Recent Belle Results

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Representing the Belle collaboration

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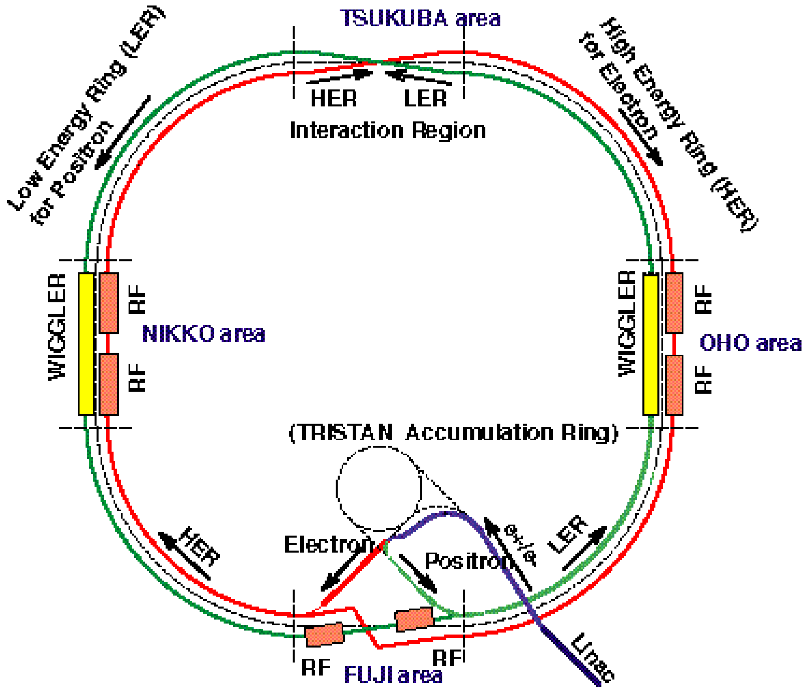
Plan

CPV phase angle map :
$$\phi_1 = \beta$$
$$\phi_2 = \alpha$$
$$\phi_3 = \gamma$$

1. ϕ_1-related modes
2. $\pi^+\pi^-$ analysis (ϕ_2)
3. Modes useful for ϕ_3
4. $b \to s$ radiative decays ($b \to s\gamma$, $b \to s\ell\ell$)
5. Understanding basic B decay mechanisms and long-distance QCD
6. CKM matrix elements (→ G.Majumder's talk)

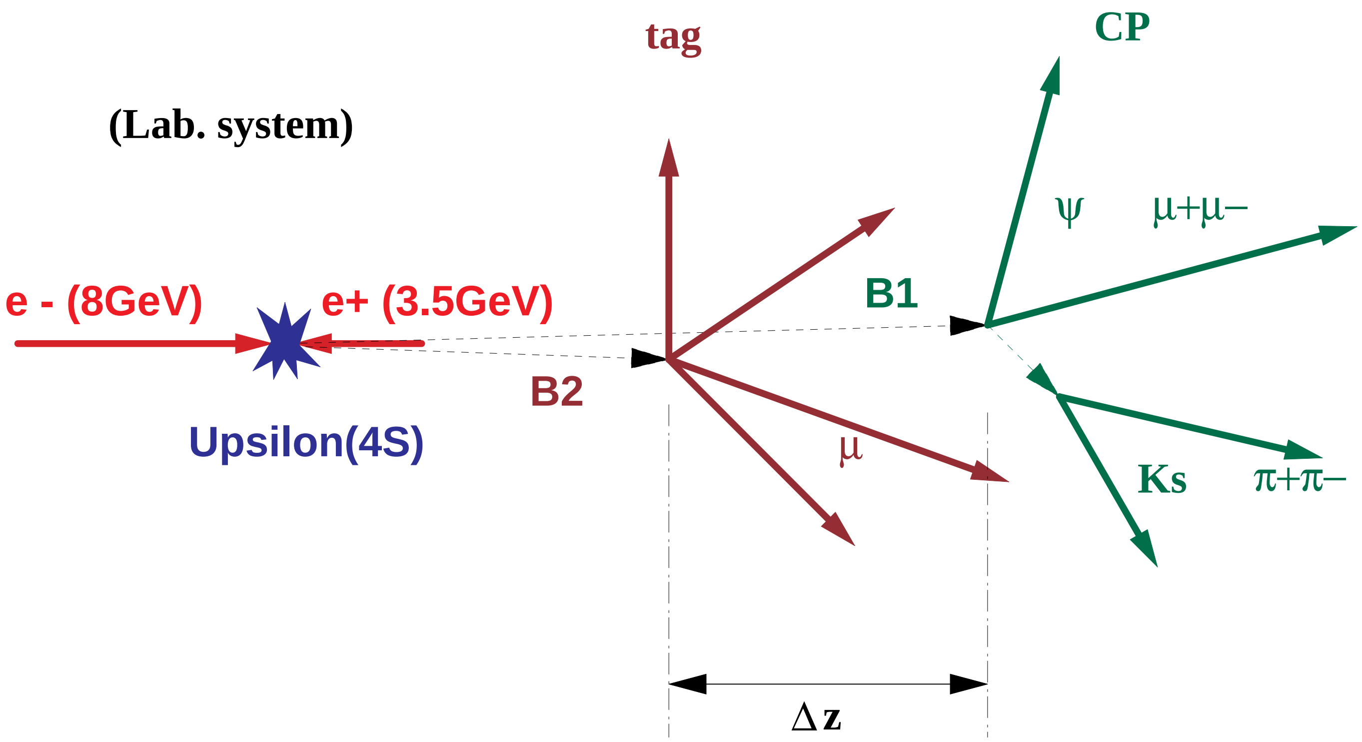
KEKB Performance



Belle-recoded luminosities	
$\int \mathcal{L}dt/\text{day}_{\max}$	$434\ \text{pb}^{-1}$
$\int \mathcal{L}dt/\text{week}_{\max}$	$2.48\ \text{fb}^{-1}$
$\int \mathcal{L}dt/\text{month}_{\max}$	$8.62\ \text{fb}^{-1}$
$\int \mathcal{L}dt/\text{total}$	$101.7\ \text{fb}^{-1}$
$\mathcal{L}_{\max}$	$8.26 \times 10^{33}/\text{cm}^2\text{s}$

About to restart after a 2-month shoutdown to replace the IP beampipe. Dead SVD channels fixed.

Measurement of $\sin 2\phi_1$ (78fb^{-1})



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

(t: decay time in the B rest frame)

CP-side Reconstruction

CP mode	CP	N_{evt}	purity
ΨK_S	$-$	1278	0.96
$\Psi' K_S$	$-$	172	0.93
$\chi_{c1} K_S$	$-$	67	0.96
$\eta_c K_S$	$-$	122	0.71
$CP-$ total		1639	0.94
ΨK_L	$+$	1230	0.63
$\Psi K^{*0}(\rightarrow K_S \pi^0)$	$+/-$	89	0.92

Detection modes
$\Psi \rightarrow \ell^+\ell^-$ $(\ell = e, \mu)$
$K_S \rightarrow \begin{cases} \pi^+\pi^- \\ \pi^0\pi^0 (\Psi K_S \text{ only}) \end{cases}$
$\Psi' \rightarrow \ell^+\ell^-, \Psi\pi^+\pi^-$
$\chi_{c1} \rightarrow \Psi\gamma$
$\eta_c \rightarrow K^+K^-\pi^0, K_S K^-\pi^+, p\bar{p}$

2958 events total

(all flavor-tagged and vertexes reconstructed)

Full B Reconstruction

(When all B decay products are detected)

(In this talk, all E's and $\vec{P}$'s are in the $\Upsilon 4S$ frame.)

$$B \longrightarrow f_1 \cdots f_n$$

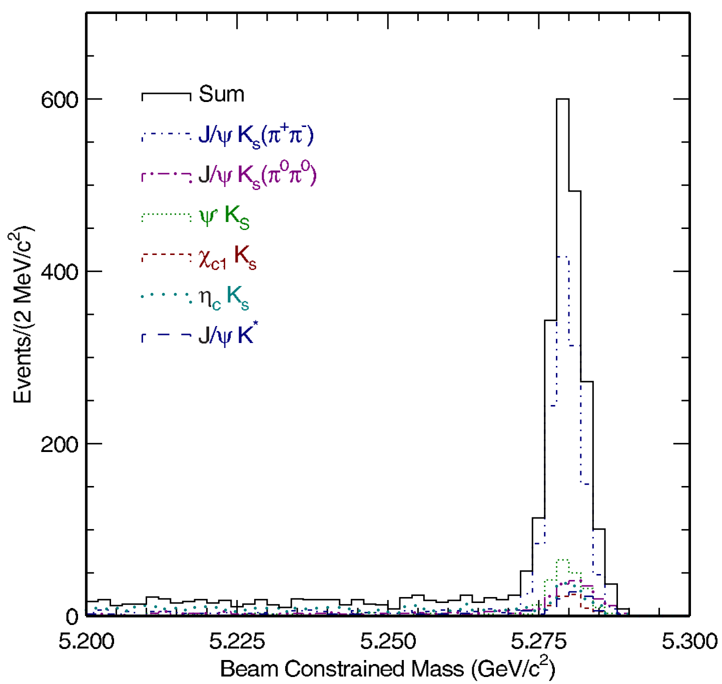
$E_B = 5.28$ GeV and $|\vec{P}_B| = 0.35$ GeV/c are known.

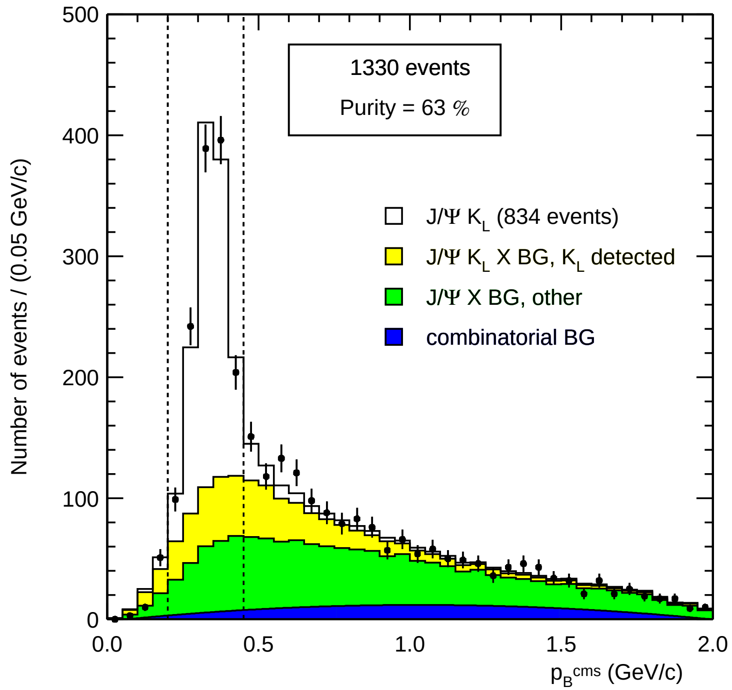
Use energy-momentum conservation:

- $E_{\text{tot}} = \Sigma_i^n E_i$
  $\longrightarrow \Delta E \equiv E_{\text{tot}} - E_{\text{beam}}$ (Energy difference)

- $\vec{P}_{\text{tot}} = \Sigma_i^n \vec{P}_i$
  $\longrightarrow M_{bc} \equiv \sqrt{E_{\text{beam}}^2 - P_{\text{tot}}^2}$ (beam-constrained mass)
  Same M_{bc} for different E_{beam}.

$CP-$ modes $(+J/\Psi K^*)$ $\qquad$ $J/\Psi K_L$ $(CP+)$





M_{bc} (beam constrained mass)

Tagging of B Flavor

What distinguish B^0 and $\bar{B}^0$?

1. Leptons (e, μ)

   - $b \longrightarrow \ell^-$: high-P lepton.
   - $b \longrightarrow c \longrightarrow \ell^+$: low-P lepton.

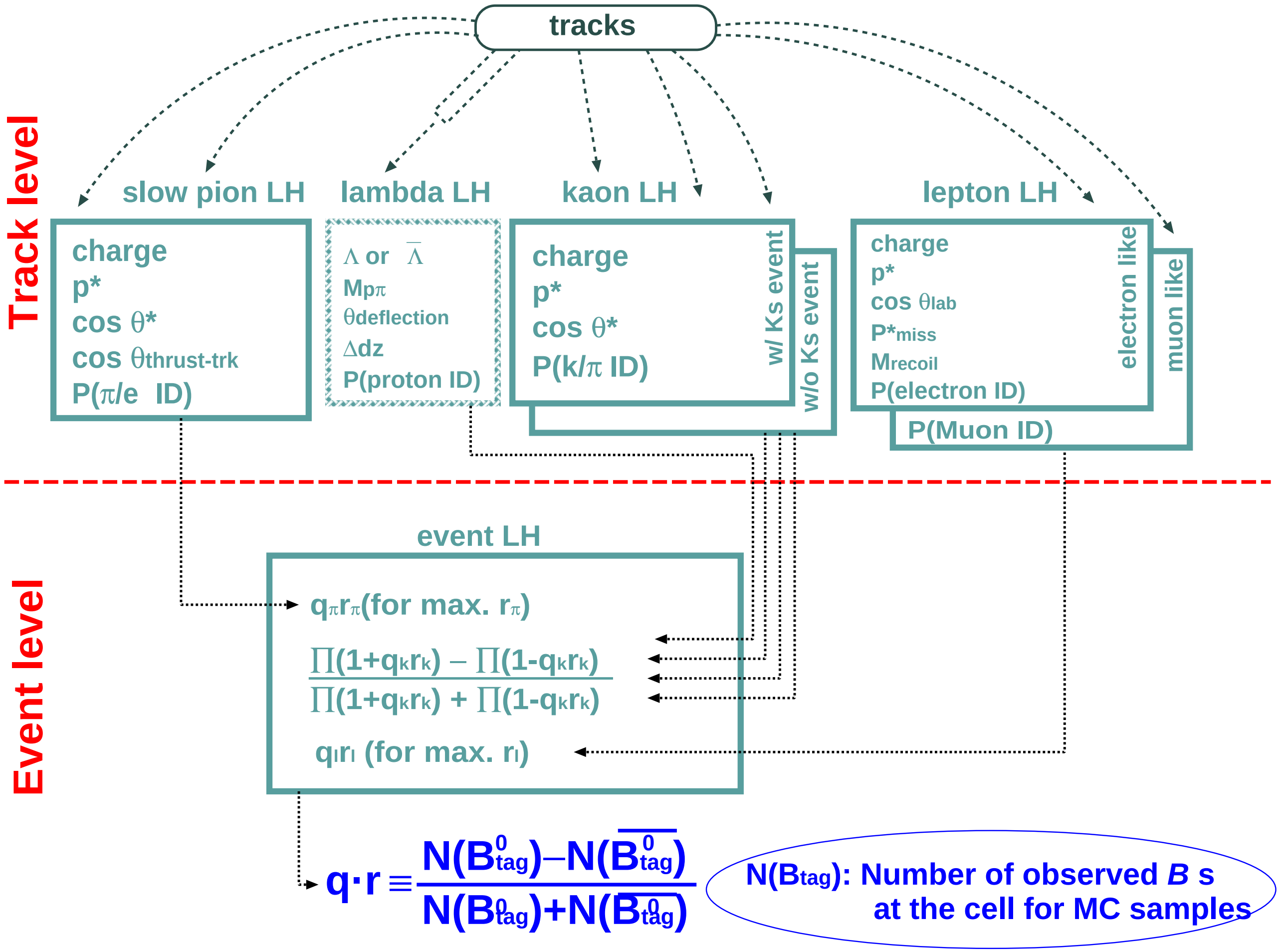
2. Charged kaons. $b \longrightarrow c \longrightarrow s(K^-)$

