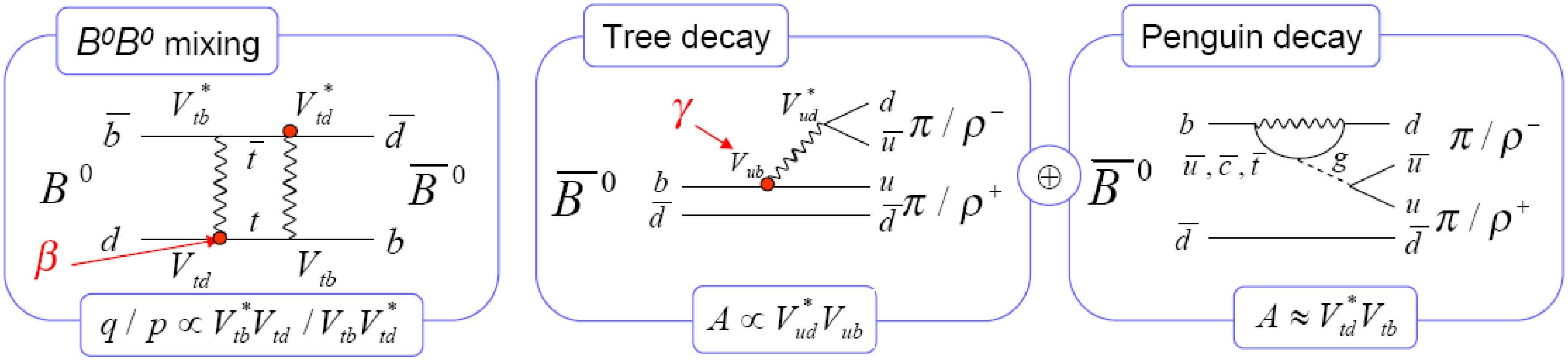
for α determination is: $B^{0} \to \rho^{+}\rho^{-}$



BABAR [PRL95, 041805 (2005),232M BB]

Measuring α in $b \to uud$ transitions

$\alpha = \pi - (\beta + \gamma)$ is measured analyzing the decays: $B^0 \to \pi\pi, \rho\pi, \rho\rho$



$$\lambda_{hh} \equiv \frac{q}{p}\frac{\bar{A}}{A} = -e^{2i\alpha}\frac{1 - P/T\, e^{-i\alpha}}{1 - P/T\, e^{i\alpha}} \equiv |\lambda| e^{-2i\alpha_{eff}} \longrightarrow A_{CP} = \sin 2\alpha_{eff} \sin(\Delta m \Delta t)$$

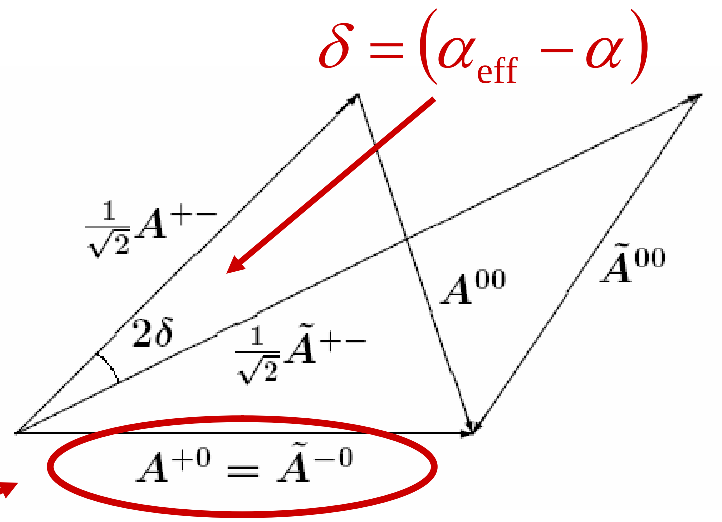
Penguin contribution cannot be neglected (see $Br(B^0 \to K^+\pi^-)$ which is pure penguin).

That is why what we measure is α_{eff}!

- An isospin analysis allows to estimate the penguin contribution.
- Recently a proposal of determination of penguin effect in $B^0 \to \rho^+\rho^-$ from *SU(3)* related decay $B^+ \to K^{*0}\rho^+$, which should reduce the theoretical error on α (*hep-ph/0604005*).

The $\rho\rho$ isospin analysis

- The decays $B \to \rho^+\rho^-, \rho^+\rho^0, \rho^0\rho^0$ are related by *SU(2)*, thus we have isospin relations between amplitudes A^{+-}, A^{+0}, A^{00}
- $\rho\rho$ states can have *I* = *2* or *0*, but gluonic penguins only contribute to *I* = *0* (ΔI = ½ rule).
  But $\rho^+\rho^0$ is pure I = 2, so only tree amplitude $\to$ $|A^{+0}| = |A^{-0}|$



Gronau and London, Phys. Rev. Lett. 65, 3381 (1990)

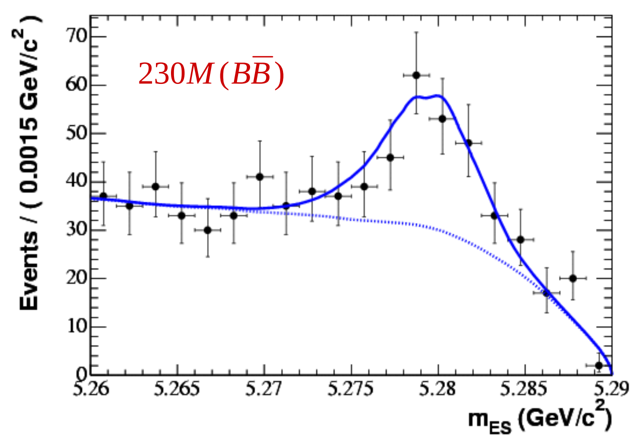
NEW measurement of $\rho^+\rho^0$:

~100% longitudinally polarized:

$$f_L(B^\pm \to \rho^\pm\rho^0) = 0.96 \pm 0.04 \pm 0.05$$

$$Br(B^\pm \to \rho^\pm\rho^0) = (17.2 \pm 2.5 \pm 2.8) \cdot 10^{-6}$$

$$A_{CP}(B^\pm \to \rho^\pm\rho^0) = 0.10 \pm 0.14 \pm 0.09$$



New approaches: α from a_1?

