Measurements of γ at *BABAR* and *BELLE*

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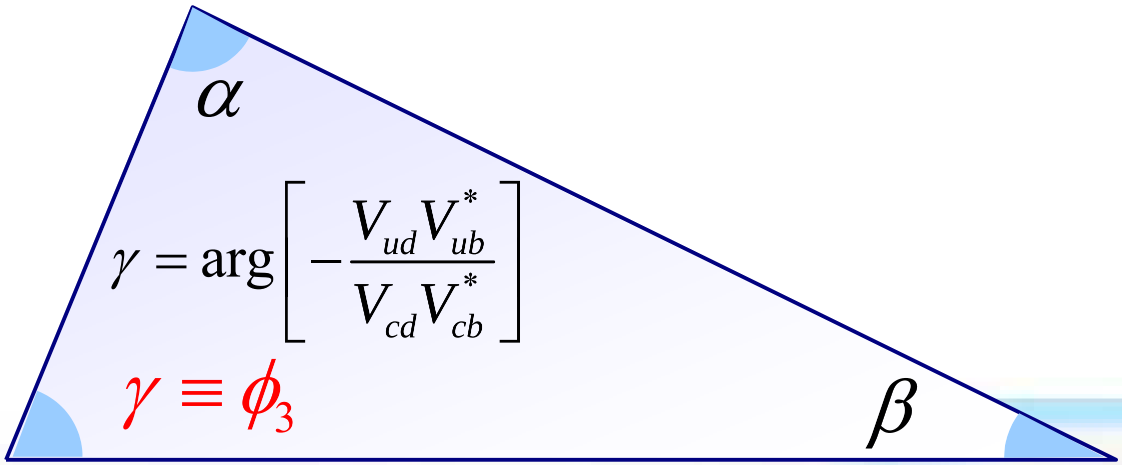
on behalf of the *BABAR* and *BELLE* Collaborations

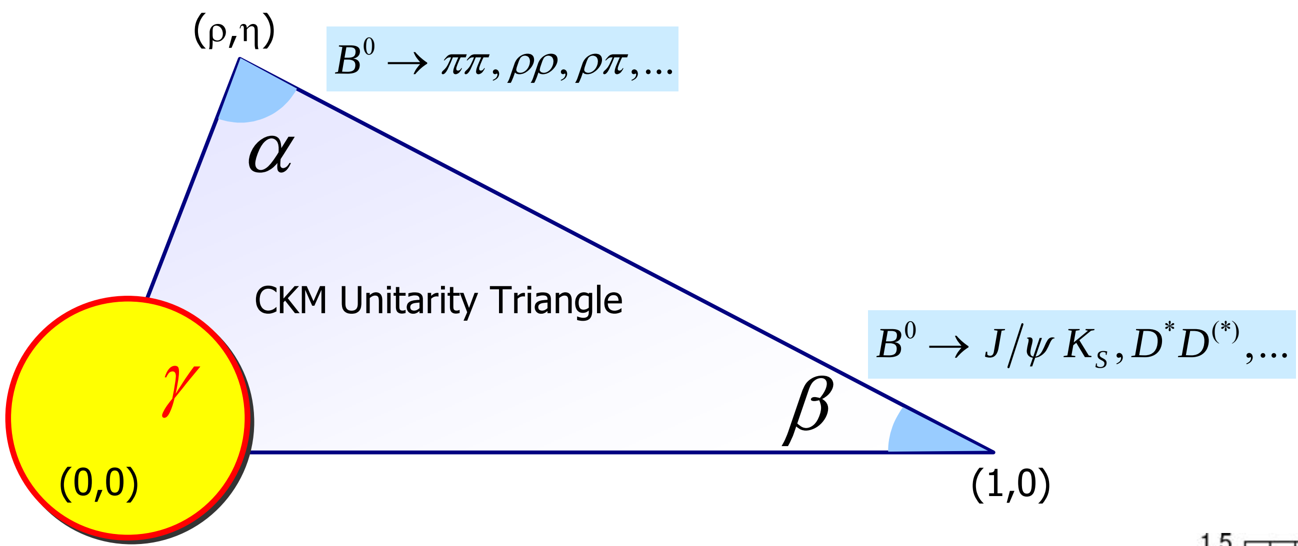
Beauty 2005, Assisi



Outline

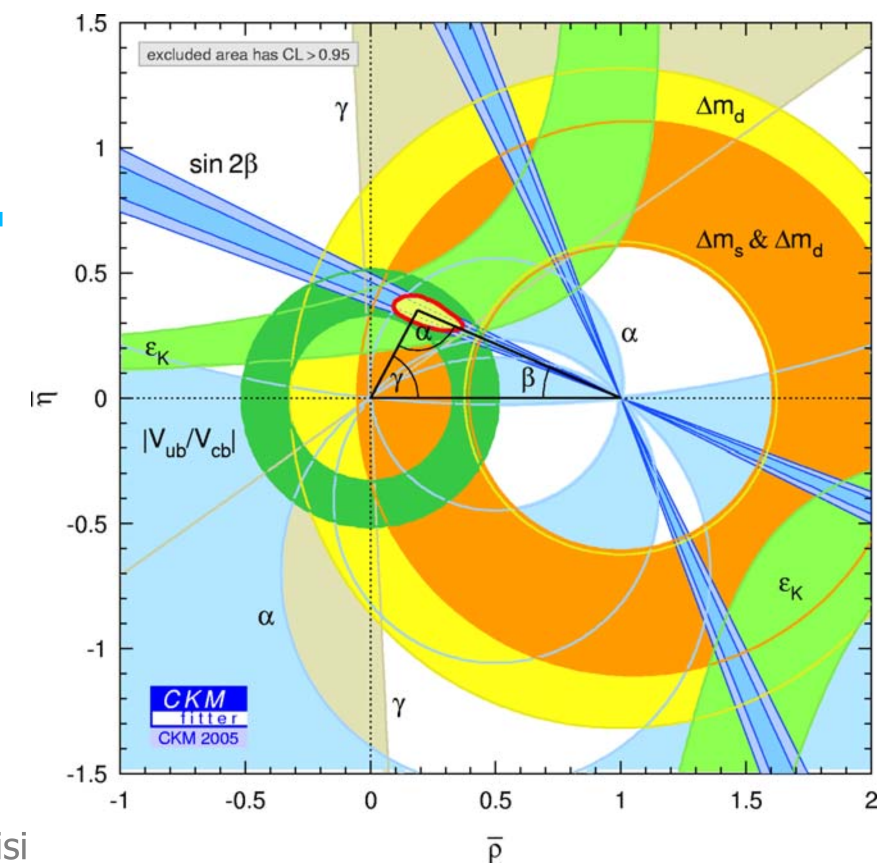
1. Measurements of γ using $B^{\pm} \to D^{(*)} K^{(*)\pm}$
   - GLW Method
   - ADS Method
   - D^0 Dalitz Method (GGSZ)
2. Measurements of $\sin(2\beta+\gamma)$ using $B^0 \to D^{(*)\pm} \pi^{\mp}/\rho^{\mp}$
3. Outlook

γ in the Unitarity Triangle



$$\gamma = \arg\left[-\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right]$$

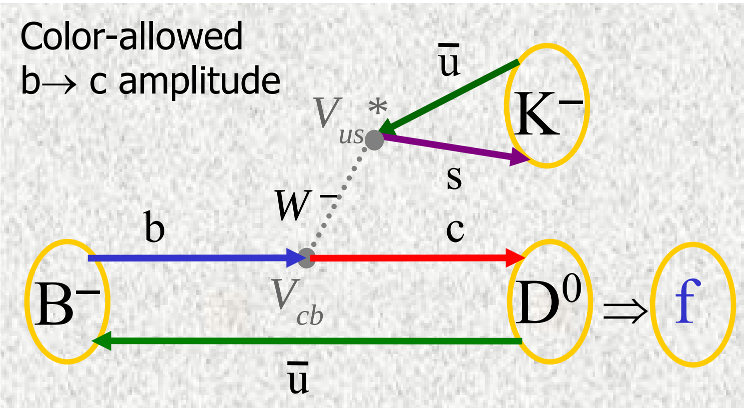
- Expect $\gamma \approx (60 \pm 6)°$ from SM fit to: $\sin 2\beta$, $|V_{ub}/V_{cb}|$, Δm_d, Δm_s, ε_K



- Most challenging angle to measure experimentally:
  - Low branching fractions
  - Low reconstruction efficiencies
  - Small interferences
- The only solution with γ is statistics

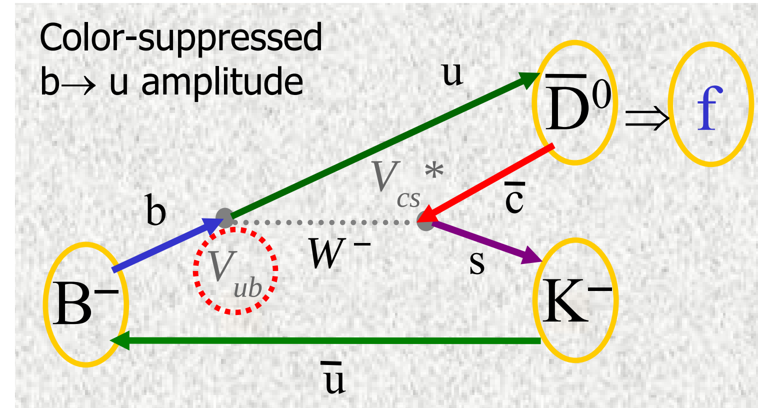
γ from $B^- \rightarrow D^{(*)} K^-$

- Access γ via interference between $B^- \rightarrow D^{(*)0} K^-$ and $B^- \rightarrow \bar{D}^{(*)0} K^-$.



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

amplitude ratio r_B
relative weak phase γ
and strong phase δ_B



- Reconstruct D in final state f accessible both to D^0 and $\bar{D}^0$.

- Will discuss 3 methods with different final states f in this talk:

1. GLW — Gronau – London – Wyler — $B^- \rightarrow \overset{(-)}{D}{}^{(*)0}_{CP} K^{(*)-}$, $\overset{(-)}{D}{}^0 \rightarrow$ CP eigenstate
2. ADS — Atwood – Dunietz – Soni — $B^- \rightarrow \overset{(-)}{D}{}^0 K^-$, $\overset{(-)}{D}{}^0 \rightarrow K\pi$
3. GGSZ — Giri – Grossman – Soffer – Zupan — $B^- \rightarrow \overset{(-)}{D}{}^{(*)0} K^{(*)-}$, $\overset{(-)}{D}{}^0 \rightarrow K_S \pi^+ \pi^-$
   Belle collaboration

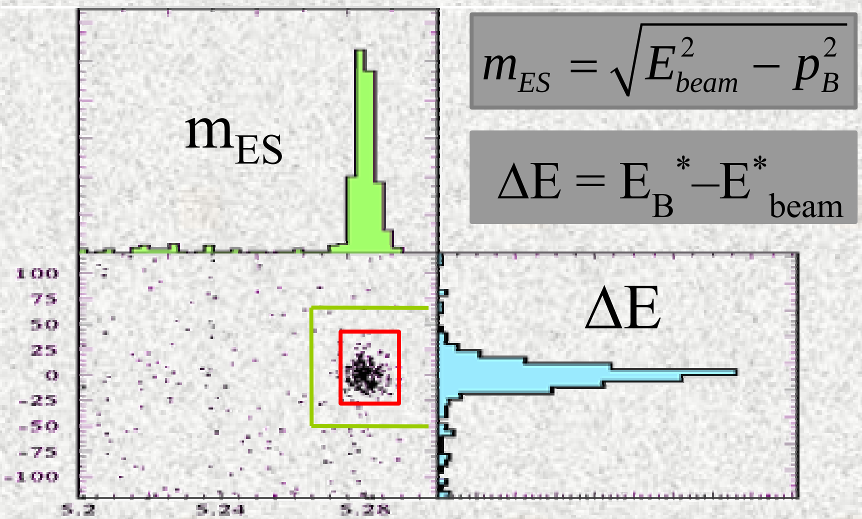
$$A_{CP} = \frac{\Gamma\left(B^- \rightarrow DK^-\right) - \Gamma\left(B^+ \rightarrow DK^+\right)}{\Gamma\left(B^- \rightarrow DK^-\right) + \Gamma\left(B^+ \rightarrow DK^+\right)} \propto r_B \sin\gamma$$

Critical parameter $r_B \sim 0.1$ for sensitivity to γ !

- In order to determine r_B, γ, δ_B simultaneously, need to measure as many $D^{(*)0}$ modes as possible.

Preface: Analysis Techniques

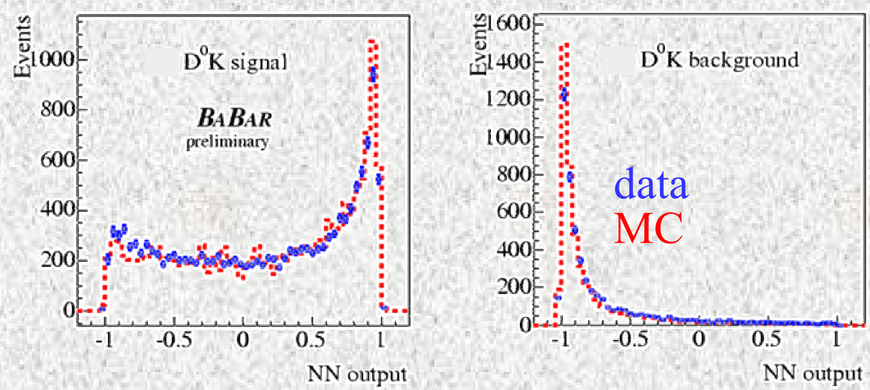
1. B-meson identification



$$m_{ES} = \sqrt{E_{beam}^2 - p_B^2}$$

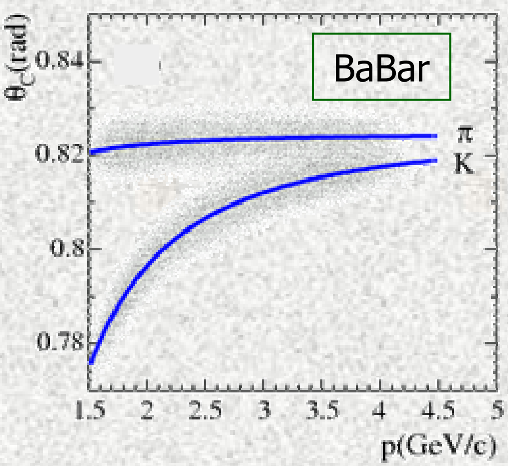
$$\Delta E = E_B^* - E_{beam}^*$$

2. Combinatoric $e^+e^- \to q\bar{q}$ bkg suppression



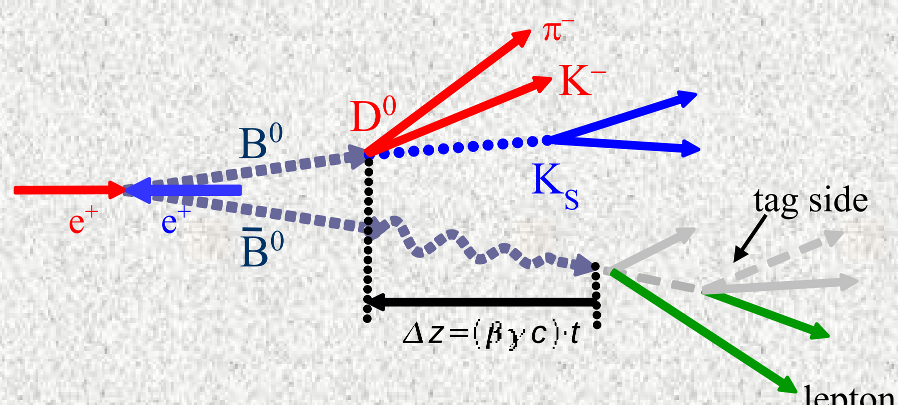
Event topological variables combined in *Neural Network* or *Fisher discriminant*

3. K/π separation (Cherenkov angle / TOF)



Excellent separation between 1.5 and 4 GeV/c

4. Time-dependent measurements (only $B^0/\bar{B}^0$)



Coherent $B^0\bar{B}^0$ production from $\Upsilon(4S)$
boost $\beta\gamma \approx 0.55/0.42$ allows Δt measurement

GLW Method

$B^+ \to D^{(*)}_{CP} K^{(*)+}$

- Reconstruct D meson in CP-eigenstates (accessible to D^0 and $\bar{D}^0$)
- Theoretically very clean ("golden mode") to determine γ
- Relatively large BFs (10^{-5}), small CP asymmetry

CP even modes:	K^+K^-, $\pi^+\pi^-$
CP odd modes:	$K_S\pi^0$, $K_S\omega$, $K_S\phi$, $K_S\eta$

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

$$R_{CP\pm} = \frac{R^{D_{CP\pm}}}{R^{D^0}} = 1 + r_B^2 \pm 2 r_B \cos\gamma \cos\delta_B$$

Phys. Lett. B253, 483 (1991); Phys. Lett. B265, 172 (1991); Phys. Lett. B557, 198 (2003)

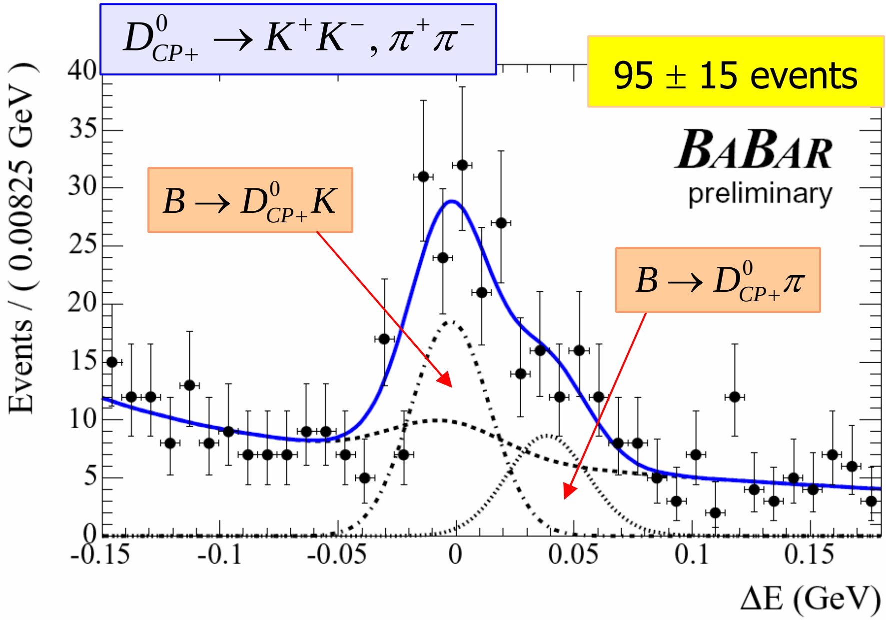
$\Rightarrow$ 3 Independent measurements ($A_+R_+ = -A_-R_-$) and 3 unknowns (r_B, γ, δ_B)

