Measurements of direct CP violation in two-body decays of B meson with Belle

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1 Direct CP Violation in B Meson System

- Mixing-induced "indirect" CP violation (ICPV) has already been observed.

— $\sin 2\phi_1 = 0.82 \pm 0.12 \pm 0.05$ (Belle @42 fb^{-1})

— The Kobayashi-Maskawa (KM) scheme is highly supported.

$$\begin{array}{c} B^0 \searrow \\ \updownarrow \quad f_{CP} \\ \overline{B}^0 \nearrow \end{array} \qquad \mathcal{A}_{CP}(t) = \frac{\Gamma(\overline{B}^0(t) \to \overline{f}) - \Gamma(B^0(t) \to f)}{\Gamma(\overline{B}^0(t) \to \overline{f}) + \Gamma(B^0(t) \to f)}$$

- Decay rate asymmetry "direct CP violation (DCPV)" has not been observed yet in B meson system.

— More than two amplitudes for a single decay,

— Different weak phases ($\Delta\phi \neq 0$),

— Different strong phases ($\Delta\delta \neq 0$).

$$|A_1 + A_2|^2 \neq |A_1^* + A_2^*|^2 \qquad \mathcal{A}_{CP} = \frac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \overline{f}) + \Gamma(B \to f)}$$

- Search for the DCPV is an important issue in B-factory experiments.

— ϕ_3 through $b \to u$ tree.

— New physics through a loop diagram.

— DCPV could be an important hint for the present baryonic universe.

2 Search for DCPV at Belle

In this talk, DCPV search using time-integrated analysis will be shown for the following decays.

- Charmless hadronic decays

— $B \to K\pi$, $\pi\pi$ @29.1 fb^{-1}, 78 fb^{-1} (Preliminary)

— $B^+ \to \eta' K^+$ @41.8 fb^{-1}

— $B \to \eta K^*$ @29.4 fb^{-1}

— $B^+ \to \omega K^+$ @29.4 fb^{-1}

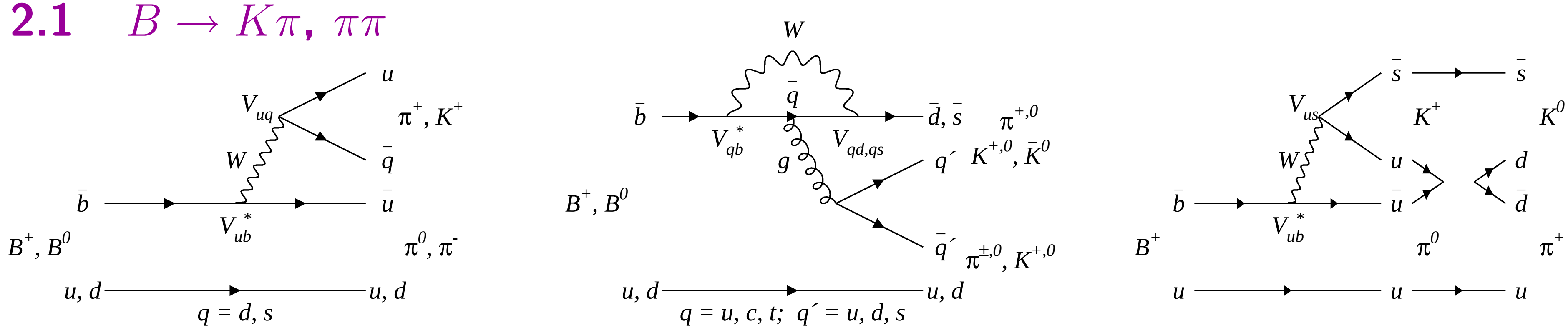
- Charmed hadronic decay

— $B^+ \to D^0 K^+$ @29.1 fb^{-1}

- Radiative decay

— $B \to K^*\gamma$ @60 fb^{-1} (Preliminary)

2.1 $B \to K\pi,\ \pi\pi$



- $\circ$ $B \to K^+\pi^-,\ K^+\pi^0$
  - Interference between "Tree" and "Penguin" diagrams
  - ϕ_3 through a $b \to u$ transition