NEW $B^0 \to a_1(1260)^+\pi^-$

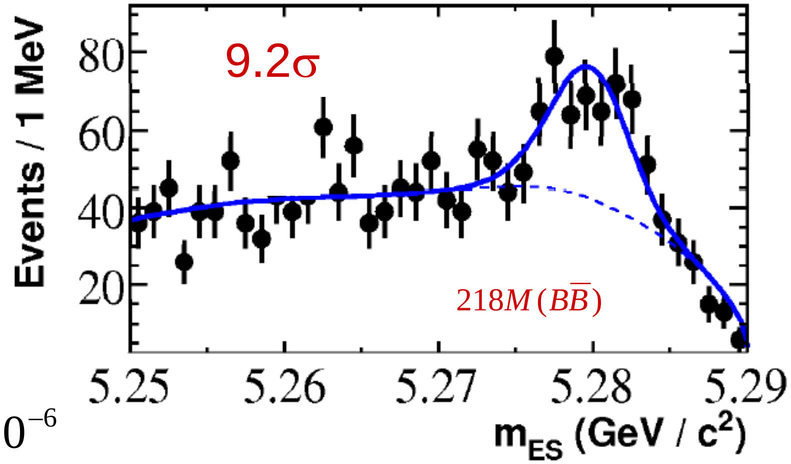
Interesting by itself since:

- Little is known about the a_1
- Can test of factorization

Signal has been observed!

$$Br(B^0 \to a_1^+\pi^-)\cdot Br(a_1^+ \to (3\pi)^+) = (16.6 \pm 1.9 \pm 1.5)\cdot 10^{-6}$$

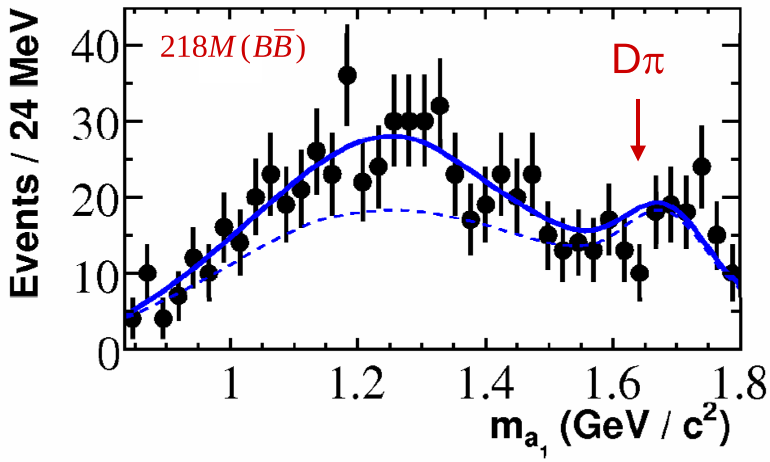
hep-ex/0603050



NEW Search for $B^0 \to a_1(1260)^+\rho^-$

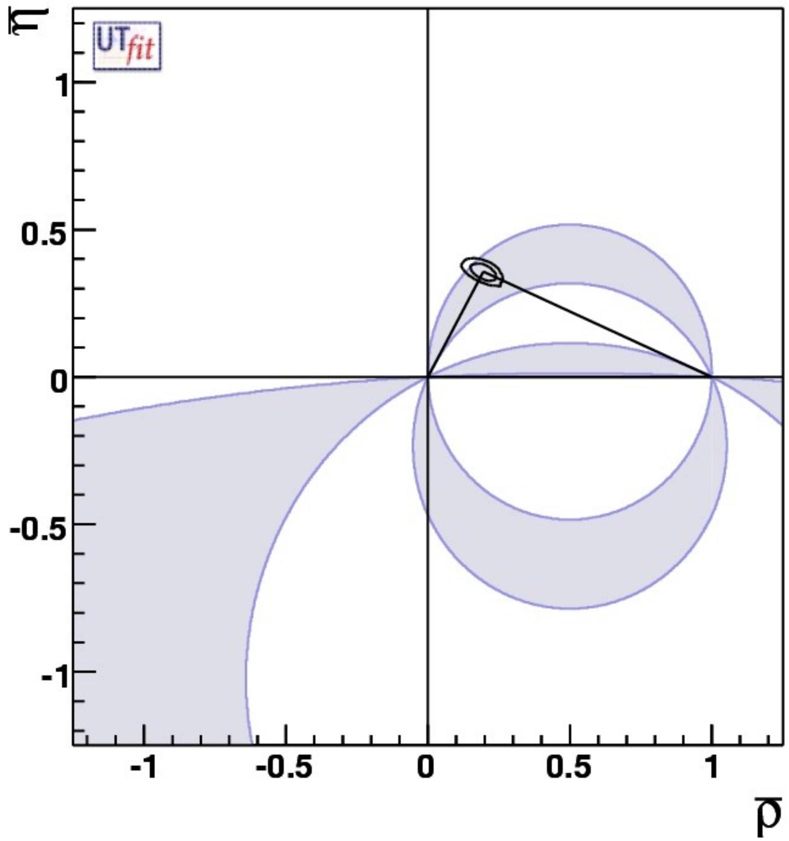
- Background to $\rho\rho$
- (in principle) sensitive to α

$$Br(B^0 \to a_1^+\rho^-)\cdot Br(a_1^+ \to (3\pi)^+) < 61\cdot 10^{-6} (@90\%CL)$$



Status of α

Up to now, if we combine all world measurements (*BaBar*+*Belle*), we can determine the Standard Model solution for α like this:



α = *(99 +12 – 9)*^{0} *(direct measurement, HFAG)*

α = *(91.9 ± 5.5)*^{0} *(indirect UTfit prediction from the other UT bounds)*

Measurements of β

$B^0 \to J/\psi\, \pi^0$

$B^0 \to K^{*0} K^0$

$B \to K_s K_s K_L, \eta' \eta K^0$

$B \to \rho K_s, \omega K_s$

$B \to D^* D^* K_s$

$B \to K \eta^{(\prime)} \gamma$

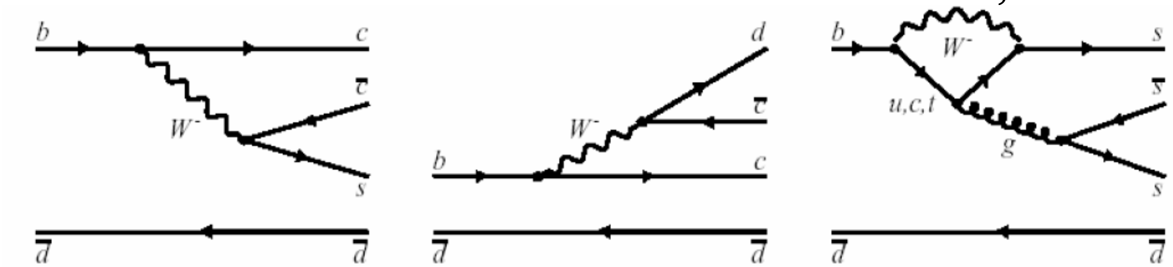
$B \to \eta^{(\prime)} \pi^0, \eta' \eta$

Many modes to measure β:

Charmonium: $b \to c\bar{c}s$

Charm (and charmonium): $b \to c\bar{c}d$

Penguin dominated: $b \to d\bar{d}s, b \to s\bar{s}s$



But ***B→J/ψ K_S*** is the cleanest mode!

