Results on CP Violation from B-factories

- Recent Results from Babar and Belle -

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Plan:

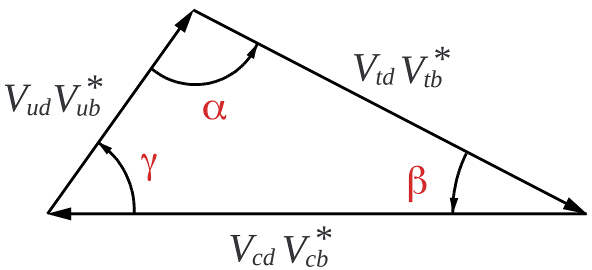
1. $\sin 2(\phi 1/\beta)$ by $(c\bar{c})K_{S,L}$ modes
2. $\sin 2(\phi 1/\beta)$ by $b \to s$ penguin modes
3. $\sin 2(\phi_2/\alpha)$ by $\pi\pi$ modes
4. Modes related to ϕ_3/γ
5. Future prospects

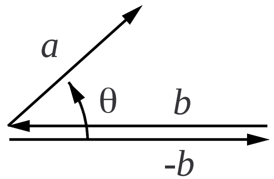
CPV in B Meson System

$$\mathcal{L}_{qW}(x) = \frac{g}{\sqrt{2}} \sum_{i,j=1,3} V_{ij}\, \bar{u}_{iL}\, \gamma_\mu d_{jL}\, W^\mu$$

$u_i = (u, c, t)$, $d_i = (d, s, b)$, and V=CKM matrix (unitary):
e.g: orthogonality of d-column and b-column:

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





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

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

e^+e^- B-Factories

$$e^+e^- \to \Upsilon(4S) \to B^0\bar{B}^0, B^+B^-$$

B's nearly at rest in the $\Upsilon(4S)$ frame:

$$\beta_B \sim 0.06$$

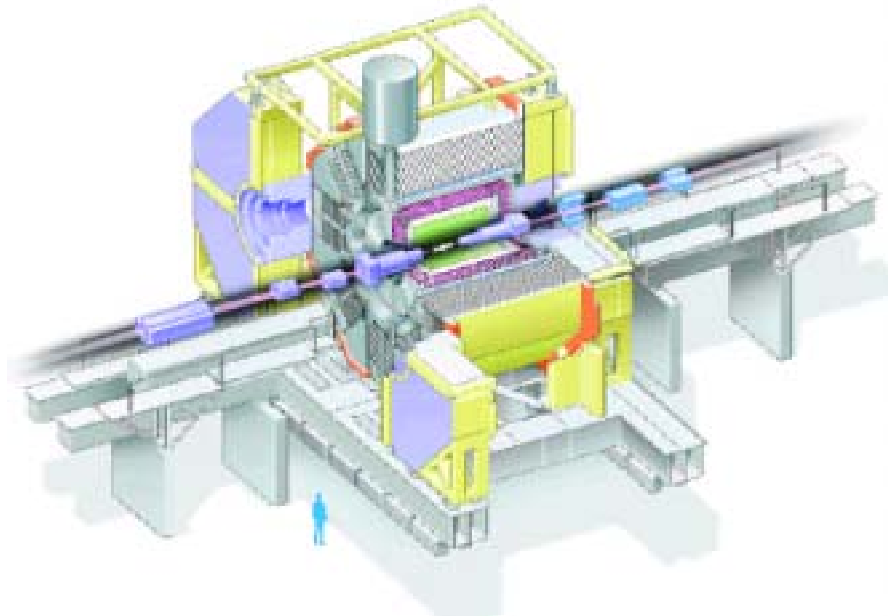
10-Nov-03	PEPII(BaBar)	KEKB(Belle)	CESR(CLEO2.x)
type	asymmetric	asymmetric	symmetric
#ring	double	double	single
$E_{\rm beam}$ (GeV)	$9(e^-)/3.1(e^+)$	$8(e^-)/3.5(e^+)$	$5.29(e^\pm)$
$\beta_{\Upsilon(4S)}$ in lab.	0.49	0.39	0
full xing angle	0 mrad	22 mrad	4.6 mrad
$\mathcal{L}_{\rm max}(\times 10^{33}/{\rm cm}^2{\rm s})$	6.6	10.6	1.25
$\int \mathcal{L}dt$ (recd. fb^{-1})	141.2	160.0	13.7
off resonance	9%	9%	1/3

Basic design: Vertexing(Si)-Central tracker(DC)-PID-SC coil -EM calorimeter(CsI)-Muon system(RPC)

BaBar detector

- PID=DIRC(Cerenkov)

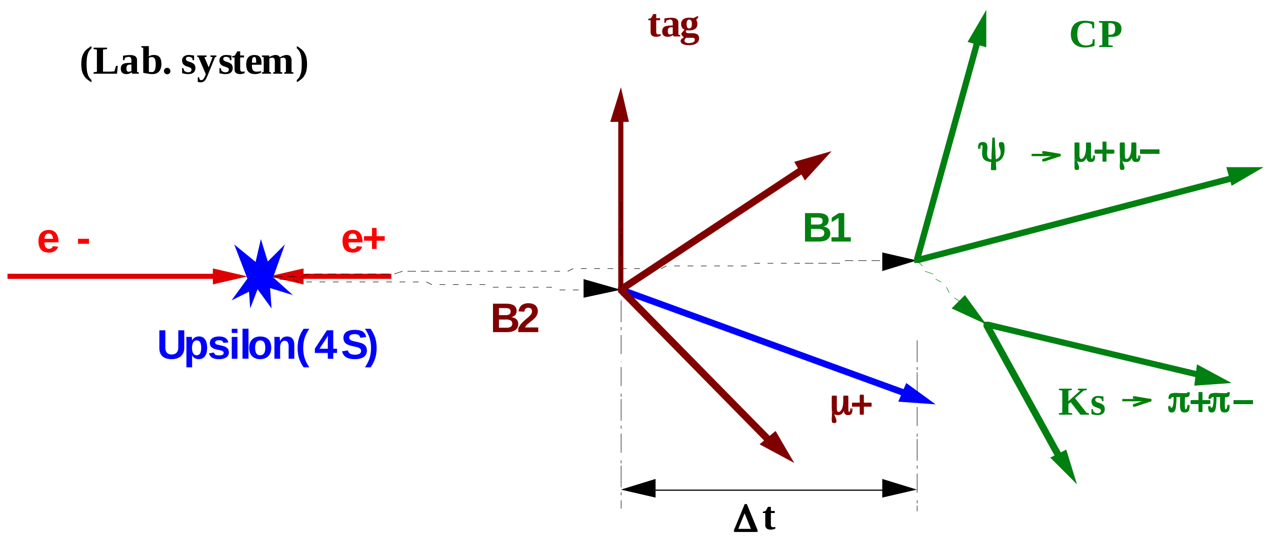
Belle detector



- PID=Aerogel+TOF

Measurement of $\sin 2(\phi_1/\beta)$ at asym. B-factories

$$\Upsilon(4S) \to B^0\bar{B}^0 \to (tag)(J/\Psi K_S)$$



$$\Delta t \equiv t_{CP} - t_{tag} \sim \frac{\Delta z}{\beta\gamma\, c}$$

(t: decay time in the B rest frame)

CP-side Reconstruction and Flavor Tagging

Belle(78 fb^{-1})/BaBar(82 fb^{-1})

mode	CP	N_{evt}	purity
ΨK_S	$-$	1278/1144	0.96/0.96
$\Psi' K_S$	$-$	172/150	0.93/0.97
$\chi_{c1} K_S$	$-$	67/80	0.96/95
$\eta_c K_S$	$-$	122/132	0.71/0.73
$CP-$ total		1639/1506	0.94/0.94
ΨK_L	$+$	1230/988	0.63/0.55
ΨK^{*0}	$+/-$	89/147	0.92/0.81

Flavor tagging:
lepton ($b \to \ell^- X$)
$K^\pm$ ($b \to c \to s$)
Λ ($b \to c \to s$)
low-energy $\pi^\pm$ (D^{*+})
high-energy tracks

Full B Reconstruction

(When all B decay products are detected)

$$B \to f_1 \cdots f_n$$

(In the $\Upsilon 4S$ frame)

$E_B = 5.28$ GeV and $|\vec{P}_B| = 0.35$ GeV/c are known.

Use energy-momentum conservation:

- $E_B = \Sigma_i^n E_i \to \Delta E \equiv E_B - E_{\text{beam}}$
- $\vec{P}_B = \Sigma_i^n \vec{P}_i \to M_{bc} \equiv \sqrt{E_{\text{beam}}^2 - P_B^2}$

(In the lab. frame: no need to boost)

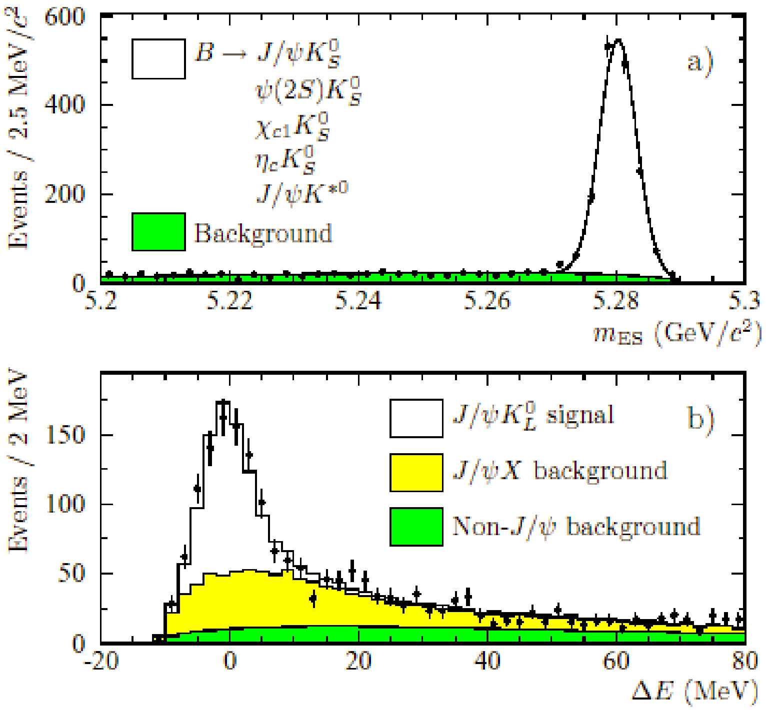
$$q_\Upsilon = (E_\Upsilon, \vec{P}_\Upsilon), \quad q_B = (E_B, \vec{P}_B)$$

- $M_{ES} = \sqrt{s/2 + \vec{P}_\Upsilon \cdot \vec{P}_B)^2 / E_\Upsilon^2 - \vec{P}_B^2}$
- $\Delta E = (q_\Upsilon \cdot q_B)/\sqrt{s} - \sqrt{s}$

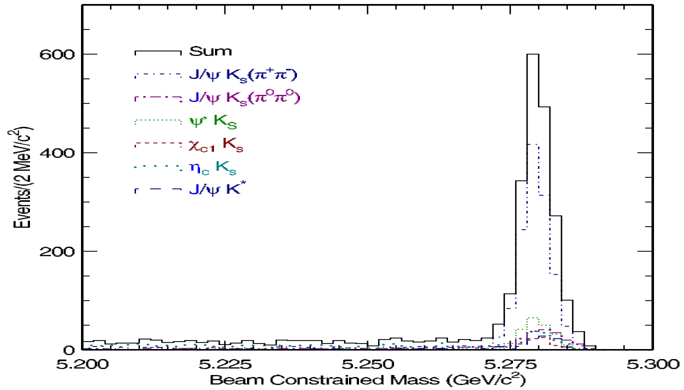
$M_{bc} = M_{ES}$ if masses are correct.

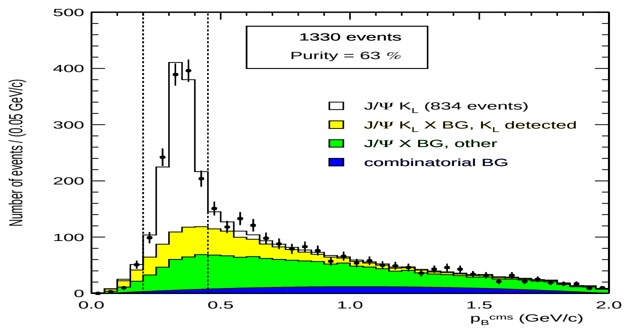
Charmonium$K_{S,L}$ Mode Reconstruction

BaBar



Belle

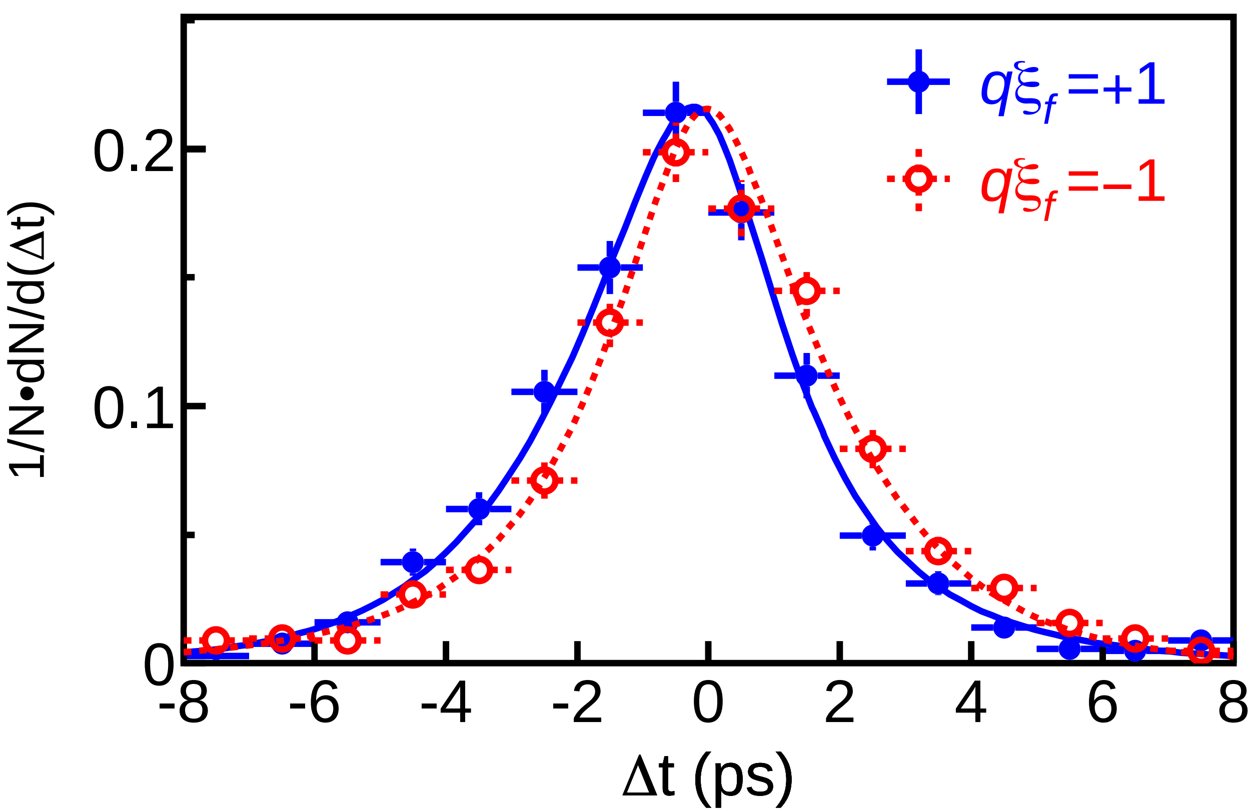




K_S modes: cut on ΔE, plot M.

