$\phi_3(\gamma)$ extraction in B decays

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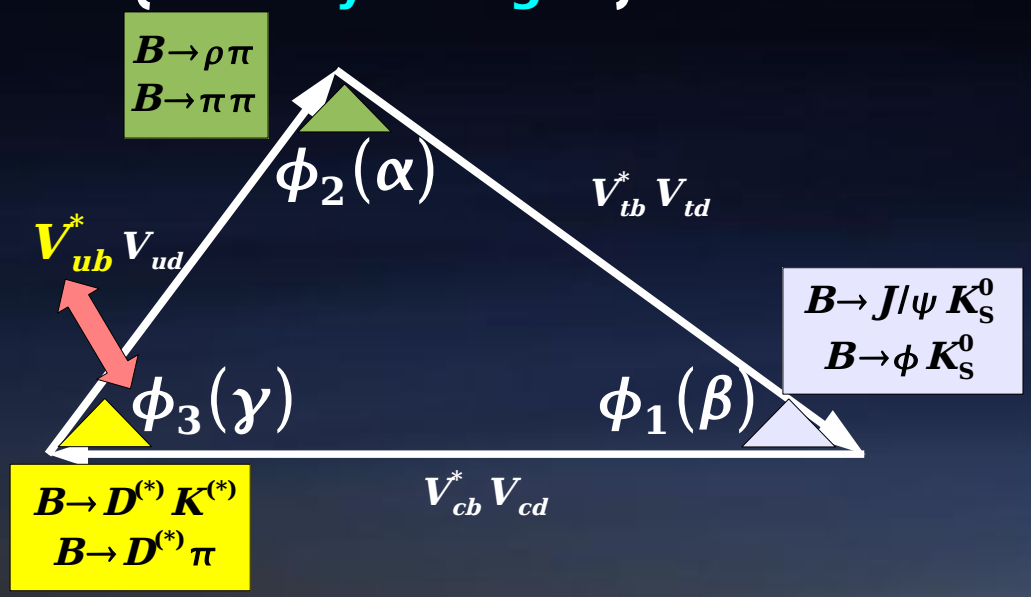
C H A R M 2006, Beijing, China

ϕ_3 related decay modes

(unitary triangle)



(CKM matrix)

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$D^{(*)}\pi$ system [interference between CFD, DCSD]

Time dependent analysis of $B^0 \to D^{(*)-}\pi^+$, [I. Dunietz, J. Rosner, R.G.Sachs]

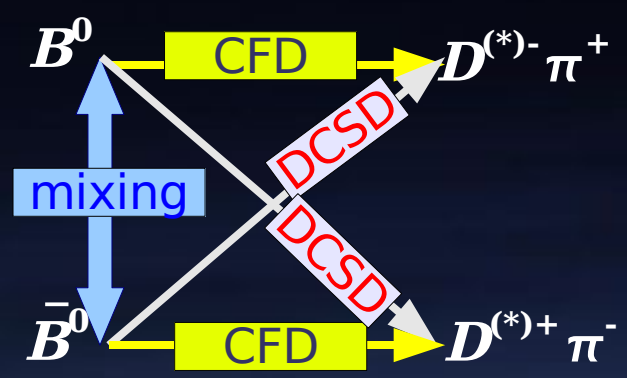
$D^{(*)}K$ system [interference between same final states of D-meson decays]

Analysis of $B^+ \to D_{CP} K^+$, [Gronou, London, Wyler]

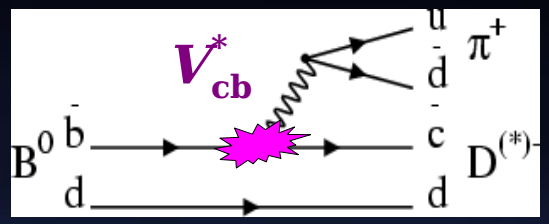
Analysis of $B^+ \to D_{sup} K^+$, [Atwood, Dunietz, Soni]

Dalitz analysis of $B^+ \to [K^0_S \pi^+ \pi^+]_D K^+$, [Giri, Grossman, Soffer, Zupan]

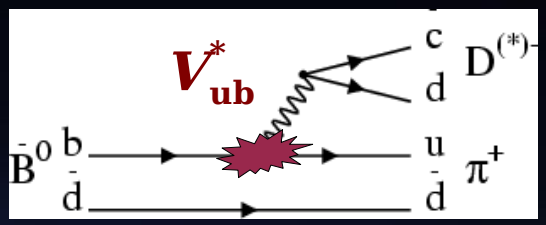
$\sin(2\phi_1+\phi_3)$ in $B^0 \to D^{(*)-}\pi^+$ decays



(2 B x 2 different final states)



$$A_1 \propto V^*_{cb}\, V_{ud}$$



$$A_2 \propto V^*_{ub}\, V_{cd}$$

Interference b -> c (Cabibbo-Favoured), b -> u(Doubly-Cabibbo-Supressed)

ratio between DCSD and CFD, $R = \left|\frac{A_2}{A_1}\right| \approx 0.02$ → **Small size of CP violation**

Advantages

- ☆Only tree diagrams, no penguins
- ☆Clean methods of extraction, no model dependency
- ☆High branching fraction for favored decay(3x10^-3)

Extraction mechanism

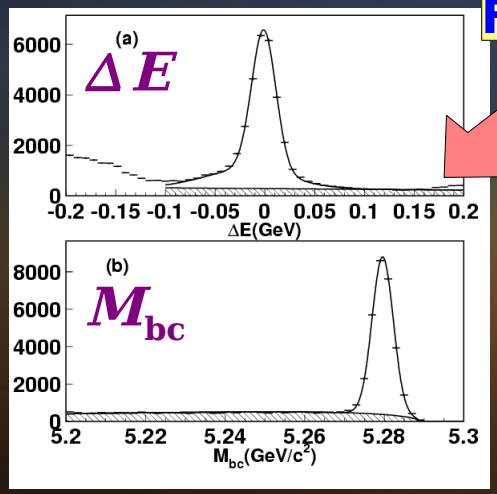
Two methods ⇒ **Full reconstruction, Partial reconstruction**

Full reconstruction : $\bar{B}^0 \to D^{(*)+}\pi_f^-;\ D^{*+} \to D^0\pi_s^+,\ D^+\pi_s^0$

$D^0 \to K^-\pi^+,\ K^-\pi^+\pi^0,\ K^-\pi^+\pi^+\pi^-,\ K_S\pi^+\pi^-;\ \ D^+ \to K^-\pi^+\pi^+;\ \ K_S \to \pi^+\pi^-$

Partial reconstruction : Don't reconstruct D-meson
only need two pion(π_f , π_s)information
use only lepton tag

FULL REC

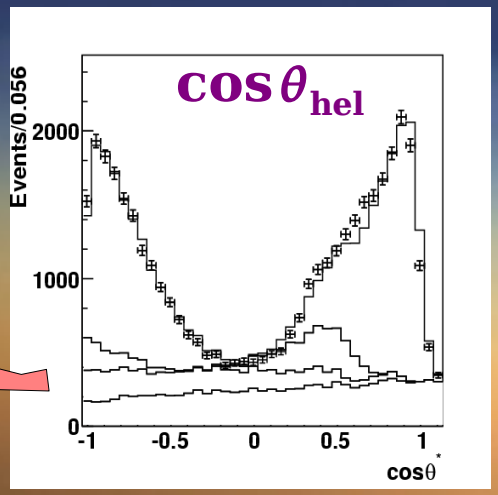


$B^0 \to D^*\pi$ ~31500 evts. (89% purity)

$B^0 \to D\pi$ ~31800 evts. (83% purity)