3. $\Lambda(\longrightarrow p\pi^-)$. $b \longrightarrow c \longrightarrow s(\Lambda)$

4. Charged pions.

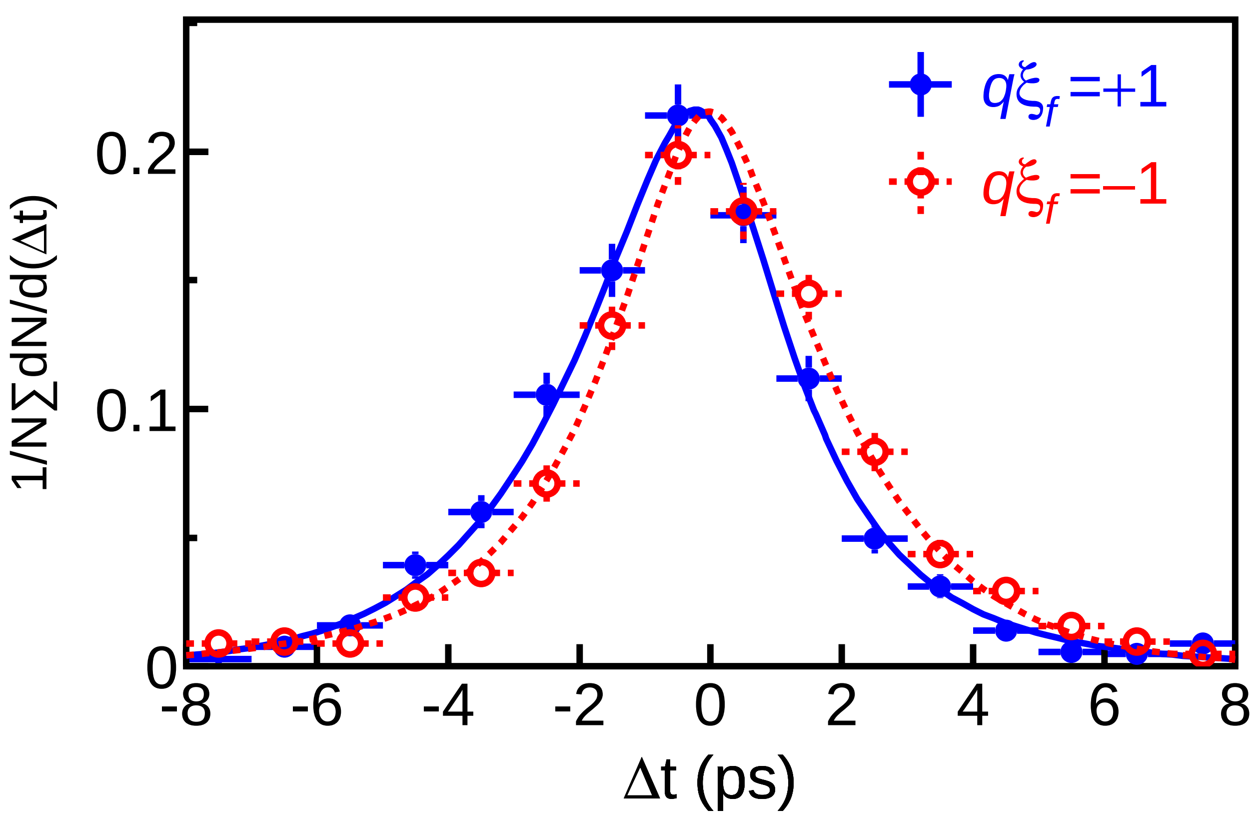
   - $\bar{B} \longrightarrow D^{(*)}\pi^-$ etc.: high-P pion.
   - $b \longrightarrow D^{*+} \longrightarrow D^0\pi^+$: low-P pion.

Multi-dimentional likelihood tagging



$$q\cdot r \equiv \frac{N(B^0_{tag}) - N(\overline{B^0_{tag}})}{N(B^0_{tag}) + N(\overline{B^0_{tag}})}$$

$q=+1$ **Tag side is** B^0
$q=-1$ **Tag side is** $\bar{B}^0$, ξ_f : CP eigenvalue



We observed:

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

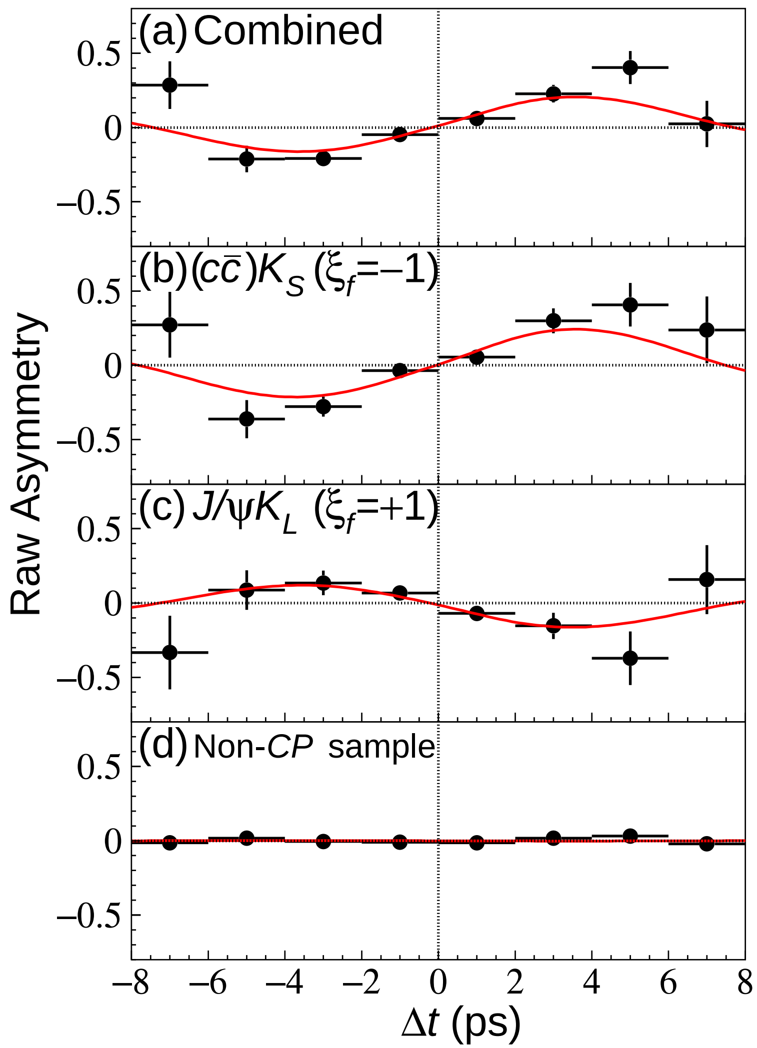
$$\Big\downarrow$$

$$CP\begin{cases}\text{particle}\leftrightarrow\text{antiparticle}\\ \text{mirror inversion (no effect)}\end{cases}$$

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

:Inconsistent with observation.

$\longrightarrow CP$ violation



$$A_{CP}(t) \equiv \frac{\Gamma_{B^0\text{tag}} - \Gamma_{\bar{B}^0\text{tag}}}{\Gamma_{B^0\text{tag}} + \Gamma_{\bar{B}^0\text{tag}}}$$

$$= d\,\xi_f \sin 2\phi_1 \sin \delta m\, \Delta t$$

$(d :$ dilution$)$

Unbinned likelihood fit:

$$\boxed{\sin 2\phi_1 = 0.719 \pm 0.074 \pm 0.035}$$

(Belle 78 fb^{-1})

Non-CP: Flavor-specific B^0 decays

$D^{(*)}\pi^{(*)}, J/\Psi K^{*0}(K^+\pi^-), D^*\ell\nu$

General form:

$$\frac{d\Gamma}{d\Delta t} \propto e^{-\frac{|\Delta t|}{\tau_B}} \left[1 + qd(S \sin \delta m \Delta t + A \cos \delta m \Delta t)\right]$$

$$S \equiv \frac{2\,\mathrm{Im}\lambda}{|\lambda|^2 + 1}, \qquad A \equiv \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}, \qquad \lambda \equiv \frac{q_B A(\bar{B}^0 \to f)}{p_B A(B^0 \to f)}$$

$$\begin{pmatrix} B_H = p_B B^0 + q_B \bar{B}^0 \\ B_L = p_B B^0 - q_B \bar{B}^0 \end{pmatrix}$$

In SM: expect

$$S \sim -\xi_f \sin 2\phi_1 \,, \qquad |\lambda| \sim 1 \;\; (\text{or } \; A \sim 0)$$

The final state CP sign is included in the def. of S

$$\left|\frac{p_B}{q_B}\right| \sim 1 \text{ experimentally:}$$

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

(direct CPV)

Fit results:

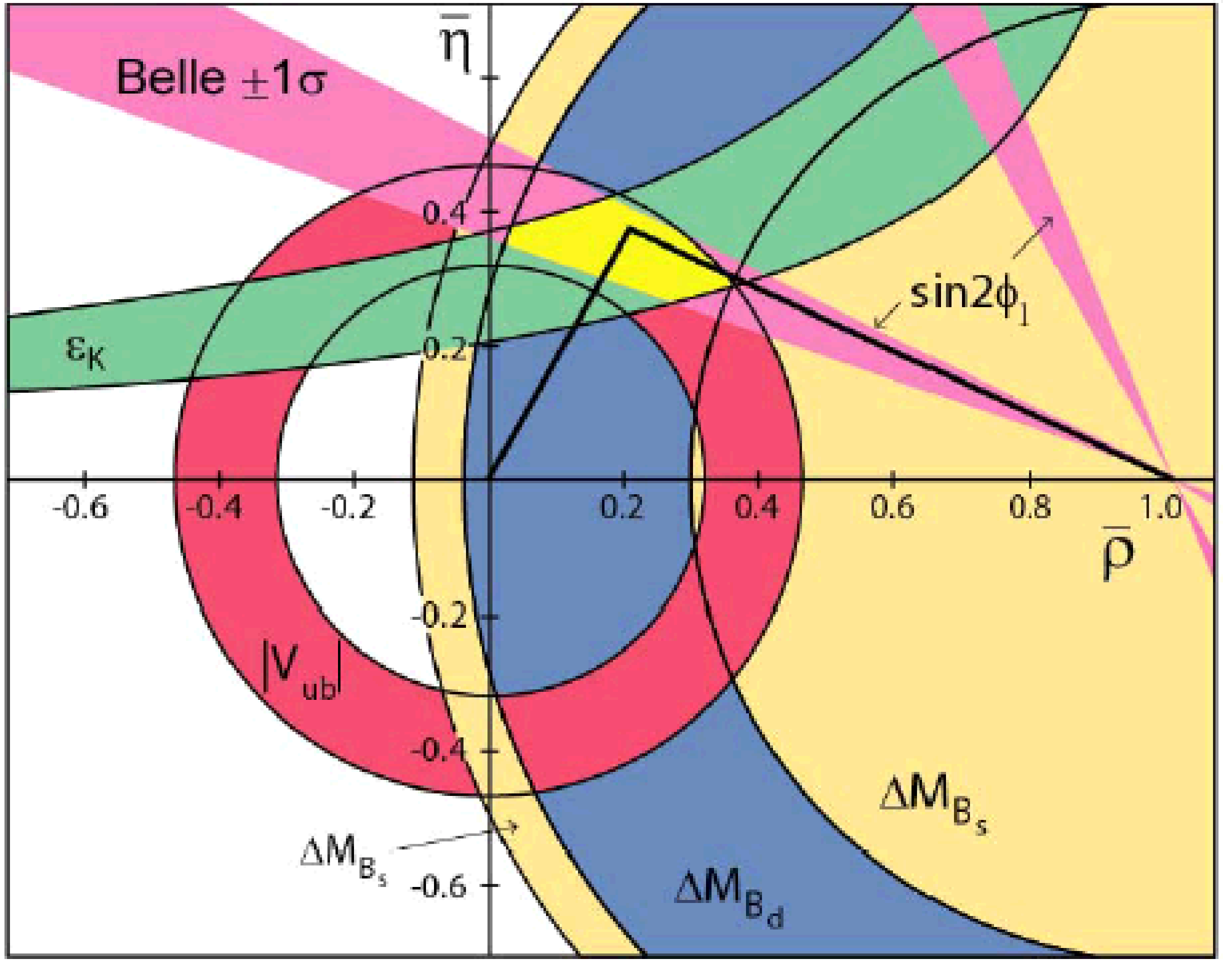
$$S = 0.720 \pm 0.074(\text{stat})$$

$$|\lambda| = 0.950 \pm 0.049(\text{stat}) \pm 0.025(\text{sys})$$

No indication of direct CPV

in the (charmonium)$K_{S/L}$ modes.