K_L: only its direction measured $\longrightarrow$ either P_B or ΔE.

$q=+1$ Tag side is B^0
$q=-1$ Tag side is $\bar{B}^0$, ξ_f : CP eigenvalue. -1 for $J/\Psi K_S$



We observed:

If the tagside is B^0, the $J/\Psi K_S$ side tends to decay later than the tagside.

$$\Big|$$

$$CP \left\{ \begin{array}{c} \textbf{particle} \leftrightarrow \textbf{antiparticle} \\ \textbf{mirror inversion (no effect)} \end{array} \right.$$

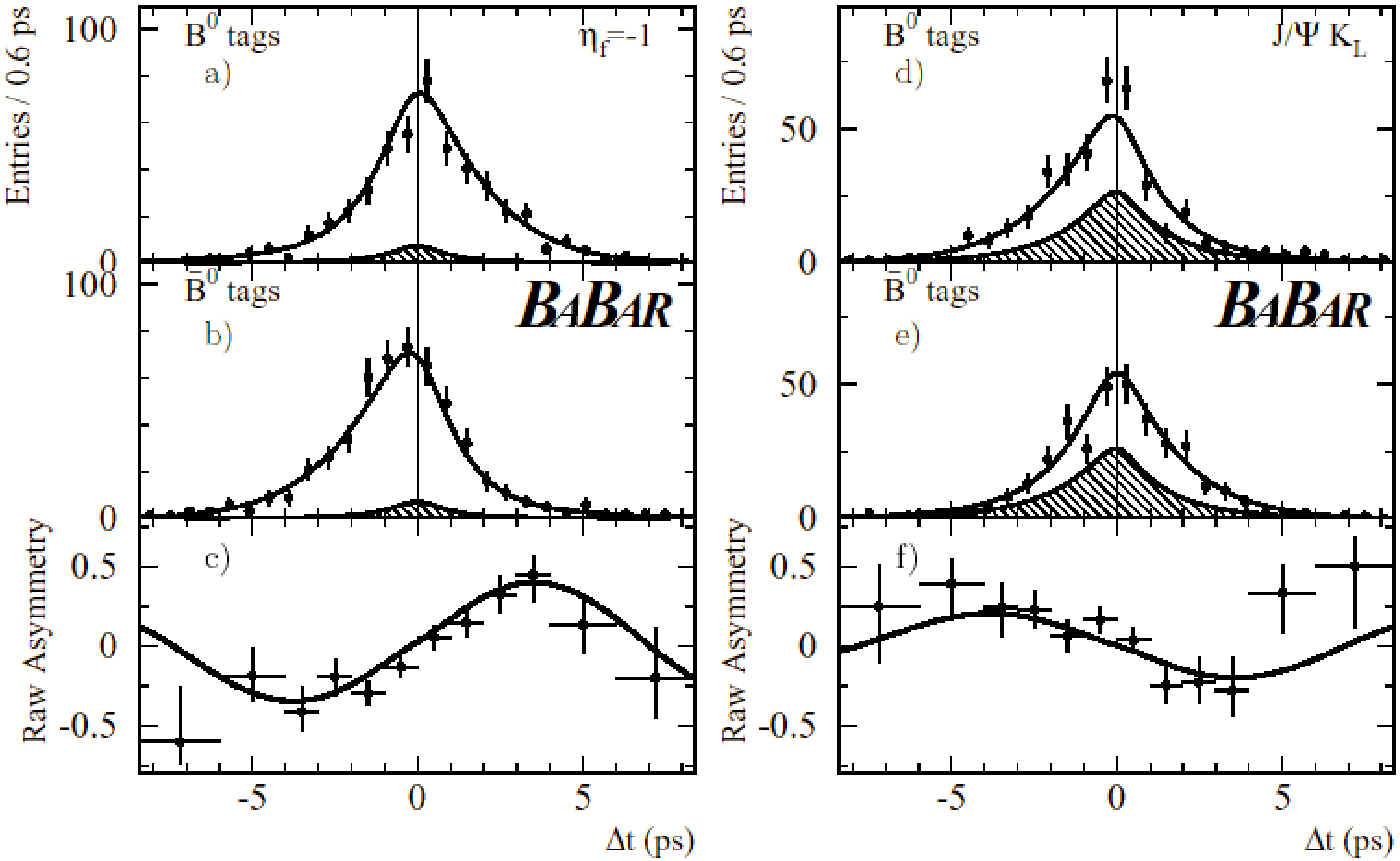
$$\downarrow$$

If the tagside is $\bar{B}^0$, the $J/\Psi K_S$ side tends to decay later than the tagside.

:Inconsistent with observation.

$\rightarrow CP$ **violation**

CP− CP+



Asymmetry is opposite for CP + and −.

Flavor-tagged $\Upsilon(4S) \to B^0 \bar{B}^0$

General expression for the decay time distribution.

$$\begin{cases} B_H = pB^0 - q\bar{B}^0 \\ B_L = pB^0 + q\bar{B}^0 \end{cases}, \qquad \begin{matrix} B_i(t) = B_i\, e^{-i\omega_i t} \\ (\omega_i = m_i - i\frac{\gamma}{2}) \end{matrix} \qquad (i = H, L)$$

(**Assume** CPT **and** $\gamma_H = \gamma_L \equiv \gamma$)

$$\boxed{\Gamma(\Delta t) \propto e^{-\gamma|\Delta t|}\,[1 + q(S \sin \delta m \Delta t + A \cos \delta m \Delta t)]}$$

$$\Delta t \equiv t_{\rm signal} - t_{\rm tag}$$

$q = +, -$ **for** $B^0, \bar{B}^0$ **tag**

$$S \equiv \frac{2\,{\rm Im}\lambda}{|\lambda|^2 + 1}, \qquad A \equiv \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}, \qquad \lambda \equiv \frac{q\bar{A}}{pA}$$

f : CP Eigenstate

In SM, we expect (phase convention: $CP|B^0\rangle = |\bar{B}^0\rangle$)

$$\frac{q}{p} = e^{-2i\phi_1} \quad \rightarrow \quad \left|\frac{q}{p}\right| = 1$$

$|\lambda| \neq 1(A \neq 0)$ **means** $|A(\bar{B}^0 \to f)| \neq |A(B^0 \to f)|$**: (direct CPV)**

If $CP|f\rangle = \xi_f|f\rangle$, and the decay is CP invariant
$((CP)S(CP)^\dagger = S)$,

$$\lambda \equiv \frac{q\bar{A}}{pA} = \underbrace{\frac{q}{p}}_{e^{-2i\phi_1}} \frac{\langle f|S|\bar{B}^0\rangle}{\underbrace{\langle f|(CP)^\dagger}_{\xi_f^*\langle f|}\underbrace{(CP)S(CP)^\dagger}_{S}\underbrace{(CP)|\bar{B}^0\rangle}_{|\bar{B}^0\rangle}} = e^{-2i\phi_1}\xi_f$$

With $A = 0$,

$$\Gamma(\Delta t) \propto e^{-\gamma|\Delta t|}(1 + qS\sin\delta m\Delta t)\,, \qquad S = -\xi_f \sin 2\phi_1$$

Results on Charmonium-$K_{S,L}$ Analyses

S : $\Delta t \leftrightarrow -\Delta t$ asymmetry

A : $q+ \leftrightarrow q-$ area asymmetry

$$\sin 2(\phi_1/\beta) = \begin{cases} 0.733 \pm 0.057(\text{stat}) \pm 0.028(\text{sys}) \ \ (\text{Belle}) \\ 0.741 \pm 0.067(\text{stat}) \pm 0.034(\text{sys}) \ (\text{BaBar}) \end{cases}$$

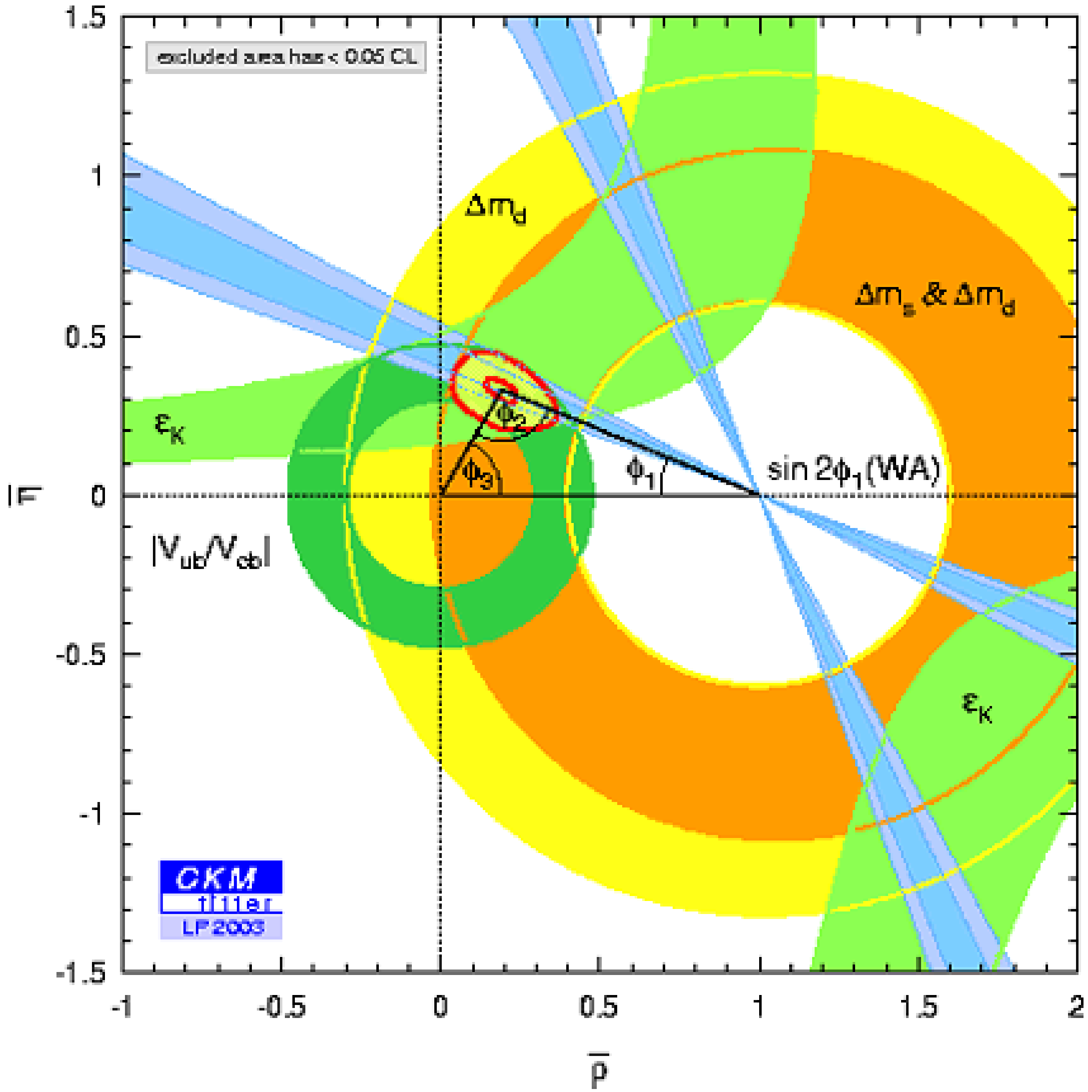
(World average) $\sin 2(\phi_1/\beta) = 0.736 \pm 0.049$

Direct CPV (Belle, BaBar combined)

$$A_{Belle}(\equiv -C_{BaBar}) = -0.052 \pm 0.047$$

No indication of direct CPV.

Unitarity triangle



All regions cross at one point!

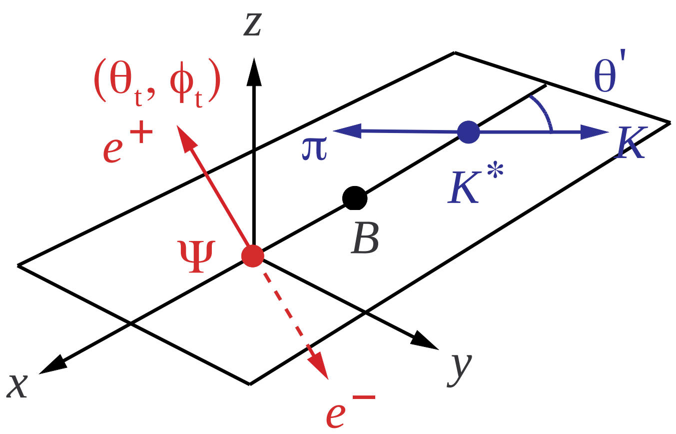
CP contents in $\Psi K^{*0}(\to K_S\pi^0)$

B (spin-0) $\to$ Ψ (spin-1) K^{*0} (spin-1)
3 polarization states: helicities $= (++, --, 00)$

$$\to A_{\parallel} = \tfrac{1}{2}(H_{++} + H_{--}), \quad A_0 = H_{00}, \quad A_{\perp} = \tfrac{1}{2}(H_{++} - H_{--})$$

$$A_{\parallel}, A_0: CP+, \quad A_{\perp}: CP-$$

Full angular analysis of the isospin-related modes
$[\Psi K^{*0}(K^+\pi^-), \Psi K^{*+}(K^+\pi^0, K^0\pi^+)]$



$$|A_{\parallel}|^2 + |A_0|^2 + |A_{\perp}|^2 = 0$$

$\|A_0\|^2$	0.617 ± 0.020
$\|A_{\perp}\|^2$	0.192 ± 0.023
$\arg(A_{\parallel})$	2.83 ± 0.19
$\arg(A_{\perp})$	-0.09 ± 0.13

(Belle 29.4 fb^{-1})

No indication of FSI phases.
$\mathrm{frac}(CP-) = 0.191 \pm 0.023(\mathrm{stat}) \pm 0.026(\mathrm{sys})$

(ΨK^{*0} used as incoherent sum of $CP\pm$ in the previous analysis)

ΨK^{*0} Δt Fulll Angular Analysis (Belle 78fb^{-1})

$$\frac{d\Gamma}{d\vec{\theta}d\Delta t} \propto e^{-\frac{|\Delta t|}{\tau_B}} \sum_{i=1}^{6} g_i(\vec{\theta})a_i(\Delta t)$$