PARTIAL REC

$B^0 \to D^*\pi$ ~32800 events



Experimental methods

Decay rates and experimental PDFs

$$P(B^0 \to D^{(*+)}\pi^-) = N[1 - C\cos(\Delta mt) - (S^+ - S^+_{tag})\sin(\Delta mt)]$$

$$P(B^0 \to D^{(*-)}\pi^+) = N[1 + C\cos(\Delta mt) - (S^- + S^+_{tag})\sin(\Delta mt)]$$

$$P(\bar{B}^0 \to D^{(*+)}\pi^-) = N[1 + C\cos(\Delta mt) + (S^+ + S^-_{tag})\sin(\Delta mt)]$$

$$P(\bar{B}^0 \to D^{(*-)}\pi^+) = N[1 - C\cos(\Delta mt) + (S^- - S^-_{tag})\sin(\Delta mt)]$$

$$C = \frac{1 - R_*^2}{1 + R_*^2} \approx 1$$

$$S^{+-} = \frac{2R_*}{1 + R_*^2}\sin(2\phi_1 + \phi_3 \pm \delta_*)$$

CP violation parameter

$2\phi_1 + \phi_3 \Rightarrow$ weak phase difference

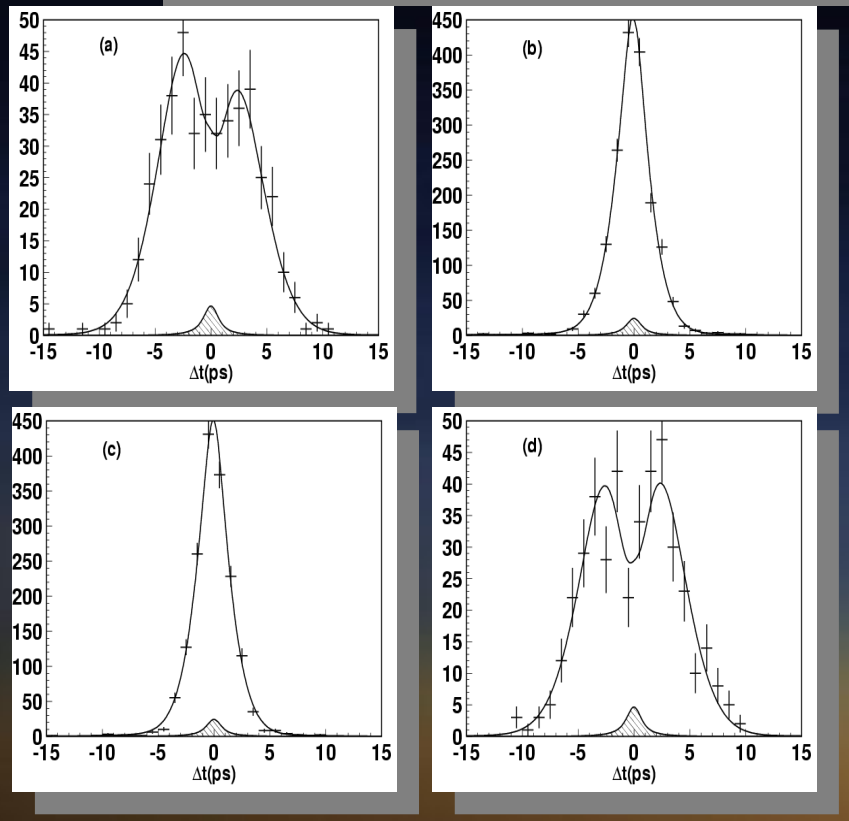
$\delta_* \Rightarrow$ strong phase difference

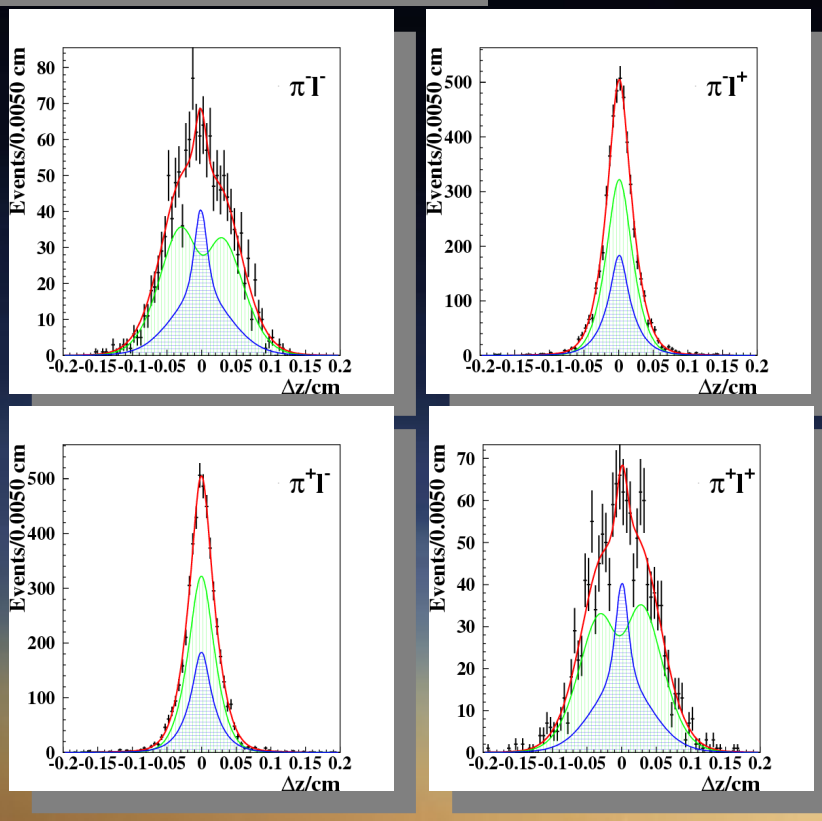
$S^{+-}_{tag} \Rightarrow$ effective parameters for tag side CP violation effect

- tag side B -> DX can mimic the CP asymmetry of signal side
- Obtained experimentally from $B \to D^* l\nu$ flavor specific decay
- Systematic only for full reconstruction
- Partial reconstruction uses only lepton tags

Results from Belle

New! published in Phys. Rev. D 73, 092003(2006)
Using 386 M BB pair





$D^*\pi$ Full Rec

$S^+_{D^*\pi}=0.050\pm0.029\pm0.013$

$S^-_{D^*\pi}=0.028\pm0.028\pm0.013$

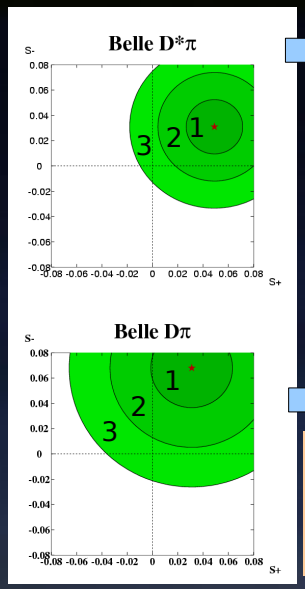
$D^*\pi$ Partial Rec

$S^+_{D^*\pi}=0.048\pm0.028\pm0.017$

$S^-_{D^*\pi}=0.034\pm0.027\pm0.017$

Combined Result

Phys. Rev. D 73, 092003(2006)