Both theoretically: $A_{CP}(\Delta t) = -\eta_f \sin 2\beta \sin(\Delta m \Delta t)$

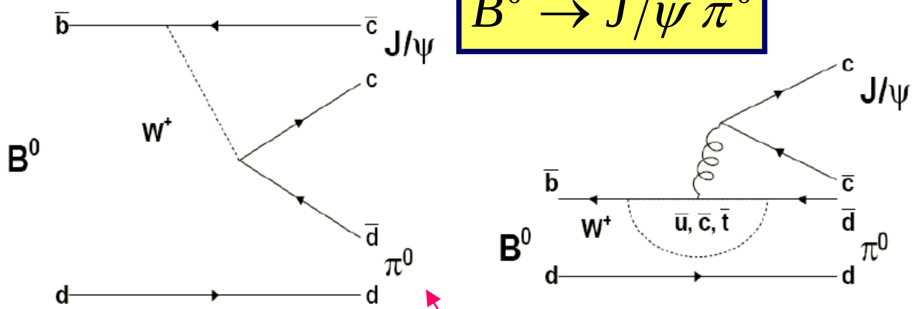
and experimentally (large branching ratio and clean signature).

$$\sin 2\beta = 0.722 \pm 0.040 \pm 0.023$$

BABAR [PRL94, 161803 (2005),227M BB]

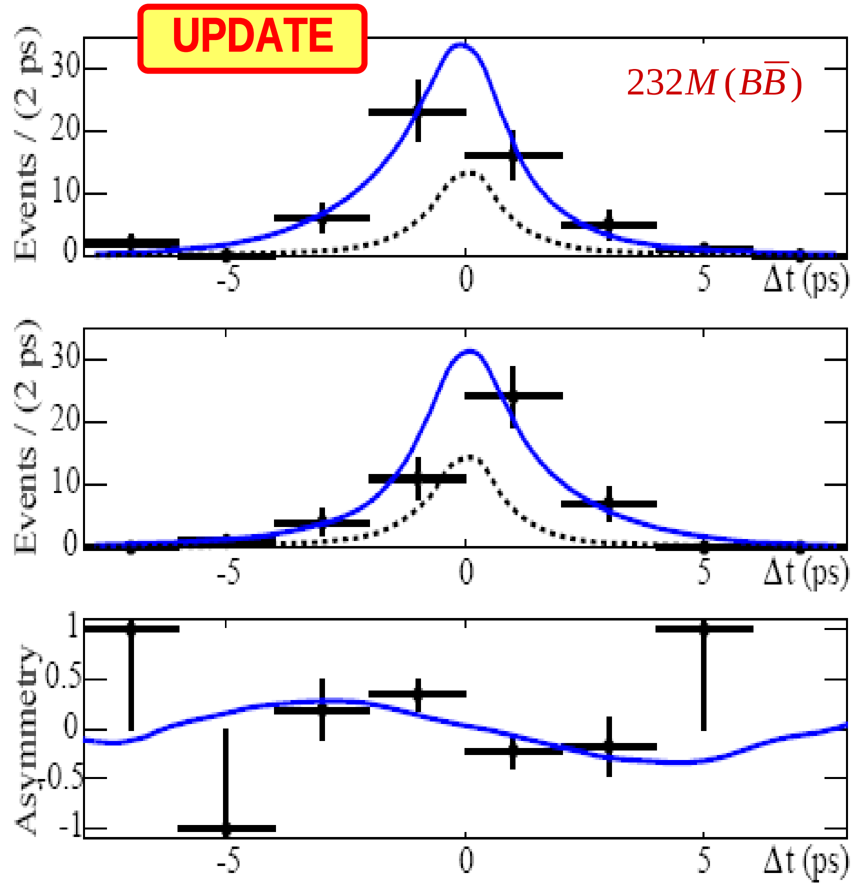
The $b \to d$ penguin pollution

$B^0 \to J/\psi\,\pi^0$



The color-suppressed tree has same weak phase as $J/\psi K_{S}$.

The $b \to d$ penguin has a different weak (and strong) phase respect to the tree.



- Penguin pollution causes deviations in the values of C and S parameters respect to $J/\psi K_s$.
- Also a way for a model independent constraint on the penguin dilution within charmonium modes.

$$Br(B^0 \to J/\psi\,\pi^0) = (1.94 \pm 0.22 \pm 0.17) \times 10^{-5}$$

$$S = 0.68 \pm 0.30 \pm 0.04$$

$$C = -0.21 \pm 0.26 \pm 0.06$$

hep-ex/0603012

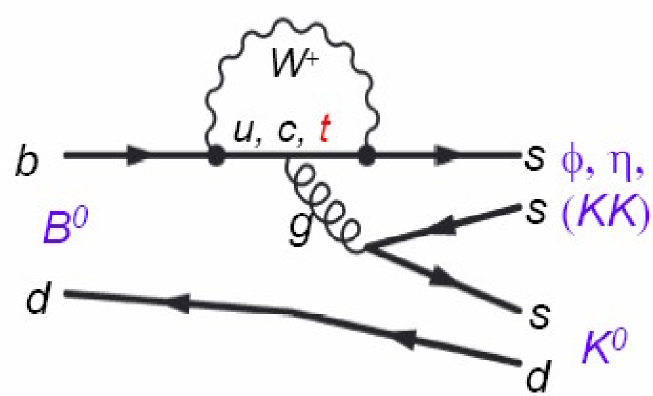
The $b \rightarrow s$ penguins: $\sin 2\beta_{eff}$

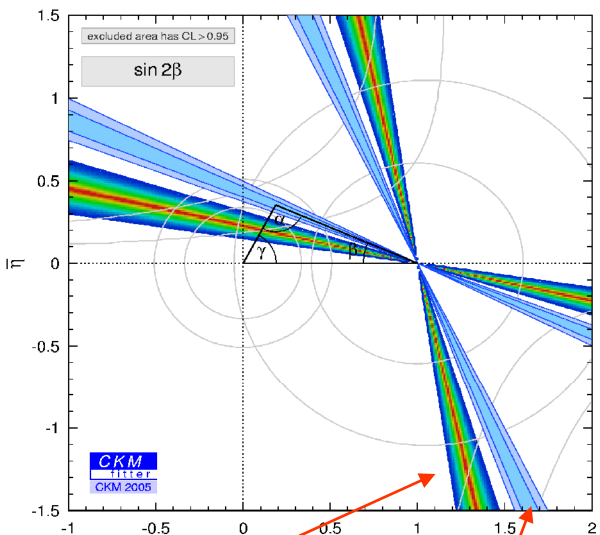
New Physics could contribute in the loop.

They are small effects, here more easily detectable since Tree is missing or negligible.