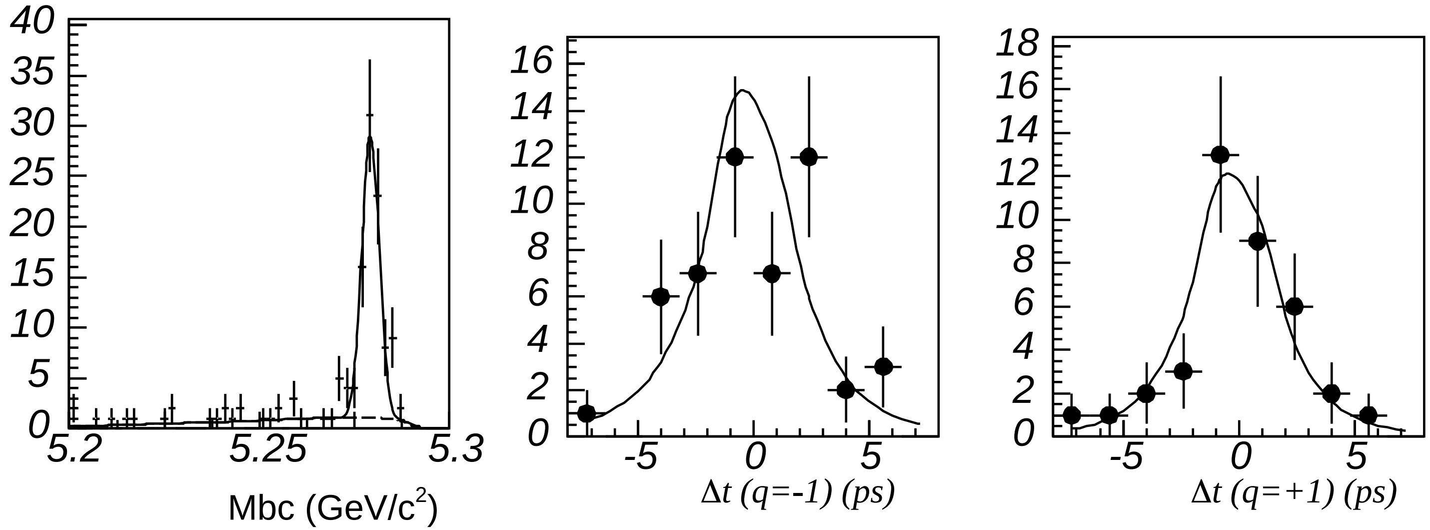
$$\vec{\theta} \equiv (\cos\theta_t, \phi_t, \cos\theta')$$

Information on $\cos 2\phi_1$ (as well as on $\sin 2\phi_1$) thourgh interference of $A_{\|/0}$ and $A_\perp$: (B. Kaiser)

$$a_{5/6} = q\big[\mathrm{Im}(A^*_{\|/0}A_\perp)\cos\delta m\Delta t \\ -\mathrm{Re}(A^*_{\|/0}A_\perp)\cos 2\phi_1 \sin\delta m\Delta t\big]$$

$$\begin{cases} g_5 = \sin^2\theta' \sin 2\theta_t \sin\phi_t \\ g_6 = \frac{1}{\sqrt{2}}\sin 2\theta' \sin 2\theta_t \cos\phi_t \end{cases}$$

$\Psi K^{*0}(\rightarrow K_S\pi^0)$ Results (Belle)



Unbinned likelihood fit to $(\vec{\theta}, \Delta t)$ distribution.

$\sin 2\phi_1$ floated:

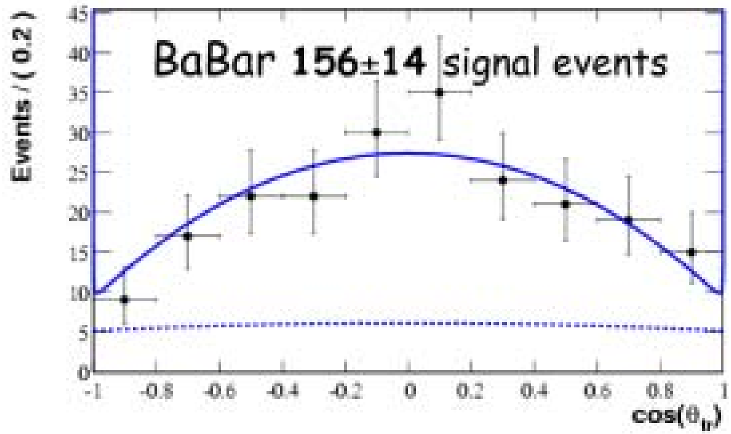
$$\sin 2\phi_1 = 0.13 \pm 0.51 \pm 0.06\,, \qquad \cos 2\phi_1 = 1.40 \pm 1.28 \pm 0.19\,.$$

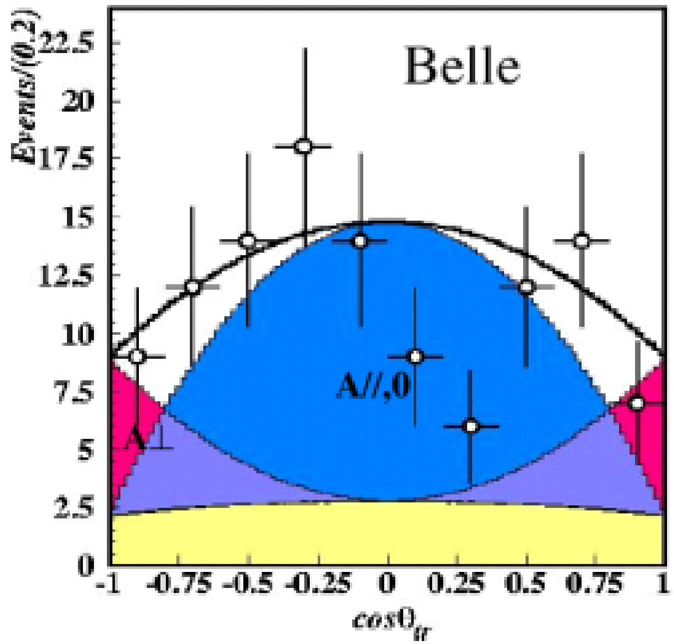
$\sin 2\phi_1 = 0.82$ fixed:

$$\cos 2\phi_1 = 1.02 \pm 1.05 \pm 0.19\,.$$

$B \to D^{*+}D^{*-}$ CP Fractions

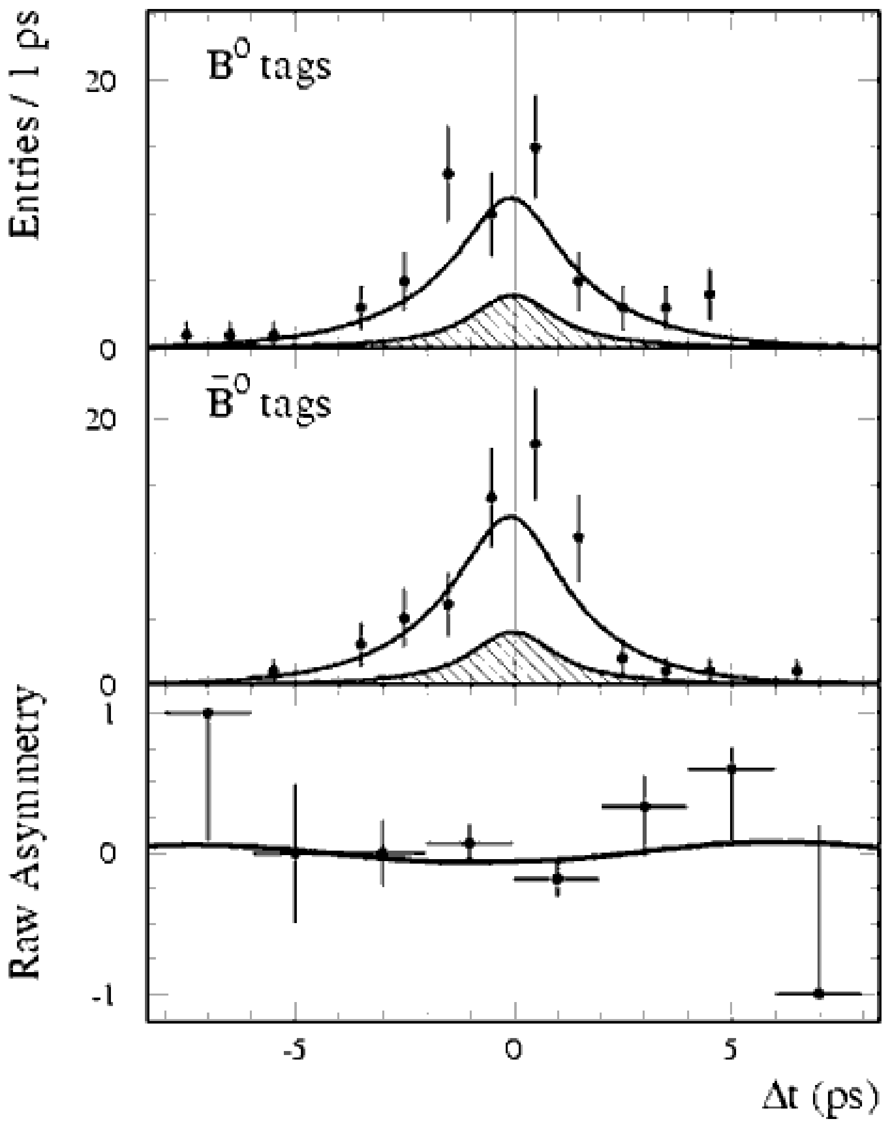
$CP+$ $(A_{\parallel}, A_0)$: $\cos^2\theta_t$
$CP-$ $(A_{\perp})$: $\sin^2\theta_t$





- frac($CP-$) $= 0.063 \pm 0.055 \pm 0.009$ (BaBar)
- Consistent with HQET+Factoriization (Rosner).

$B \to D^{*+}D^{*-}$ $(\Delta t, \theta_t)$ Fit (BaBar)



$$f(\theta_t, \Delta t) = e^{-\frac{\Delta t}{\tau_B}}[G(\lambda_i;\theta_t) + q(S(\lambda_i;\theta_t)\sin\Delta m\Delta t - C(\lambda_i;\theta_t)\cos\Delta m\Delta t)]$$

$\lambda_-(CP-)$ fixed in fit.

$\mathrm{Im}\lambda_+ = 0.05 \pm 0.29 \pm 0.10$
$|\lambda_+| = 0.75 \pm 0.19 \pm 0.02$

If no Penguin (SM):
$\mathrm{Im}\lambda_+ = -\sin 2\beta,\ |\lambda_+| = 1$

$\mathrm{Im}\lambda_+ :\ > 2\sigma$ from $\sin 2\beta$

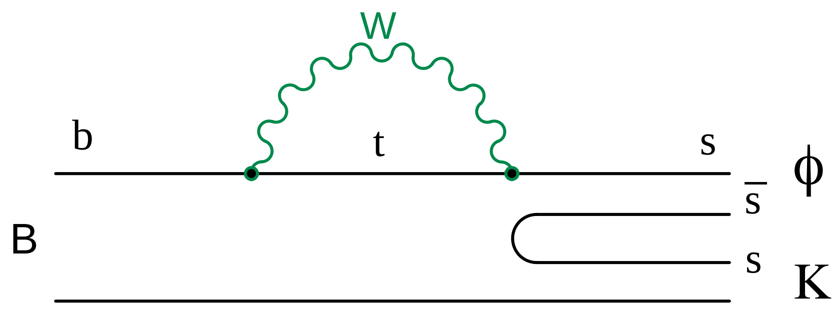
Time-dependent CPV of $b \to s$ penguin modes

$$\bar{B}^0 \to \begin{cases} \phi K_S \\ K^+K^-K_S(\text{no } \phi, D0, \chi_{c0}) \\ \eta' K_s \end{cases}$$

In SM, expect $S \sim -\xi_f \sin 2\phi_1$, $A \sim 0$

Deviation therefrom $\to$ new physics in $b \to s$

(e.g. the W-loop replaced by a charged Higgs loop)



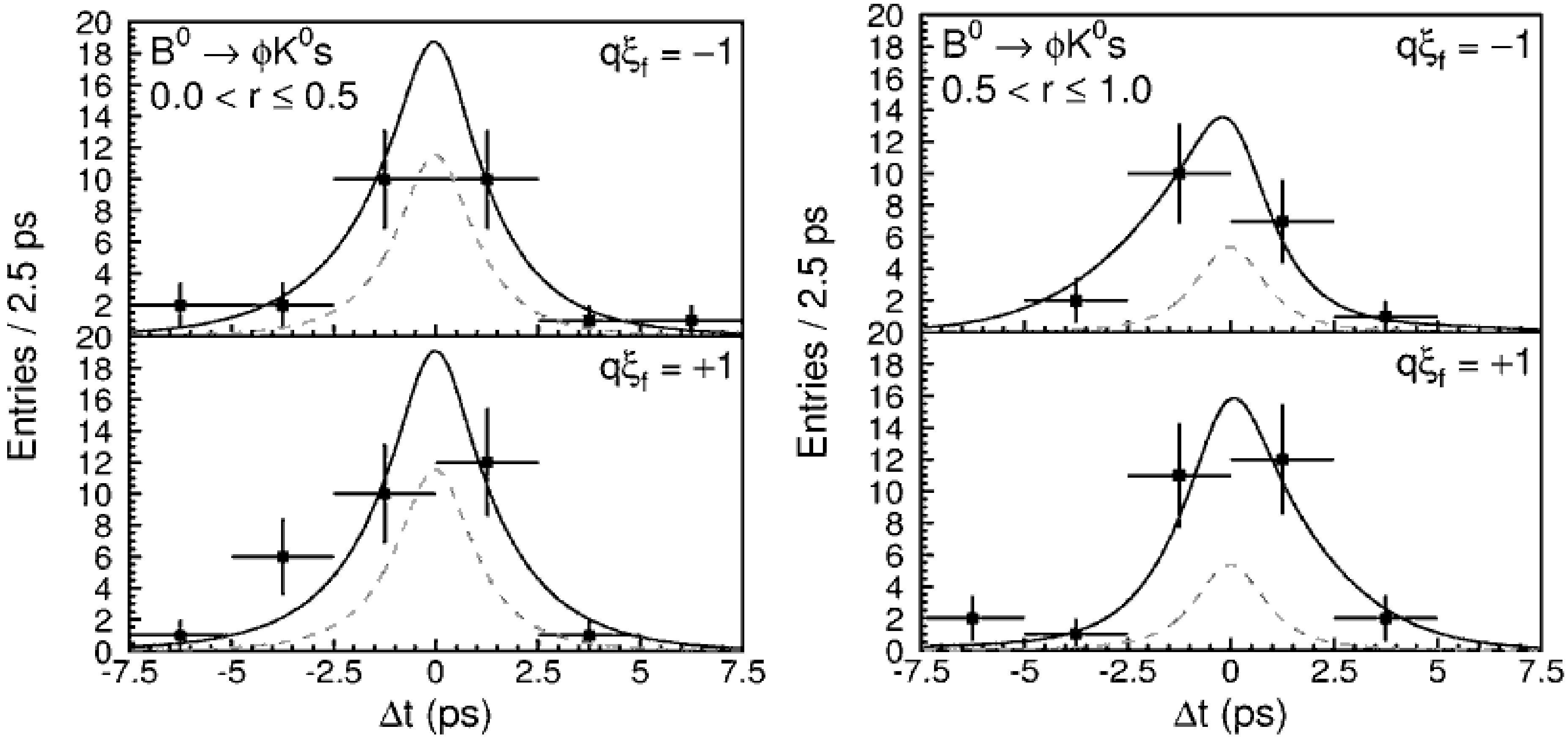
Continuum Suppression

Most rare modes: background is dominated by continuum $e^+e^- \to q\bar{q}$ 2-jet events.

- Event shape variables: Fox-Wolfram R_l, thrust, etc.
  continuum: skinny, $B\bar{B}$: spherical.
- Angle(B candidate axis, axis of the rest)
  continuum: aligned, $B\bar{B}$: uniform.
- Angle(B, beam)
  continuum: $1 + \cos^2\theta$, B: $\sin^2\theta$.
- Fisher: $F = \sum_i c_i X_i$ (above+X_i energy flow etc.)
  Adjust c_i to maximize the separation.

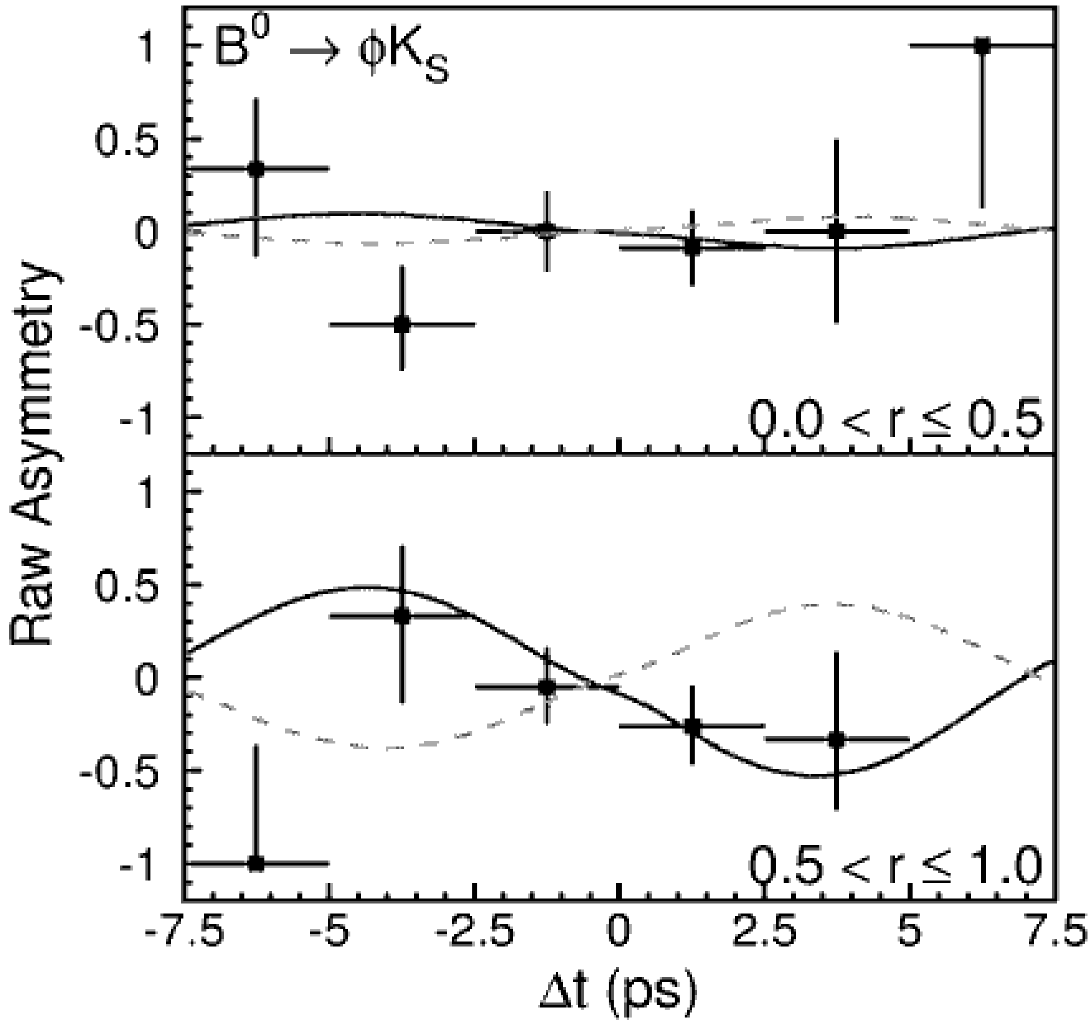
Belle ϕK_S (140 fb^{-1})

r: tagging purity



Belle ϕK_S (140 fb^{-1})

r: tagging purity

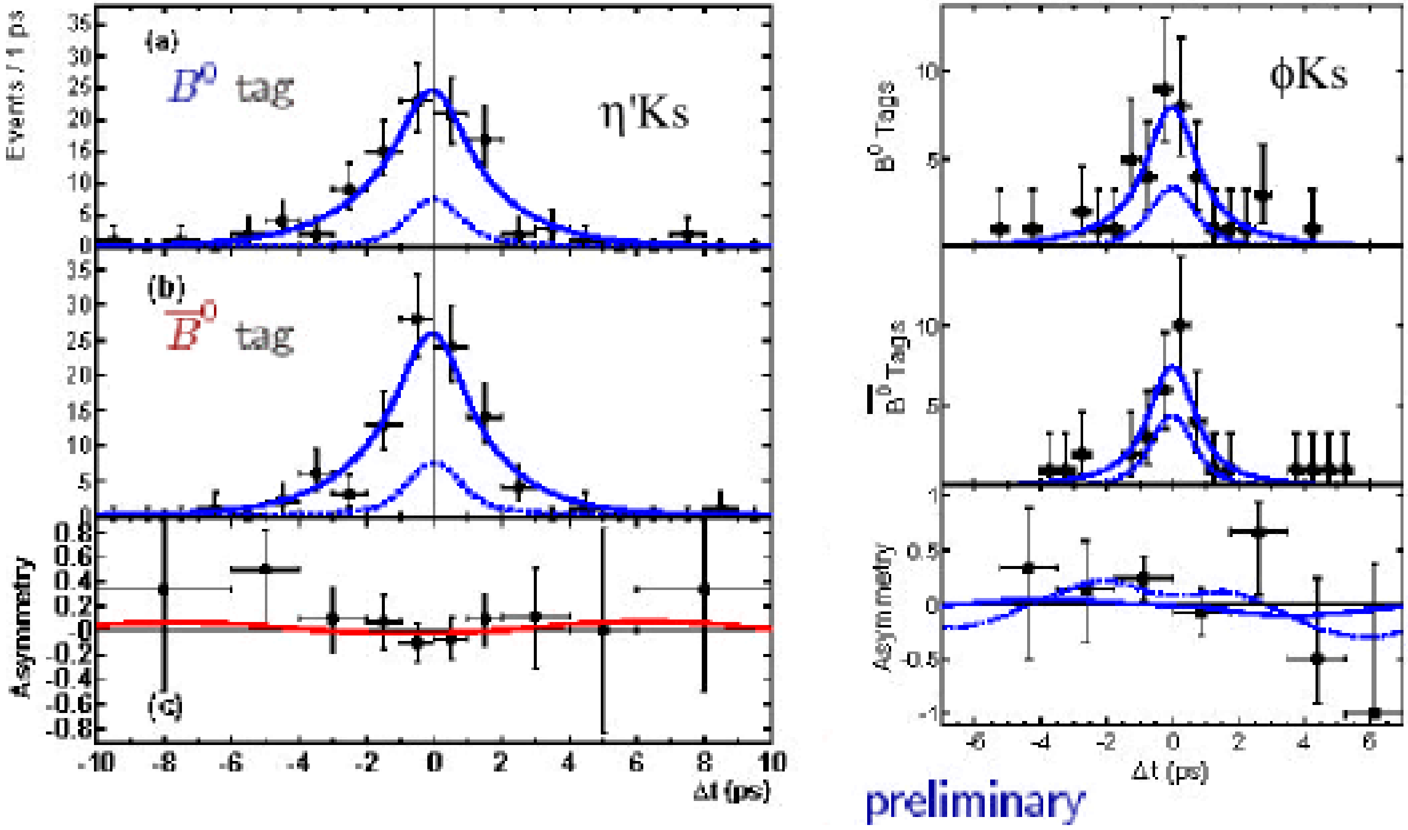


Belle $b \to s$ Penguins Results

$(140\mathrm{fb}^{-1})$	"$\sin 2\phi_1$" $(-\xi_f S)$	A
ϕK_S	$-0.96 \pm 0.50^{+0.09}_{-0.11}$	$-0.15 \pm 0.29 \pm 0.07$
$K^+K^-K_S$(non res.)	$+0.51 \pm 0.26 \pm 0.05^{+0.18}_{-0}$	$-0.17 \pm 0.16 \pm 0.04$
$\eta' K_S$	$+0.43 \pm 0.27 \pm 0.05$	$-0.01 \pm 0.16 \pm 0.04$
$J/\Psi K_{S/L}$ etc.	0.736 ± 0.049	~ 0

$CP(K^+K^-K_S) = +$ mostly (the last sys errors).

BaBar $b \to s$ Penguins



$$S_{\eta' K_S} = 0.02 \pm 0.34 \pm 0.03 \qquad S_{\phi K_S} = +0.45 \pm 0.43 \pm 0.07$$

$$C_{\eta' K_S} = 0.10 \pm 0.22 \pm 0.03 \qquad C_{\phi K_S} = +0.38 \pm 0.37 \pm 0.12$$

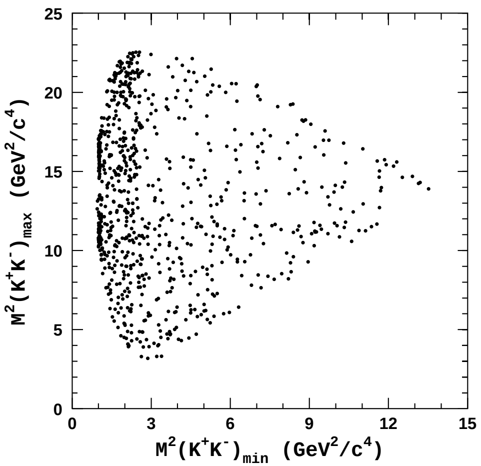
$$S_{\eta' K_s} = S_{\phi K_s} = \text{"}\sin 2\beta\text{"}\,(SM)$$

CP content of $K^+K^-K_S$ (Belle)

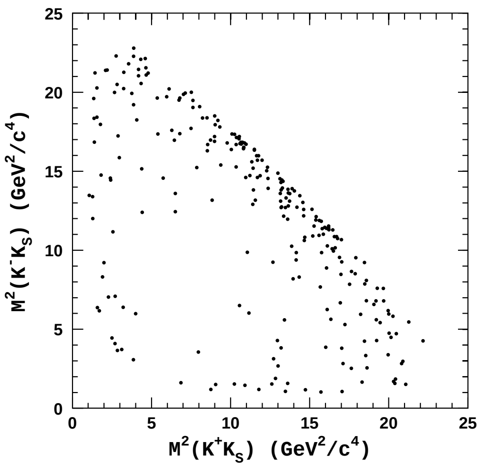
(Belle 79 fb^{-1})

	Signal yield (evts)	$\mathcal{B}$(90% U.L.)($\times 10^{-6}$)
$K^+K^-K^+$	565 ± 30	$33.0 \pm 1.8 \pm 3.2$
$K^0K^+K^-$	149 ± 15	$29.0 \pm 3.4 \pm 4.1$
$K_SK_SK^+$	66.5 ± 9.3	$13.4 \pm 1.9 \pm 1.5$
$K_SK_SK_S$	$12.2^{+4.5}_{-3.8}$	$4.3^{+1.6}_{-1.4} \pm 0.75$
$K^+K^-\pi^+$	93.7 ± 23.2	$9.3 \pm 2.3 (< 13)$
$K^0K^-\pi^+$	26.8 ± 16.6	$8.4 \pm 5.2 (< 15)$

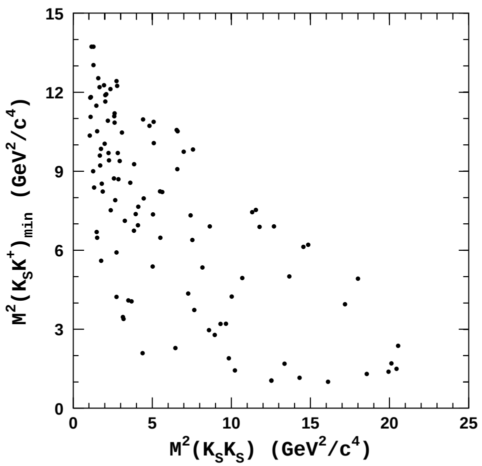
$K^+K^-K^+$



$K_SK^+K^-$



$K_SK_SK^+$



$(K^+K^-)K_S$ system:

- $L_{(K^+K^-)-K_S} = L_{K^+-K^-} \equiv L$ (B is spinless)
- $CP(K^+K^-) = +$ (any L, since $C = P$)
- $CP(K^+K^-K_S) = \underbrace{CP(K^+K^-)}_{+}\,\underbrace{CP(K_S)}_{+}(-)^L = (-)^L$

Even/odd $L_{K^+-K^-} \longrightarrow$ even/odd $CP(K^+K^-K_S)$

On the other hand,

Expect $B \to K\bar{K}K$ to be dominated by $b \to s$ penguin. In fact: since no $b \to s$ penguin (odd $s/\bar{s}$) in $K\bar{K}\pi$ (even $s/\bar{s}$),

$$F \equiv \frac{\Gamma^{3K}_{b\to u}}{\Gamma^{3K}_{\text{total}}} \sim \frac{\mathcal{B}(K^+K^-\pi^+)}{\mathcal{B}(K^+K^-K^+)} \left(\frac{f_K}{f_\pi}\right)^2 \tan^2\theta_c = 0.022 \pm 0.005$$

($F = 0.023 \pm 0.013$ using $K_S K^-\pi^+$ and $K_S K^- K^+$)

We can assume $3K$ modes are 100% due to $b \to s$ penguin.

Then,

$$\bar{B}^0(b\bar{d}) \longrightarrow \begin{pmatrix} s \\ \bar{d} \end{pmatrix} + \begin{matrix} (s\bar{s}) \\ (u\bar{u}) \end{matrix} \longrightarrow \begin{matrix} K^-(s\bar{u})\ K^+(\bar{s}u) \\ \bar{K}^0(s\bar{d}) \end{matrix}$$

$u \leftrightarrow d,\ \bar{u} \leftrightarrow \bar{d}$ everywhere
(isospin)
$\downarrow$

$$B^-(b\bar{u}) \longrightarrow \begin{pmatrix} s \\ \bar{u} \end{pmatrix} + \begin{matrix} (s\bar{s}) \\ (d\bar{d}) \end{matrix} \longrightarrow \begin{matrix} \bar{K}^0(s\bar{d})\ K^0(\bar{s}d) \\ K^-(s\bar{u}) \end{matrix}$$

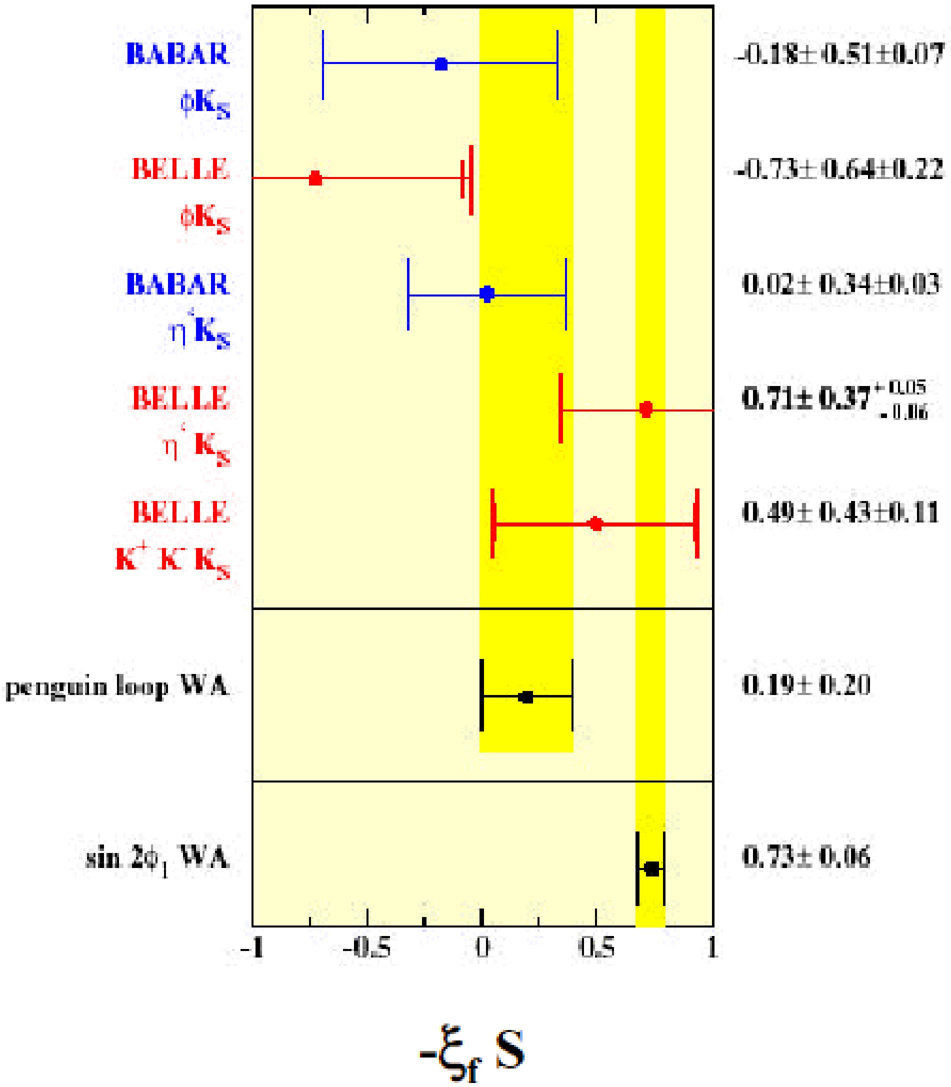
$\bar{B}^0 \rightarrow K^+K^-\bar{K}^0$ and $B^- \rightarrow \bar{K}^0K^0K^-$ have the same rate and the same kinematic configuration.

also : $(\bar{K}^0K^0)_{L\text{even}} \rightarrow K_SK_S, K_LK_L$, $(\bar{K}^0K^0)_{L\text{odd}} \rightarrow K_SK_L$.

$$\frac{CP(K^+K^-\bar{K}^0)+}{CP(K^+K^-\bar{K}^0)\text{any}} = \frac{K^+K^-\bar{K}^0(L_{K^+K^-}\text{even})}{K^+K^-\bar{K}^0(L_{K^+K^-}\text{any})} = \frac{\bar{K}^0K^0K^-(L_{\bar{K}^0K^0}\text{even})}{\bar{K}^0K^0K^-(L_{\bar{K}^0K^0}\text{any})}$$

$$= \frac{2(K_SK_SK^-)}{(K^+K^-\bar{K}^0)} = \begin{cases} 0.86 \pm 0.15 \pm 0.05 & (\text{incl. } \phi K_S) \\ 1.04 \pm 0.19 \pm 0.06 & (\phi K_S \text{ removed}) \end{cases}$$

$b \to s$ Penguin Δt Analyses Summary



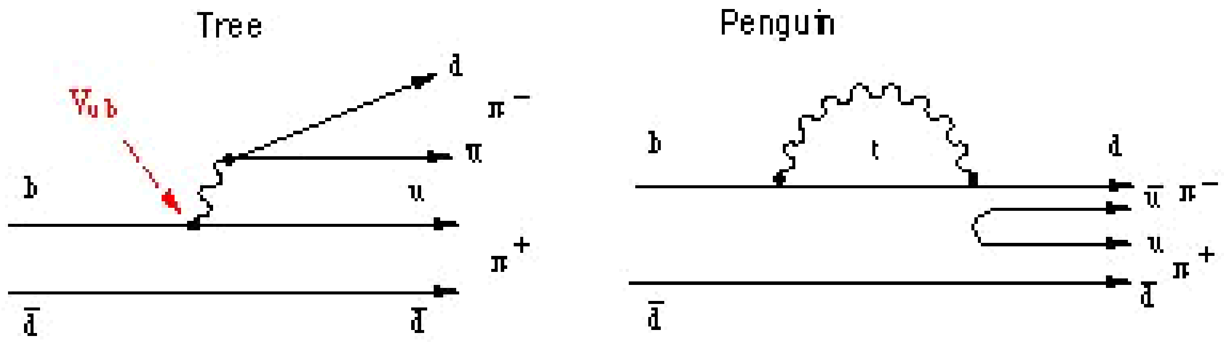
Average of sss modes:
(if such has any meaning)
more than 2σ away
from $(c\bar{c})X_s$ mode.

Time-dependent CPV analysis of $\pi^+\pi^-$

$$\frac{d\Gamma}{d\Delta t} \propto e^{-\frac{|\Delta t|}{\tau_B}} [1 + q(S_{\pi\pi} \sin \delta m \Delta t + A_{\pi\pi} \cos \delta m \Delta t)]$$

$$S_{\pi\pi} = \frac{\mathrm{Im}\lambda}{|\lambda|^2 + 1}, \qquad A_{\pi\pi} = -C_{\pi\pi} = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}.$$

$$|S_{\pi\pi}|^2 + |C_{\pi\pi}|^2 \leq 1$$



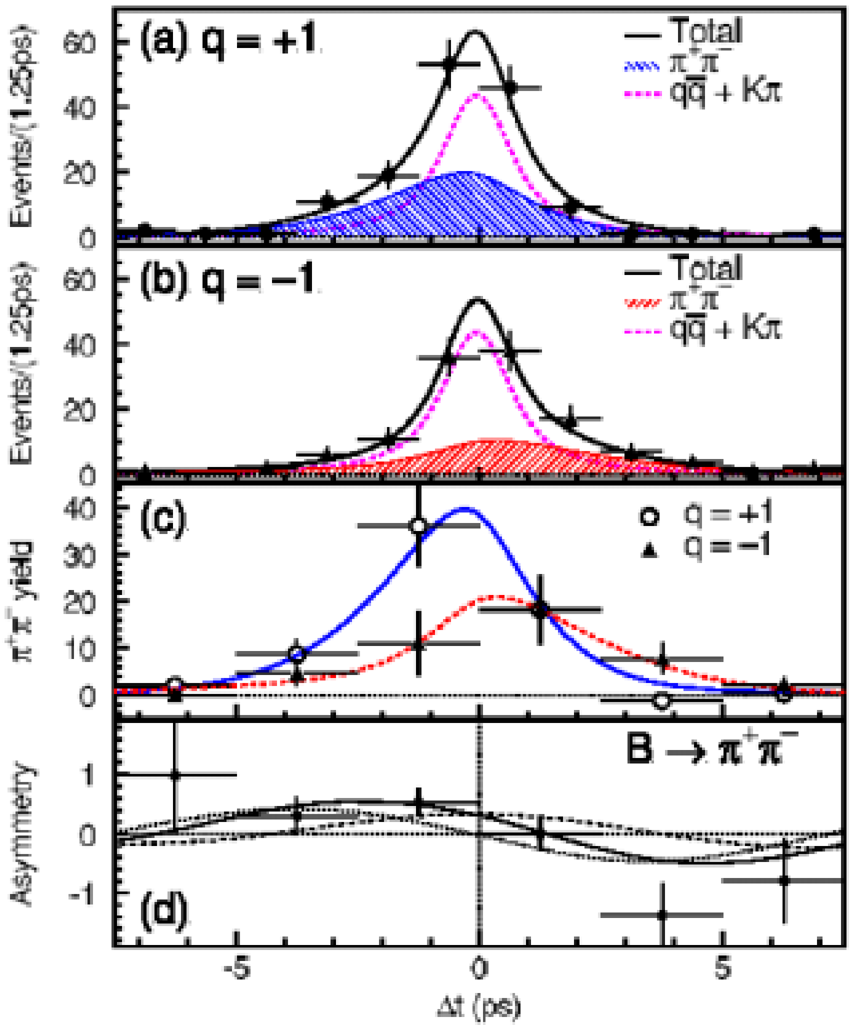
Expect:

$S_{\pi\pi} = \sin 2(\phi_2/\alpha)$ IF SM no penguin polution

$A_{\pi\pi} = 0$ IF no direct CPV

Belle $\pi^+\pi^-$ Δt Fit

Belle (78 fb^{-1})



- Use the same flavor tagging as the ϕ_1 analysis.
- Unbinned likelihood fit for Δt distribution.
- $K^-\pi^+$ asymmetry known (~ 0).
  $\longrightarrow$ Its shape is known.

- $(q+\ \text{area}) > (q-\ \text{area}) \rightarrow A_{\pi\pi} > 0$.
- Left-right asymmetry $\rightarrow S_{\pi\pi}$.
  (opposite signs for $q\pm$)

$$S_{\pi\pi} = -1.23 \pm 0.41^{+0.08}_{-0.07}$$
$$A_{\pi\pi} = +0.77 \pm 0.27 \pm 0.08$$

Statical errors estimated by 'pseudo experiments' (Gives more consevative errors in general than the fit output.)

Belle $\pi^+\pi^-$ Result

CPV ($S_{\pi\pi}$,$A_{\pi\pi}$) at 3.4σ.
Direct CPV ($A_{\pi\pi}$) at 2.2σ.

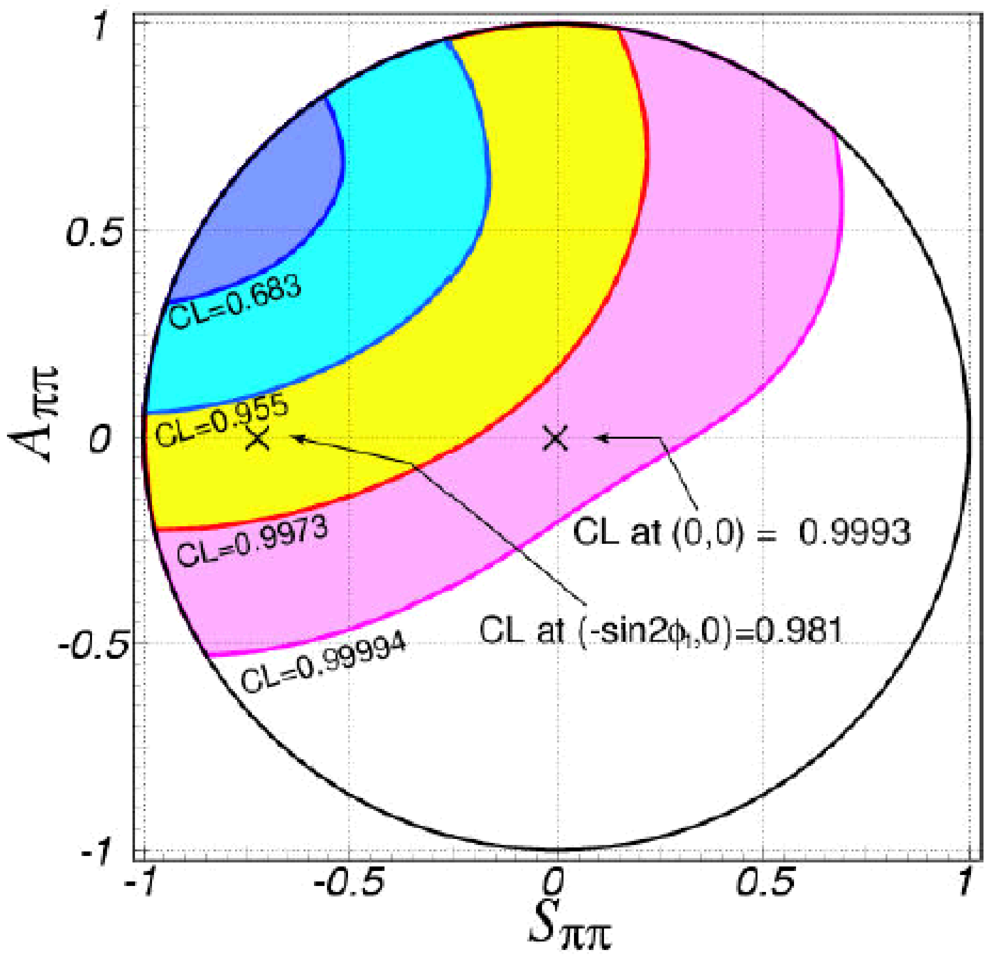
$$\lambda = e^{-2i\phi_2} \frac{1 + |P/T| e^{i(\delta+\phi_3)}}{1 + |P/T| e^{i(\delta-\phi_3)}}$$

Assuming, $\phi_3 = \pi - \phi_1 - \phi_2$,
$\phi_1 = 23.5^\circ$ (Belle, BaBar), and
$|P/T| = 0.15 \sim 0.45$ (th. av.~ 0.3)
fit for ϕ_2 and δ :

$$\rightarrow 78 < \phi_2 < 152^\circ$$

$\delta \sim -100^\circ$: large strong phase

Feldman-Cousin

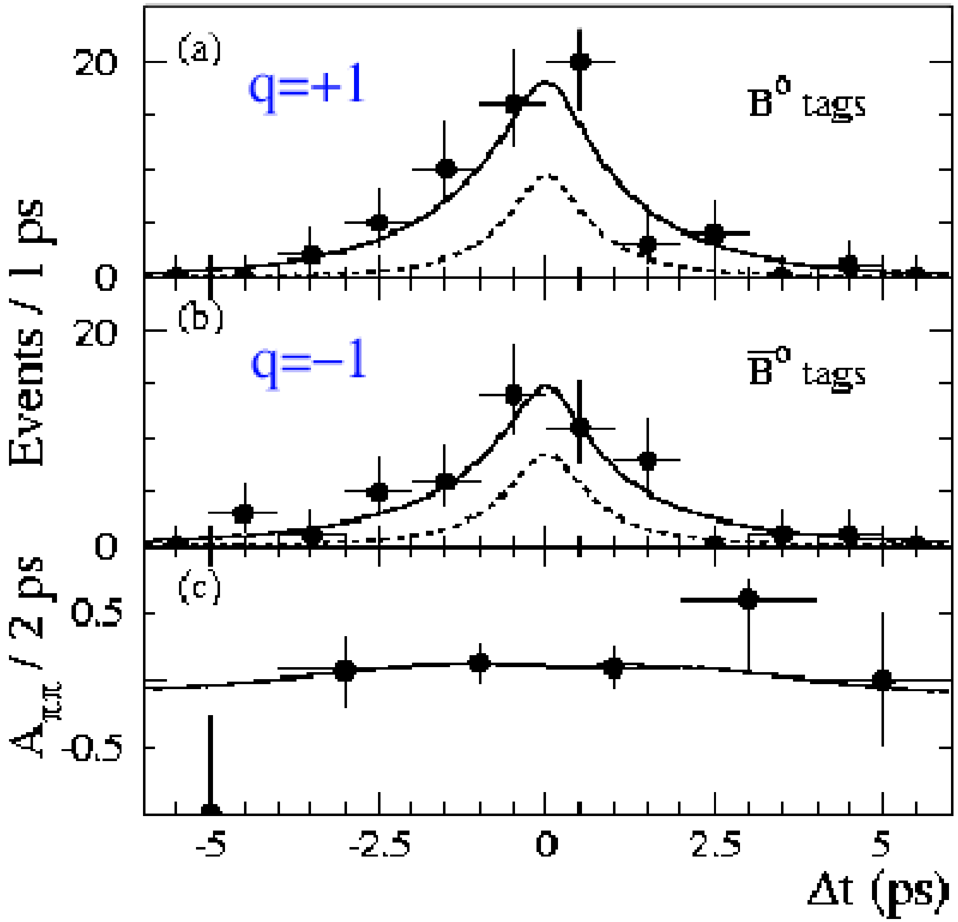


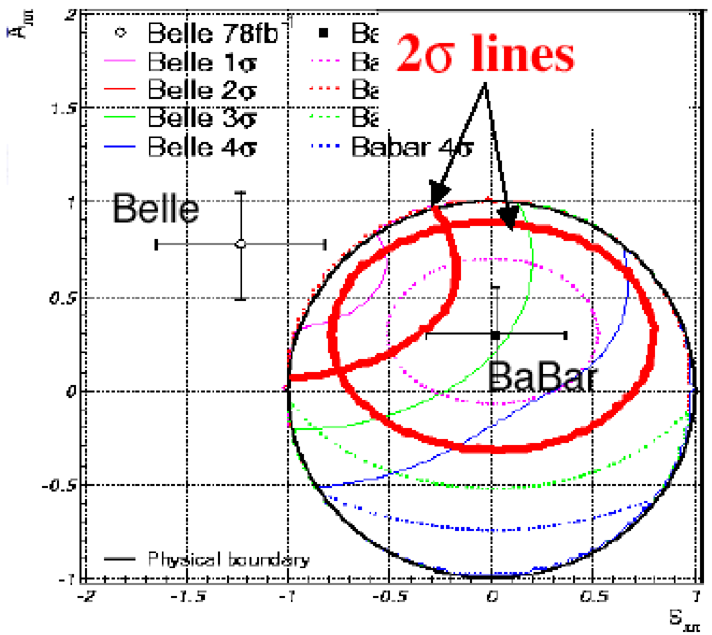
BaBar $\pi^+\pi^-$ Δt Analysis

BaBar (81 fb^{-1})

$$S_{\pi\pi} = \quad 0.02 \pm 0.34 \pm 0.05$$
$$C_{\pi\pi} = -0.30 \pm 0.25 \pm 0.04$$

No indication of CPV (indirect or direct).





Feldman & Cousins confidence interval

$\rho^{\pm}\pi^{\mp}$ Δt Analyses (BaBar)

Two final states :

$\rho^{+}\pi^{-}$ and $\rho^{-}\pi^{+} \longrightarrow (S, C)$ for each.

Total integrated yield asummetry A :

$\rho^{+}\pi^{-} \leftrightarrow \rho^{-}\pi^{+}$ (regardless of tag)

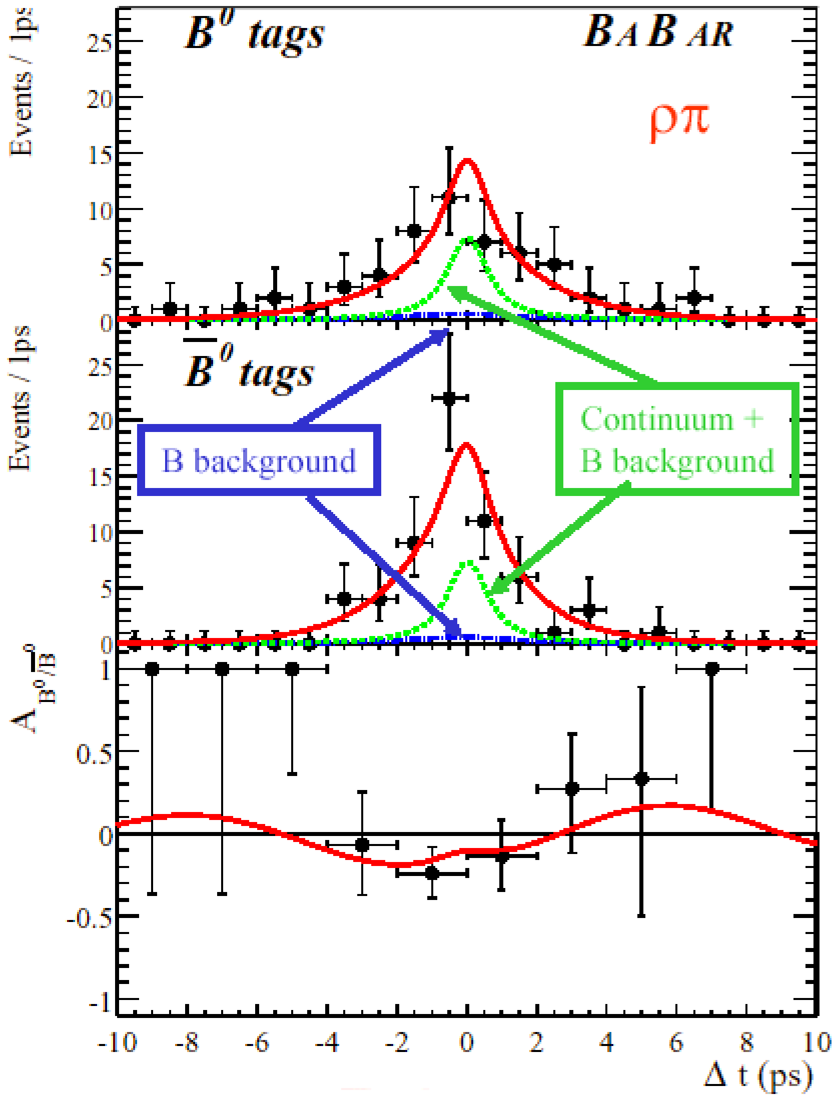
(different from A_{CP} or from $A(\mathrm{Belle}) = -C(\mathrm{BaBar})$)

Parametrize as

$$f_{\rho^{\pm}}(\Delta t) = (1 \pm A)e^{-\frac{\Delta t}{\tau_B}}\left[1 + q\left\{(S \pm \Delta S)\sin\delta m t - (C \pm \Delta C)\cos\delta m t\right\}\right]$$

$\rho^{\pm}\pi^{\mp}$ Results (BaBar)

BaBar (81 fb^{-1})



$$A_{\rho\pi} = -0.18 \pm 0.08 \pm 0.03$$

$$S_{\rho\pi} = 0.19 \pm 0.24 \pm 0.03$$
$$\Delta S_{\rho\pi} = 0.15 \pm 0.25 \pm 0.03$$

$$C_{\rho\pi} = 0.36 \pm 0.18 \pm 0.04$$
$$\Delta C_{\rho\pi} = 0.28 \pm 0.18 \pm 0.04$$

From all these, one can extract usual A_{CP}:

$$A_{CP}(\bar{B}^0 \to \rho^+\pi^-) = -0.62^{+0.24}_{-0.28} \pm 0.06$$
$$A_{CP}(\bar{B}^0 \to \rho^-\pi^+) = -0.11^{+0.16}_{-0.17} \pm 0.04$$

Slightly more than 2σ of DCPV.

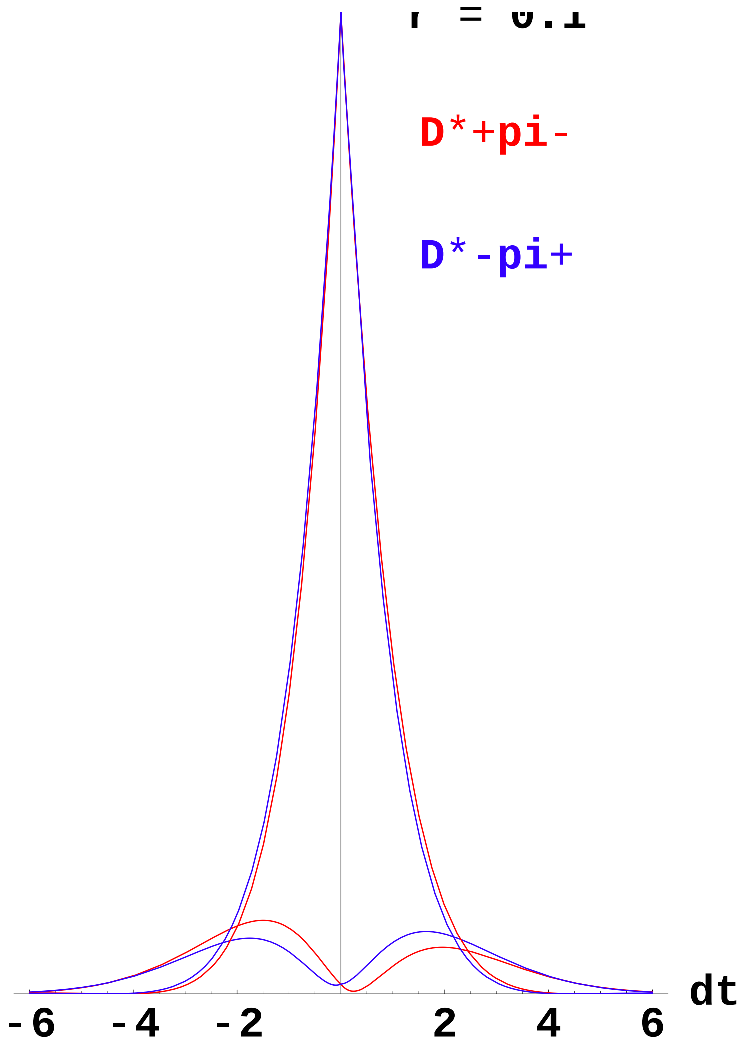
$D^{(*)}\pi$, Δt Analyses ($2\beta+\gamma$, BaBar)

$$D^+\pi^- \propto e^{-\gamma\Delta t}\left[1+q(C\cos\delta m t - S^+\sin\delta m t)\right]$$
$$D^-\pi^+ \propto e^{-\gamma\Delta t}\left[1-q(C\cos\delta m t - S^-\sin\delta m t)\right]$$

$$C\sim 1\,, \qquad S^\pm \sim 2r\sin(2\beta+\gamma\pm\delta)$$

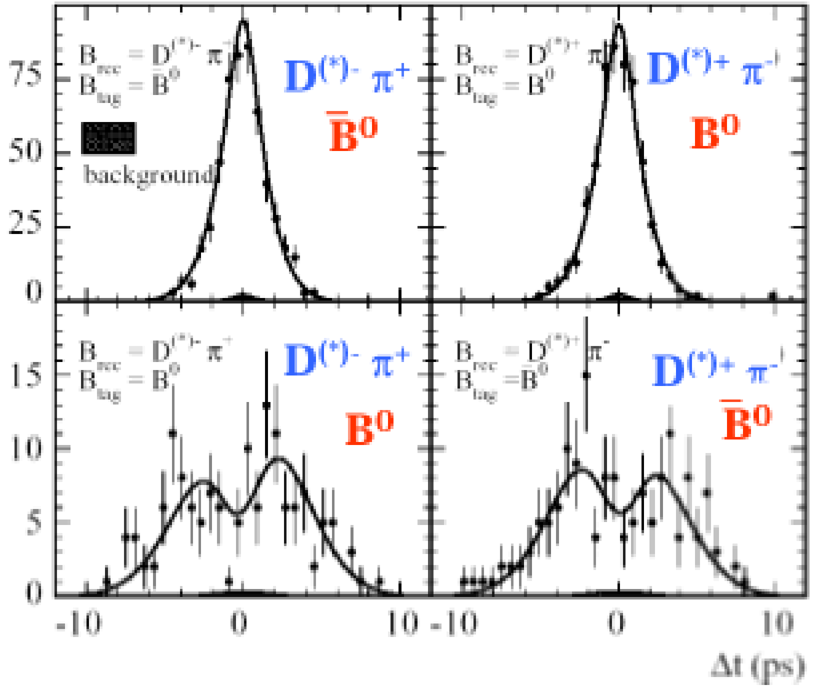
$$r^{(*)} = \frac{|A(B^0\to D^+\pi^-)|}{|A(\bar{B}^0\to D^+\pi^-)|} \qquad \text{(expect} \sim 0.02)$$

- Most of the info on mixed modes. Dip location + height asymmetry.
- Existense of negative Δt is advantageous (vs hadron machines)
- $\delta^{(*)}$: strong phase on $r^{(*)}$.

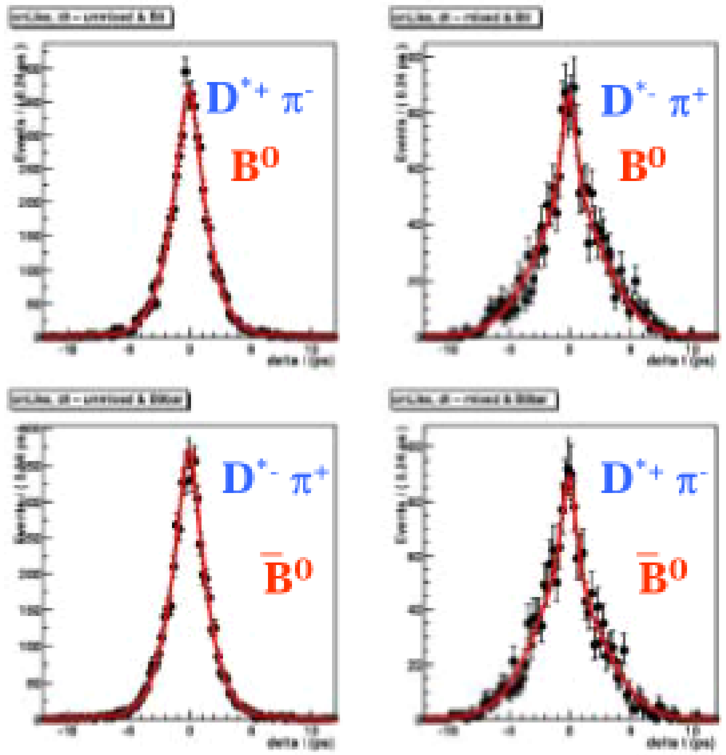


$D^{(*)}\pi$ Δt Distributions (BaBar)

Full reconstruction
$D^{+}\pi^{-}$ (5207 evs)
$D^{*+}\pi^{-}$ (4746 evs).