PDG2002 + this result

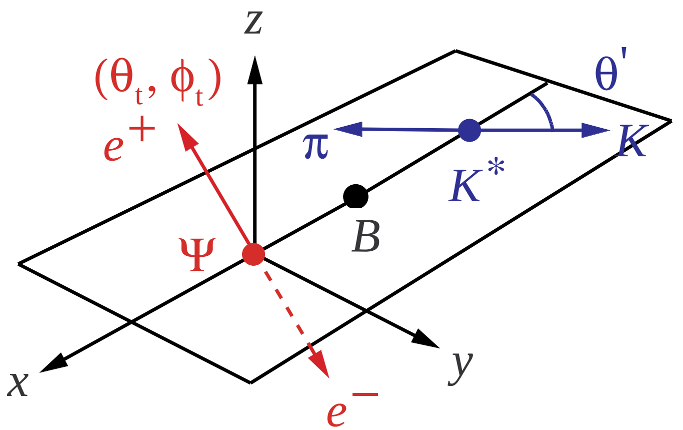


CP contents in $\Psi K^{*0}(\to K_S \pi^0)$

B (spin-0) $\to$ Ψ (spin-1) K^{*0} (spin-1)

3 polarization states: helicities $= (++, --, 00) \to A_{\|}, A_0, A_{\perp}$

Extract P (CP) contents by full angular analysis of the isospin-related modes.



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

$\lvert A_0\rvert^2$	0.617 ± 0.020
$\lvert A_{\perp}\rvert^2$	0.192 ± 0.023
$\arg(A_{\|})$	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)

Time-dependent CPV of $\Psi K^{*0}(\to K_S\pi^0)$ (78fb^{-1})

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

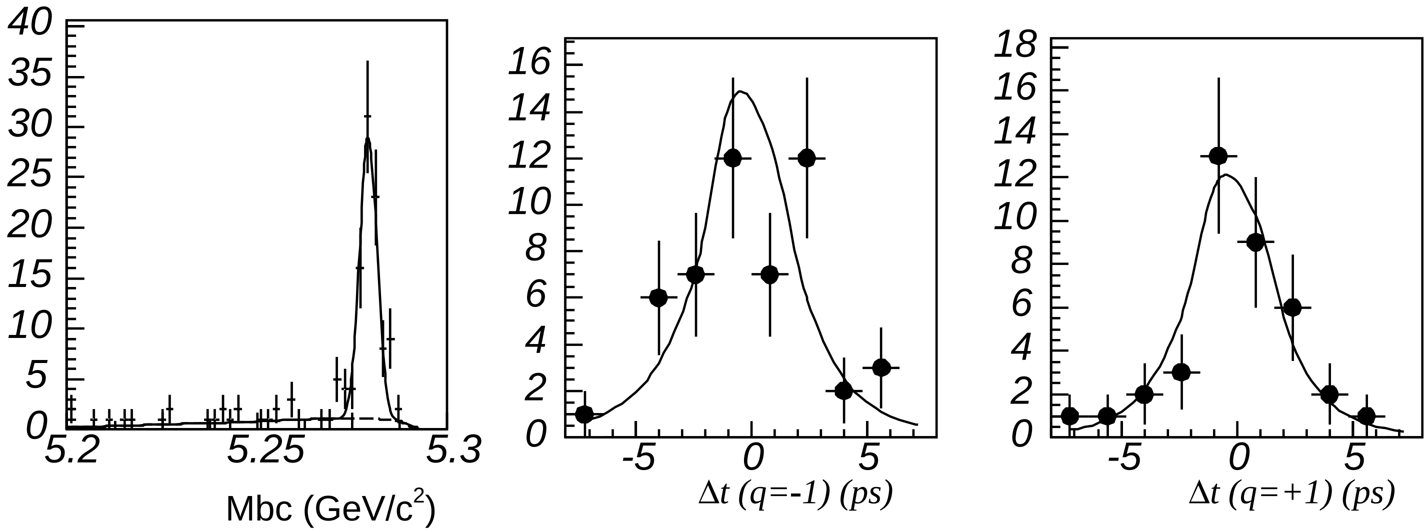
$$\vec{\theta} \equiv (\cos\theta_t, \phi_t, \cos\theta')$$

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

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

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

Time-dependent CPV of $\Psi K^{*0}(\to K_S\pi^0)$



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:

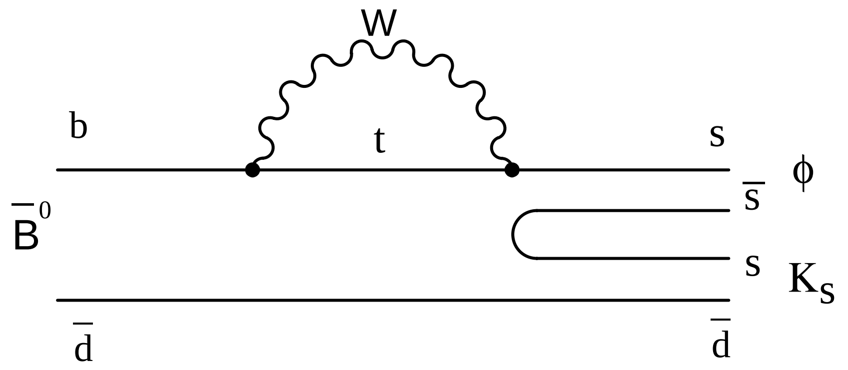
$$\cos 2\phi_1 = 1.02 \pm 1.05 \pm 0.19\,.$$

Time-dependent CPV of $b \to s$ penguin modes (78fb^{-1})

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

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

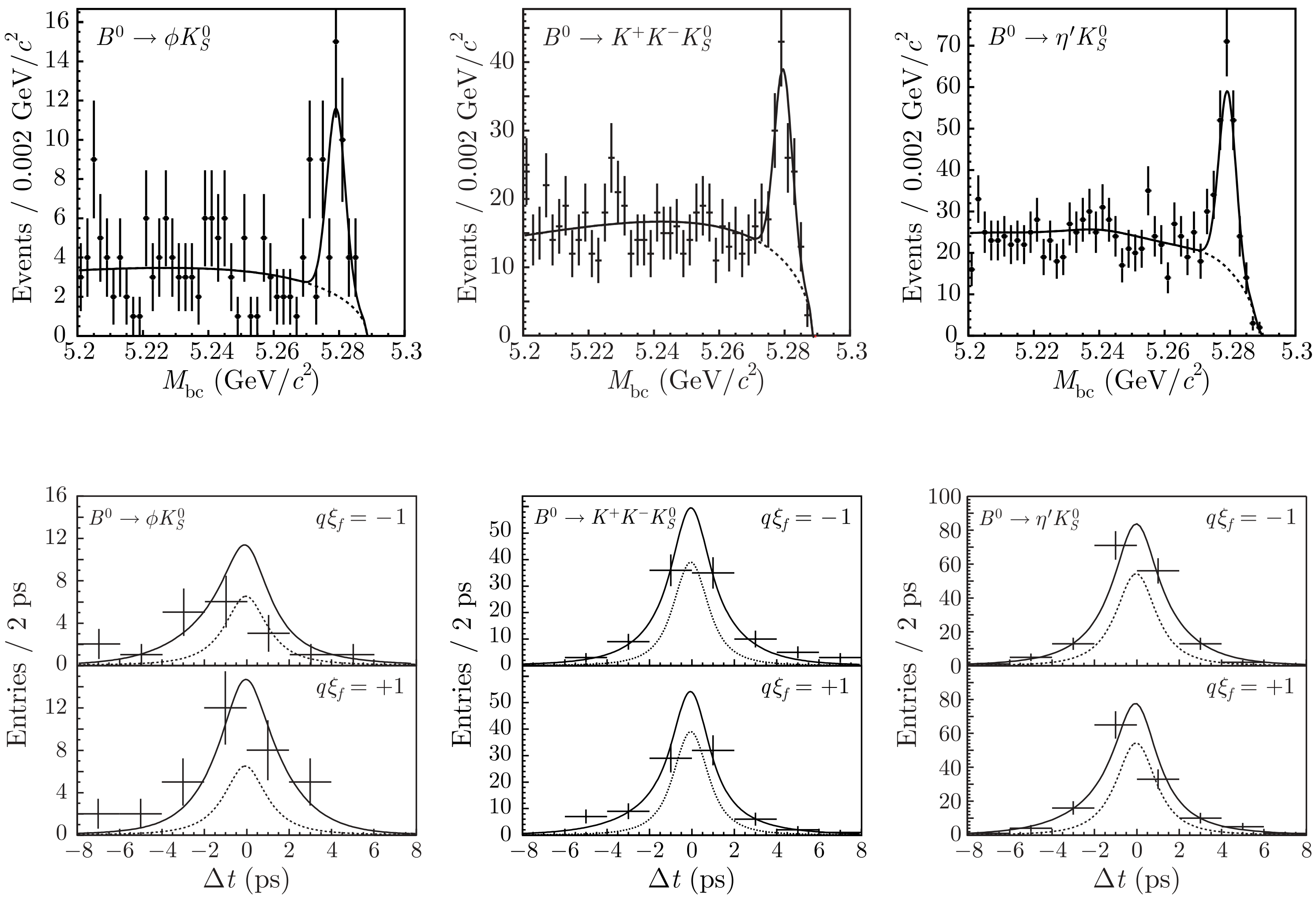
Deviation therefrom $\to$ new physics in $b \to s$
(e.g. the W-loop replaced by a charged Higgs loop)



Continuum Suppression

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

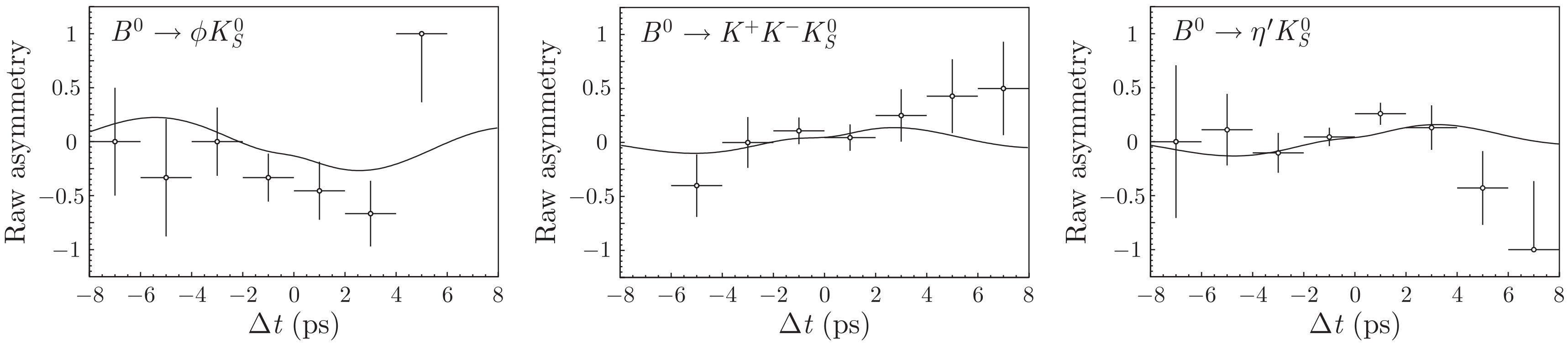
- Event shape variables: Fox-Wolfram R_l, thrust, etc.
  continuum: skinny, $B\bar{B}$: spherical.
- Angle(B candidate axis, axis of the rest)
  continuum: aligned, $B\bar{B}$: uniform.
- Angle(B, beam)
  continuum: $1+\cos^2\theta$, B: $\sin^2\theta$.
- Fisher: $F = \Sigma_i c_i X_i$ (above+X_i energy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



$B^0 \to \phi K_S^0$
$B^0 \to K^+K^-K_S^0$
$B^0 \to \eta' K_S^0$
Events / 0.002 GeV/c^2
$M_{\rm bc}$ (GeV/c^2)
$q\xi_f = -1$
$q\xi_f = +1$
Entries / 2 ps
Δt (ps)

$$A_{cp}(\Delta t) = d(S \sin \delta m \Delta t + A \cos \delta m \Delta t)$$

Plot $-\xi_f A_{cp}$:



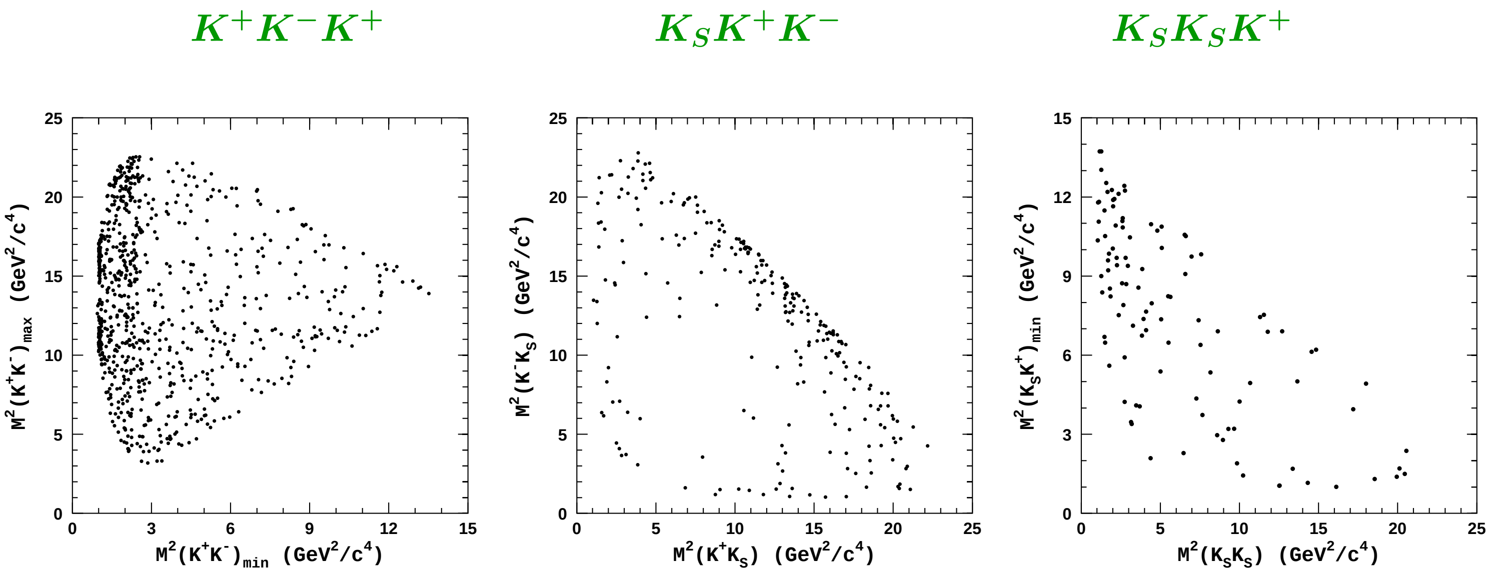
(78fb^{-1})	"$\sin 2\phi_1$"$(-\xi_f S)$	A
ϕK_S	$-0.73 \pm 0.64 \pm 0.22$	$-0.56 \pm 0.41 \pm 0.16$
$K^+K^-K_S$(non res.)	$+0.49 \pm 0.43 \pm 0.11^{+0.33}_{-0}$	$-0.40 \pm 0.33 \pm 0.10^{+0}_{-0.26}$
$\eta' K_S$	$+0.71 \pm 0.37^{+0.05}_{-0.06}$	$+0.26 \pm 0.22 \pm 0.03$
$J/\Psi K_{S/L}$ etc.	0.720 ± 0.074	-0.050 ± 0.049

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

CP content of $K^+K^-K_S$

(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	$8.4 \pm 5.2 (< 15)$



$(K^+K^-)K_S$ 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,

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

$$\Big\downarrow$$

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

$$\downarrow$$

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

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

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

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

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

Other ϕ_1-related modes

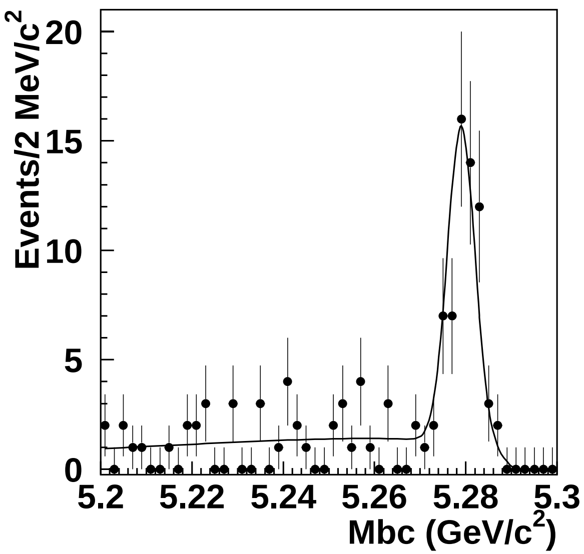
$b \to c\bar{c}d(s)$ **tree process**
($b \to c\bar{c}d$**: penguin has** V_{td} **phase)**

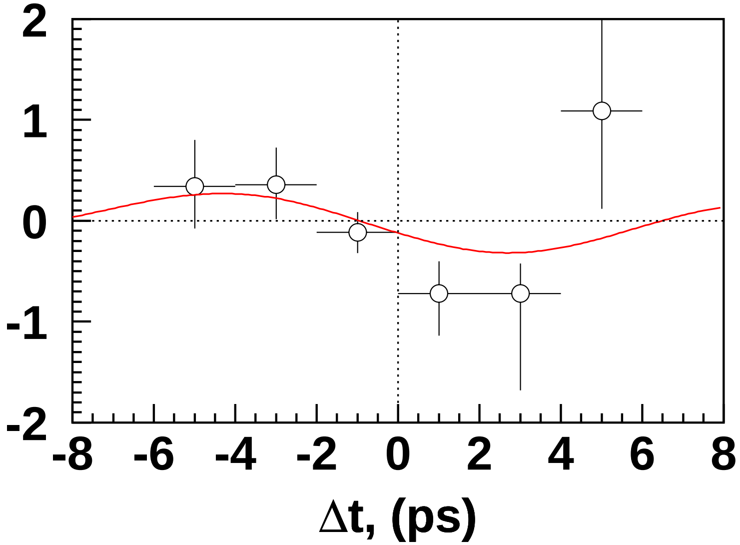
- $J/\Psi\pi^0(CP+), D^+D^-(CP+), D^{*+}D^{*-}(CP\pm)$
  ($b \to c\bar{c}d$**):**
  $-\xi_f S \sim \sin 2\phi_1$
- $D^{*+}D^-$ **(**$b \to c\bar{c}d$**),** $D^{(*)+}D^{(*)-}K_S$ **(**$b \to c\bar{c}s$**):**
  CP**-diluted.**
  $r \equiv |Amp(\bar{B}^0 \to f)/Amp(B^0 \to f)| \neq 1$ **in general.**
  $-\xi_f S \sim r \sin(2\phi_1 + \delta_{\mathrm{strong}})$

Time-dependent CPV of $\Psi\pi^0$

(Belle 78 fb^{-1}, Preliminary)

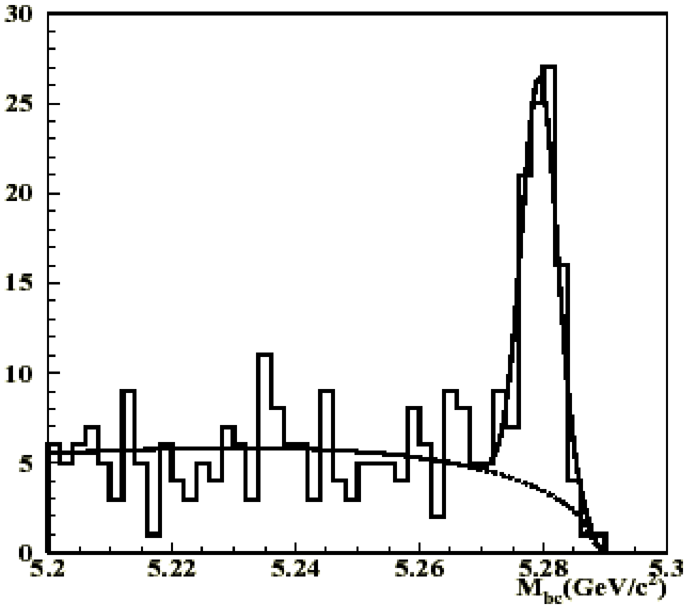
$\mathcal{B}(J/\Psi\pi^0) = (2.0 \pm 0.3 \pm 0.2) \times 10^{-5}$

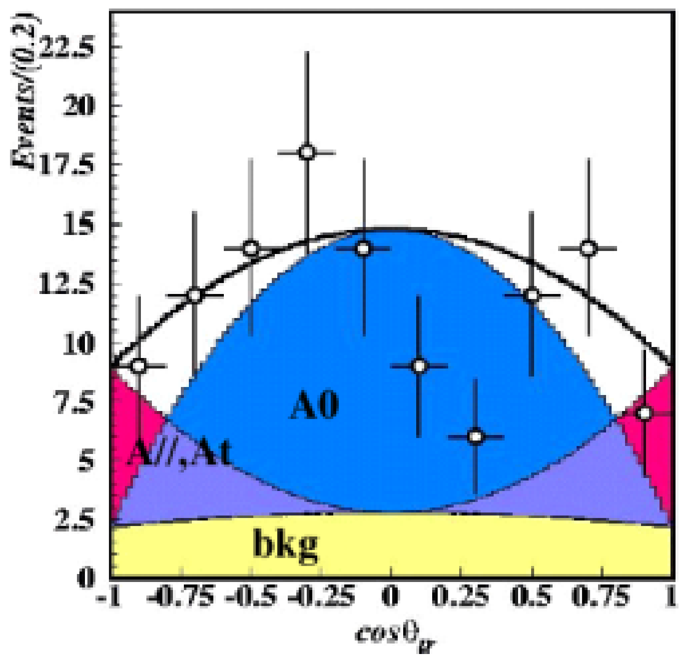




$$-\xi_f S(\text{“}\sin 2\phi_1\text{”}) = 0.93 \pm 0.49 \pm 0.08\,, \qquad A = -0.25 \pm 0.39 \pm 0.06$$

$B \to D^{*+}D^{*-}$ (78 fb^{-1})





- $\mathcal{B}(D^{*+}D^{*-}) = (7.6 \pm 0.9 \pm 0.4) \times 10^{-4}$.
- **Helicity-0 is dominant.**

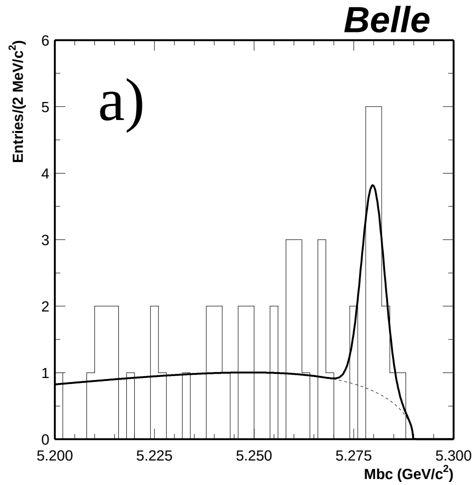
$D^{*+}D^-$ $(D^{*+} \to D^0\pi_{\rm slow})$

Full reconstruction:

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

$$Br(B^0 \to D^{*\pm}D^{\mp}) = (1.17 \pm 0.26^{+0.22}_{-0.25}) \times 10^{-3}$$

$$(29.4\text{fb}^{-1})$$

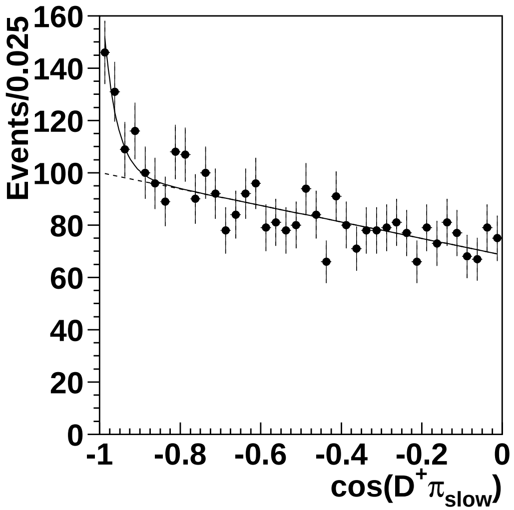


Partial reconstruction:

D^- and π^+_{slow} back-to-back
No reconstruction of D^0.

$$Br(B^0 \to D^{*\pm}D^{\mp}) = (1.25 \pm 0.28) \times 10^{-3}$$

$$(78\text{fb}^{-1})$$



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

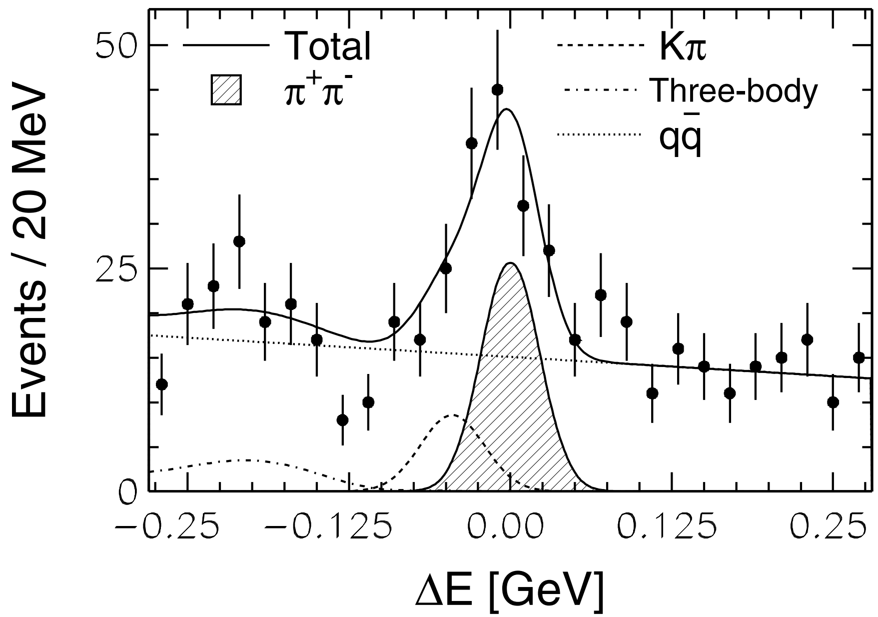
$$\frac{d\Gamma}{d\Delta t} \propto e^{-\frac{|\Delta t|}{\tau_B}} \left[1 + qd(S_{\pi\pi} \sin \delta m \Delta t + A_{\pi\pi} \cos \delta m \Delta t)\right]$$

$S_{\pi\pi}$: $\Delta t \pm$ asymmetry
$A_{\pi\pi}$: $q \pm$ (i.e. $B^0/\bar{B}^0$) asymmetry

$S_{\pi\pi} = \sin 2\phi_1$ if SM no penguin polution
$A_{\pi\pi} = 0$ if no direct CPV

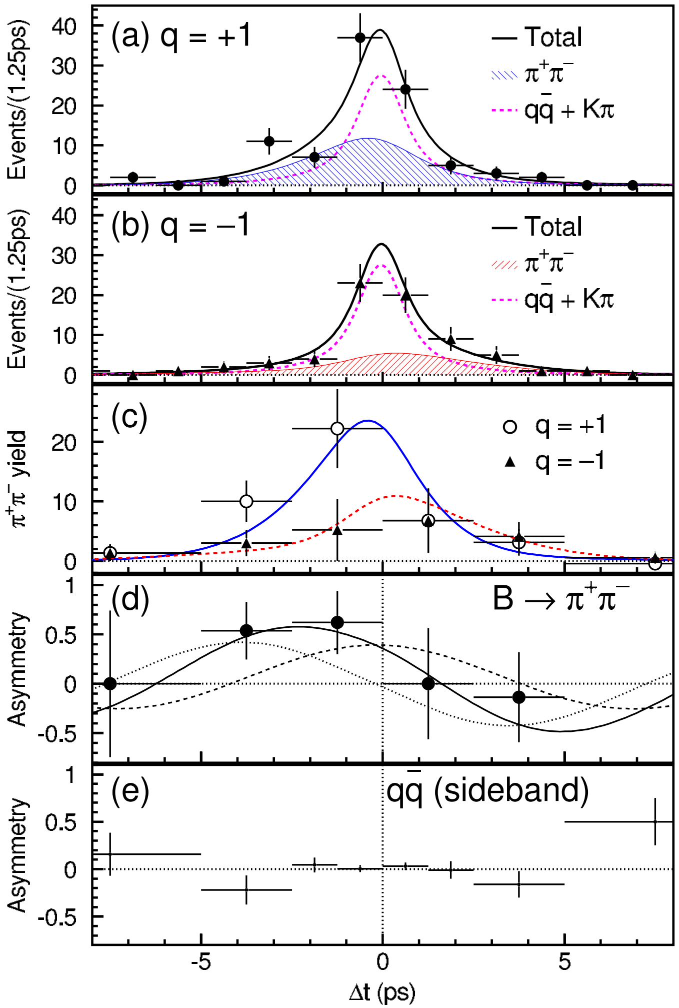
[Note: $S_{\pi\pi}$ (Belle) = $S_{\pi\pi}$ (Babar)
$A_{\pi\pi}$ (Belle) = $-C_{\pi\pi}$ (Babar)]

$\pi^+\pi^-$ (Belle 41.8 fb^{-1})



- 73.5 $\pi\pi$ signal, 28.4 $K\pi$, 98.7 continuum ($q\bar{q}$).
- 3-body bkg (3π etc.) negligible in the signal region.