$D^*\pi$ full rec + partial rec

$S^+_{D^*\pi}=0.049\pm0.020\pm0.011$

$S^-_{D^*\pi}=0.031\pm0.019\pm0.011$

$D\pi$ full rec

$S^+_{D\pi}=0.031\pm0.030\pm0.012$

$S^-_{D\pi}=0.068\pm0.029\pm0.012$

$(S^+ + S^-) \propto \sin(2\phi_1+\phi_3)\cos\delta$

$\sim 2.5\sigma$ CP violation $\rightarrow D^*\pi$

$\sim 2.2\sigma$ CP violation $\rightarrow D\pi$

constraint on $\sin(2\phi_1+\phi_3)$

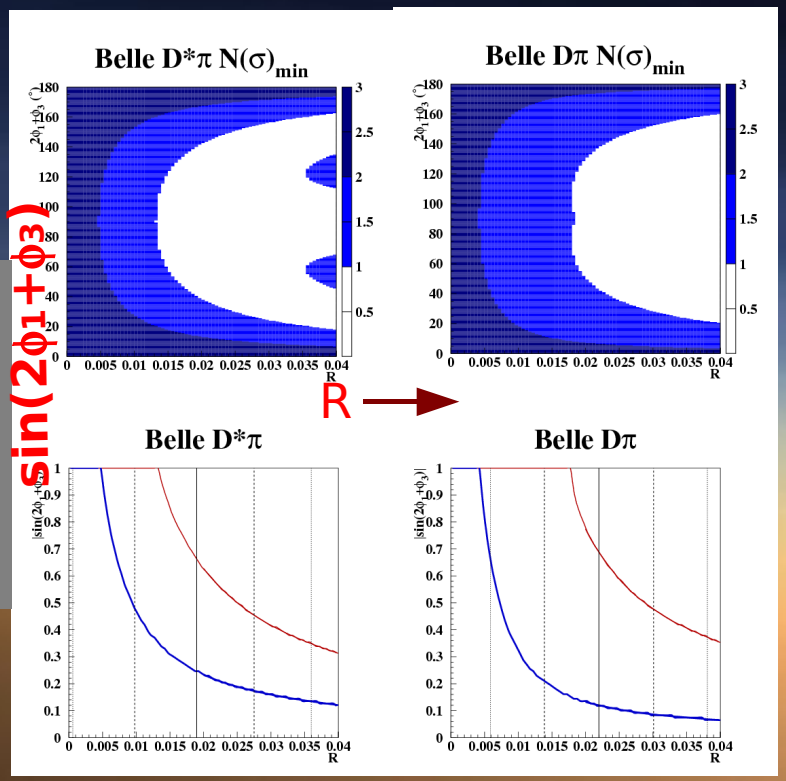
Need more info. about R, and δ

★Using SU(3) symmetry we measured,

$$R^2_{D^{(*)}\pi}=\tan^2\theta_c\frac{f_{D^{(*)}}B(B^0\rightarrow D_s^{(*)+}\pi^-)}{f_{D_s^{(*)}}B(B^0\rightarrow D^{(*)-}\pi^+)}$$

$R_{D^*\pi}=0.020\pm0.007\pm0.006(theory)$

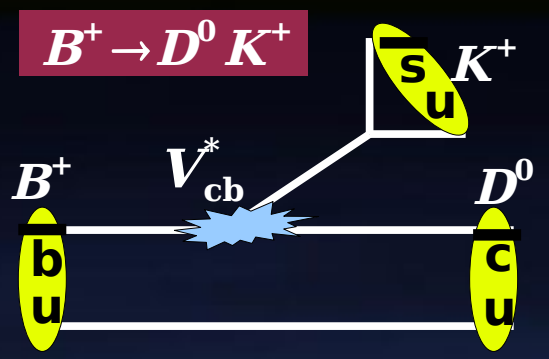
$R_{D\pi}=0.021\pm0.004\pm0.006(theory)$

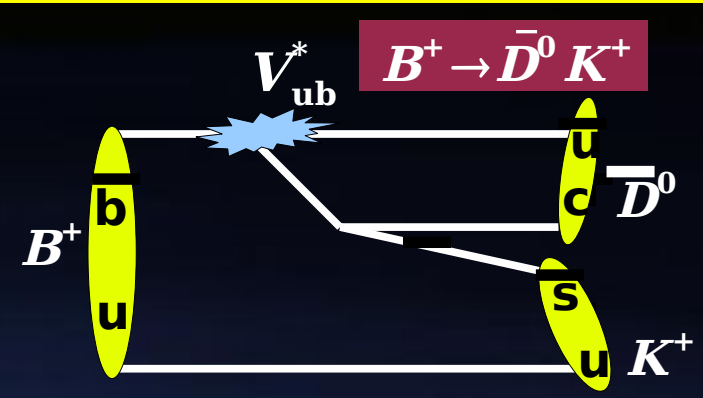


$|\sin(2\phi_1+\phi_3)| > 0.44$ at 68% CL for $D^*\pi$

$|\sin(2\phi_1+\phi_3)| > 0.52$ at 68% CL for $D\pi$

ϕ_3 from $B^+ \to D^{(*)0} K^{(*)+}$ system





★Interference of two amplitudes producing opposite flavors of D-meson

B+ Decay — mixed state $\tilde{D}_+ = \bar{D}^0 + r e^{i\theta_+} D^0$

B- Decay — $\tilde{D}_- = D^0 + r e^{i\theta_-} \bar{D}^0$

$$r = \left| \frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \bar{D}^0 K^+)} \right| \approx \left| \frac{V^*_{ub} V^*_{cs}}{V^*_{cb} V_{us}} \right| \approx 0.1 - 0.3$$

relative phase difference $\theta_+ = \phi_3 + \delta$, $\theta_- = -\phi_3 + \delta$

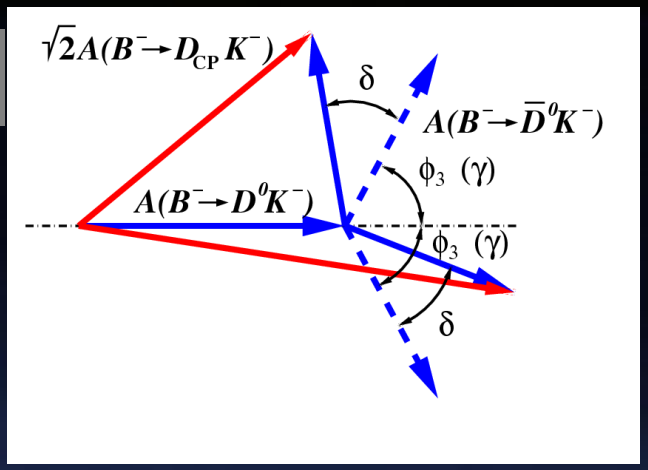
ϕ_3 weak phase difference

δ strong phase difference

GLW method

☆Reconstruct CP-even(D1), CP-odd(D2) eigenstates

$$D_1 \to K^+K^-,\ \pi^+\pi^-$$
$$D_2 \to K_S^0\pi^0,\ K_S^0\omega,\ K_S^0\phi$$



Partial rate asymmetry :

$$A_{1,2} \equiv \frac{\Gamma(B^- \to D_{1,2}K^-) - \Gamma(B^+ \to D_{1,2}K^+)}{\Gamma(B^- \to D_{1,2}K^-) + \Gamma(B^+ \to D_{1,2}K^+)} = \frac{2r_B \sin\delta_B^{'} \sin\phi_3}{1 + r_B^2 + 2r_B \cos\delta_B^{'} \cos\phi_3}$$

$$\delta_B^{'} \begin{cases} \delta & \text{for } D_1 \\ \delta + \pi & \text{for } D_2 \end{cases}, \quad R_{1,2} \equiv \frac{Br(B \to D_{1,2}K)/Br(B \to D_{1,2}\pi)}{Br(B \to D^0K)/Br(B \to D^0\pi)}, \quad A_1R_1 = -A_2R_2$$