Partial reconstruction.
$D^{*+}\pi^{-}$,
$D^{*+} \to (D^0)\pi^{+}$.



Tag: lepton+K. lepton tags are shown.

$D^{(*)}\pi$ Results (BaBar)

Include tag-side $b \to u$ interference (K-tag only):

$$q2r\sin(2\beta+\gamma-\delta) + 2r'\sin(2\beta+\gamma+q\delta')$$

Same order as the original CPV effect.

Partial $D^*\pi$:

$$2r_*\sin(2\beta+\gamma)\cos\delta_* = -0.063 \pm 0.024 \pm 0.017$$
$$2r_*\cos(2\beta+\gamma)\sin\delta_* = -0.004 \pm 0.037 \pm 0.020$$

Full $D^{(*)}\pi$:

$$2r\sin(2\beta+\gamma)\cos\delta = -0.022 \pm 0.038 \pm 0.021$$
$$2r\cos(2\beta+\gamma)\sin\delta = 0.025 \pm 0.068 \pm 0.035$$
$$2r_*\sin(2\beta+\gamma)\cos\delta_* = -0.068 \pm 0.038 \pm 0.021$$
$$2r_*\cos(2\beta+\gamma)\sin\delta_* = 0.031 \pm 0.070 \pm 0.035$$

Implication of $D^{(*)}\pi$ Analysis on γ (BaBar)

BaBar result on $Br(D_s^{(*)+}\pi^-)$ + SU(3)

$$r = 0.021^{+0.004}_{-0.005}\,, \qquad r_* = 0.017^{+0.005}_{-0.007}\,.$$

Fit $\sin(2\beta+\gamma)$ and δ, δ_*:

$$\sin(2\beta+\gamma) > 0.76 \qquad (90\%\ C.L.)$$

Note: with $\sin 2\beta = 0.735$

$\sin(2\beta+\gamma) > 0.76$ **means** $-3^\circ < \gamma < 97^\circ$

$B \to DK$ for ϕ_3/γ

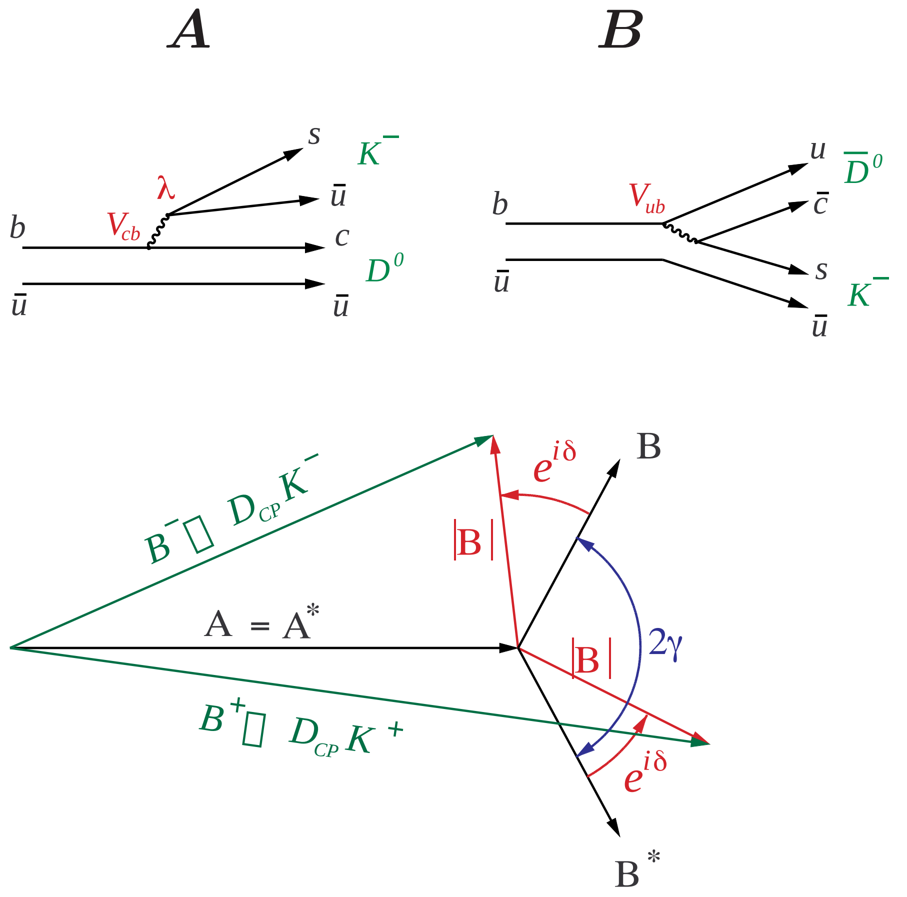
$$B^- \to D_{CP} K^-$$

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

$r \equiv \frac{|B|}{|A|} = 0.1\text{-}0.2$

$\sim 10\%$ asymmetry expected.
Depends on strong phase δ.

$\#c = 1$ in final state
$\to$ no penguin polution.
Eventually extract γ.

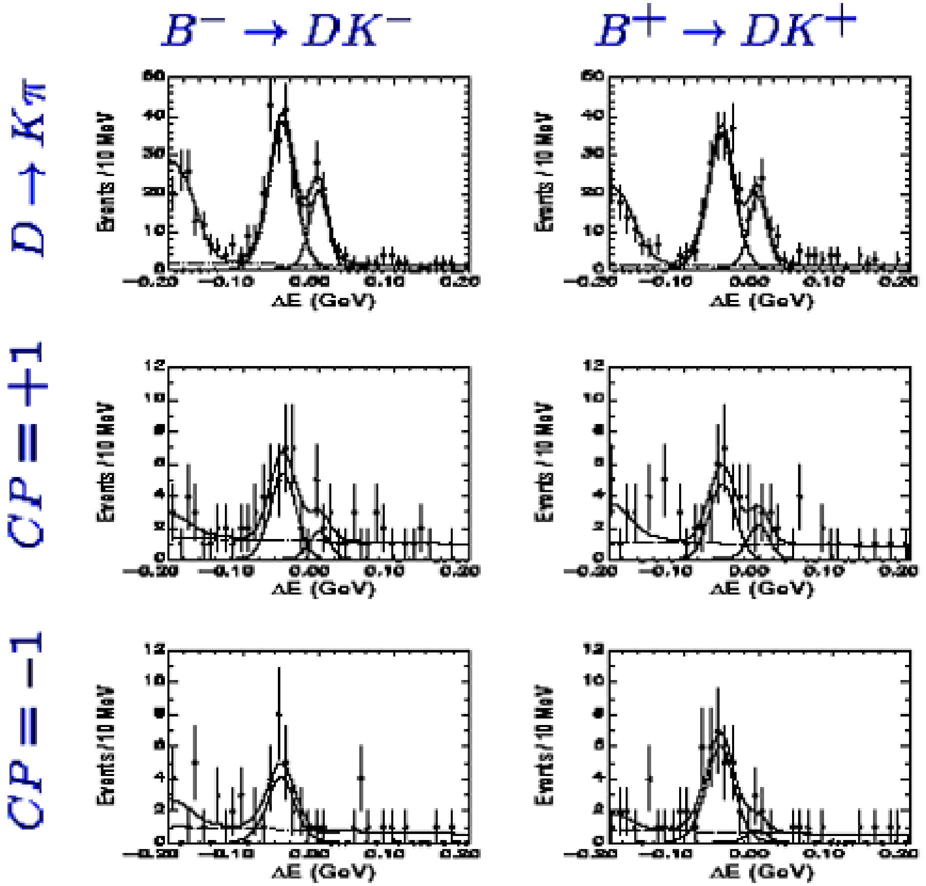


$B^{\pm} \to D_{CP} K^{\pm}$ (Belle 78 fb^{-1})

$D^0 h^-$: assign π mass to h^-.
Signal at $\Delta E = -49$ MeV.

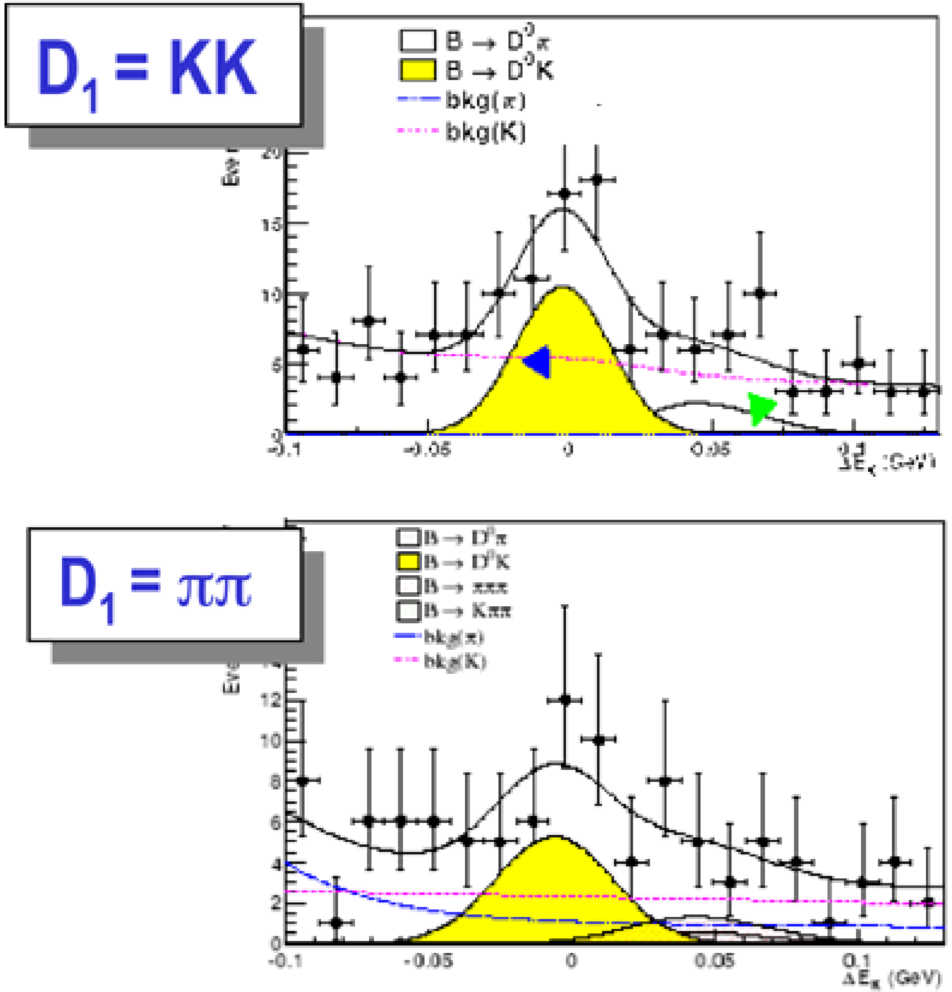
D^0 : $K^- \pi^+$
CP+ (D_1) :
$K^+ K^-, \pi^+ \pi^-$
CP− (D_2) :
$K_S \pi^0, K_S \omega, K_S \eta, K_S \eta'$

PID (π / K separation) important.



$B^- \to D_{CP}K^-$ (BaBar 81.2 fb^{-1})

$B^\pm \to D_1 K^\pm$



ΔE(GeV)

$B^- \to D_{CP}K^-$ Parameters

Rate asymmetry :

$$A_{1/2} = \frac{\mathcal{B}(B^- \to D_i K^-) - \mathcal{B}(B^+ \to D_i K^+)}{\mathcal{B}(B^- \to D_i K^-) + \mathcal{B}(B^+ \to D_i K^+)} = \frac{\pm 2r \sin\phi_3 \sin\delta}{1 + r^2 \pm 2r\cos\phi_3\cos\delta}$$

Ratio of Cabibbo suppression factors, D_i vs D^0 :

$$R_i = \frac{CS_{Di}}{CS_{D^0}}\ (i = 1, 2)\,, \qquad CS_X = \frac{\Gamma(B^- \to XK^-) + c.c.}{\Gamma(B^- \to X\pi^-) + c.c.}\ (X = D_i, D^0)$$

$$R_{1/2} = 1 + r^2 \pm 2r\cos\phi_3\cos\delta$$

(Error at $O(r^2)$ if $K^-\pi^+$ is used for D^0 (DCSD).)

Sensitivity to r at $O(r^2)$ $\to$ r cannot be obtained by fit to $A_{1/2}$ and $R_{1/2}$.

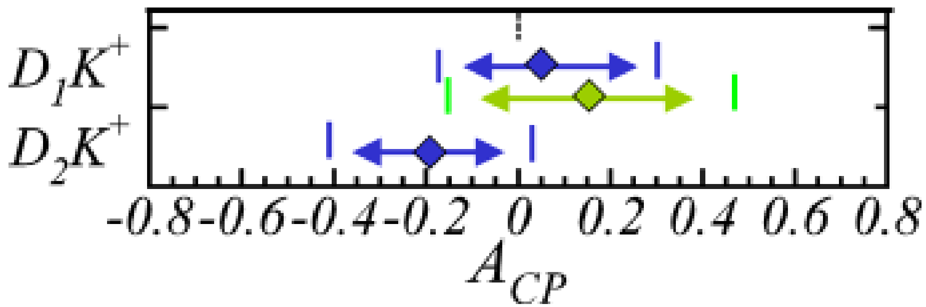
However,

$$A_2 \sim -A_1 \quad O(r)\,, \qquad \frac{A_1 - A_2}{2} \sim 2r\sin\phi_3\sin\delta \quad O(r^2)$$

Also, $A_1 R_1 = -A_2 R_2$

$B^{\pm} \to D_{CP} K^{\pm}$ Results

	$CP+$	$CP-$
Belle (DK)	$A_1 = 0.06 \pm 0.19 \pm 0.04$ $R_1 = 1.21 \pm 0.25 \pm 0.14$	$A_2 = -0.19 \pm 0.17 \pm 0.05$ $R_2 = 1.41 \pm 0.27 \pm 0.15$
BaBar (DK)	$A_1 = 0.17 \pm 0.23 \pm 0.08$ $R_1 = 1.06 \pm 0.26 \pm 0.17$	
Belle(DK^*)	$A_1 = -0.02 \pm 0.33 \pm 0.07$	$A_2 = 0.09 \pm 0.50 \pm 0.04$



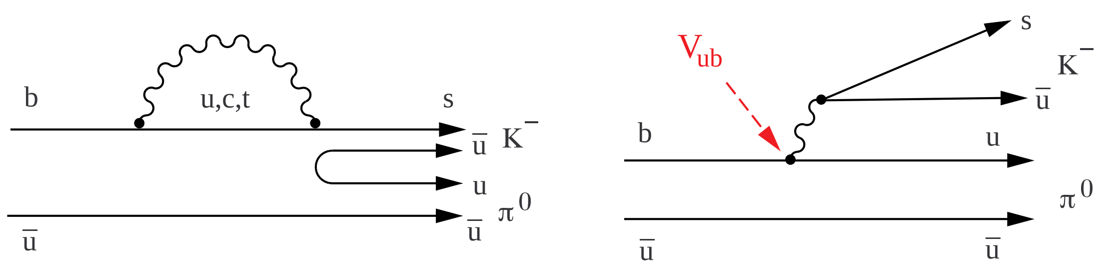
From DK results,

$$2r \sin\phi_3 \sin\delta = \frac{A_1 - A_2}{2} = 0.15 \pm 0.12 \,.$$

$B \to$non-charm Rate Asymmetries

Direct CPV by tree-penguin interference.

e.g. for $K^-\pi^0$:



Statistically more favorable than DK modes,
but theoretically challenging.

Future: use theoretical models (PQCD, QCD factorization, Charming penguin, etc.) for A_{CP} and Br's to extract ϕ_3.

$B \to$non-charm Rate Asymmetries

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

A_{CP} by HFAG (Heavy Flavor Averaging Group) 2003 Winter

RPP#	Mode	PDG2002 Avg.	BABAR	Belle	CLEO	A_{CP} Avg.
86	$K^0\pi^+$	-0.05 ± 0.14	$-0.17 \pm 0.10 \pm 0.02$	$0.02 \pm 0.09 \pm 0.01$	$0.18 \pm 0.24 \pm 0.02$	-0.05 ± 0.07
87	$K^+\pi^0$	-0.10 ± 0.12	$-0.09 \pm 0.09 \pm 0.01$	$-0.02 \pm 0.19 \pm 0.02$	$-0.29 \pm 0.23 \pm 0.02$	-0.10 ± 0.08
88	$\eta' K^+$	-0.02 ± 0.07	$0.04 \pm 0.05 \pm 0.01$	$-0.02 \pm 0.07 \pm 0.01$	$0.03 \pm 0.12 \pm 0.02$	0.02 ± 0.04
92	ωK^+			$-0.21 \pm 0.28 \pm 0.03$		-0.28 ± 0.19
117	ϕK^+	-0.05 ± 0.20	$-0.05 \pm 0.20 \pm 0.03$			-0.05 ± 0.20
120	ϕK^{*+}	$-0.43^{+0.36}_{-0.31}$	$0.16 \pm 0.17 \pm 0.04$			0.16 ± 0.17
131	$\pi^+\pi^0$		$-0.03^{+0.18}_{-0.17} \pm 0.02$	$0.30 \pm 0.30^{+0.30}_{-0.06}$		0.05 ± 0.15
143	$\omega\pi^+$	-0.21 ± 0.19	$-0.01^{+0.29}_{-0.31} \pm 0.03$		$-0.34 \pm 0.25 \pm 0.02$	-0.21 ± 0.19
88	$K^+\pi^-$	-0.09 ± 0.06	$-0.10 \pm 0.05 \pm 0.02$	$-0.06 \pm 0.09^{+0.09}_{-0.01}$	$-0.04 \pm 0.16 \pm 0.02$	-0.05 ± 0.05
89	$K^0\pi^0$		$0.03 \pm 0.36 \pm 0.09$			0.03 ± 0.37
99	$K^+\rho^-$		$0.19 \pm 0.14 \pm 0.11$			0.19 ± 0.18
103	$K^{*+}\pi^-$				$0.26^{+0.33+0.10}_{-0.34-0.08}$	$0.26^{+0.33+0.10}_{-0.34-0.08}$
115	ϕK^{*0}	0.00 ± 0.27	$0.04 \pm 0.12 \pm 0.02$			0.04 ± 0.12
53	$K^*\gamma$	-0.01 ± 0.07	$-0.044 \pm 0.076 \pm 0.012$	$-0.022 \pm 0.048 \pm 0.017$	$-0.08 \pm 0.13 \pm 0.03$	-0.03 ± 0.04

(In PDG 2002 New since PDG2002)

$B \rightarrow$non-charm Rate Asymmetries (New)

New since HFAG03,Winter:

A_{CP}	BaBar	Belle
$K^+\pi^-$		$-0.07 \pm 0.06 \pm 0.01$
$K^+\pi^0$		$0.23 \pm 0.11^{+0.01}_{-0.04}$
$K^0\pi^+$		$0.07^{+0.09+0.01}_{-0.08-0.03}$
$\pi^+\pi^0$		$-0.14 \pm 0.24^{+0.05}_{-0.04}$
$\eta\pi^+$	$-0.51^{+0.20}_{-0.18} \pm 0.01$	
ηK^+	$-0.32^{+0.22}_{-0.18} \pm 0.01$	
$\omega\pi^+$	$0.04 \pm 0.17 \pm 0.01$	$0.48^{+0.23}_{-0.20} \pm 0.02$
ωK^+	$-0.05 \pm 0.16 \pm 0.01$	$0.06^{+0.20}_{-0.18} \pm 0.01$
ϕK^+	$0.039 \pm 0.086 \pm 0.011$	$0.01 \pm 0.12 \pm 0.05$
$\rho^0\pi^+$	$-0.17 \pm 0.11 \pm 0.02$	
$\rho^+\pi^0$	$0.23 \pm 0.16 \pm 0.06$	
ρ^+K^-	$0.28 \pm 0.17 \pm 0.08$	$0.22^{+0.22+0.06}_{-0.23-0.02}$
$K^+\pi^-\pi^0$		$0.07 \pm 0.11 \pm 0.01$
$\pi^+\pi^-\pi^+$	$-0.39 \pm 0.33 \pm 0.12$	
$K^+\pi^-\pi^+$	$0.01 \pm 0.07 \pm 0.03$	
$K^+K^-K^+$	$0.02 \pm 0.07 \pm 0.03$	

Remarks on $B \to$non-charm Rate Asymmetries

- Some modes are penguine-dominated.
  ($K^0\pi^+$, $\eta' K^+$) $\to A_{CP} \sim 0$. OK.

- $A_{CP}(\eta\pi^+) = -0.51 \pm 0.20$ significant?
  $\eta\pi^+$,ηK^+, $\eta'\pi^+$ are thoretically expected to have large A_{CP}. Interesting to see more stat.

- Theoretical uncertainties are still large.

A_{CP}	exp.	PQCD	QCDF	Charming Penguin
$K^+\pi^-$	-0.08 ± 0.04	$-0.129 \sim -0.219$	0.05 ± 0.09	0.21 ± 0.22
$K^+\pi^0$	0.00 ± 0.07	$-0.100 \sim -0.173$	0.07 ± 0.09	0.22 ± 0.13
$K^0\pi^+$	0.02 ± 0.06	$-0.006 \sim 0.0015$	0.01 ± 0.01	0.0

Models do not agree well, except for $K^0\pi^+$ (penguin dom.).

Future Prospects

e^+e^- machines

- CLEO-c : 30M $D\bar{D}$'s (now running).
- Belle/BaBar : 3-400 fb^{-1} each by 2005 ($\times 5$ more than presented today)
- Proposed : Super-KEKB/Belle, Super-PEPII/BaBar.

	Super-Belle	Super-BaBar	now
$I_{\rm beam}(A)$	$3.5/8$	$9.6/22$	$1/1.5$
$\mathcal{L}(/cm^2s)$	$10^{35\sim36}$	10^{36}	10^{34}
Starts	~ 2007	~ 2010	
sensitivities	(1yr)	(1yr)	
$\sigma_{\sin 2\phi_{2\rm eff}}$	0.060	0.032	0.2
$\sigma_{\sin(2\phi_1+\phi_3)}$	0.077	0.030	0.3
$\sigma_{\phi_3}(DK)$	$\sim 10^\circ$	$\sim 2.5^\circ$	-
$N(X_s\nu\bar{\nu})$		160	
$N(\tau\nu)$		350	

General Purpose Detectors at Hadron Machines

1. Tevatron Run2. (CDF, D0)
   - 150 pb^{-1} now $\longrightarrow$ 4-5 fb^{-1} by LHC (2007)
   - With 2 fb^{-1} ($+B_s, \Lambda_b$ physics)

     $\sigma_{\sin 2\beta} \sim 0.06$ (~B-factory now, different sys.)

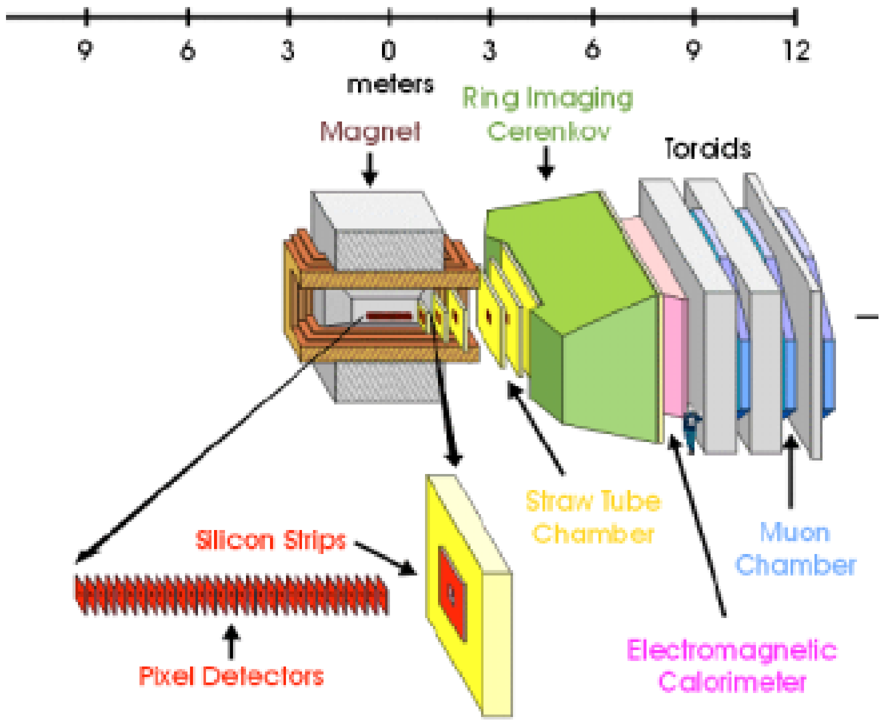
     $\sigma_{A_{CP}(K^+\pi^-)} \sim 1 \sim 10\%$.
2. LHC. (ATLAS, CMS)
   - B-physics while intensity is not too high.
   - $\sigma_{\sin 2\alpha_{\text{eff}}} \sim 0.09$ ($\#\pi^+\pi^- \sim 2.3K$)

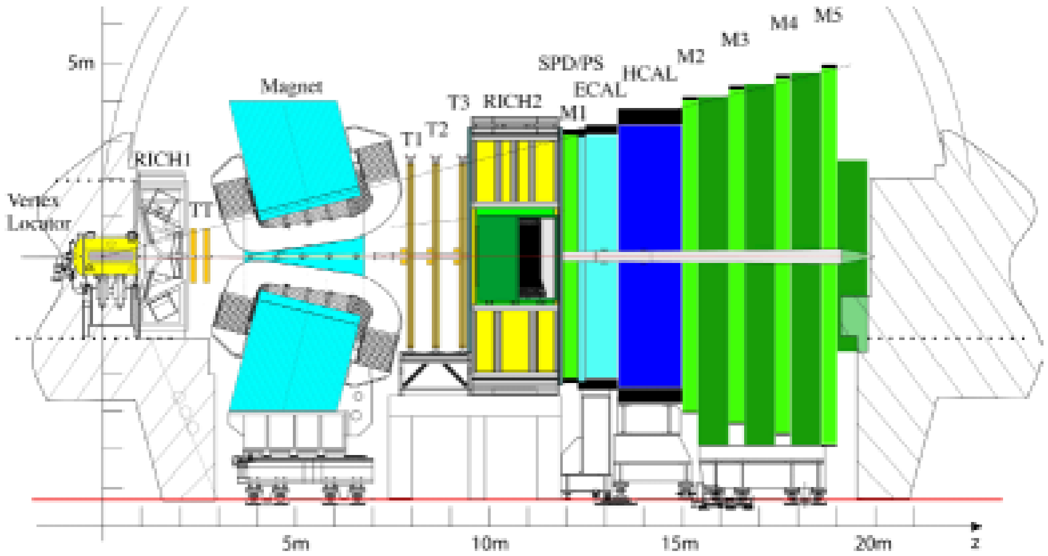
     Not as good as BTeV/LHCb.
   - $\#(B \longrightarrow \mu\mu) \sim 30$

     $\#(B \longrightarrow s\mu\mu) \sim 5K$

     As good as BTeV/LHCb

Dedicated B-Facilities at Hadron Machines





BTeV at Tevatron

$p\bar{p}$ at $E_{CM} = 2$ TeV

Approved by lab.

Pending P5 panel. 2009$\longrightarrow$

LHCb at LHC

pp at $E_{CM} = 14$ TeV

Under construction.

2007$\longrightarrow$

BTeV/LHCb Sensitivities/1yr(10^7s)

(#events sinsitivity)

	LHCb		BTeV	
$\sigma_{b\bar{b}}$		$500\mu b$		$100\mu b$
$\#b\bar{b}$		10^{12}		1.5×10^{11}
$B_d \to J/\Psi K_S$	$119K$	$\sigma_\beta \sim 0.6^\circ$	$168K$	$\sigma_{\sin 2\beta} \sim 0.017$
$B_d \to \rho^0\pi^0$			$0.78K$	$\sigma_\alpha \sim 4^\circ$
$\left\{ B_d \to \pi^+\pi^- \right.$	$27K$	$\sigma^*_\alpha \sim 5\text{-}10^\circ$	$14.6K$	$\sigma_A \sim 0.03$
$B_s \to K^+K^-$	$35K$		$18.9K$	$\sigma_A \sim 0.02$
$B_s \to D_s K$	$8K$	$\sigma_\gamma \sim 10^\circ$	$7.5K$	$\sigma_{\gamma-2\chi} \sim 8^\circ$
$B_s \to J/\Psi\phi$	$128K$	$\sigma_{2\delta\gamma} \sim 2^\circ$		
$B_s \to J/\Psi\eta/\eta'$			$12.6K$	$\sigma_{\sin 2\chi} \sim 0.024$

* Requires SU(3) modeling.

pros: B_s, PID, long decay lengths

Summary

- CPV in charmonium$K_{S,L}$ modes firmly established. $\sin 2(\phi_1/\beta) = 0.736 \pm 0.049$ cosistent with SM.
- Hint of deviation of "$\sin 2\phi_1$"(ϕK_S) from SM by Belle, but not by BaBar.
- HInt of direct CPV in $\pi^+\pi^-$ by Belle, but not by BaBar.
- Hint of direct CPV in $\rho^+\pi^-$ (BaBar).
- Accuracy of ϕ_3/γ by $D^{(*)}\pi$ modes is becoming meaningful.
- Sensitivity in A_{CP} of DK modes is approaching interesting region.
- No clear direct CPV in rate asymmetries A_{CP}, except for some hint in $\eta\pi^+$.