Look for ***Δsin2β ≠ 0*** in many modes:

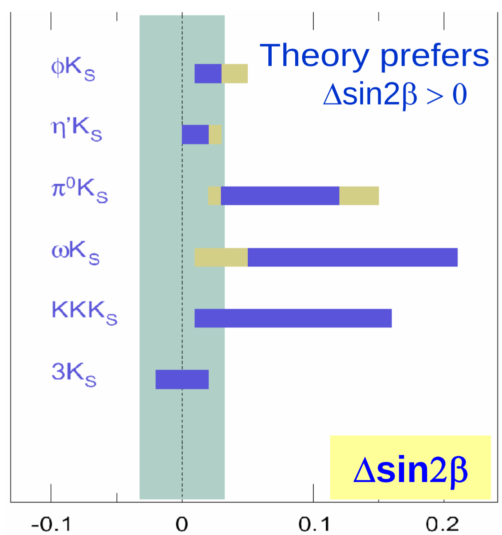
$$B^0 \rightarrow (\phi, \eta', f_0, \pi^0, \pi^0\pi^0, K^+K^-, K_S^0K_S^0)K^0$$



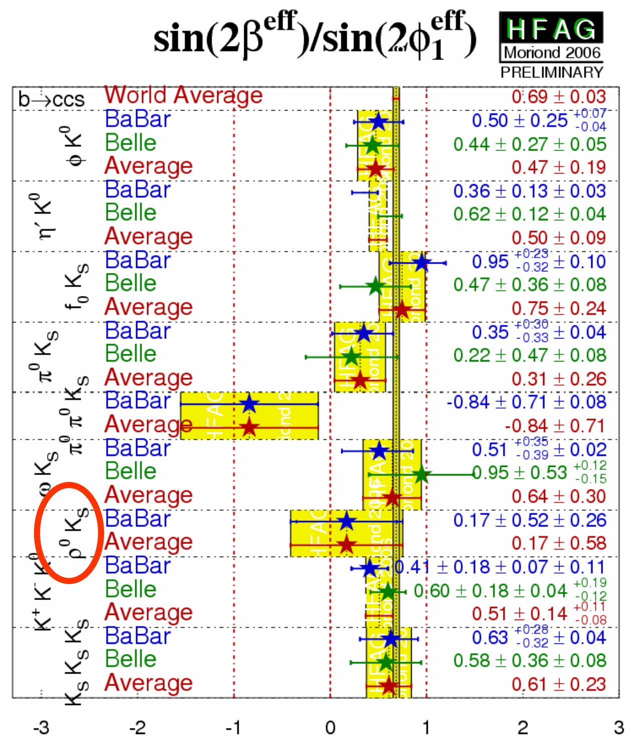


Experimental: penguin modes

Experimental: J/ψ mode

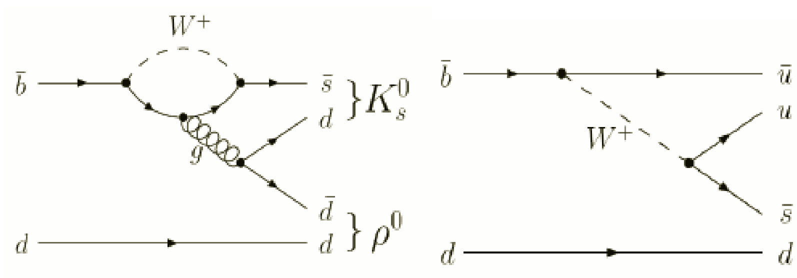


Examples of QCD factorization:
Beneke - PL B620, 143 (2005)
Cheng,chua,soni - PRD72, 094003 (2005)



New results for *sin2β$_{eff}$ in* b→s penguins

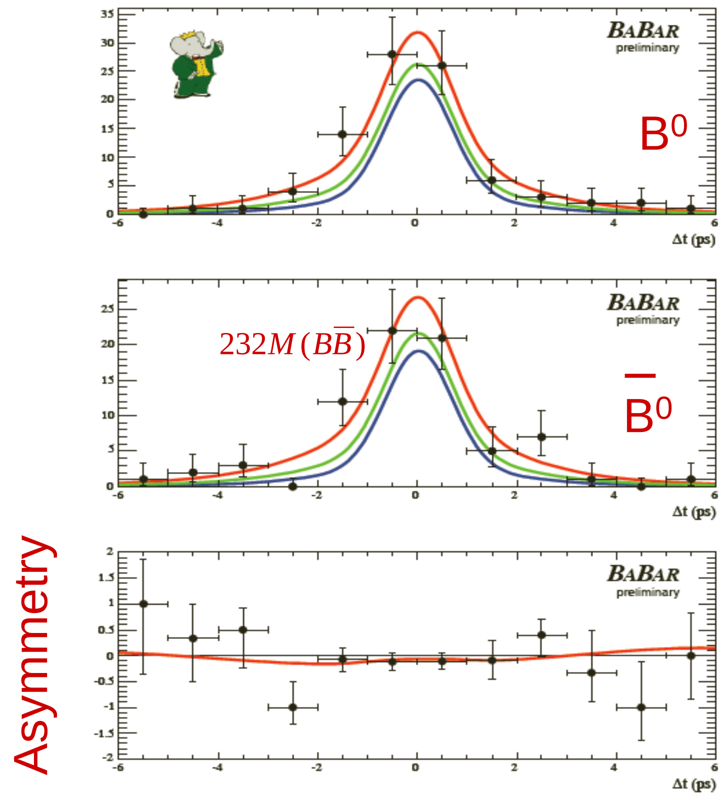
NEW $B^0 \to \rho K_s^0$: first measurement !



Complicated analysis since:

- f_0/ρ overlap, *BB* background
- Color-suppressed tree, but $\Delta\sin2\beta$ expected to be small

$$S_{\rho K_S} = 0.17 \pm 0.52 \pm 0.26$$
$$C_{\rho K_S} = 0.64 \pm 0.41 \pm 0.25$$



UPDATE $B^0 \to \omega K^0$

$$Br(B^0 \to \omega K^0) = (6.2 \pm 1.0 \pm 0.4)\cdot 10^{-6}$$
$$S = 0.51^{+0.35}_{-0.39} \pm 0.02$$
$$C = -0.55^{+0.28}_{-0.26} \pm 0.03$$

hep-ex/0603040

NEW Other searches:

$$Br(B^0 \to K_S^0 K_S^0 K_L^0) < 14\cdot 10^{-6} (@90\%CL)$$
$$Br(B^0 \to \eta'\eta' K^0) < 31\cdot 10^{-6} (@90\%CL)$$
$$Br(B^+ \to \eta'\eta' K^+) < 25\cdot 10^{-6} (@90\%CL)$$

β :other searches

NEW Search for $B^0 \to K^{*0} K^0$

It is a penguin $b \to d s\bar{s}$

Allows to interpret $B^0 \to \phi K_s$ and to put a bound on its ΔS.

