Measurements of ϕ_3 at SuperKEKB

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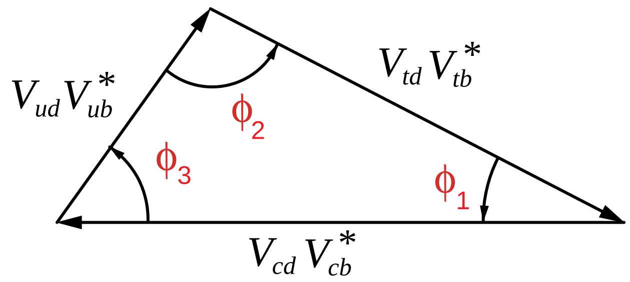
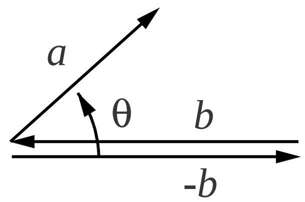
SuperKEKB workshop. KEK, Jan 29, 2002.

1. Definition of ϕ_3.
2. Mixing-decay inteference: $D^{(*)+}\pi^-$
3. $\quad + $ angles: $D^{*+}\rho^-$ mode
4. Direct CPV in $D^{(*)}K^{(*)}$
5. $K\pi, \pi\pi$ modes

V_{CKM} **is unitary: e.g. orthogonality of d- and b-column:**

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





$$\theta = \arg\frac{a}{-b}$$

$$\phi_1 \equiv \arg\left(\frac{V_{cd}V_{cb}^*}{-V_{td}V_{tb}^*}\right),\ \phi_2 \equiv \arg\left(\frac{V_{td}V_{tb}^*}{-V_{ud}V_{ub}^*}\right),\ \phi_3 \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{-V_{cd}V_{cb}^*}\right)$$

$\phi_1 + \phi_2 + \phi_3 = \pi \quad (\mathrm{mod} 2\pi)$ **regardless of unitarity**

In general models, there are 5 phase differences for 6 quarks
$\longrightarrow$ 5 elements of V can be set to real always.

For example ('our phase convention')

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

$V_{i,j}$: real
$V_{i,j}$: complex

In SM (in our phase convention), V_{cs}, V_{tb} ~real :

$$V \sim \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \quad \text{(Wolfenstein)}$$

$(A, \rho, \eta, \lambda : \text{real.} \quad \lambda \sim 0.22)$

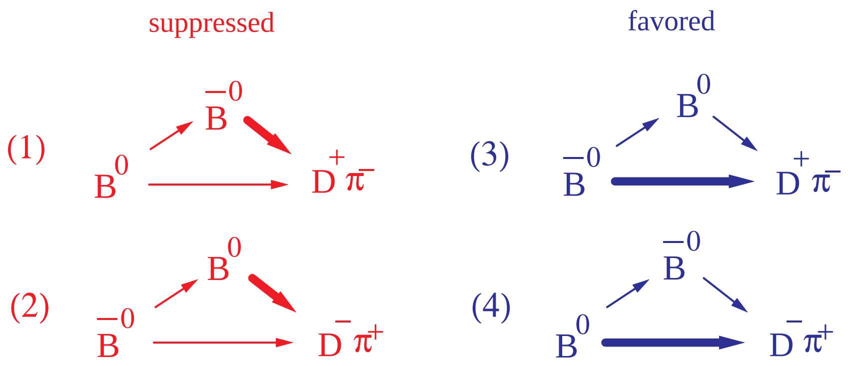
Noting that $V_{cd} \sim -\lambda < 0$,

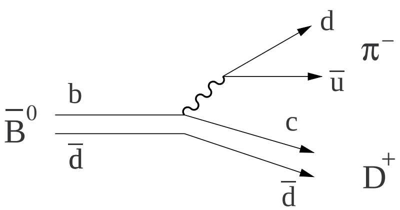
$\phi_3 = \arg V_{ub}^*$ in our phase convention.

$B \to D^{(*)+}\pi^-$

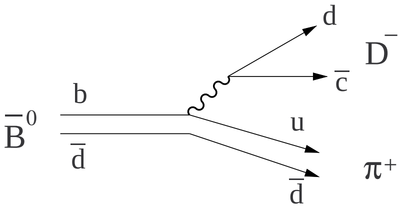
Mixing $\longrightarrow$ non-CP final state

Sachs (1985), Dunietz, Rosner PRD34 (1986) 1404.





$\bar{a} : V_{cb}V_{ud}^*$



$\bar{b} : V_{ub}V_{cd}^*$

$$r \equiv \left|\frac{\bar{b}}{\bar{a}}\right| \sim \left|\frac{V_{ub}V_{cd}^*}{V_{cb}V_{ud}^*}\right| \sim 0.4\lambda^2 \sim 0.02$$

Strong phase differenc $\equiv \delta$

General time-dependent decay amplitudes (Flavor-specific final states)

Assume $\gamma_a = \gamma_b$ ($B_{a,b}$: mass eigenstates)

$$A_{B^0\to f}(t) = e^{-\frac{\gamma}{2}t}a\left(\cos\frac{\delta m\, t}{2} - \rho\, i\sin\frac{\delta m\, t}{2}\right) \quad \text{('favored')}$$

$$A_{\bar{B}^0\to \bar{f}}(t) = e^{-\frac{\gamma}{2}t}\bar{a}\left(\cos\frac{\delta m\, t}{2} - \bar{\rho}\, i\sin\frac{\delta m\, t}{2}\right) \quad \text{('favored')}$$

$$A_{B^0\to \bar{f}}(t) = e^{-\frac{\gamma}{2}t}\bar{a}\left(\bar{\rho}\cos\frac{\delta m\, t}{2} - i\sin\frac{\delta m\, t}{2}\right) \quad \text{('suppressed')}$$

$$A_{\bar{B}^0\to f}(t) = e^{-\frac{\gamma}{2}t}a\left(\rho\cos\frac{\delta m\, t}{2} - i\sin\frac{\delta m\, t}{2}\right) \quad \text{('suppressed')}$$

$$\rho \equiv \frac{q\,\bar{b}}{p\,a}, \qquad \bar{\rho} \equiv \frac{p\,b}{q\,\bar{a}}, \qquad \begin{array}{r} a \equiv Amp(B^0 \to f) \\ \bar{a} \equiv Amp(\bar{B}^0 \to \bar{f}) \\ b \equiv Amp(B^0 \to \bar{f}) \\ \bar{b} \equiv Amp(\bar{B}^0 \to f) \end{array},$$

$D^{(*)}\pi$ flavor-tagged decay time difference analysis

Assume $|p/q| = 1$.

$$\bar{\rho} = r e^{i(2\phi_1+\phi_3+\delta)}\,, \qquad \rho = r e^{-i(2\phi_1+\phi_3-\delta)}\,.$$

