Measurements of the CKM-angle ϕ_3/γ

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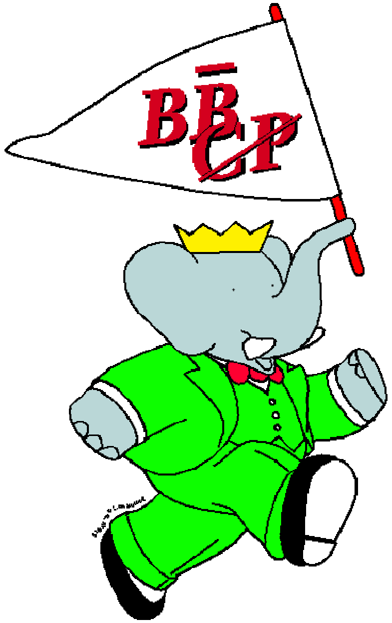
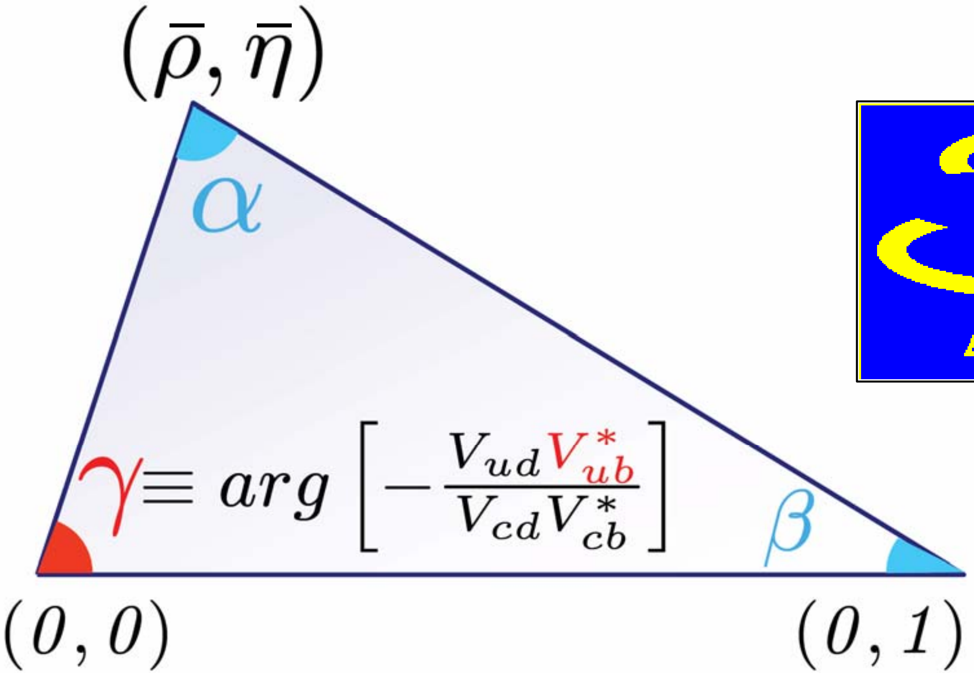
for the Belle and BABAR collaborations,
FPCP 2007, Bled (Slovenia), May 12-16.





$\beta \equiv \phi_1$, $\alpha \equiv \phi_2$, and $\gamma \equiv \phi_3$

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The various measurements of $\phi_3/\gamma \equiv \arg(V_{ub})$

➔ why is it difficult ?

1\.

➔ Measurement of γ using direct CP violation (interference $V_{ub} \leftrightarrow V_{cb}$) in charged $B^- \to \tilde{D}^{(*)0} K^{(*)-}$ decays (no time dependence), 3 methods:

- GLW: many modes, but small asymmetry.
- ADS: large asymmetry, but very few events.
- GGSZ/Dalitz: better than a mixture of ADS+GLW $\Rightarrow$ large asymmetry in some regions, but strong phases varying other the Dalitz plane.

2\.

➔ Measurement of $\sin(2\beta+\gamma)$ in CPV from mixing (time dependence) and interferences ($V_{ub} \leftrightarrow V_{cb}$) in neutral B decays:

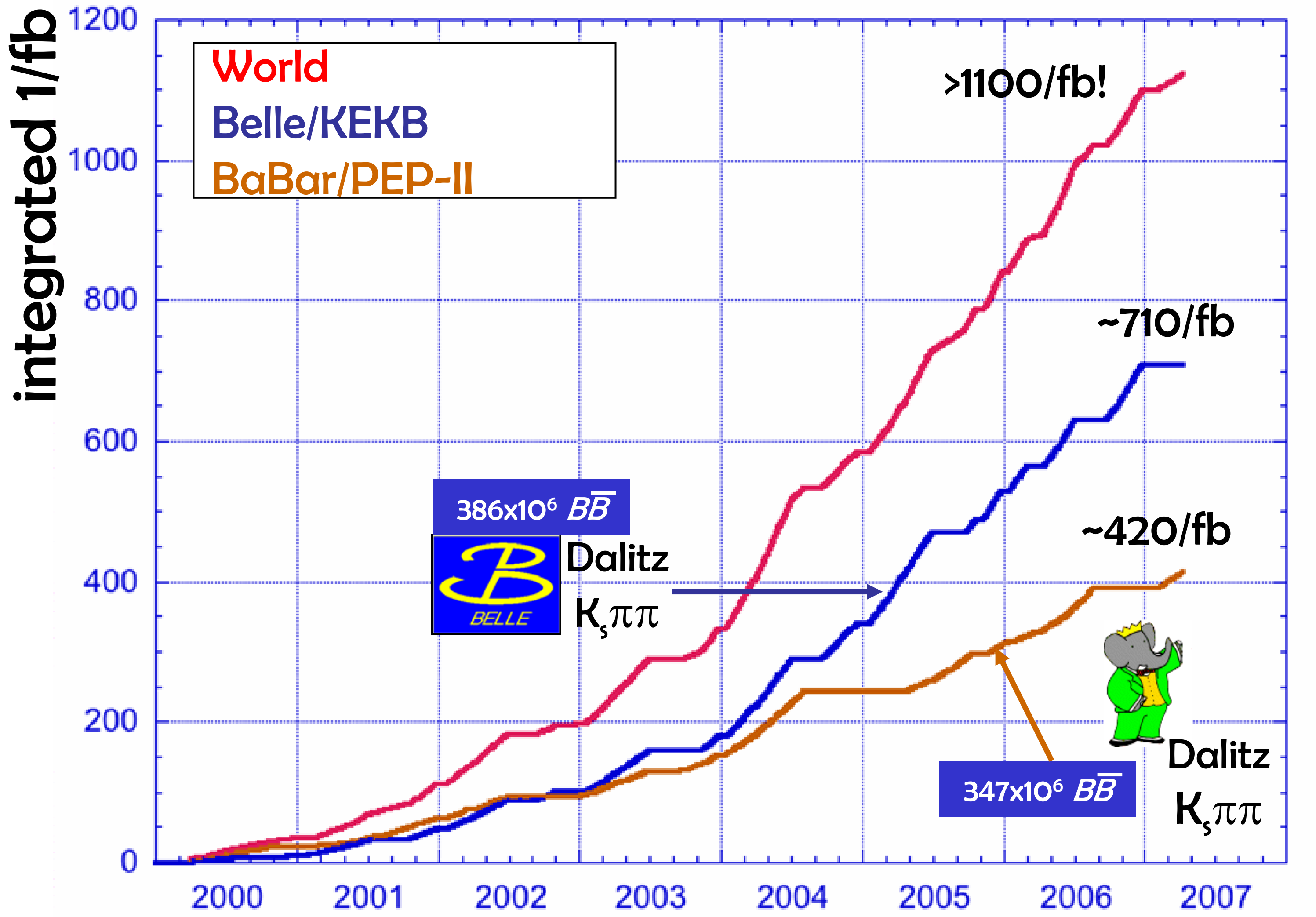
- the modes $D^{(*)\pm}\pi^{\mp}$ and $D^{\pm}\rho^{\mp}$ (partial and full reconstruction): large BFs, but very small asymmetry.
- other, eg.: $\tilde{D}^{(*)0}\overline{K}^{(*)0}$ → expect large asymmetry ? but small BFs.

3\.

➔ Long term perspectives and other methods: see Working Group 5 at CKM-WS 2006 at Nagoya (Japan) and especially talk by J. Zupan.

Belle/KEK-B and BaBar/PEPII

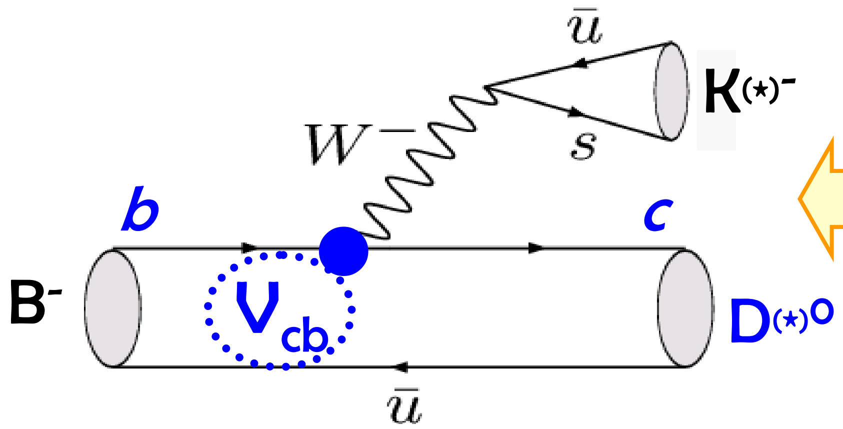
➔ Not all the statistics used for the results shown here
only about ½ or more ⇒ updates expected !



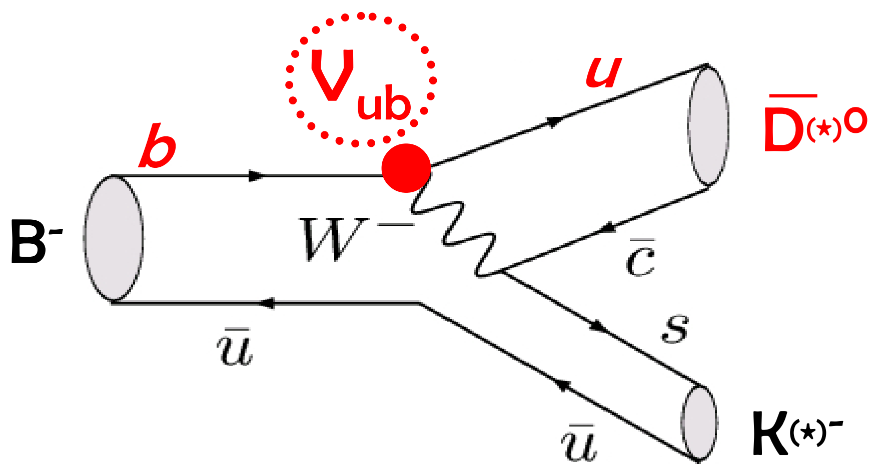
γ from interference in charged $B^- \to \tilde{D}^{(*)0} K^{(*)-}$ decays

Same $\tilde{D}^{(*)0} \equiv [\, D^{(*)0} / \bar{D}^{(*)0} \,]$ final states

Cabibbo-“favored”



(Cabibbo & color)-suspressed



$\mathcal{A}\,(D^{(*)0}K^{(*)-}) \propto \lambda^3$

$\mathcal{A}\,(\bar{D}^{(*)0}K^{(*)-}) \propto \lambda^3 \sqrt{\bar{\eta}^2 + \bar{\rho}^2}\; e^{i(\delta_B - \gamma)}$

relative strong & weak phases

$\mathcal{A}_{tot} = \mathcal{A} + \mathcal{A}$

Size of CP asymmetry: r_B is the critical parameter

$r_B \equiv |\mathcal{A}/\mathcal{A}| \sim 0.05\text{-}0.30$ PLB557,198(2003)

if r_B small, how ? $\Rightarrow$ small experimental sensitivity to γ

Methods to extract γ in $B^{\pm} \to \tilde{D}^{(*)0} K^{(*)\pm}$ decays

Use of direct CPV in $B^{\pm}$ [$b \to c \Leftrightarrow b \to u$] interference

The unknowns to measure : γ, δ_B, r_B, δ^*_B, r^*_B, δ_{sB}, r_{sB}

(! one (δ_B,r_B) pair for each D^0K^-, $D^{*0}K^-$ or D^0K^{*-} channel !)

Same $\tilde{D}^0 \equiv [\ D^0/\bar{D}^0\ ]$ → various final states to enhance the V_{ub}/V_{cb} interference

3 theoretically "clean" methods (no penguins) :

- $\tilde{D}^0 \equiv$[CP-eigenstate] : GLW — PLB253,483(1991) PLB265,172(1991)
- $D^0 \to [K^+\pi^-]$ & $\bar{D}^0 \to [K^-\pi^+]$ (Wrong Sign): ADS — PRL78,3257(1997) PRD63,036005(2001)
- $\tilde{D}^0 \equiv [K^0_S \pi^+\pi^-]$: Dalitz/GGSZ (not just counting). — PRL78,3257(1997) PRD68,054018(2003)

GLW method : $B^- \to \tilde{D}^{(*)0}[\text{CP-eigenstate}]_D K^{(*)-}$

- Theoretically very clean to determine γ (but 8 fold-ambiguities)
- Relatively small BFs ~10^{-6} (including sec. BFs) STATISTICS LIMITED !

  $\Rightarrow$ small CP asymmetry (r_B=?)
- Reconstruct D meson in CP-eigenstates (accessible to D^0 and $\bar{D}^0$), & in many modes (normalize to D^0 flavour state decays ($K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-3\pi$)):
  - CP-even (CP+) : K^+K^-, $\pi^+\pi^-$
  - CP-odd (CP-) : $K^0_S\pi^0$, $K^0_S\omega$, $K^0_S\phi$, ($K^0_S\eta$)

  Use D^{*0} to $D^0\pi^0$ and K^{*-} to $K^0_S\pi^-$

Schematic view:

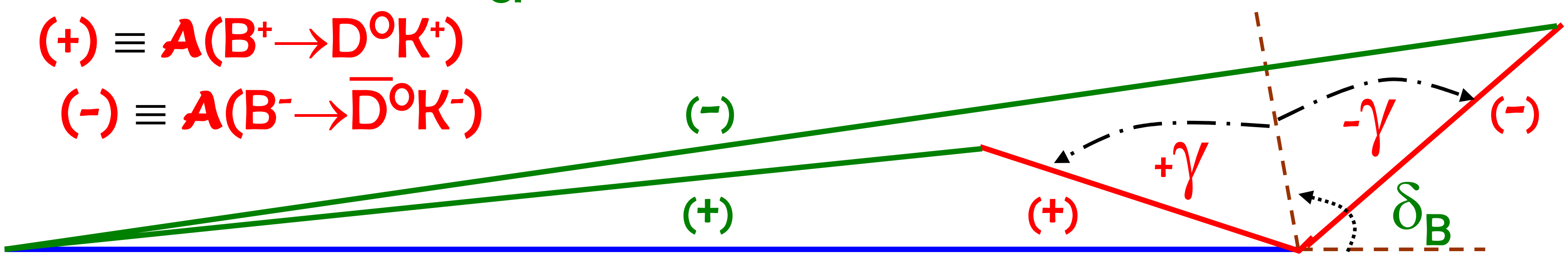
$\mathcal{A}_{tot}=\mathcal{A}+\mathcal{A}$

(±) $\equiv \sqrt{2}\ \mathcal{A}(B^\pm \to D_{CP}K^\pm)$

(+) $\equiv \mathcal{A}(B^+ \to D^0K^+)$

(-) $\equiv \mathcal{A}(B^- \to \bar{D}^0K^-)$

Here we plot: γ~60°, δ_B~100°,
and $r_B \equiv |\mathcal{A}/\mathcal{A}|$~0.25 (very optimistic)



$\mathcal{A}(B^+ \to \bar{D}^0K^+)=\mathcal{A}(B^- \to D^0K^-)$

GLW : observables

- **ratio of BFs:** (CP eigenstates/flavor es)

$$R_{CP\pm} \equiv \frac{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)}{[\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \bar{D}^0 K^+)]/2} = 1 + r_B^2 \pm 2\, r_B \cos(\delta_B)\cos(\gamma)$$

- **direct ACPV ($B^+ \leftrightarrow B^-$):** (double ratios normalized with $D^{(*)0}\pi^-$ for systematic cancellations)

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

8 fold ambiguity on γ

Weak sensitivity to r_B

$$\frac{R_{CP+} + R_{CP-}}{2} = 1 + r_B^2$$

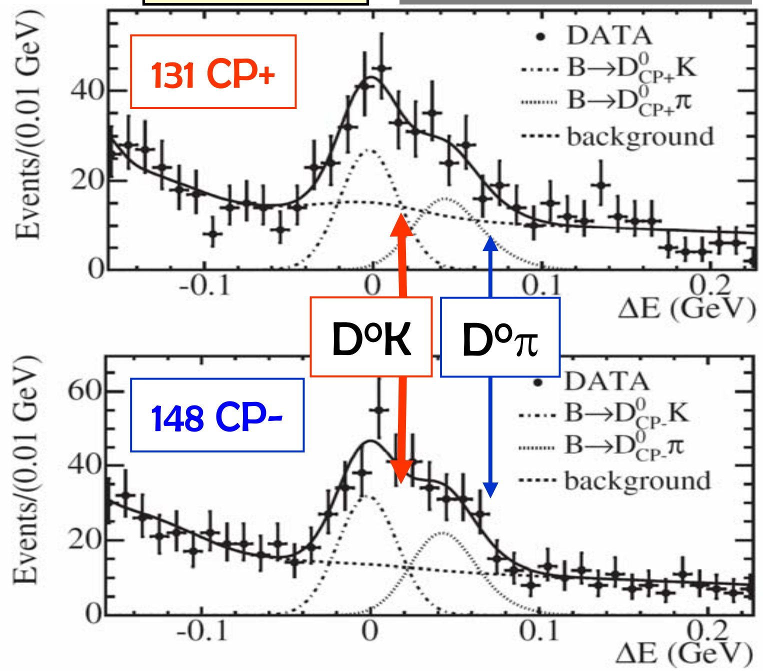
➔ 3 observables are independent ($A_{CP+}R_{CP+} = - A_{CP-}R_{CP-}$)
and 3 unknowns (r_B, γ, δ_B)

BaBar/Belle GLW results

232x10⁶ $B\bar{B}$

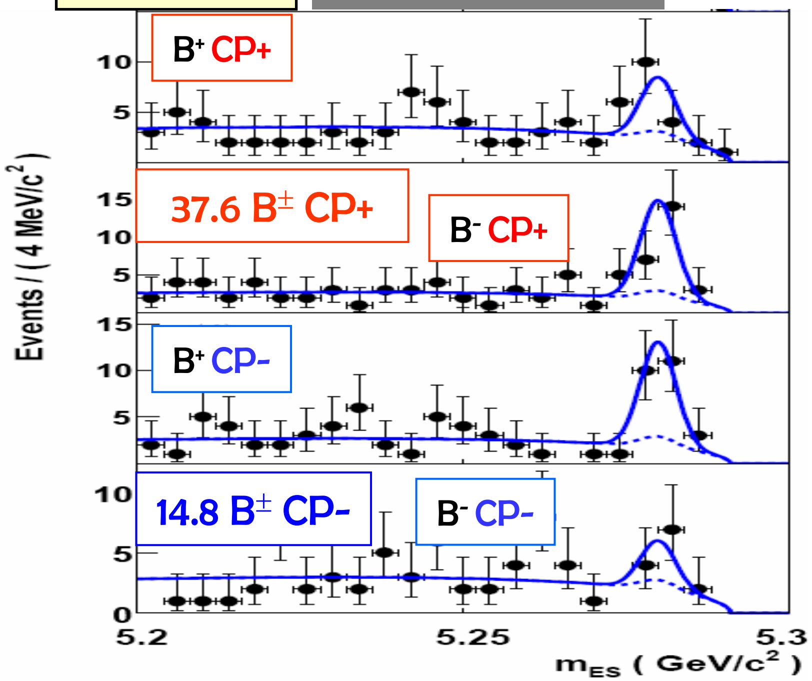
B→D⁰K

PRD 73, 051105 (2006)



B→D⁰K*

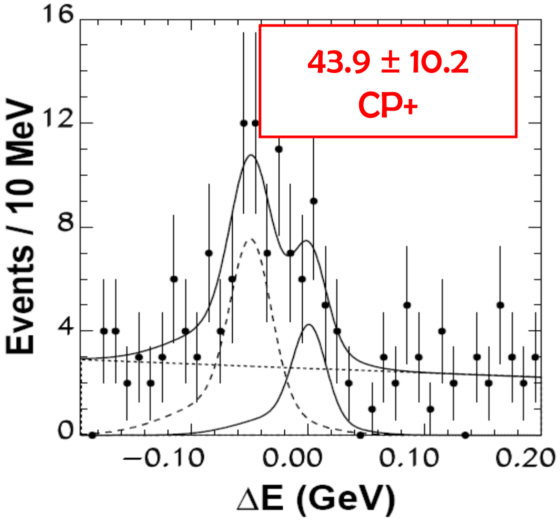
PRD 72, 071103 (2005)

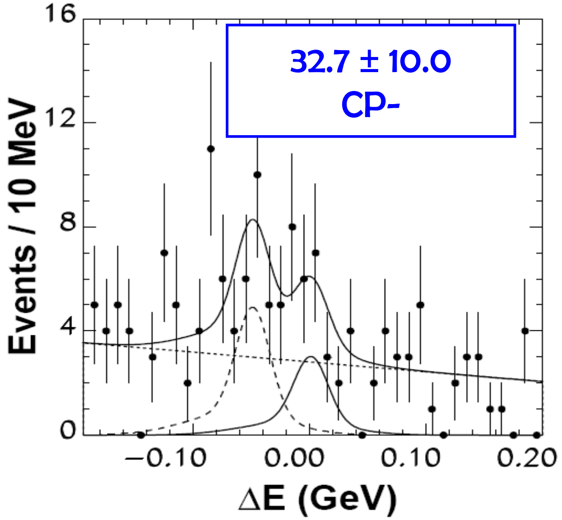


275x10⁶ $B\bar{B}$

PRD 73, 051106 (2006)

B→ D*⁰K±





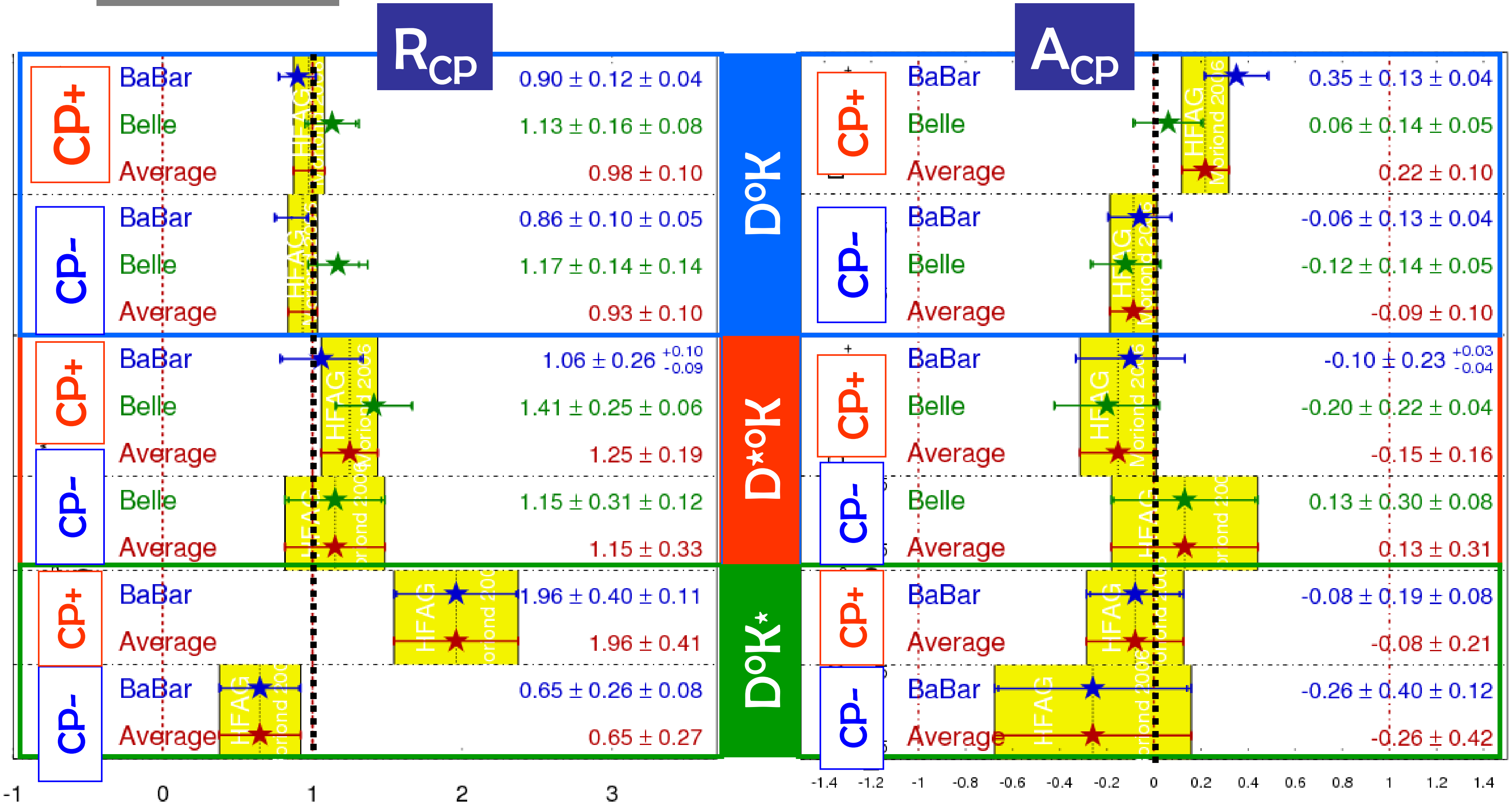
232x10⁶ $B\bar{B}$

PRD 73, 051105 (2006)
PRD 72, 071103 (2005)

GLW averages : *frozen since ~ 2 years !*

275x10⁶ $B\bar{B}$

PRD 73, 051106 (2006)



- With current statistics it is not possible to constraint γ with GLW measurements alone, but help significantly to improve global constraint on γ and r_B.
- Note : BaBar and Belle use only about ½ of the available $B\bar{B}$ pairs.

ADS method : $B^- \to \tilde{D}^{(*)0}[K^+\pi^-]_D K^{(*)-}$

- Same idea as for GLW, same final state in different $\tilde{D}^0$[$\bar{D}^0/D^0$] states:

$[K^+\pi^-]_D K^-$:Doubly-Cabibbo-Suppressed (DCS) decays instead of CP-es.

Suppressed (V_{ub})

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

Favored (Right-Sign)

interference

Favored

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

DCS

Suppressed (Wrong-Sign)

- Small BFs(~10^{-6}), but amplitudes ~ comparable in size: expect larger CPV!
- Count B candidates with opposite sign K !

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

$$r_D^2 = \left|\frac{A(D^0 \to K^+\pi^-)}{A(D^0 \to K^-\pi^+)}\right|^2 = (0.365 \pm 0.021)\%$$

PLB 592,1 (PDG 2004)

δ_D : D decay strong phase unknown (scan all possible values).

ADS : observables

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

$B^- \to B^+ \Rightarrow -\gamma \to +\gamma$, $K^- \leftrightarrow K^+$, $K^+ \leftrightarrow K^-$

2 observables

- ratio of BFs: (Wrong Sign $D^0 \to K^+\pi^-$/Right Sign $D^0 \to K^-\pi^+$)

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

good sensitivity to r_B^2

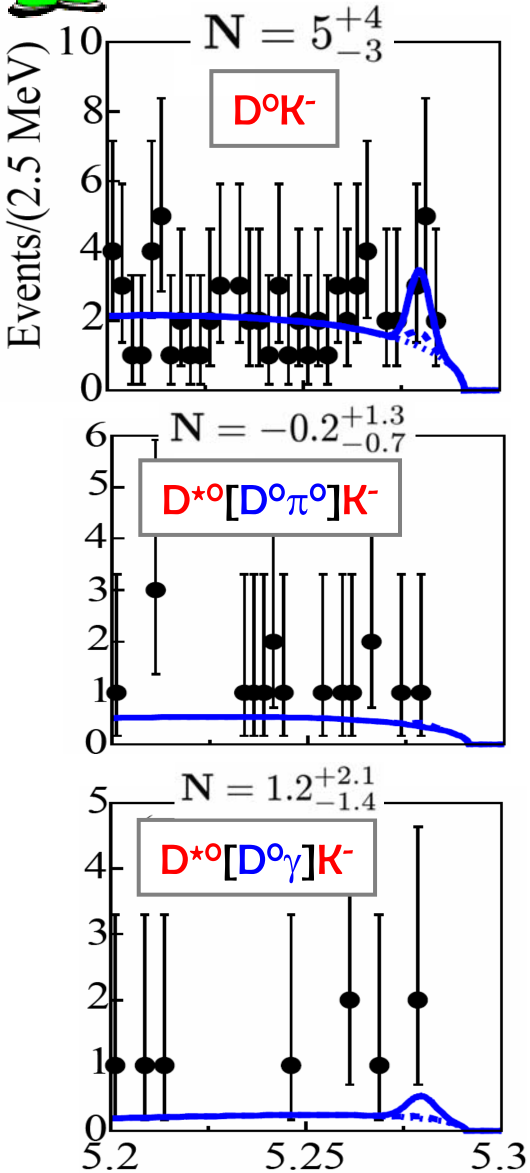
- direct ACPV:

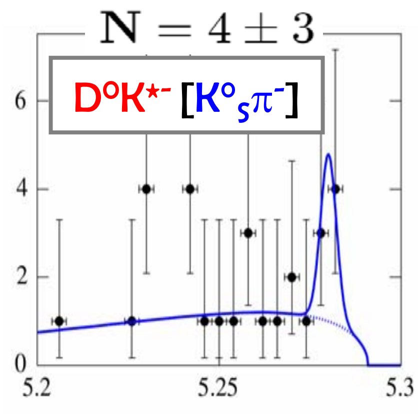
$B^+ \leftrightarrow B^-$ direct asymmetry in yield if enough events seen

BABAR ADS [$K^+\pi^-$] results

PRD 72, 032004 (2005)
PRD 72, 071104 (R) (2005)

232x10^6 $B\overline{B}$





m_{ES} (GeV/c²)

No significant signal yet

⇒ only (Bayesian) limits on R_{ADS} and $r(s)^{(*)}_B$

(using: $|\cos(\delta_B+\delta_D)\cos\gamma|<1$)

	R_{ADS}	"r_B"
D^0K	<0.029 90% CL	r_B <0.23 90% CL
$D^{*0}K$	<0.023 ($D^{*0}\to D^0\pi^0$) <0.045 ($D^{*0}\to D^0\gamma$) 90% CL	$(r^*_B)^2<(0.16)^2$ 90% CL + Bondar & Gershon PRD70,091503(2004)
D^0K^*	0.046±0.032	r_{SB}=0.20±0.14*

*+ GLW ⇒ $0.28^{+0.06}_{-0.10}$

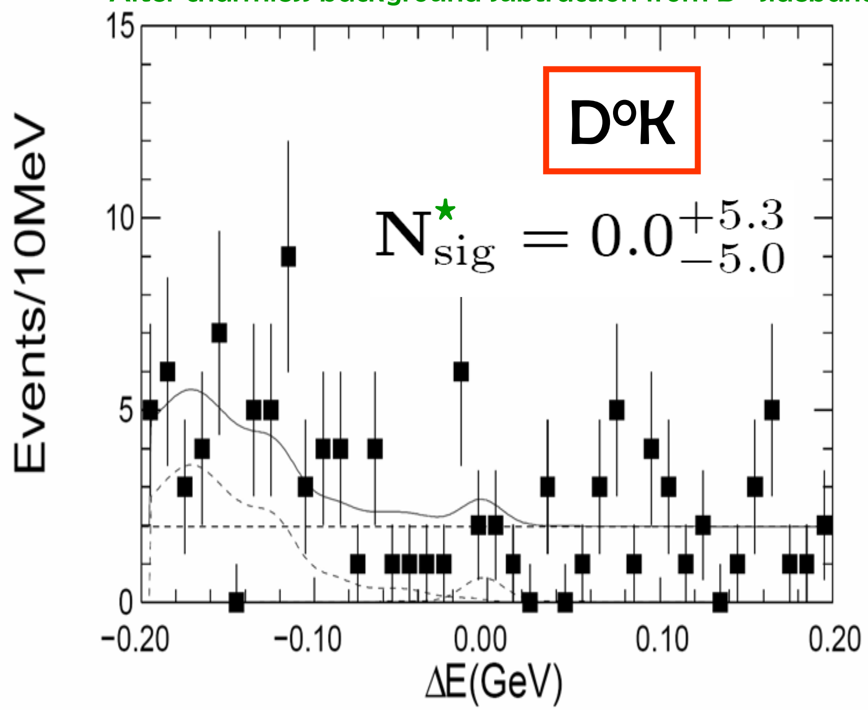
Belle CONF 0552
hep-ex/0508048

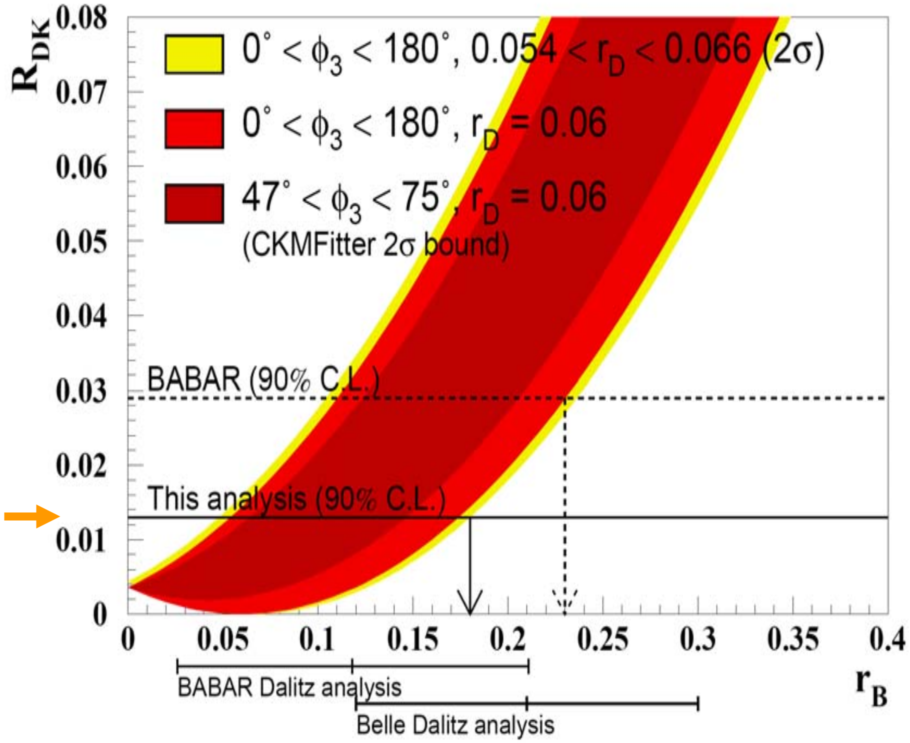
Belle ADS [$K^+\pi^-$] results

386×10^6 $B\bar{B}$

Despite larger statistics (x 1.7 BaBar) , the $D^0\to K^+\pi^-$ suppressed channel is not yet visible either:

*After charmless background subtraction from D° sidebands





R_{ADS}<13.9 x 10^{-3} @ 90% CL

maximum interference (ϕ_3=0, δ=180°):
r_B<0.18 @ 90% C.L. (Bayesian)

Here too, using avaible and more statistics will help!

hep-ex/0607065 (ICHEP2006)

BaBar ADS [$K^+\pi^-\pi^0$] results

$226\times10^6\ B\bar{B}$

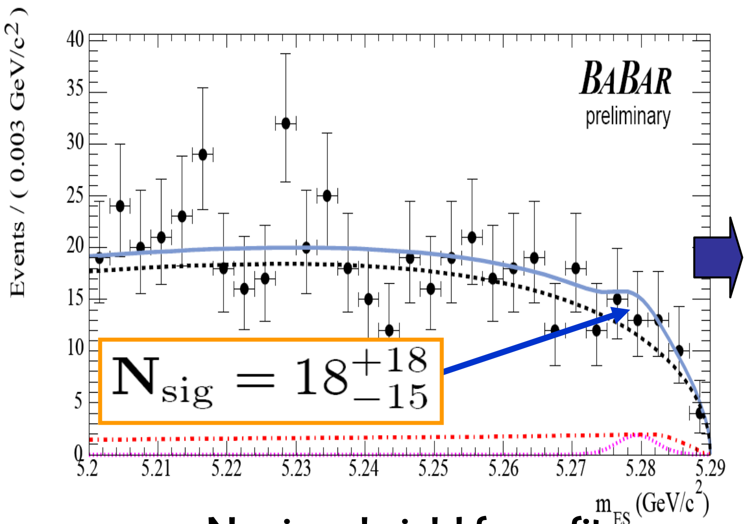
- Similar to previous analyses with DCS $D^0 \to K^+\pi^-\pi^0$
- Complication for γ extraction from $|A_D|$, δ_D varying across the D^0 Dalitz plane

$$R_{ADS} \equiv r_B^2 + r_D^2 + 2 r_B r_D C\cos(\gamma)$$

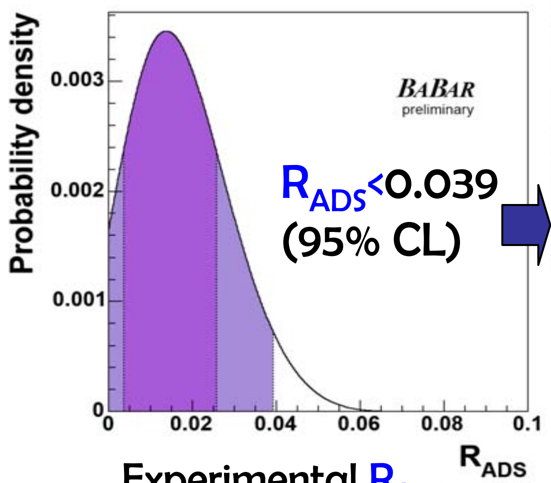
$$C = \frac{\int A_D(\vec{s})\bar{A}_D(\vec{s})\cos(\delta_D(\vec{s}) + \delta_B(\vec{s}))d\vec{s}}{\sqrt{\int |A_D(\vec{s})|^2 d\vec{s}}\sqrt{\int |\bar{A}_D(\vec{s})|^2 d\vec{s}}}$$

$$\vec{s} = (m^2_{K\pi}, m^2_{K\pi^0})$$

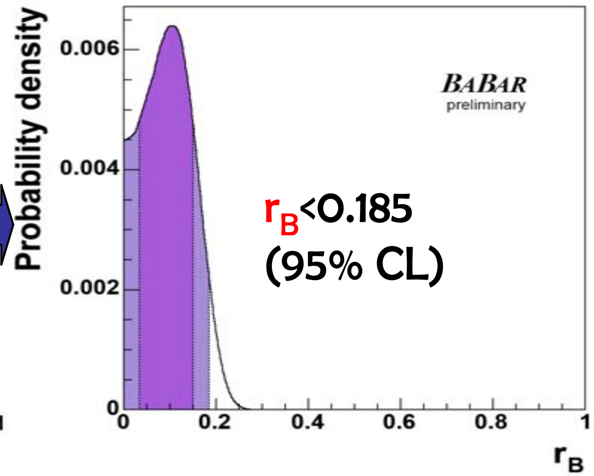
  - C is unknown, $|C| \le 1$
  - $r_D^2 = (0.214 \pm 0.011)\%$ BaBar, PRL 91, 171801(2003)
  - Compared to $K\pi$: more background but higher BF and smaller r_D (better r_B sensitivity)
- Similar sensitivity to r_B (limit on R_{ADS} using $|C\cos\gamma| \le 1$)



~No signal yield from fit

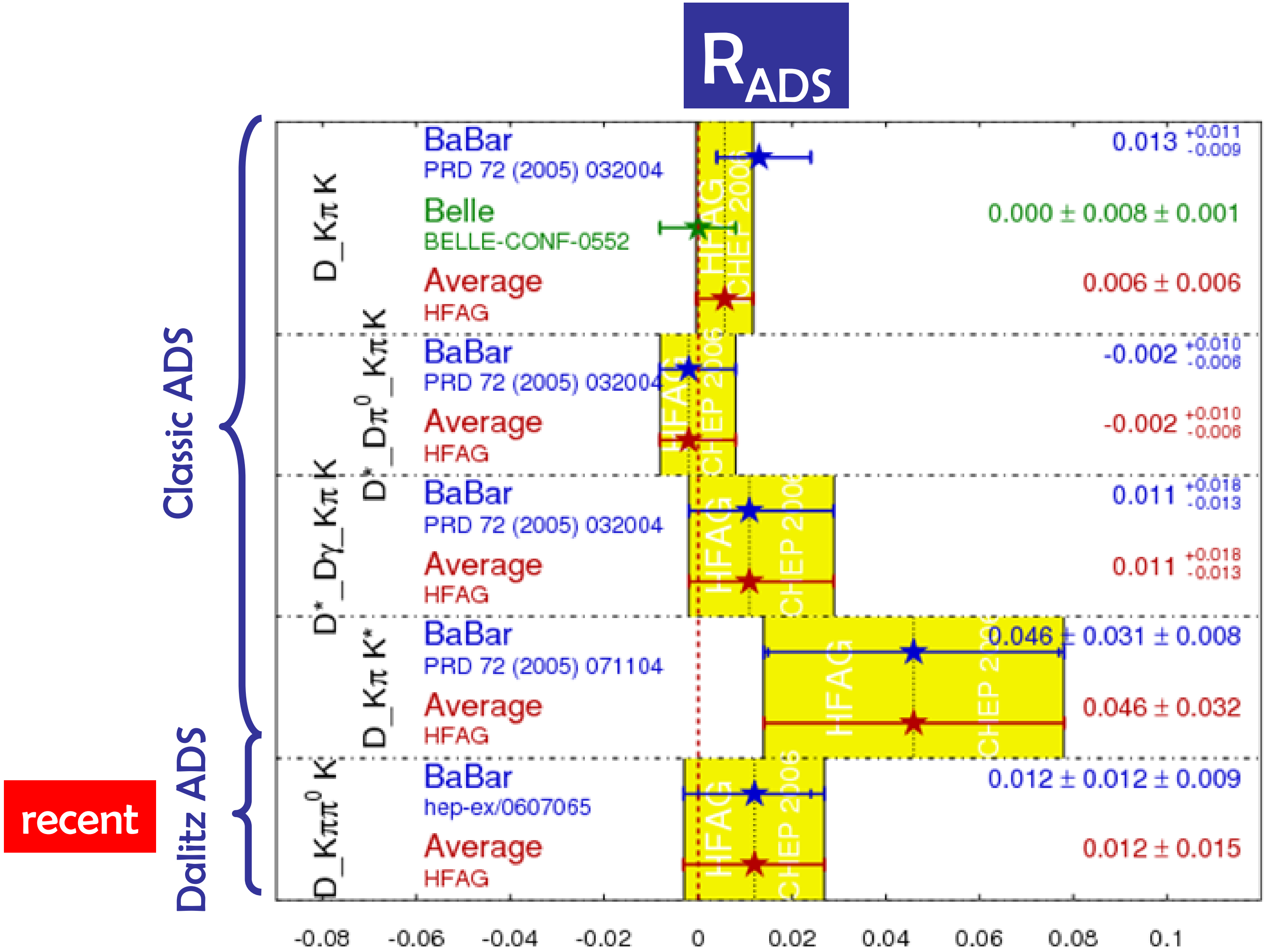


Experimental R_{ADS} likelihood



Bayesian $\mathcal{L}(r_B)$ (flat r_B and $|C\cos\gamma|$ prior PDFs)

ADS averages : *classic methods frozen since 2 years !*



- With current statistics is not possible to constraint r_B with R_{ADS} measurements alone (nothing for A_{ADS}).
- Note : BaBar and Belle use only about ½ of the available $B\bar{B}$ pairs.

Dalitz GGSZ : $B^- \to \tilde{D}^{(*)0}[K^0_s\pi^+\pi^-]_D K^{(*)-}$

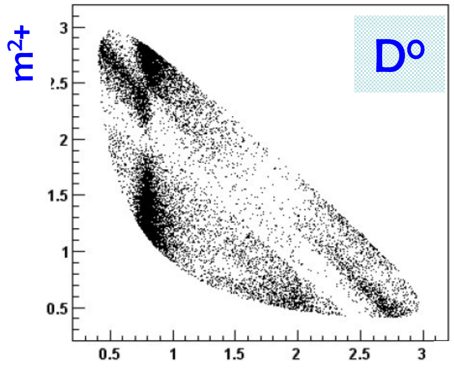
- $\tilde{D}^0 \to K^0_s\pi^+\pi^-$ final state accessible through many different decays. Only $\pi^{\pm}$'s: clean, efficient, and reasonable $BF([K^0_s\pi\pi]_D K^-)\sim 10^{-5}$ ($\times$10 D^0_{CP}).

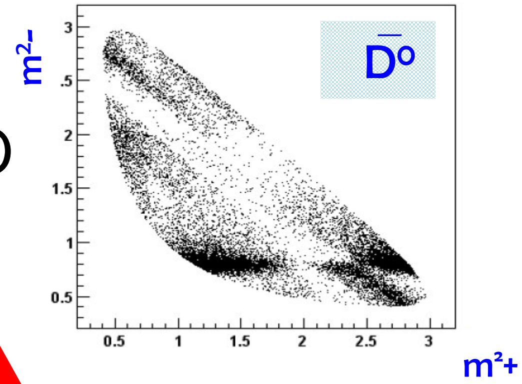
→ need Dalitz structure analysis : amplitudes $A_D(m^2_-,m^2_+)$ to separate interferences between resonances ⇒ precise modelization.

$m^2_+ = m^2(K^0_s\pi^+)$
$m^2_- = m^2(K^0_s\pi^-)$

- schematic view of interference ($b\to c$) ⇔ ($b\to u$): $B^-\to B^+$ → $-\gamma \to +\gamma$, $m_- \leftrightarrow m_+$, $\bar{D}^0 \leftrightarrow D^0$

$$\mathcal{A}(B^-) = |\mathcal{A}_B(D^0K^-)| \times \left(\times A_D(m^2_-,m^2_+) + r_B e^{i(\delta_B - \gamma)} \times A_D(m^2_+,m^2_-) \right)$$





sensitivity varies strongly over Dalitz plane
⇒ model + mixture ADS+GLW

- No D^0 mixing, nor CPV in D decays.
- 2 fold ambiguity : $(\gamma,\delta_B)\to(\gamma+\pi,\delta_B+\pi)$

Simultaneous fit to $\tilde{D}^0 \to K^0_s\pi^+\pi^-$ Dalitz plot density of B^+/B^- data to extract r_B's, δ_B's, and γ

D° Dalitz model for $A_D(m^2_-, m^2_+)$

- Model dependent fits to experimental data on flavor tagged D° mesons:

  $(260\text{-}390)\times 10^3$ $D^{*\pm}\rightarrow D^0\pi^\pm$ continuum events, high purity (97-98%).

- Use isobar model with coherent sum of quasi-2-body amplitudes using Breit-Wigner line-shapes (except: σ(500),σ'(1000) broad resonances, to describe the ππ S-wave) + constant NR term:

$$A_D(m^2_-, m^2_+) = \Sigma_r a_r e^{i\phi_r} A_r(m^2_-, m^2_+) + a_{NR} e^{i\phi_{NR}}$$

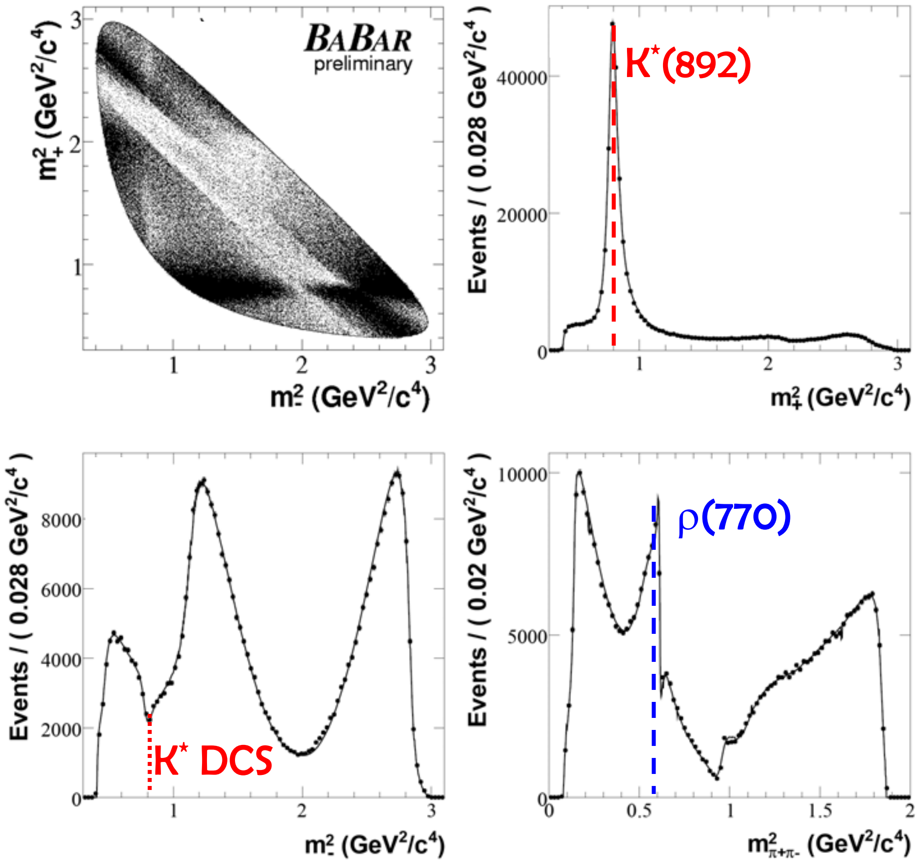
➔ additional unknown complex phase of D°decay, $\phi(m^2_-, m^2_+)$:
the Dalitz model γ systematic uncertainty (≠ pure 2 body ADS/GLW ⇒ phase varies vs the Dalitz plane position → the purpose the model)

➔ 16 resonances (3 DCS) + 1 non-resonant, with parameters from PDG/other exp.
(make also use of K-matrix for systematic uncertainties)

➔ 18 resonances (5 DCS) + 1 non-resonant, with parameters from PDG/other exp.

hep-ex/0607104
hep-ex/0507101
PRL95, 121802 (2005)

BaBar Dalitz model



16 resonances (3 DCS) + 1 NR:

Component	$Re\{a_r e^{i\phi_r}\}$	$Im\{a_r e^{i\phi_r}\}$	Fit fraction (%)	
$K^*(892)^-$	-1.223 ± 0.011	1.3461 ± 0.0096	58.1	CA $K^*\pi$
$K_0^*(1430)^-$	-1.698 ± 0.022	-0.576 ± 0.024	6.7	
$K_2^*(1430)^-$	-0.834 ± 0.021	0.931 ± 0.022	3.6	
$K^*(1410)^-$	-0.248 ± 0.038	-0.108 ± 0.031	0.1	
$K^*(1680)^-$	-1.285 ± 0.014	0.205 ± 0.013	0.6	
$K^*(892)^+$	0.0997 ± 0.0036	-0.1271 ± 0.0034	0.5	DCS $K^*\pi$
$K_0^*(1430)^+$	-0.027 ± 0.016	-0.076 ± 0.017	0.0	
$K_2^*(1430)^+$	0.019 ± 0.017	0.177 ± 0.018	0.1	
$\rho(770)$	1	0	21.6	$\pi\pi$ P,D-waves
$\omega(782)$	-0.02194 ± 0.00099	0.03942 ± 0.00066	0.7	
$f_2(1270)$	-0.699 ± 0.018	0.387 ± 0.018	2.1	
$\rho(1450)$	0.253 ± 0.038	0.036 ± 0.055	0.1	
Non-resonant	-0.99 ± 0.19	3.82 ± 0.13	8.5	$\pi\pi$ S-wave Non-resonant
$f_0(980)$	0.4465 ± 0.0057	0.2572 ± 0.0081	6.4	
$f_0(1370)$	0.95 ± 0.11	-1.619 ± 0.011	2.0	
σ	1.28 ± 0.02	0.273 ± 0.024	7.6	
σ'	0.290 ± 0.010	-0.0655 ± 0.0098	0.9	

χ^2/ dof≈1.2
Σ *amplitudes Fit Fraction=1.2*

with all parameters from PDG except:

- K*⁰(1430) from E791 experiment (isobar: ≠PDG)
- "Ad hoc" σ(500),σ'(1000) (broad ππ S waves) resonances extracted from D*⁺→D⁰π⁺ fit

Data sample : Belle

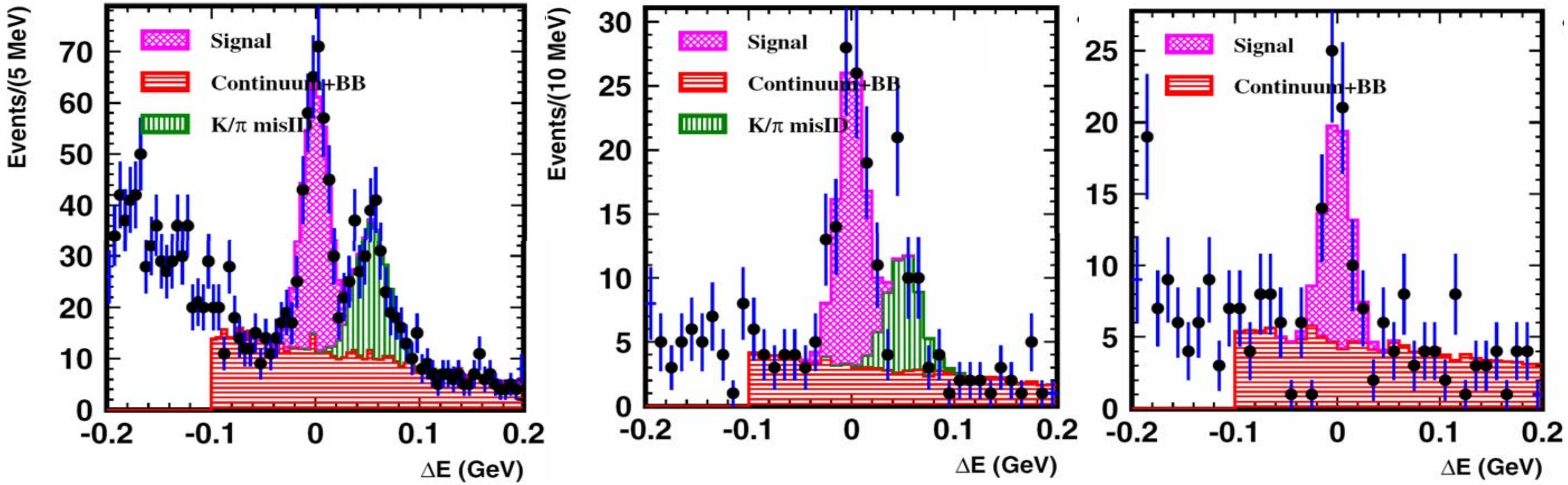
PRD 73,112009(2006) | 386×10^6 $B\bar{B}$

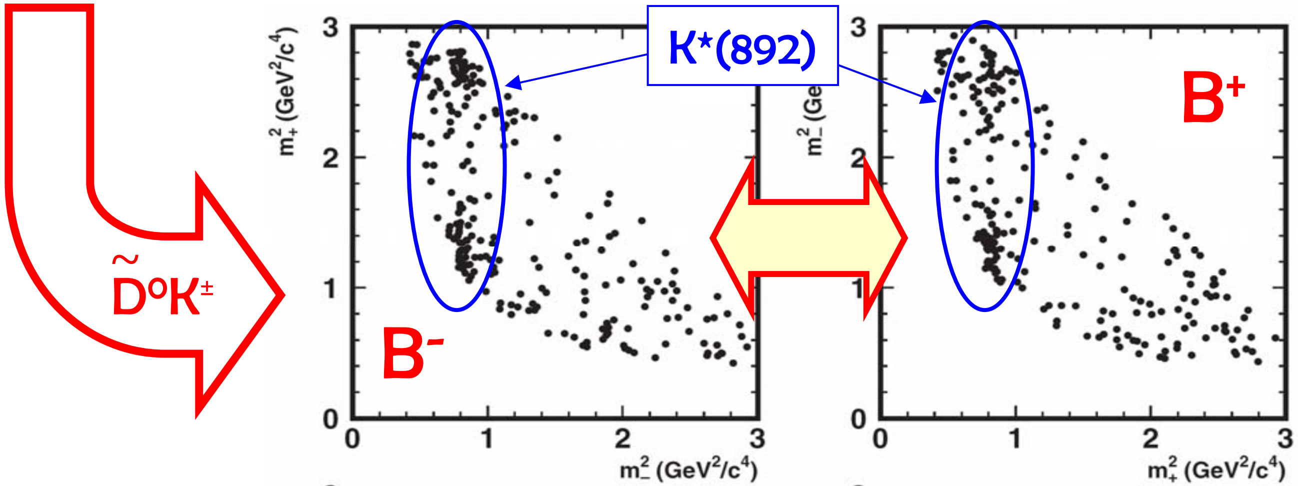
Simultaneous fit uses m_{BC}, ΔE, $m^2_\pm$(model)

$\tilde{D}^0K^-$ N_{sig}=331±17 Purity=67%

$\tilde{D}^{*0}[\tilde{D}^0\pi^0]K^-$ N_{sig}=81±11 Purity=77%

$\tilde{D}^0K^{*-}[K^0_S\pi^-]$ N_{sig}=54±8 Purity=65%





B+ ⇔ B- differences mean CPV

BABAR has similar eff'cies but slightly higher

Dalitz : Fit Parameters for $B^- \to \tilde{D}^{(*)0} K^{(*)-}$

→ 3 kinds of decays: 7 unknowns:

- r_B, r^*_B, r_{sB}
- δ_B, δ^*_B, δ_{sB}
- γ

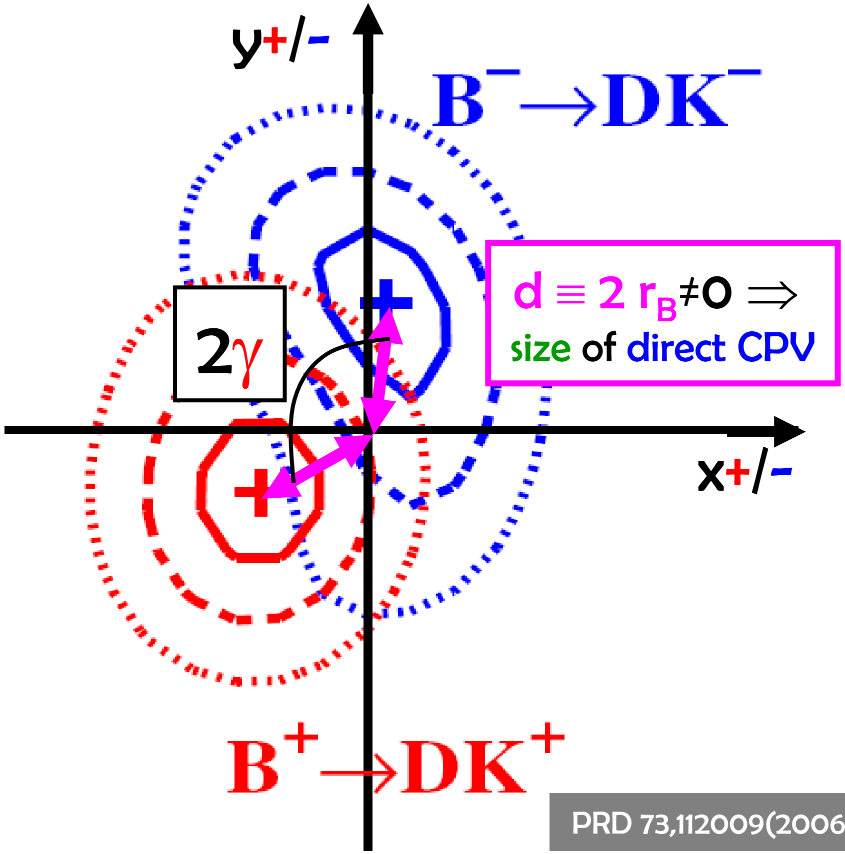
Non Gaussian effects + biases : low stat. sample & low sensitivity near physical bound r_B~0

Extraction of CP parameters from Multivariable max. Likelihood simultaneous fit to almost Gaussian and uncorrelated Cartesian coordinates (3×4):

$(x\pm, y\pm)$, $(x^*\pm, y^*\pm)$, & $(x_s\pm, y_s\pm)$.

Natural choice from $\mathcal{A}(B^\pm)$ definition:

$$\left(x_{(s)}^{(*)}\pm, y_{(s)}^{(*)}\pm\right) \equiv (\mathrm{Re}, \mathrm{Im})\left\{r_{(s)}^{(*)}{}_B\, e^{i\left(\delta_{(s)}^{(*)}{}_B \pm \gamma\right)}\right\}$$



PRD 73,112009(2006)

for $\tilde{D}^0K^{*-}$

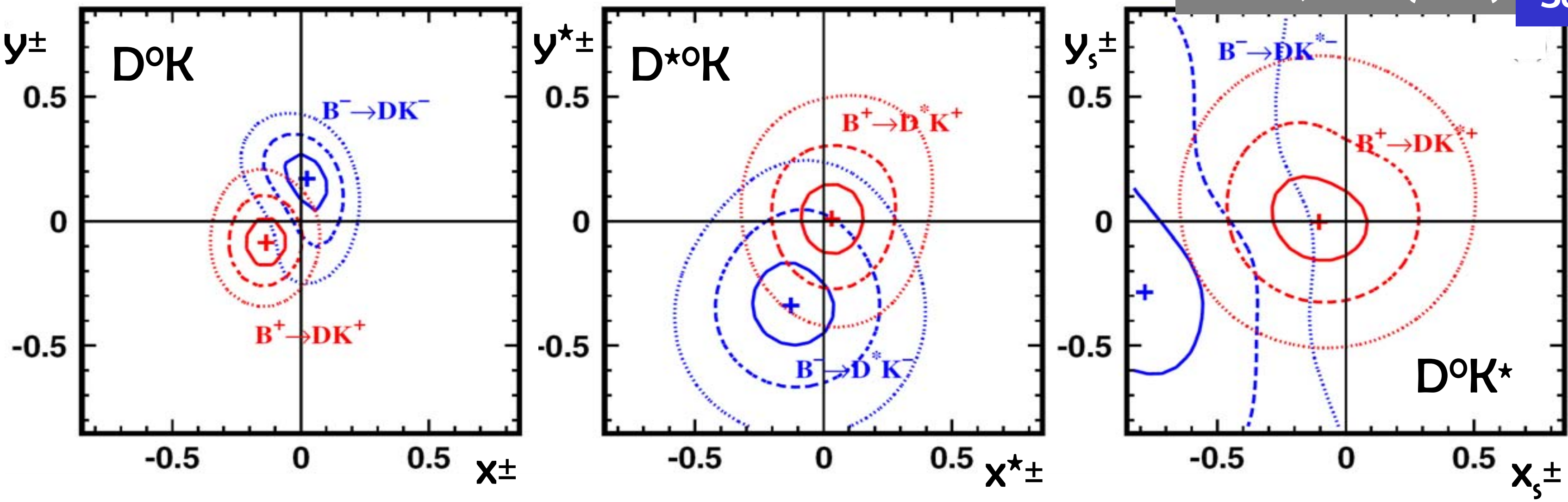
$$\left(x_{s}\pm, y_{s}\pm\right) \equiv (\mathrm{Re}, \mathrm{Im})\left\{\kappa . r_{sB}\, e^{i\left(\delta_{sB} \pm \gamma\right)}\right\}$$

Gronau PLB557, 198(2003)

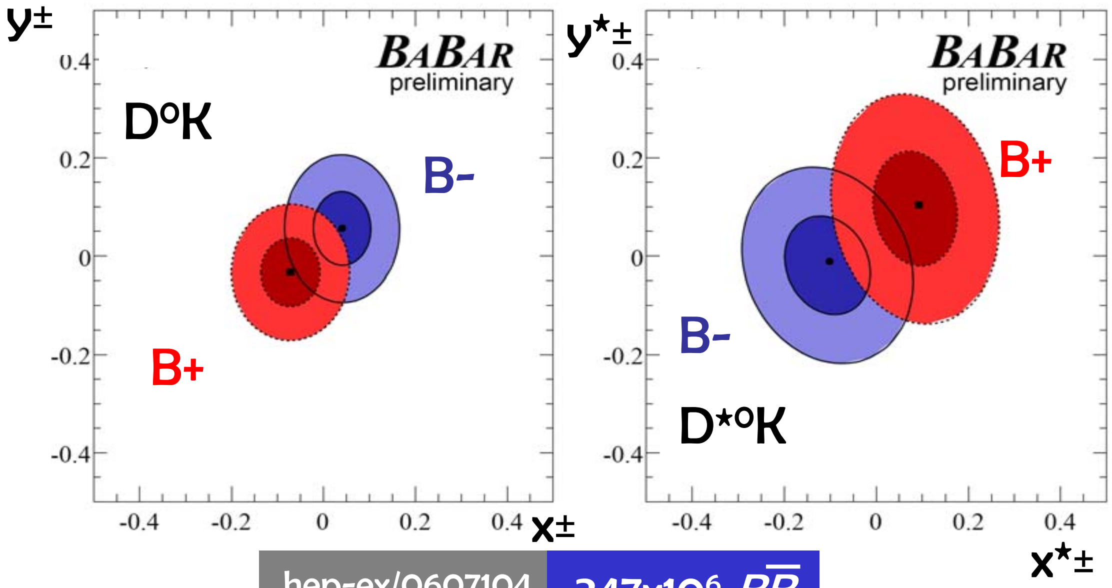
$\kappa \in [0,1]$: accounts for $(K^0_s\pi^-)$non-K^{*-} large natural width bckgd ⇒ no assumptions on: nature, number, strong phases ...

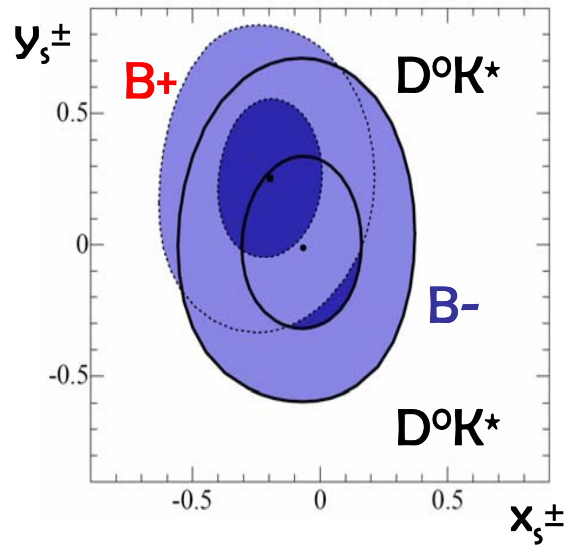
$(x_\pm, y_\pm)$: Fits results BABAR and Belle

PRD 73,112009(2006) | 386×10^6 $B\bar{B}$



1, 2, 3σ (stat)





1, 2σ (stat)

hep-ex/0607104 | 347×10^6 $B\bar{B}$

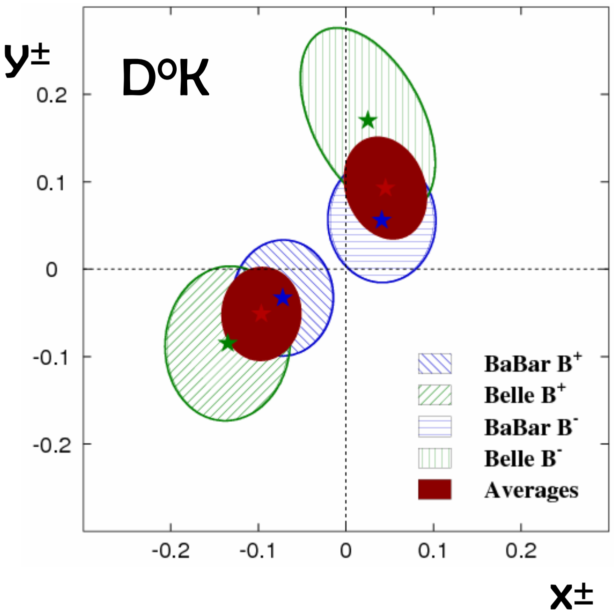
hep-ex/0507101 | 227×10^6 $B\bar{B}$

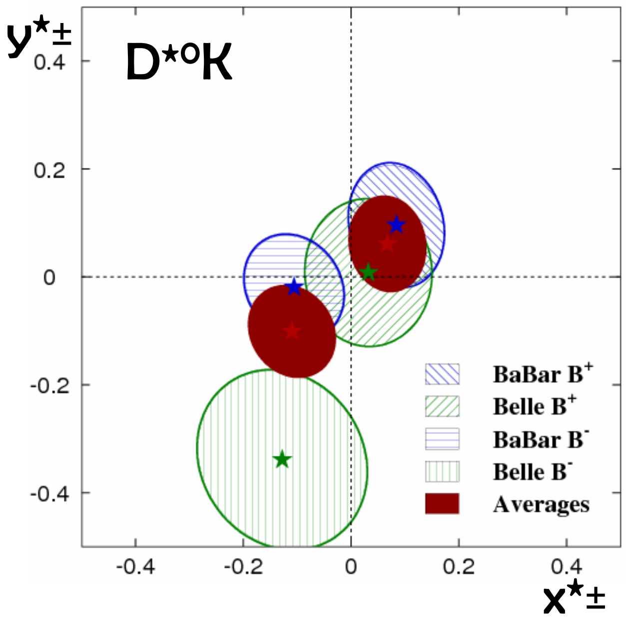
$(x\pm, y\pm)$: World average

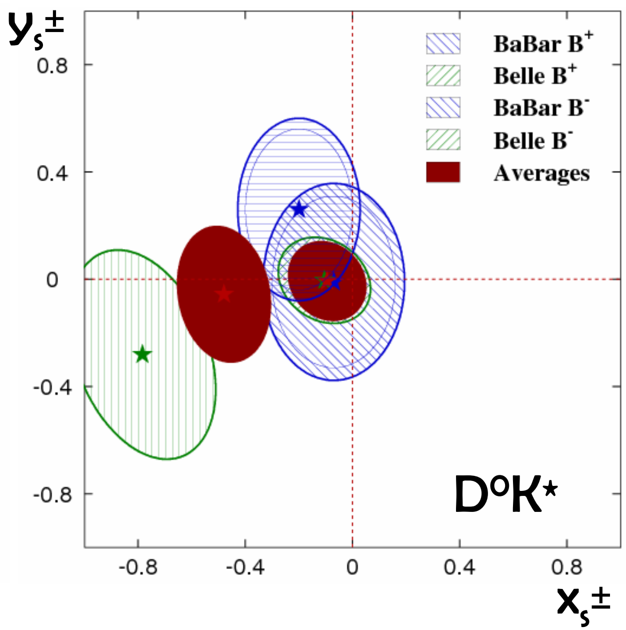
$$\left(x^{(*)}_{(s)}\pm, y^{(*)}_{(s)}\pm\right) \equiv (\mathbf{Re}, \mathbf{Im})\{\mathbf{r}^{(*)}_{(s)}{}_{\mathbf{B}} e^{\mathbf{i}(\delta^{(*)}_{(s)}{}_{\mathrm{B}}\pm\gamma)}\}$$

HFAG winter 2007

No Dalitz model error







Note that the BABAR GLW analyzes are competitive !

PRD 73, 051105 (2006)
PRD 72, 071103 (2005)

$$x_\pm = \frac{R_{CP+}(1 \mp A_{CP+}) - R_{CP-}(1 \mp A_{CP+})}{4}$$

B→D⁰K

$$x_+ = -0.082 \pm 0.052 \pm 0.018$$
$$x_- = 0.102 \pm 0.062 \pm 0.022$$
$$r_B^2 = -0.12 \pm 0.08 \pm 0.03$$

B→D⁰K*

$$x_{s+} = 0.32 \pm 0.18 \pm 0.07$$
$$x_{s-} = 0.33 \pm 0.16 \pm 0.06$$
$$r_{sB}^2 = 0.30 \pm 0.25$$

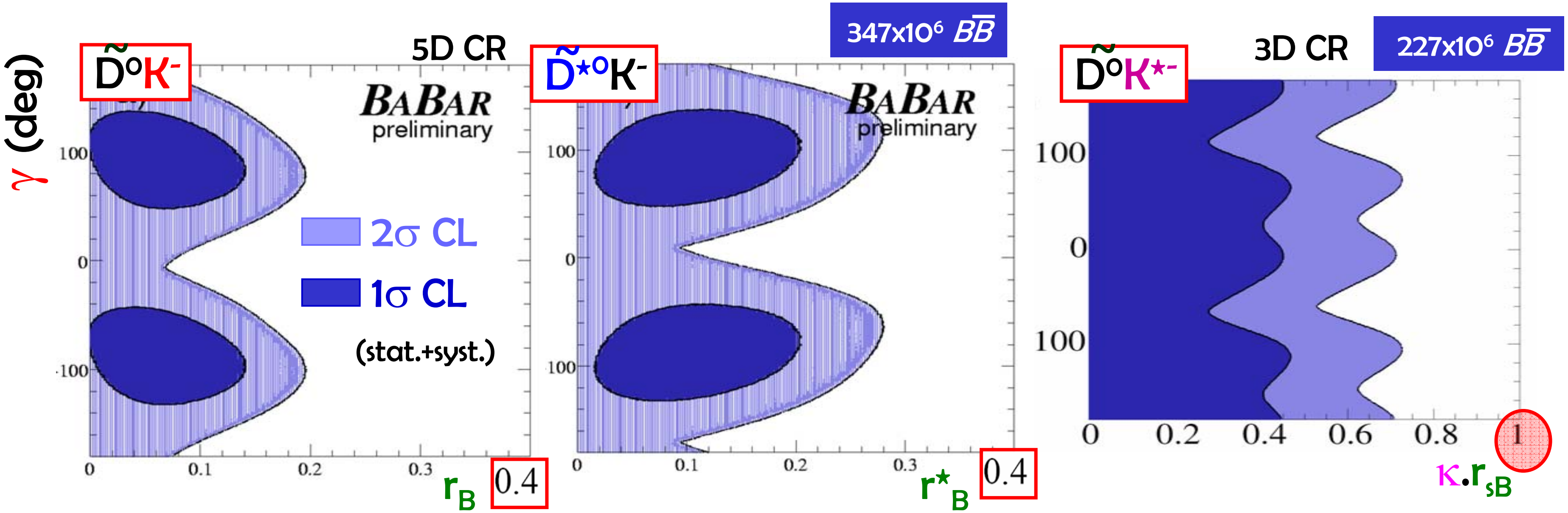
hep-ex/0607104
hep-ex/0507101

BABAR Dalitz: γ results for $B^- \to \tilde{D}^{(*)0} K^{(*)-}$

From measured CP parameters: $(x_\pm, y_\pm)$, $(x^*_\pm, y^*_\pm)$, $(x_{s\pm}, y_{s\pm})$ perform combined fit to pseudo experiments (nD Neyman Confidence Regions (CR) [frequentist])

extract

- r_B, r^*_B, $\kappa.r_{sB}$
- δ_B, δ^*_B, δ_{sB}
- γ



γ [mod π] =$(92 \pm 41 \pm 11 \pm 12)^\circ$
stat. ± syst. ±Dalitz model

no 2σ constraint

$r_B < 0.142$
$r^*_B \in [0.016, 0.206]$

Smaller than in 2005

No 1σ limit on γ with D^0K^{*-} alone

$\kappa.r_{sB} < 0.50$

Belle Dalitz: γ results for $B^- \to \tilde{D}^{(*)0} K^{(*)-}$

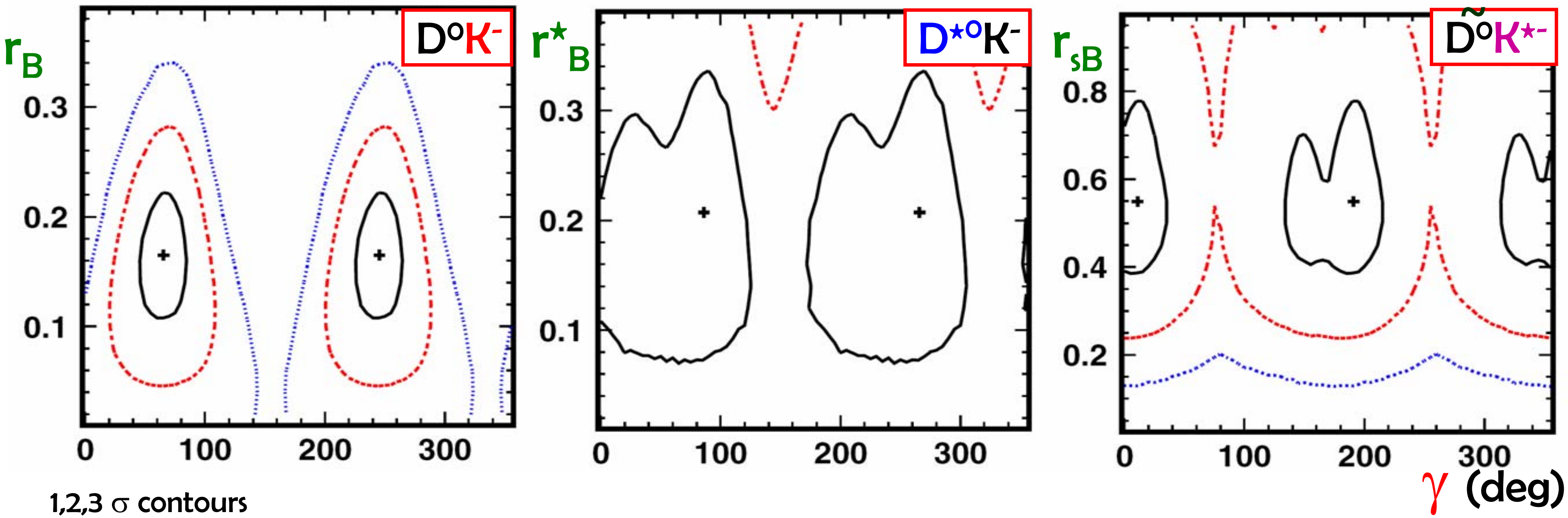
PRD 73,112009(2006)

386×10^6 $B\bar{B}$

From measured CP parameters: $(x_\pm, y_\pm)$, $(x^*_\pm, y^*_\pm)$, $(x_{s\pm}, y_{s\pm})$ perform combined fit to pseudo experiments (7D Feldman Cousins Confidence Regions (CR) [frequentist])

extract

- r_B, r^*_B, r_{sB}
- δ_B, δ^*_B, δ_{sB}
- γ



1,2,3 σ contours

Combined for 3 modes: $\gamma = (53^{+15}_{-18} \pm 3\ (\text{syst}) \pm 9\ (\text{model}))^\circ$

$8^\circ < \gamma < 111^\circ$ (2σ interval)

$r_B = 0.159^{+0.054}_{-0.050} \pm 0.012\ (\text{syst}) \pm 0.049\ (\text{model})$

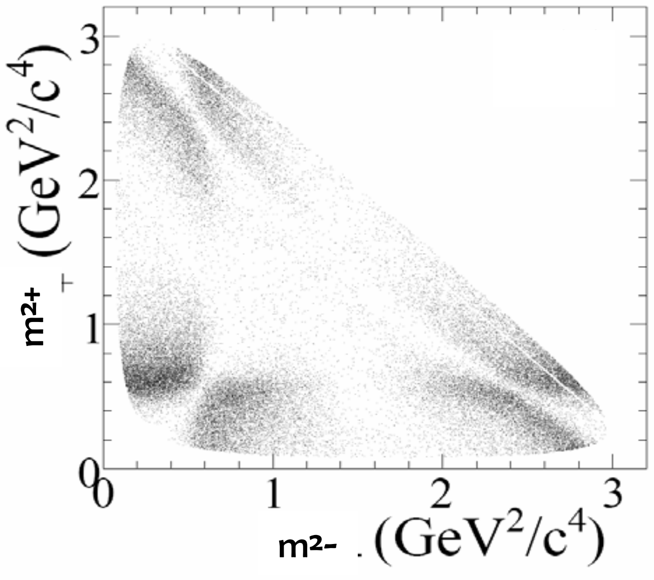
CPV significance: 78% $r^*_B = 0.175^{+0.108}_{-0.099} \pm 0.013\ (\text{syst}) \pm 0.049\ (\text{model})$

$r_{sB} = 0.564^{+0.216}_{-0.155} \pm 0.041\ (\text{syst}) \pm 0.084\ (\text{model})$

BABAR Dalitz first results for $B^- \to \tilde{D}^0[\pi\pi\pi^0]K^-$

Compared to $\tilde{D}^0[K^0_S\pi\pi]K^-$:

- ~0.5 signal rate (170±29).
- larger background and different Dalitz structure.

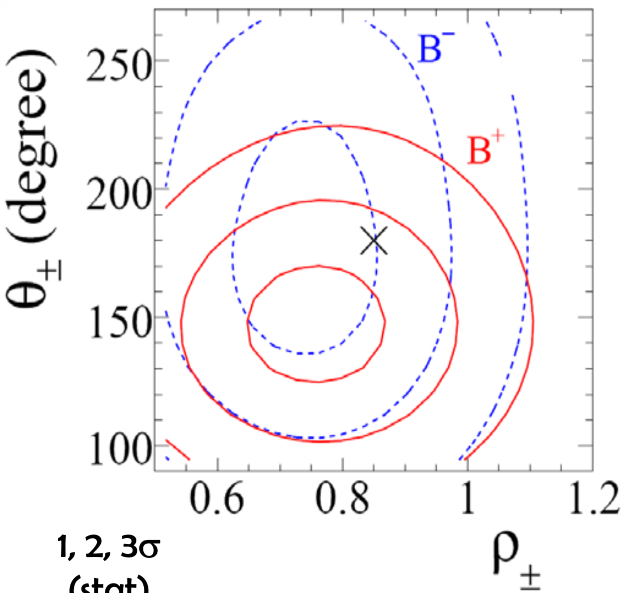


➔ due to significant nonlinear correlations use polar coordinates, instead of Cartesian, and r_B, δ and γ, defined as:

$$\rho_\pm \equiv \sqrt{(x_\pm - x^0)^2 + y_\pm^2}$$

$$\theta_\pm \equiv \mathrm{atan}\left(\frac{y_\pm}{x_\pm - x^0}\right)$$

$$x^0 \equiv \int A_D(m^-, m^+)\bar{A}_D(m^+, m^-)dm^-dm^+ = 0.85$$



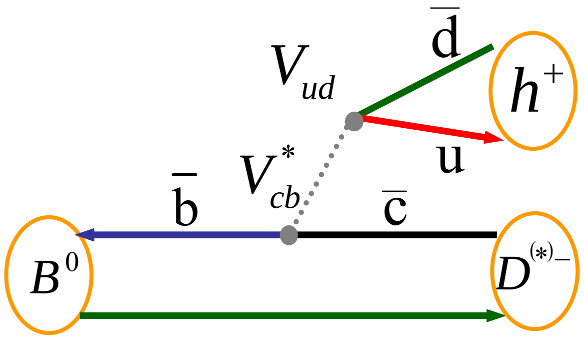
1, 2, 3σ (stat)

ρ_-=0.72±0.11±0.06
ρ_+ =0.75±0.11±0.06
θ_-=(173±42±19)°
θ_+=(147±23±13)°

Dalitz model dominates for syst.

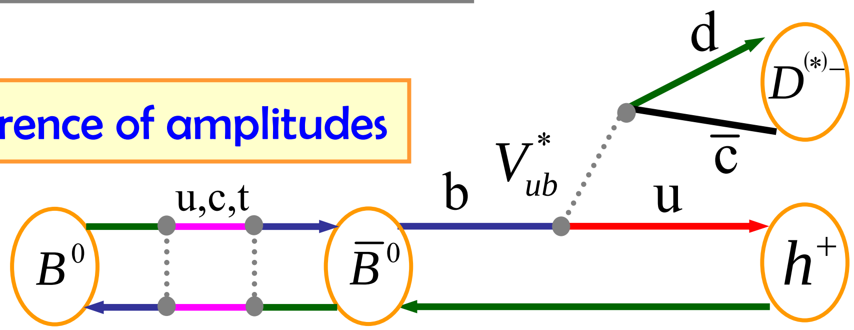
Expect low sensitivity on γ alone (not extracted here)

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



Cabibbo Favored (CF)

Interference of amplitudes



Doubly Cabibbo Suppressed (DCS)

- δ relative strong phase & weak phase
- $2\beta+\gamma$ (2β from mixing, γ from V_{ub})

- Pure tree decays, large BF(~1%), time CP evolution (unmixed/mixed):

$$P(B^0 \to D^{(*)\mp}\pi^\pm, \Delta t) \propto 1 \pm C^{(*)} cos(\Delta m_d \Delta t) + S^{(*)\mp} sin(m_d \Delta t)$$
$$P(\overline{B}^0 \to D^{(*)\mp}\pi^\pm, \Delta t) \propto 1 \mp C^{(*)} cos(\Delta m_d \Delta t) - S^{(*)\pm} sin(m_d \Delta t)$$

$$S^{(*)\pm} = \frac{2r^{(*)}}{1+r^{(*)2}} sin(2\beta + \gamma \pm \delta^{(*)}) \qquad C^{(*)} = \frac{1-r^{(*)2}}{1+r^{(*)2}} \simeq 1$$

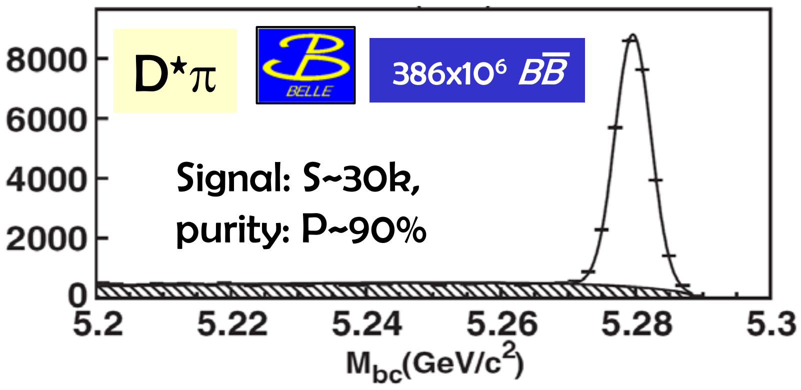
- Method "à la" $\sin 2\beta$ B^0 flavor from other side B-tag
- But small CPV asymmetries: $r^{(*)} = \frac{|\mathcal{A}_{DCS}|}{|\mathcal{A}_{CF}|} \sim 2\%$ → *statistics crucial !*

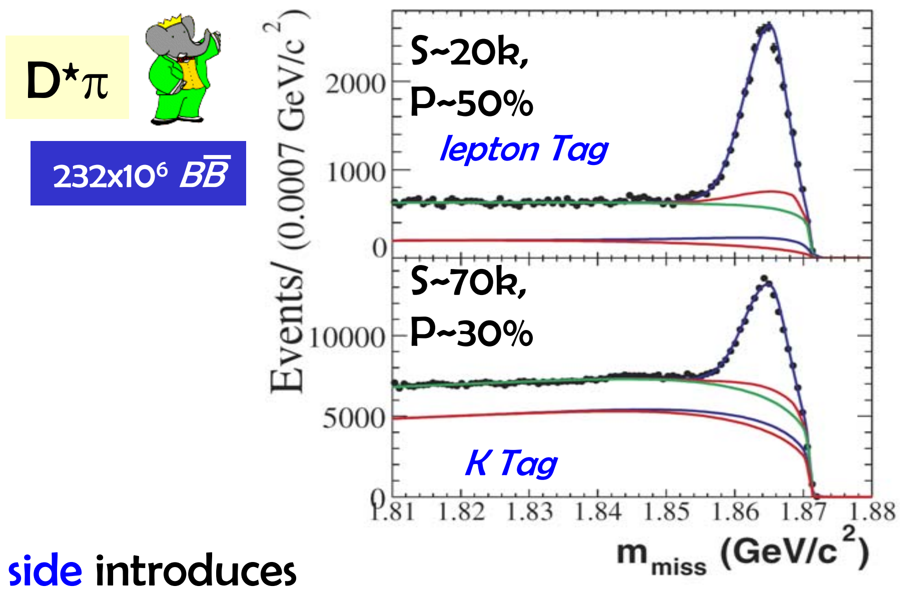
→ Can't be fitted ($1-C^{(*)} \sim 10^{-4}$), need external inputs + SU(3) flavor symmetry

Experimental techniques and issues

PRD 73,092003(2006)
PRD71,112003(2005)
PRD73,111101(R)(2006)

- 2 methods of reconstruction:
  - → Full exclusive (high purity)
  - → Partial inclusive (lower purity, depending B-tag) but larger total stat ~×5 (reconstruct only hard-B and slow-D* π s)





- Presence of the DCS $D^{(*)}\pi/\rho$ decays on B-tag side introduces extra-CPV (additional r' and δ') (~ order as $r^{(*)}$), rewrite:

$$S^{(*)\pm} = (a^{(*)} \pm c^{(*)}) + b$$

$$\begin{cases} a^{(*)} = 2r^{(*)} sin(2\beta+\gamma) cos\delta^{(*)} \\ b = 2r' sin(2\beta+\gamma) cos\delta' \\ c^{(*)} = 2cos(2\beta+\gamma)(r^{(*)} sin\delta^{(*)} - r' sin\delta') \end{cases}$$

→ free of B-tag CPV

↑ if lepton

232x10⁶ $B\overline{B}$

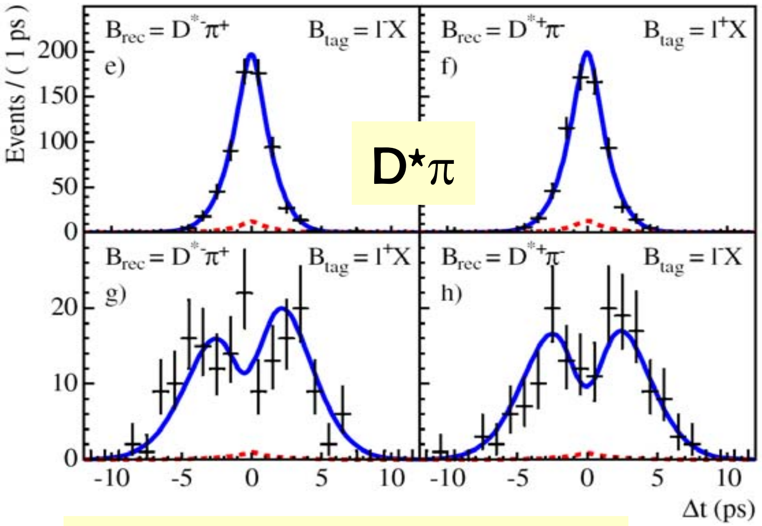
PRD71,112003(2005)
PRD73,111101(R)(2006)

BaBar/Belle results

386x10⁶ $B\overline{B}$

PRD 73,092003(2006)

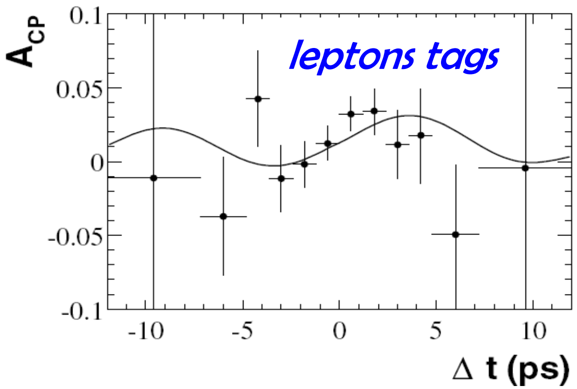
- **Full reconstruction:**



- **Partial reconstruction** (D*π):

$$a = 2r^{*} \sin(2\beta+\gamma)\cos\delta^{*}$$
$$= -0.034 \pm 0.014 \pm 0.009$$

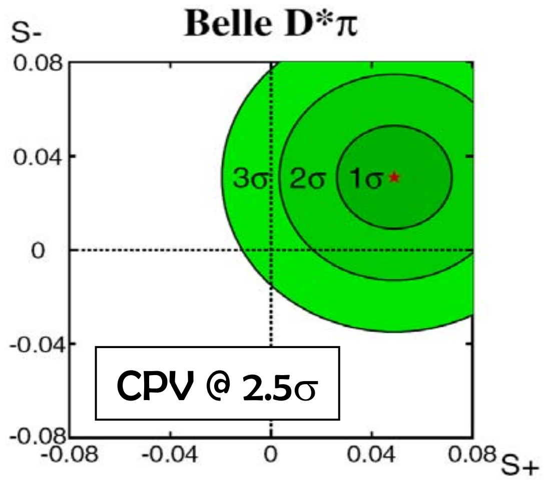
CPV @2σ

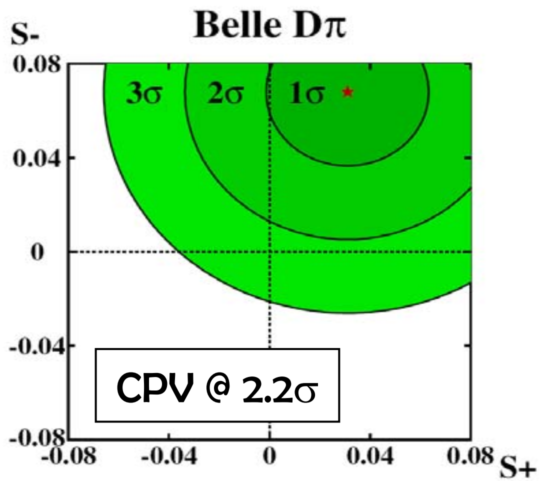


Most precise time-dependent CP asymmetry

$$A_{CP} = \frac{N(B^0) - N(\overline{B}^0)}{N(B^0) + N(\overline{B}^0)}$$

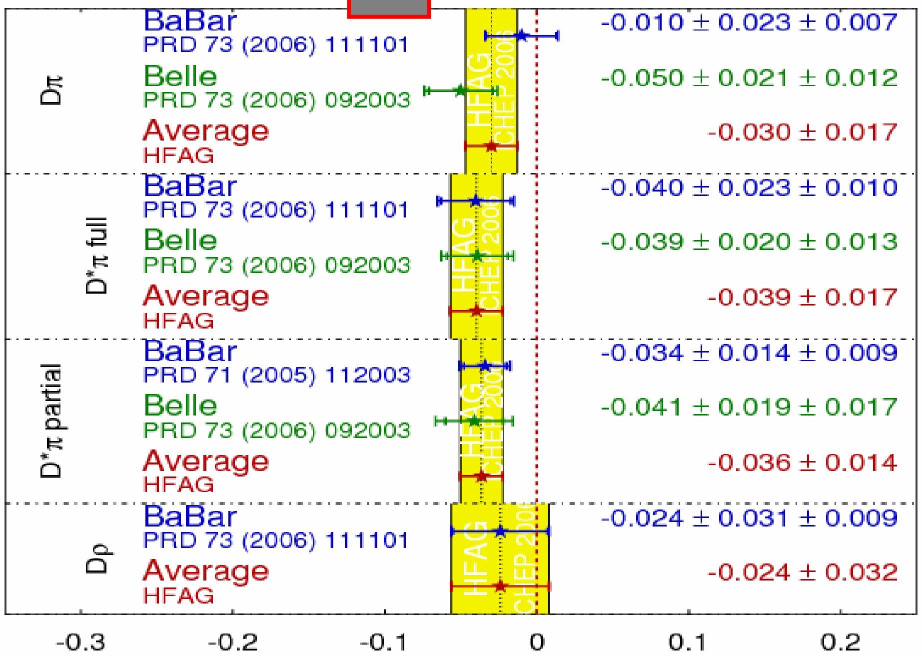
Combination Partial+Full

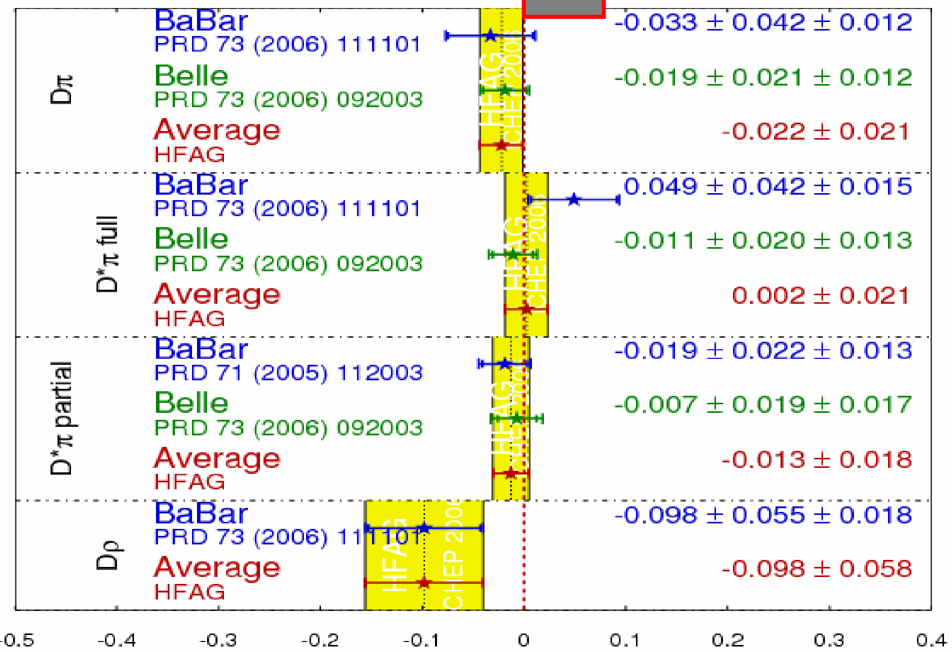




a's and c's : World average

HFAG winter 2006

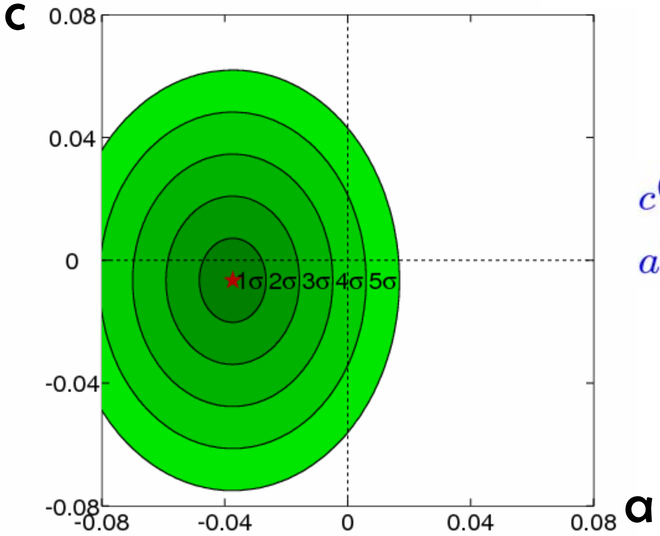




Combined for D*π (Partial+Full):

a=-0.037±0.011 (3.4σ CPV!)

c=-0.006±0.014



$$a^{(*)} = (-1)^l (S^+ + S^-)/2$$

$$c^{(*)} = (-1)^l (S^+ - S^-)/2$$

$$c^{(*)}{}_{lept} = 2r^{(*)} cos(2\beta+\gamma) sin\delta^{(*)}$$

$$a^{(*)} = 2r^{(*)} sin(2\beta+\gamma) cos\delta^{(*)}$$

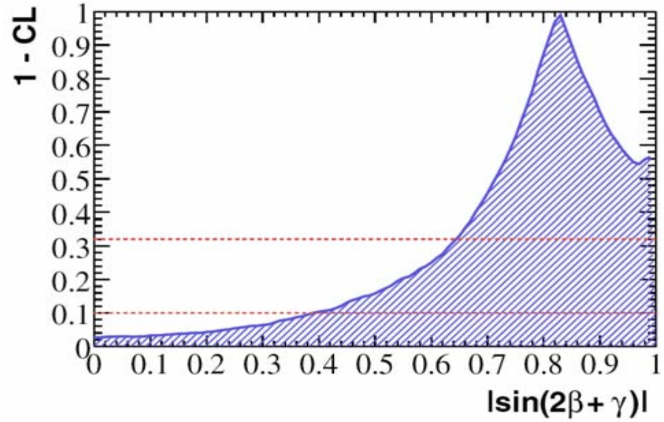
- Good agreement between experiments
- Observation of CPV within reach (when add more stat) !
- Possibly add D*ρ (partial reco and angular analysis)

$\sin(2\beta+\gamma) \equiv \sin(2\phi_1+\phi_3)$ constraints

PRD 73,092003(2006)
PRD71,112003(2005)
PRD73,111101(R)(2006)

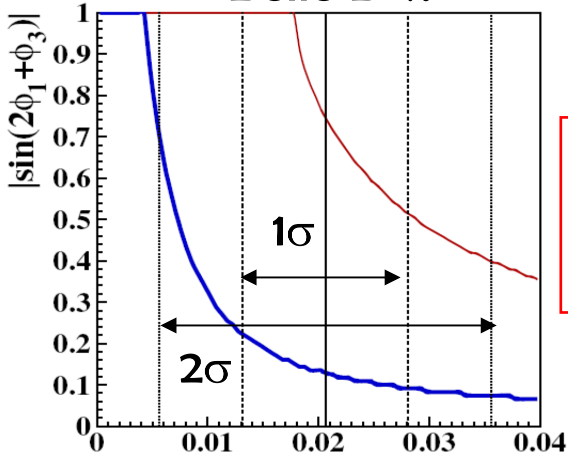
Frequentist approach (BABAR) + estimates of r(*) fixed to external measurements★ + SU(3) flavor symmetry (including 30% theoretical errors due to SU(3) breaking and W-exchange & annihilation diagrams)

BABAR D*π



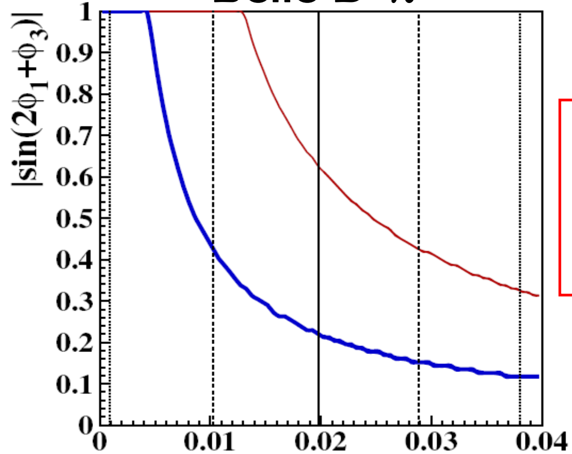
$\sin(2\beta+\gamma) > 0.64(0.40)$ at 68(90) % CL

Belle D*π



$\sin(2\beta+\gamma) > 0.52$ (0.07) at 68 (90) % CL

Belle D*π

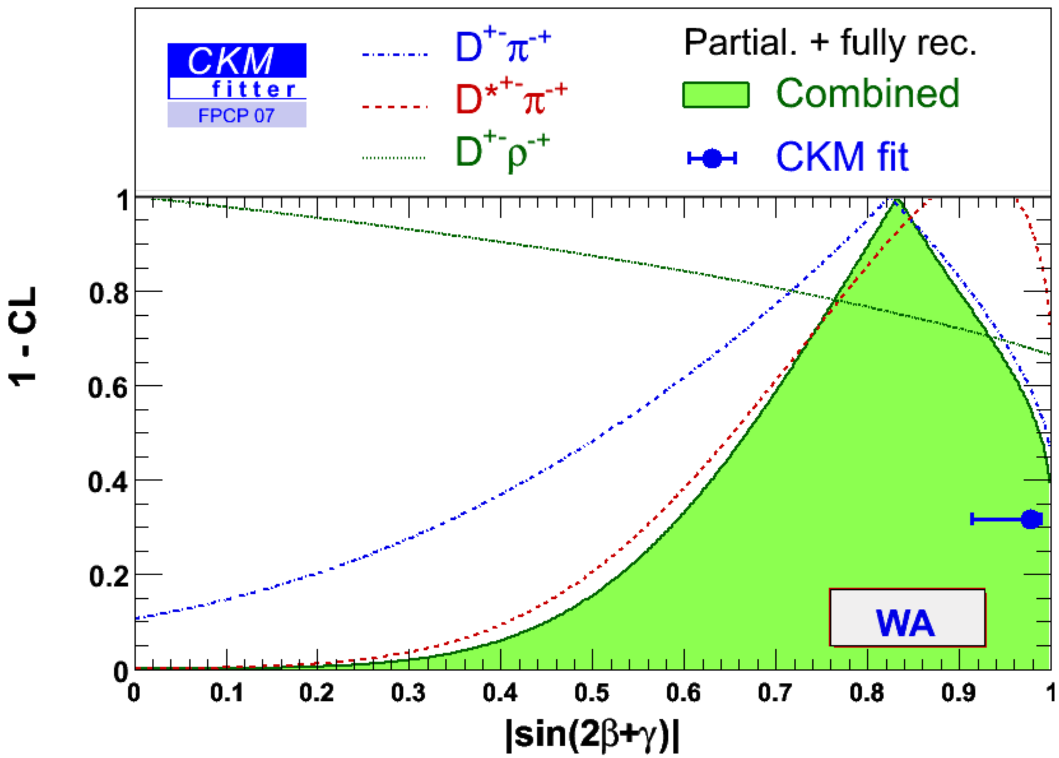


$\sin(2\beta+\gamma) > 0.44$ (0.13) at 68 (90) % CL

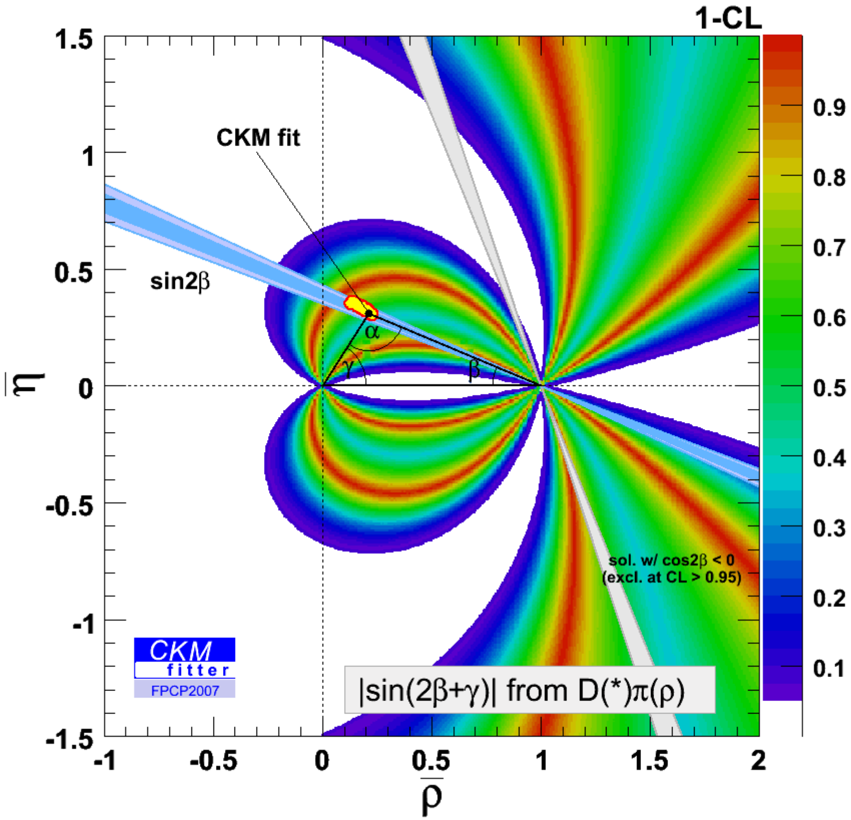
★ Including recent BF($D_s^*\pi$) by BaBar:

PRL98,081801(2007)

Constraints on γ from $D^{(*)}\pi/\rho$ modes



CKM-Fit: $0.978^{+0.010}_{-0.065}$



Combine BABAR and Belle, partial and fully reco. results for the a and c_{lep} parameters and use the $r^{(*)}$ parameters from SU(3) symmetry (see Max Baak's talk at CKM WS 06, re-scattering model).

$r(D\pi) = (1.53 \pm 0.33 \pm 0.08)\%$
$r(D^*\pi) = (2.10 \pm 0.47 \pm 0.11)\%$
$r(D\rho) = (0.31 \pm 0.59 \pm 0.02)\%$

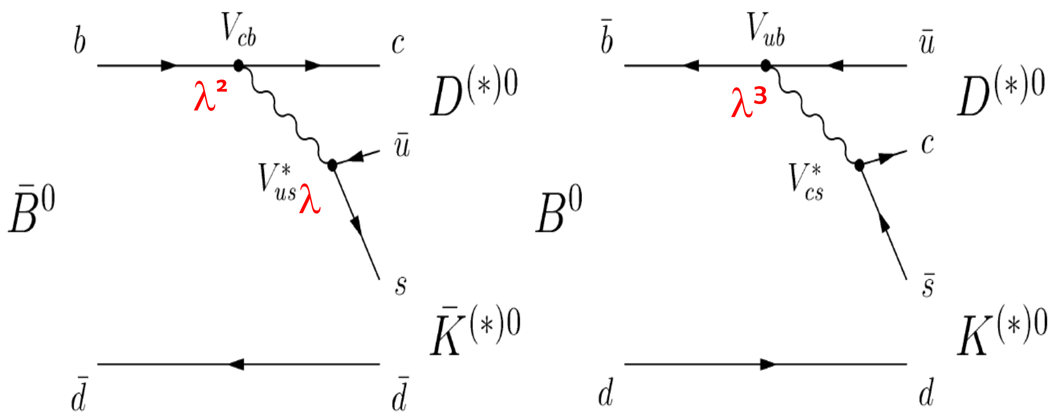
Gaussian errors for SU(3) from non-factorizable contributions + 5% flat errors for SU(3) breaking from W-exchange diagrams

226x10[6] $B\bar{B}$

PRD74,031101(R)(2006)

Perspectives on $B^0 \rightarrow D^{(*)0}K^{(*)0}$

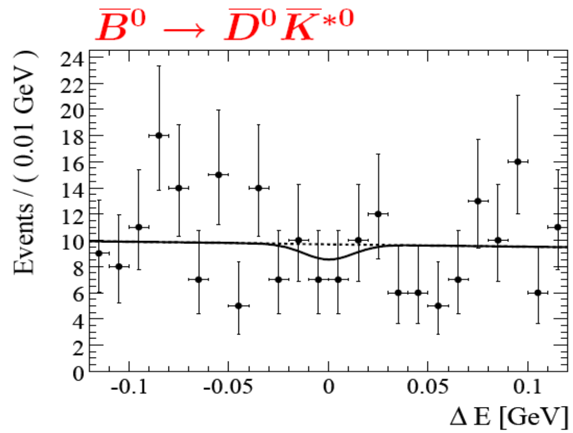
- expect large asymmetry (r_B~0.4) but small BF~10^{-5}



Both b→c and b→u color suppressed (∝ λ³)

$$\mathcal{B}(\bar{B}^0 \rightarrow D^0\bar{K}^0) = (5.3 \pm 0.7 \pm 0.3) \times 10^{-5}$$
$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*0}\bar{K}^0) = (3.6 \pm 1.2 \pm 0.3) \times 10^{-5}$$
$$\mathcal{B}(\bar{B}^0 \rightarrow D^0\bar{K}^{*0}) = (4.0 \pm 0.7 \pm 0.3) \times 10^{-5}$$
$$\mathcal{B}(\bar{B}^0 \rightarrow \bar{D}^0\bar{K}^{*0}) < 1.1 \times 10^{-5} \text{ at } 90\% \text{ C.L.}$$

Similar to BELLE 88x10[6] $B\bar{B}$ PRL90,141802(2003)



⇒ Measure r_B in self-tagging final state $\bar{D}^0\bar{K}^{*0}$ [$\bar{K}^{*0}\rightarrow K^-\pi^+$] (assuming that r_B for DK^{0*} ~ same as r_B for DK^0):

$$\mathcal{R}_i = \frac{\Gamma(\bar{B}^0 \rightarrow (K^+X_i^-)_D\bar{K}^{*0})}{\Gamma(\bar{B}^0 \rightarrow (K^-X_i^+)_D\bar{K}^{*0})} = \tilde{r}_B^2 + r_{D_i}^2 + 2\tilde{r}_B r_{D_i}\cos(\gamma + \delta_i)$$

- No signal seen in suppressed mode
- Bayesian constraint from observables:

$$\tilde{r}_B < 0.40 \text{ at } 90\% \text{ C.L.}$$

- smaller than theo. expectations.
- much larger dataset needed for sin(2β+γ) Measurement

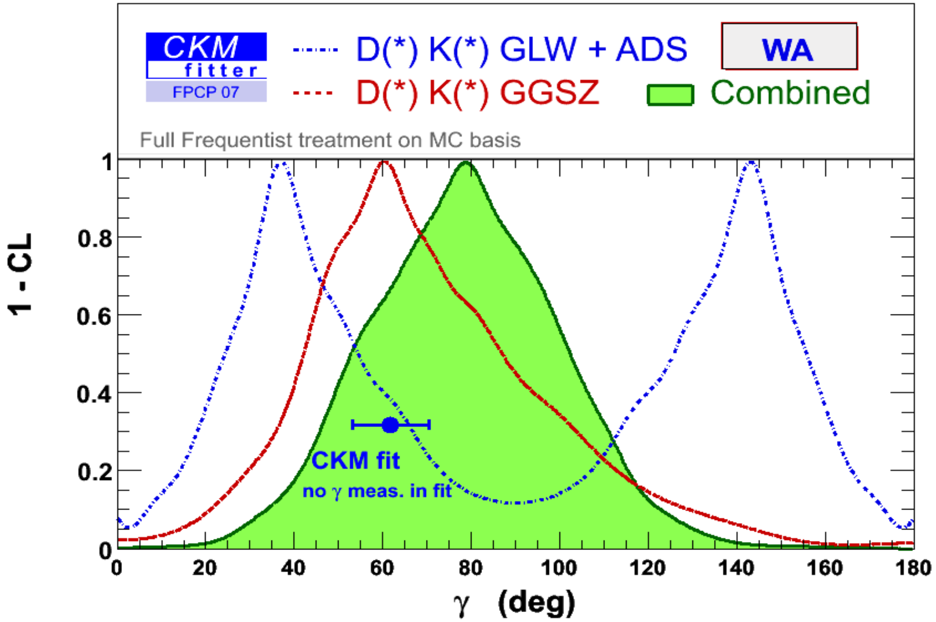
Conclusions and perspectives

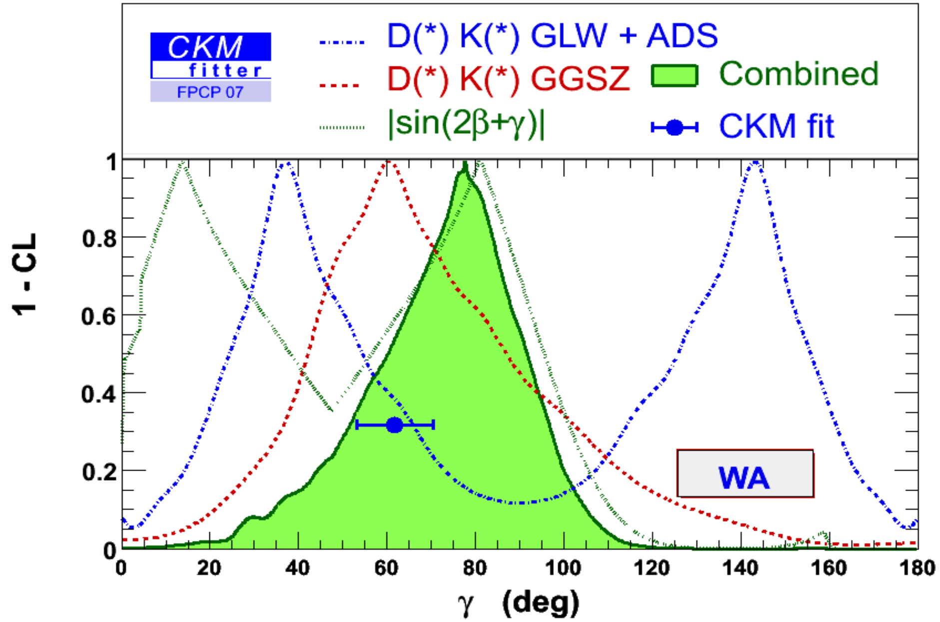
➔ Measure ϕ_3/γ at B-Factories ~ impossible mission few years ago ! ... But not yet there !

➔ Using direct CPV and interference in charged $B^{\pm}$ decays to $\tilde{D}^{(*)0}K^{(*)\pm}$: not yet there !

- 3 clean theoretical methods ~ all the machinery in place ⇒ Dalitz is still the most powerful
- Need much more data/channels (r_B=?!) ⇒ wait for more statistics and update with existing one !
- Need model independent approach for Dalitz (input from CLEO-C) at higher stat.

➔ Using Neutral $D^{(*)}\pi/\rho$ B decays for $\sin(2\beta+\gamma)$ can help but theo. errors for $r^{(*)}$?+ limited stat.





$\phi_3/\gamma = (77\pm31)^\circ$

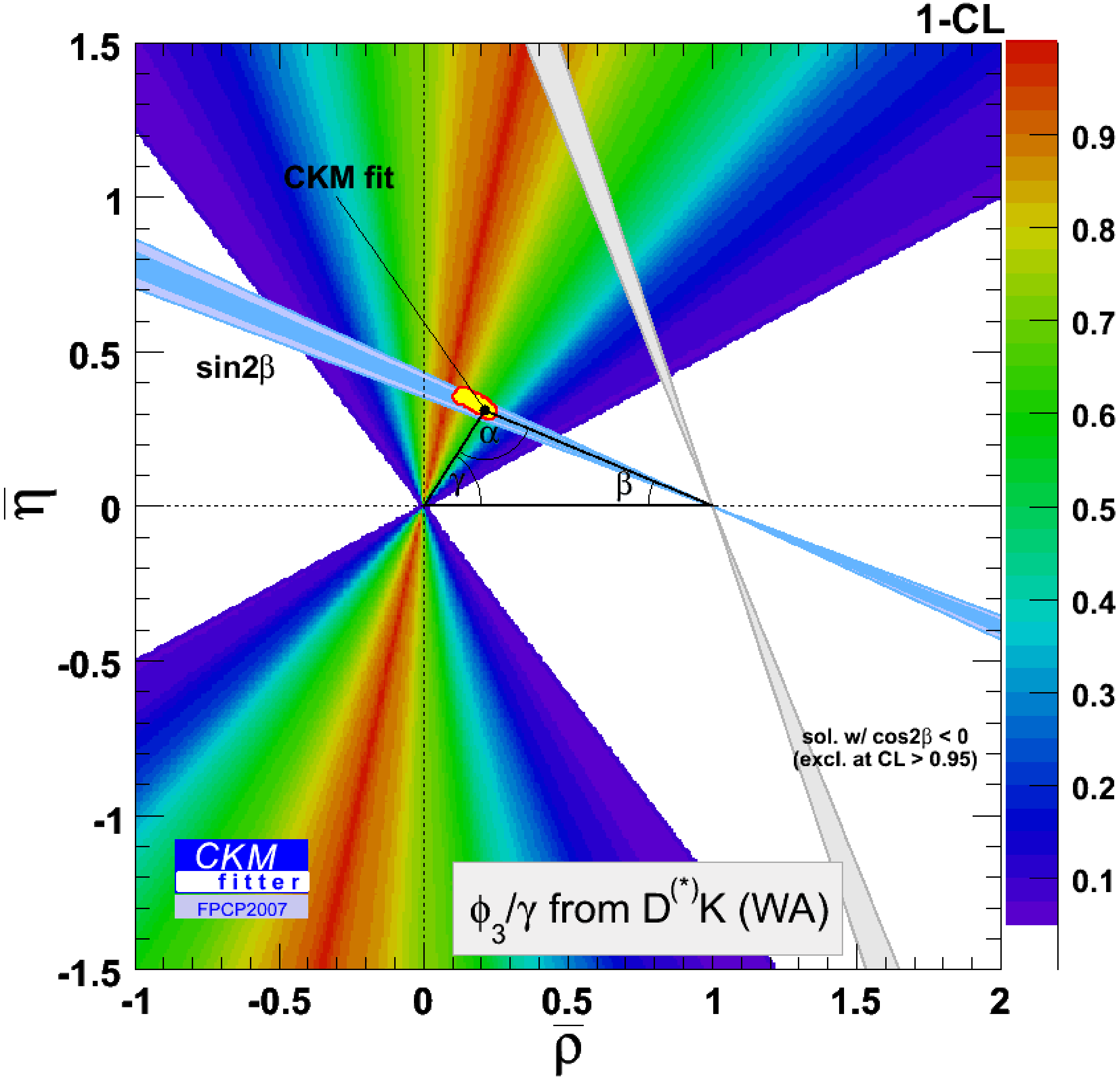
CKM-Fitter@1σ: $[52.8,70.1]^\circ$

$r_B(DK)<0.13$, $r_B(D^*K)<0.13$, $r_B(DK^*)<0.27$ @ 90% C.L.

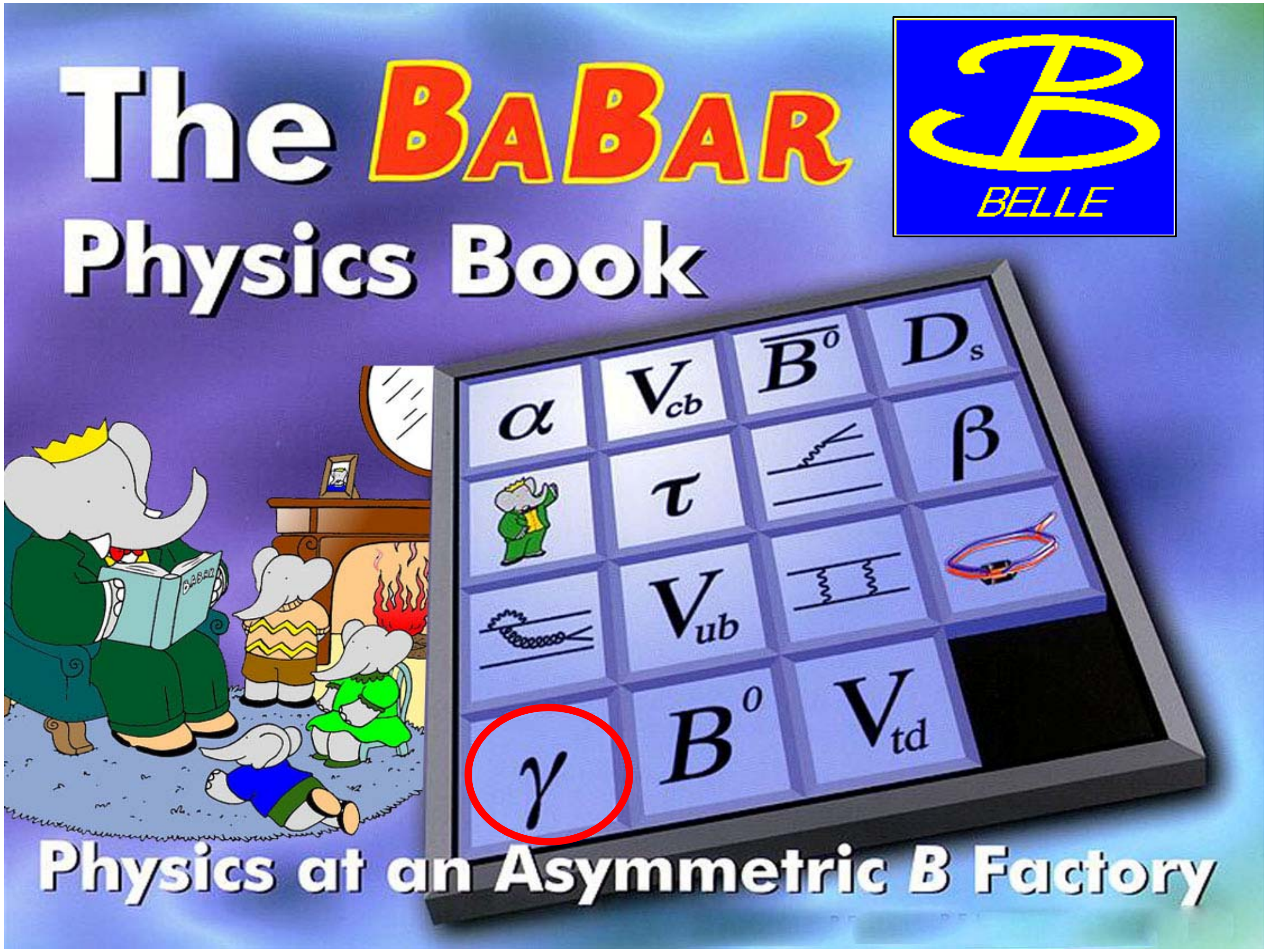
$\phi_3/\gamma = (78\ ^{+19}_{-26})^\circ$

+ $D^{(*)}\pi/\rho$ modes

$(\bar{\rho},\bar{\eta})$ plane



Backup slides



GLW : observables

• **ratio of BFs:** (CP Eigen-States/flavor ES)

$$R_{CP\pm} \equiv \frac{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)}{[\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \bar{D}^0 K^+)]/2} = 1 + r_B^2 \pm 2\, r_B \cos(\delta_B)\cos(\gamma)$$

• **direct ACPV:** (double ratios normalized with $D^{(*)0}\pi^-$ for systematic cancellations)

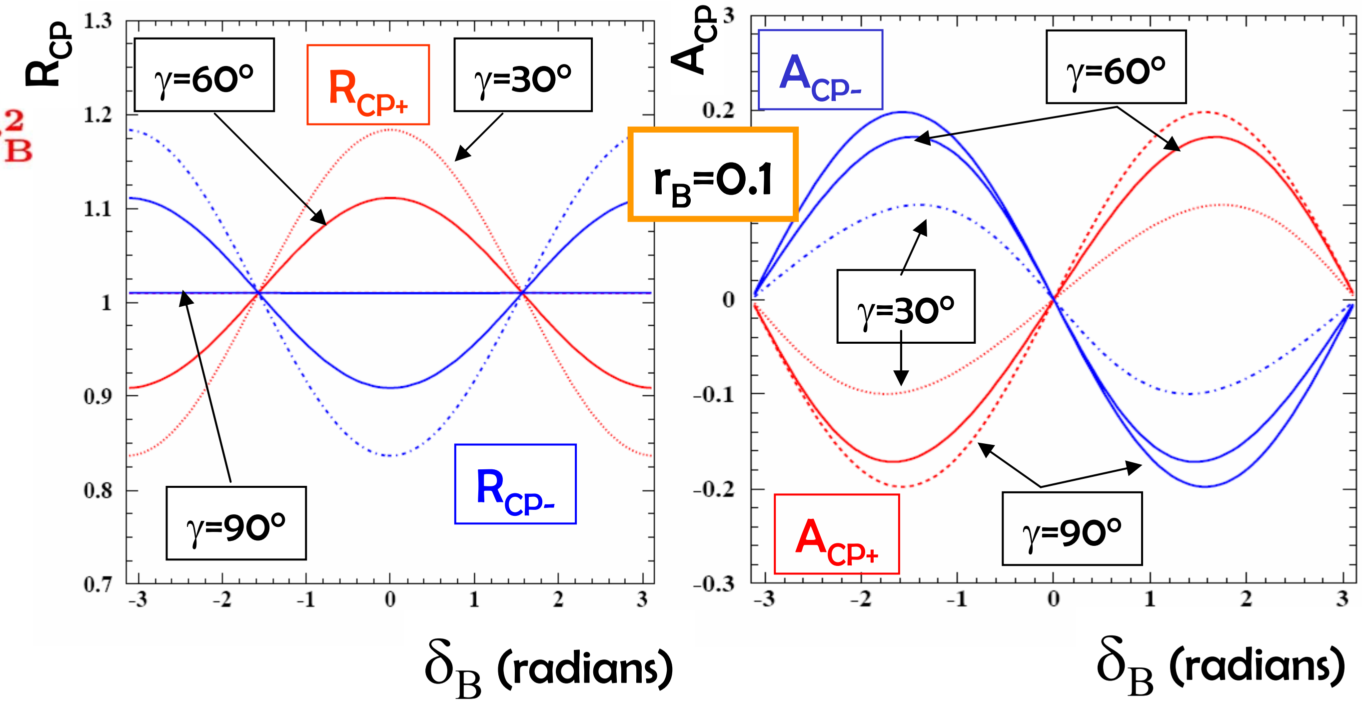
$$A_{CP\pm} \equiv \frac{\Gamma(B^- \to D_\pm K^-) - \Gamma(B^+ \to D_\pm K^+)}{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)} = \frac{\pm 2\, r_B \sin(\delta_B)\sin(\gamma)}{R_{CP\pm}}$$

8 fold ambiguity on γ

Weak sensitivity to r_B

$$\frac{R_{CP+} + R_{CP-}}{2} = 1 + r_B^2$$

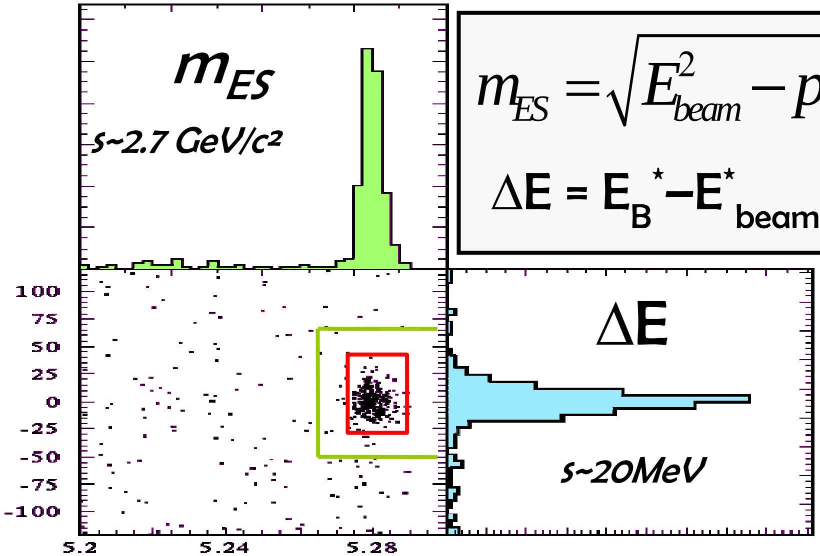
➔ 3 observables are independent ($A_{CP+}R_{CP+} = -A_{CP-}R_{CP-}$) and 3 unknowns ($r_B$, γ, δ_B)



Analysis Techniques

1. *B-meson identification*

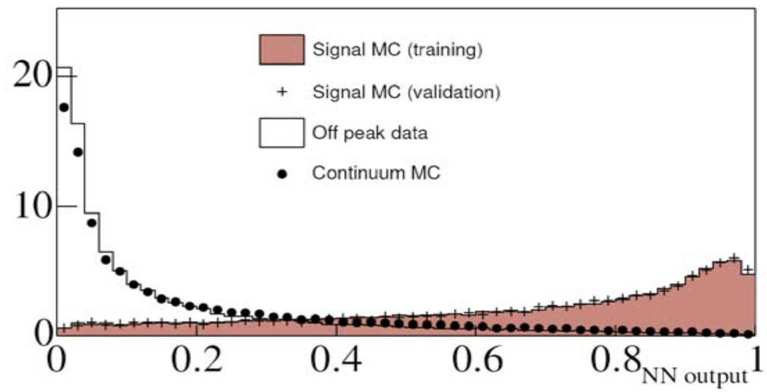
$\Upsilon(4S) \rightarrow \bar{B}B$ kinematic constraint:



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

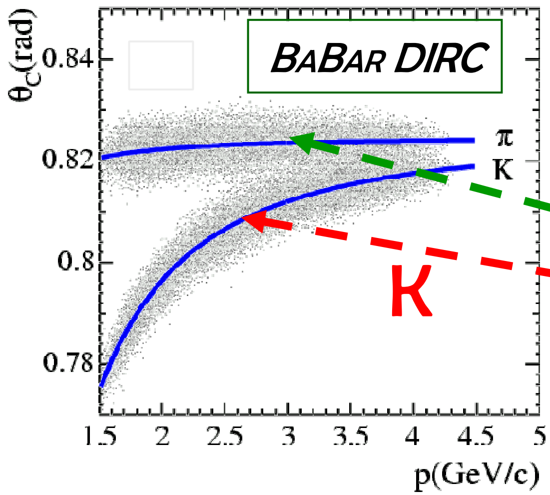
$$\Delta E = E_B^* - E_{beam}^*$$

2. *Combinatoric $e^+e^- \rightarrow \bar{q}q$ (light quarks) background suppression:*

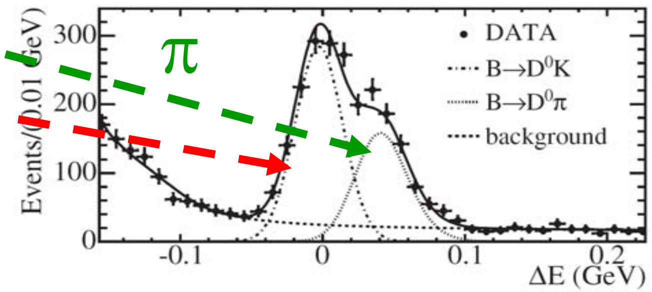


Event topological variables combined in Neural Network (NN) or Fisher discriminant.

3. *K/π separation (Cherenkov angle):*



Excellent K/p separation between 1.5 and 4 GeV/c (DK : 2 body decay).



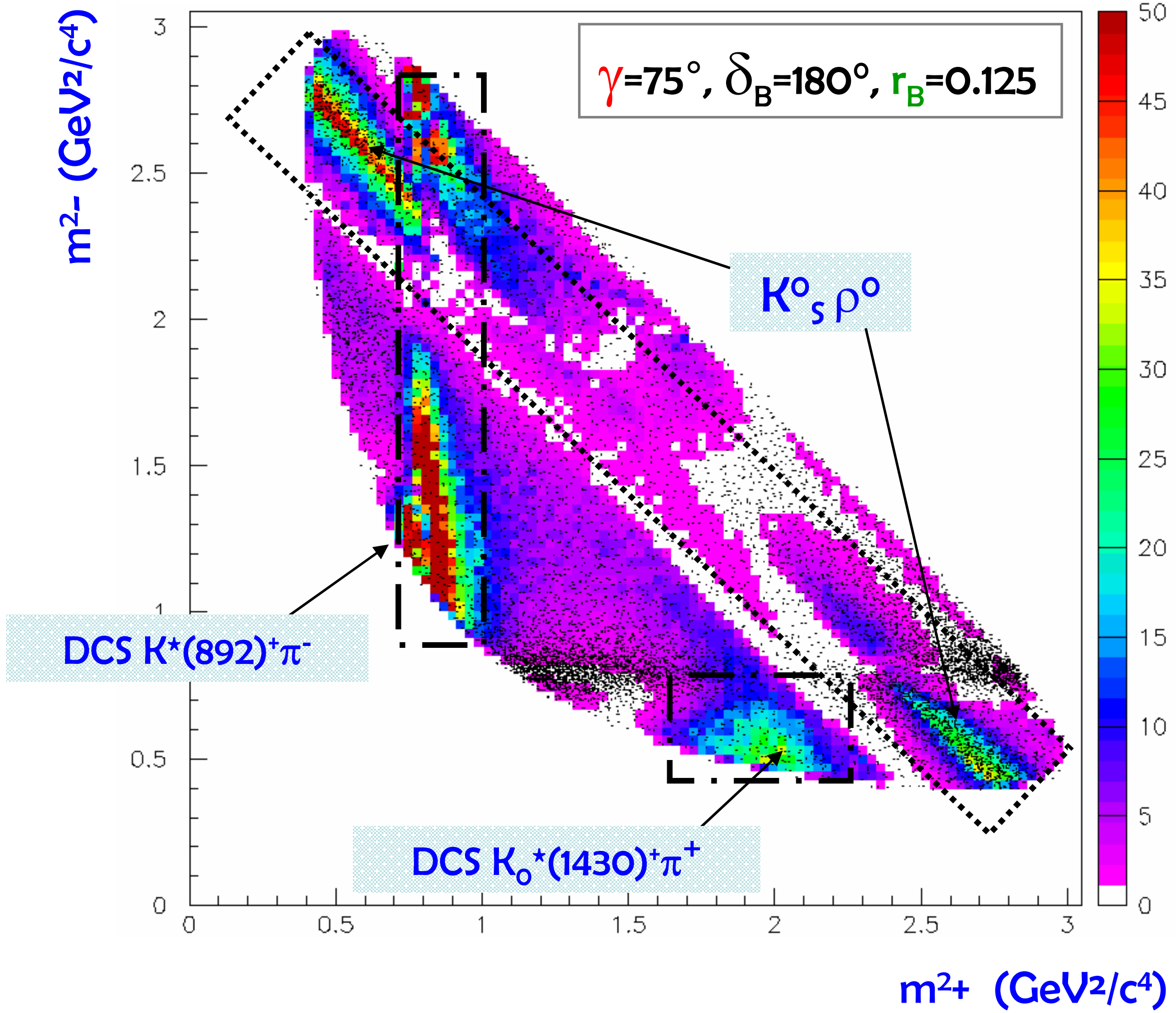
4. *Use of other properties:*

For other intermediate particles: $D^{(*)0}$, π^0/γ, K^{*-} ($K^0_S\pi^-$), K^0_S ($\pi^+\pi^-$), $\omega(\pi\pi\pi^0)$, $\phi(K^+K^-)$ ...

- Use of helicity (J^P) properties ⇒ angular distributions
- Reco'ed (D-)mass resolutions & side-bands.
- ...

Dalitz method: sensitivity to γ

... varies strongly across the Dalitz $K_S^0\pi^+\pi^-$ plot !



Relative event weight:

$W = 1/(d^2\mathcal{L} / d\gamma^2)$ and

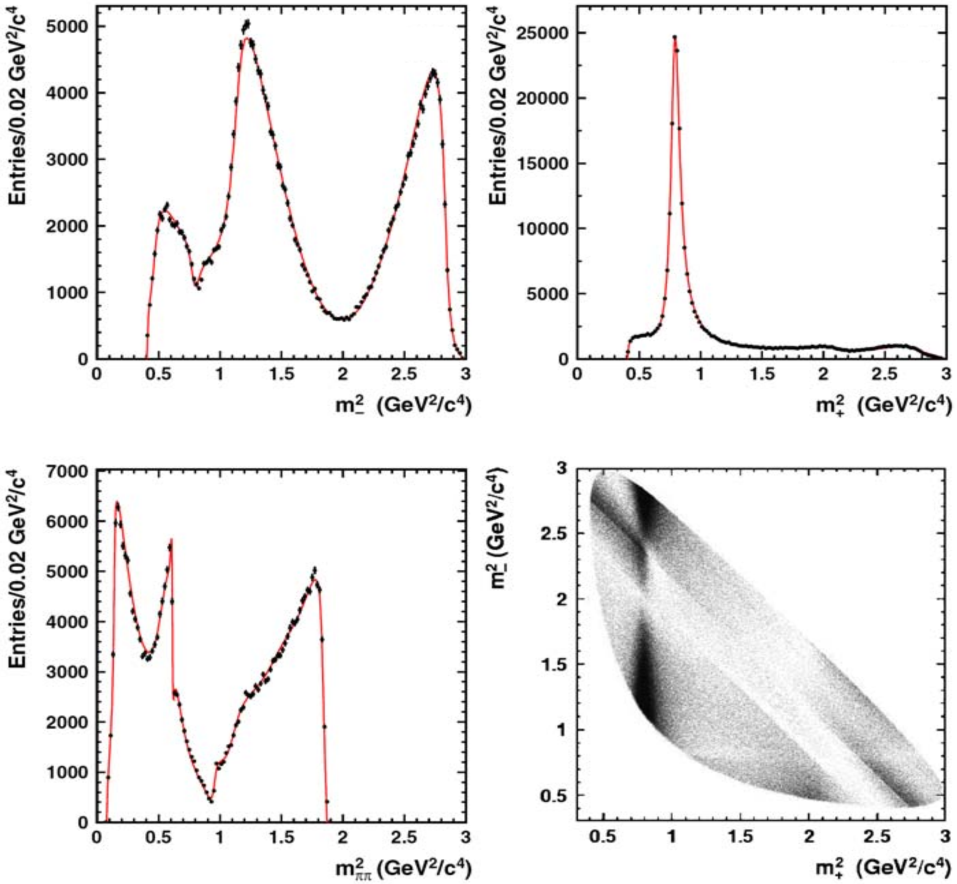
$\sigma^2(\gamma) \sim 1/W$

Interference of
$B^- \rightarrow D^0 K^-$, $D^0 \rightarrow K^0_S \rho^0$
with
$B^- \rightarrow \bar{D}^0 K^-$, $\bar{D}^0 \rightarrow K^0_S \rho^0$
$\equiv$ GLW like

Interference of
$B^- \rightarrow D^0 K^-$, $D^0 \rightarrow K^{*+}\pi^-$
(suppressed) with
$B^- \rightarrow \bar{D}^0 K^-$, $\bar{D}^0 \rightarrow K^{*+}\pi^-$
$\equiv$ ADS like

Belle Dalitz model

PRD 73, 112009 (2006)



Fitted similar to E791,CLEO

$$M_{\sigma_1}=519\pm6\ MeV/c^2$$
$$\Gamma_{\sigma_1}=454\pm12\ MeV/c^2$$
$$M_{\sigma_2}=1050\pm8\ MeV/c^2$$
$$\Gamma_{\sigma_2}=101\pm7\ MeV/c^2$$

18 resonances (5 DCS) + 1 non-resonant

Intermediate state	Amplitude	Phase (°)	Fit fraction
$K_S^0\sigma_1$	1.43 ± 0.07	212 ± 3	9.8%
$K_S^0\rho^0$	1.0 (fixed)	0 (fixed)	21.6%
$K_S^0\omega$	0.0314 ± 0.0008	110.8 ± 1.6	0.4%
$K_S^0 f_0(980)$	0.365 ± 0.006	201.9 ± 1.9	4.9%
$K_S^0\sigma_2$	0.23 ± 0.02	237 ± 11	0.6%
$K_S^0 f_2(1270)$	1.32 ± 0.04	348 ± 2	1.5%
$K_S^0 f_0(1370)$	1.44 ± 0.10	82 ± 6	1.1%
$K_S^0\rho^0(1450)$	0.66 ± 0.07	9 ± 8	0.4%
$K^*(892)^+\pi^-$	1.644 ± 0.010	132.1 ± 0.5	61.2%
$K^*(892)^-\pi^+$	0.144 ± 0.004	320.3 ± 1.5	0.55%
$K^*(1410)^+\pi^-$	0.61 ± 0.06	113 ± 4	0.05%
$K^*(1410)^-\pi^+$	0.45 ± 0.04	254 ± 5	0.14%
$K_0^*(1430)^+\pi^-$	2.15 ± 0.04	353.6 ± 1.2	7.4%
$K_0^*(1430)^-\pi^+$	0.47 ± 0.04	88 ± 4	0.43%
$K_2^*(1430)^+\pi^-$	0.88 ± 0.03	318.7 ± 1.9	2.2%
$K_2^*(1430)^-\pi^+$	0.25 ± 0.02	265 ± 6	0.09%
$K^*(1680)^+\pi^-$	1.39 ± 0.27	103 ± 12	0.36%
$K^*(1680)^-\pi^+$	1.2 ± 0.2	118 ± 11	0.11%
nonresonant	3.0 ± 0.3	164 ± 5	9.7%

$5\times2\ K^*\pi$, $8\ K^0_S\pi\pi$

χ^2/ dof≈2.72 for 1081 ndof

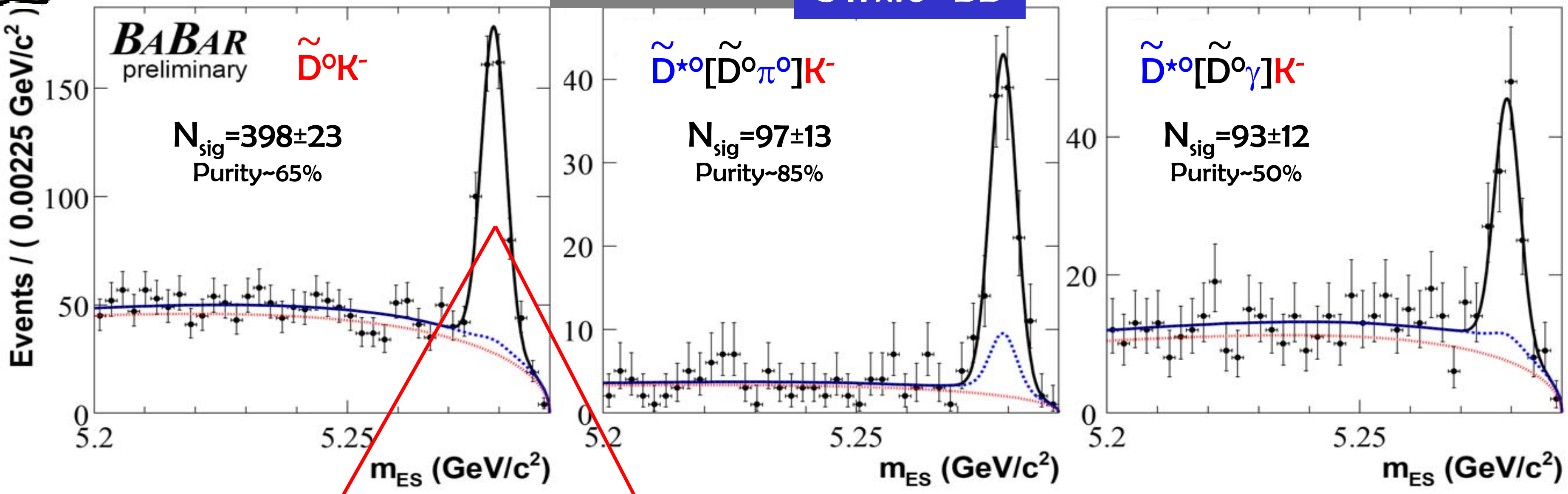
Σ *amplitudes Fit Fraction=1.2*

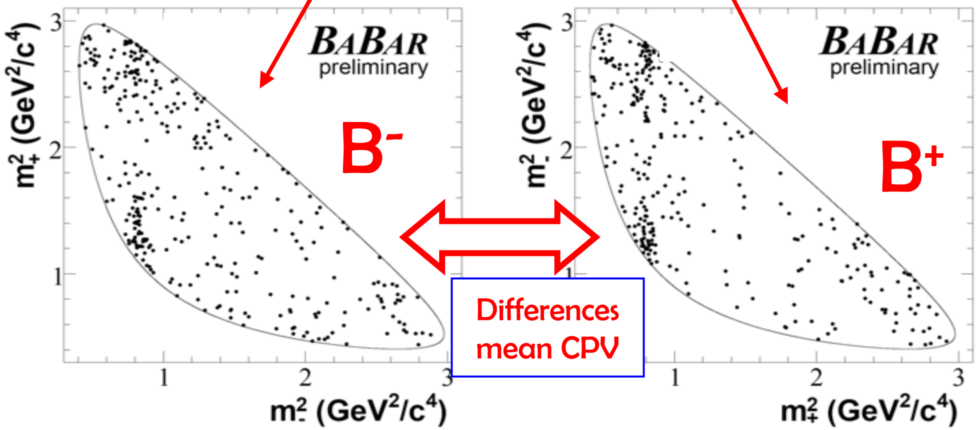
Data sample : BABAR

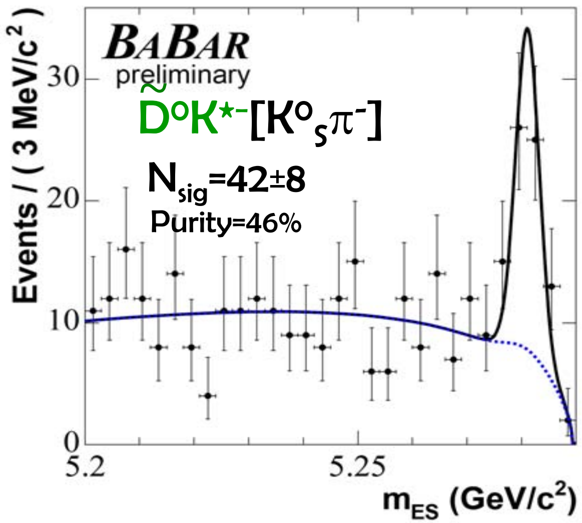
hep-ex/0607104 $347 \times 10^6\ B\bar{B}$

.... $D^{(*)0}\pi$

Simultaneous fit uses m_{ES}, ΔE, $\mathcal{Fisher}$, $m^2_\pm$ (model)





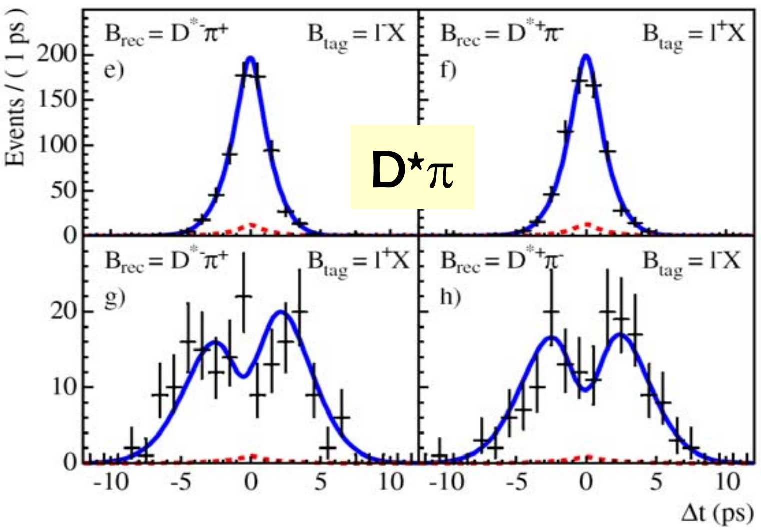


hep-ex/0507101 $227 \times 10^6\ B\bar{B}$

BaBar results

PRD71,112003(2005)
PRD73,111101(R)(2006)

• Full reconstruction:



a(Dπ) = -0.010 ± 0.023 ± 0.007
a(D*π)= -0.040 ± 0.023 ± 0.010
a(Dρ)= -0.024 ± 0.031 ± 0.009

Lepton tags only

c(Dπ)=-0.033 ± 0.042 ± 0.012
c(D*π)=+0.049 ± 0.042 ± 0.015
c(Dρ)=-0.098 ± 0.055 ± 0.018

• Partial reconstruction (D*π):

leptons tags

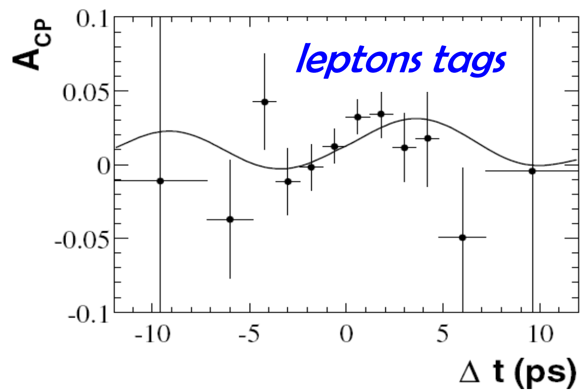
a = -0.042 ± 0.019 ± 0.010
c = -0.019 ± 0.023 ± 0.013

Kaons tags

a =-0.025 ± 0.020 ± 0.013
b =-0.004 ± 0.010 ± 0.010
c=-0.002 ± 0.020 ± 0.015

➔ a= $2r^* sin(2\beta+\gamma)cos\delta^*$ = -0.034±0.014±0.009

Most precise time-dependent CP asymetry



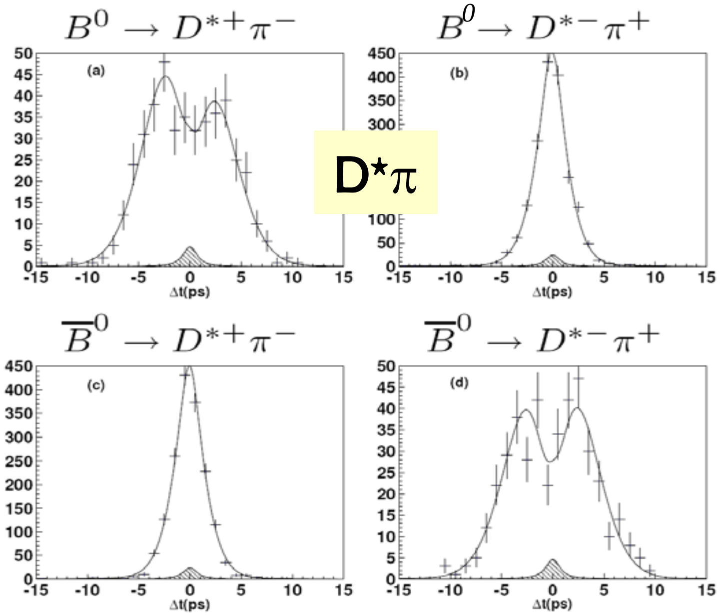
$$A_{CP} = \frac{N(B^0) - N(\overline{B}^0)}{N(B^0) + N(\overline{B}^0)}$$

386x10⁶ $B\bar{B}$

Belle results

PRD 73,092003(2006)

• Full reconstruction:



→ use all tags but measure tag side CPV params $S'_{\pm}$ from D*lν evts

$$
\begin{aligned}
S^+(D^*\pi) &= 0.050 \pm 0.029 \pm 0.013, \\
S^-(D^*\pi) &= 0.028 \pm 0.028 \pm 0.013, \\
S^+(D\pi) &= 0.031 \pm 0.030 \pm 0.012, \\
S^-(D\pi) &= 0.068 \pm 0.029 \pm 0.012
\end{aligned}
$$

• Partial reconstruction:

$$
\begin{aligned}
S^+ &= 0.048 \pm 0.028 \pm 0.017, \\
S^- &= 0.034 \pm 0.027 \pm 0.017,
\end{aligned}
$$

Only lepton tags

combination