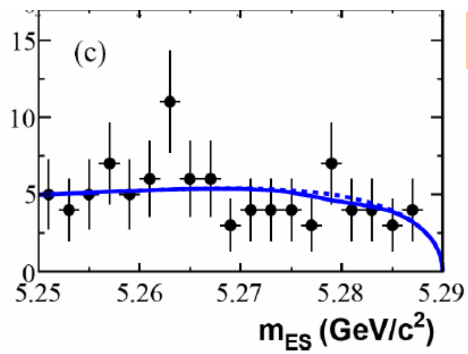
$Br(B^0 \to \overline{K}^{*0} K^0) + Br(B^0 \to K^{*0}\overline{K}^0) = (0.2^{+0.9+0.1}_{-0.8-0.3}) \cdot 10^{-6}$ → $\Delta S_{\phi K^0} < 0.43 @ 90\% CL$

NEW Search for $B \to K\eta^{(\prime)}\gamma$

hep-ex/0603054

Confirmed $B \to K\eta\gamma$ from Belle.

No signal for $B \to K\eta'\gamma$ (unexpected).



NEW Searches for $B \to \eta^{(\prime)}\pi^0, \eta'\eta$

hep-ex/0603013

Can reduce theoretical uncertainty of Color Suppressed tree amplitudes for $\eta' K_s$ decays in *SU(3)*-based analysis

[Gronau,Rosner,Zupan PLB596,107(2004)]

$Br(B^0 \to \eta'\eta) < 1.7 \cdot 10^{-6} (@90\% CL)$

$Br(B^0 \to \eta\pi^0) < 1.3 \cdot 10^{-6} (@90\% CL)$

$Br(B^0 \to \eta'\pi^0) < 2.1 \cdot 10^{-6} (@90\% CL)$

Measurements of γ

$B^{\pm} \to D^{o}_{CP}(K_s\omega, K_s\phi)K^{\pm}$

$B \to DK\pi$

$B^{\pm} \to D_s^{*} a_{0(2)}$

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

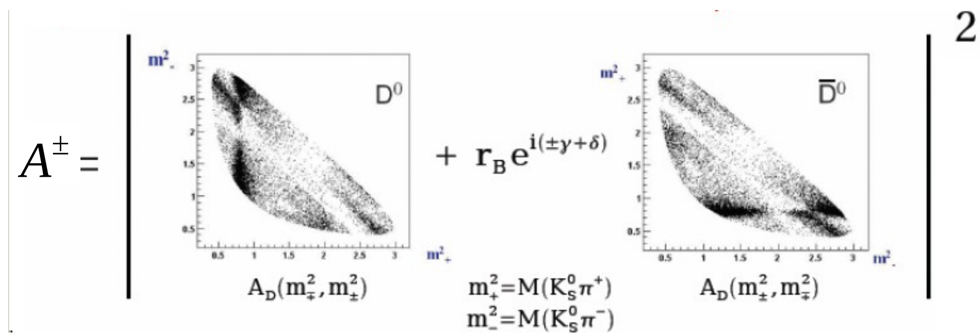
$B^{\pm} \to D_s\pi, D_s K$

$B^{0} \to D^{(*)0}K^{(*)0}$

$B^{0} \to D^{(*)}\pi, D\rho$

Best method to γ determination:

$$B^{-} \to D^{0}K^{-}(D^{0} \to K_s\pi^{+}\pi^{-})$$

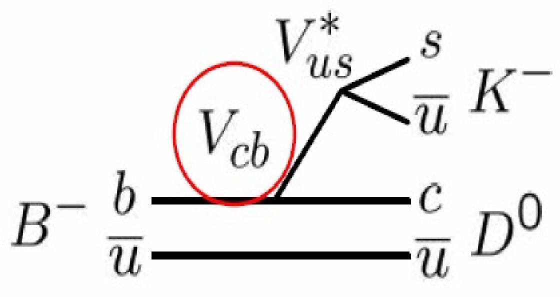


$$\gamma = (67 \pm 28 \pm 13 \pm 11)^{0}$$

BABAR [PRL95, 121802 (2005),227M BB]

γ from *DK* decays

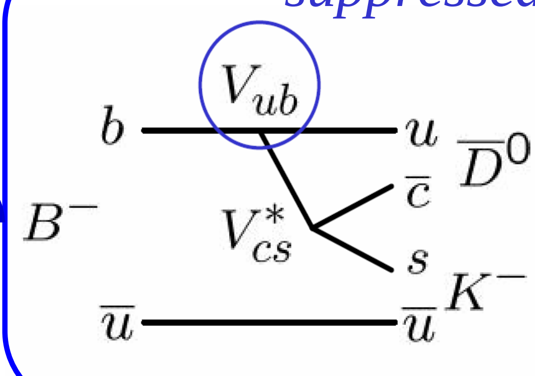
favored



If common final state to D^0 and $\bar{D}^0$

interference

suppressed



$$A_{CP} \equiv \frac{\Gamma(B^- \to DK^-) - \Gamma(B^+ \to DK^+)}{\Gamma(B^- \to DK^-) + \Gamma(B^+ \to DK^+)} \propto r_B \sin\gamma \sin\delta_B$$

weak phase

strong phase

Critical parameter:

$$r_B = \left| \frac{A(b \to u)}{A(b \to c)} \right|$$

Three methods:

D^0 to common flavor state
(ADS)

suppressed
$D^0 \to K^+\pi^-$
favored
$\bar{D}^0 \to K^+\pi^-$

*$D^0 \to$ CP modes(**GLW**)*

$$D^0_{CP\pm} \equiv \frac{(D^0 \pm \bar{D}^0)}{\sqrt{2}}$$

*D^0 Dalitz (**GGSZ**)*
$D^0 \to K_s\pi\pi$
(only2ambiguities)

New results for the *GLW* Method

4 observables (A_{CP+-},R_{CP+-}) for three unknown (r_B, γ, δ_B):

$$A_{CP\pm} = \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{R_{CP\pm}}$$

$$R_{CP\pm} = \frac{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}{\frac{2}{}\qquad \Gamma(B^- \to D^0 K^-)} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma$$

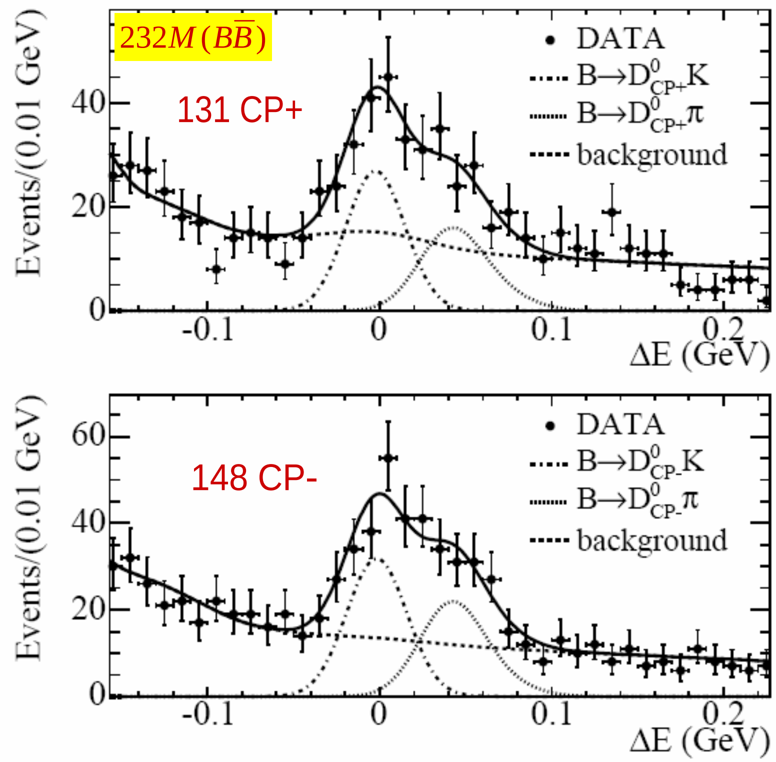
Some issues:

- $B \to D\pi$ background
- D^0_{CP} have small BRs
- 8 ambiguities

NEW **from BaBar: added $D^0 \to K_S\omega$, $K_S\phi$**

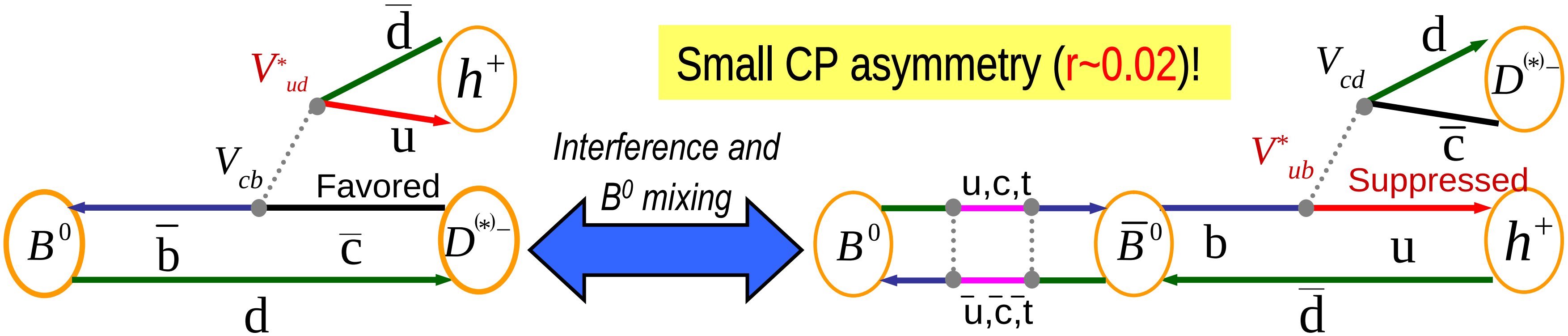
$D^0_{CP} K$	$D^0_{CP} K^*$
$R_{CP+} = 0.90 \pm 0.12 \pm 0.04$	$R_{CP+} = 1.96 \pm 0.40 \pm 0.11$
$R_{CP-} = 0.86 \pm 0.10 \pm 0.05$	$R_{CP-} = 0.65 \pm 0.26 \pm 0.08$
$A_{CP+} = 0.35 \pm 0.13 \pm 0.04$	$A_{CP+} = -0.08 \pm 0.19 \pm 0.08$
$A_{CP-} = -0.06 \pm 0.13 \pm 0.04$	$A_{CP-} = 0.26 \pm 0.40 \pm 0.12$

hep-ex/0512067



$\sin(2\beta+\gamma)$ from $B\rightarrow D^{(*)}\pi(\rho)$

Small CP asymmetry (r~0.02)!



To consider tag-side *CP* violation, fit for:

***a* = 2r sin(2β+γ) cos (δ)**

***c*= cos(2β+γ) [2r sin(δ)+2r'sin(δ')]**

***b* = 2r' sin(2β+γ) cos (δ')**

Extract result from ***a***, c_{lep} and:

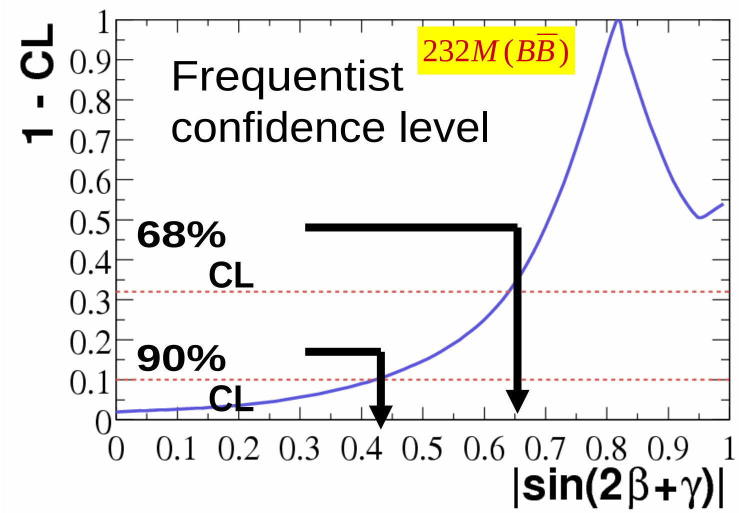
$r(D\pi) = 0.019 \pm 0.004$
$r(D^*\pi) = 0.015 \pm 0.006$
$r(D\rho) = 0.003 \pm 0.006$

+30% theoretical error on r
(Due to use of SU(3) simmetry and W-exchange neglection)

UPDATE

hep-ex/0602049

$|\sin(2\beta+\gamma)| > 0.64$ (@ 68 % C.L.)
$|\sin(2\beta+\gamma)| > 0.42$ (@ 90 % C.L.)



$B^0 \to D_s^* \pi$ and $B^0 \to D_s^* K$ observations.

Decays proceeding through *W-exchange* diagrams.