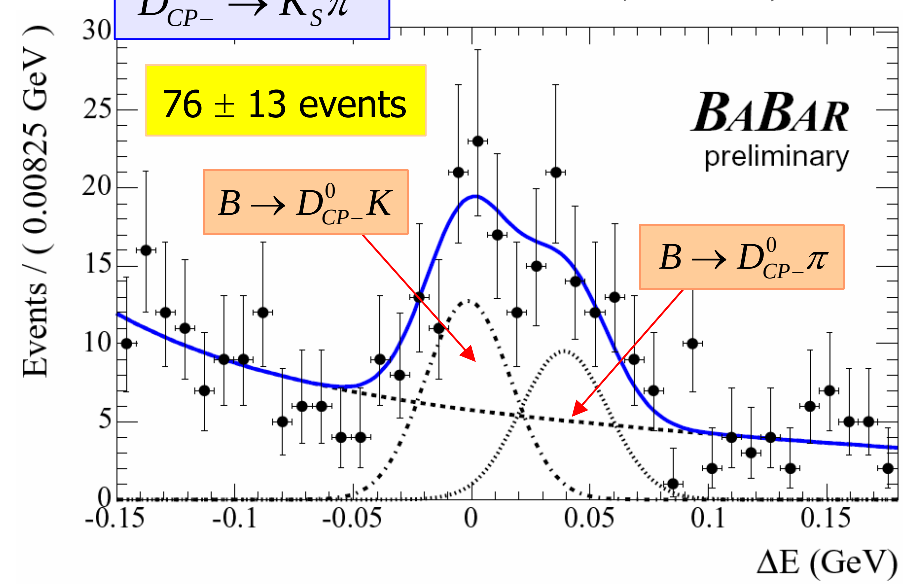
$$\left(R^{D_{CP\pm}} = \frac{\Gamma\left(B^- \to D_{CP\pm}K^-\right) + \Gamma\left(B^+ \to D_{CP\pm}K^+\right)}{\Gamma\left(B^- \to D_{CP\pm}\pi^-\right) + \Gamma\left(B^+ \to D_{CP\pm}\pi^+\right)} \quad ; \quad R^{D^0} = \frac{\Gamma\left(B^- \to D^0 K^-\right) + \Gamma\left(B^+ \to \bar{D}^0 K^+\right)}{\Gamma\left(B^- \to D^0\pi^-\right) + \Gamma\left(B^+ \to \bar{D}^0\pi^+\right)} \right)$$

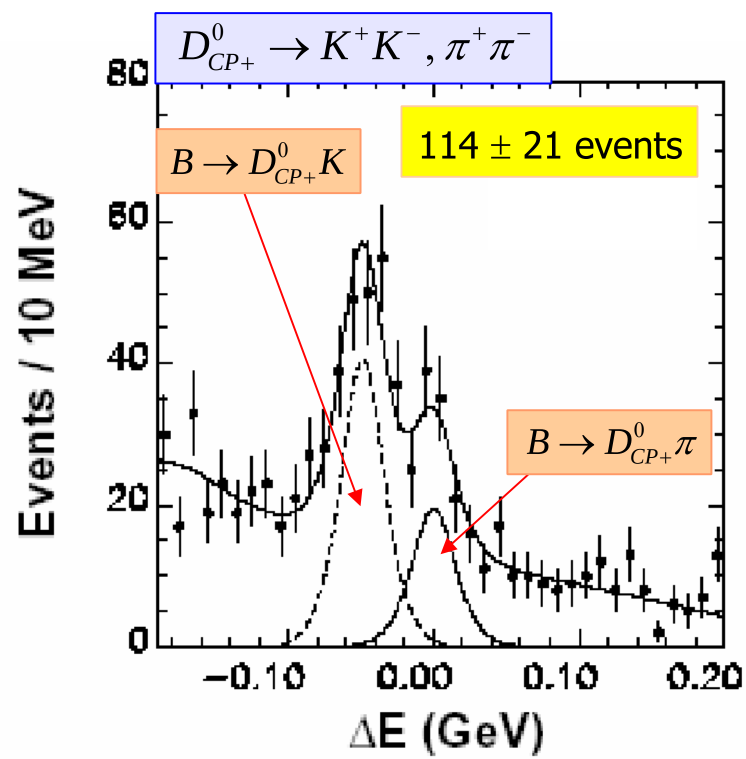
GLW Method Results

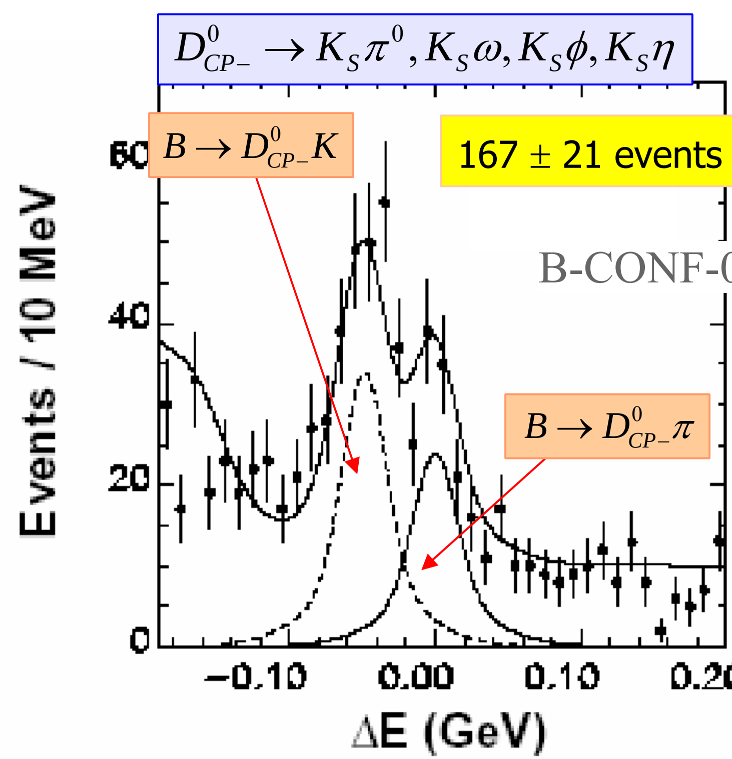
$B^+ \rightarrow D_{CP}^{(*)} K^{(*)+}$

PRL92,202002, 214M $B\bar{B}$









B-CONF-0443, 275M $B\bar{B}$

GLW Results Combined $B^+ \rightarrow D^{(*)}_{CP} K^{(*)+}$

$D^0_{CP}\ K^-$	BaBar PRL92,202002, 214M $B\bar{B}$	Belle B-CONF-0443, 275M $B\bar{B}$	Average (HFAG)
R_{CP}^+	$0.87 \pm 0.14 \pm 0.06$	$0.98 \pm 0.18 \pm 0.10$	0.91 ± 0.12
R_{CP}^-	$0.80 \pm 0.14 \pm 0.08$	$1.29 \pm 0.16 \pm 0.08$	1.02 ± 0.12
A_{CP}^+	$+0.40 \pm 0.15 \pm 0.08$	$+0.07 \pm 0.14 \pm 0.06$	$+0.22 \pm 0.11$
A_{CP}^-	$+0.21 \pm 0.17 \pm 0.07$	$-0.11 \pm 0.14 \pm 0.05$	$+0.02 \pm 0.12$

$D^{*0}_{CP}\ K^-$ ($D^* \rightarrow D^0_{CP}\pi^0$)	BaBar PRD71,031102, 123 M $B\bar{B}$	Belle B-CONF-0443, 275M $B\bar{B}$	Average (HFAG)
R_{CP}^+	$+1.06 \pm 0.26\ ^{+0.10}_{-0.09}$	$1.43 \pm 0.28 \pm 0.06$	1.24 ± 0.20
R_{CP}^-		$0.94 \pm 0.28 \pm 0.06$	0.94 ± 0.29
A_{CP}^+	$-0.10 \pm 0.23\ ^{+0.03}_{-0.04}$	$-0.27 \pm 0.25 \pm 0.04$	-0.18 ± 0.17
A_{CP}^-		$+0.26 \pm 0.26 \pm 0.03$	$+0.26 \pm 0.26$

$D^0_{CP}\ K^{*-}$ ($K^{*-} \rightarrow K_S\pi^-$)	BaBar hep-ex/0408069, 227M $B\bar{B}$		Average (HFAG)
R_{CP}^+	$1.77 \pm 0.37 \pm 0.12$		1.77 ± 0.39
R_{CP}^-	$0.76 \pm 0.29 \pm 0.06\ ^{+0.04}_{-0.14}$ (*)	Belle hep-ex/0307074, 96M $B\bar{B}$	$0.76\ ^{+0.30}_{-0.33}$
A_{CP}^+	$-0.09 \pm 0.20 \pm 0.06$	$-0.02 \pm 0.33 \pm 0.07$	-0.07 ± 0.18
A_{CP}^-	$-0.33 \pm 0.34 \pm 0.10 \pm^{(0.15\pm0.10)}_{\times (A_{CP-}-A_{CP+})}$ (*)	$0.19 \pm 0.50 \pm 0.04$	-0.16 ± 0.29

No useful constraints on γ yet due to small branching ratios and limited statistics.

(*) CP-even pollution in the CP-odd channels

ADS Method

$B^+ \to D^0_{K\pi} h^+$

- Reconstruct D in final state Kπ - small BF (10^{-6})

Phys. Rev. Lett. 78, 3257 (1997)

suppressed

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

$\hookrightarrow K^+\pi^-$

favored

interference

favored

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

$\hookrightarrow K^+\pi^-$

suppressed

- Amplitude: $A\left(B^- \to \left[K^+\pi^-\right]K^-\right) \propto r_B e^{i\delta_B} e^{-i\gamma} + r_D e^{i\delta_D}$

PDG, Phys.Lett. B592, 1 (2004)

$$r_D \equiv \left|\frac{A\left(D^0 \to K^+\pi^-\right)}{A\left(D^0 \to K^-\pi^+\right)}\right| \approx 0.060 \pm 0.003$$

δ_D : D decay strong phase unknown. Scan over all values.

☺ Amplitudes comparable in size $\to$ large CP violation

$$\left|\frac{A\left(B^- \to K^-\bar{D}^0\left[\to K^+\pi^-\right]\right)}{A\left(B^- \to K^- D^0\left[\to K^+\pi^-\right]\right)}\right|^2 \sim \left|\frac{V_{ub}V_{cs}^*}{V_{cb}V_{us}^*}\right|^2 \left|\frac{a_2}{a_1}\right|^2 \frac{\Gamma\left(\bar{D}^0 \to K^+\pi^-\right)}{\Gamma\left(D^0 \to K^+\pi^-\right)} \sim 1$$

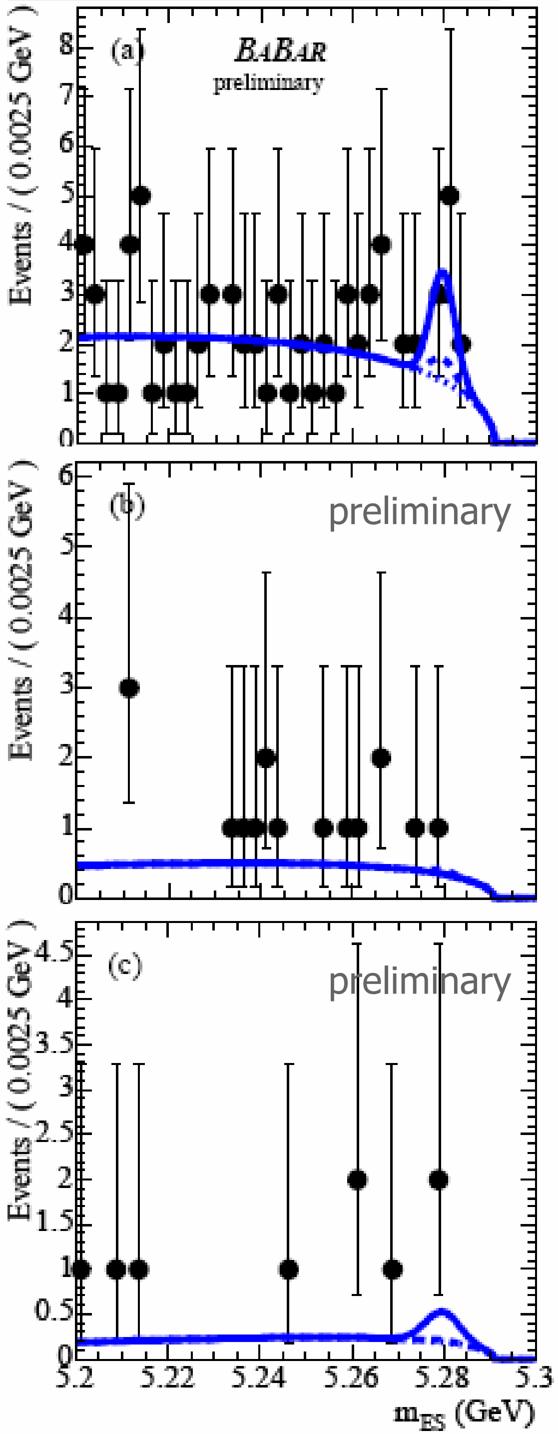
- Count B candidates with opposite sign kaons!

2 observables vs 3 unknowns: r_B, γ, δ_B

$$A_{ADS} = \frac{\Gamma\left(B^- \to \left[K^+\pi^-\right]K^-\right) - \Gamma\left(B^+ \to \left[K^-\pi^+\right]K^+\right)}{\Gamma\left(B^- \to \left[K^+\pi^-\right]K^-\right) + \Gamma\left(B^+ \to \left[K^-\pi^+\right]K^+\right)} = \frac{2 r_B r_D \sin\gamma \sin\left(\delta_B - \delta_D\right)}{R_{ADS}}$$

$$R_{ADS} = \frac{\Gamma\left(B^- \to \left[K^+\pi^-\right]K^-\right) + \Gamma\left(B^+ \to \left[K^-\pi^+\right]K^+\right)}{\Gamma\left(B^- \to \left[K^-\pi^+\right]K^-\right) + \Gamma\left(B^+ \to \left[K^+\pi^-\right]K^+\right)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\gamma \cos\left(\delta_B + \delta_D\right)$$

BABAR: 227M $B\bar{B}$ — ADS Method Results — $B^+ \to D^0_{K\pi} h^+$



227 M $B\bar{B}$ preliminary

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

N $= 4.7^{+4.0}_{-3.2}$

$R_{ADS} = 0.013^{+0.011}_{-0.009}$

$B^+ \to [D^0\pi^0]_{D*} K^+$

N $= -0.2^{+1.3}_{-0.8}$

$R_{ADS} = -0.002^{+0.010}_{-0.006}$

No signal observed!

$B^+ \to [D^0\gamma]_{D*} K^+$

N $= 1.2^{+2.1}_{-1.4}$

$R_{ADS} = 0.011^{+0.018}_{-0.013}$

hep-ex/0408028

275 M $B\bar{B}$ PRL 94, 091601

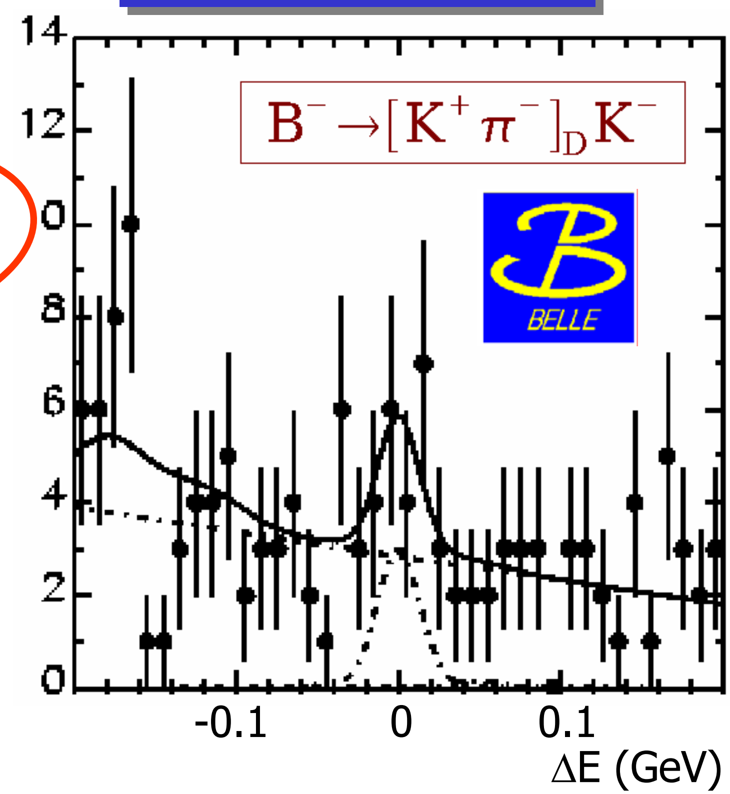
$B^+ \to D^0K^+$

N $= 8.5^{+6.0}_{-5.3}$ (2.3σ)

$R_{ADS} = 0.023^{+0.016}_{-0.014} \pm 0.001$

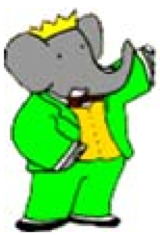
$A_{ADS} = +0.88^{+0.77}_{-0.62} \pm 0.06$

BELLE: 275M $B\bar{B}$



ADS Method Results

$B^+ \rightarrow D^0_{K\pi} h^+$

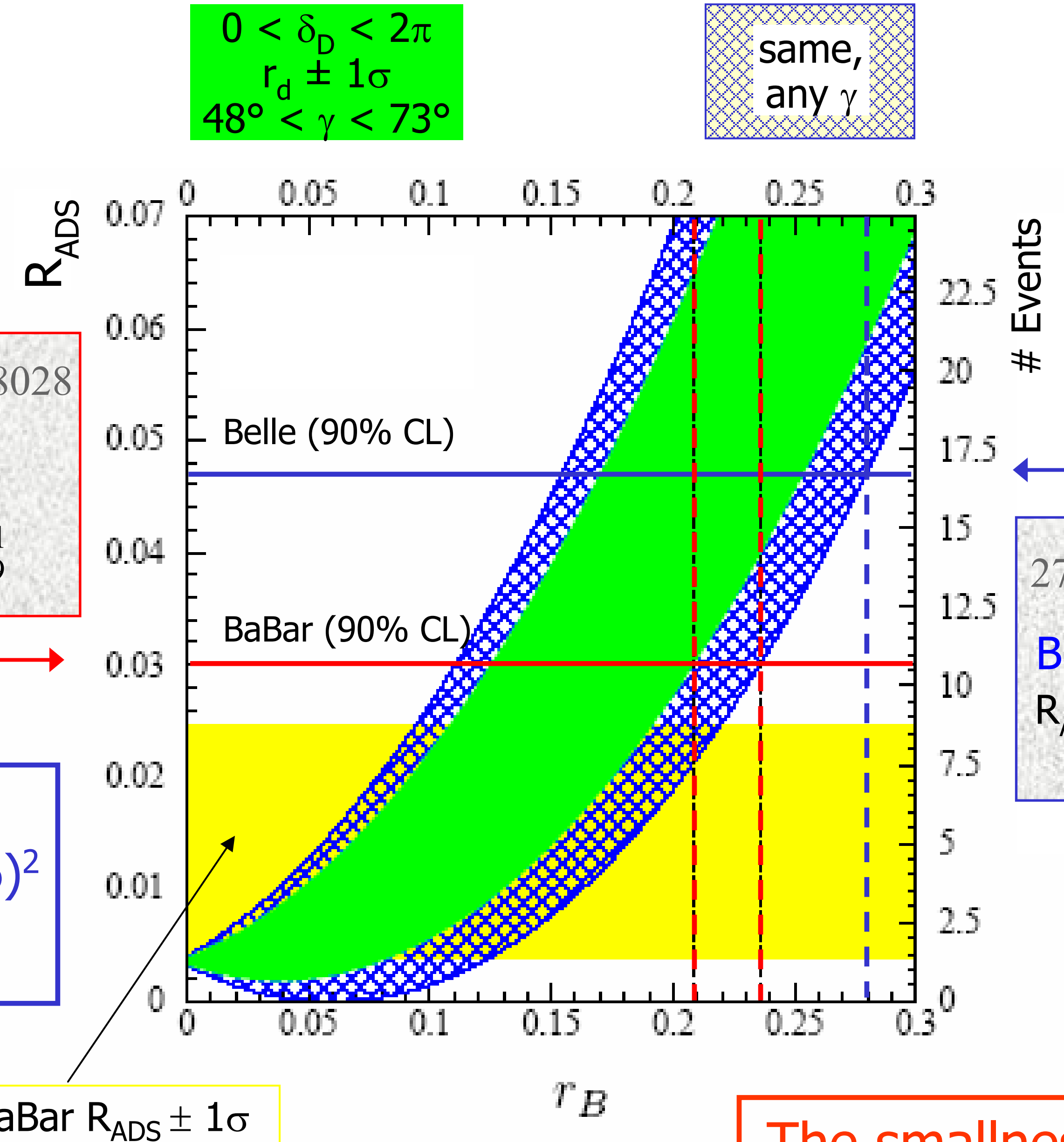


227 M $B\bar{B}$ hep-ex/0408028

$B^+ \rightarrow D^0 K^+$

$R_{ADS} = 0.013^{+0.011}_{-0.009}$

DK: $r_B < 0.23$
D*K: $r^{*2}_B < (0.16)^2$
@ 90% C.L.