$\pi^+\pi^-$ Δt fit



- 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.

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

$$S_{\pi\pi} = -1.21^{+0.38+0.16}_{-0.27-0.13}$$

$$A_{\pi\pi} = +0.94^{+0.25}_{-0.31} \pm 0.09$$

(Belle 41.8 fb^{-1})

$A_{\pi\pi}$: indication of direct CPV.

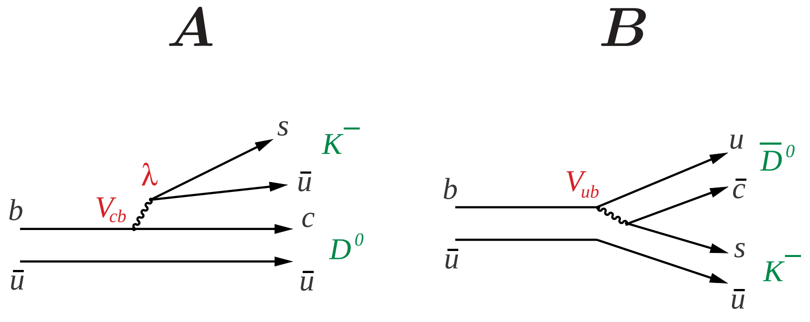
Modes useful for ϕ_3

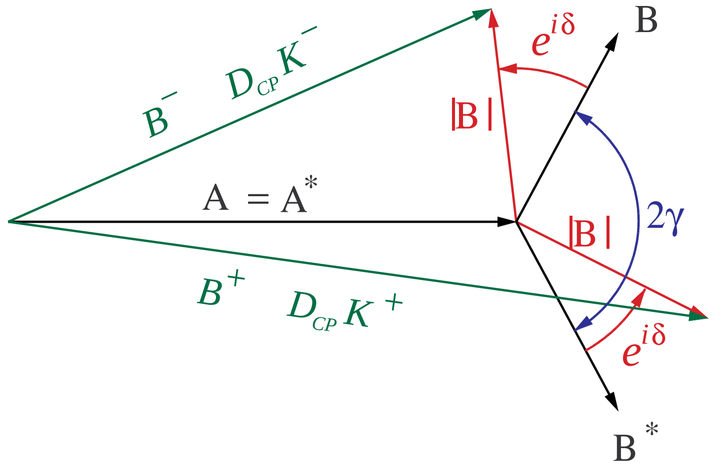
$$B^- \to D_{CP} K^-$$

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

$r \equiv \frac{|B|}{|A|} \sim 0.1$
$\sim 10\%$ asymmetry expected.
Depends on strong phase δ.

Eventually extract γ
(No penguin polution)

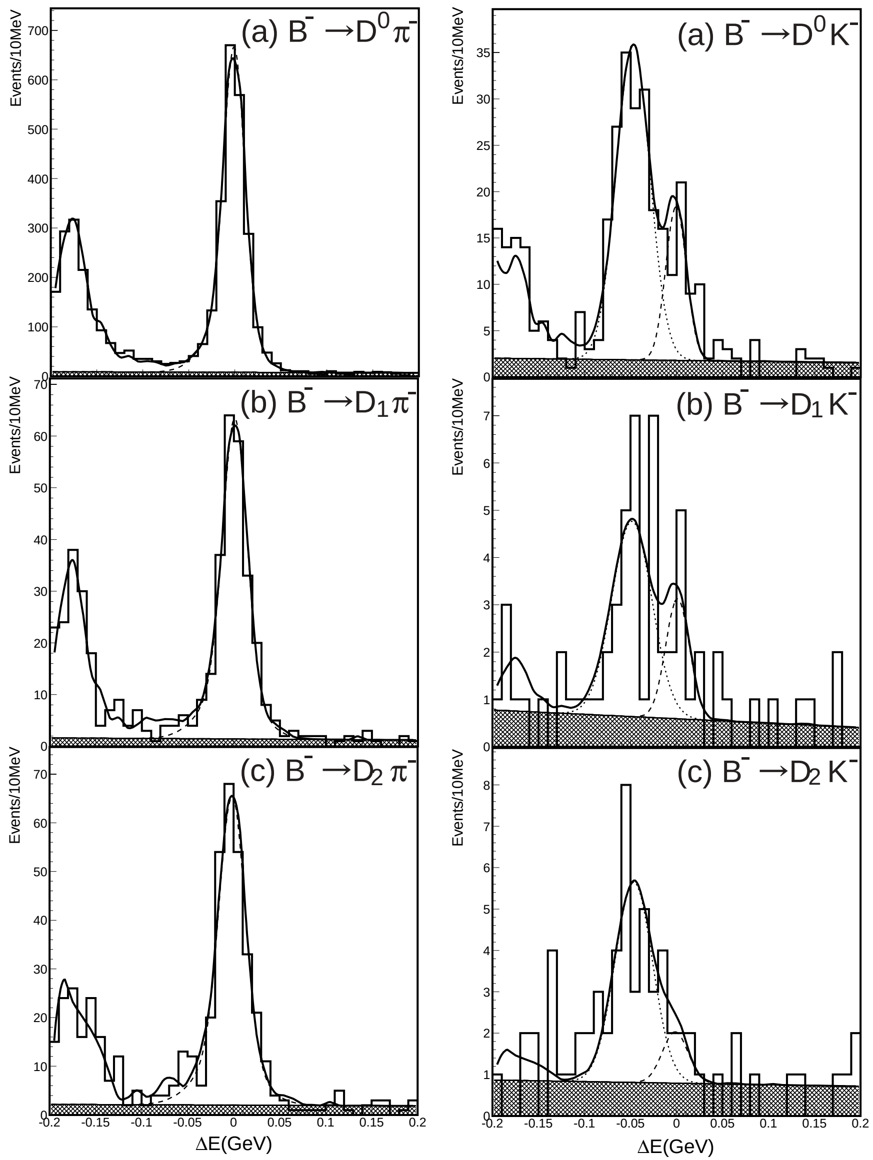




$B^- \to D_{CP}K^-$ (29.1 fb^{-1})

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

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



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

(Belle 29.1 fb^{-1})

	$CP+$	$CP-$
A_{CP}	$A_1 = 0.29 \pm 0.26 \pm 0.05$ $-0.14 < A_1 < 0.79$	$A_2 = -0.22 \pm 0.24 \pm 0.04$ $-0.60 < A_2 < 0.21$
R_{CP}	$R_1 = 1.38 \pm 0.38 \pm 0.15$	$R_2 = 1.37 \pm 0.36 \pm 0.12$

$$R_i \equiv \frac{Br(B^\pm \to D_i K^\pm)/Br(B^\pm \to D_i \pi^\pm)}{Br(B^\pm \to D^0 K^\pm)/Br(B^\pm \to D^0 \pi^\pm)}$$

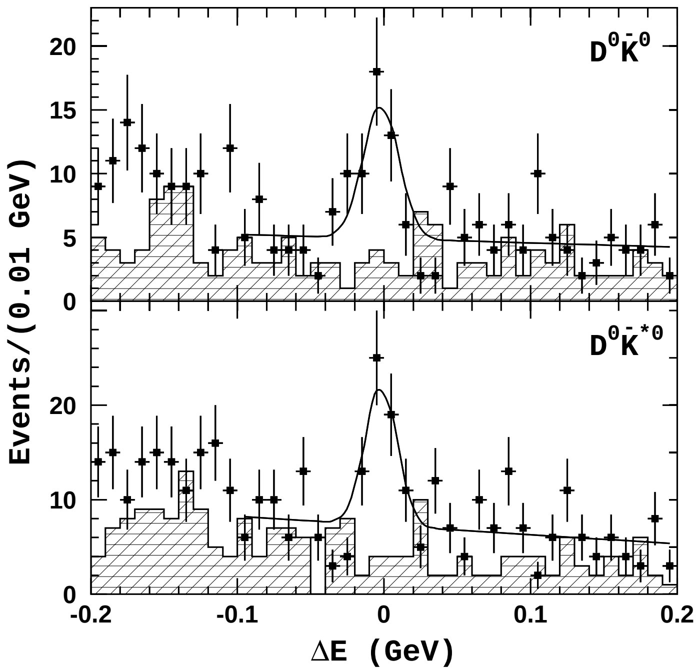
(Cabibbo suppression factor ratio, D_{CP} vs D^0: expect ~ 1.)

$A_1 \sim -A_2$ expected (to order r)

$$\left[\frac{A_1 - A_2}{2} = 2r \sin\delta \sin\phi_3 \text{ (order } r^2) = 0.26 \pm 0.18 \ (stat)\right]$$

Still consistent with no asymmetry.

$\bar{B}^0 \to D^0\bar{K}^0, D^0\bar{K}^{*0}$ (Belle 78 fb^{-1})

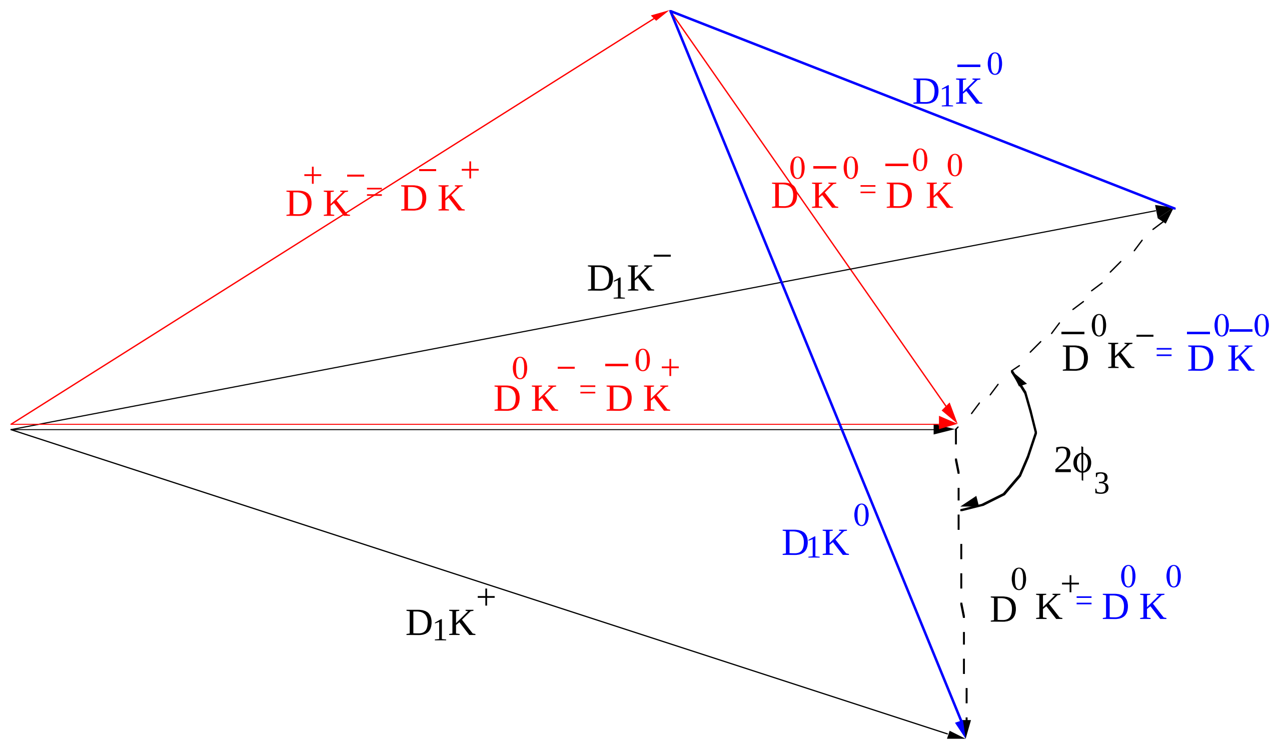


- Time-dependent analysis possible.
- $D_{cp}\bar{K}^{*0}(\bar{K}^{*0} \to K^-\pi^+)$ may have a large A_{cp}.
  (“r” ~ 0.5 instead of ~ 0.1).
- Needed for the Jang-Ko method of extracting ϕ_3.

mode	$\mathcal{B}(90\%U.L.)(10^{-5})$
$D^0\bar{K}^0$	$5.0^{+1.3}_{-1.2} \pm 0.6$
$D^0\bar{K}^{*0}$	$4.8^{+1.1}_{-1.0} \pm 0.5$
$D^{*0}\bar{K}^0$	(< 6.6)
$D^{*0}\bar{K}^{*0}$	(< 6.9)
D^0K^{*-}	$5.4 \pm 0.6 \pm 0.8$

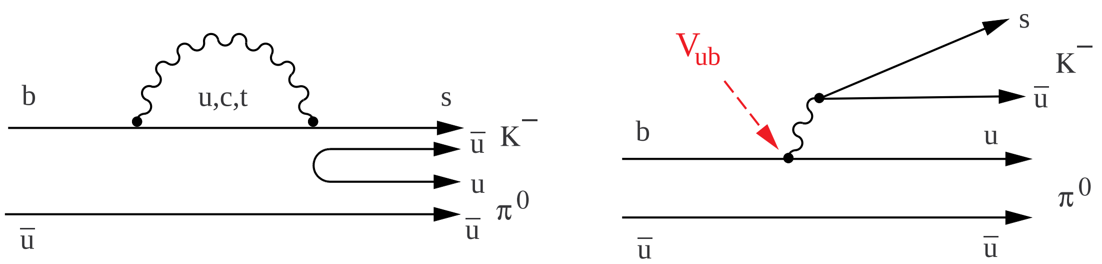
Jang-Ko method of extracting ϕ_3

(assumes no annihilation)



$B \to \pi\pi / K\pi / KK$

Direct CPV by tree-penguin interference.