(In unit of $|A(B^0 \to D^-\pi^+)A(B^0 \to \ell^+)|^2$)

$$(1)\ \Gamma(D^+\pi^-, \ell^-) = \frac{e^{-\gamma_+|t_-|}}{4\gamma_+}\Big[(1+r^2) - (1-r^2)\mathrm{c}_{\delta m t_-} - 2r\,\xi\,\mathrm{s}_{\delta m t_-}\Big]$$

$$(2)\ \Gamma(D^-\pi^+, \ell^+) = \frac{e^{-\gamma_+|t_-|}}{4\gamma_+}\Big[(1+r^2) - (1-r^2)\mathrm{c}_{\delta m t_-} + 2r\,\xi'\,\mathrm{s}_{\delta m t_-}\Big]$$

$$(3)\ \Gamma(D^+\pi^-, \ell^+) = \frac{e^{-\gamma_+|t_-|}}{4\gamma_+}\Big[(1+r^2) + (1-r^2)\mathrm{c}_{\delta m t_-} + 2r\,\xi\,\mathrm{s}_{\delta m t_-}\Big]$$

$$(4)\ \Gamma(D^-\pi^+, \ell^-) = \frac{e^{-\gamma_+|t_-|}}{4\gamma_+}\Big[(1+r^2) + (1-r^2)\mathrm{c}_{\delta m t_-} - 2r\,\xi'\,\mathrm{s}_{\delta m t_-}\Big]$$

$$(c_x \equiv \cos x\,, \qquad s_x \equiv \sin x)$$

$$t_- \equiv t_{\mathrm{sig}} - t_{\mathrm{tag}}, \qquad r \sim 0.02$$

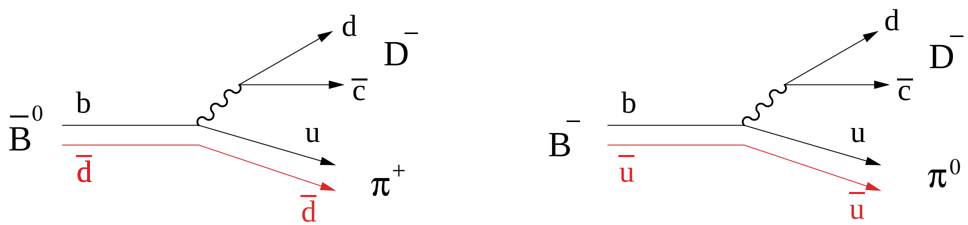
$$\xi \equiv \sin(2\phi_1+\phi_3+\delta)\,, \qquad \xi' \equiv \sin(2\phi_1+\phi_3-\delta)$$

r^2 is very small. $\longrightarrow$ two obtainable parameters:
asymmetries between positive and negative t_- give
(an advantage of a e^+e^- B-factories)

$$r\xi = r\sin(2\phi_1 + \phi_3 + \delta)\,, \quad \text{and} \quad r\xi' = r\sin(2\phi_1 + \phi_3 - \delta)\,.$$

r cannot be obtained by the fit.
Needs to come from theory or separate measurement.

An experimental possibility to measure r (Rosner)



$$\Gamma(\bar{B}^0 \to D^-\pi^+) = \underbrace{2}_{isospin}\,\Gamma(B^- \to D^-\pi^0)$$

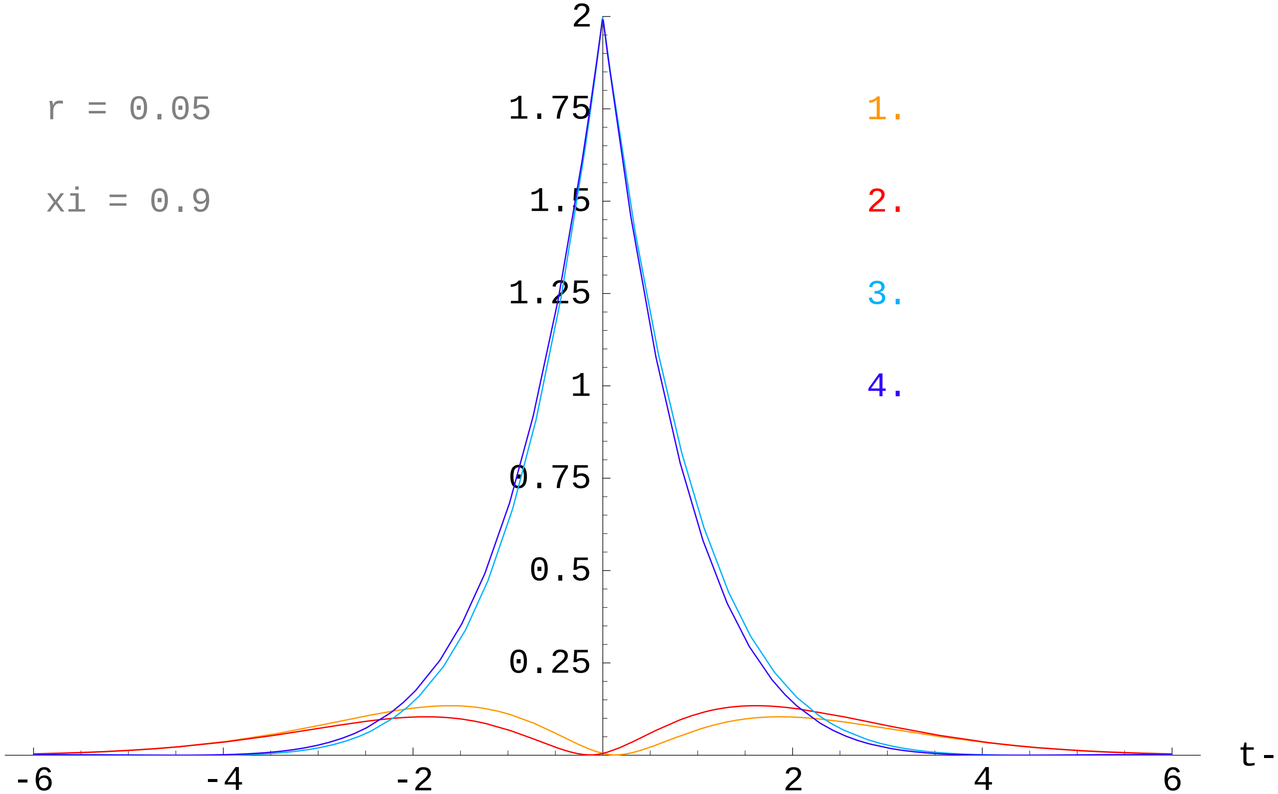
$$Br(B^- \to D^-\pi^0) = \frac{1}{2}Br(\bar{B}^0 \to D^+\pi^-)r^2 \sim 6\times 10^{-7}$$

At 300 (3000) fb^{-1}: $\#(B^- \to D^-\pi^0) = 6\times 10^{-7}\cdot 3\times 10^8 \cdot \underbrace{0.05}_{det.eff.} = 9\;(90)$

Requires SuperKEKB.

t_- distributions (unit $= \tau_B$)

($\delta = 0$ for simplicity)



Asymmetry in the suppressed modes (1) $\leftrightarrow$ (2)

Smaller asymmetry in the favored modes (3) $\leftrightarrow$ (4)

Asymmetry in the suppressed ('mixed') modes:
$(r = 0.02,\ x = \delta m/\gamma = 0.71)$

$$A_s \equiv \frac{(1) - (2)}{(1) + (2)} \sim -\frac{2r}{x}\,\xi \sim -0.057\,\xi$$

Asymmetry in the favored ('unmixed') modes:

$$A_f \equiv \frac{(3) - (4)}{(3) + (4)} \sim \frac{2rx}{2 + x^2}\,\xi \sim 0.011\,\xi$$

The favored modes has 5 times stat, but 5 times less asym.
$\rightarrow \sqrt{5}$ **times less in** $\#\sigma$.

Most of the info is in the suppressed modes.

Crude statistics estimates for $D^{(*)}\pi$

$$\sigma_\xi = 0.1 \longrightarrow \sigma_{A_s} = 0.0057 \longrightarrow N_s = 30K$$

(of the suppressed modes)

We need $6 \times 30K = 180K$ total tagged $D\pi$'s for $\sigma_\xi = 0.1$

Belle preliminary:
3.7 fb^{-1} $\longrightarrow 282 \pm 25$ lepton-tagged $D^*\pi$'s
(partial reconstruction)

No-bkg equivalent: $\left(\frac{282}{25}\right)^2 \sim 127$

300 (3000) fb^{-1} $\longrightarrow 10K(100K)$
to be compared with 180K needed for $\sigma_\xi = 0.1$.

- Need to improve background.
- Need to improve tagging efficiency.
- Fitting Δt improves stat. power ($\times 2$?)
- Add various modes (exclusive and partial).