275 M $B\bar{B}$ PRL 94, 091601

$B^+ \rightarrow D^0 K^+$

$R_{ADS} = 0.023^{+0.016}_{-0.014} \pm 0.001$

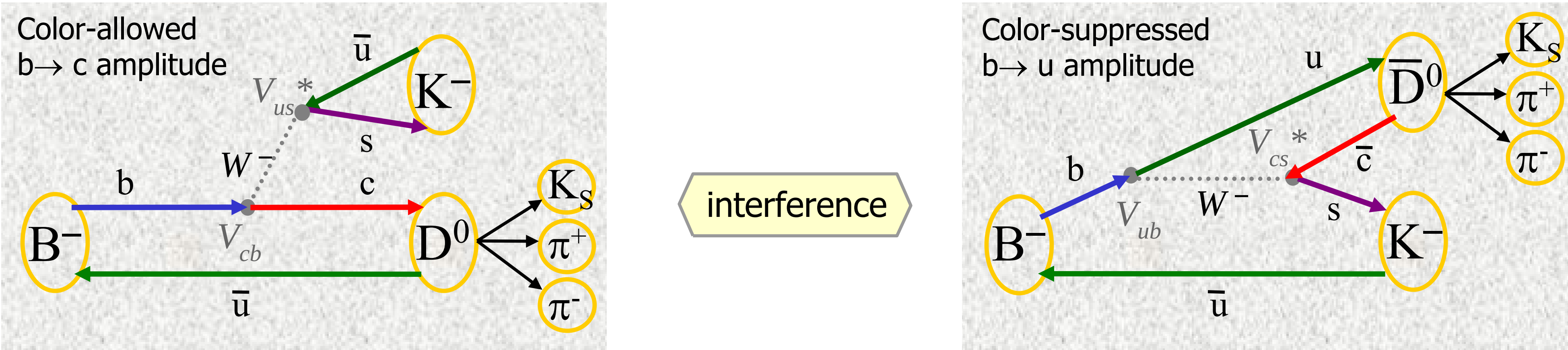
DK: $r_B < 0.27$
@ 90% C.L.

The smallness of r_B makes the extraction of γ with GLW/ADS difficult!

GGSZ Method

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

Phys. Rev. D68, 054018 (2003)

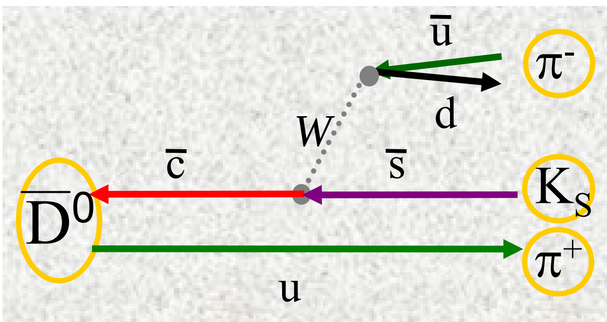


- Reconstruct D in final state: $K_S\, \pi^+\pi^-$ (not a CP-eigenstate)
- Employs K-$\bar{K}$ mixing ("cheap" decay-mode: high BF ~2.2×10^{-5})
- Final state accessible through many intermediate non-CP states. Need Dalitz analysis to separate resonance interferences!

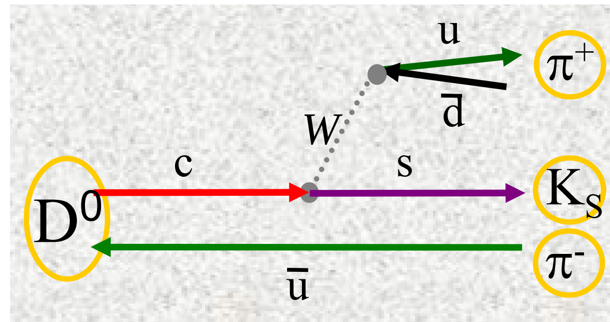
GGSZ Method

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

- D decay amplitude f consists of sum of many resonances (more on next slide).
- Amplitude f parameterized in terms of Dalitz variables m_+^2 and m_-^2



$\bar{D}^0 \to K_S \pi^+ \pi^- \propto f\left(m_+^2, m_-^2\right)$

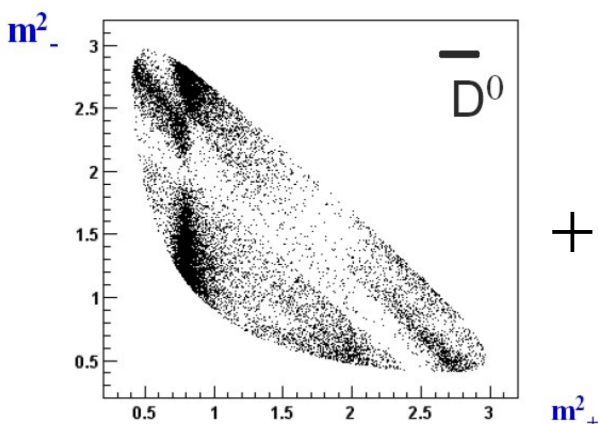


$D^0 \to K_S \pi^+ \pi^- \propto f\left(m_-^2, m_+^2\right)$

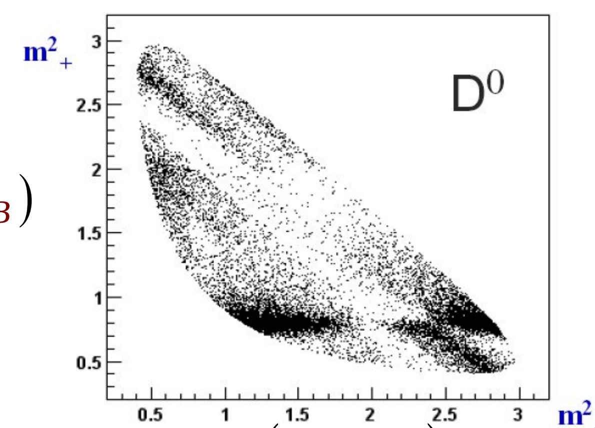
$$m_+^2 = m_{K_S \pi^+}^2$$
$$m_-^2 = m_{K_S \pi^-}^2$$

- Decay rates Γ of B^+ and B^- written as:

$$\Gamma^\pm = \Bigg| \quad + r_B\, e^{i(\pm\gamma + \delta_B)} \quad \Bigg|^2$$



$f\left(m_\pm^2, m_\mp^2\right)$



$f\left(m_\mp^2, m_\pm^2\right)$

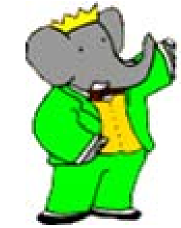
Simultaneous fit to $D \to K_S \pi^+ \pi^-$ Dalitz planes of B^+ and B^- to extract r_B, γ, and δ

$D^0 \to K_S\, \pi^+ \pi^-$ Dalitz Model

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

- To extract r_B and γ need high-precision D decay model $f(m_+^2, m_-^2)$
- Obtain $f(m_+^2, m_-^2)$ using fit to "tagged" D^0 sample:

$\Rightarrow$ Use large $D^{*+} \to D^0\pi^+$ sample. Charge of the pion gives flavor of D.

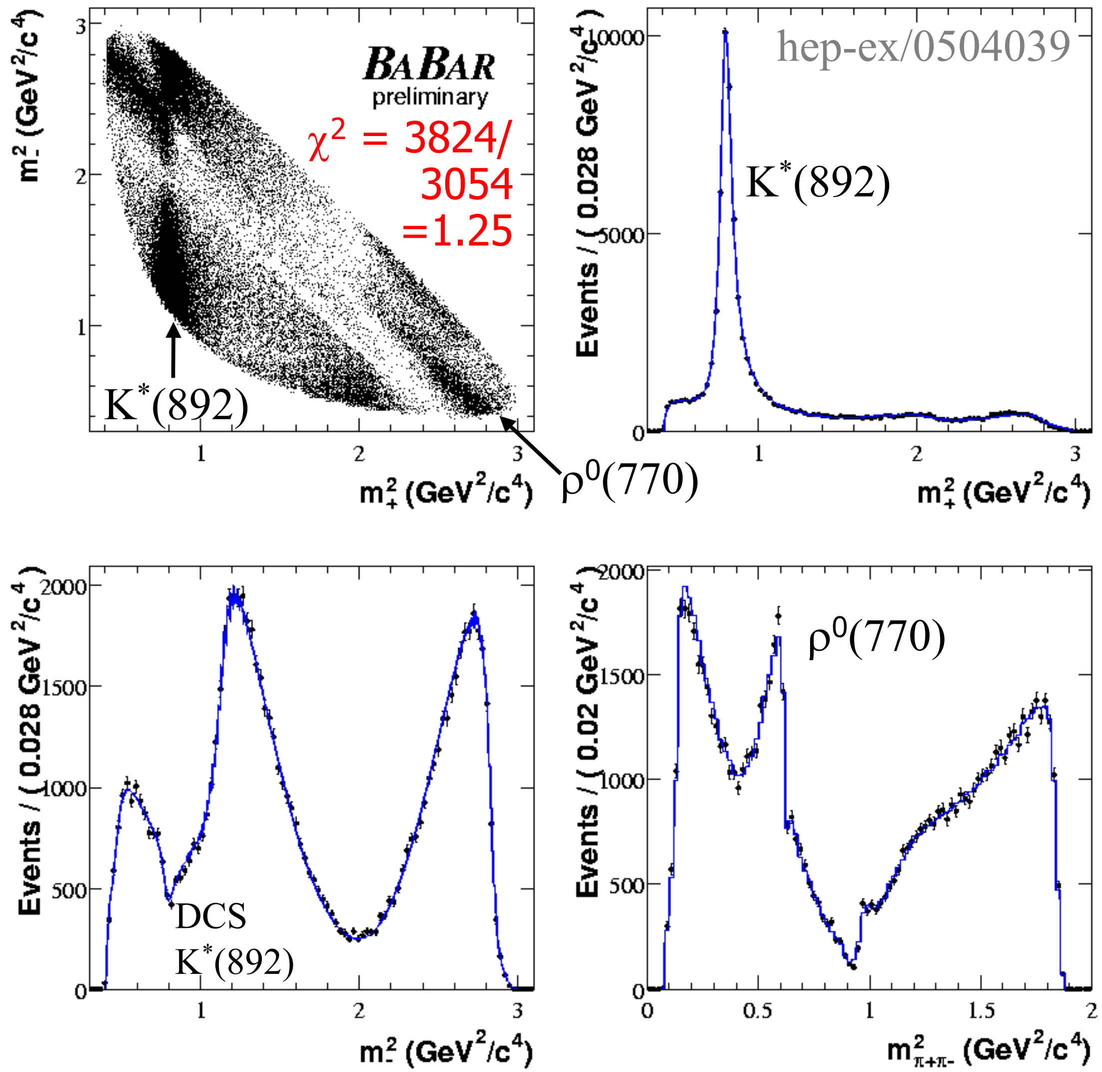


Isobar formalism, no D mixing, no CPV in D decays

Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.781 ± 0.018	131.0 ± 0.82	0.586
$K_0^*(1430)^-$	2.447 ± 0.076	-8.3 ± 2.5	0.083
$K_2^*(1430)^-$	1.054 ± 0.056	-54.3 ± 2.6	0.027
$K^*(1410)^-$	0.515 ± 0.087	154 ± 20	0.004
$K^*(1680)^-$	0.89 ± 0.30	-139 ± 14	0.003
			DCS
$\rho(770)$	1 (fixed)	0 (fixed)	0.224
$\omega(782)$	0.0391 ± 0.0016	115.3 ± 2.5	0.006
$f_0(980)$	0.4817 ± 0.012	-141.8 ± 2.2	0.061
$f_0(1370)$	2.25 ± 0.30	113.2 ± 3.7	0.032
$f_2(1270)$	0.922 ± 0.041	-21.3 ± 3.1	0.030
$\rho(1450)$	0.516 ± 0.092	38 ± 13	0.002
Non Resonant	3.53 ± 0.44	127.6 ± 6.4	0.073

13 resonances ,
1 non-resonant component

$D^{*+} \to D^0\pi^+$, 81.5k events from 91 fb-1, purity 97%



$D^0 \to K_S \pi^+ \pi^-$ Dalitz Model

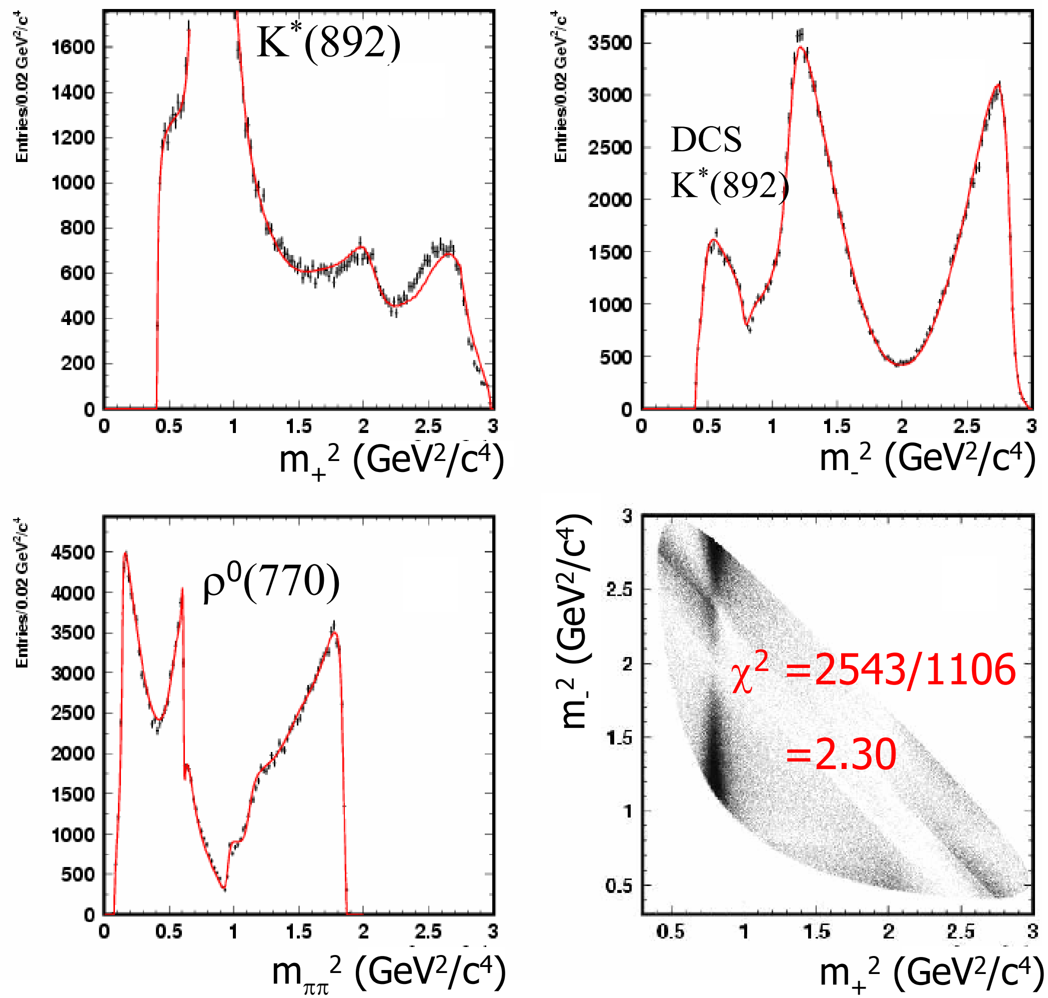
$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

hep-ex/0411049

- Belle: indentical approach
- Include two more DCS resonances: $K^{*+}(1410)\,\pi^-$, $K^{*+}(1680)\pi^-$
- 13 resonances , , 1 non-resonant component

$D^{*+} \to D^0\pi^+$, 186.9k events, purity 97%

Intermediate state	Amplitude	Phase (°)	Fit fraction
$K_S\rho^0$	1.0 (fixed)	0 (fixed)	21.6%
$K_S\omega$	0.0310 ± 0.0010	113.4 ± 1.9	0.4%
$K_S f_0(980)$	0.394 ± 0.006	207 ± 3	4.9%
$K_S f_2(1270)$	1.32 ± 0.04	348 ± 2	1.5%
$K_S f_0(1370)$	1.25 ± 0.10	69 ± 8	1.1%
$K_S\rho^0(1450)$	0.89 ± 0.07	1 ± 6	0.4%
$K^*(892)^+\pi^-$	1.621 ± 0.010	131.7 ± 0.5	61.2%
$K^*(1410)^+\pi^-$	0.22 ± 0.04	120 ± 14	0.05%
$K_0^*(1430)^+\pi^-$	2.15 ± 0.04	348.7 ± 1.1	7.4%
$K_2^*(1430)^+\pi^-$	1.11 ± 0.03	320.5 ± 1.8	2.2%
$K^*(1680)^+\pi^-$	2.34 ± 0.26	110 ± 5	0.36%
non-resonant	3.8 ± 0.3	157 ± 4	9.7%

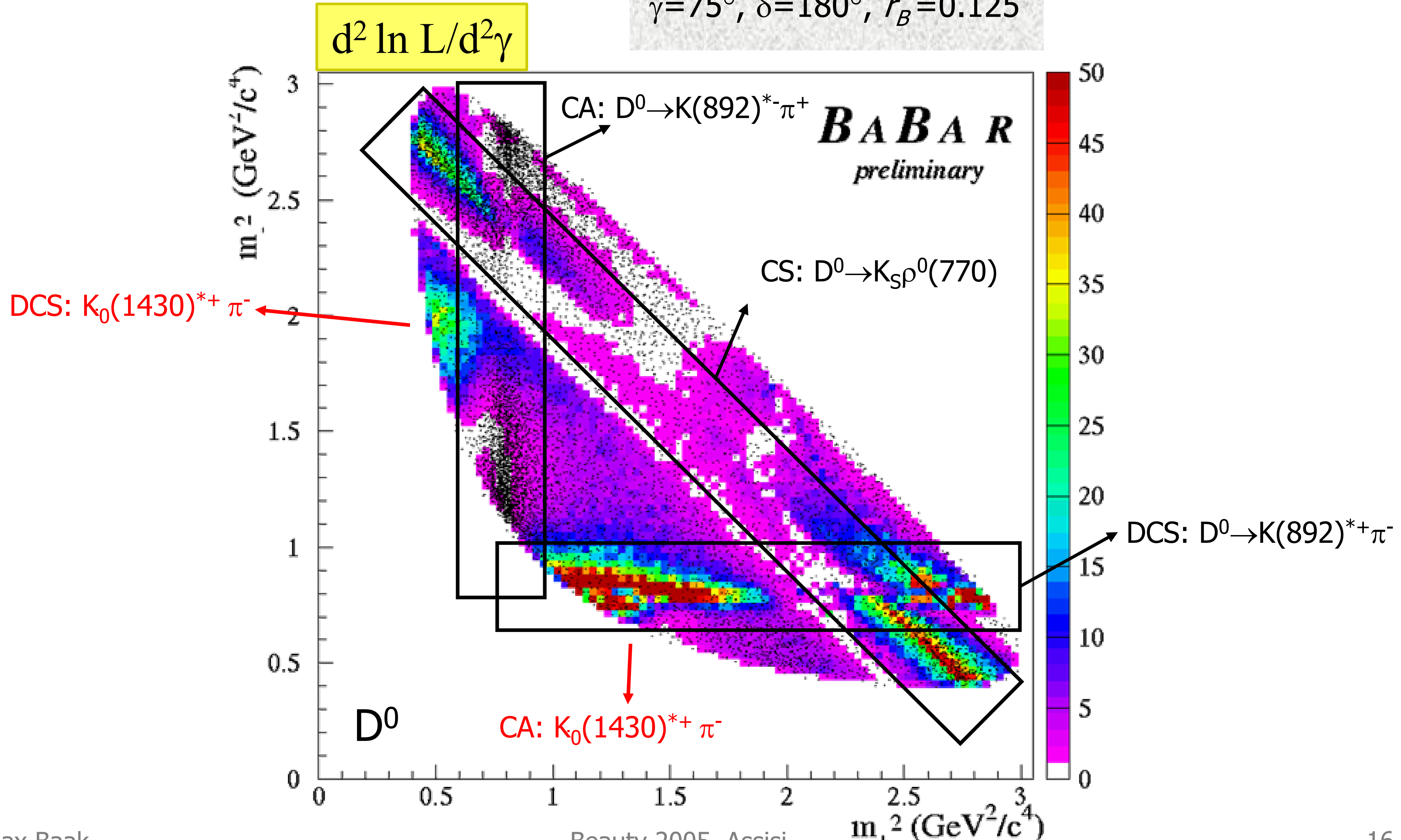


Dalitz sensitivity scan to γ

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

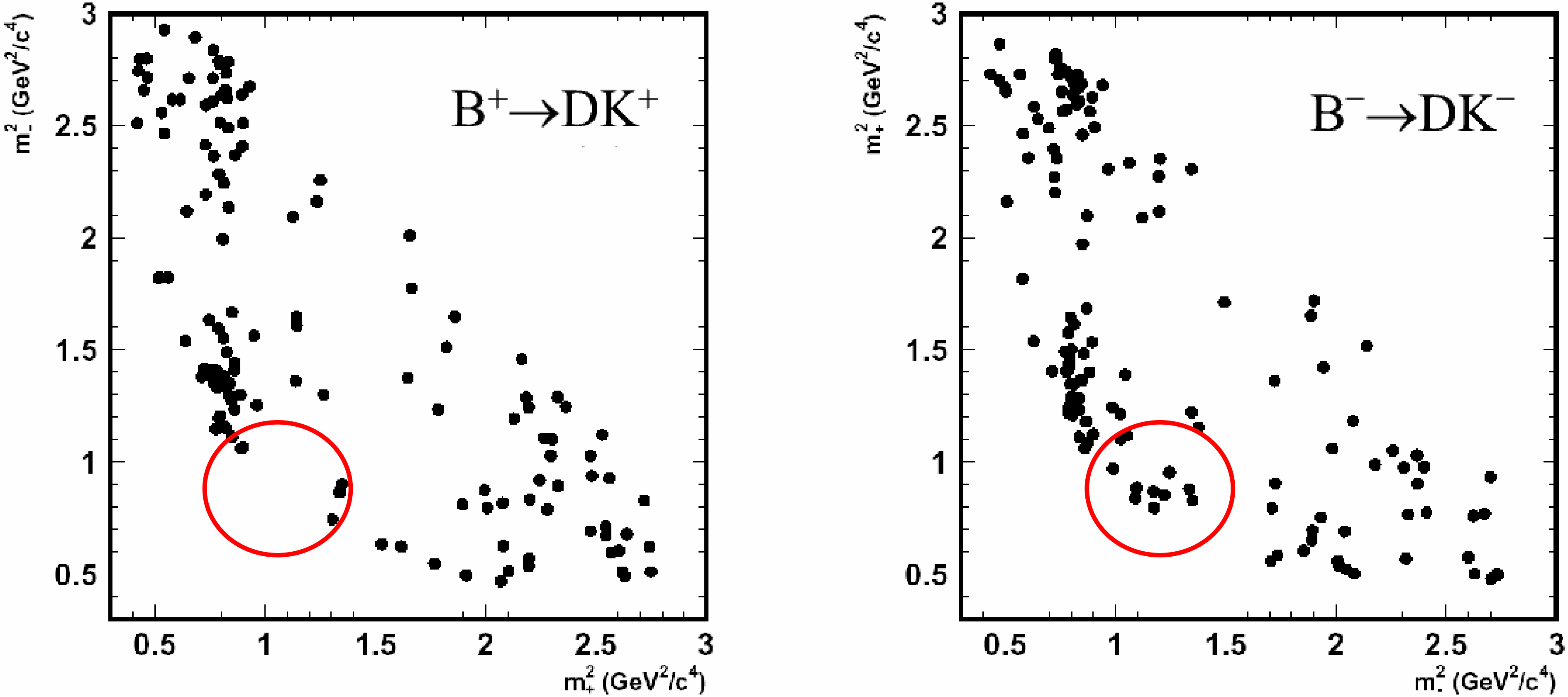
CA: Cabibbo Allowed
DCS: Doubly-Cabibbo Suppressed
CS: Color Suppressed

Sensitivity to γ (MC)
γ=75°, δ=180°, r_B=0.125



Belle B→DK with D→ $K_S \pi^+\pi^-$

275M $B\bar{B}$ hep-ex/0411049



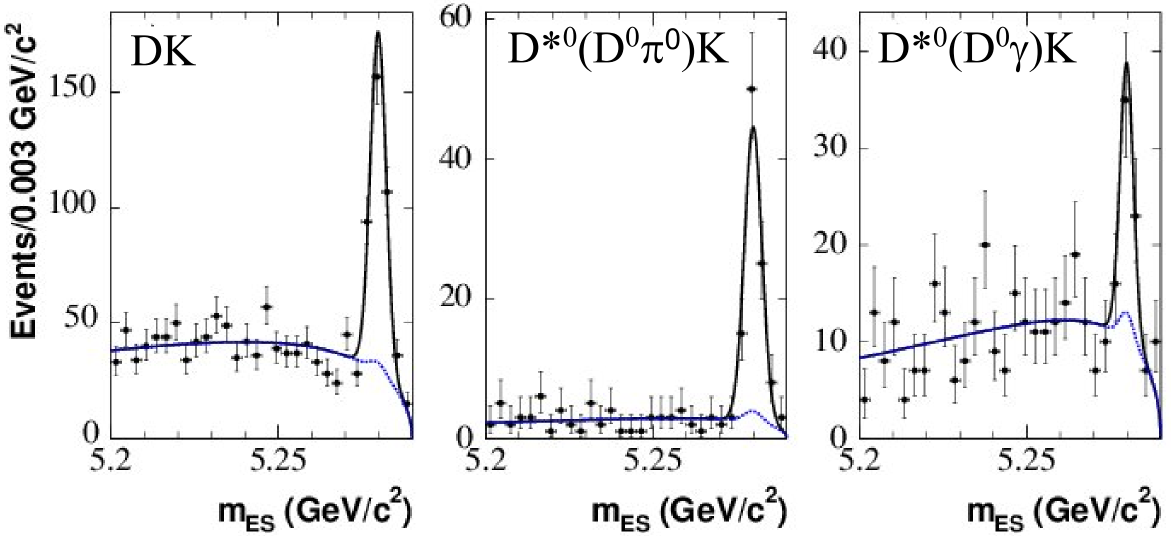
The two plots would be the same without CP violation. Are they?

BaBar GGSZ Method Results

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

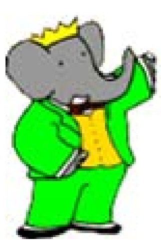
hep-ex/0504039

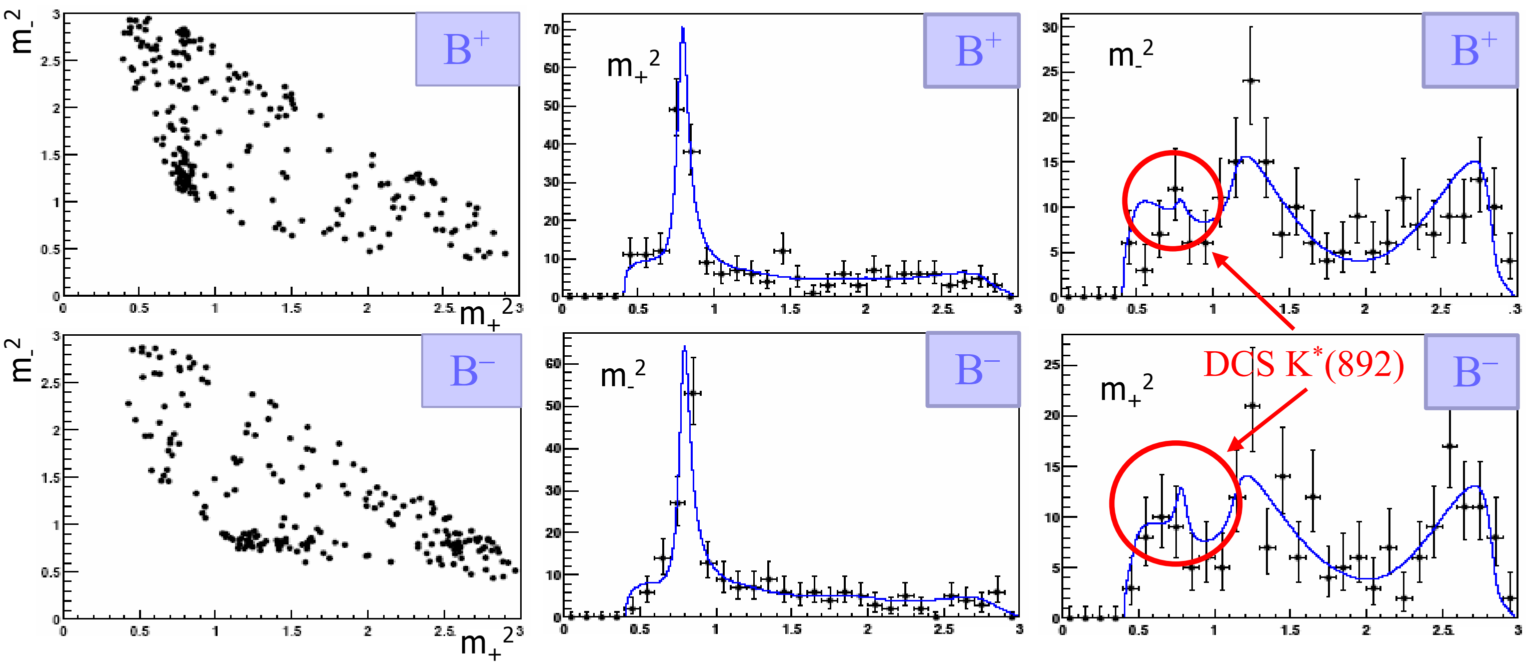
Mode	Signal (events)
$B^+ \to D^0 K^+$	282 ± 20
$B^+ \to D^{*0} K^+$ ($D^{*0} \to D^0 \pi^0$)	90 ± 11
$B^+ \to D^{*0} K^+$ ($D^{*0} \to D^0 \gamma$)	44 ± 8



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

BABAR: 227M $B\bar{B}$

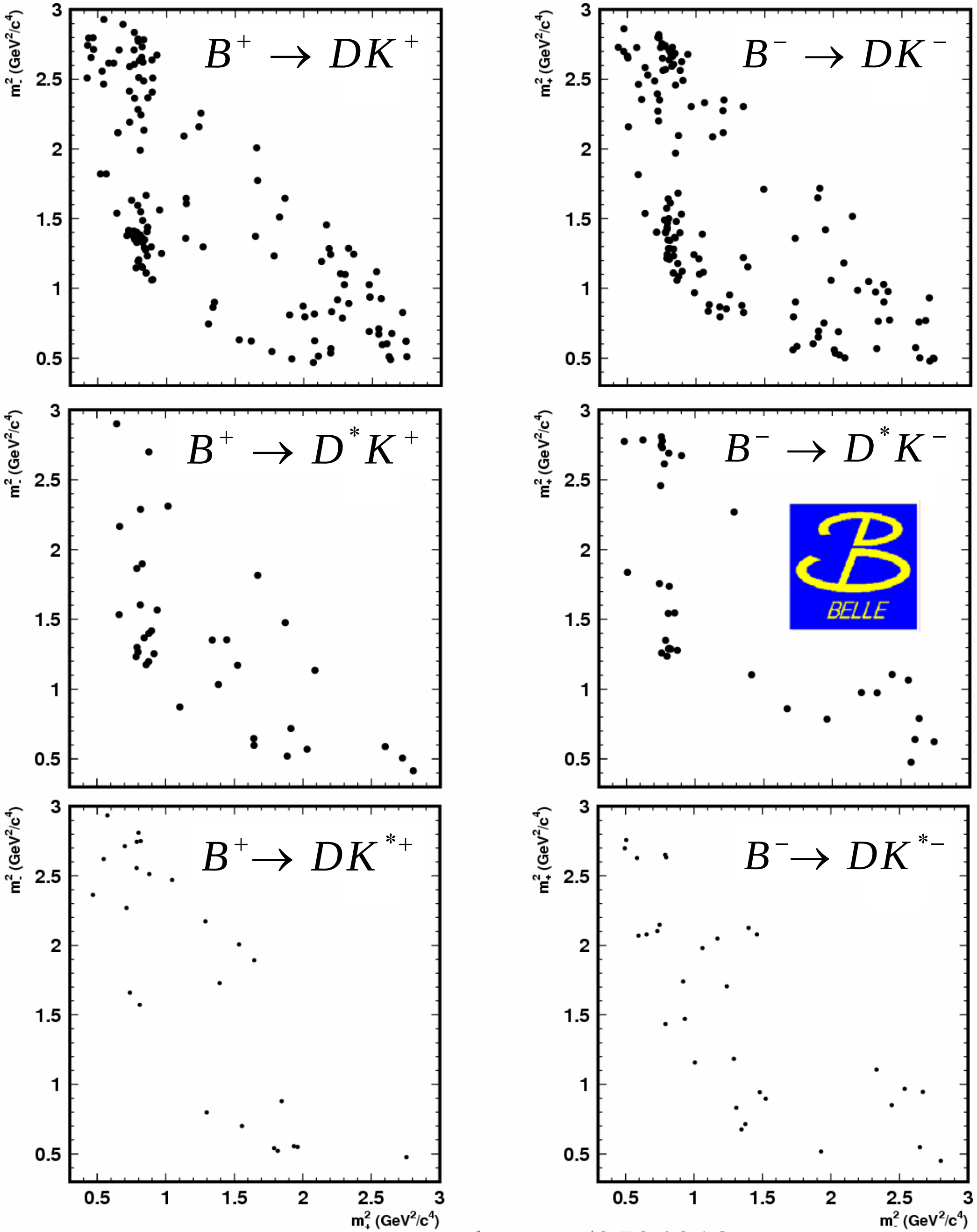




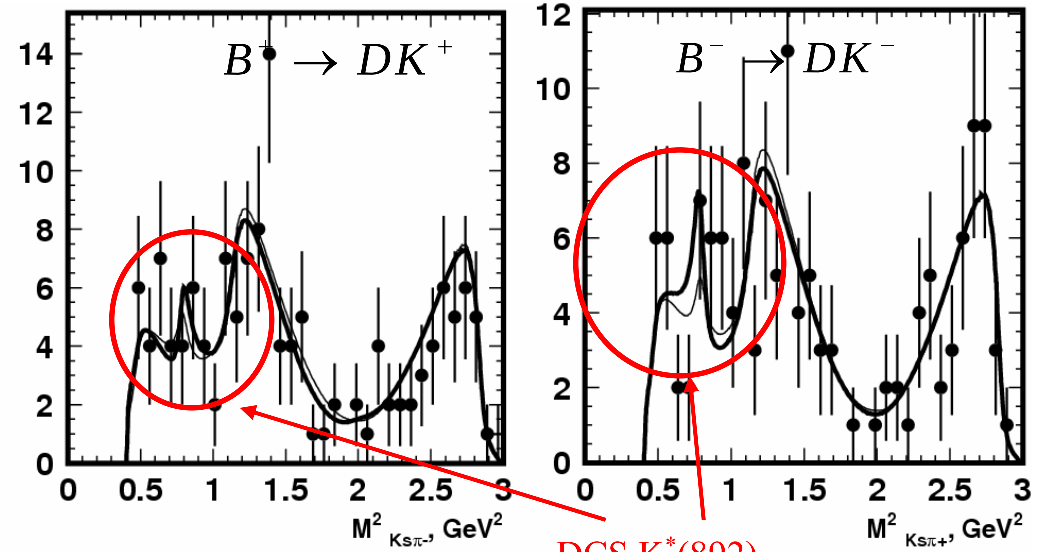
Belle GGSZ Method Results

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

hep-ex/0411049



hep-ex/0504013



- thick black line: with interference
- thin grey line: without interference

BELLE: 275M $B\bar{B}$

Mode	Signal (events)	Bkg.frac. (%)
$B^\pm \to D^0 K^-$	209 ± 16	25 ± 2
$B^\pm \to D^{*0} K^-$	58 ± 8	13 ± 2
$B^\pm \to D^0 K^{*-}$	36 ± 7	27 ± 5

BaBar GGSZ Method Results

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

BABAR: 227M $B\bar{B}$

hep-ex/0504039 preliminary

Frequentist CLs

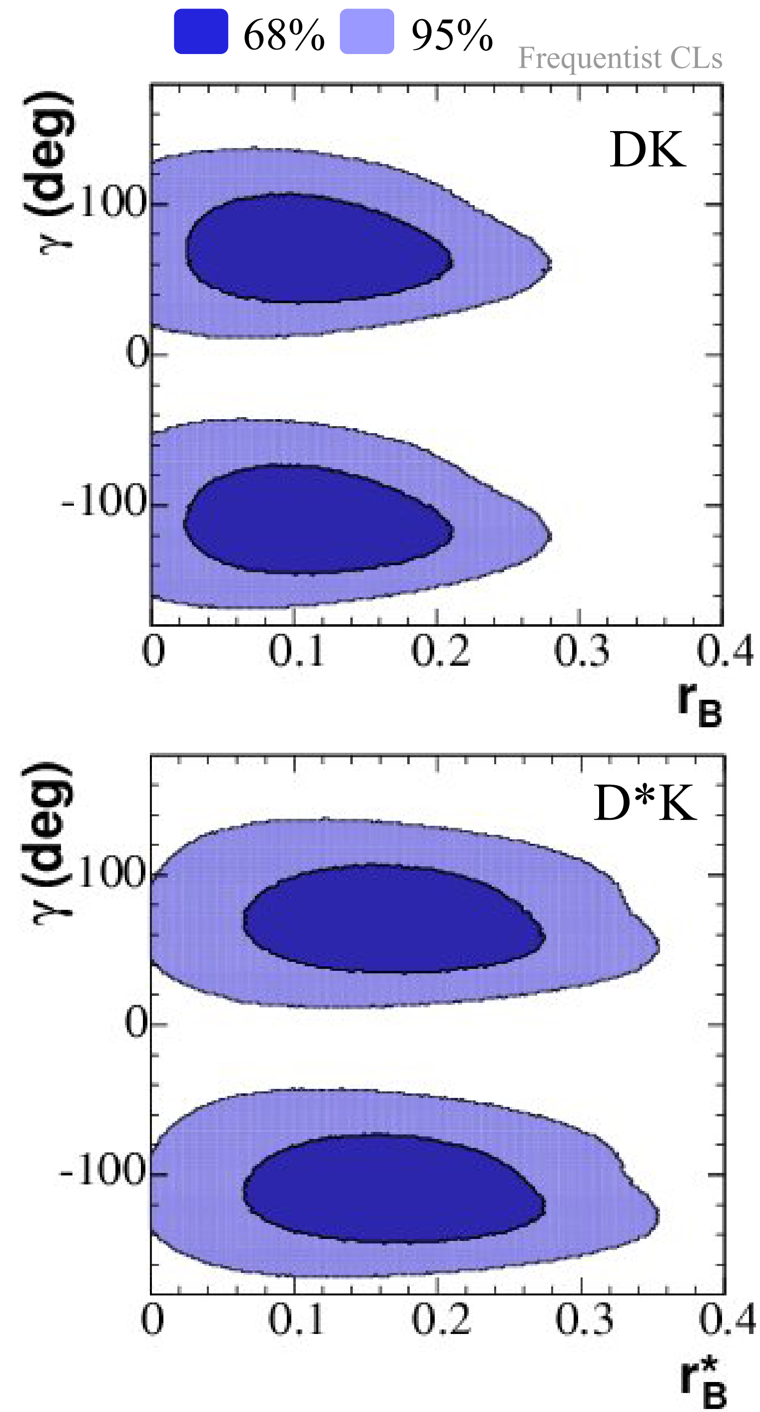
$$DK: \quad r_B = 0.118 \pm 0.079 \pm 0.034\ {}^{+0.036}_{-0.034}$$

$$\delta_B = (\,104 \pm 45\ {}^{+17}_{-21}\ {}^{+16}_{-24}\,)^\circ$$

$$D^*K: \quad r_B^{\,*} = 0.169 \pm 0.096\ {}^{+0.030}_{-0.028}\ {}^{+0.029}_{-0.026}$$

$$\delta_B^{\,*} = (\,296 \pm 41\ {}^{+14}_{-12} \pm 15\,)^\circ$$

$$\gamma = (\,70 \pm \underset{\text{stat.}}{31}\ \underset{\text{syst.}}{{}^{+12}_{-10}}\ \underset{\text{Dalitz}}{{}^{+14}_{-11}}\,)^\circ$$



Belle GGSZ Method Results

$B^+ \to D^{(*)0} K^{(*)+}$
$\overset{(-)}{D}{}^0 \to K_S \pi^+ \pi^-$

hep-ex/0411049
hep-ex/0504013
Frequentist CLs

BELLE: 275M $B\bar{B}$

DK :

$r_B = 0.21 \pm 0.08 \pm 0.03 \pm 0.04$

$\delta_B = (\,157 \pm 19 \pm 11 \pm 21\,)^\circ$

$\gamma = (\,64 \pm 19 \pm 13 \pm 11\,)^\circ$

*D*K* :

$r_B^* = 0.12\,^{+0.16}_{-0.11} \pm 0.02 \pm 0.04$

$\delta_B^* = (\,321 \pm 57 \pm 11 \pm 21\,)^\circ$

$\gamma = (\,75 \pm 57 \pm 11 \pm 11\,)^\circ$

Promising results!

*DK** :

$r_B(K^*) = 0.25\,^{+0.17}_{-0.18} \pm 0.09 \pm 0.04 \pm 0.08$ (*)

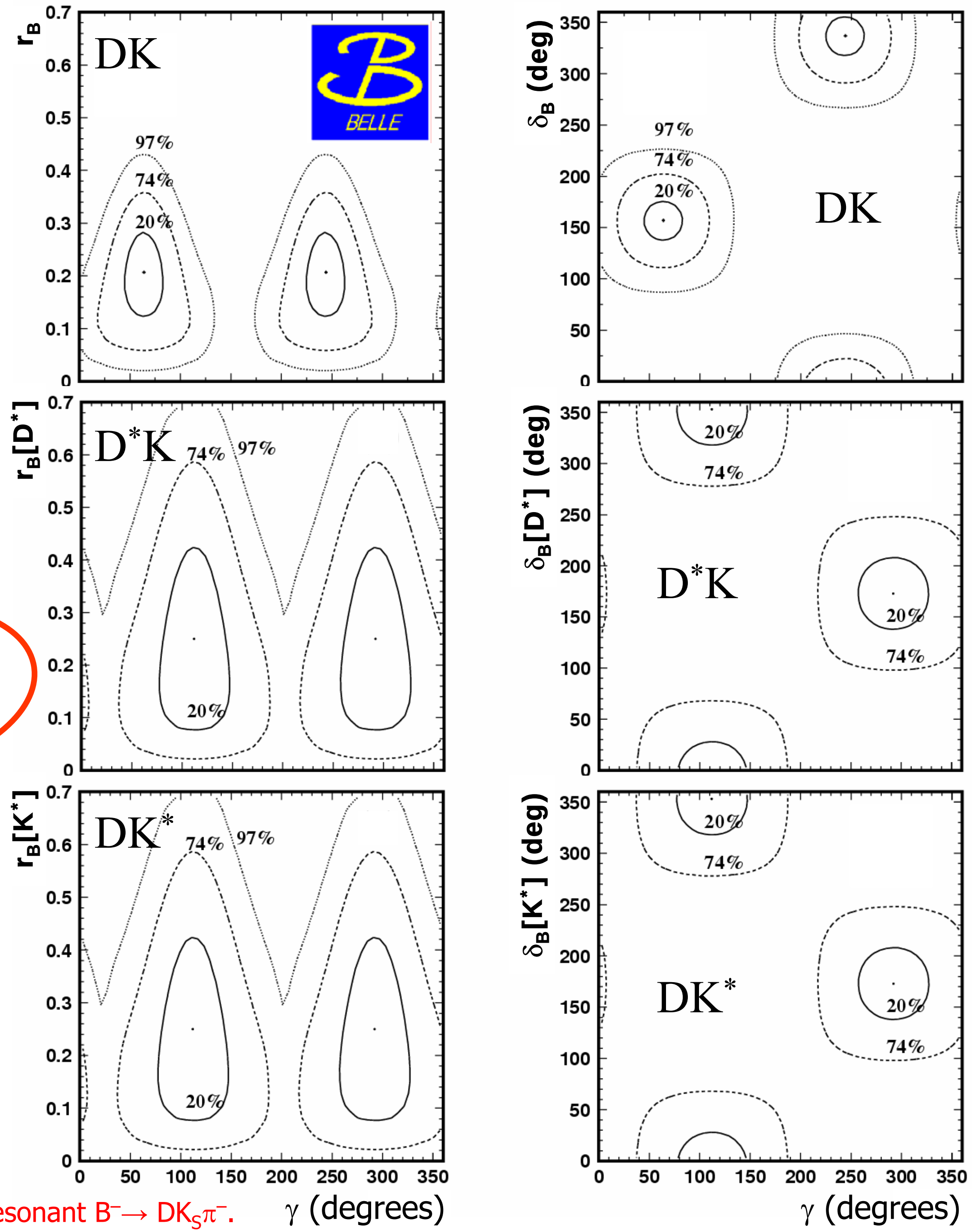
$\delta_B(K^*) = (\,353 \pm 35 \pm 8 \pm 21 \pm 49\,)^\circ$ (*)

$\gamma = (\,112 \pm 35 \pm 9 \pm 11 \pm 8)^\circ$ (*)

Combined result of DK and D*K:

$$\gamma = (\,68\,^{+14}_{-15} \pm 13 \pm 11\,)^\circ$$

stat. syst. Dalitz

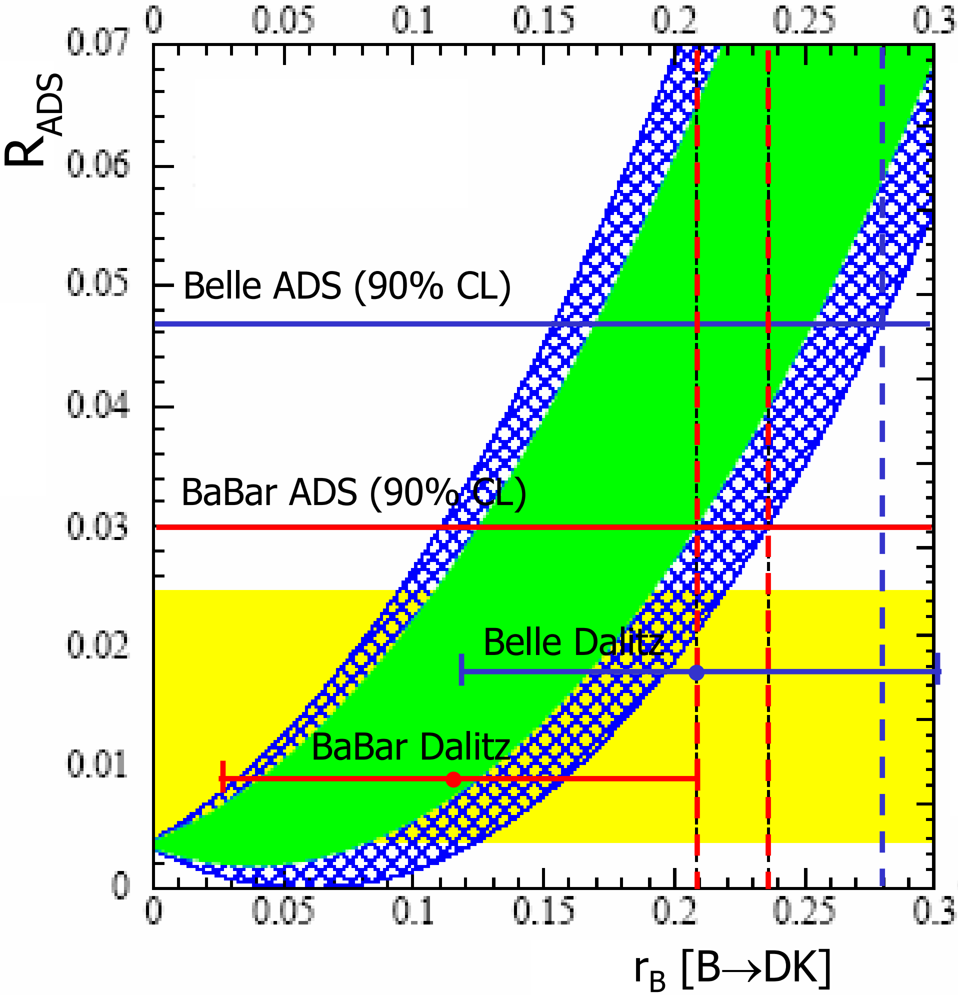


(*) Possible bias caused by a contribution from non-resonant $B^- \to D K_S \pi^-$.

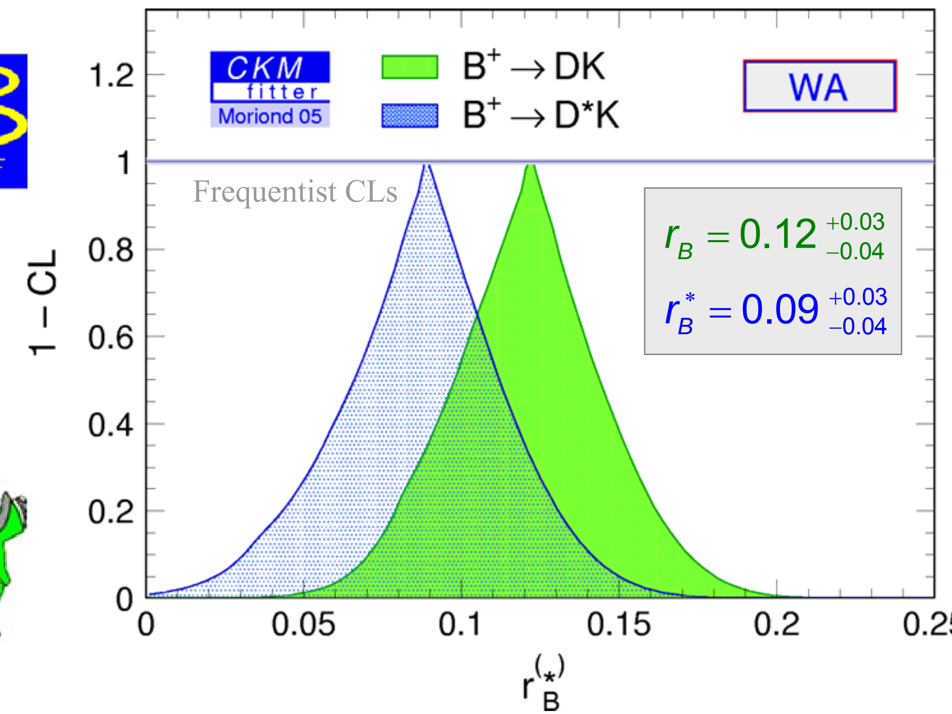
$0 < \delta_D < 2\pi$
$r_d \pm 1\sigma$
$48° < \gamma < 73°$

same, any γ

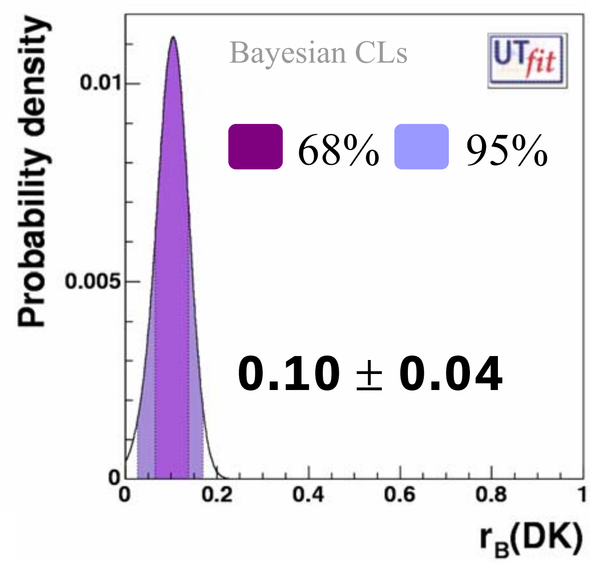
$r_B^{(*)}$ World Average

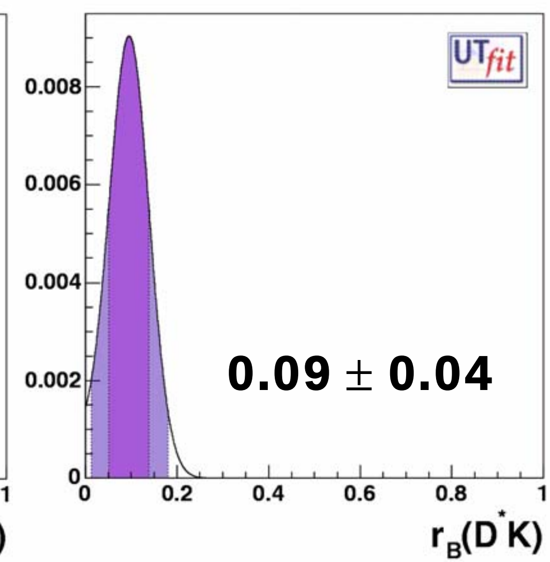


[no improved constraint when adding γ from CKM fit]



Using GLW, ADS, GGSZ results

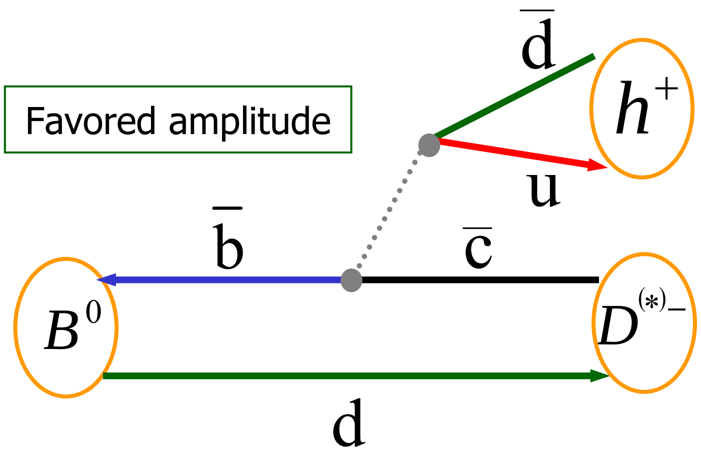


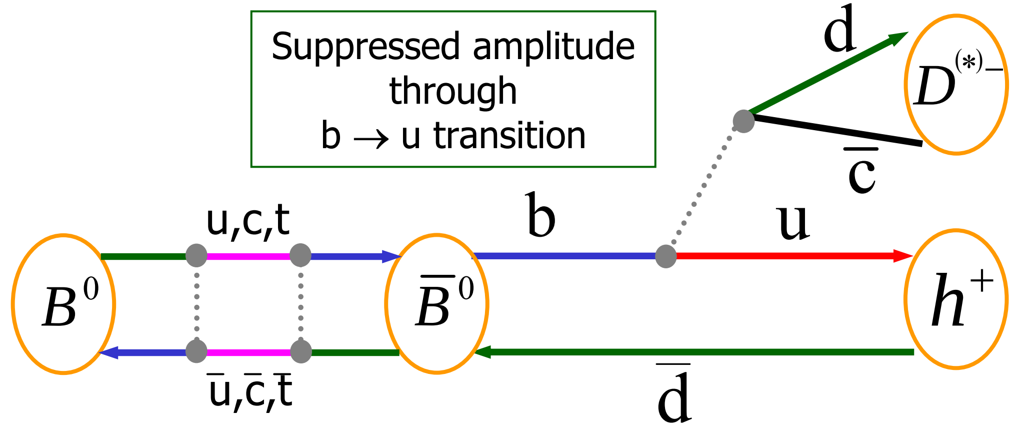


- BaBar ADS limit pushing r_B down.
- Belle Dalitz value (0.21) relatively large.

CP violation in $B^0 \to D^{(*)}\pi/\rho$

- CP violation through B^0-$\bar{B}^0$ mixing and interference of amplitudes:





$$V_{cb}V_{ud}^{*} = A \qquad\qquad V_{ub}V_{cd}^{*}\,e^{i\delta} = r\,A\,e^{-i\gamma}e^{i\delta}$$

Strong phase difference

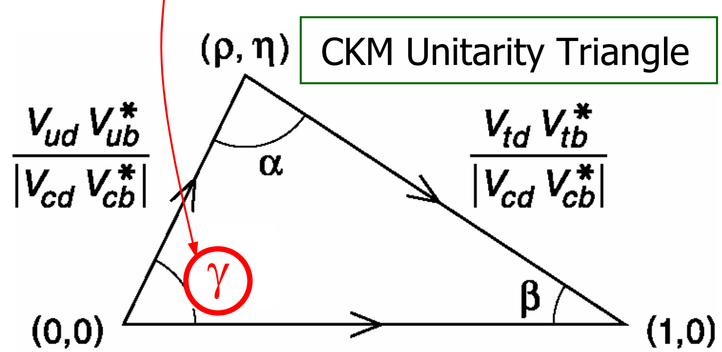
☹ CP violation proportional to ratio r of amplitudes

⇒ Small: $r \approx |V^*_{ub}V_{cd} / V_{cb}V^*_{ud}| \approx 0.020$

☺ Large BF's, at level of 1%

☺ No penguin pollution → theoretically clean

- Relative weak phase γ from b→u transition
- Relative strong phase δ



$\sin(2\beta+\gamma)$ from $B^0 \rightarrow D^{(*)}\pi/\rho$

- Time evolution for B^0 decays and $\overline{B}^0$ decays (R_{mix}) to $D^{(*)}\pi/\rho$:

$$f(B^0(\Delta t) \rightarrow D^{(*)-}\pi^+) = N\exp^{-\Gamma|\Delta t|}\{1 + C\cos(\Delta m\Delta t) - (-)^L S_- \sin(\Delta m\Delta t)\}$$
$$f(B^0(\Delta t) \rightarrow D^{(*)+}\pi^-) = N\exp^{-\Gamma|\Delta t|}\{1 - C\cos(\Delta m\Delta t) - (-)^L S_+ \sin(\Delta m\Delta t)\}$$

$$f(\overline{B}^0(\Delta t) \rightarrow D^{(*)+}\pi^-) = N\exp^{-\Gamma|\Delta t|}\{1 + C\cos(\Delta m\Delta t) + (-)^L S_+ \sin(\Delta m\Delta t)\}$$
$$f(\overline{B}^0(\Delta t) \rightarrow D^{(*)-}\pi^+) = N\exp^{-\Gamma|\Delta t|}\{1 - C\cos(\Delta m\Delta t) + (-)^L S_- \sin(\Delta m\Delta t)\}$$

$$C = \frac{1 - r_{(*)}^2}{1 + r_{(*)}^2} \approx 1 \qquad S_\pm = \frac{2r_{(*)}}{1 + r_{(*)}^2}\sin(2\beta + \gamma \pm \delta_{(*)}) \approx [-0.04, 0.04]$$

SMALL sine terms

- CP asymmetry: small sine terms

$\Rightarrow$ Need S_+ and S_- together to give $(2\beta+\gamma)$ and δ

- From $D^{(*)}\pi/\rho$ sine coefficients, 4 ambiguities in $(2\beta+\gamma)$

$\Rightarrow$ Express result as $|\sin(2\beta+\gamma)|$

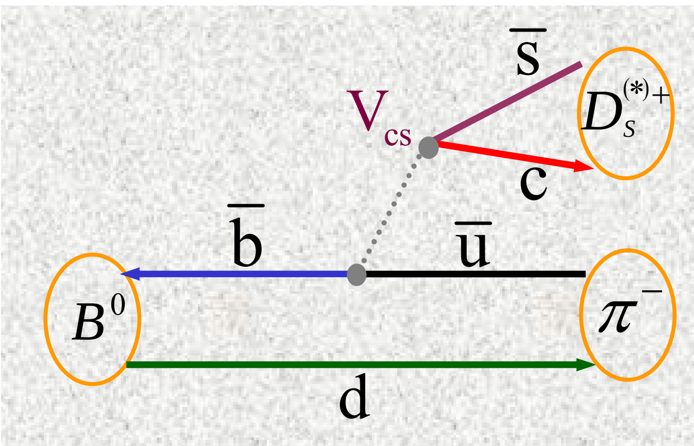
- SM: $\sin(2\beta+\gamma) \sim 1$ Factorization theory: δ is small

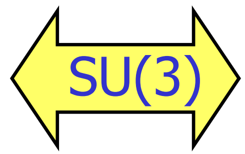
sin(2β+γ) Caveat: determination of $r_{(*)}$

- Simultaneous determination of sin(2β+γ) and $r_{(*)}$ from time-evolution not possible with current statistics ⇒ need $r_{(*)}$ as external inputs !

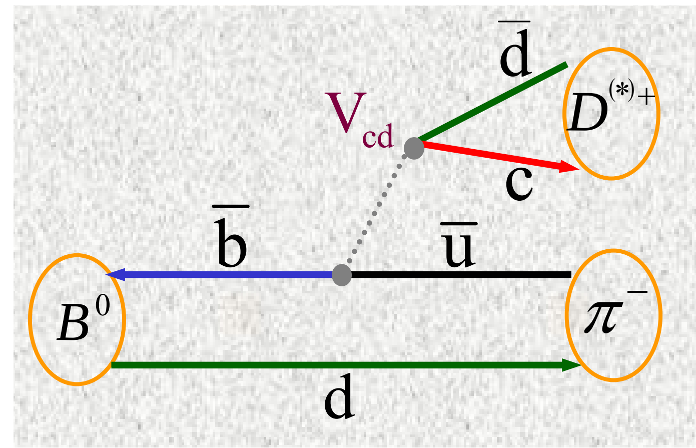
[1] I. Dunietz, Phys. Lett. B 427, 179 (1998)

- Estimate $r_{(*)}$ from $B^0 \to D_s^{(*)+}\pi^-/\rho^-$ using SU(3) symmetry [1]





$$\left|\frac{V_{cs}}{V_{cd}}\right|^2 \approx 20$$



- Using: $r_{(*)} \approx \sqrt{\frac{\mathcal{B}(B^0 \to D_s^{(*)+}\pi^-)}{\mathcal{B}(B^0 \to D^{(*)-}\pi^+)}} \left|\frac{V_{cd}}{V_{cs}}\right| \frac{f_{D^{(*)}}}{f_{D_s^{(*)}}}$ [2] ⇒

Inputs used in CKMFitter/ UTFit :

r(Dπ)	= 0.019 ± 0.004
r(D*π)	= 0.015 ± 0.006
r(Dρ)	= 0.003 ± 0.006

We add 30% theoretical errors to account for:
- Unknown SU(3) breaking uncertainty
- Missing W-exchange diagrams in calculation
- Missing rescattering diagrams

(Can be estimated with $B^0 \to D_s^{(*)+}K^-$)

no theoretical errors included

[2] f_D : decay constants

BaBar: Inclusive $B^0 \to D^* \pi$

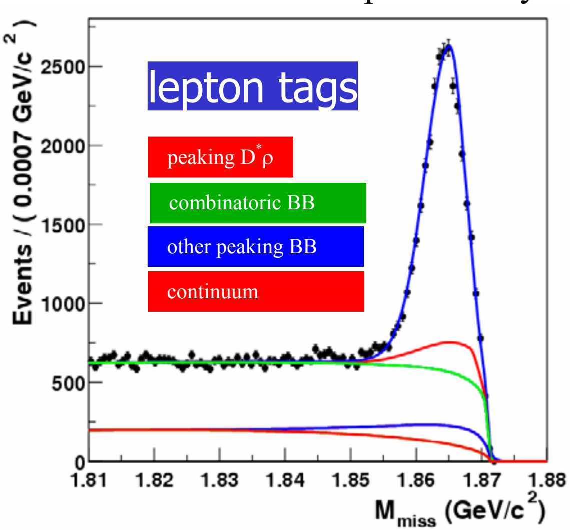
BABAR: 227M $B\bar{B}$

D* partial reconstruction:

$$B^0 \to D^{*-}\pi^+_{fast}$$
$$\quad\quad \hookrightarrow \bar{D}^0 \pi^-_{soft}$$
$$\quad\quad\quad \hookrightarrow X$$

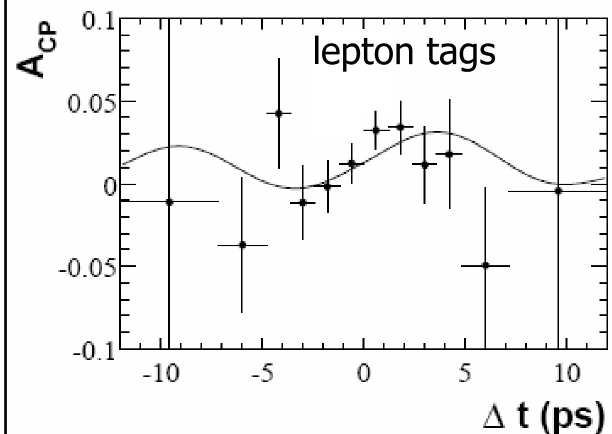
- High statistics!
- Large backgrounds

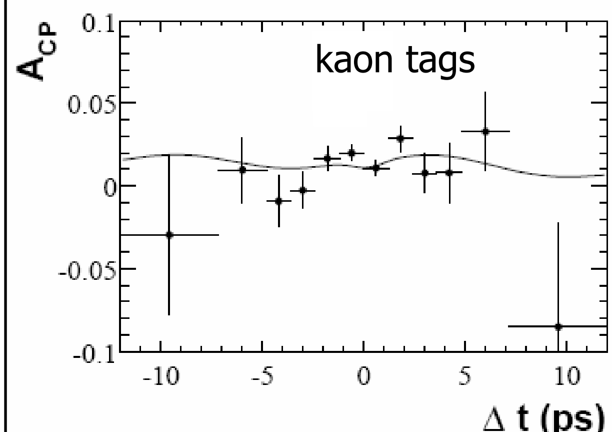
$B^0 \to D^* \pi$ preliminary



18710 ± 270 lepton tags
70580 ± 660 kaon tags

$$A_{CP} = \frac{N\left(B^0\text{ tags}\right) - N\left(\bar{B}^0\text{ tags}\right)}{N\left(B^0\text{ tags}\right) + N\left(\bar{B}^0\text{ tags}\right)}$$





Using a,b,c parametrization:

$$a = 2r\sin(2\beta+\gamma)\cos\delta$$
$$b = 2r'\sin(2\beta+\gamma)\cos\delta'$$
$$c = 2\cos(2\beta+\gamma)(r\sin\delta - r'\sin\delta')$$

Tag side interference: PRD68, 034010

r', δ' are the ratio and phase difference between the $b\to u$ and $b\to c$ amplitudes in the B_{tag} decay. $r'\equiv 0$ in lepton tags.

hep-ex/0504035 preliminary

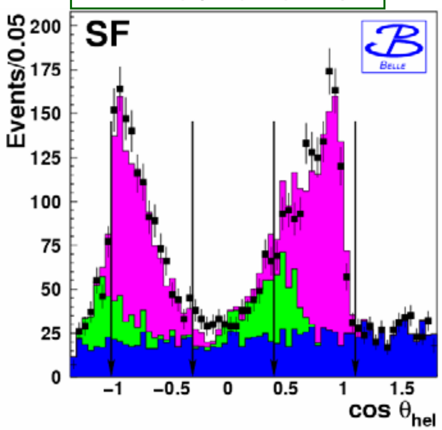
$a^{lep}_{D^*\pi}$	=	$-0.042 \pm 0.019 \pm 0.010$
$a^{K}_{D^*\pi}$	=	$-0.025 \pm 0.020 \pm 0.013$
$b^{K}_{D^*\pi}$	=	$-0.004 \pm 0.010 \pm 0.010$
$c^{K}_{D^*\pi}$	=	$-0.002 \pm 0.020 \pm 0.015$

Belle: Inclusive $B^0 \to D^* \pi$

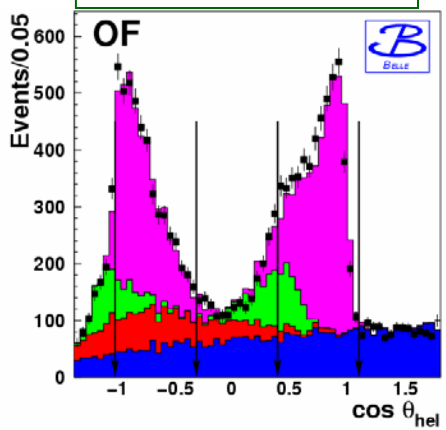
BELLE: 152M $B\bar{B}$

- Belle: only uses lepton tags
  (no tag-side interference)

Same Flavor: mixed events



Opposite Flavor: unmixed events



Mode	Data	Signal	$D^*\rho$	Corr. bkg	Uncorr. bkg	S/N
SF ($\pi_f^\pm \ell_{tag}^\pm$)	2823	1908	311	—	637	67%
OF ($\pi_f^\pm \ell_{tag}^\mp$)	10078	6414	777	928	1836	64%

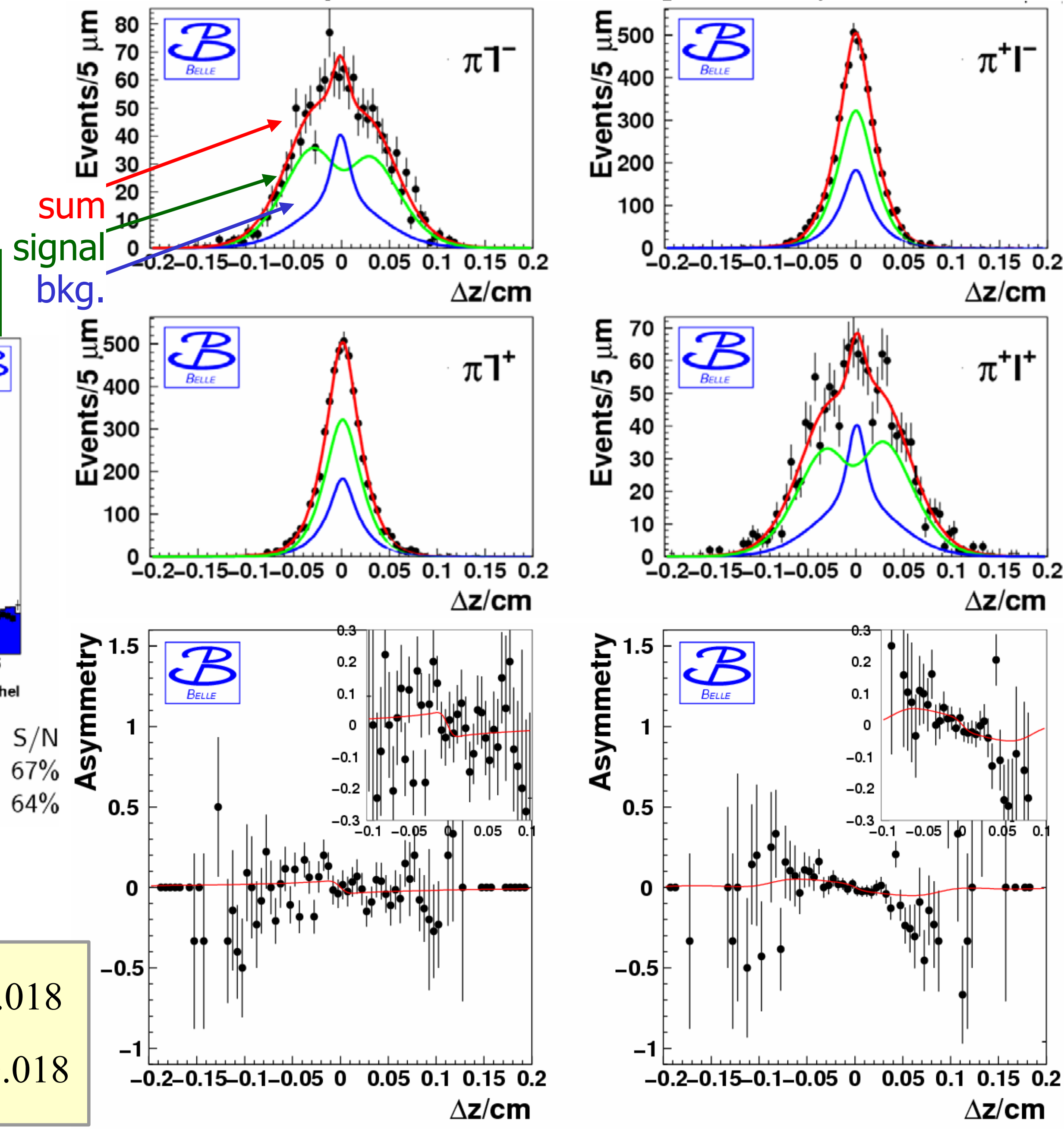
8322 signal lepton tags

$$2r^{D^*\pi}\sin(2\beta+\gamma)\cos\delta^{D^*\pi} = -0.030 \pm 0.028 \pm 0.018$$

$$2r^{D^*\pi}\cos(2\beta+\gamma)\sin\delta^{D^*\pi} = -0.005 \pm 0.028 \pm 0.018$$

hep-ex/0408106

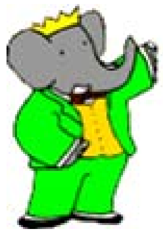
preliminary



$$\mathcal{A}^{SF} = \frac{N_{\pi^-\ell^-} - N_{\pi^+\ell^+}}{N_{\pi^-\ell^-} + N_{\pi^+\ell^+}} \qquad \mathcal{A}^{OF} = \frac{N_{\pi^+\ell^-} - N_{\pi^-\ell^+}}{N_{\pi^+\ell^-} + N_{\pi^-\ell^+}}$$

BaBar: Exclusive $B^0 \to D^{(*)}\ \pi/\rho$

BABAR: 110M $B\bar{B}$



- Exclusive reconstruction of channels:
  - $B \to D^{\pm}\ \pi^{\mp}$
  - $B \to D^{*\pm}\ \pi^{\mp}$
  - $B \to D^{\pm}\ \rho^{\mp}$

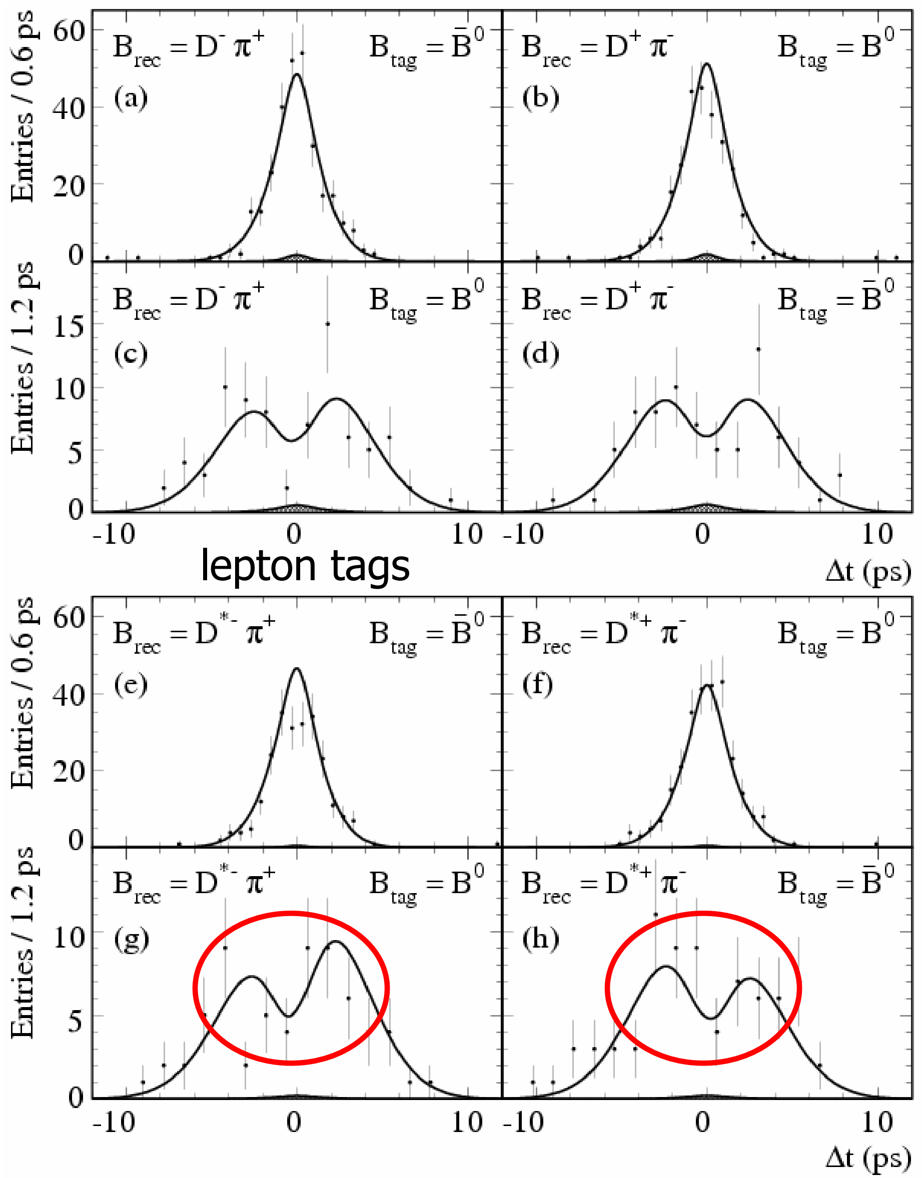
- Full reco.: ~10x less efficient; far lower backgrounds
- Same sensitivity to sin(2β+γ) as inclusive approach

Sample	Yields	Purity
Fully Reconstructed	(110 M $B\bar{B}$)	
$D^{\pm}\pi^{\mp}$ (all tag)	7611 ± 97	91%
$D^{*\pm}\pi^{\mp}$ (all tag)	7068 ± 89	95%
$D^{\pm}\rho^{\mp}$ (all tag)	4400 ± 79	88%

hep-ex/0408059 preliminary

$$2r^{D\pi}\sin(2\beta+\gamma)\cos\delta^{D\pi} = -0.032 \pm 0.031 \pm 0.020$$
$$2r^{D\pi}\cos(2\beta+\gamma)\sin\delta^{D\pi} = -0.059 \pm 0.055 \pm 0.055$$
$$2r^{D^*\pi}\sin(2\beta+\gamma)\cos\delta^{D^*\pi} = -0.049 \pm 0.031 \pm 0.020$$
$$2r^{D^*\pi}\cos(2\beta+\gamma)\sin\delta^{D^*\pi} = +0.044 \pm 0.054 \pm 0.033$$
$$2r^{D\rho}\sin(2\beta+\gamma)\cos\delta^{D\rho} = -0.005 \pm 0.044 \pm 0.021$$
$$2r^{D\rho}\cos(2\beta+\gamma)\sin\delta^{D\rho} = -0.147 \pm 0.074 \pm 0.035$$

Phys.Rev.Lett. 92:251801(2004), 88 M $B\bar{B}$



Belle: Exclusive $B^0 \to D^{(*)}\pi$

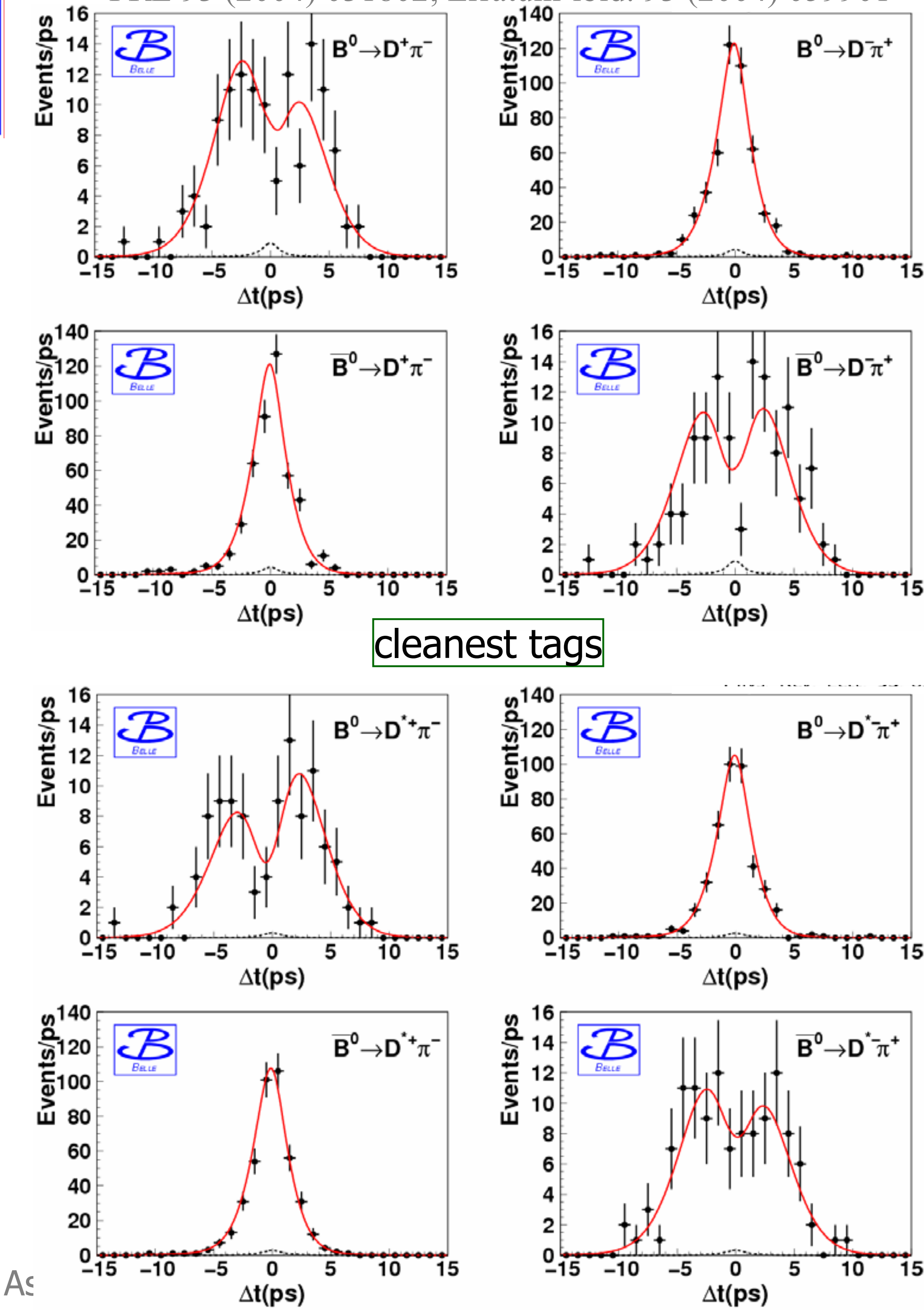
BELLE: 152M $B\bar{B}$

- Exclusive reconstruction of channels:
  - $B \to D^{\pm}\pi^{\mp}$
  - $B \to D^{*\pm}\pi^{\mp}$
- Uses $B \to D^{*}l\nu$ as control sample for tag-side interference

Decay mode	Candidates	Selected(*)	Purity
$B \to D\pi$	9711	9351	91%
$B \to D^{*}\pi$	8140	7763	96%

$$2r^{D\pi}\sin(2\beta+\gamma)\cos\delta^{D\pi} = -0.062 \pm 0.037 \pm 0.018$$
$$2r^{D\pi}\cos(2\beta+\gamma)\sin\delta^{D\pi} = -0.025 \pm 0.037 \pm 0.018$$
$$2r^{D^*\pi}\sin(2\beta+\gamma)\cos\delta^{D^*\pi} = +0.060 \pm 0.040 \pm 0.019$$
$$2r^{D^*\pi}\cos(2\beta+\gamma)\sin\delta^{D^*\pi} = +0.049 \pm 0.040 \pm 0.019$$

PRL 93 (2004) 031802; Erratum-ibid. 93 (2004) 059901

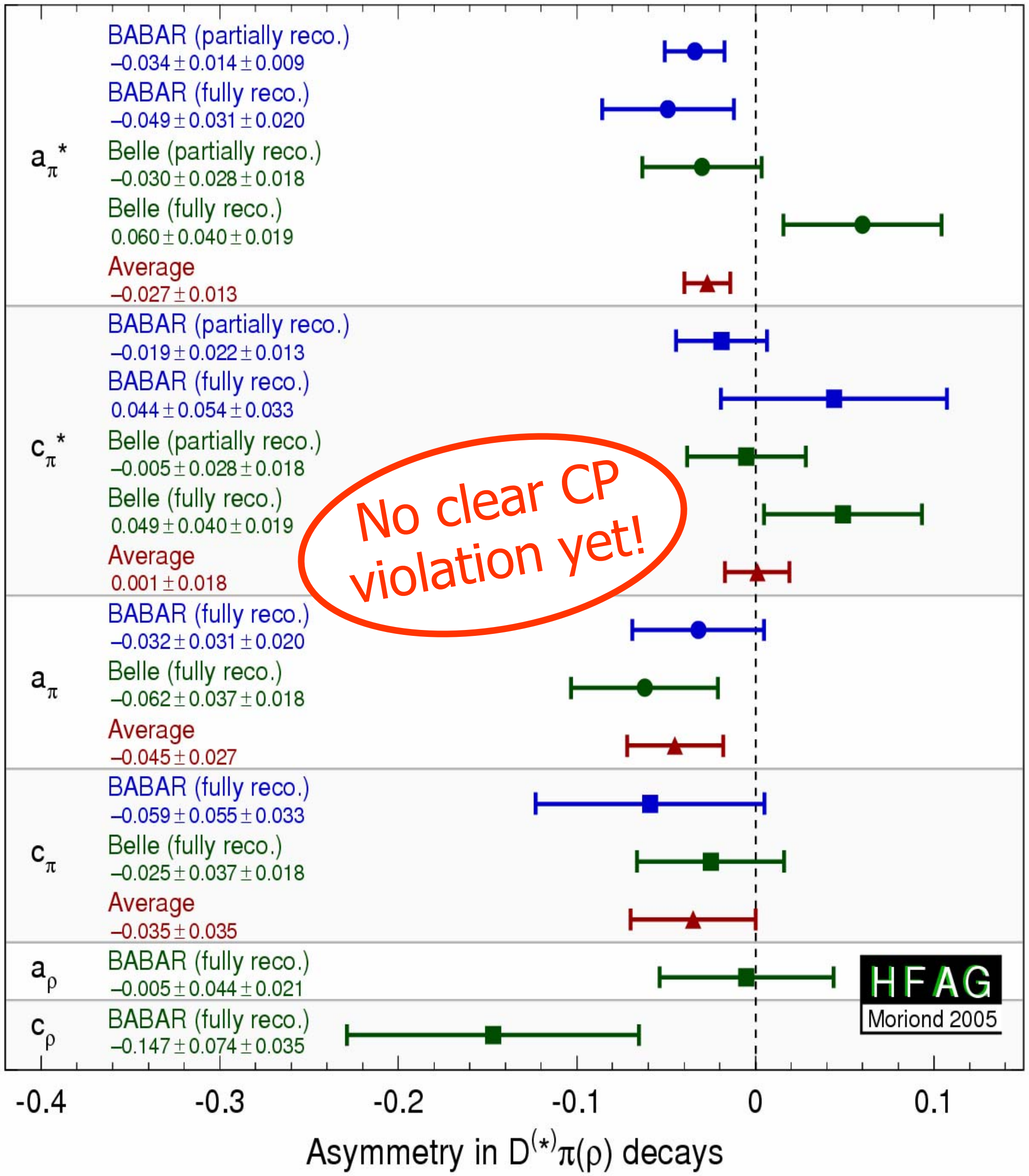


(*) After tagging and vertexing

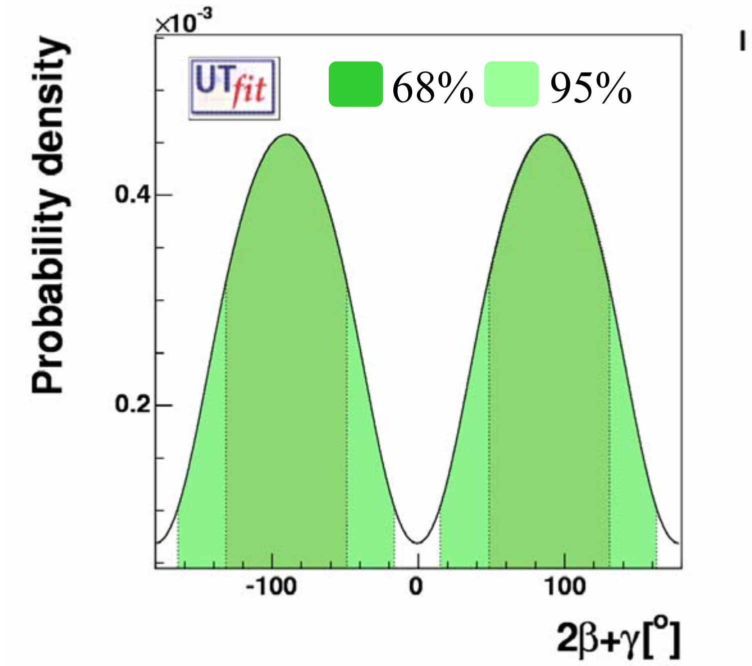
HFAG on |sin(2β+γ)|

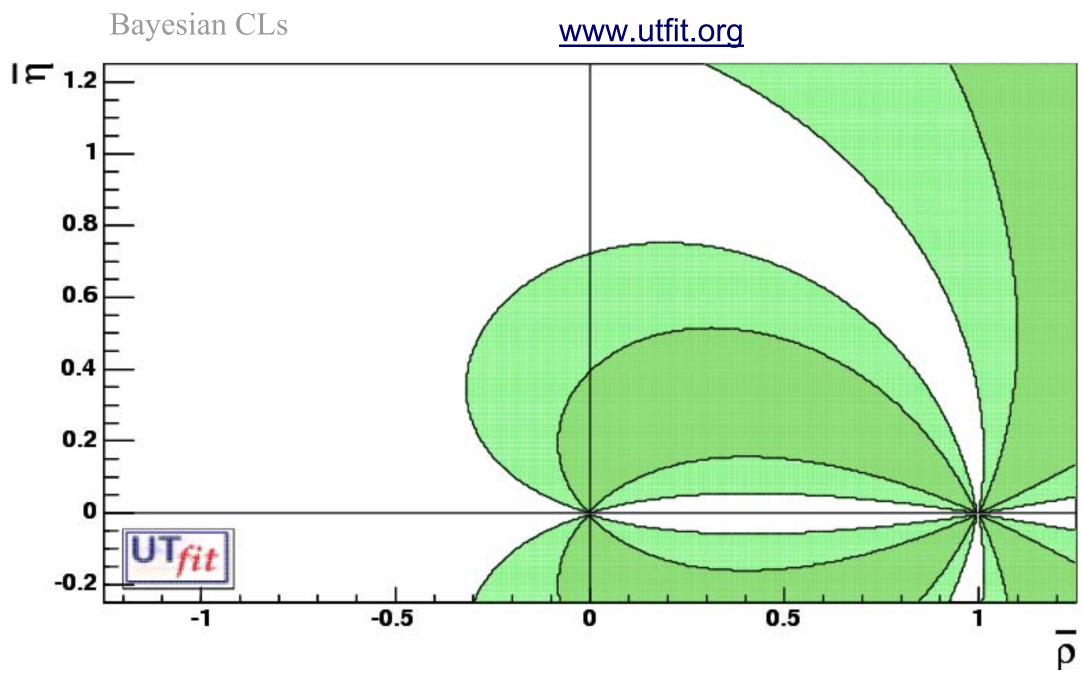
HFAG Averages:

$$a^i = 2r^i \sin(2\beta+\gamma)\cos\delta^i$$
$$c^i = 2r^i \cos(2\beta+\gamma)\sin\delta^i$$



Combined Limit on $|\sin(2\beta+\gamma)|$

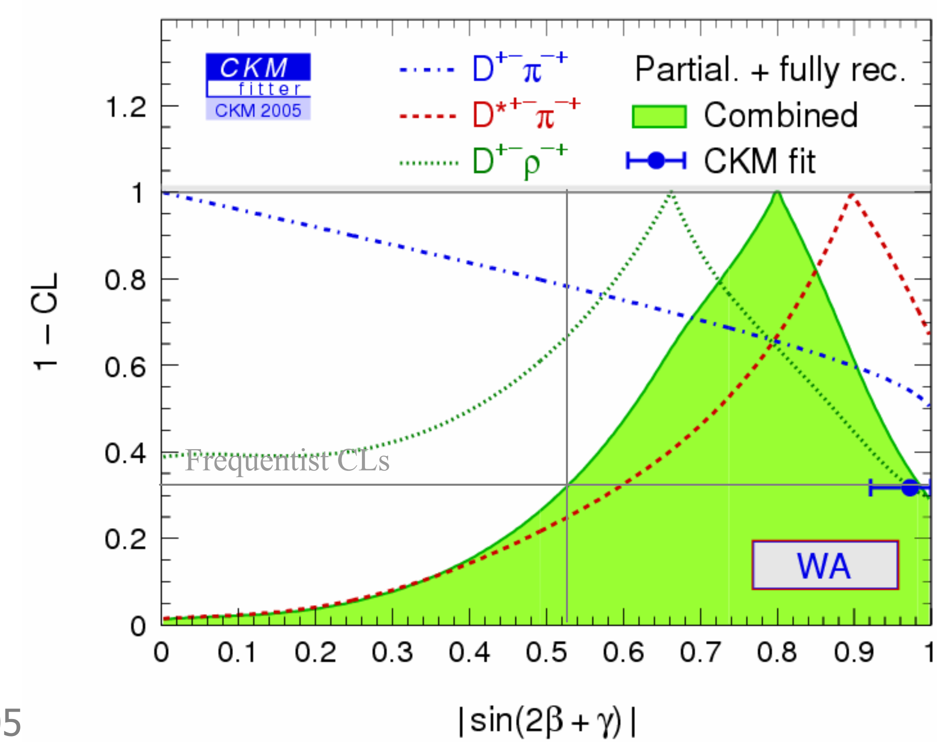




Combined limit on $|\sin(2\beta+\gamma)|$:

Assuming 30% error on $r^{(*)}$ for SU(3) breaking:

CKMFitter: $|\sin(2\beta+\gamma)| > 0.53$ @ 68% C.L.
UTFit: $|\sin(2\beta+\gamma)| > 0.74$ @ 68% C.L.



Outlook

Many approaches to measure γ have been investigated by BaBar and Belle.

GLW and ADS methods don't provide strong constraints on γ when considered alone. Current experimental results favour small values of r_B. GGSZ results are promising!

<u>GLW+ADS+GGSZ</u>:

CKMFitter: $\gamma = [\ 63\ ^{+15}_{-13}\ ]° + n\pi$

UTFit: $\gamma = [\ 64 \pm 18\ ]° + n\pi$

<u>$\sin(2\beta+\gamma)$ from $D^{(*)}\pi/\rho$</u>:

CKMFitter: $|\sin(2\beta+\gamma)| > 0.53$ @ 68% C.L.

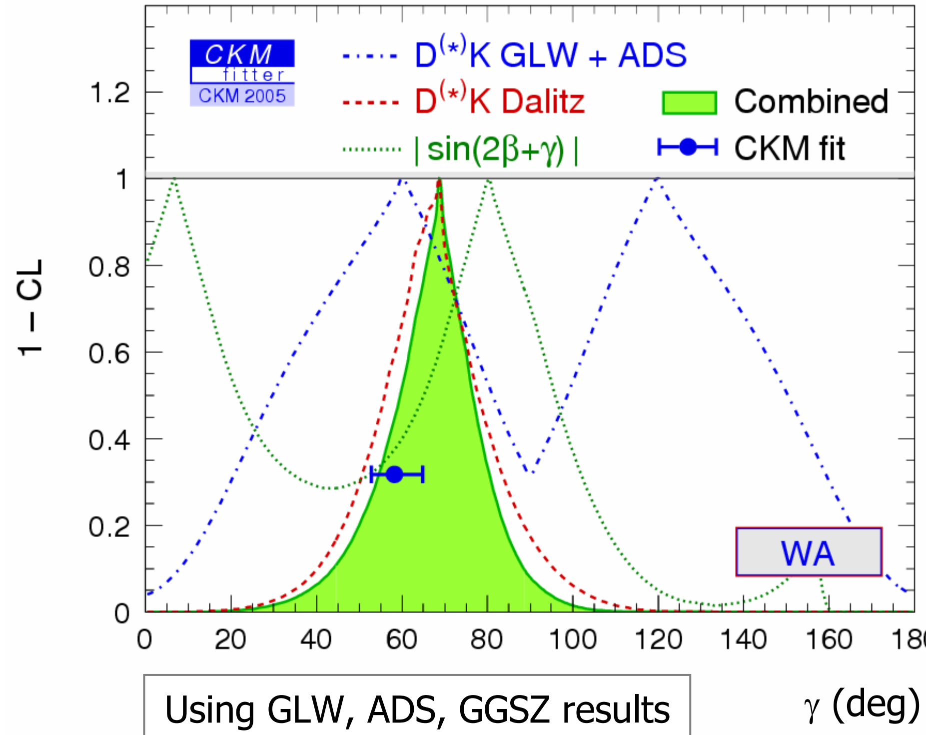
UTFit: $|\sin(2\beta+\gamma)| > 0.74$ @ 68% C.L.

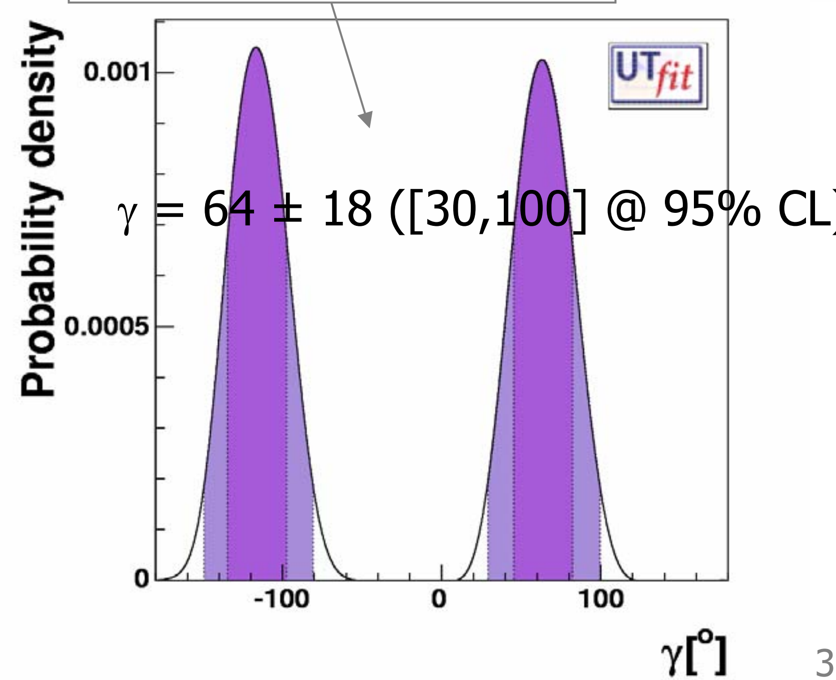
<u>GLW+ADS+GGSZ+$\sin(2\beta+\gamma)$</u>:

CKMFitter: $\gamma = [\ 70\ ^{+12}_{-14}\ ]° + n\pi$

All results are in good agreement with the global CKM fit ($\gamma = [\ 60 \pm 6\ ]°$)

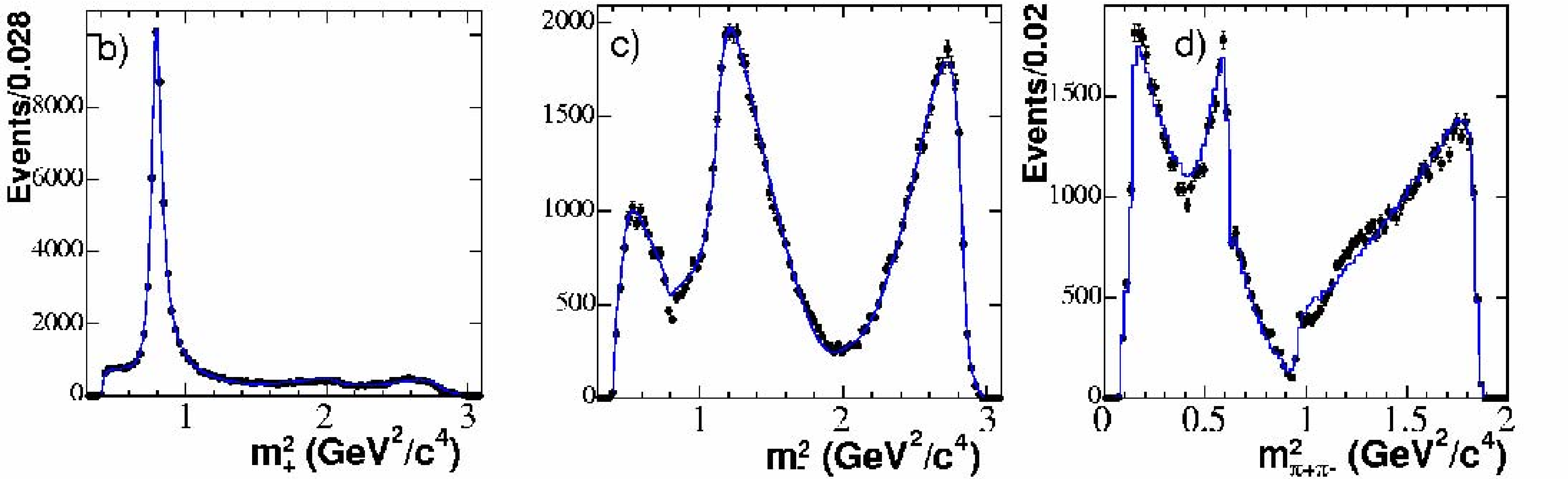
All decay modes can use lots more statistics!
High statistics expected in next years may allow BaBar and Belle to measure γ to < 10°.





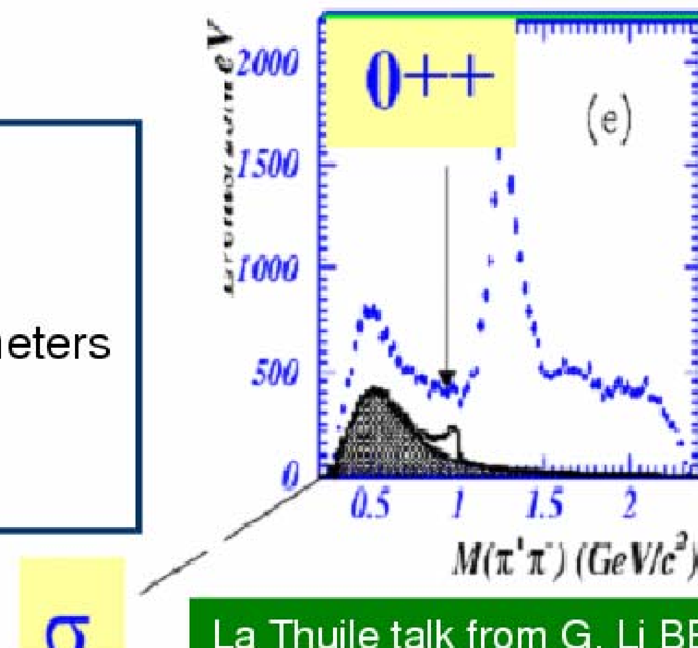

BACKUP
slides ...

BaBar: Removing the Imaginary (?) σ



This model is clearly a bad fit to the tagged D^0 sample

The σ is seen by BES :



From an adaptative binned χ^2 fit on the tagged sample :

χ^2= 3824/(3054-32) ~1.27 standard fit

χ^2 ~ 4000/(3054-32)~ 1.35 fit with changes in the other parameters

χ^2= 4757/(3054-32) ~1.57 fit without σ

La Thuile talk from G. Li BES collaboration $B \rightarrow J/\Psi\omega\pi\pi$

Belle GGSZ: Systematic Errors

$B^+ \to D^{(*)0} K^{(*)+}$
$\overleftrightarrow{D}^0 \to K_S \pi^+ \pi^-$

Experimental

Source	$DK^{\pm}$			$D^*K^{\pm}$			$DK^{*\pm}$		
	Δr	$\Delta\phi_3$ ($^\circ$)	$\Delta\delta$ ($^\circ$)	Δr	$\Delta\phi_3$ ($^\circ$)	$\Delta\delta$ ($^\circ$)	Δr	$\Delta\phi_3$ ($^\circ$)	$\Delta\delta$ ($^\circ$)
Background shape	0.027	5.7	4.1	0.014	3.1	5.3	0.093	4.4	3.5
Background fraction	0.006	0.2	1.0	0.005	0.7	1.4	0.006	0.6	1.5
Efficiency shape	0.012	4.9	2.4	0.002	3.5	1.0	0.002	4.8	2.3
Momentum resolution	0.002	0.3	0.3	0.002	1.7	1.4	0.001	0.2	0.1
Control sample bias	0.004	10.2	10.2	0.004	9.9	9.9	0.003	6.8	6.8
Total	0.03	13	11	0.02	11	11	0.093	9.4	8.1

$\bar{D}^0 \to K_S\pi\pi$ Model

Fit model	Δr	$\Delta\phi_3$ ($^\circ$)	$\Delta\delta$ ($^\circ$)
$F_r = F_D = 1$	0.01	3.1	3.3
$\Gamma(q^2) = \mathrm{const}$	0.02	4.7	9.0
Narrow resonances plus non-resonance term	0.04	11	21
Total	0.04	11	21

Estimated at $r = 0.13$
For larger r, errors get smaller
Narrow resonances:
$K^*(892)^{\pm}$, ρ, $f^0(980)$

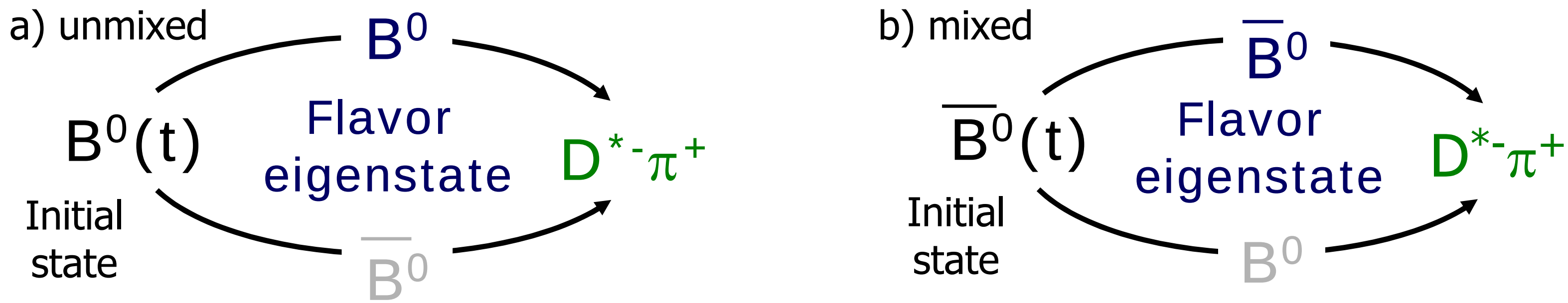
Non-resonant $DK_S\pi$ (only for $DK^{*\pm}$)

	Δr	$\Delta\phi_3$ ($^\circ$)	$\Delta\delta$ ($^\circ$)
non-resonant $DK_S\pi$	0.08	8	49

Non-resonant $DK_S\pi$ can contribute to ϕ_3
but with different r and δ in general

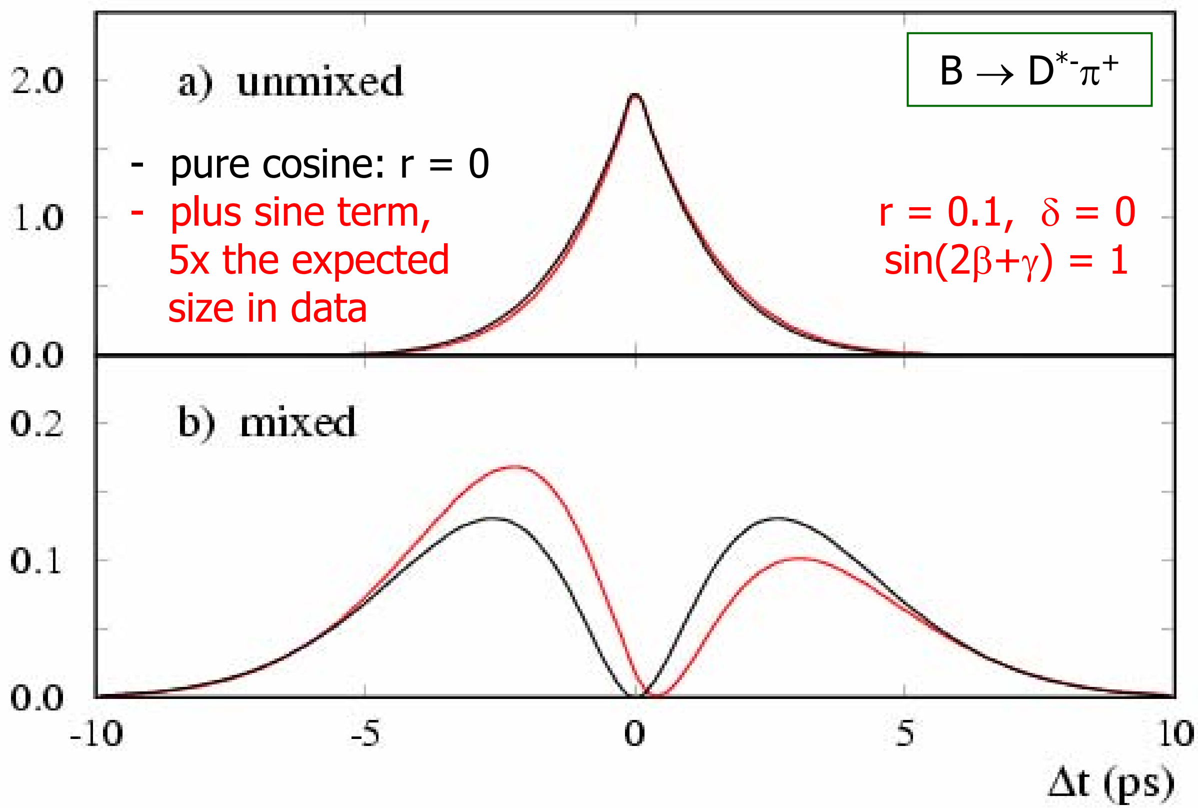
$B \to D^{*-}\pi^+$ time-dependent evolution

With $b \to u$ transition



a) $$f_{unmixed}(D^{*-}\pi^+, \Delta t) = \frac{\Gamma}{4} e^{-\Gamma|\Delta t|}\,[1 + C\cos(\Delta m_d \Delta t) + S\sin(\Delta m_d \Delta t)]$$

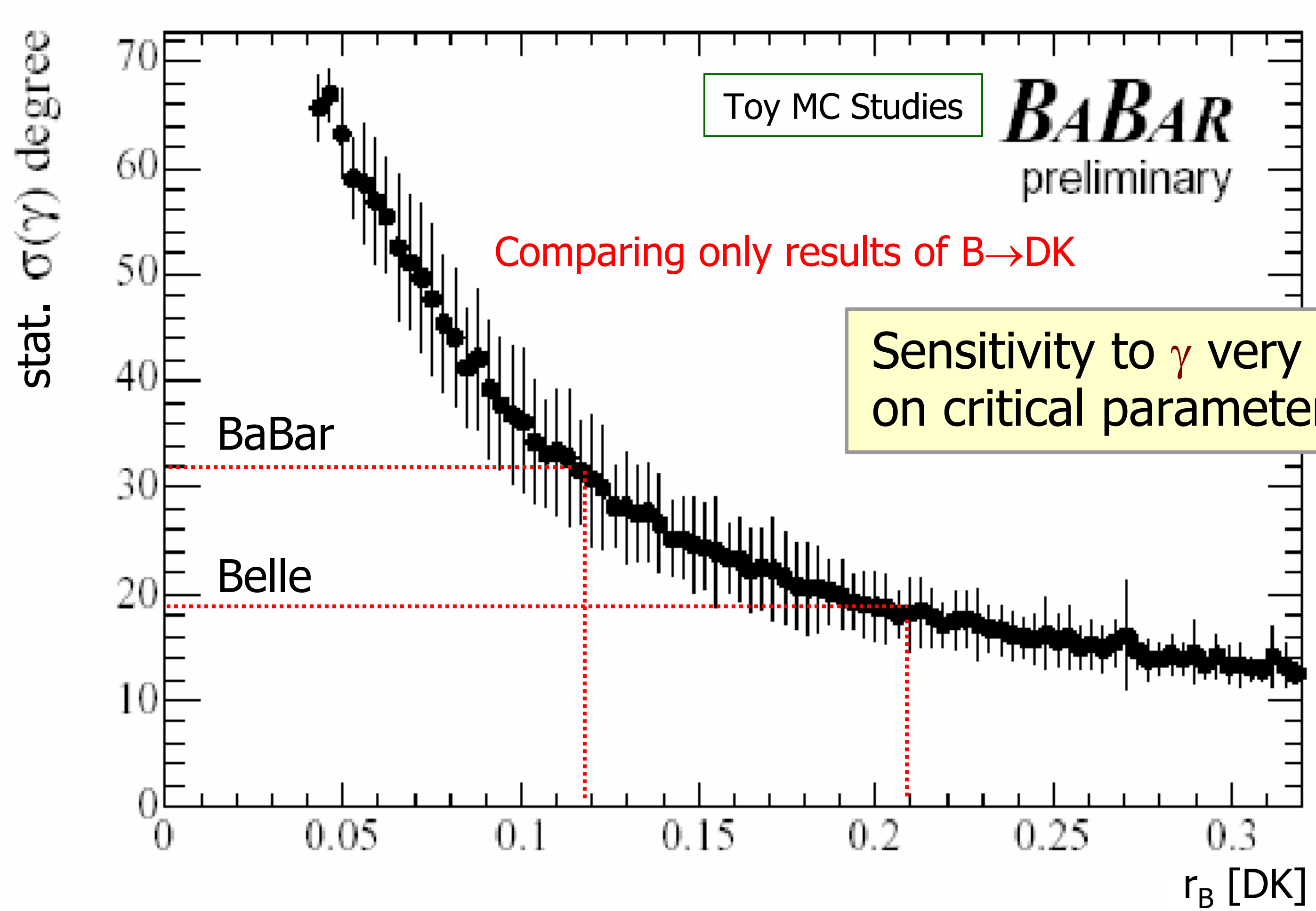
b) $$f_{mixed}(D^{*-}\pi^+, \Delta t) = \frac{\Gamma}{4} e^{-\Gamma|\Delta t|}\,[1 - C\cos(\Delta m_d \Delta t) - S\sin(\Delta m_d \Delta t)]$$



- CP asymmetry: small additional sine term
- Smallness of amplitude ratio *r* greatly reduces sensitivity to sin(2β+γ)

$\sigma(\gamma)$ Dependency on r_B

- BaBar and Belle show quite different sensitivities to γ
- Both find quite different values for r_B (BaBar: ~0.12, Belle: ~0.21)



Sensitivity to γ very dependent on critical parameter r_B (~0.1)!

- Different sensitivity to γ caused by dependency on r_B .