Statistically more favorable than DK modes,
but theoretically challenging.

Future: use theoretical expressions (QCD factorization etc.)
for multiple modes and perform fit for ϕ_3.

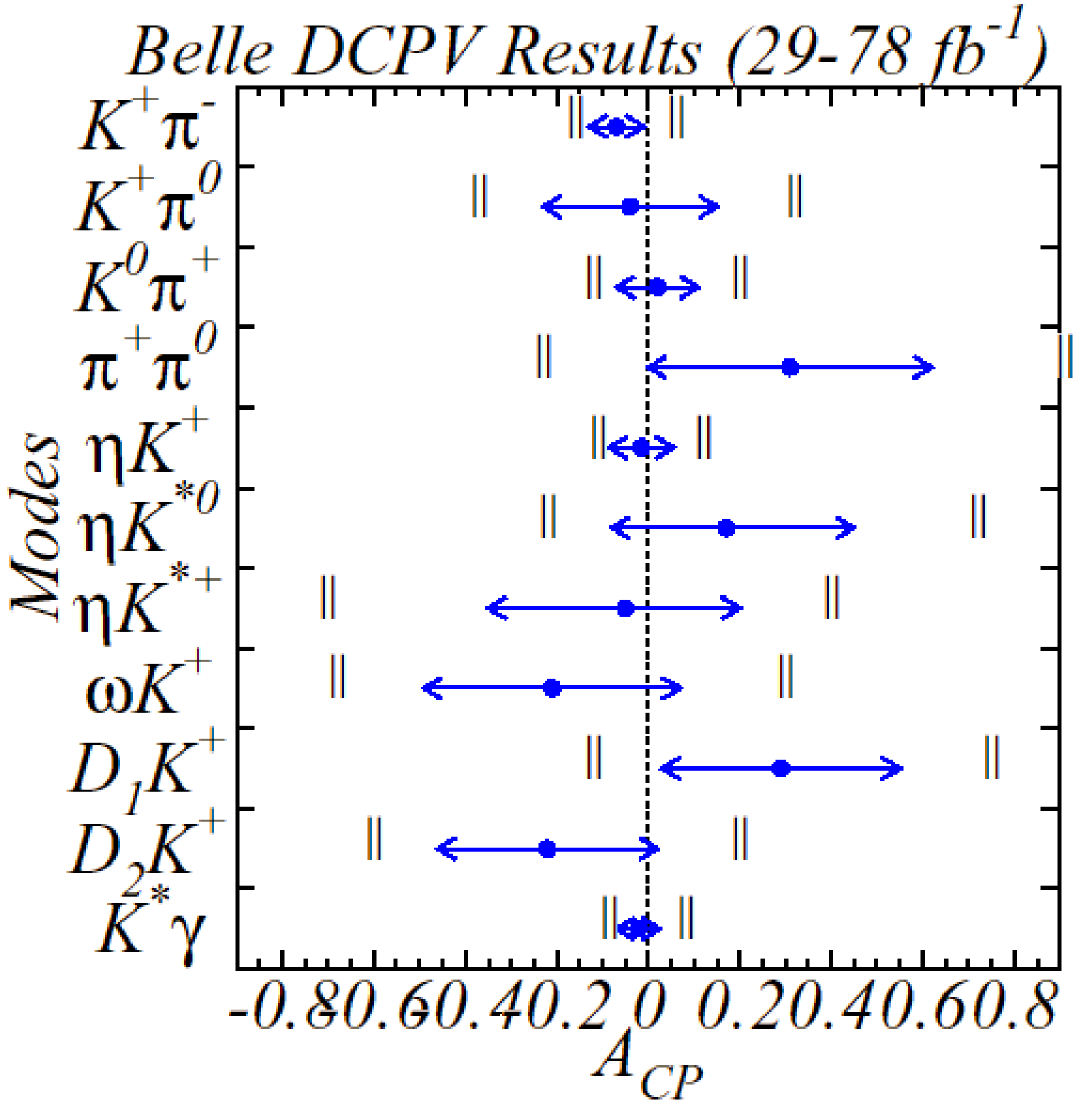
$\pi\pi/K\pi/KK$ (Belle 29 fb^{-1})

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

mode	$\mathcal{B}(90\%U.L.)(10^{-5})$	A_{cp}	$(90\%C.I.)$
$K^+\pi^-$	$2.25 \pm 0.19 \pm 0.18$	$-0.06 \pm 0.09^{+0.01}_{-0.02}$	$(-0.21, 0.09)$
$K^+\pi^0$	$1.30^{+0.25}_{-0.24} \pm 0.13$	$-0.02 \pm 0.19 \pm 0.02$	$(-0.35, 0.30)$
$K^0\pi^+$	$1.94^{+0.31}_{-0.30} \pm 0.16$	$0.46 \pm 0.15 \pm 0.02^*$	$(0.19, 0.72)^*$
$K^0\pi^0$	$0.80^{+0.33}_{-0.31} \pm 0.16$		
$\pi^+\pi^-$	$0.54 \pm 0.12 \pm 0.05$		
$\pi^+\pi^0$	$0.74^{+0.23}_{-0.22} \pm 0.09$	$0.30 \pm 0.30^{+0.06}_{-0.04}$	$(-0.23, 0.86)$
$\pi^0\pi^0$	(< 0.64)		
K^+K^-	(< 0.09)		
$K^+\bar{K}^0$	(< 0.20)		
$K^0\bar{K}^0$	(< 0.41)		

$* \; A_{cp}(K^0\pi^+) = 0.02 \pm 0.09 \pm 0.01 \; (-0.14, 0.18)$ (78 fb^{-1} preliminary)

A_{cp} Summary


Belle DCPV Results (29-78 fb^{-1})
Modes
$K^+\pi^-$
$K^+\pi^0$
$K^0\pi^+$
$\pi^+\pi^0$
ηK^+
ηK^{*0}
ηK^{*+}
ωK^+
D_1K^+
D_2K^+
$K^*\gamma$
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
A_{CP}

Exclusive charmonium modes

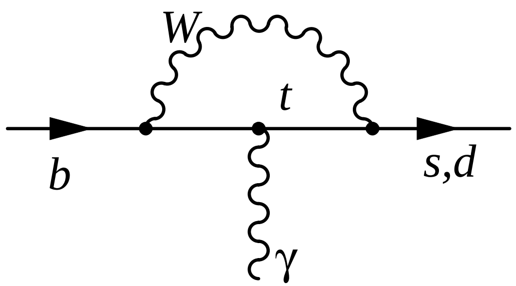
mode	$\mathcal{B}(90\%U.L.)(10^{-4})$	A_{cp}
$J/\Psi\pi^-$	$0.38 \pm 0.06 \pm 0.03$	-0.023 ± 0.164
$J/\Psi\pi^0$	$0.23 \pm 0.05 \pm 0.02$	
$J/\Psi K^-$	$10.1 \pm 0.2 \pm 0.7$	-0.081 ± 0.078
$J/\Psi K^0$	$7.9 \pm 0.4 \pm 0.9$	
$\Psi'(\ell^+\ell^-)K^-$	$7.3 \pm 0.6 \pm 0.7$	-0.081 ± 0.078
$\Psi'(J/\Psi\pi^+\pi^-)K^-$	$6.4 \pm 0.5 \pm 0.8$	-0.200 ± 0.075
$\Psi' K^0$	6.7 ± 1.1	

$$\frac{\mathcal{B}(\eta_c(2S)K)}{\mathcal{B}(\eta_c K)} \cdot \frac{\mathcal{B}(\eta_c(2S) \to K_S K^- \pi^-)}{\mathcal{B}(\eta_c \to K_S K^- \pi^-)} = 0.38 \pm 0.12 \pm 0.05$$

Radiative Charmless Decays

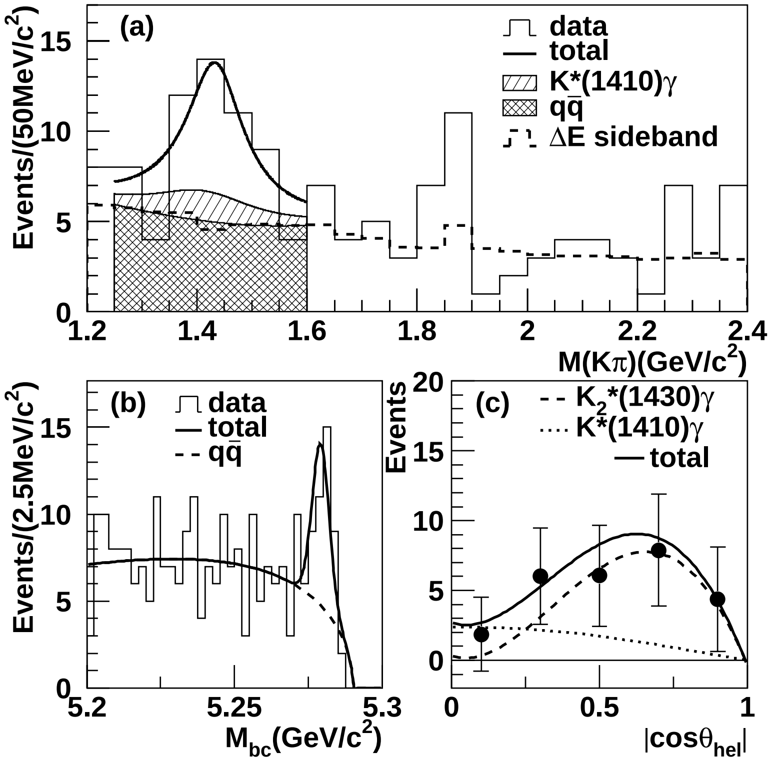
$$\frac{\Gamma(b \to d\gamma)}{\Gamma(b \to s\gamma)} \propto \left|\frac{V_{td}}{V_{ts}}\right|^2$$

$$|V_{ts}| \sim |V_{cd}| \text{ (unitarity)} \longrightarrow |V_{td}|$$



- Large pQCD correction ($\sim \times 3$) $\longrightarrow$ A good test of pQCD.
- Complete next-to-leading calculation done.
- New physics may enter the loop. (e.g. Higgs replacing W)
- Inclusive $b \to d\gamma$ has a large background from $b \to s\gamma$.
  Try exclusive ($B \to \rho\gamma$ etc.).

$B^0 \to K^+\pi^-\gamma$ (29.4 fb^{-1})

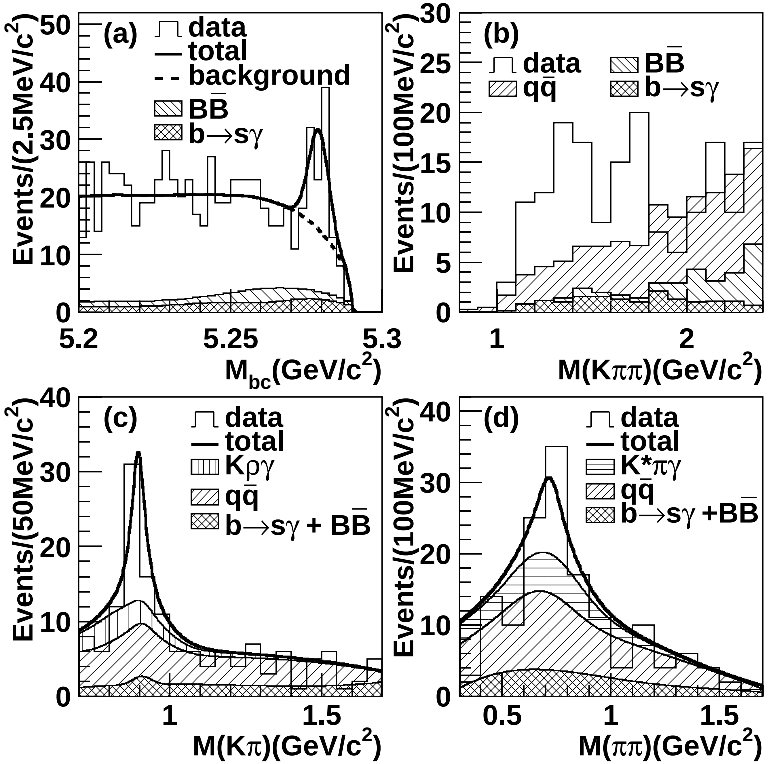


- Resonance at $m_{K\pi} \sim 1.4$ GeV is mostly spin-2:
  $K_2^*(1430) : |Y_{\pm 1}^2| \propto \sin^2 2\theta$
  $K^*(1410) : |Y_{\pm 1}^1| \propto \sin^2 \theta$

	$\mathcal{B}(90\%U.L.)(10^{-5})$
$K_2^{*0}(1430)$	$1.3 \pm 0.5 \pm 0.1$
$K^{*0}(1410)$	(< 13)
$K^+\pi^-\gamma(N.R.)$	(< 0.26)

$$\mathcal{B}(K_2^*(1430) \to K\pi) = 49.9 \pm 1.2\%$$
$$\mathcal{B}(K^*(1410) \to K\pi) = 6.6 \pm 1.2\%$$

$B^+ \to K^+\pi^-\pi^+\gamma$ (29.4 fb^{-1})



- May be used to measure γ helicity. (Gronau)
- $m_{K\pi\pi} < 2.4$ GeV is applied.
- Resonance analysis difficult. $K_1(1270), K_1(1400), K^*(1680)$ etc.
- $K^*(892)$ and ρ are identifiable.