Allows a more precise estimation of the theoretical error on *r* from *SU(3)*-related decays $D_s^{(*)}\pi$:

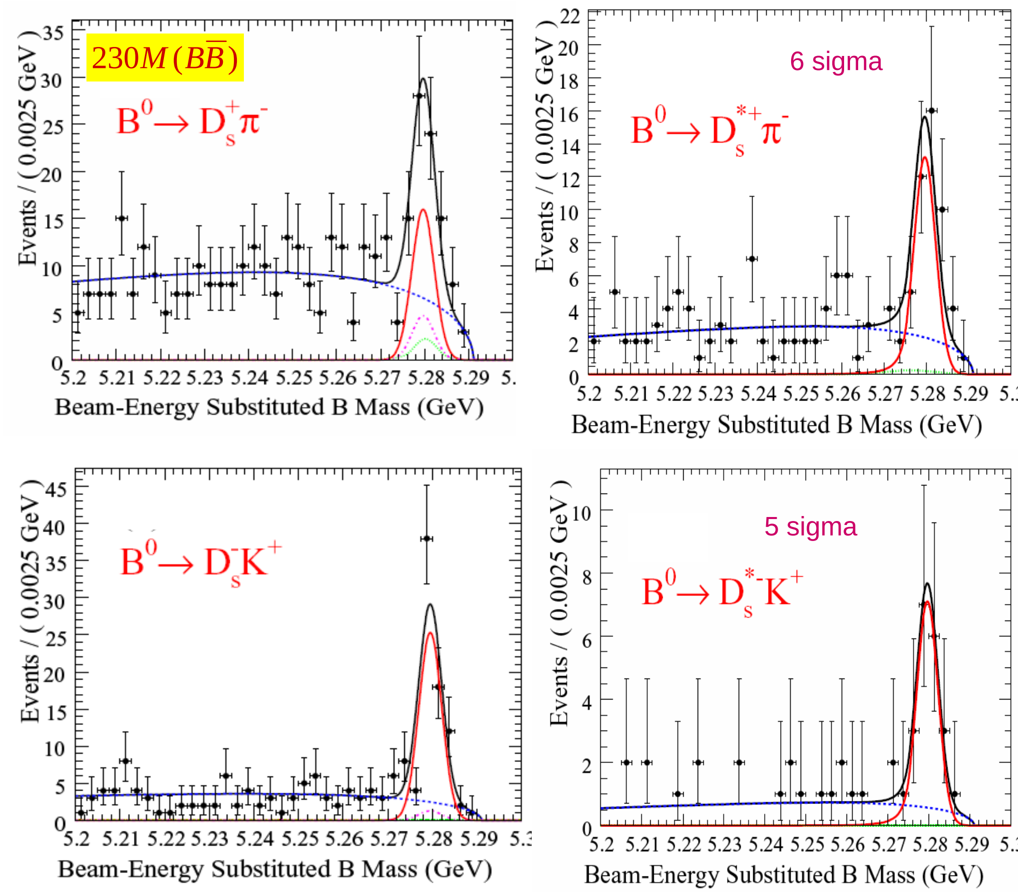
$$r_{D\pi} \approx \sqrt{\frac{BR(B^0 \to D_s^{(*)+}\pi^- / \rho^-)}{BR(B^0 \to D^{(*)-}\pi^+ / \rho^+)}} \left|\frac{V_{cd}}{V_{cs}}\right| \frac{f_{D^{(*)}}}{f_{D_s^{(*)}}}$$

First observations for $B^0 \to D_s^{*+}\pi^-, D_s^{*-}K^+$

hep-ex/0604012

NEW

$$Br(B^0 \to D_s^- K^+) = (2.5 \pm 0.4 \pm 0.4) \times 10^{-5}$$
$$Br(B^0 \to D_s^{*-} K^+) = (2.0 \pm 0.5 \pm 0.4) \times 10^{-5}$$
$$Br(B^0 \to D_s^+ \pi^-) = (1.3 \pm 0.3 \pm 0.2) \times 10^{-5}$$
$$Br(B^0 \to D_s^{*+} \pi^-) = (2.8 \pm 0.6 \pm 0.5) \times 10^{-5}$$



But D_sK smaller than before, so smaller $r_{D\pi}$ and less sensitivity!

$\sin(2\beta+\gamma)$ from $B^0 \to D^{(*)0}K^{(*)0}$

Charge correlation allows to tag the B^0:

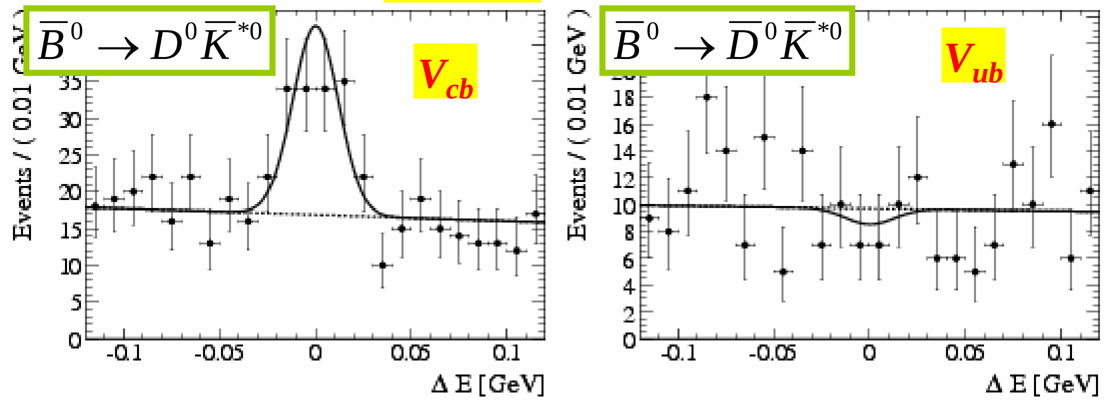
$$\overline{B}^0 \to D^0 \overline{K}^{*0}, \quad D^0 \to K^- X^+, \quad \overline{K}^{*0} \to K^- \pi^+$$

$$\overline{B}^0 \to \overline{D}^0 \overline{K}^{*0}, \quad \overline{D}^0 \to K^+ X^+, \quad \overline{K}^{*0} \to K^- \pi^+$$

You can distinguish V_{ub} from V_{cb} and measure r!

But no V_{ub} observed…

$226M(B\overline{B})$



$$Br(\overline{B}^0 \to D^0 \overline{K}^{*0}) = (4.0 \pm 0.7 \pm 0.3) \times 10^{-5}$$

$$Br(\overline{B}^0 \to \overline{D}^0 \overline{K}^{*0}) < 1.1 \times 10^{-5} \ @90\%CL$$

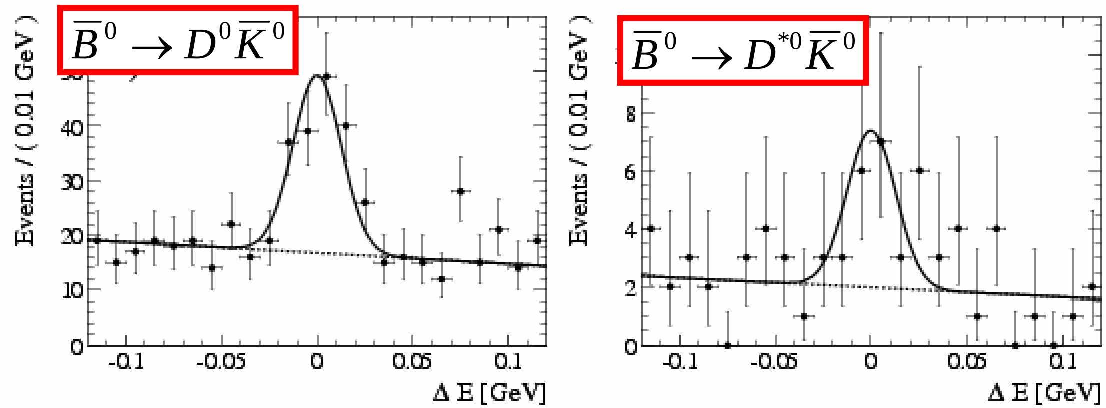
$r < 0.4$ @90%CL **NEW**

NEW

$$Br(\overline{B}^0 \to D^0 \overline{K}^0) = (5.3 \pm 0.7 \pm 0.3) \times 10^{-5}$$

$$Br(\overline{B}^0 \to D^{*0} \overline{K}^0) = (3.6 \pm 1.2 \pm 0.3) \times 10^{-5}$$

hep-ex/0604016



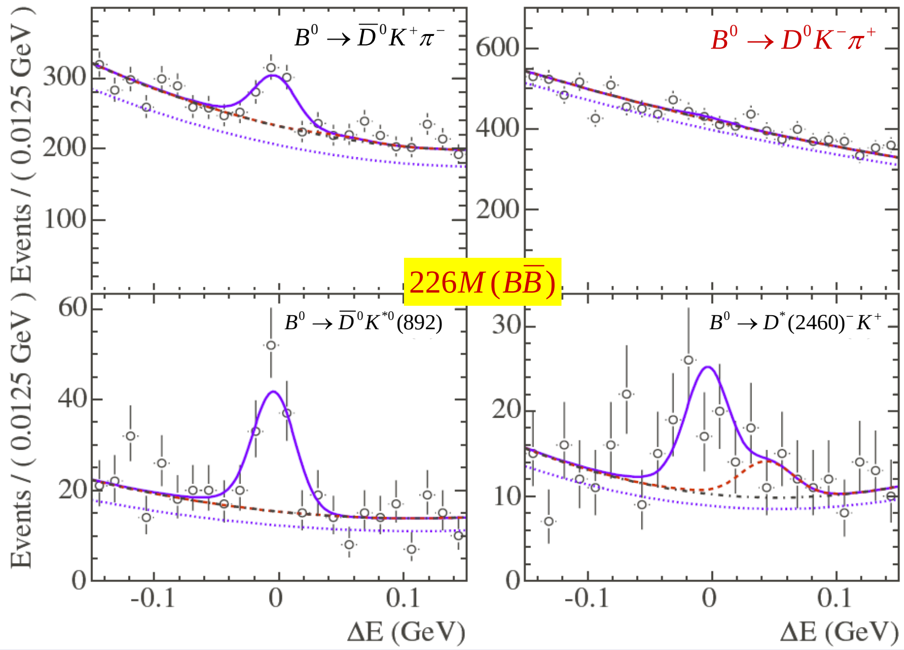
Two other approaches for γ

NEW **$B \to DK\pi$** *hep-ex/0509036*

- Self-tagging.
- $b \to ucs$ decay includes color-allowed diagrams, so (possibly) large *CP*-violating effects.
- Strong phase difference accessed through Dalitz plot, so 8-fold $\to$ 2-fold ambiguity.

Unfortunately, didn't find $b \to u$!

$$BF\left(B^0 \to D^0 K^- \pi^+\right) < 19\times10^{-6}\ (@90\%CL)$$
$$BF\left(B^0 \to \overline{D}^0 K^+ \pi^-\right) = (88\pm15\pm9)\times10^{-6}$$



NEW **$B \to D^{(*)}a_{0(2)}$** *hep-ex/0512031*

- Due to form-factor suppression in $B \to a_{0(2)}X$, favored and suppressed amplitudes become comparable.
- First step: search for the ($b \to u$) *SU(3)*-related decays $D_s^{(*)}a_{0(2)}$

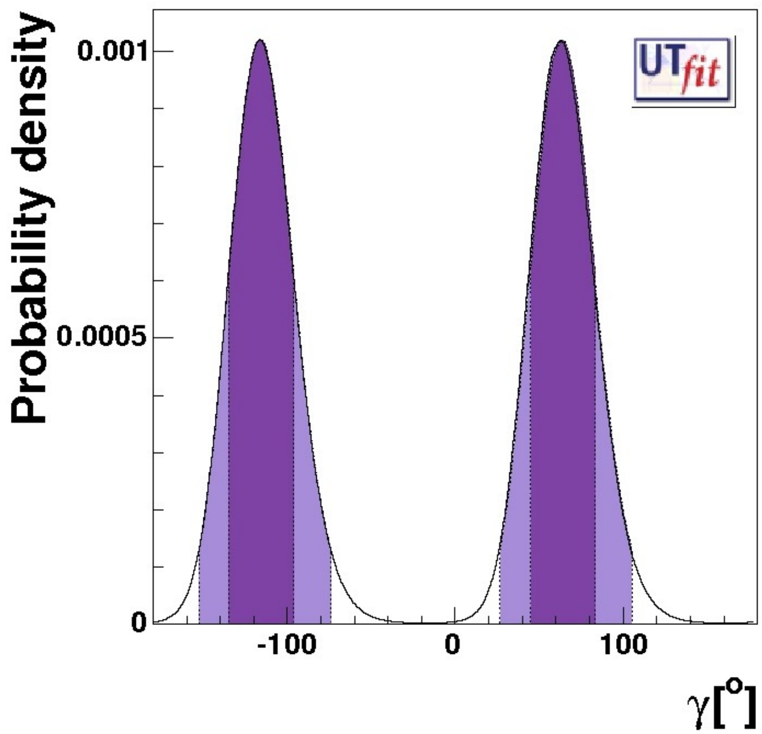
Again, V_{ub} component is missing!

$230M(B\overline{B})$

$$@90\%CL:$$
$$Br\left(B^0 \to D_s^+ a_0^-\right) < 1.9\times10^{-5}$$
$$Br\left(B^0 \to D_s^+ a_2^-\right) < 19\times10^{-5}$$
$$Br\left(B^0 \to D_s^{*+} a_0^-\right) < 3.6\times10^{-5}$$
$$Br\left(B^0 \to D_s^{*+} a_2^-\right) < 20\times10^{-5}$$

Status of γ

Combining all direct world measurements (*BaBar*+*Belle*):



$\gamma = (65 \pm 20)^o$ & $\gamma = (-115 \pm 20)^o$

Conclusions

- Angles measurements are still being performed at ***BaBar*** both updating old results to the full available dataset and exploring new methods.
- Some satellites measurements have been performed, which provides a better understanding of old results.
- This field is sensitive to new physics effects, expecially in the penguin diagrams
- Measurements of the angles of the Unitarity Triangle contribute to the precise determination of the allowed region in the $\rho-\eta$ plane.
- More results are expected to come in the future.