3 observables, 3 unknowns $r_B,\ \delta,\ \phi_3$ unknowns

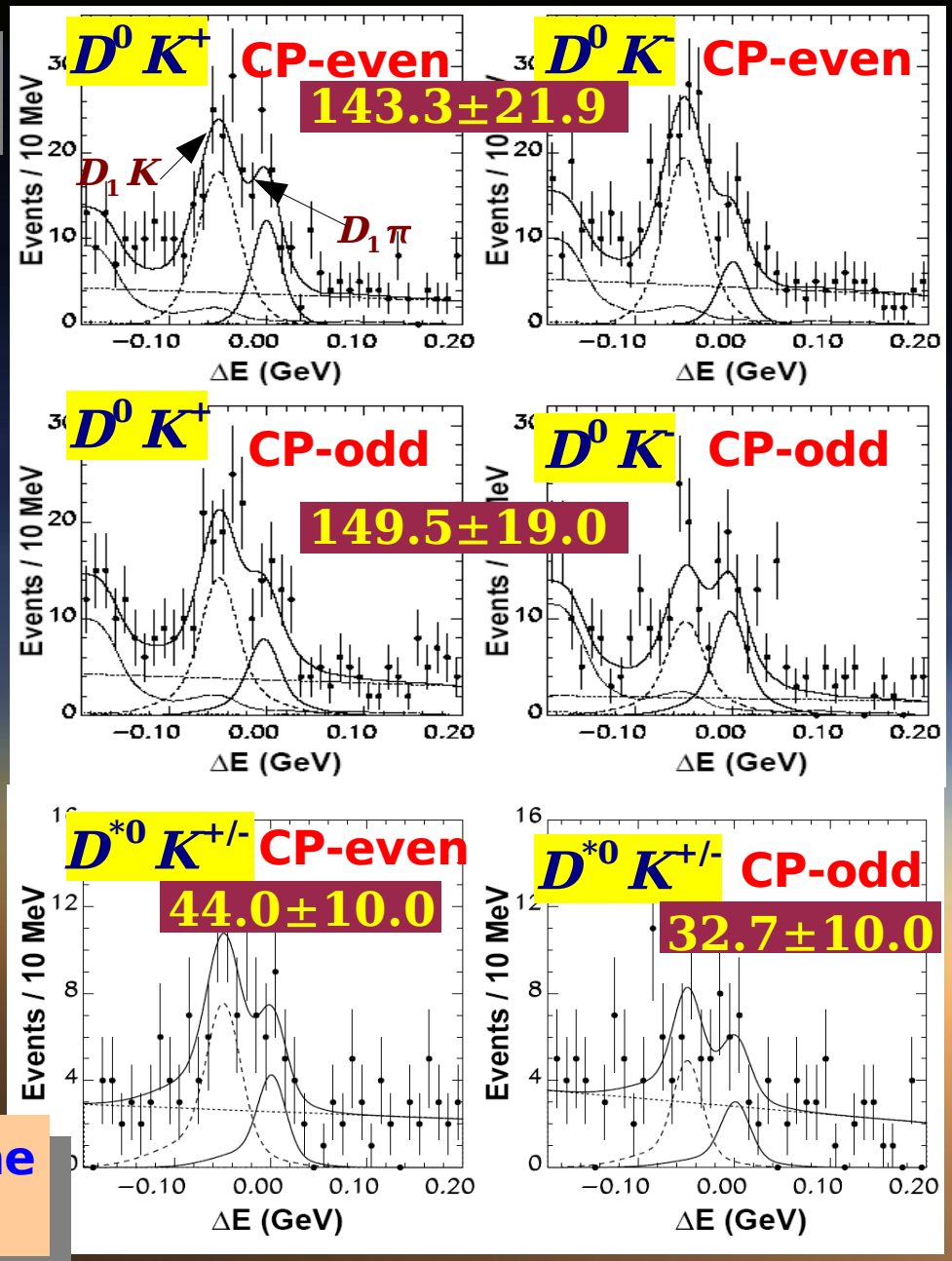
Results from GLW method

Phys. Rev. D 73, 051106(R) (2006)
275 M BB pairs

modes used $\Rightarrow D_{CP}\mathrm{K},\ D^*_{CP}K$

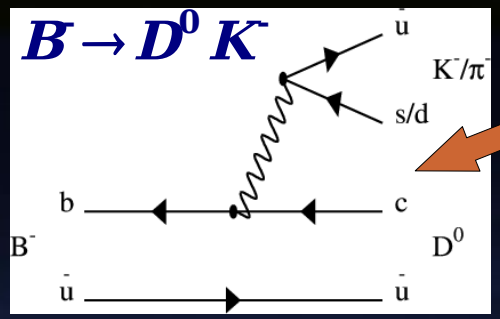
$$R_1 = 1.13 \pm 0.16(stat.) \pm 0.08(syst.)$$
$$R_2 = 1.17 \pm 0.14(stat.) \pm 0.14(syst.)$$
$$A_1 = 0.06 \pm 0.14(stat.) \pm 0.05(syst.)$$
$$A_2 = -0.12 \pm 0.14(stat.) \pm 0.05(syst.)$$

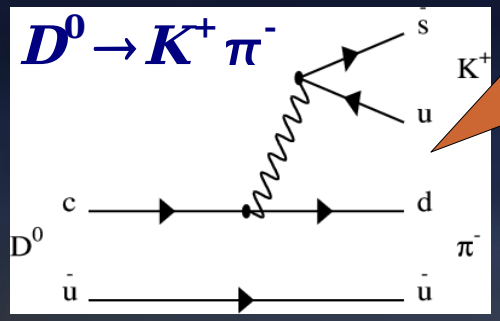
$$R_1^* = 1.41 \pm 0.25(stat.) \pm 0.06(syst.)$$
$$R_2^* = 1.15 \pm 0.31(stat.) \pm 0.12(syst.)$$
$$A_1^* = -0.20 \pm 0.22(stat.) \pm 0.04(syst.)$$
$$A_2^* = 0.13 \pm 0.30(stat.) \pm 0.08(syst.)$$



Can't constrain r from this method alone
need more statistics

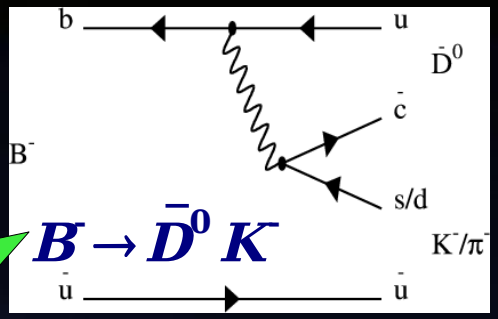
$B^- \to [K^+\pi^-]_D K^-$ ADS method

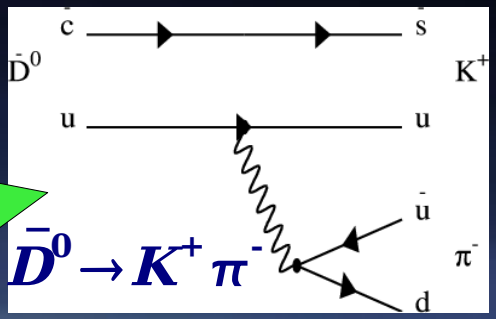




A favored decay followed by a suppressed decay

A suppressed decay followed by a favored decay





Similar order of magnitude enhances the CP violation

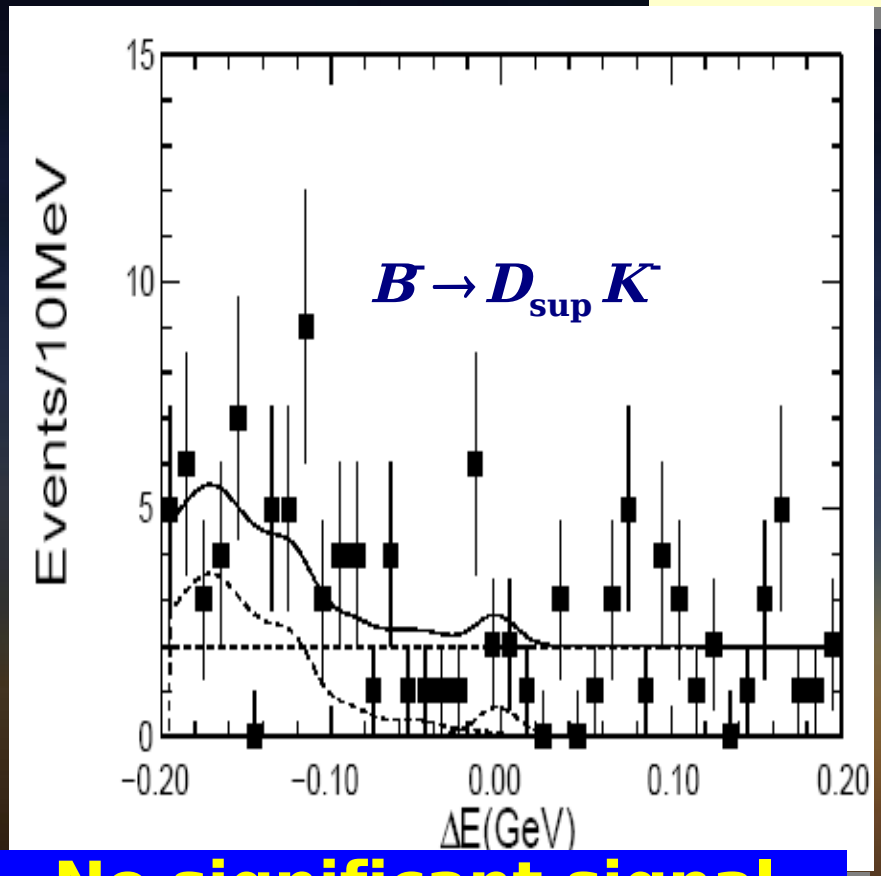
$$R_{DK} = \frac{Br(B^- \to D^-_{sup} K^-)}{Br(B^- \to D^-_{fav} K^-)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\phi_3 \cos\delta$$

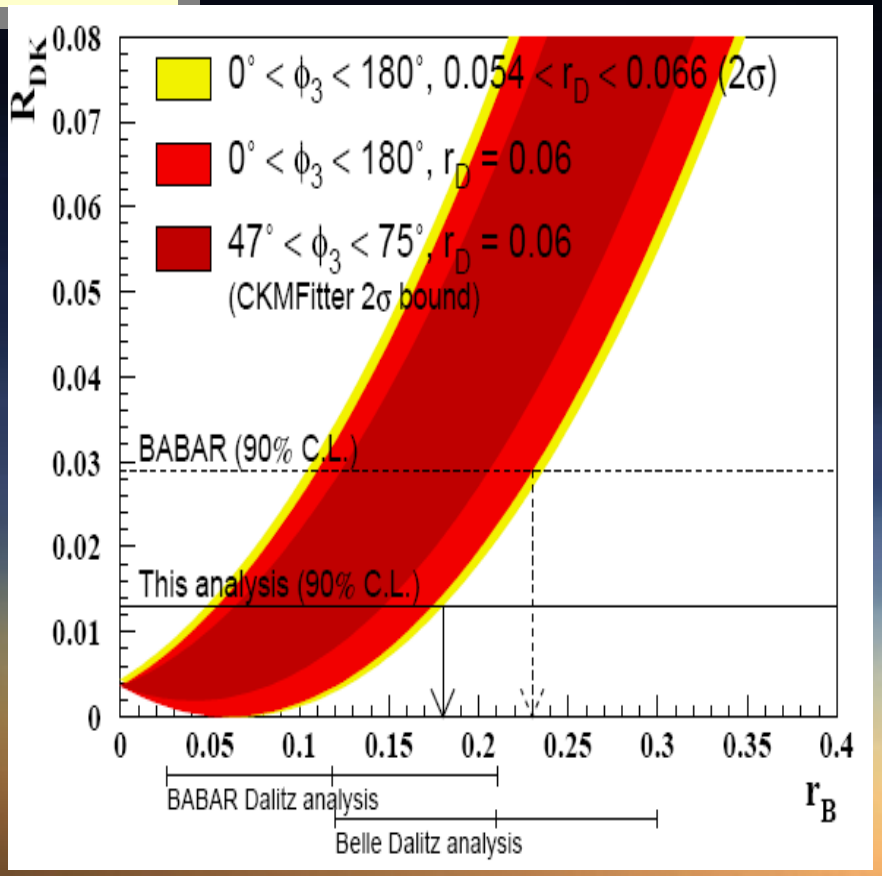
$$r_B \equiv \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)}, \qquad \delta = \delta_B + \delta_D$$

$$r_D \equiv \frac{A(D^0 \to K^+\pi^-)}{A(\bar{D}^0 \to K^+\pi^-)} = 0.060 \pm 0.003 \, (input)$$

Results from ADS method

hep-ex/0508048
386 M BB pairs





No significant signal
Need more statistics

$$r_B < 0.18 \; @90\% \, CL$$

$$0^0 < \phi_3 < 180^0, \;\; 0.054 < r_D < 0.066 \, (2\sigma \, interval)$$

$B^+ \to [K_S^0 \pi\pi]_D K^+$ Dalitz analysis

- A.Giri, Y.Grossman, A.Soffer & J.Zupan, Phys. Rev. D68, 054018 (2003)
- A. Bondar, Proc. of Belle Dalitz analysis meeting, 24-26 Sep. 2002

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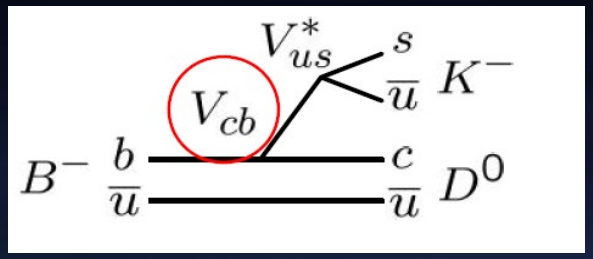
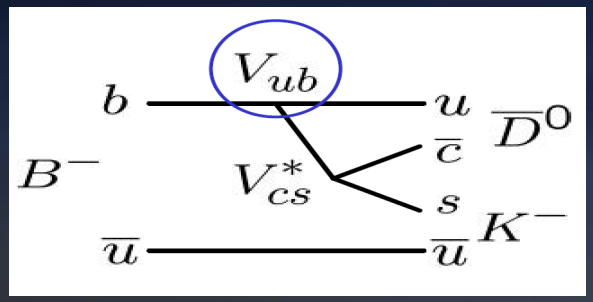




3 modes are used for this analysis

$$B^+ \to D^0 K^+,\ D^{*0} K^+,\ D^0 K^{*+}$$

same final states for

$D^0, \bar{D}^0 \to K_S^0 \pi^+ \pi^-$ (quasi 2-body decay)

$$\tilde{D} = |D^0\rangle + r e^{i\theta} |\bar{D}^0\rangle$$

Dalitz plot density gives information about r, and θ

- **Amplitude for each Dalitz plot point :**

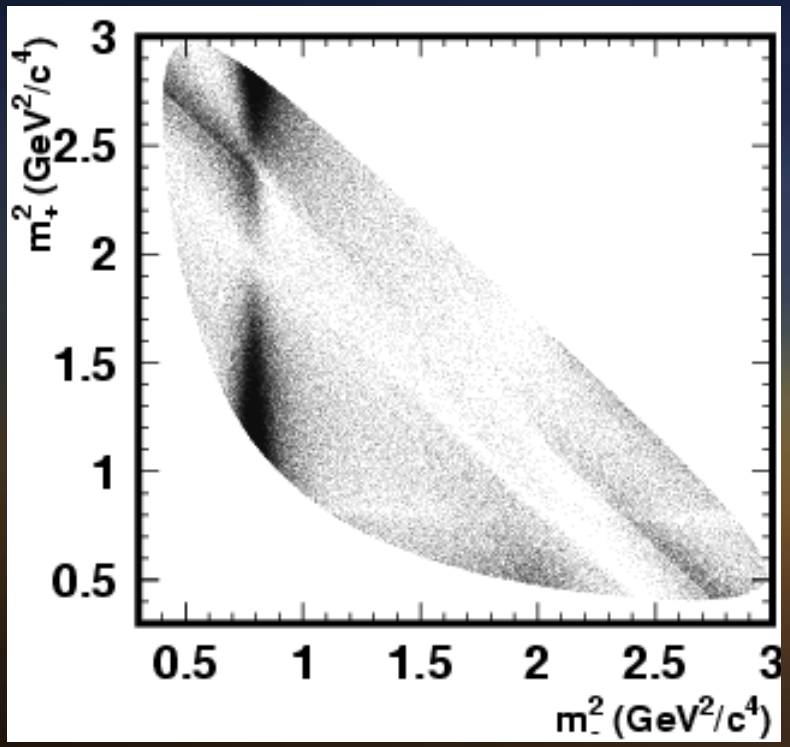
$$B^+ \to DK^+ \Rightarrow M_+ \equiv f(m_+^2, m_-^2) + r e^{i\phi_3 + i\delta} f(m_-^2, m_+^2)$$

$$B^- \to DK^- \Rightarrow M_- \equiv f(m_-^2, m_+^2) + r e^{-i\phi_3 + i\delta} f(m_+^2, m_-^2)$$

$$m_+^2 = m^2_{K_S^0 \pi^+}, \qquad m_-^2 = m^2_{K_S^0 \pi^-}$$

Dalitz analysis method

- Statistical sensitivity of the method depends on the properties of the 3-body decay involved
- (For $|M|^2$=**Const.** there is no sensitivity to the phase θ)
  Large variations of D^0 decay strong phase are essential



$f(m^2_{K^0_S\pi^+}, m^2_{K^0_S\pi^-})$ are known paramters

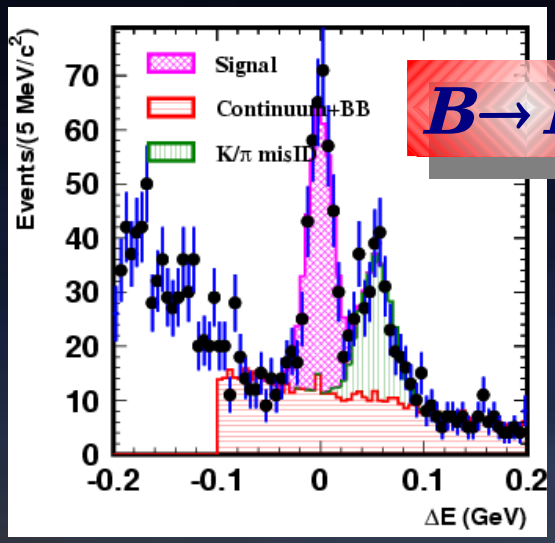
simultaneous fit to the B^+, B^- data

obtain parameters ϕ_3, r, δ

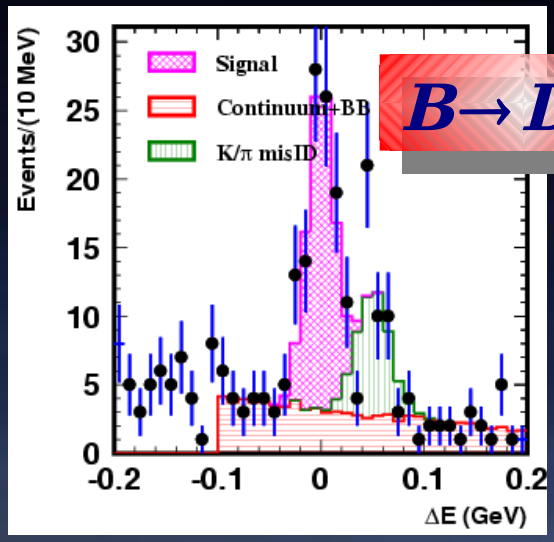
- Model dependent fit to the experimental data from flavor tagged $D^* \to D^0\pi$
- Model is described by a set of two-body decay amplitudes + NR term
- As a result, model uncertainty in the $\phi 3/\gamma$ measurement

Dalitz analysis

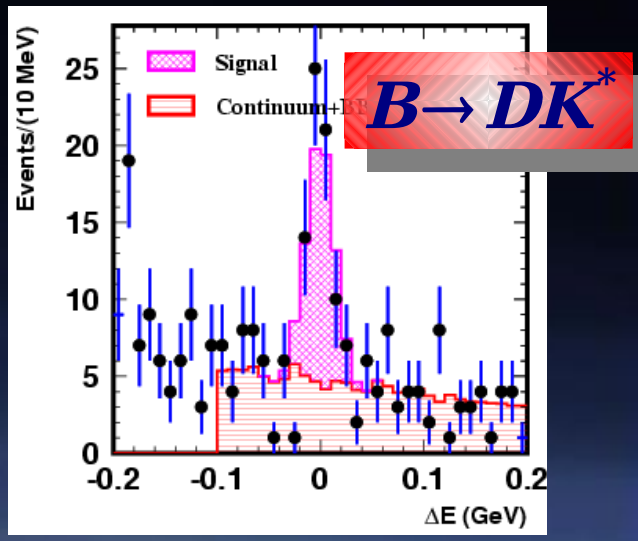
hep-ex/0604054, submitted to Phys. Rev. D



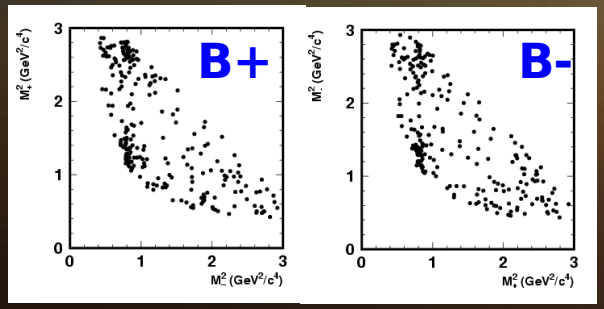
331±17 events

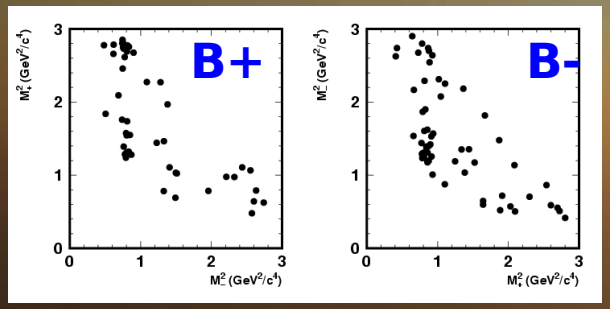


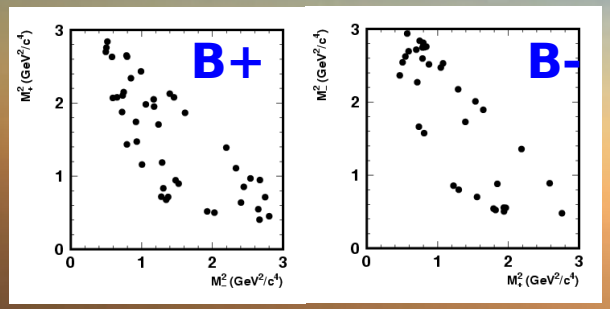
81±8 events



54±8 events







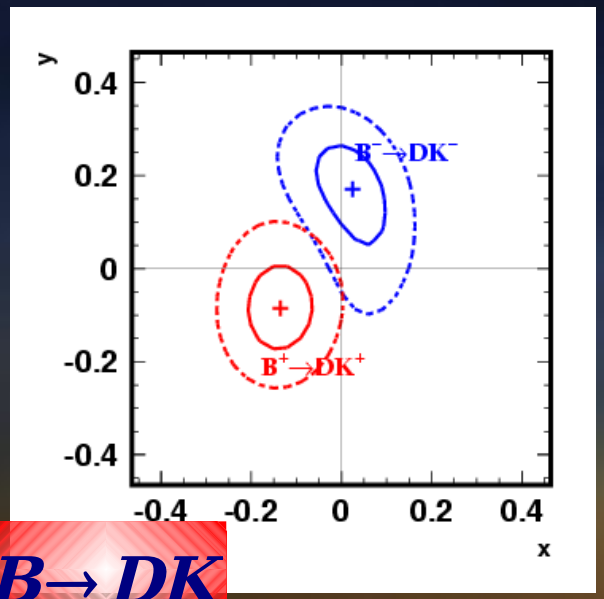
Dalitz analysis

Fitting x_{+-}, y_{+-} instead of r, ϕ_3, δ

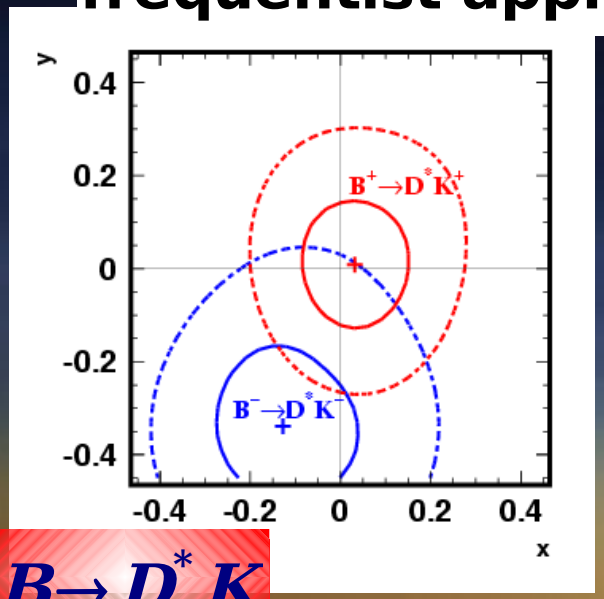
New approach has low bias, better sensitivity, and easy plots

$$x_{+-} = \Re\left(r_B e^{i\phi_3 \pm \delta}\right) = r_B \cos(\pm\phi_3 + \delta), \quad y_{+-} = \Im\left(r_B e^{i\phi_3 \pm \delta}\right) = r_B \sin(\pm\phi_3 + \delta)$$