	$\mathcal{B}(90\% U.L.)(10^{-5})$
$K^+\pi^-\pi^+\gamma$	$2.4 \pm 0.5^{+0.4}_{-0.07}$
$K^{*0}\pi^+\gamma$	$2.0 \pm^{+0.7}_{-0.6} \pm 0.2$
$K^+\rho^0\gamma$	$1.0 \pm 0.5^{+0.2}_{-0.3}(< 2.0)$
$K^+\pi^-\pi^+\gamma(N.R.)$	(< 0.92)

Accounting of total $b \to s\gamma$

Assume $I(X_s) = \frac{1}{2}$: (true for any $b \to s$ process)

$$\mathcal{B}(K^{*+}\pi^0) = \frac{1}{2}\mathcal{B}(K^{*0}\pi^+)\,, \quad \mathcal{B}(K^0\rho^+\gamma) = 2\mathcal{B}(K^+\rho^0\gamma)$$

	$\mathcal{B}(10^{-5})$
$K^*\gamma$	4.2 ± 0.4
$B \to K_2^*(1430)$ (excl.$K^*\pi\gamma, K\rho\gamma$)	0.9 ± 0.3
$K^*\pi\gamma$	3.1 ± 1.6
$K\rho\gamma$	3.0 ± 1.6
total	11.2 ± 2.1
$b \to s\gamma$(incl.)	32.2 ± 4.0

(35 ± 8)% of inclusive is accounted for.

$B \to X_s \ell^+ \ell^-$ inclusive (Belle 60 fb^{-1})

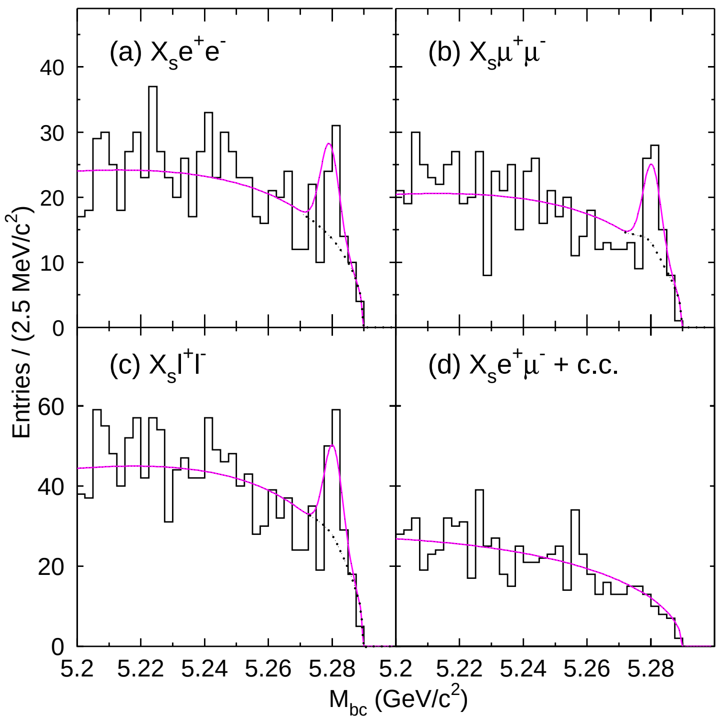
Semi-inclusive Reconstruction

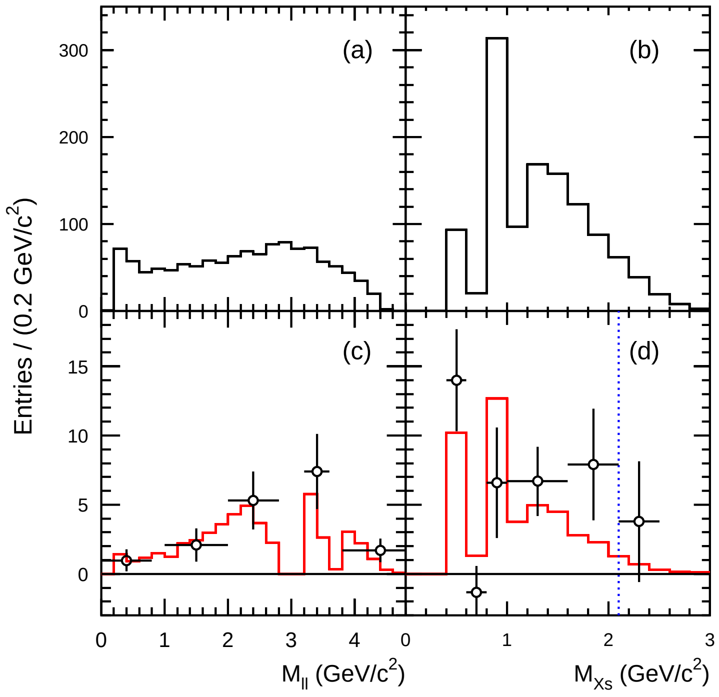
(Continuum suppression for rare inclusive measurements)

$B \to X_s \ell\ell$

- Select a candidate $\ell^+\ell^+$ pair.
- $X_s = K^\pm/K_S + n\pi$ ($1 \leq n \leq 4$, upto one π^0)
  Take all combinations.
- Require that ΔE and M_{bc} of the $X_s\ell\ell$ system are in the signal region.
- MC: it covers $\sim 80\%$ of the total inclusive rate.

$B \to X_s \ell^+ \ell^-$ semi-inclusive





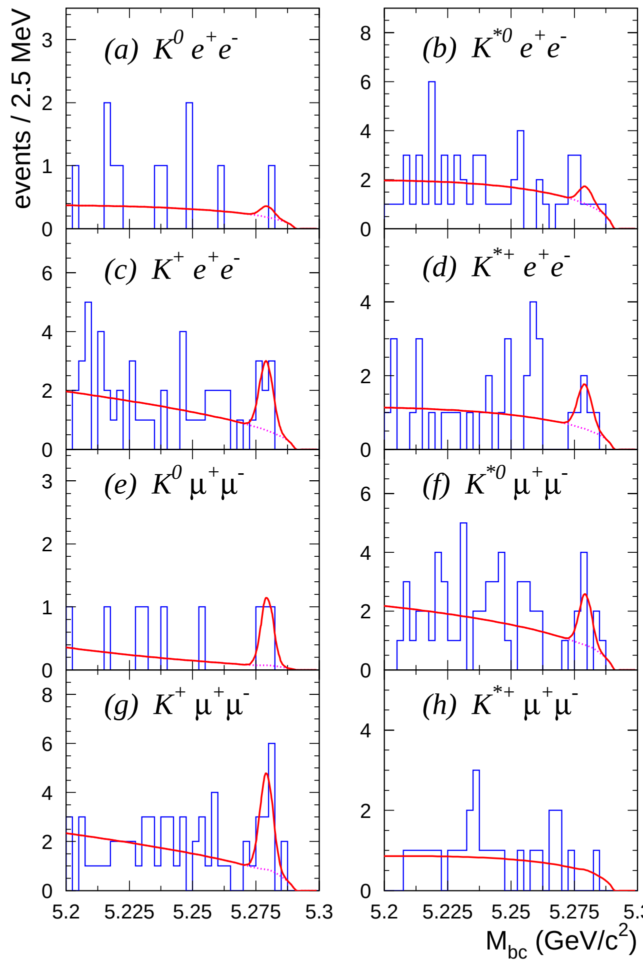
(Belle 60 fb^{-1})

	$\mathcal{B}(\times 10^{-6})$
$X_s \mu^+ \mu^-$	$7.9 \pm 2.1^{+2.1}_{-1.5}$
$X_s e^+ e^-$	$5.1 \pm 2.3^{+1.3}_{-1.1}$
$X_s \ell^+ \ell^-$	$6.1 \pm 1.4^{+1.4}_{-1.1}$

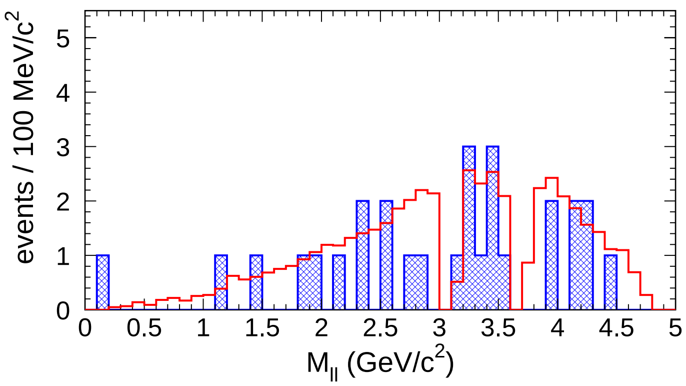
m_{X_s}, $m_{\ell\ell}$, and rates are consistent with SM.

$K^{(*)}\ell^+\ell^-$ exclusive (Belle 60 fb^{-1})

	$\mathcal{B}(90\%U.L.)(\times 10^{-6})$
$K\ell^+\ell^-$	$0.58^{+0.17}_{-0.15} \pm 0.06$
$K\mu^+\mu^-$	$0.80^{+0.28}_{-0.23} \pm 0.09$
$K^*\ell^+\ell^-$	< 1.4



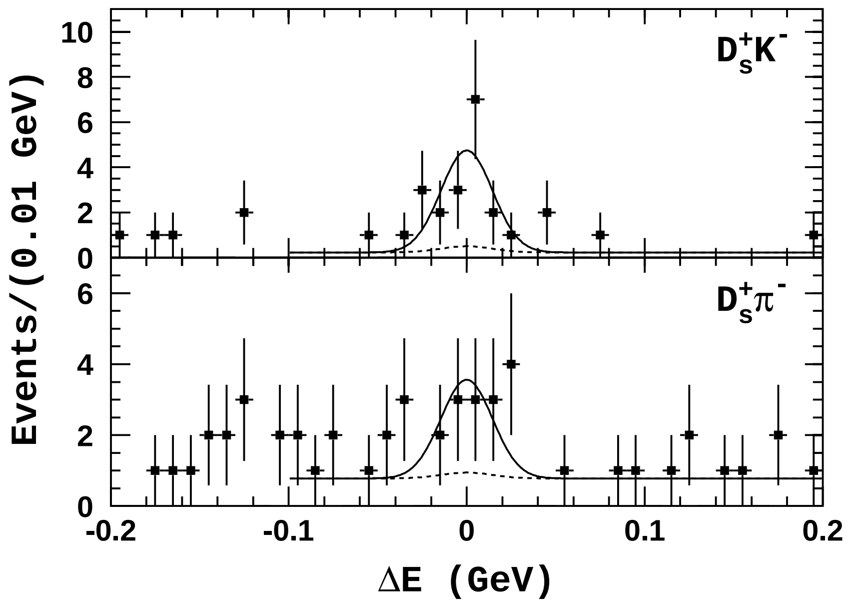
Rates and $m_{\ell\ell}$ are consistent with SM.



Understanding Basic Decay Mechanisms

- $B^0 \to D_s^- K^+$ (annihilation, FSI)
- Color-suppressed $b \to c\bar{u}d$. (FSI)
- $B^+ \to \chi_{c0} K^+$. (factorization)
- $B \to \chi_{c2} X$. (factorization)

$B^0 \rightarrow D_s^- K^+/\pi^+$ (79 fb^{-1})



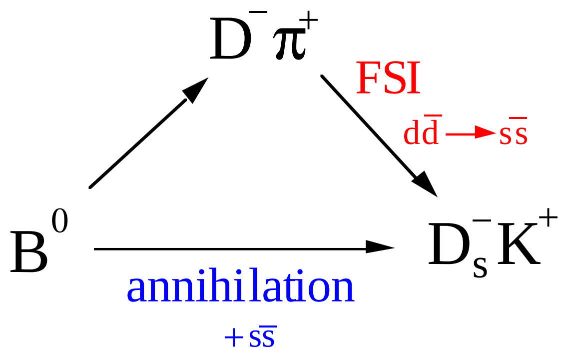
mode	$\mathcal{B}(10^{-5})$	significance
$B^0 \rightarrow D_S^- K^+$	$4.6^{+1.2}_{-1.1} \pm 1.3$	6.4σ
$B^0 \rightarrow D_S^- \pi^+$	$2.4^{+1.0}_{-0.8} \pm 0.7$	3.6σ

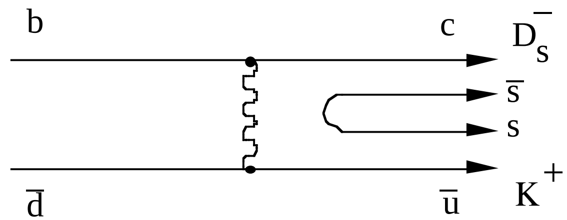
$\longrightarrow$ V_{ub}: Majumder

Large $D_S^- K^+$ (surprise !)