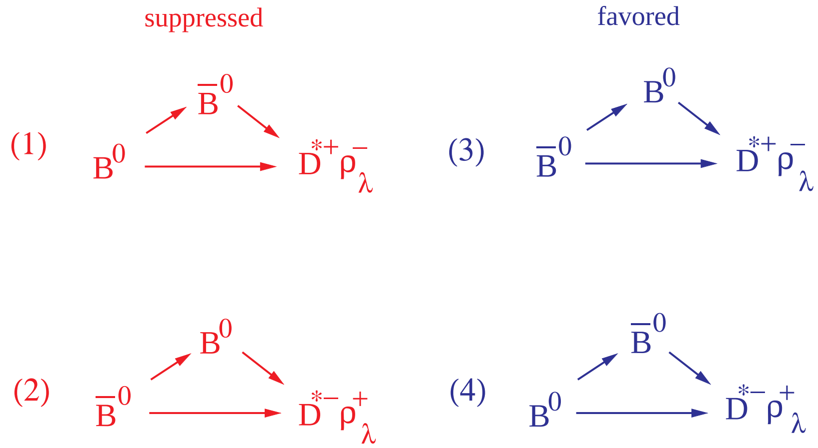
$$\sigma_{\sin(2\phi_1+\phi_3)} \sim (4 \text{ to } 5) \times \sigma_{\sin 2\phi_1}$$

$B \to D^{*+}\rho^-$

Mixing $\to$ non-CP eigenstate + angular correlation

London, Sinha, Sinha, hep-ph/0005248.

Similar to $B \to D\pi$ (needs to be flavor-tagged): (Measures $2\phi_1 + \phi_3$)



Repeats for each helicity final state.

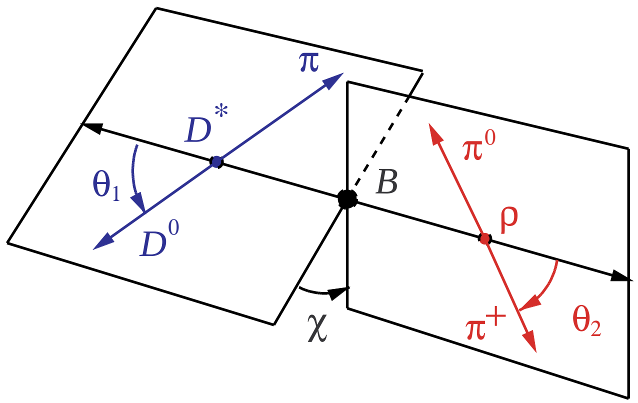
$$\lambda = \begin{cases} +, -, 0 \text{ (helicity basis)}, & \text{or} \\ ||, \perp, 0 \text{ (tranversity basis)} \end{cases}$$

|Amplitude ratio| $r \sim 0.02$

$\to$ asymmetry in each $\lambda \sim 0.02$

Angular correlation in $B \to D^* \rho$

(helicity basis)



$$\frac{d^3\Gamma}{dc_{\theta_1} dc_{\theta_2} d\chi} = |\sum_{\lambda} H_\lambda \, g_\lambda(\Omega)|^2$$

$H_{\pm,0}$: time-dependent helicity amplitudes
$(\Omega = (\chi, \theta_1, \theta_2))$.

$$g_{+1} = \frac{1}{2} e^{i\chi} \sin\theta_1 \sin\theta_2 \,, \quad g_0 = \cos\theta_1 \cos\theta_2 \,, \quad g_{-1} = \frac{1}{2} e^{-i\chi} \sin\theta_1 \sin\theta_2$$

New ingredients in $D^*\rho$:

Interference between different polarization states.
Time dependent decay amplitude to $\Omega = (\chi, \theta, \psi)$:

$$A_{B^0\to f}(\Omega,t) = \sum_\lambda e^{-\frac{\gamma}{2}t}\, a_\lambda \left(\cos\frac{\delta m\, t}{2} - \rho_\lambda\, i \sin\frac{\delta m\, t}{2}\right) g_\lambda(\Omega)$$

$$A_{\bar{B}^0\to \bar{f}}(\Omega,t) = \sum_\lambda e^{-\frac{\gamma}{2}t}\, \bar{a}_\lambda \left(\cos\frac{\delta m\, t}{2} - \bar{\rho}_\lambda\, i \sin\frac{\delta m\, t}{2}\right) g_\lambda(\Omega)$$

$$A_{B^0\to \bar{f}}(\Omega,t) = \sum_\lambda e^{-\frac{\gamma}{2}t}\, \bar{a}_\lambda \left(\bar{\rho}_\lambda \cos\frac{\delta m\, t}{2} - i \sin\frac{\delta m\, t}{2}\right) g_\lambda(\Omega)$$

$$A_{\bar{B}^0\to f}(\Omega,t) = \sum_\lambda e^{-\frac{\gamma}{2}t}\, a_\lambda \left(\rho_\lambda \cos\frac{\delta m\, t}{2} - i \sin\frac{\delta m\, t}{2}\right) g_\lambda(\Omega)\,,$$

$$\rho_\lambda = r_\lambda e^{i(2\phi_1+\phi_3+\delta_\lambda)}\,, \qquad \bar{\rho}_{-\lambda} = r_\lambda e^{-i(2\phi_1+\phi_3-\delta_\lambda)}\,, \qquad (\lambda = \pm 1, 0)$$

ρ_λ,$\bar{\rho}_\lambda$: defined as before for each helicity state λ.
(also use CP relations between B and $\bar{B}$)

Statistics for $D^*\rho$

CLEO: 6 fb^{-1} $\to 197 \pm 15$ ($K\pi$ mode) signal events.
$\sim \times 2$ including $K\pi\pi^0$, $K3\pi$.

300 fb^{-1} $\to$ 20K events. With the high-p_t lepton tag efficiency of 12%, we have 2.4K tagged $D^*\rho$.

This is compared with 10K (bkg-free equivalent for 300 fb^{-1}) of $D^*\pi$ partial reconstruction analysis. Or compared with 180K needed for $\sigma_\xi = 0.1$.

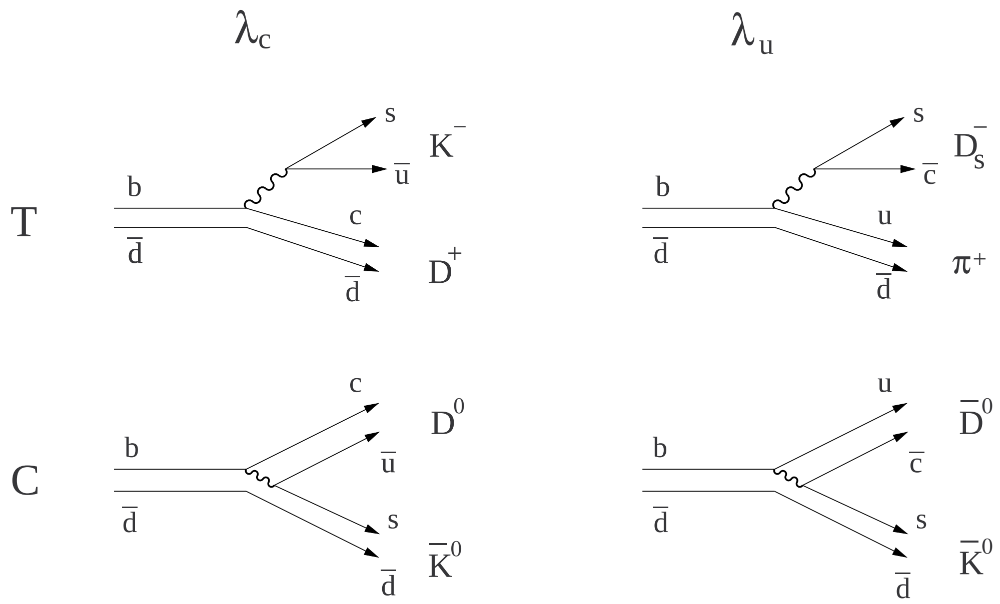
$\to$ Number of events is $\sim \frac{1}{4}$ of $D^*\pi$,
but more paramters to measure.

Comments:

- Partical reconstruction cannot be used.
  This may not be too big a problem since partial reconstruction efficiency is not that good.
- Need to tackle with the systematics of non-resonant component of ρ.
- Also check the sys. of ρ mass dependence of amplitudes.
- Definitely a SuperKEKB mode.

Direct CPV in $D^{(*)}K^{(*)}$

Classification of $\bar{B}^0 \to DK$

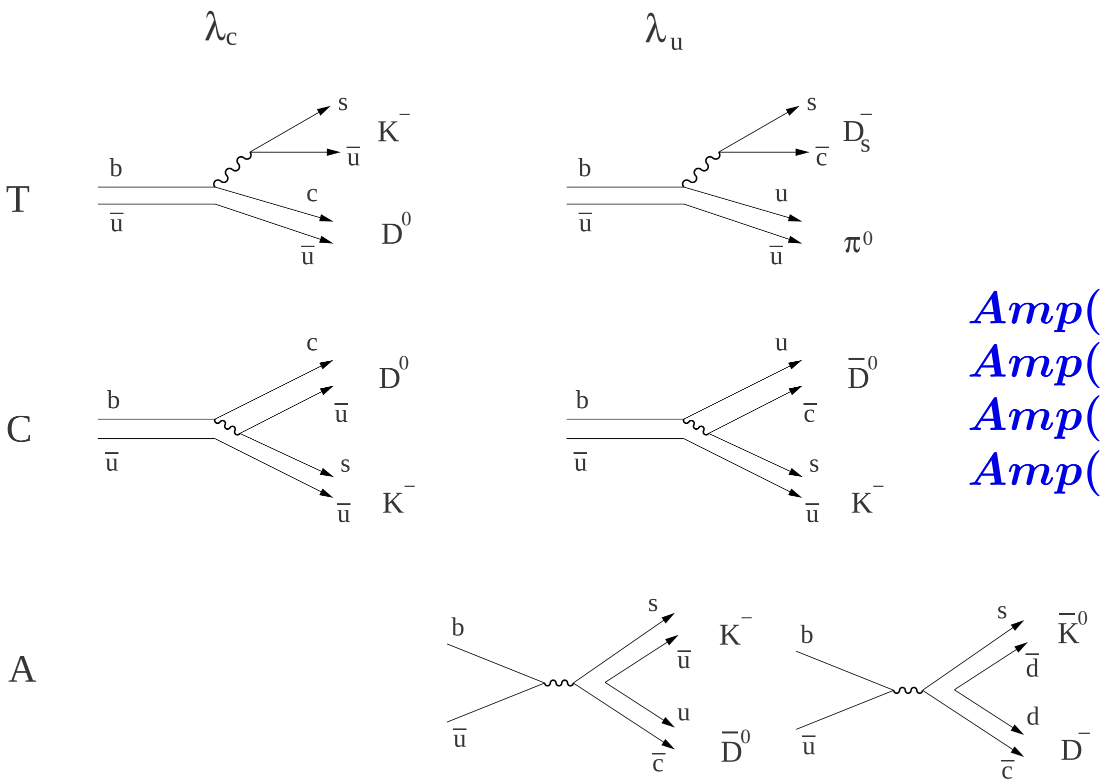


$$Amp(\bar{B}^0 \to D^+K^-) = \lambda_c T_c$$
$$Amp(\bar{B}^0 \to D^0\bar{K}^0) = \lambda_c C_c$$
$$Amp(\bar{B}^0 \to \bar{D}^0\bar{K}^0) = \lambda_u C_u$$
$$Amp(\bar{B}^0 \to D_s^-\pi^+) = \lambda_u T_u$$

T: tree, C: color-suppressed
(T, C: depends on $b \to c$ or $b \to u$)

$$\lambda_c = V_{cb}V_{cs}^*\,, \qquad \lambda_u = V_{ub}V_{us}^*\,.$$

Classification of $B^- \to DK$

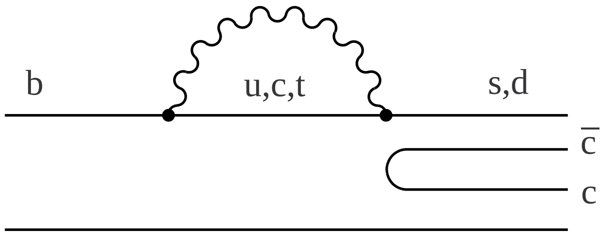


$$Amp(B^- \to D^0 K^-) = \lambda_c T_c + \lambda_c C_c$$
$$Amp(B^- \to \bar{D}^0 K^-) = \lambda_u C_u + \lambda_u A$$
$$Amp(B^- \to D^- \bar{K}^0) = \lambda_u A$$
$$Amp(B^- \to D_s^- \pi^0) = \frac{1}{\sqrt{2}} \lambda_u T_u$$

$B \to DK$ Modes

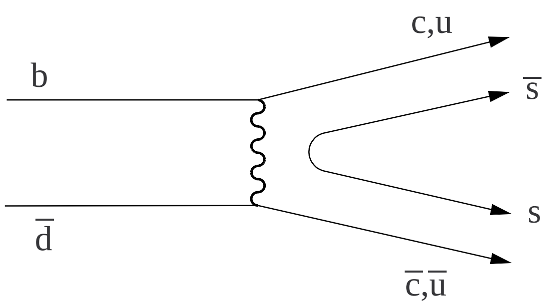
Final state: one charm, one strange.

- **No penguine contaminations**



Penguine should have even number of charms.
(True for charged and neutral B)

- **Neutral B has no annihilations**



Annihilations should have even number of stranges.

- **All tree diagrams (no complications by loops)**

Final-state Rescatterings

Final-state rescattering can occur:

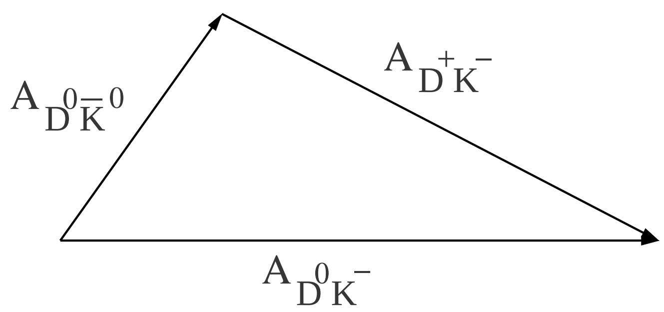
$$\bar{B}^0 \longrightarrow D^+K^-(T_c) \longrightarrow D^0\bar{K}^0(C_c)$$
$$\bar{B}^0 \longrightarrow D_s^-\pi^+(T_u) \longrightarrow \bar{D}^0\bar{K}^0(C_u)$$

We define T_c, C_c, T_u, C_u including rescattering effects.

Then,

$$\begin{aligned} Amp(B^- \longrightarrow D^0K^-) &= \lambda_c T_c + \lambda_c C_c \\ &= Amp(\bar{B}^0 \longrightarrow D^+K^-) + Amp(\bar{B}^0 \longrightarrow D^0\bar{K}^0) \end{aligned}$$

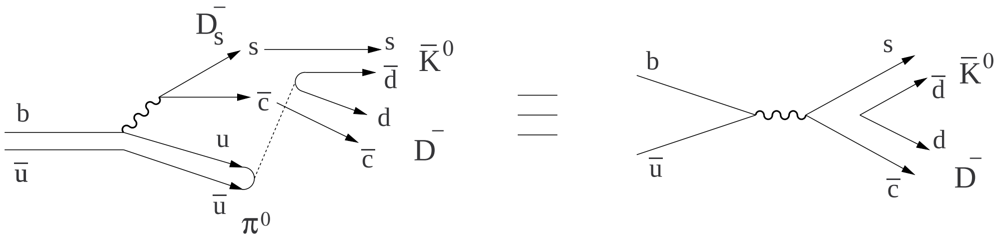
is still true, which is nothing but the isospin relation
for $H_{\rm eff}$ having $|1/2,-1/2\rangle$ structure:
(good to all orders as long as $m_u = m_d$)



Final-state Rescatterings - annihilation

Final-state $D^-\bar{K}^0$ can be reached by

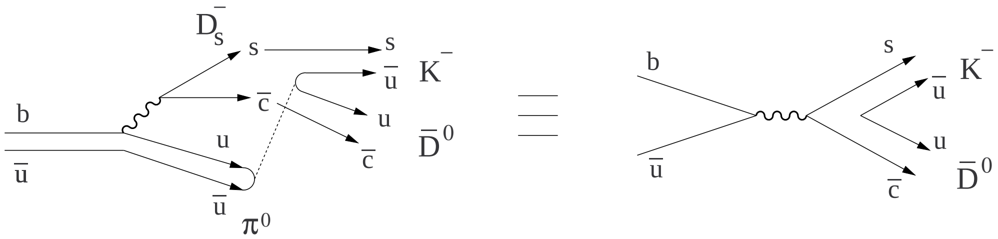
$$B^- \longrightarrow D_s^-\pi^0 \longrightarrow D^-\bar{K}^0$$



We thus define A including the rescattering effect:

$$Amp(B^- \longrightarrow D^-\bar{K}^0) = \lambda_u A$$

$\lambda_u A$ in $B^- \longrightarrow \bar{D}^0 K^-$ has exactly the same rescattering contribution:



$\longrightarrow$ No modification needed for the classification expressions.

Gronau-London-Wyler (GLW) method

$$a \equiv A(B^- \to D^0 K^-) = \lambda_c (T_c + C_c)$$
$$b \equiv A(B^- \to \bar{D}^0 K^-) = \lambda_u (C_u + A)$$

Detect D^0 in CP eigenstates:

D^0_{CP} : CP **eigenstate. e.g.** $K_S \pi^0, K^+ K^- \cdots$

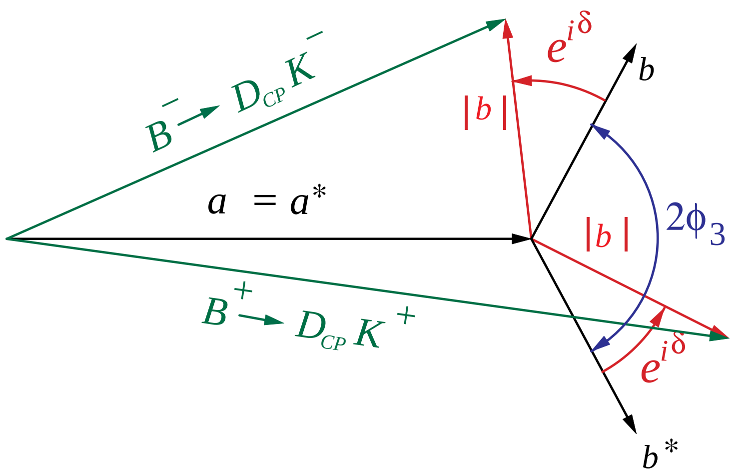
Separate out the strong final-state-interaction phase:
b **relative to** a : $e^{i\delta}$

$$D_{1,2} = \frac{1}{\sqrt{2}} (D^0 \pm \bar{D}^0) \quad (CP\pm),$$

$$A(B^- \to D_{1,2} K^-) = \frac{1}{\sqrt{2}} (a \pm b\, e^{i\delta})$$

$$A(B^+ \to D_{1,2} K^+) = \frac{1}{\sqrt{2}} (a^* \pm b^* e^{i\delta})$$

For $D_{CP} = D_1$ (w/ phase convention: $a = a^*$)



$$\left(\arg \frac{b}{a} = \arg \frac{\lambda_u}{\lambda_c} = \arg \frac{V_{ub} V_{cs}^*}{V_{cb} V_{us}^*} = -\phi_3 \right)$$

$\Gamma(B^- \to D_1 K^-) \neq \Gamma(B^+ \to D_1 K^+)$: direct CPV

Measure $|a|$, $|b|$, $A(B^- \to D_1 K^-)$, and $A(B^+ \to D_1 K^+)$.
Reconstruct the two triangles $\to \phi_3$.

CP asymmetry expected:

$$A_{cp} \equiv \frac{\Gamma[B^- \to D^0_{CP} K^-] - \Gamma[B^+ \to D^0_{CP} K^+]}{\Gamma[B^- \to D^0_{CP} K^-] + \Gamma[B^+ \to D^0_{CP} K^+]}$$

$$\frac{|b|}{|a|} \sim \underbrace{(\text{color factor})}_{\frac{C_u}{T_c + C_c} \sim 0.2} \underbrace{(\text{CKM factor})}_{\frac{\lambda_u}{\lambda_c} \sim 0.4} \sim 0.08$$

$\rightarrow$ A_{cp} is of order 10%.

Relevant D^0 decay modes:

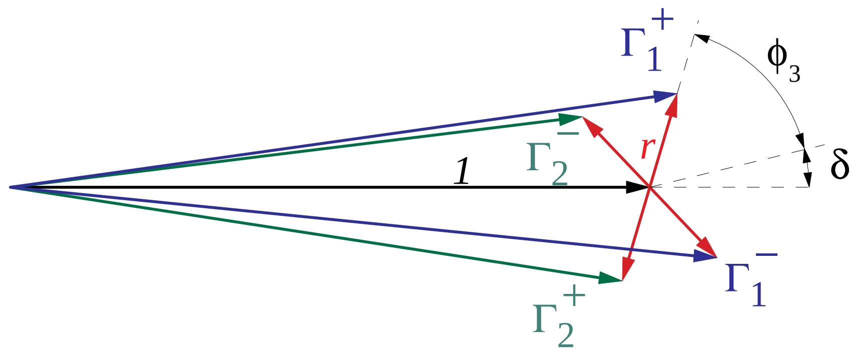
CP eigenstates	$K_S\,\pi^0$	$1.06 \pm 0.11\%$	$CP-$
	$K_S\,\rho^0$	$0.60 \pm 0.09\%$	$CP-$
	$K_S\,\phi$	$0.84 \pm 0.10\%$	$CP-$
	K^+K^-	$0.43 \pm 0.03\%$	$CP+$
	$\pi^+\pi^-$	$0.15 \pm 0.01\%$	$CP+$
calibration	$K^-\pi^+$	$3.83 \pm 0.12\%$	

r~ 0.08: if known from external input (experiment, theory):

Measure

$$\Gamma_1^- \equiv \Gamma(B^- \to D_1 K^-) = 1 + r^2 + 2r\cos(\phi_3 - \delta)$$
$$\Gamma_2^- \equiv \Gamma(B^- \to D_2 K^-) = 1 + r^2 - 2r\cos(\phi_3 - \delta)$$
$$\Gamma_1^+ \equiv \Gamma(B^+ \to D_1 K^+) = 1 + r^2 + 2r\cos(\phi_3 + \delta)$$
$$\Gamma_2^+ \equiv \Gamma(B^+ \to D_2 K^+) = 1 + r^2 - 2r\cos(\phi_3 + \delta)$$

in unit of $\Gamma(B^- \to D^0 K^-)$.



FSI phase of D^0 decay does not matter.

Ambiguity: the equations are symmetric under

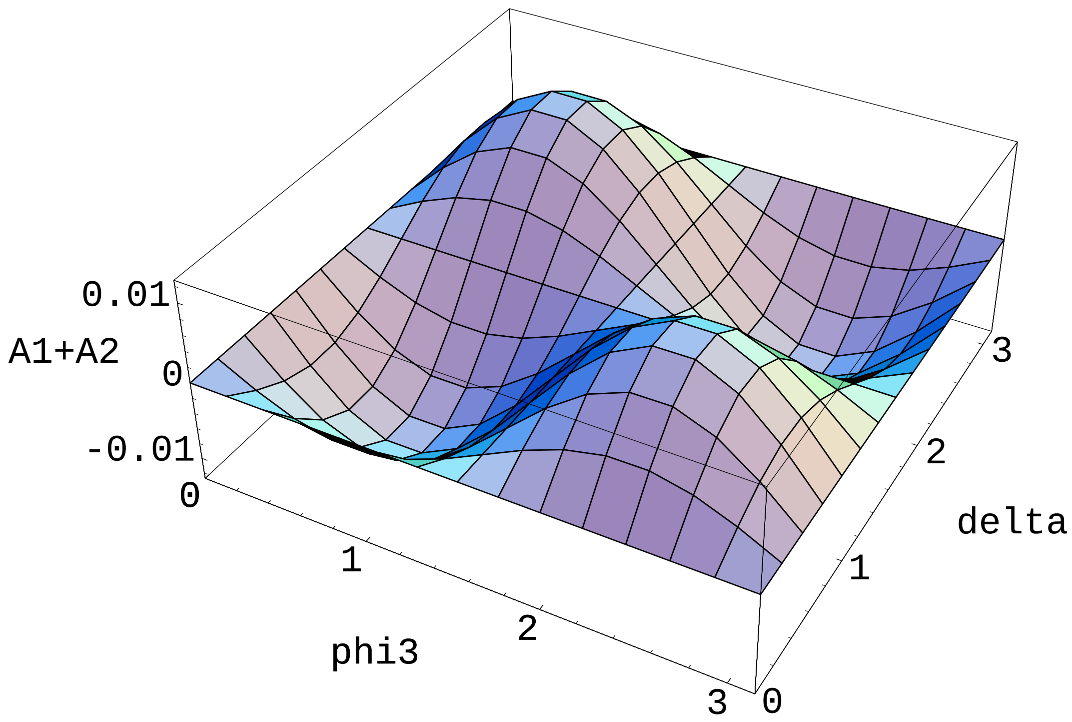
$$\begin{cases} \phi_3 \longrightarrow & n\pi + \delta \\ \delta \longrightarrow & -n\pi + \gamma \end{cases} \text{or} \begin{cases} \phi_3 \longrightarrow n\pi - \delta \\ \delta \longrightarrow n\pi - \phi_3 \end{cases} \qquad (n : \text{integer})$$

A_{cp} : $CP+$ vs $CP-$

$$A_1 \equiv \frac{\Gamma_1^- - \Gamma_1^+}{\Gamma_1^- + \Gamma_1^+} = \frac{2r \sin\delta \sin\phi_3}{1 + r^2 + 2r\cos\delta\cos\phi_3},$$
$$A_2 \equiv \frac{\Gamma_2^- - \Gamma_2^+}{\Gamma_2^- + \Gamma_2^+} = -\frac{2r \sin\delta \sin\phi_3}{1 + r^2 - 2r\cos\delta\cos\phi_3}$$

$A_1 \sim -A_2$ to order r of iteself

For $r = 0.08$, $A_1 = -A_2$ within ± 0.01.



We also note:

$$\frac{A_1 - A_2}{2} \text{ (average of } A_1 \text{ and } -A_2) = 2r \sin\delta \sin\phi_3$$

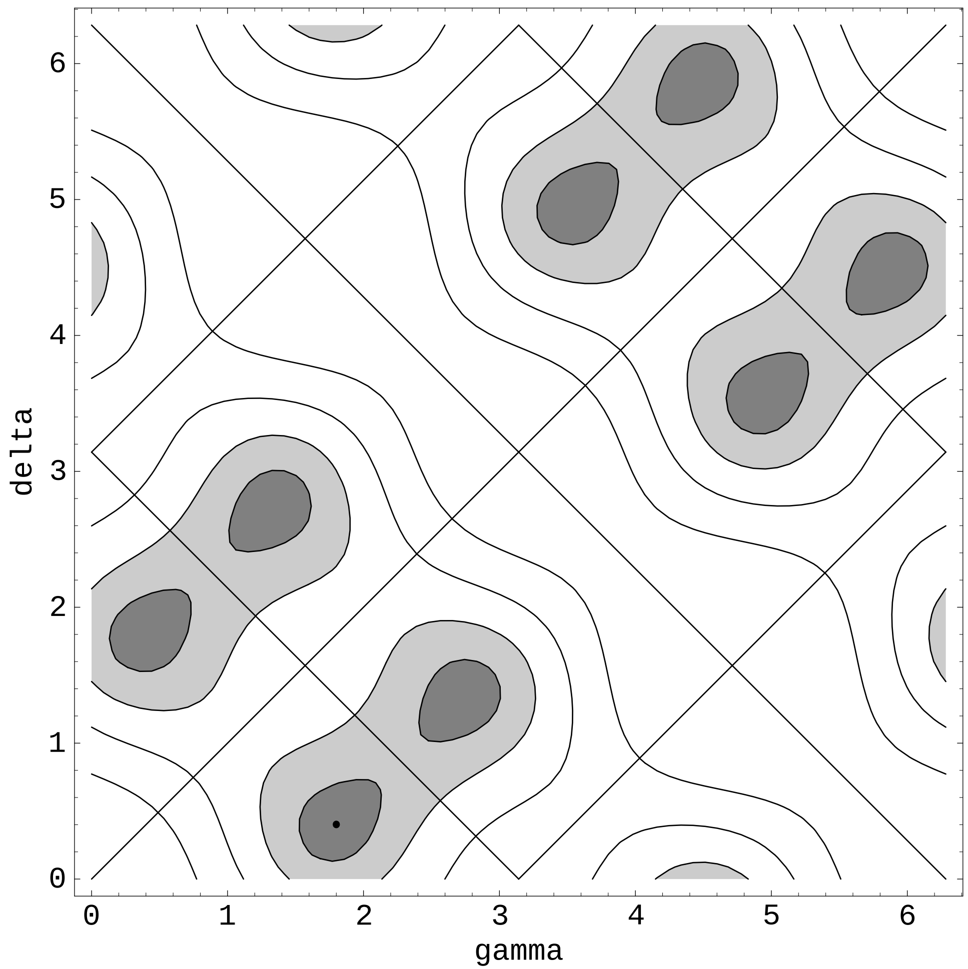
to order r^2 of itself.

Fit result for ϕ_3 and δ (300 fb^{-1})
Assuming that r is known.

$Inputs:$
$\phi_3 = 1.8\,,\delta = 0.4$
$\sigma(\Gamma' s) = 10\%$
(100 events each)

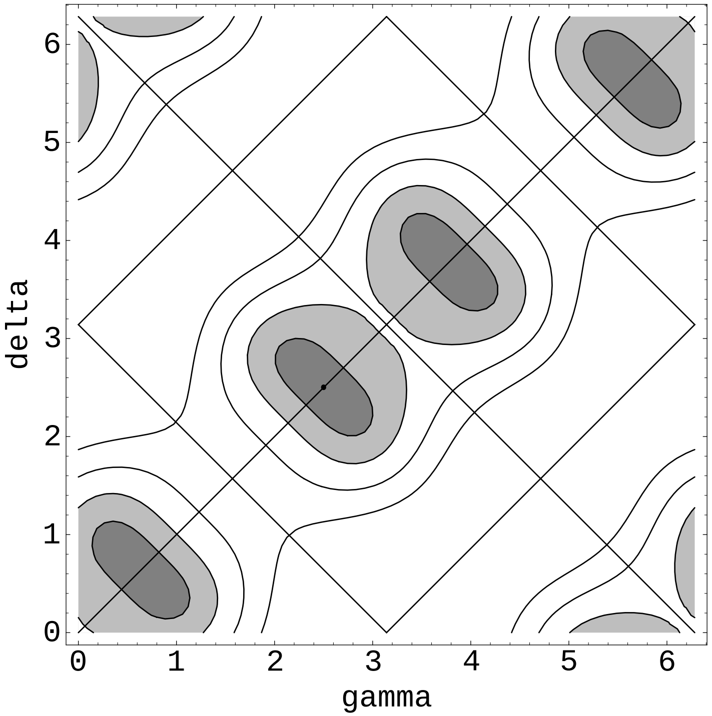
8-fold ambiguity

$\sigma_{\phi_3} \sim 0.3$
(~ 0.1 for 3000fb^{-1})

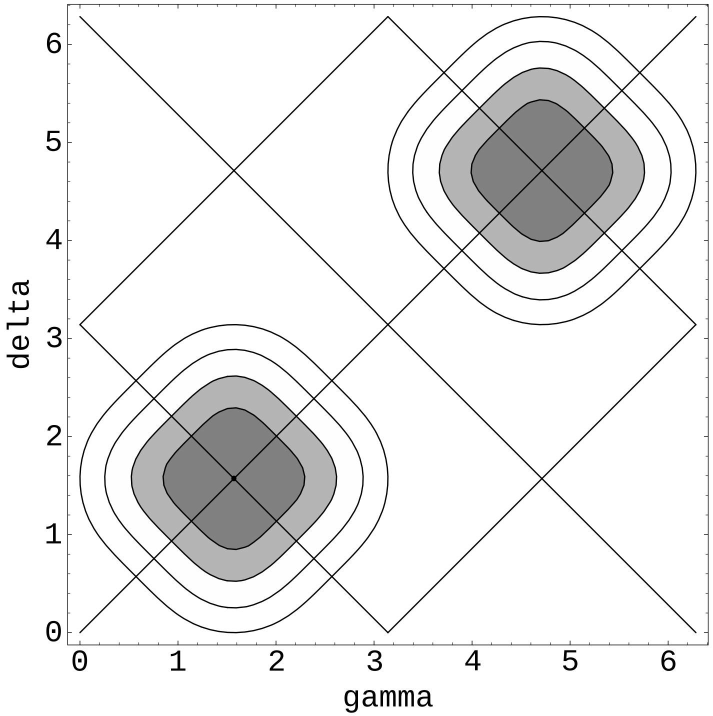


Fit result for ϕ_3 and δ

$\phi_3 = 2.5\,, \delta = 2.5$



$\phi_3 = 1.57\,, \delta = 1.57$



Problem:

How to measure $B = Amp(B^- \to \bar{D}^0 K^-)$?

$$B^- \xrightarrow{b} \bar{D}^0 K^- \hookrightarrow K^+\pi^- \quad \textbf{but also} \quad B^- \xrightarrow{a} D^0 K^- \hookrightarrow K^+\pi^- \ (DCSD)$$

The ratio of the two amplitudes ($\equiv r_{DCSD}$):

$$r_{DCSD} = \underbrace{\frac{a}{b}}_{\sim \frac{1}{0.08}} \underbrace{\frac{Amp(D^0 \to K^+\pi^-)}{Amp(D^0 \to K^-\pi^+)}}_{0.088 \pm 0.020} \sim 1$$

(CLEO 94)

Phase of r_{DCSD} not known $\to$ difficult to measure $|b|$.
(Difficult to detect $D^0 \to X_s^- \ell^+ \bar{\nu}$)

The interference of DCSD and B-amplitude causes CP asymmetry of order unity in the wrong-sign $K\pi$ modes:

ADS method to extract ϕ_3

Measure $B^- \to DK^-$ in two decay modes of D:
wrong-sign flavor-specific modes or CP eigenstates,
say $K^+\pi^-$ and $K_S\,\pi^0$ (and their conjugate modes).

$$\Gamma[B^- \to (K^+\pi^-)K^-] \quad \Gamma[B^+ \to (K^-\pi^+)K^+]$$
$$\Gamma[B^- \to (K_S\,\pi^0)K^-] \quad \Gamma[B^+ \to (K_S\,\pi^0)K^+]$$

Assume we know $|A|$ and D branching fractions
$\longrightarrow$ 4 unknowns:

$$\phi_3\,, \quad \delta_{K^-\pi^+}\,, \quad \delta_{K_S\pi^0}\,, \quad r = \frac{|b|}{|a|}$$

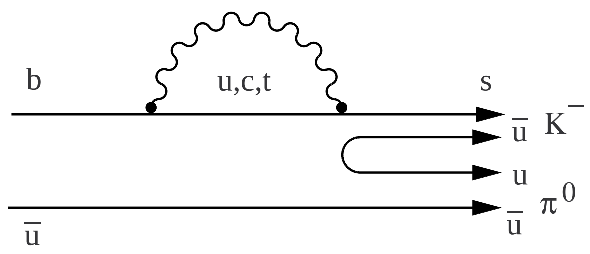
$\longrightarrow$ can be solved.

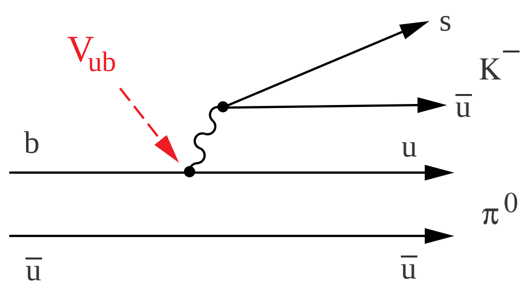
Statistics:
(Atwood: 300 fb^{-1} $\longrightarrow \sigma_{\phi_3} \sim 0.3$ rad.
To be confirmed (probably it is too optimistic).)

Using $B \to K\pi, \pi\pi$

Tree-penguin interference
$\to$ large direct CP asymmetries expected.

For example: $B^- \to K^-\pi^0$

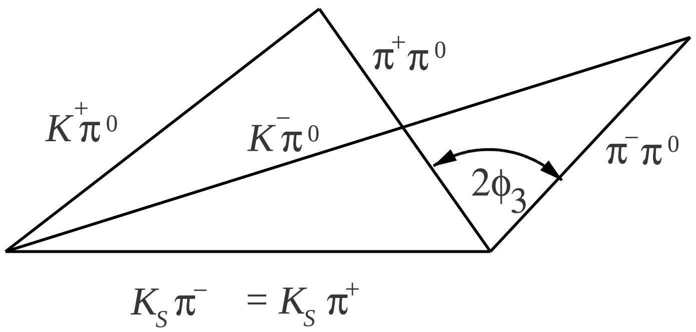




Interference $\to$ asymmetry $B^- \to K^-\pi^0$ vs $B^+ \to K^+\pi^0$
(information on arg$V_{ub} = -\phi_3$.)

Need to remove unknown strong FSI phase.

One historical method (SU(3) Triangle):



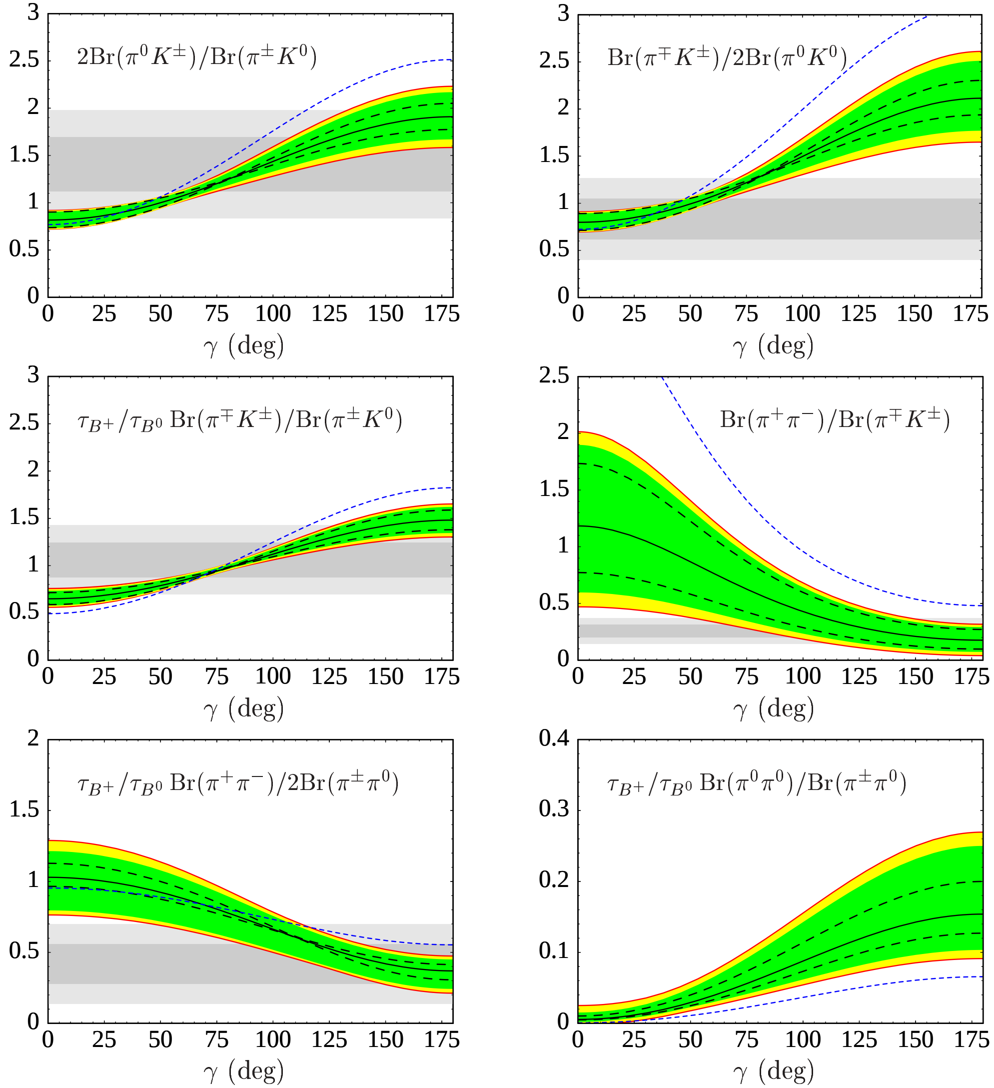
- Charged B modes $\rightarrow$ self-tagging.

- SU(3) breaking effect are reasonably under control.
  Complication by EW penguins which breaks the isospin.

- Requires substantial development in theory.
  Recent promising developments:

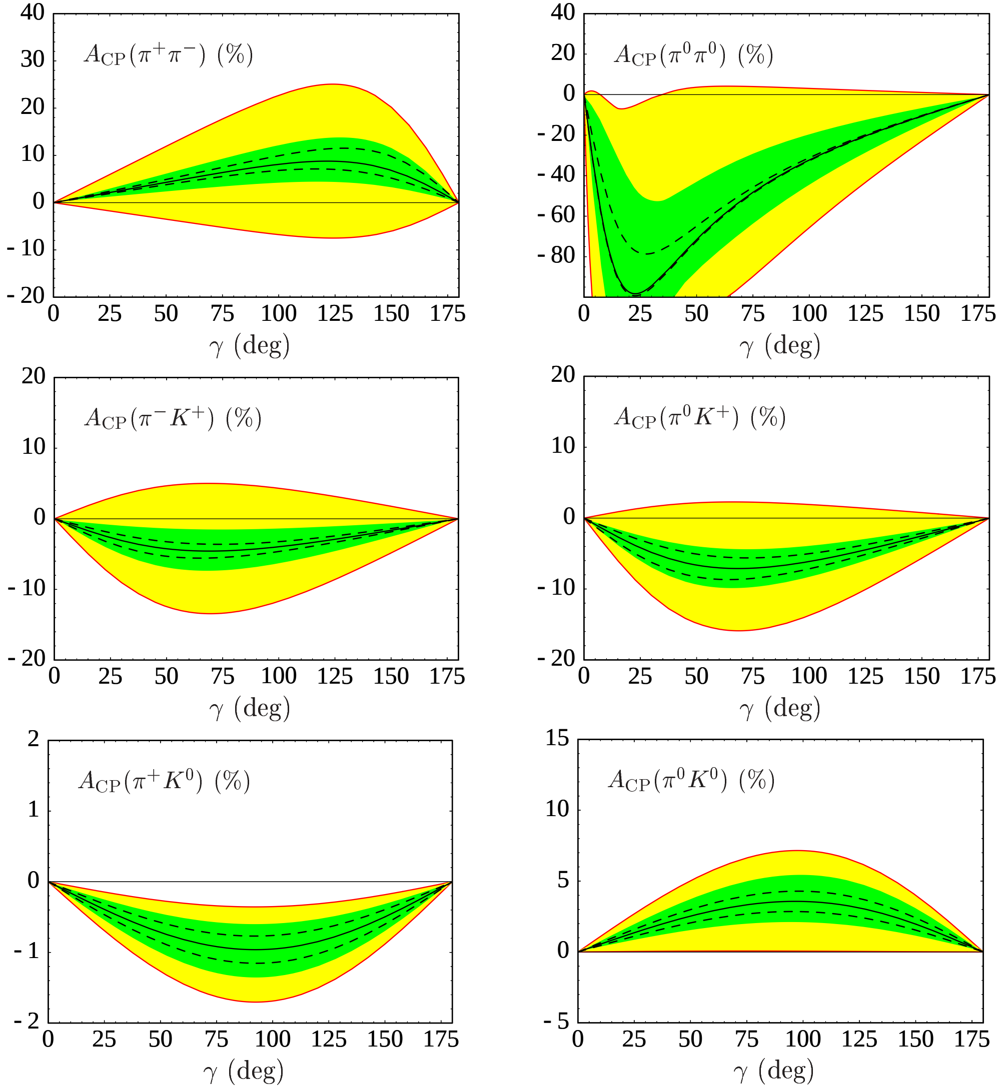
$\begin{cases} \text{QCD factorization (Beneke, Buchalla, Neubert, Sachrajda 2001)} \\ \text{pQCD (Keum,Li,Sanda 2001)} \end{cases}$

Ratios of Branching Fractions vs ϕ_3/γ



QCD factorization
BBNS

A_{CP} vs ϕ_3/γ



QCD factorization
BBNS

Direct CP Violation in $K\pi$ (10.4 fb^{-1})

$$A_{CP} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)}$$

$K^{\pm}\pi^{\mp}$: assume $B^0 \not\to K^-\pi^+$, $\bar{B}^0 \not\to K^+\pi^-$
$K^{\pm}\pi^0$, $K_S\pi^{\pm}$: self-tagged by charge.

A_{CP}	$Belle$	$(90\%C.L)$	$Ref1$	$Ref2$
$K^{\pm}\pi^{\mp}$	$0.044^{+0.186+0.018}_{-0.167-0.021}$	$-0.25 : 0.37$	0.05 ± 0.10	-0.19
$K^{\pm}\pi^0$	$-0.059^{+0.222+0.055}_{-0.196-0.017}$	$-0.40 : 0.36$	0.06 ± 0.10	-0.18
$K_S\pi^0$	$0.098^{+0.430+0.020}_{-0.343-0.063}$	$-0.53 : 0.82$	0.01 ± 0.01	-0.01

Ref1: Beneke, Buchalla, Neubert, and Sachrajda, 2001
Ref2: Kuem, Li, and Sanda, 2001

- $K_S\pi^+$ is penguin-dominated $\longrightarrow$ small A_{CP}
- A_{CP}: 20% error at 10 fb^{-1}
  $\longrightarrow$ 4% at 300 fb^{-1}
  $\longrightarrow$ 1$\sim$2% at 3000 fb^{-1}

Prospects for getting ϕ_3 by $K\pi/\pi\pi$ modes:

- At SuperKEKB, the error will be dominated by theoretical ones.
- How large? Depends on which theorists you ask.
- Best optimistic theoretical error is $\sim 10^\circ$.
- Worst case: even the A_{CP} sign cannot be predicted.
- Keep measuring Br's and A_{CP}'s.
  Understand the underlining mechanisms.
  $\longrightarrow$ Better theoretical precisions.

Conclusions

Assuming we need $\sigma_{\phi_3} = 0.1\text{-}0.2$ is needed for probing new physics,

- For $D^{(*)}\pi$, $D^{(*)}\rho$, and DK, 300 fb^{-1} is not enough. SuperKEKB will do the job.

- $K\pi, \pi\pi$ modes will be limitted by thoretical uncertainty. Substantial progress in understanding decay mechanism may change the situation.