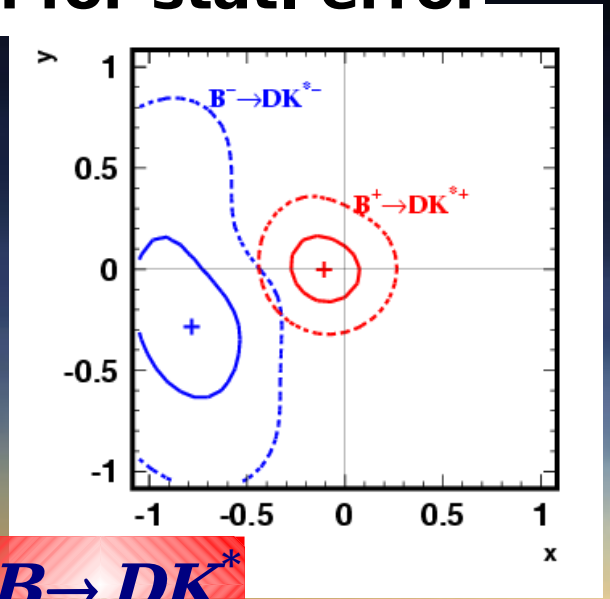
frequentist approach for stat. error



$B \to DK$



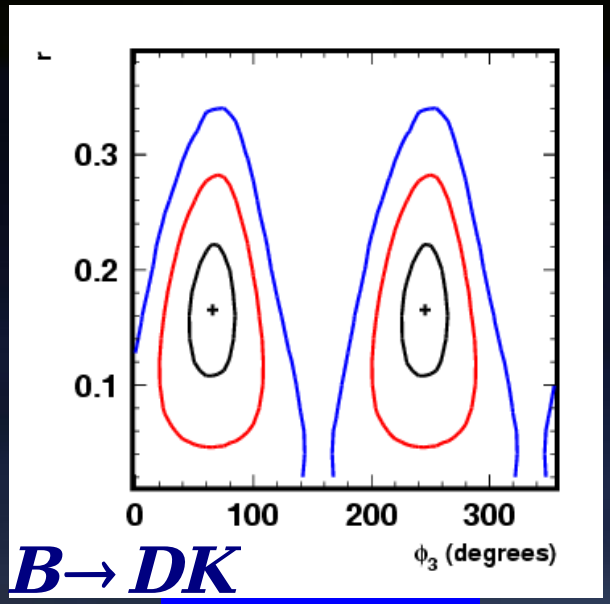
$B \to D^* K$



$B \to DK^*$

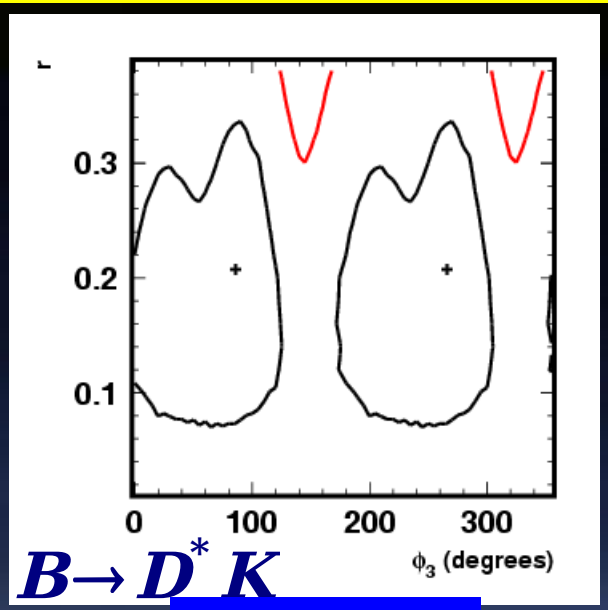
Mode	x_+	y_+	x_-	y_-
DK	$0.025^{+0.072}_{-0.080}$	$0.170^{+0.093}_{-0.117}$	$-0.135^{+0.069}_{-0.070}$	$-0.085^{+0.090}_{-0.086}$
$D^* K$	$-0.128^{+0.167}_{-0.146}$	$-0.339^{+0.172}_{-0.158}$	$0.032^{+0.120}_{-0.116}$	$0.008^{+0.137}_{0.136}$
DK	$-0.784^{+0.249}_{-0.295}$	$-0.281^{+0.440}_{-0.335}$	$-0.105^{+0.177}_{-0.167}$	$-0.004^{+0.164}_{0.156}$

Result from Dalitz analysis



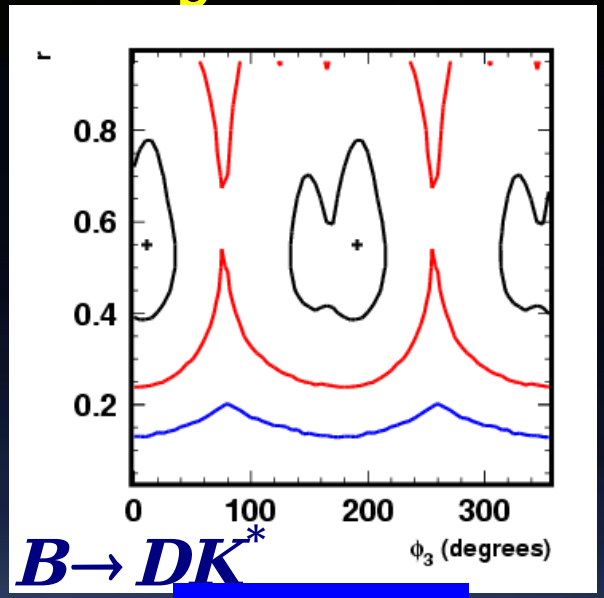
$B \to DK$

$\phi_3 = 66^{0\ +19}_{-20}$



$B \to D^* K$

$\phi_3 = 86^{0\ +37}_{-93}$



$B \to DK^*$

$\phi_3 = 11^{0\ +23}_{-57}$

Combining 3 modes :

$$\phi_3 = 53^{0\ +15}_{-18}(stat.) \pm 3^0(syst.) \pm 9^0(model) \Rightarrow 8^0 < \phi_3 < 111^0 (2\sigma\ interval)$$

$$r_{DK} = 0.159^{+0.054}_{-0.050} \pm 0.012(syst.) \pm 0.049(model)$$

CPV significance is 74%

$$r_{D^*K} = 0.175^{+0.108}_{-0.099} \pm 0.013(stat.) \pm 0.049(model)$$

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

Constraint on r_B

Slide by A. Bondar shown at capri

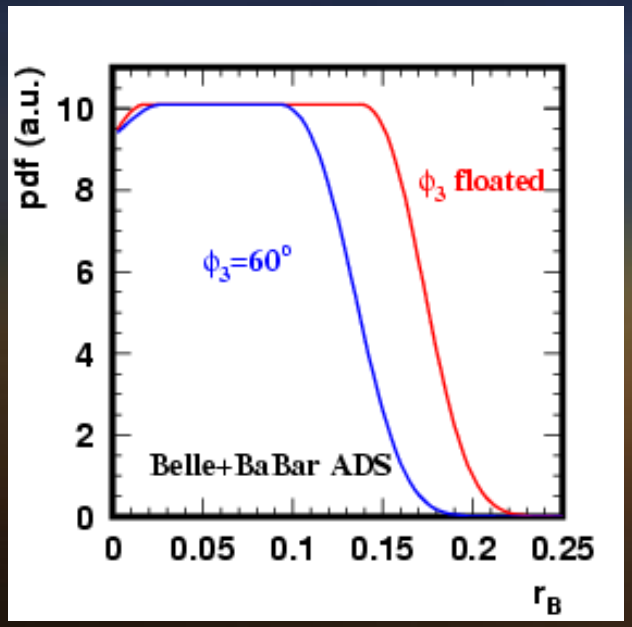
Estimates of r_B value from the combination of Belle and BaBar data

Construct PDF from different measurements using experimental observables:

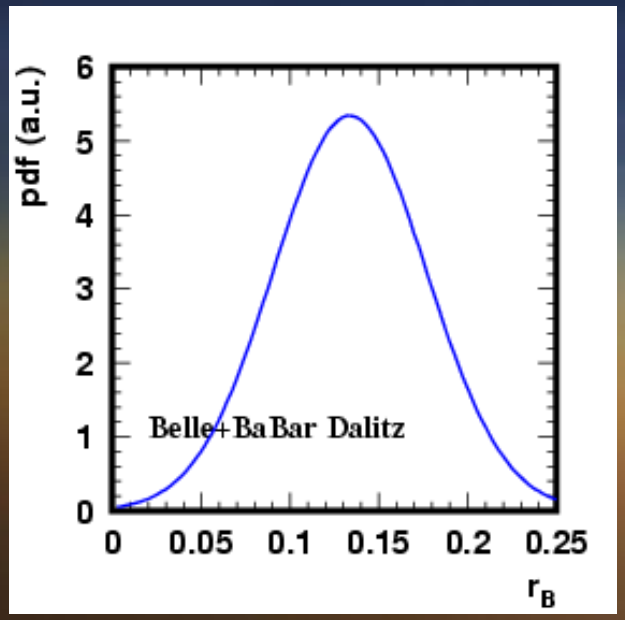
- $A_1 R_1$, $A_2 R_2$ for GLW
- R_{DK} for ADS
- $x_\pm = r\cos(\pm\varphi_3 + \delta)$, $y_\pm = r\sin(\pm\varphi_3 + \delta)$ for Dalitz

take strong phases δ_B and δ_D which maximize PDF

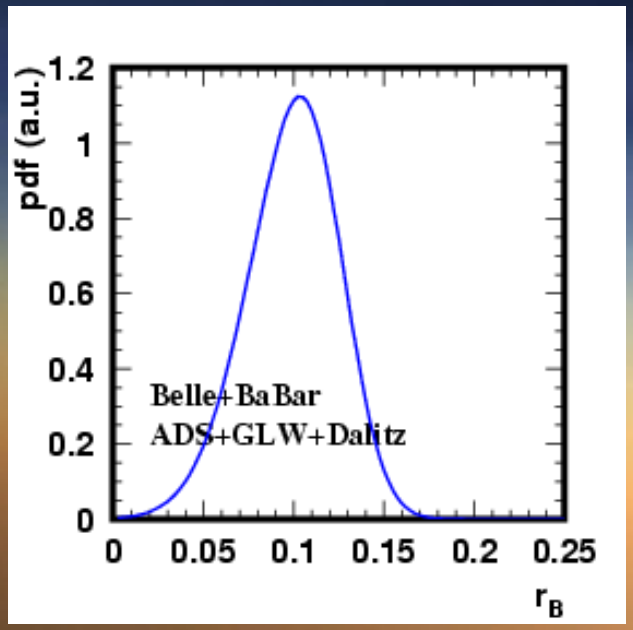
φ_3 either floated or taken from indirect UT fit (φ_3=60°)



r_B<0.18 (90% CL)



r_B=0.13±0.04



r_B= 0.10±0.04

Summary

- $D^*\pi$ system needs more experimental information on R, δ

$$|\sin(2\phi_1+\phi_3)| > 0.44 \text{ at } 68\% \ CL \ for \ D^*\pi$$
$$|\sin(2\phi_1+\phi_3)| > 0.52 \text{ at } 68\% \ CL \ for \ D\pi$$

- GLW method needs more statistics to constrain r_B

- Suppressed modes of DK has not seen yet.

$$r_B < 0.18 @ 90\% \ CL$$
$$0^0 < \phi_3 < 180^0, \ 0.054 < r_D < 0.066$$

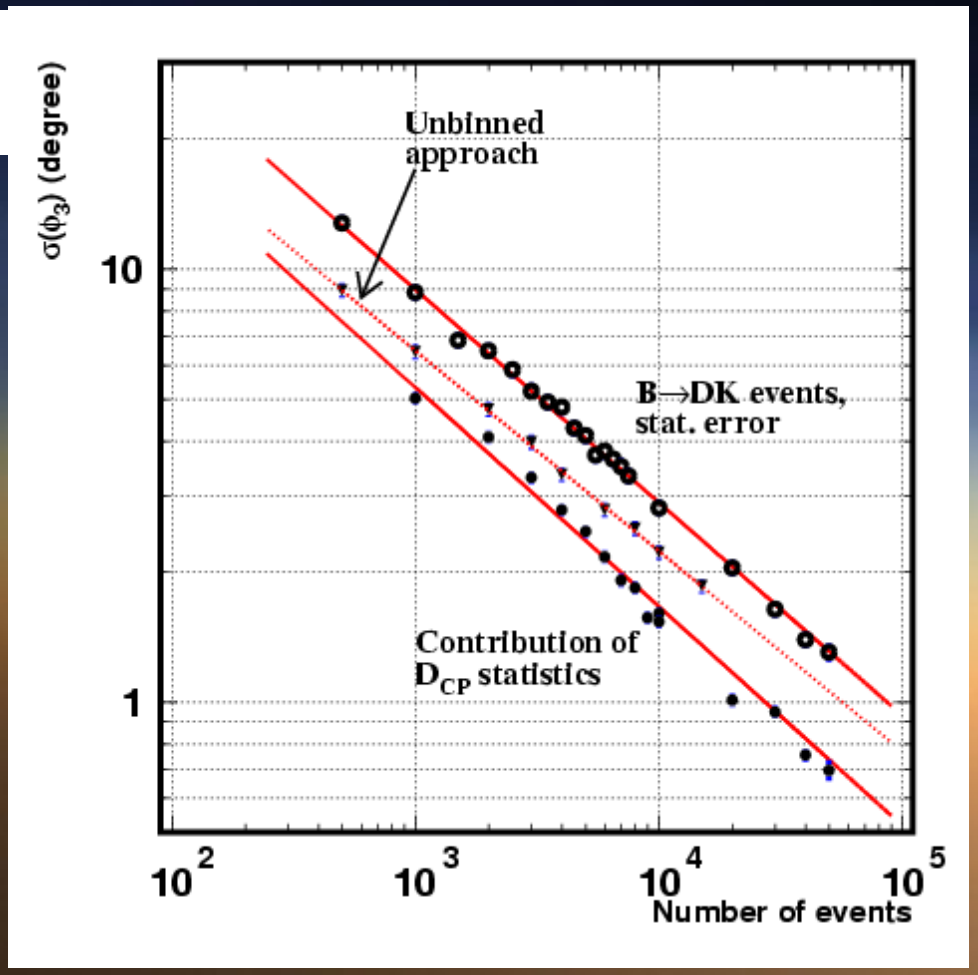
Summary–I

- DK Dalitz analysis is in a good shape.
- Model dependency is the major uncertainty, need to solve
- A model independent approach is best way

A. Bondar, A. Poluektov, hep-ph/0510246

50 ab^{-1} at SuperB factory should be enough for model-independent γ/φ_3 measurement with accuracy below 2° (compared to ~8° with GLW) ~10 fb^{-1} at $\psi(3770)$ needed to accompany this measurement. [BES-III is a good place for this]

$$\phi_3 = 53^{0}_{-18}{}^{+15}(stat.) \pm 3^0(syst.) \pm 9^0(model)$$



BACK UP

Model dependent fit

Intermediate modes	Amplitude	Phase, 0	Fit fraction
$K_S\,\sigma_1$ (M= 520± 15 MeV, Γ= 466± 31 MeV)	1.43±0.07	212±4	9.8%
$K_S\,\rho(770)$	1 (fixed)	0 (fixed)	21.6%
$K_S\,\omega$	0.0314±0.0008	110.8±1.6	0.4%
$K_S\,f_0(980)$	0.365±0.006	201.9±1.9	4.9%
$K_S\,\sigma_2$ (M= 1059± 6 MeV, Γ= 59± 10 MeV)	0.23±0.02	237±11	0.6%
$K_S\,f_2(1270)$	1.32±0.04	348±2	1.5%
$K_S\,f_0(1370)$	1.44±0.10	82±6	1.1%
$K_S\,\rho(1450)$	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%