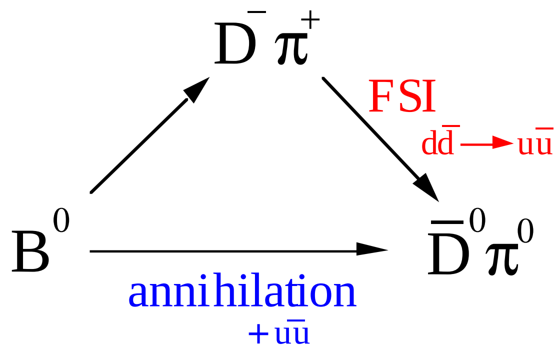
$B^0 \to D_s^- K^+$

Expected to occur through annihilation and/or FSI:





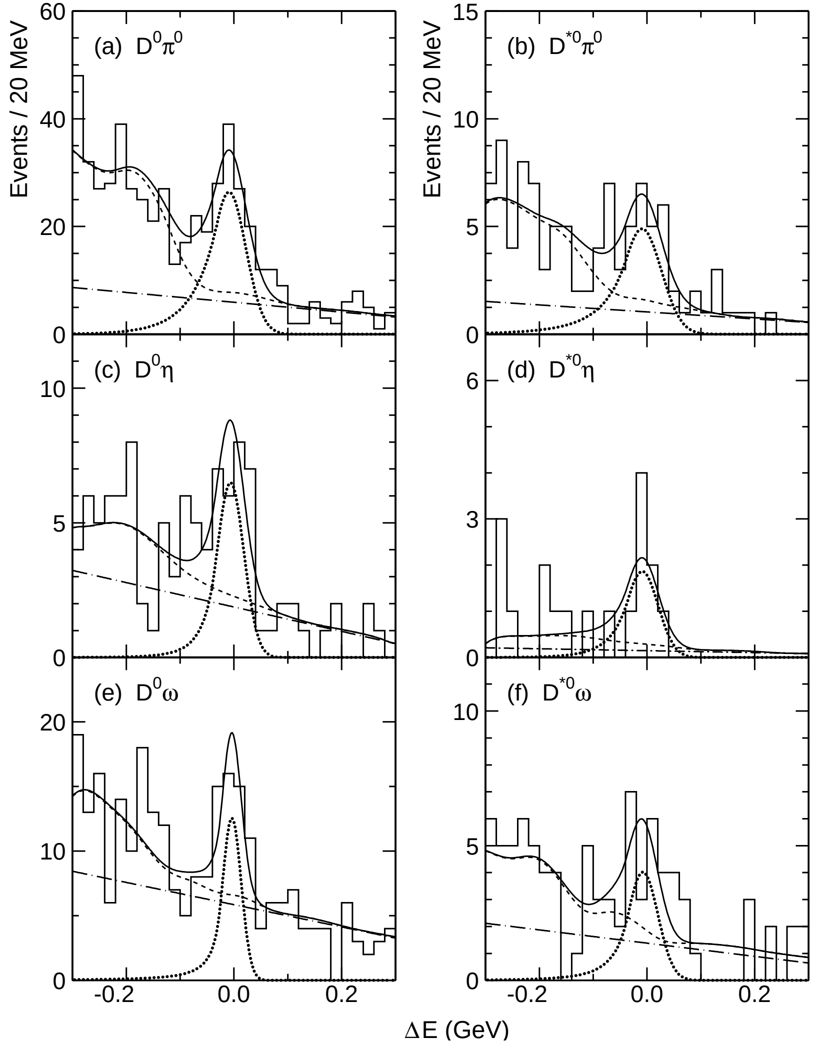
The same amplitudes enhanced by $Amp(u\bar{u})/Amp(s\bar{s})$ should exist for $D^0\pi^0$.
(+ color-suppressed tree)



$$\mathcal{B}(D^0\pi^0)_{\rm FSI+ann.} = \mathcal{B}(D_S^+ K^-) \times \frac{u\bar{u}}{s\bar{s}} \times \frac{1}{2} = (1 \sim 2) \times 10^{-4}$$

Color-suppressed $b \to c\bar{u}d$ Modes

$Br(\times 10^{-4})$	Belle	Th.Model
$D^0\pi^0$	$3.1 \pm 0.4 \pm 0.5$	0.7
$D^{*0}\pi^0$	$2.7^{+0.8+0.5}_{-0.70.6}$	1.0
$D^0\eta$	$1.4^{+0.5}_{-0.4} \pm 0.3$	0.5
$D^{*0}\eta$	$2.0^{+0.9}_{-0.8} \pm 0.4$	1.0
$D^0\omega$	$1.8 \pm 0.5^{+0.4}_{-0.3}$	0.7
$D^{*0}\omega$	$3.1^{+1.3}_{-1.1} \pm 0.8$	1.7
$D^{*0}\rho^0$	$3.0 \pm 1.3 \pm 0.4$	



Consistently larger than the factorization model (×2-3)

FSI rescattering/annihilation?

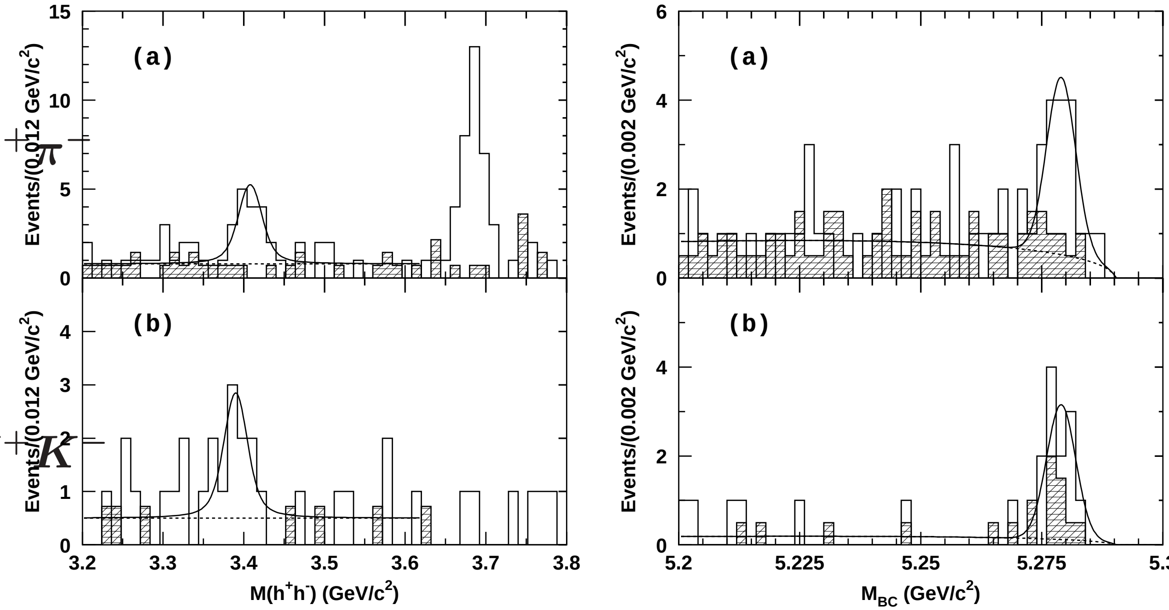
$B^+ \to \chi_{c0} K^+$ (29 fb^{-1})

Prohibitted in naive factorization: $\langle \chi_{c0} | (\bar{c}c)^{\mu}_{V-A} | 0 \rangle = 0$

(P and C conservation. CVC also is relevant.)

$\chi_{c0} \to \pi^+\pi^-$

$\chi_{c0} \to K^+K^-$



$\chi_{c0} \to K^+K^-$ mass shift probably due to interference with non-res. $K^+K^-K^+$. $\to$ Use $\pi^+\pi^-$ mode only.

$$Br(B^+ \to \chi_{c0} K^+) = (6.0^{+2.1}_{-1.8} \pm 1.1) \times 10^{-4}$$

$$\frac{Br(\chi_{c0} K^+)}{Br(J/\Psi K^+)} = 0.60^{+0.21}_{-0.18} \pm 0.05 \pm 0.08 \text{ (large!)}$$

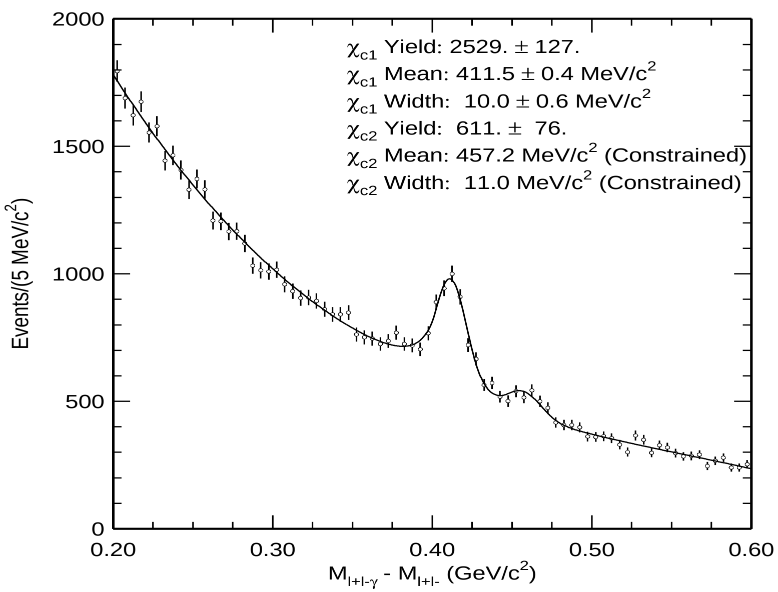
Inclusive χ_{c2} Productions (29 fb^{-1})

Prohibitted in naive factorization:

$\langle \chi_{c2} | (\bar{c}c)^{\mu}_{V-A} | 0 \rangle = 0$ **(Lorentz strucure)**

$$\chi_{c1,2} \to J/\Psi\gamma,\ J/\Psi \to \ell^+\ell^-$$

$$\left.\begin{array}{l} \mathcal{B}(B \to \chi_{c2}X) = (1.53^{+0.23}_{-0.28} \pm 0.27) \times 10^{-3} \\ \mathcal{B}(B \to \chi_{c1}X) = (3.32 \pm 0.22 \pm 0.34) \times 10^{-3} \end{array}\right\} \text{direct}$$



$$\text{Ref :} \quad \left.\begin{array}{r} \mathcal{B}(B \to J/\Psi X) = (8.0 \pm 0.8) \times 10^{-3} \\ \mathcal{B}(B \to \Psi' X) = (3.5 \pm 0.5) \times 10^{-3} \end{array}\right\} \text{direct(PDG2002)}$$

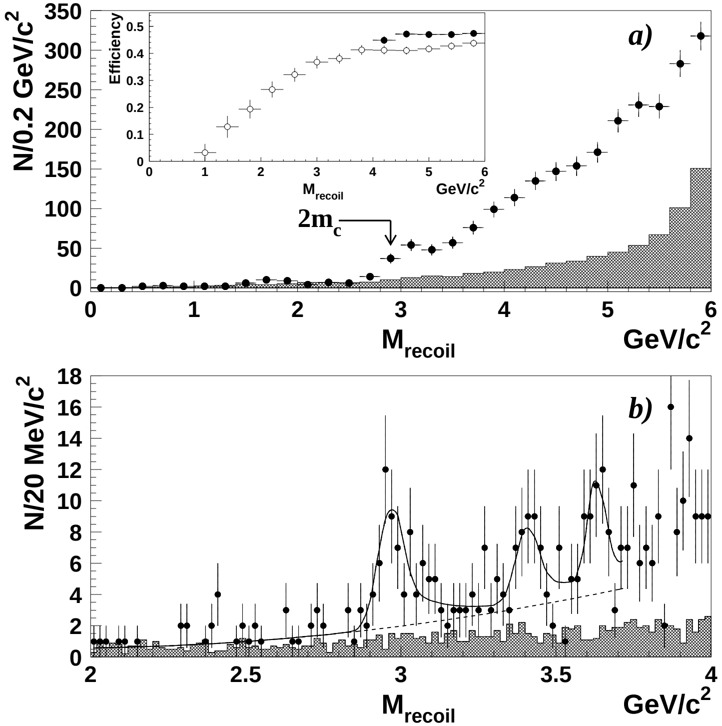
Charm Physics: continuum J/Ψ production (Belle 46.2 fb^{-1})

$$\sigma(e^+e^- \to J/\Psi\eta_c)\cdot\mathcal{B}(\eta_c \to\geq 4\mathrm{ch}) = (0.033^{+0.007}_{-0.006} \pm 0.009)\mathrm{pb}$$

$$\sigma(e^+e^- \to J/\Psi D^{*+}X) = (0.53^{+0.19}_{-0.15} \pm 0.14)\mathrm{pb}$$

$$\to \quad \frac{\sigma(e^+e^- \to J/\Psi c\bar{c})}{\sigma(e^+e^- \to J/\Psi X)} = 0.59^{+0.19}_{-0.15} \pm 0.14$$

Contradicts the $e^+e^- \to (c\bar{c})g$ color-octet model.
$c\bar{c}$ creation from vacuum is large!



τ Physics (Belle 46.2 fb^{-1})

Leptopn number violating decays

$90\% U.L. (10^{-7})$	
$\mathcal{B}(e^- e^+ e^-) < 2.7$	$\mathcal{B}(\mu^- \mu^+ \mu^-) < 3.8$
$\mathcal{B}(e^- \mu^+ \mu^-) < 3.1$	$\mathcal{B}(\mu^- e^+ e^-) < 2.4$
$\mathcal{B}(e^+ \mu^- \mu^-) < 3.2$	$\mathcal{B}(\mu^+ e^- e^-) < 2.8$
$\mathcal{B}(e^- K_S) < 2.9$	$\mathcal{B}(\mu^- K_S) < 2.7$

(1 to 3 orders improvement)

τ Electric dipole moment

Use CP-violating spin correlation in $e^- e^+ \to \tau^- \tau^+$:

$$\mathrm{Re} d_\tau = (1.15 \pm 1.70) \times 10^{-17} e\mathrm{cm}$$
$$\mathrm{Im} d_\tau = (-0.83 \pm 0.86) \times 10^{-17} e\mathrm{cm}$$

(~1 order improvement of direct measurement)

No time to cover...

B-mixing ($D^*\pi$ partial, hadronic, $\ell\ell$)

$K\pi\pi$, $\pi\pi\pi(\rho\pi)$ analyses

$D^{(*)}\pi\pi$, $D^{(*)}KK$, $D^{(*)}p\bar{p}$ modes

Baryonic modes

Two-photon and most of charm physics

Conclusion

Lots of interesting physics coming out of B-factories.

Best is yet to come: