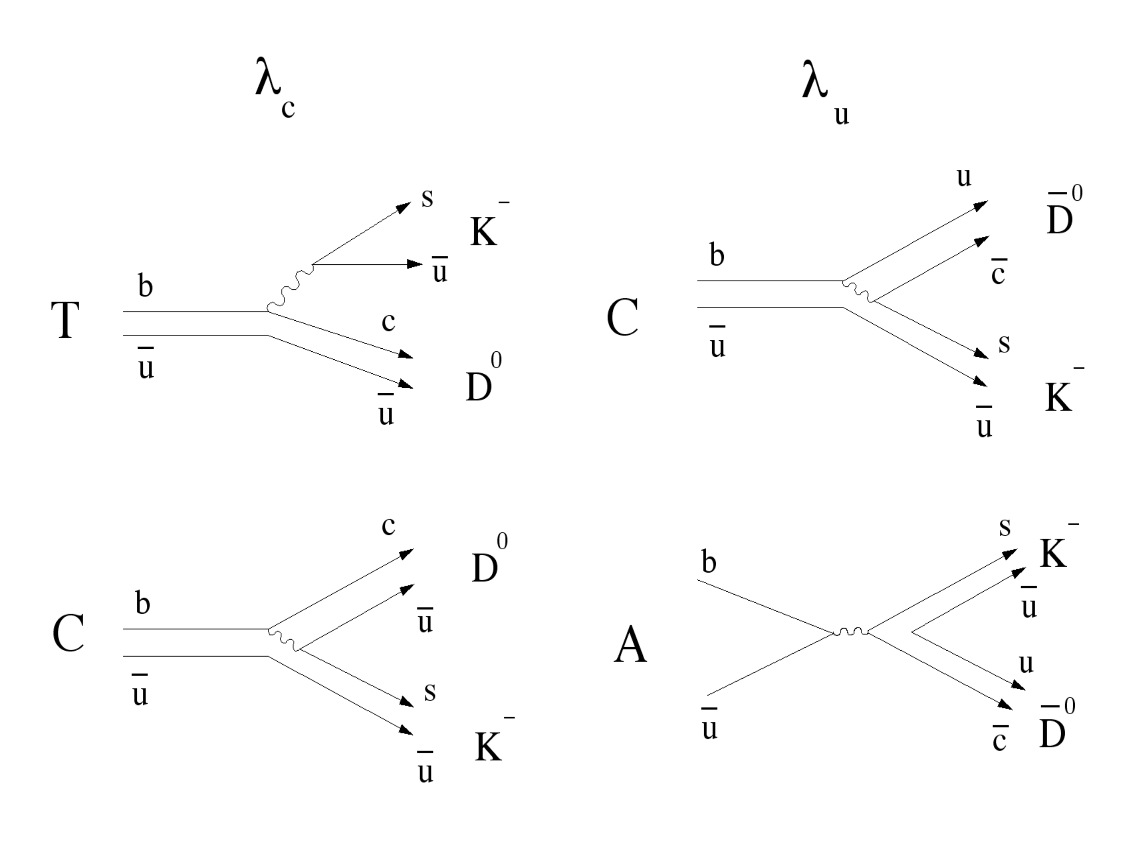
Phi3/gamma

Hitoshi Yamamoto
Tohoku University

Contents

- $B \to D^{(*)}K^{(*)}$: ϕ_3 / γ
  - $D_{CP}^{(*)}K^{(*)}$ (GLW 'method')
  - $D_{DCS}^{(*)}K^{(*)}$ (ADS 'method')
  - $D_{Ks\pi\pi}^{(*)}K^{(*)}$ (Dalitz Analysis)
- $B \to D^{(*)}\pi^{(*)}$: $(2\phi_1 + \phi_3)/(2\beta + \gamma)$ $(\pi^* = \rho)$
  - Flavor-tagged time-dependent analyses
  - Full and partial reconstructions

$B^- \to DK^-$ Diagrams



$$A(D^0K^-) \propto \lambda_c \equiv V_{cb}V_{us}^*$$

$$A(\overline{D}^0K^-) \propto \lambda_u \equiv V_{ub}V_{cs}^*$$

(T: tree, C: color-suppressed, A: annihilation)

- Includes FSI rescatterings
- #$c\bar{c}$ is odd $\to$ no penguins

$$r \equiv \left|\frac{A(\overline{D}^0K^-)}{A(D^0K^-)}\right| \sim 0.1$$

$$\arg\frac{\lambda_u}{\lambda_c} \sim -\varphi_3$$

$B^- \to D_{cp}K^- (cp = \pm)$

- Oft-used observables
  - Direct CPV between B^- and B^+:

$$A_\pm = \frac{\Gamma(D_\pm K^-) - \Gamma(D_\pm K^+)}{\Gamma(D_\pm K^-) + \Gamma(D_\pm K^+)} = \frac{\pm 2r \sin\varphi_3 \sin\delta}{R_\pm}$$

δ: strong phase between $A(D^0 K^-)$ and $A(\overline{D}^0 K^-)$

  - CP=+ or – decay rate averaged over $B^\pm$, in unit of favored rate.

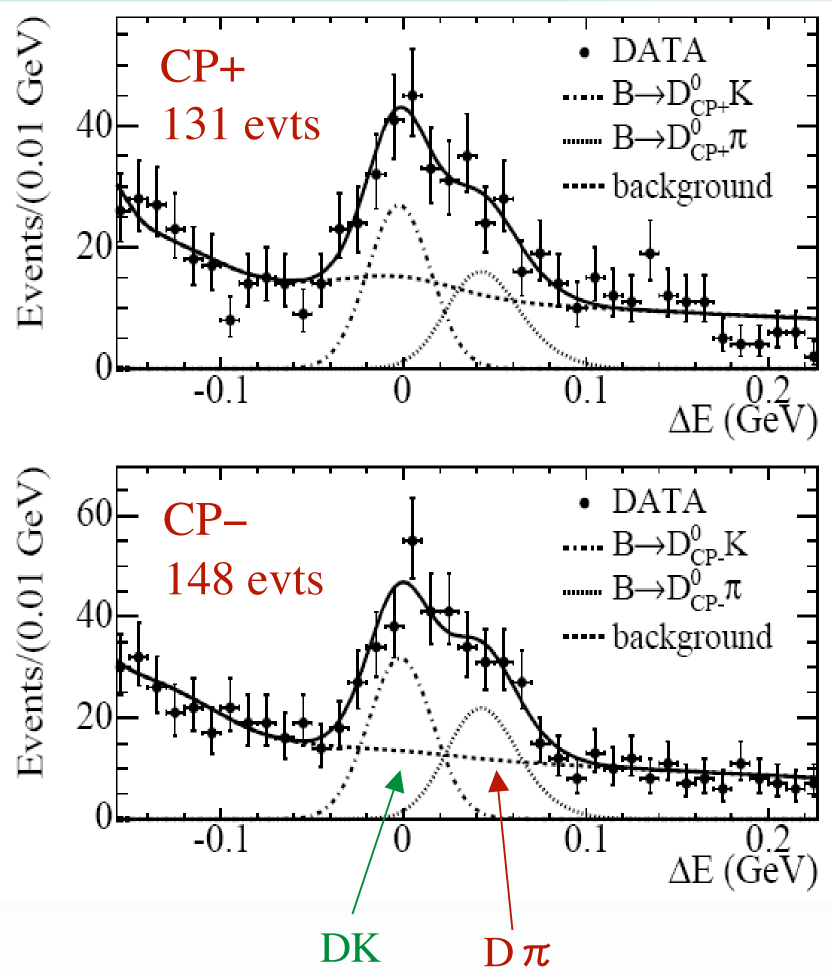
$$R_\pm = 2\frac{\Gamma(D_\pm K^-) + \Gamma(D_\pm K^+)}{\Gamma(D^0 K^-) + \Gamma(\overline{D}^0 K^+)} = 1 + r^2 \pm 2r\cos\varphi_3 \cos\delta$$

$(R_+ + R_-)/2 = 1 + r^2 \sim 1 \quad (r^2 \sim 0.01)$

Not sensitive to r.

Correction due to DCS same order.

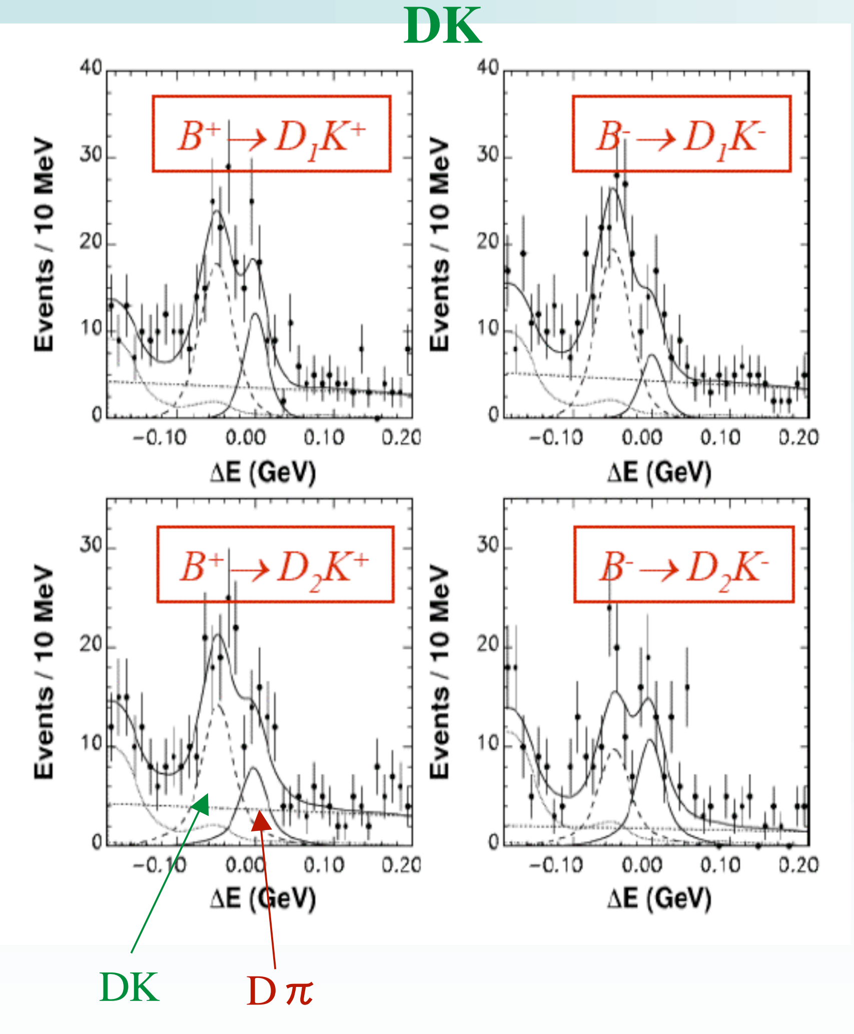
BaBar 253M $B^{\pm}$ (PRD 73, 051105(R) 2006)



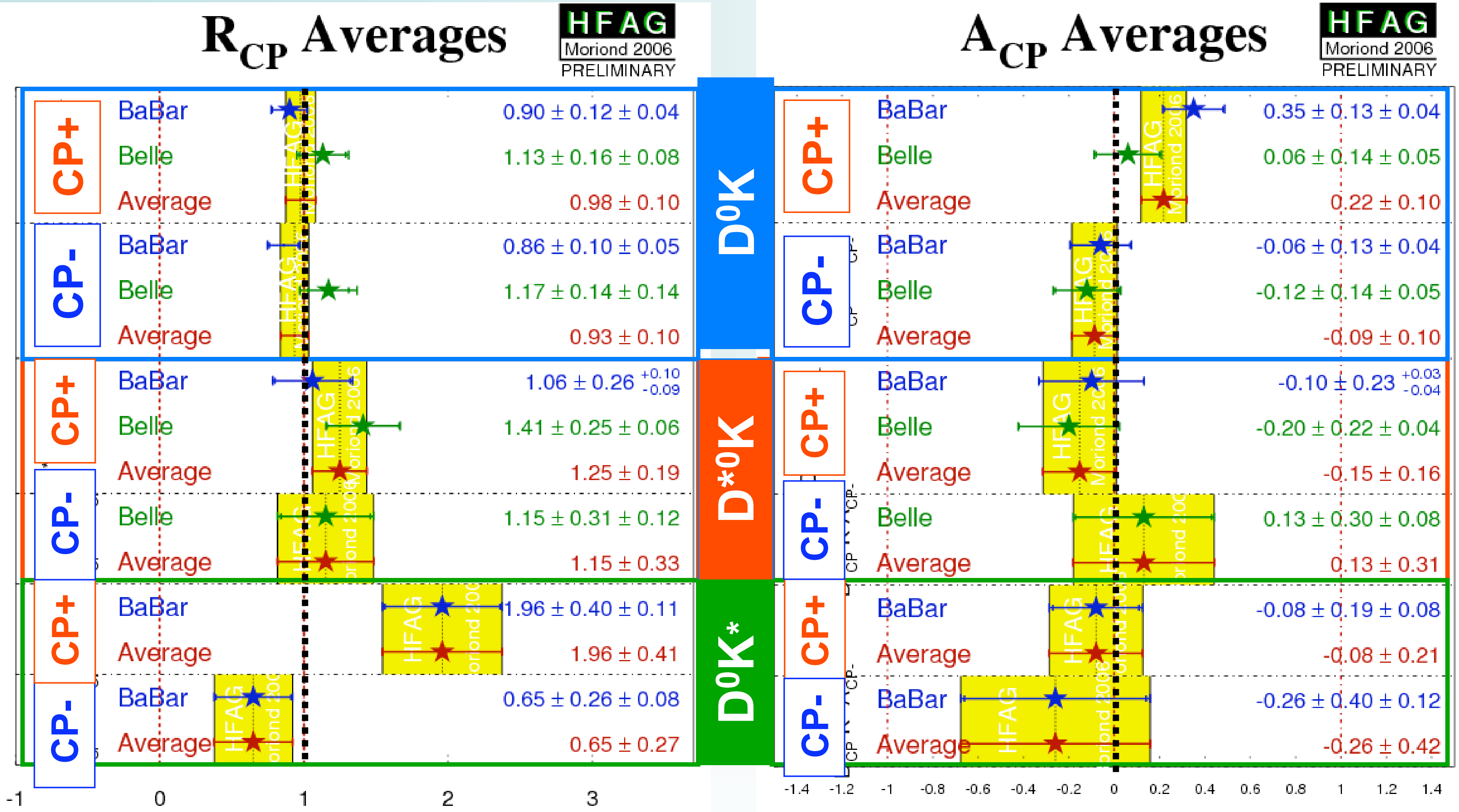
- DK modes
- D decays used
  - Favored: $K^- \pi^+$
  - CP+ : $K^+ K^-$, $\pi^+ \pi^-$
  - CP− : $K_S\ \pi^0/\omega/\phi$
- Fit ΔE and PID

$A_+ = 0.35 \pm 0.13 \pm 0.04$
$A_- = -0.06 \pm 0.13 \pm 0.04$
$R_+ = 0.90 \pm 0.12 \pm 0.04$
$R_- = 0.86 \pm 0.10 \pm 0.05$

Belle 232M B± (PRD 73, 051106(R) 2006)



- DK modes
  - $A_+ = 0.06 \pm 0.14 \pm 0.05$
  - $A_- = -0.12 \pm 0.14 \pm 0.05$
  - $R_+ = 1.13 \pm 0.16 \pm 0.05$
  - $R_- = 1.17 \pm 0.14 \pm 0.05$
- D*K modes
  - $A_+ = -0.20 \pm 0.22 \pm 0.04$
  - $A_- = 0.13 \pm 0.30 \pm 0.08$
  - $R_+ = 1.41 \pm 0.25 \pm 0.06$
  - $R_- = 1.15 \pm 0.31 \pm 0.12$



R_{cp} deviation from 1 opposite for CP+/– A_{cp} opposite sign for CP+/–

More statistics needed for the CPV to be seen

GLW method (original)

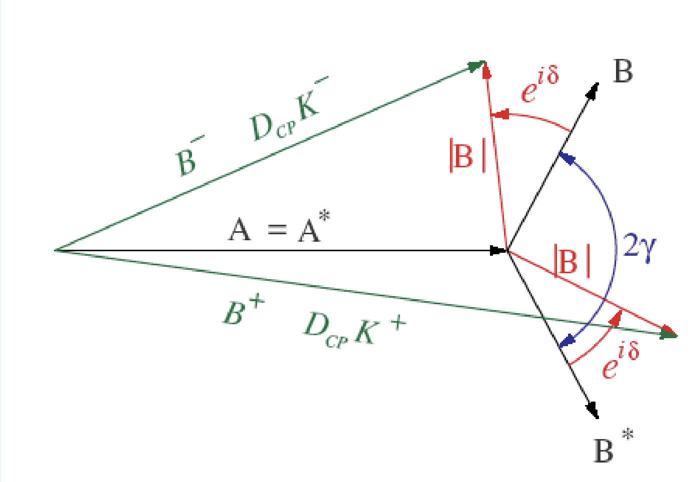
- Measure 4 quantities for given CP

$$|A(D_{CP}K^-)|, \quad |A(D_{CP}K^+)|$$

$$|A(D^0K^-)| = |A(\overline{D}^0K^+)| \equiv |A|,$$

$$|A(\overline{D}^0K^-)| = |A(D^0K^+)| \equiv |B|$$

- Construct two triangles → ϕ_3/γ



Problem :

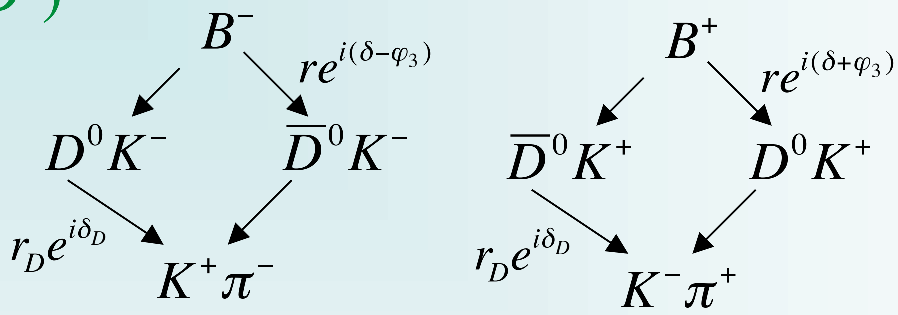
- Difficult to measure the suppressed modes due to D^0 DCSD
- ADS noticed that there is a large CPV effect in DCSD modes

ADS method

- Measure at least 4 modes including 'DCSD' modes (two types)
  - E.g. $(K^+\pi^-)K^-$, $(K^+K^-)K^-$ and conjugates
- Solve for $r, \phi_3, \delta_1, \delta_2$.

ADS Modes ('DCSD' modes)

- D decays that are flavor-specific and 'suppressed' ('DCSD')



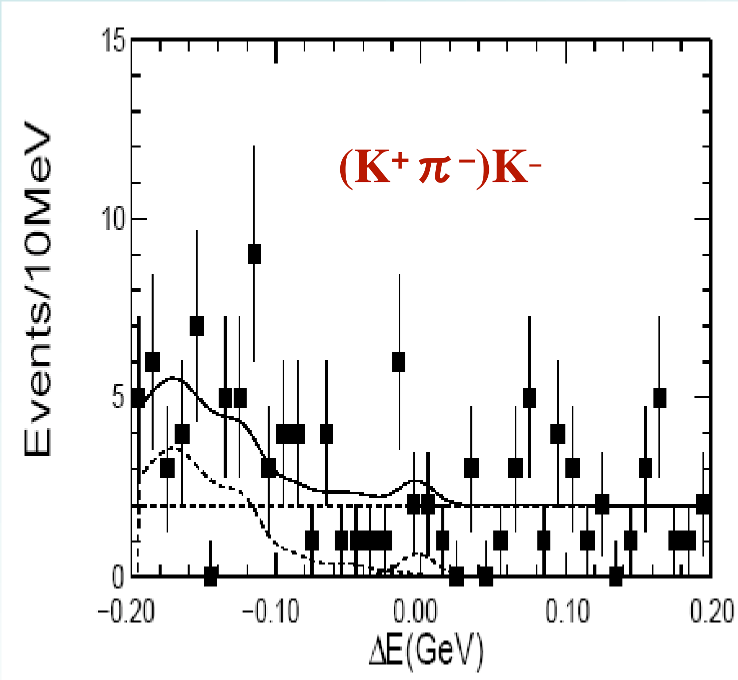
- Statistics not enough yet to perform the ADS analysis.
  - For now, measure the suppressed mode Br.

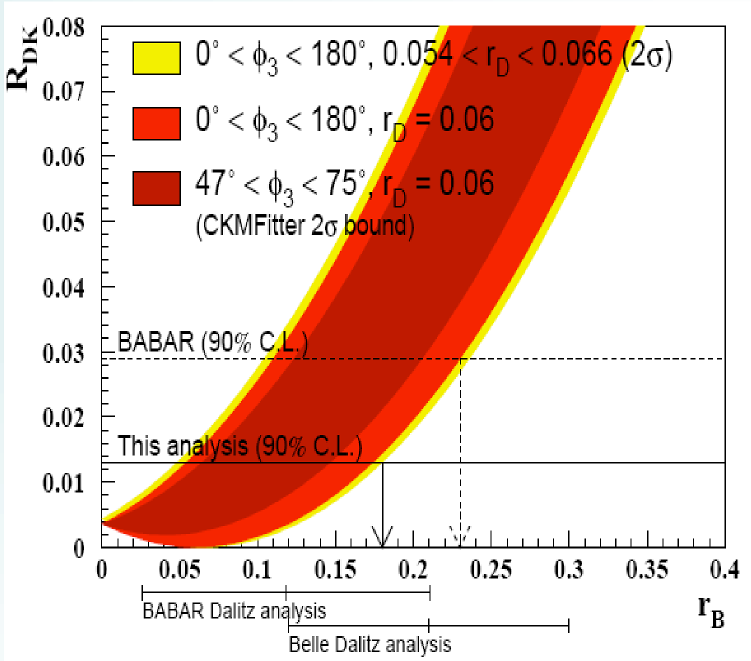
$$R_{ADS} = \frac{(K^+\pi^-)K^- + (K^-\pi^+)K^+}{(K^-\pi^+)K^- + (K^+\pi^-)K^+} \sim r^2 + r_D^2 + 2rr_D\cos(\delta-\delta_D)\cos\varphi_3$$

  - Get DCSD factor r_D from D analysis → sensitivity to r

ADS Mode : Belle Results

386M B±





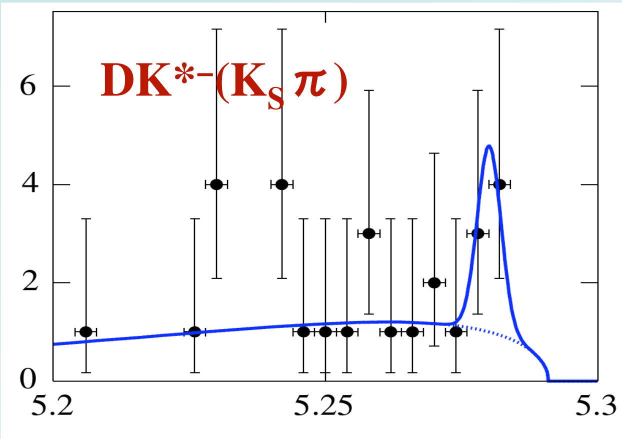
$$R_{ADS} = (0.0^{+8.4}_{-7.9} \pm 1.0) \times 10^{-3} \longrightarrow$$

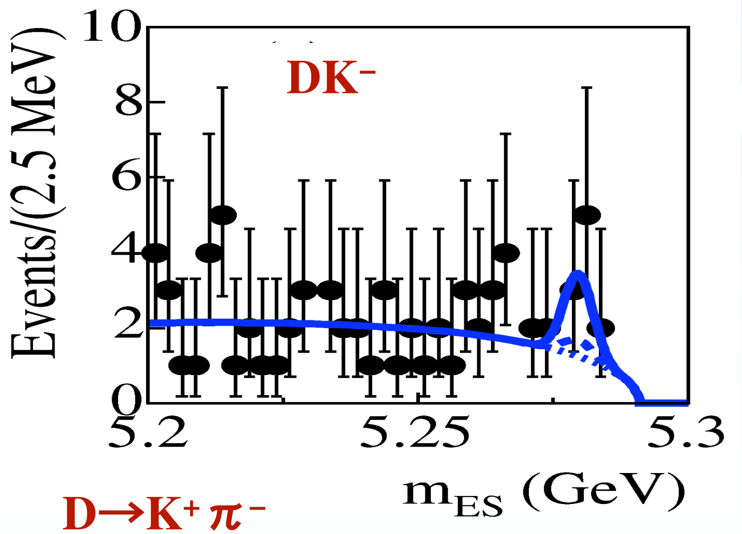
Varying $0<\phi_3<\pi$, $\pm 2\sigma$ for r_D,

$\boldsymbol{r < 0.18}$

ADS Mode : Babar Results

232M B±





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

	R_{ADS}	r
DK	<0.029	<0.23
D*K	<0.023 ($D^0 \pi^0$) <0.045 ($D^0 \gamma$)	<0.16
DK*	<0.045	0.20±0.14

Still not enough to claim signal

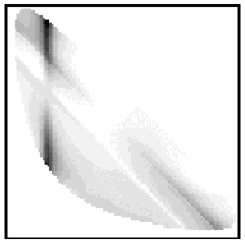
$B^{\pm} \to DK^{\pm}$, $D \to K_S \pi^+ \pi^-$ Dalitz

- Dalitz distribution (assume CP in D decay)

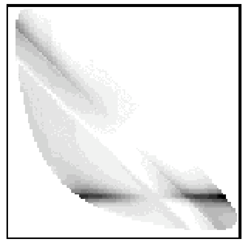
$$B^+ \to \overline{D}^0 K^+ + re^{i\theta} D^0 K^+$$

$$Amp = f(m^2_{K_S\pi^+}, m^2_{K_S\pi^-}) + re^{i\theta} f(m^2_{K_S\pi^-}, m^2_{K_S\pi^+})$$

$=$



$+ \; r\,e^{i\theta}$



$$\theta = \delta \pm \varphi_3 \quad (B^{\pm})$$

Asymmetry of *f(x,y)* under $x \Leftrightarrow y$ $\rightarrow$ Sensitivity to r, δ, ϕ_3 .

Atwood, Dunietz, Soni, PRD 2001 ($K^+\pi^-\pi^0$)
Bonder, BINP Mini-workshop on Dalitz analysis, Sep. 2002
Giri, Grossman, Soffer, Zupan, PRD 2003

Dalitz Amplitude

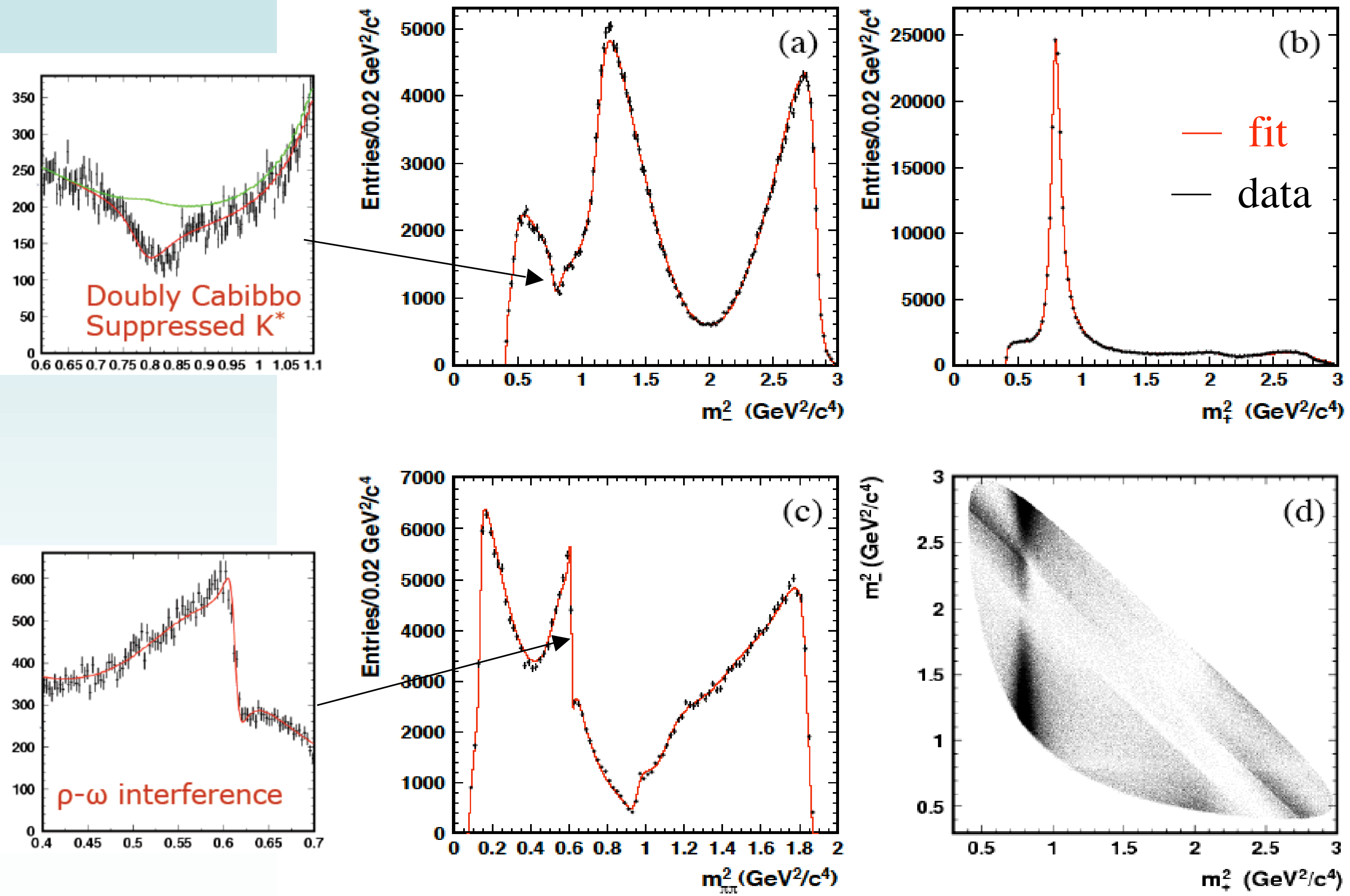
- Need to know the Dalitz amplitude $f(m_{12}^2, m_{13}^2)$
- Fit known resonances to the D^0 sample (D^{*+} tag)
  - → model dependence
  - Use Breit-Wigner form (BW)
  - BaBar : 390K samples, 16 BWs + NR, 3 are DCS.
  - Belle : 260K samples, 18 BWs + NR, 5 are DCS.
  - Different formalisms for resonances used for systematics study

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%
non-resonant	3.0 ± 0.3	164 ± 5	9.7%

Belle

Dalitz Distribution (D* tag)

Belle



Dalitz : $D^{(*)}K^{(*)}$ Signals

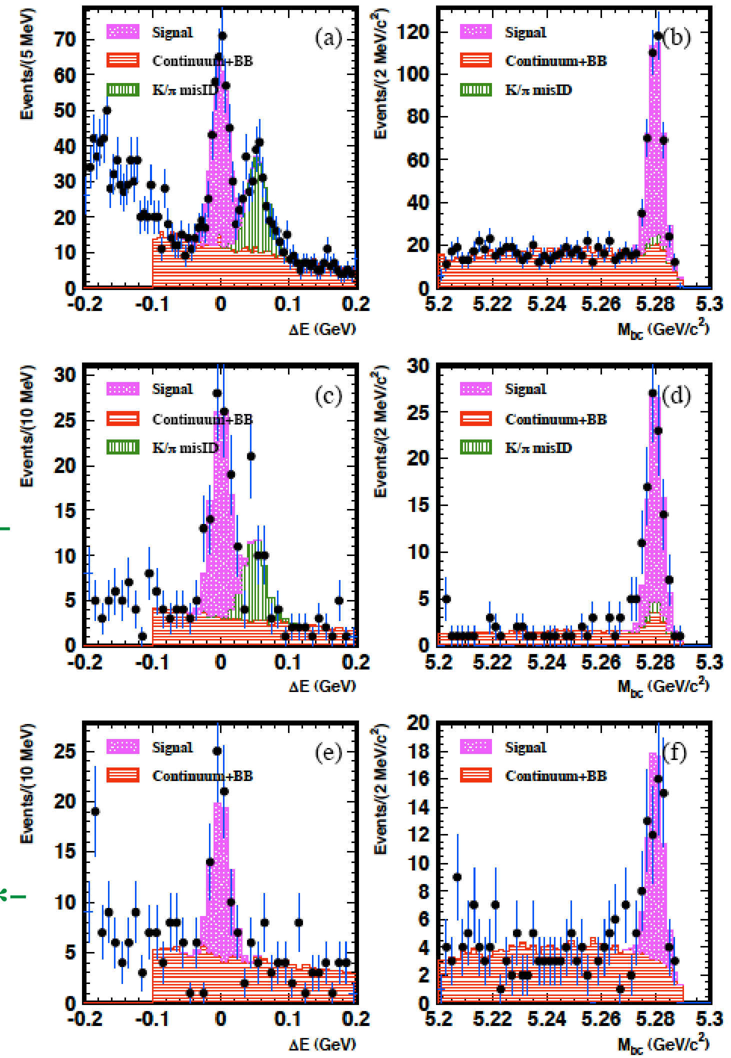
- **BaBar**
  - 347M $B^{\pm}$'s
  - DK^-, D^*K^-
  - $D^{*0} \to D^0 \pi^0$, $D^0 \gamma$
- **Belle**
  - 386M $B^{\pm}$'s
  - DK^-, D^*K^-, DK^{*-}
  - $D^{*0} \to D^0 \pi^0$
  - $K^{*-} \to K_S \pi^-$

Belle

DK⁻

D*K⁻

DK*⁻

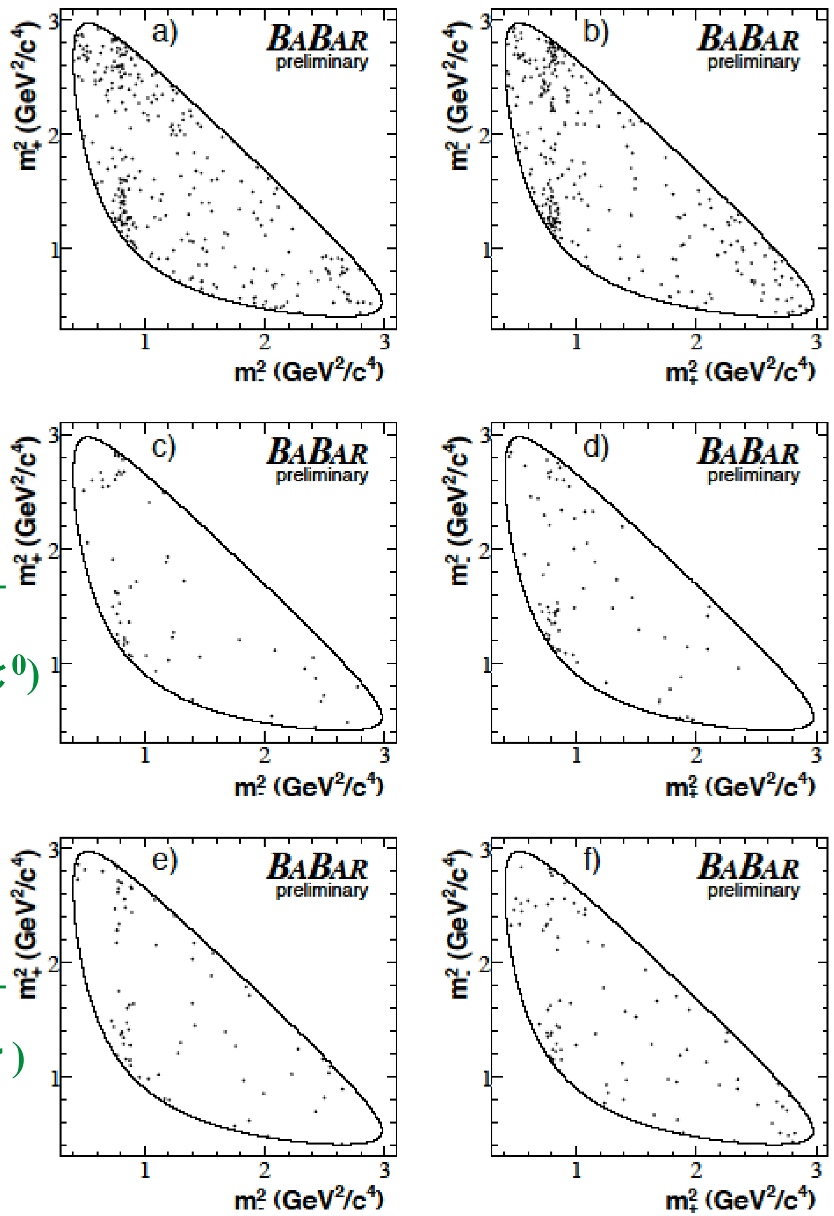


B⁻ B⁺

DK⁻

D*K⁻ ($D^0 \pi^0$)

D*K⁻ ($D^0 \gamma$)



- Fit parameters (r, δ , ϕ_3)
  do not behave well
- Fit the amplitude of the suppressed B± decay

$$x_\pm = \mathrm{Re}(re^{i(\delta \pm \varphi_3)}),$$

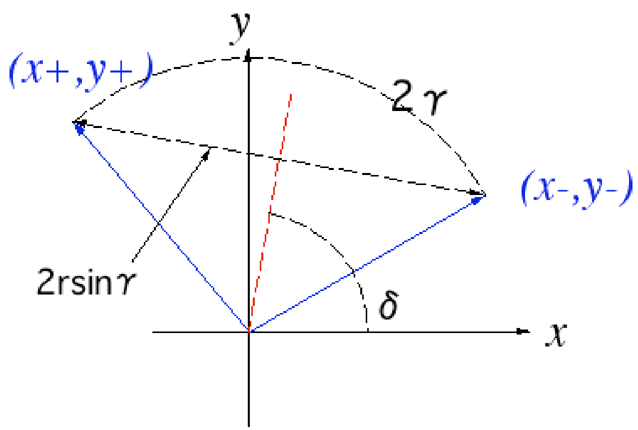
$$y_\pm = \mathrm{Im}(re^{i(\delta \pm \varphi_3)})$$

4 parameters with

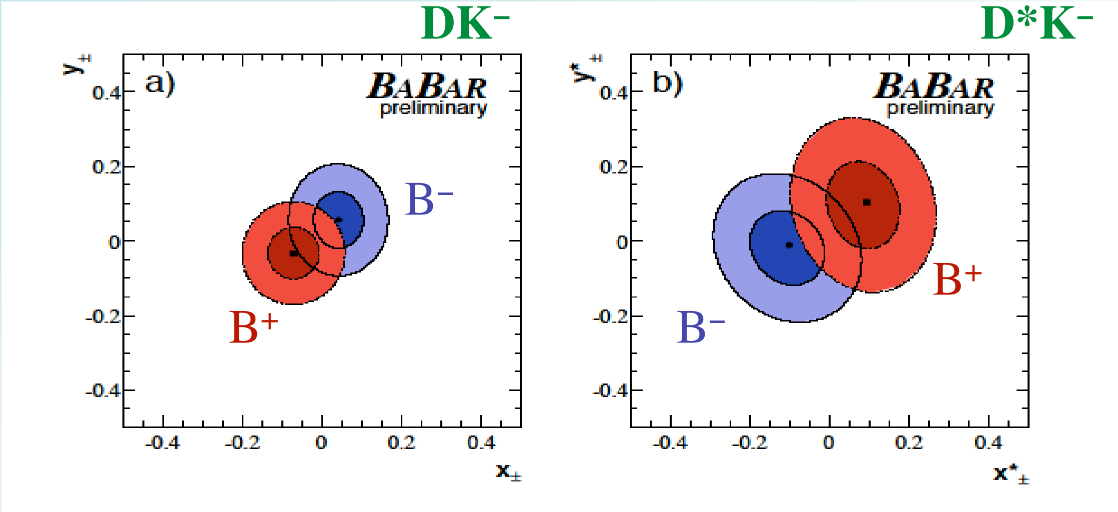
$$\sqrt{x_+^2 + y_+^2} = \sqrt{x_-^2 + y_-^2}$$

also

$$\sqrt{(x_+ - x_-)^2 + (y_+ - y_-)^2} = 2r\sin\varphi_3$$

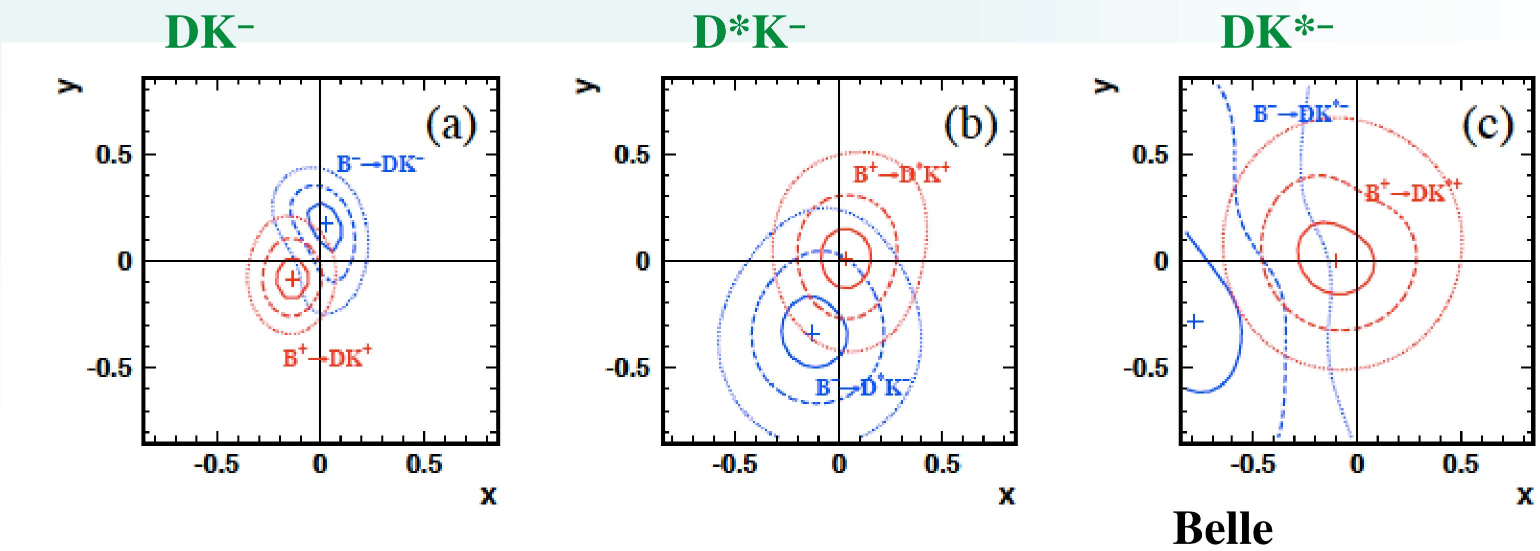


x-y fit results



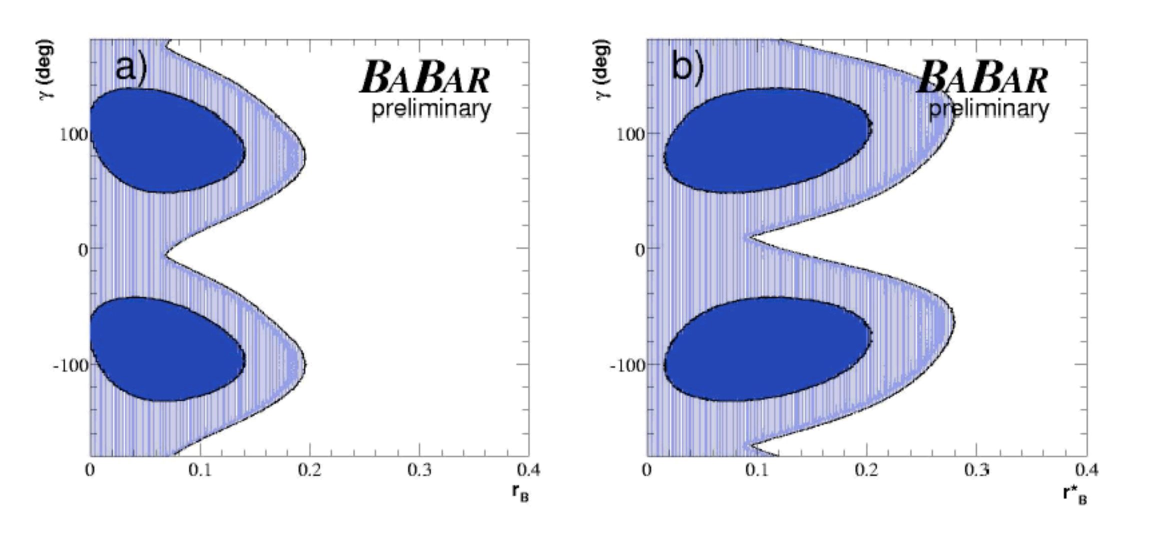
Different r, δ for different B decays

x,y: relative – for $D^0\gamma$ and $D^0\pi^0$ due to parity property. (Bonder, Gershon 2004)



Extraction of γ : BaBar

DK⁻ **D*K⁻**



$$\gamma = 91 \pm 41(\text{stat}) \pm 11(\text{sys}) \pm 12^\circ(\text{model})$$

r_{DK} = [0, 014]
r_{D*K} = [0.02, 0.20]

Extraction of ϕ_3: Belle

$$\varphi_3 = 53^{+15}_{-18}\,(\text{stat}) \pm 3\,(\text{sys}) \pm 9^\circ\,(\text{model})$$

$$r_{DK} = 0.159^{+0.054}_{-0.050} \pm 0.012 \pm 0.049$$

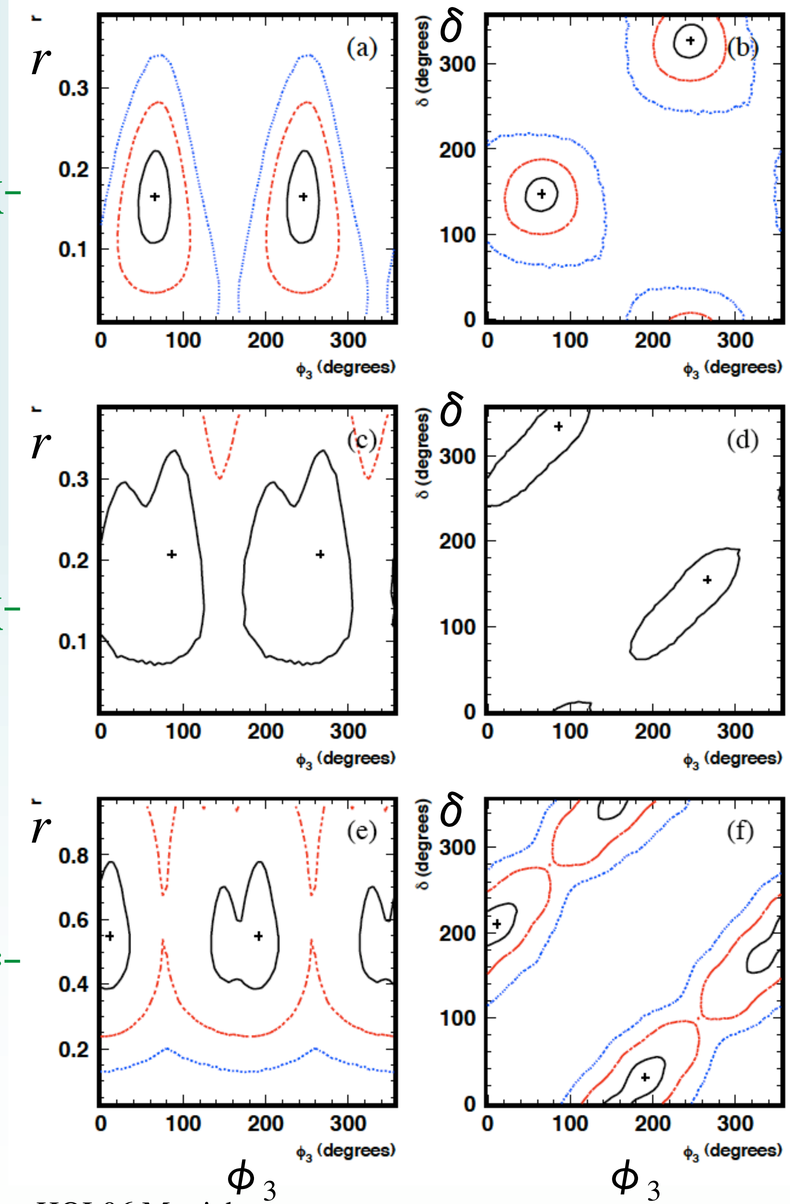
$$r_{D^*K} = 0.175^{+0.108}_{-0.099} \pm 0.013 \pm 0.049$$

$$r_{DK^*} = 0.564^{+0.216}_{-0.155} \pm 0.041 \pm 0.084$$

Ambiguities:

- $\phi_3 \to \phi_3 + (n+m)\pi$, $\delta \to \delta + (n-m)\pi$ (n,m: any integers)

Require $0 < \phi_3 < \pi$ to Resolve ambiguity.

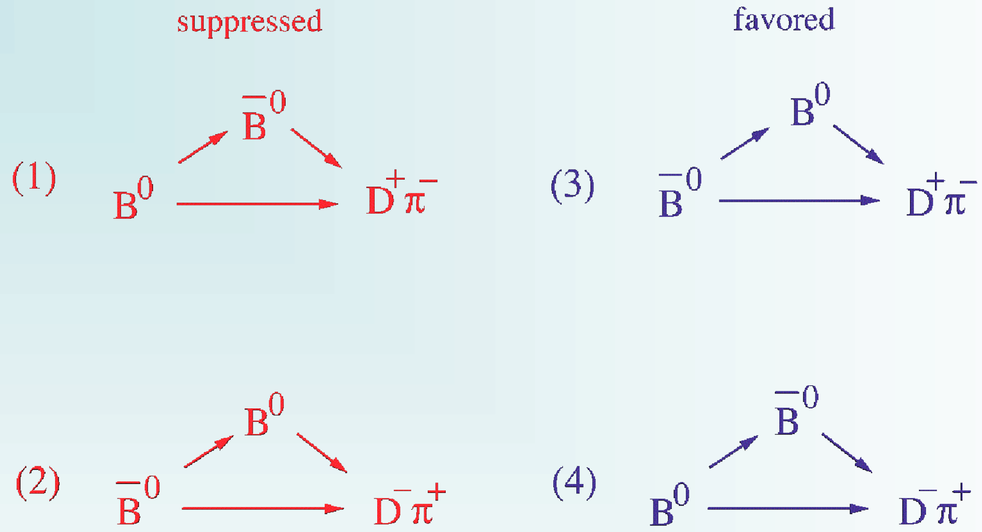


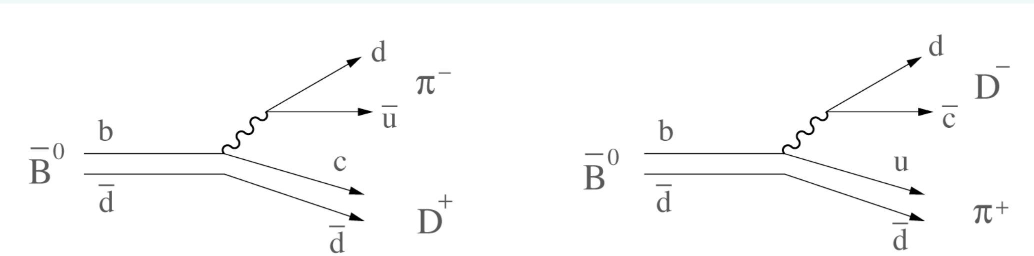
DK⁻

D*K⁻

DK*⁻

$D^{(*)}\pi^{(*)}$: mixing → flavor specific





CF **DCS**

+ annihilations

r **= DCS/CF~0.02**

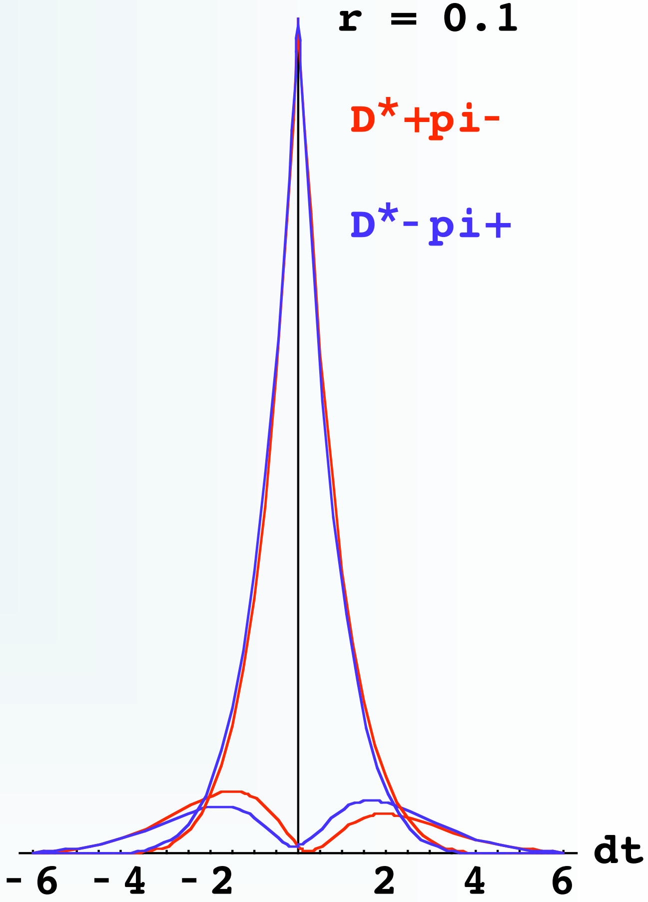
$\mathbf{D^{(*)}\,\pi^{(*)}}$

B⁰ tag

$$\Gamma_{B^0}(D^{\mp}\pi^{\pm};t) \propto 1 \pm \cos\Delta mt + s^{\mp}\sin\Delta mt$$

$$\Gamma_{\overline{B}^0}(D^{\mp}\pi^{\pm};t) \propto 1 \mp \cos\Delta mt - s^{\pm}\sin\Delta mt$$

$$s^{\pm} \sim 2r\sin(2\varphi_1 + \varphi_3 \pm \delta)$$



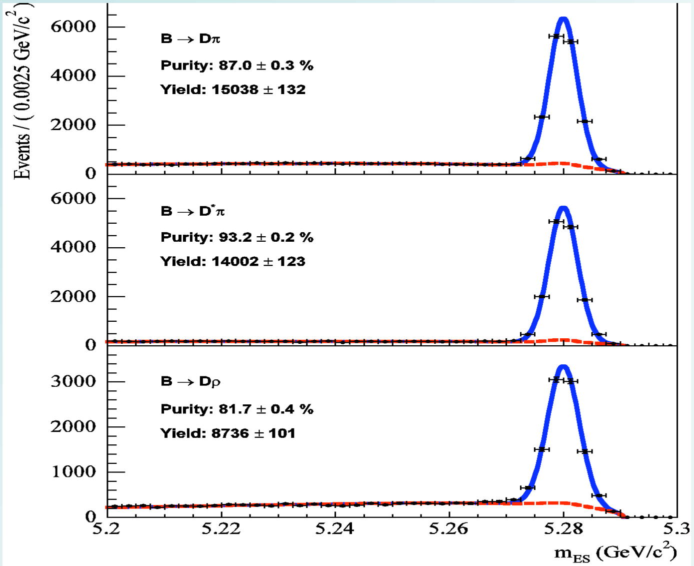
Tag-side interference

$$s^{\pm} \longrightarrow \begin{array}{l} a = 2r\sin(2\beta+\gamma)\cos\delta \\ b = 2r'\sin(2\beta+\gamma)\cos\delta' \\ c = 2\cos(2\beta+\gamma)(r\sin\delta - r'\sin\delta') \end{array}$$

Primed parameters : tag-side effects.
Absent for lepton tag.
→use a and c_{lep} to extract $2\beta+\gamma$

$D^{(*)} \pi^{(*)}$ Full-recon. BaBar

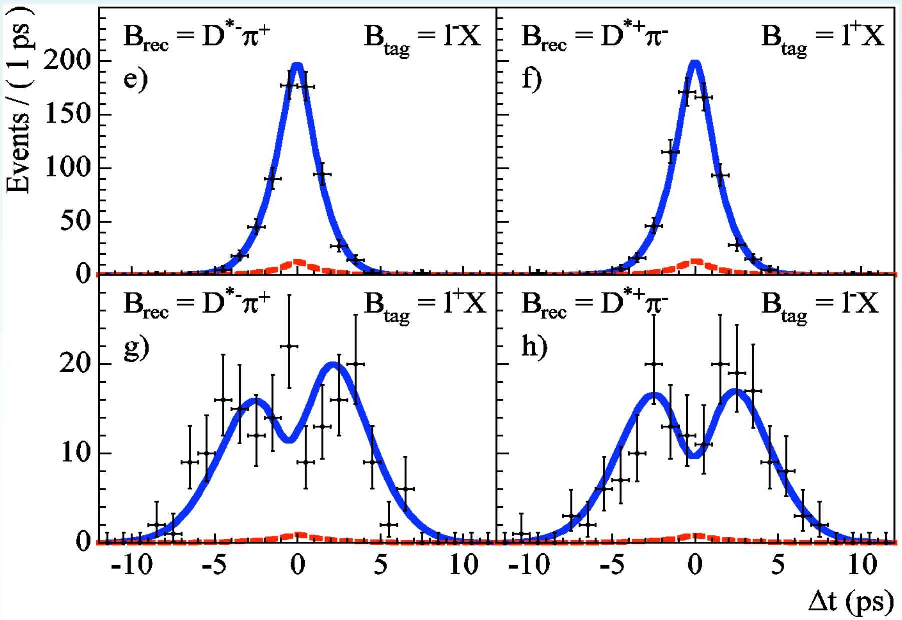
232M Bpairs



$D\pi$

$D^*\pi$

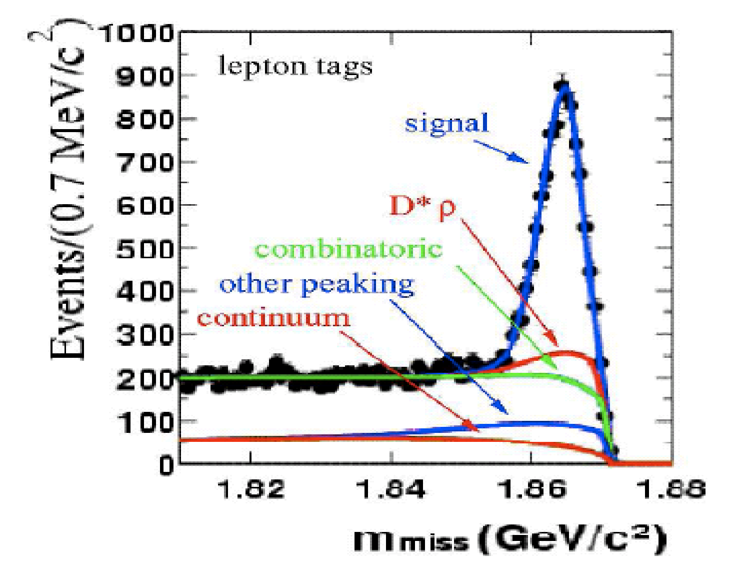
$D\rho$

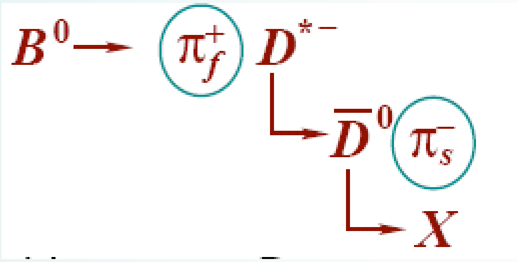


$$a^{D\pi} = -0.010 \pm 0.023 \pm 0.007$$
$$a^{D^*\pi} = -0.040 \pm 0.023 \pm 0.010$$
$$a^{D\rho} = -0.024 \pm 0.031 \pm 0.009$$

$$c^{D\pi} = -0.033 \pm 0.042 \pm 0.012$$
$$c^{D^*\pi} = +0.049 \pm 0.042 \pm 0.015$$
$$c^{D\rho} = -0.098 \pm 0.055 \pm 0.018$$

$D^{(*)}\pi^{(*)}$ partial-recon. BaBar





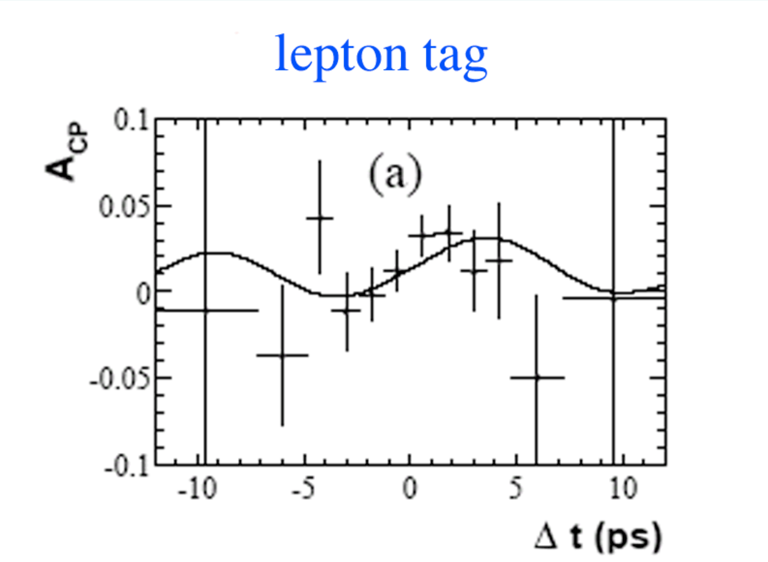
D^0 not reconstructed.

Fast and slow π's only.

Plot missing D^0 mass.

High statistics

More background



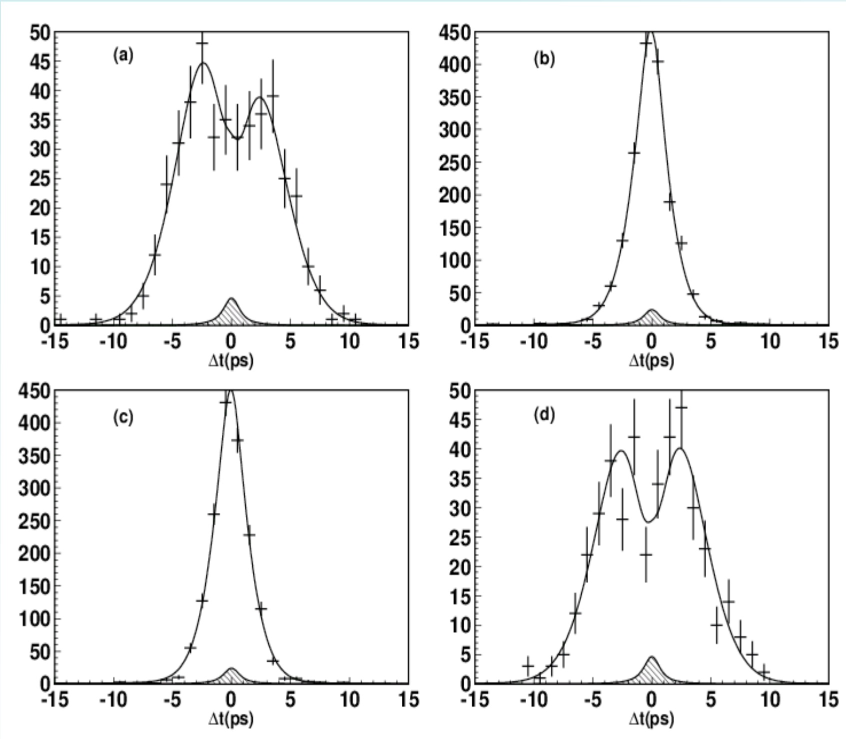
a=−0.034±0.014±0.019

c_{lep}=−0.025±0.020±0.013

$D^{(*)}\pi$ full-recon. Belle

Full reconstruction of
$D^+\pi^-$ and $D^{*+}\pi^-$

392M Bpairs



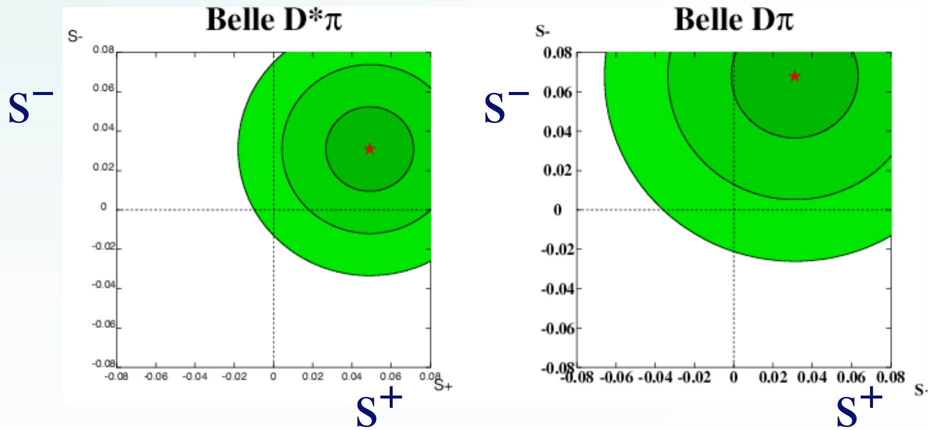
$D^{*+}\pi^-$: lepton tag

$S^+(D^*\pi)=0.049\pm0.020\pm0.011$

$S^-(D^*\pi)=0.031\pm0.019\pm0.011$

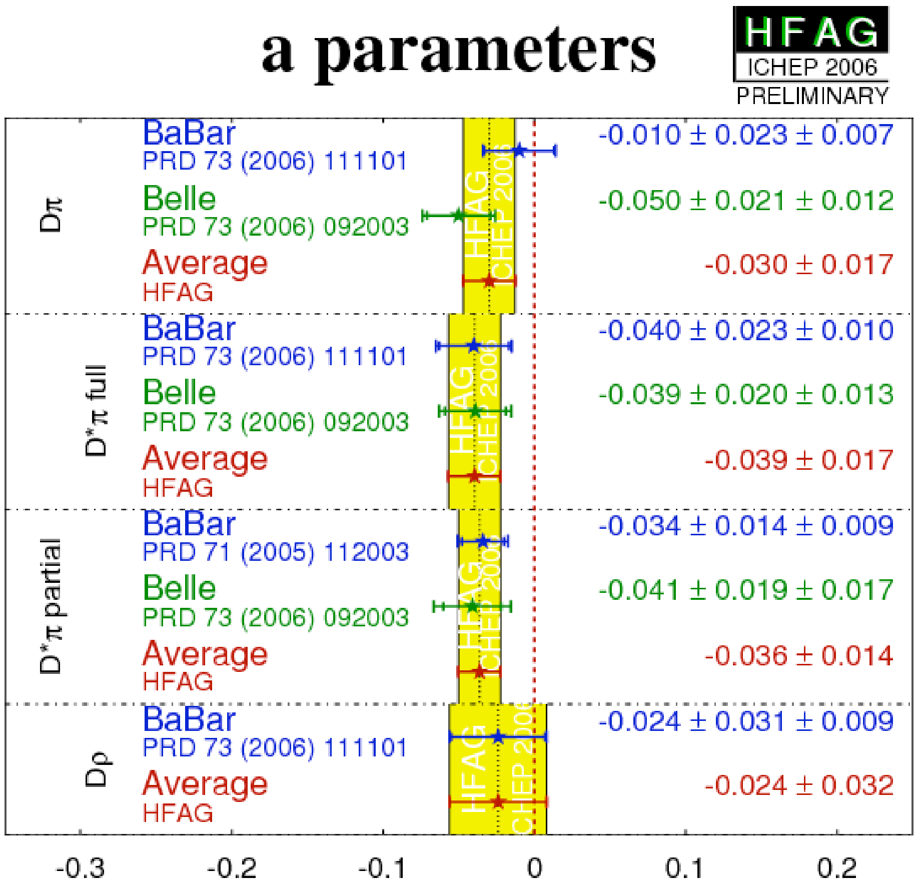
$S^+(D\pi)=0.031\pm0.030\pm0.012$

$S^-(D\pi)=0.068\pm0.029\pm0.012$

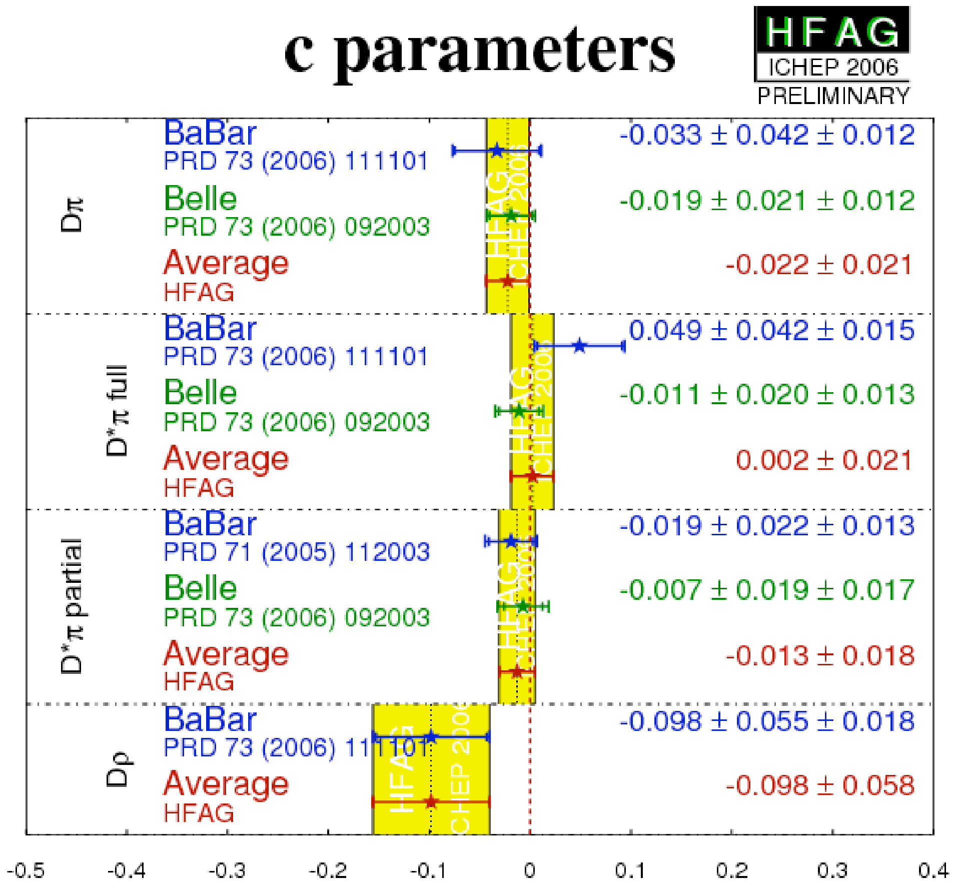


$D^{(*)}\pi^{(*)}$ World Averages

a parameters



c parameters



Deviation of a from 0 is seen

Measurement of $r(D^{(*)}\pi^{(*)})$

$Br(D_S\pi) = (1.3\pm0.3\pm0.2)\times10^{-5}$
$Br(D_S^*\pi) = (2.8\pm0.6\pm0.5)\times10^{-5}$

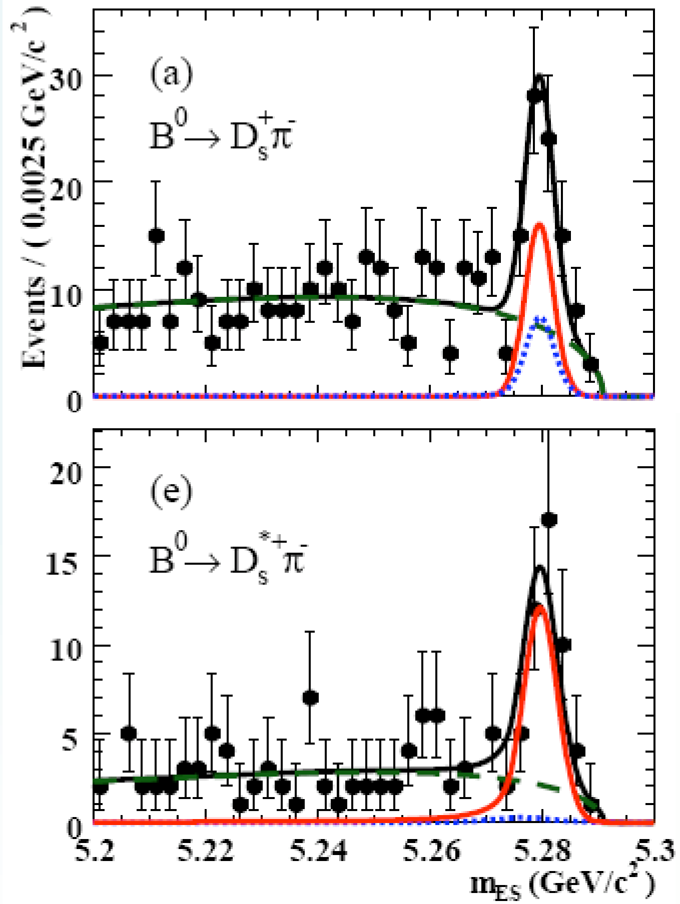
Assume SU3 with correction for decay constants f_D, f_{Ds} :

$$r = \tan\theta_c \frac{f_D}{f_{D_S}}\sqrt{\frac{Br(B^0 \to D_S^+\pi^-)}{Br(B^0 \to D^-\pi^+)}}$$

$r(D\pi) = (1.3\pm0.2\pm0.1)\times10^{-2}$
$r(D^*\pi) = (1.9\pm0.2\pm0.2)\times10^{-2}$

Annihilation diagram in $D\pi$
is ignored.
(No annihilation for $D_S\pi$, since
$\#s\bar{s}$ is odd)

BaBar

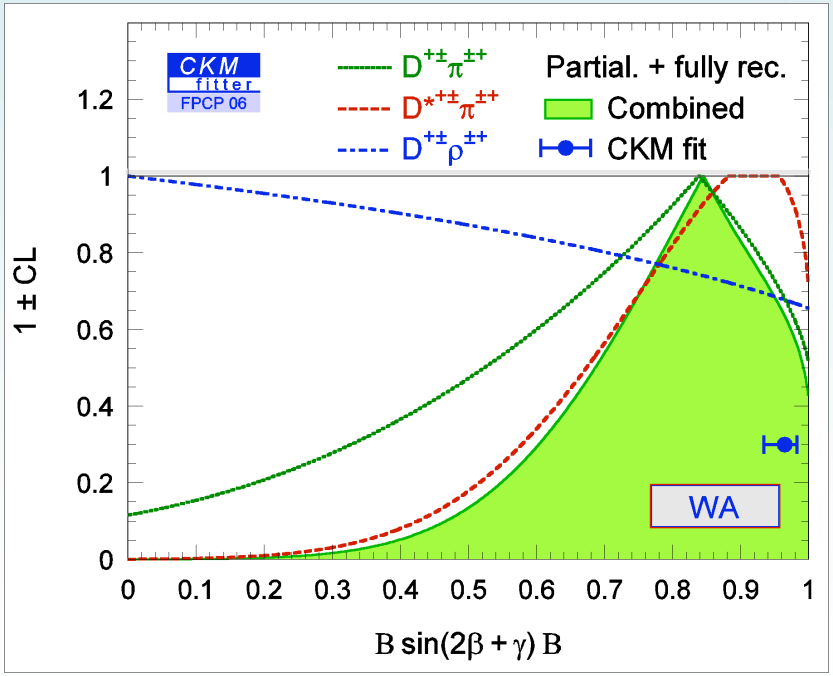


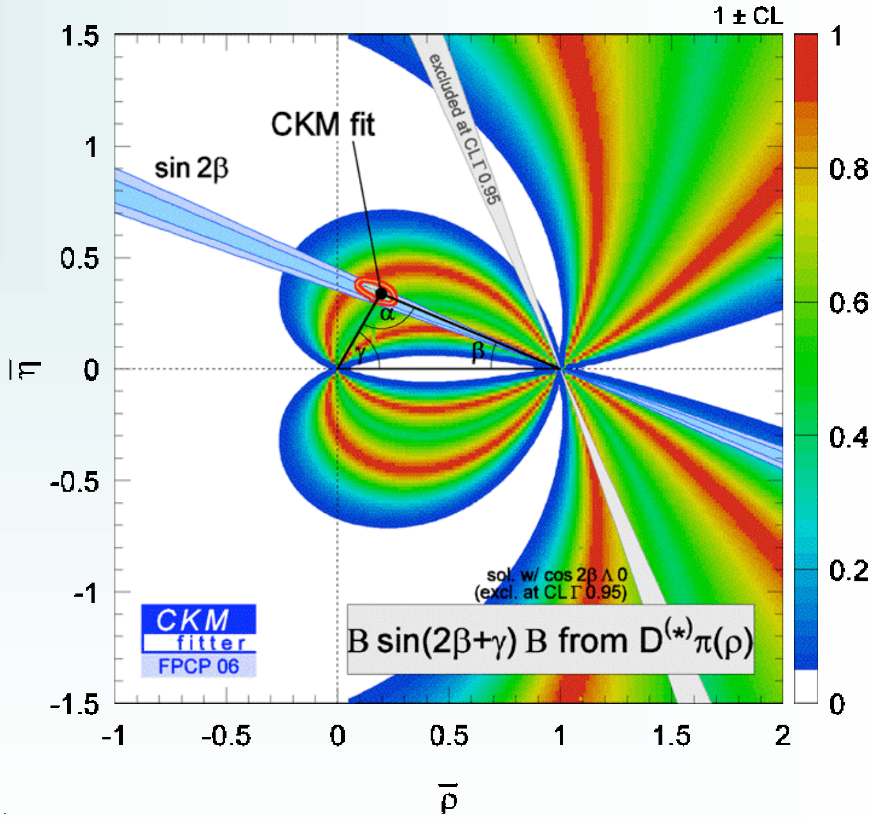
Extraction of sin(2β+γ) and γ

Combine,

- Belle and BaBar
- Full and partial reconstructions
- All $D^{(*)}\pi^{(*)}$ modes

Use r's from SU3





Summary

- $D_{CP}K$ modes :
  - Clear CPV not seen yet.
- DK ADS modes :
  - Suppressed modes are not seen (some hints?).
  - Constraints on r is obtained.
- DK Dalitz analysis :
  - ϕ_3/γ error is ~20°.
  - Improvement expected with more stat.
- $D^{(*)}\pi^{(*)}$ time-dependent analysis :
  - Beginning to produce meaningfull result for $\sin(2\phi_1+\phi_3)$.
  - Determination of $r(D\pi)$ is an issue.