— for $f = K^+\pi^-$: $\mathcal{B}(B^0 \to K^+\pi^-) = |T + P|^2,\ \mathcal{B}(\overline{B}^0 \to K^-\pi^+) = |T^* + P|^2$

$$\mathcal{A}_{CP}(K^+\pi^-) = \frac{2|T||P|\sin\Delta\delta\sin\phi_3}{|T|^2 + |P|^2 + 2|T||P|\cos\Delta\delta\cos\phi_3}$$

- $\circ$ $B^+ \to K^0_S\pi^+$
  - Pure penguin diagram, but "Rescattering" may cause partial rate asymmetry.

$$B^+ \to (K^+\pi^0)_{\rm tree} \to < \text{Rescattering} > \to K^0\pi^+$$

- $\circ$ $B \to \pi^+\pi^0$
  - Pure tree diagram, then probe a new physics.

Analysis

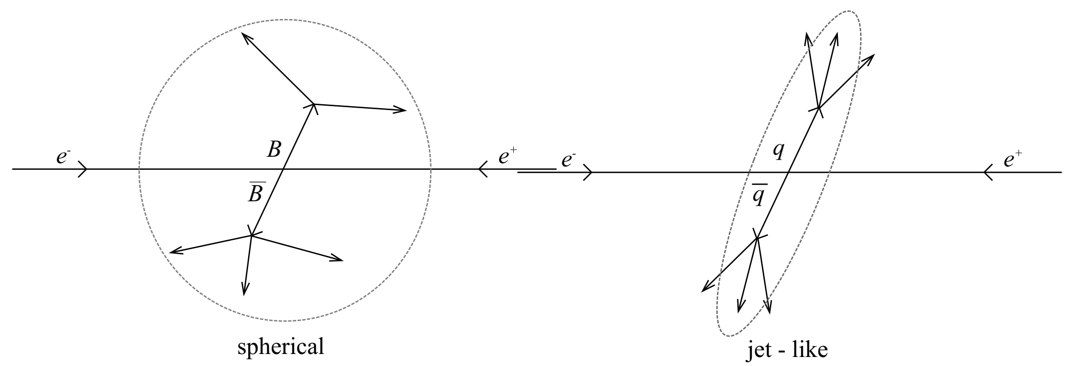
◦ B Kinematic Reconstruction

- Beam energy constrained mass: $m_{\rm bc} \equiv \sqrt{{E^*_{\rm beam}}^2 - {p^*_B}^2}$
- Energy difference: $\Delta E \equiv E^*_B - E^*_{\rm beam}$

◦ $e^+e^- \to q\overline{q}$ $(q = u, d, s, c)$ continuum background suppression

- Event topology
  - modified Fox-Wolfram moments
  - Fisher discriminant
- Angular distribution
  - B flight direction
- combined into a single likelihood ratio

$$R_{\mathcal{L}} = \frac{\mathcal{L}_s}{\mathcal{L}_s + \mathcal{L}_{q\overline{q}}}$$



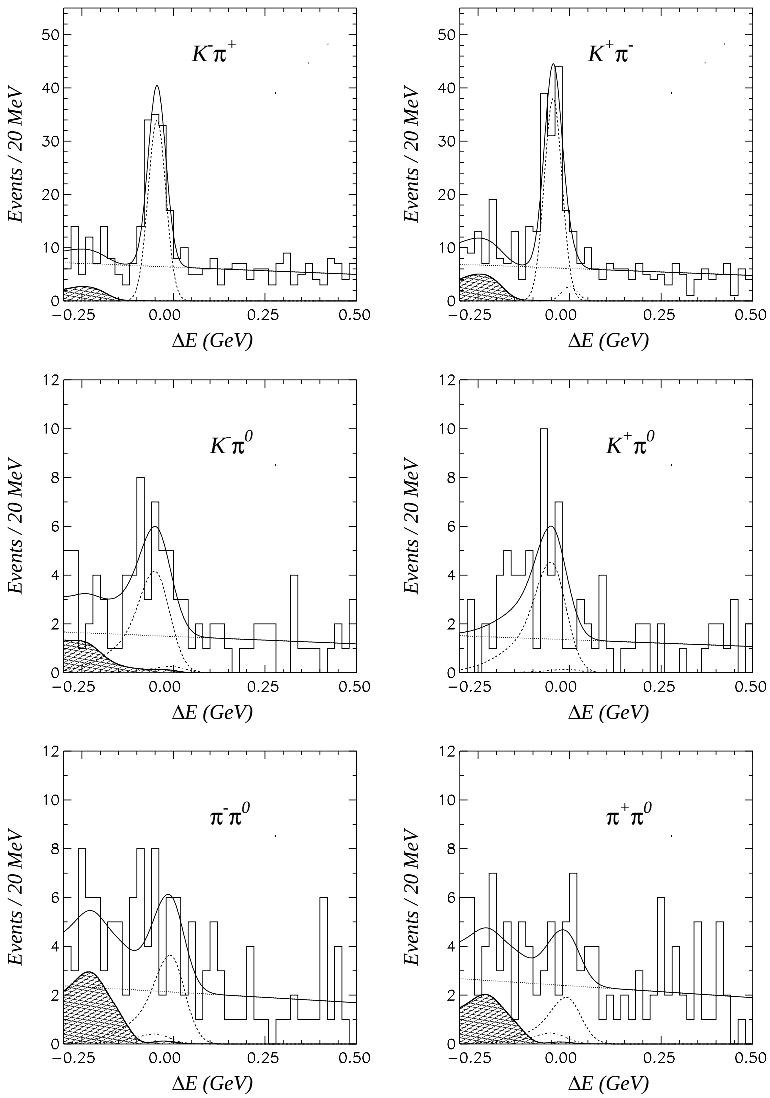
"spherical" $B\overline{B}$ events   "jet-like" $q\overline{q}$ events

◦ High Momentum Particle Identification

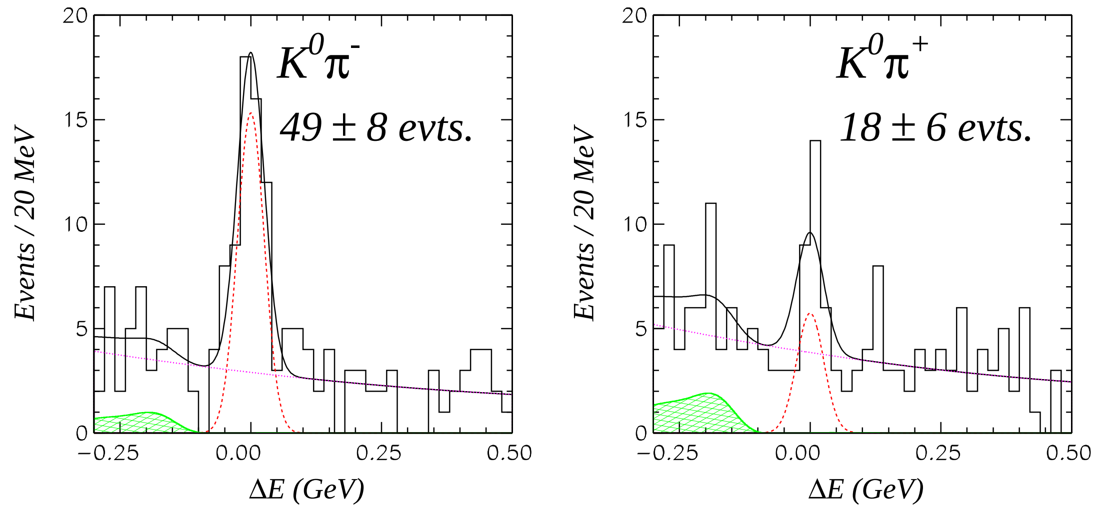
- $2.4 < p^*_h < 2.85$ GeV$/c$ $(h = \pi,\ K)$
- dE/dx (CDC), $N_{p.e.}$ (ACC)
- combined into a single likelihood ratio

$$P_K = \frac{\mathcal{L}_K}{\mathcal{L}_K + \mathcal{L}_\pi}$$

Flavor-specific $B \to K\pi$, $\pi\pi$ decays @24.1 fb^{-1}



- Binned 1D ΔE fit
- — signal (and feed-across)
- — $q\bar{q}$ background
- — 3-body/4-body charmless decays (in lower ΔE)
- — m_π assumption for charged tracks



$$\mathcal{A}_{CP}(K^0_S\pi^+) = 0.46 \pm 0.15$$

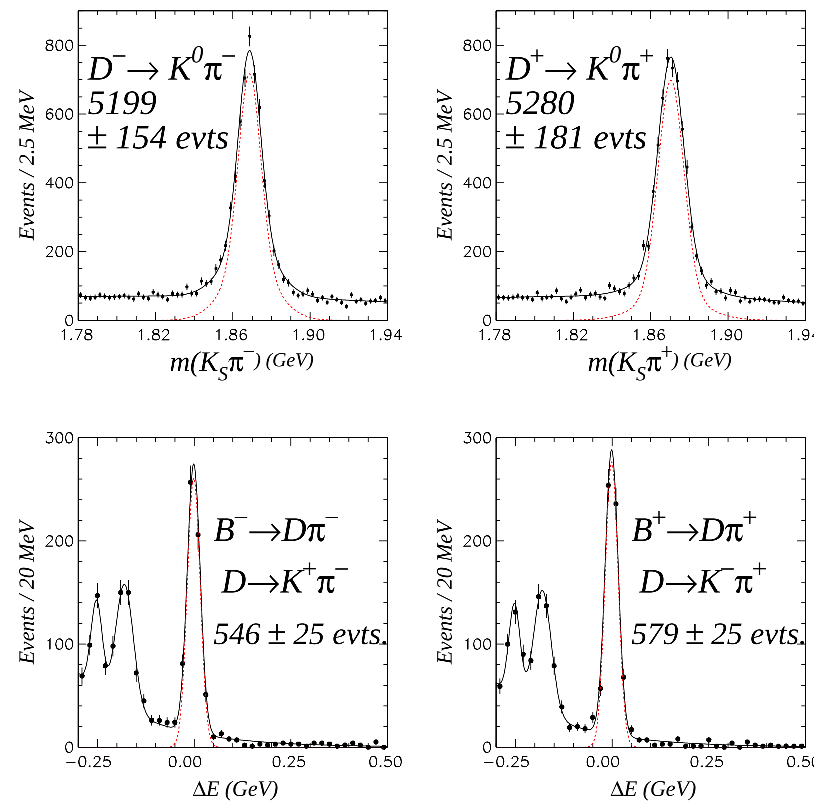
Large asymmetry in $B^+ \to K^0_S\pi^+$!

Systemtics

- Detector-based bias has confirmed to be negligible by test samples.

— $2.4 < p_h^* < 2.85$ GeV/c ($h = \pi,\ K$) is required for inclusive $h^\pm$ sample and D decays.

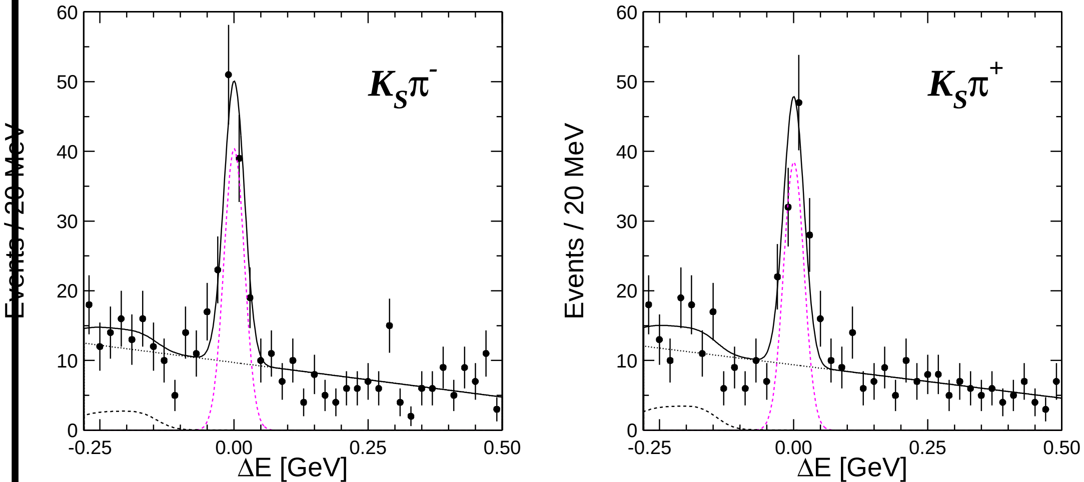
Sample	Asymmetry [%]
$h^\pm$	-0.36 ± 0.03
$h^\pm$ w/ K-id	-0.32 ± 0.05
$h^\pm$ w/ π-id	-0.37 ± 0.03
$D \to K\pi,\ K^+\pi^-\pi^0$	-0.2 ± 0.3
m_{bc} sideband	-0.007 ± 0.017
m_{bc} sideband w/ $q\bar{q}$ cuts	1 ± 5
$B \to D\pi^-$	-4.5 ± 2.5
$B \to D\pi^-$ w/ $q\bar{q}$ cuts	-5.5 ± 2.7

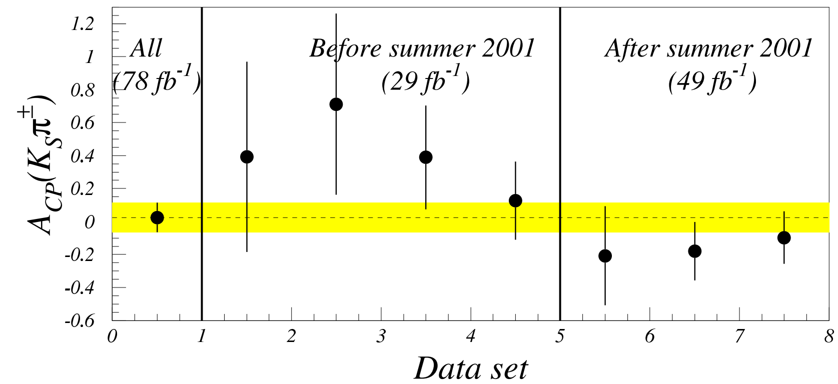


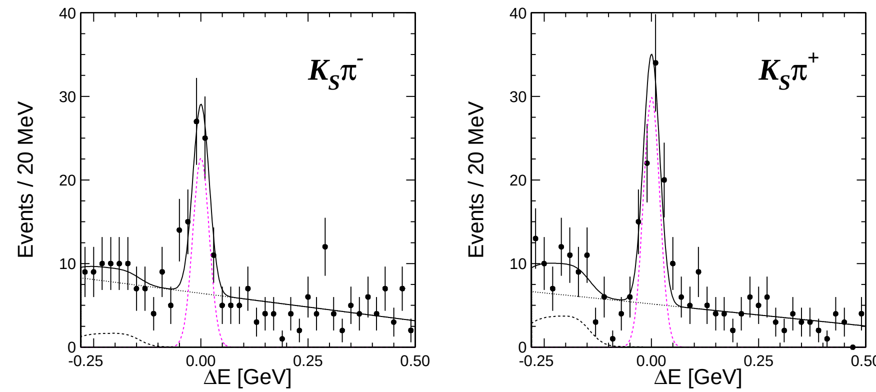
Decay Mode	$N(\overline{B})$	$N(B)$	$\mathcal{A}_{CP}$	90% C.L.
$B^0 \to K^+\pi^-$	103 ± 12	115 ± 14	$-0.06 \pm 0.08 \pm 0.01$	[-0.20, 0.09]
$B^+ \to K^+\pi^0$	28 ± 8	30 ± 8	$-0.04 \pm 0.19 \pm 0.03$	[-0.39, 0.30]
$B^+ \to K^0\pi^+$	49 ± 8	18 ± 6	$0.46 \pm 0.15 \pm 0.02$	[0.18, 0.73]
$B^0 \to \pi^+\pi^0$	24 ± 8	13 ± 7	$0.31 \pm 0.31 \pm 0.05$	[-0.25, 0.89]

Try to confirm the asymmetry in $B^+ \to K_S^0\pi^+$ with much more statistics . . .

$B^+ \to K^0_S\pi^+$ @78 fb^{-1} (Preliminary)







$N(K^0_S\pi^-) = 96 \pm 12$ $\quad$ $N(K^0_S\pi^+) = 92 \pm 12$

$$\mathcal{A}_{CP}(K^0_S\pi^+) = 0.02 \pm 0.09 \pm 0.01$$

$$-0.14 < \mathcal{A}_{CP}(K^0_S\pi^+) < 0.18 \text{ @90\% C.L.}$$

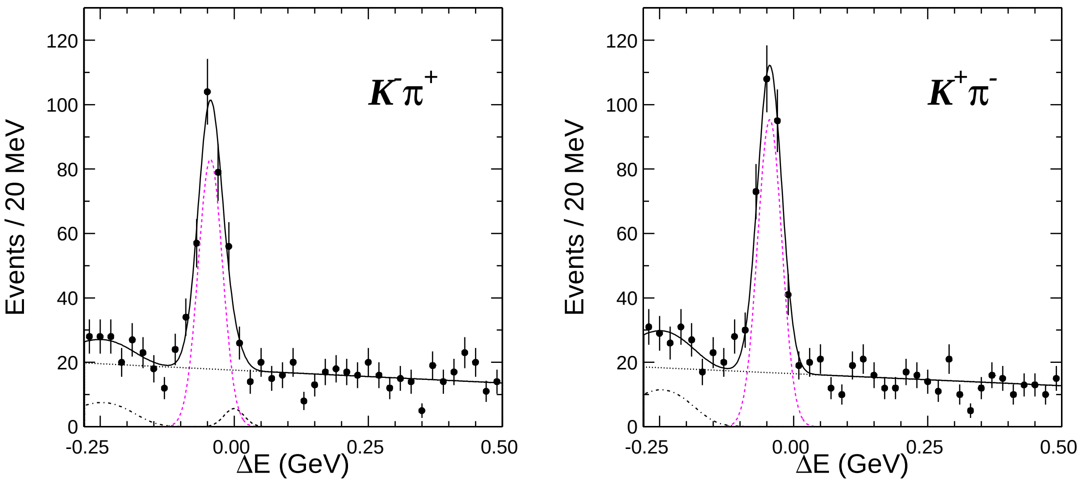
c.f. After summer 2001 (49 fb^{-1})

$$\mathcal{A}_{CP}(K^0_S\pi^+) = -0.14 \pm 0.11$$

- Large assymmetry in $B^+ \to K^0_S\pi^+$ has disappeared.

— 3σ is capricious fluctuation.

$B^0 \to K^+\pi^-$ @78 fb^{-1} (Preliminary)



$N(K^-\pi^+) = 235 \pm 19 \qquad N(K^+\pi^-) = 270 \pm 19$

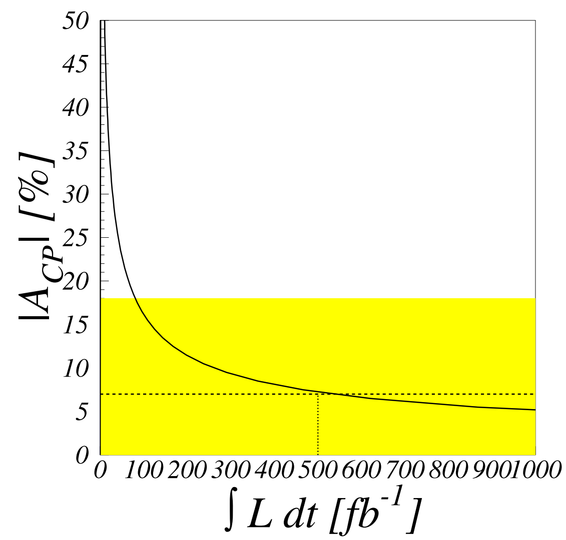
$$\mathcal{A}_{CP}(K^+\pi^-) = -0.07 \pm 0.06 \pm 0.01$$

$$-0.18 < \mathcal{A}_{CP}(K^+\pi^-) < 0.04 \text{ @90\% C.L.}$$

- Dilution of double mis-PID is corrected as

$$\mathcal{A}_{CP}^{\rm raw}(K^+\pi^-) = (1-2w)\mathcal{A}_{CP}(K^+\pi^-)$$

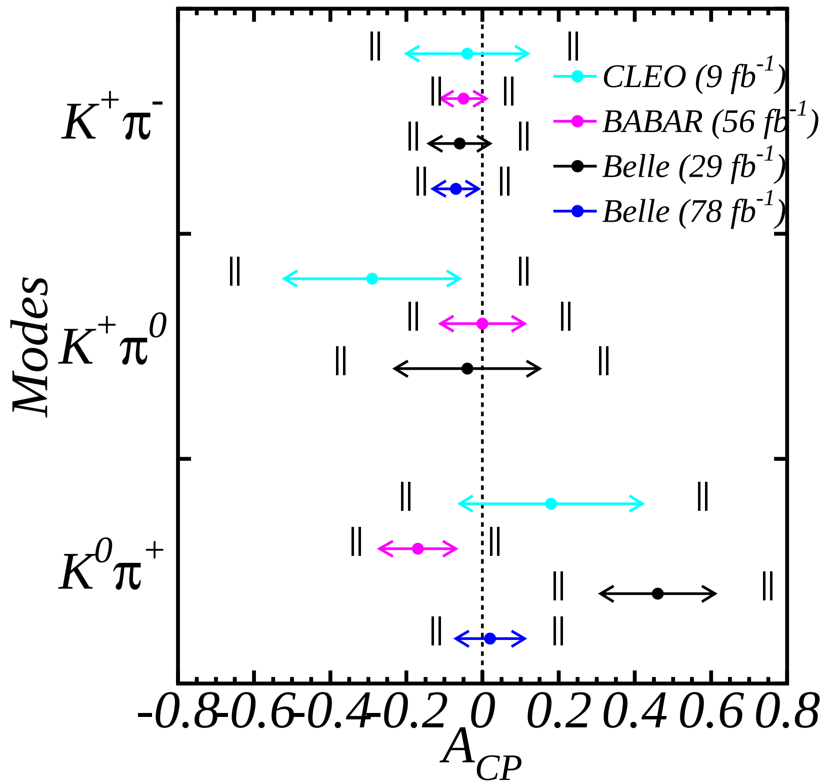
$$w = \frac{f_\pi f_K}{\epsilon_\pi \epsilon_K + f_\pi f_K} = (0.70 \pm 0.02)\%$$

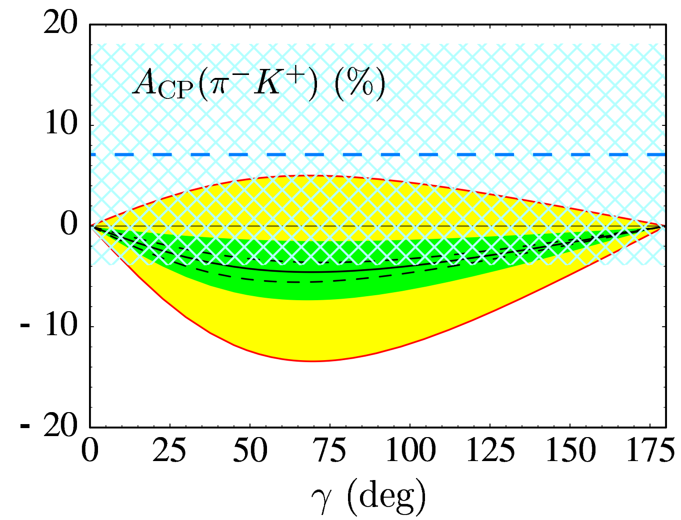


- Sensitivity for 3σ significance.

— If $\mathcal{A}_{CP}(K^+\pi^-) \sim 7\%$, the asymmetry could be seen at $\sim$500 fb^{-1} with 3σ level.

Comparison with Other Measurements and Theories





M. Beneke *et al.*, Nucl. Phys. B606 (2001)

- QCD factorization, pQCD, . . .
- Need much more statistics to constraint ϕ_3.

- Consistent results with improved precision.

— CLEO (9.7 M$B\overline{B}$): Phys. Rev. Lett. 85 (2000)

— BABAR (60 M$B\overline{B}$): Moriond and FPCP Conf. (2002)

— Belle ($32/85$ M$B\overline{B}$): Moriond and FPCP Conf. (2002)

2.2 Other Charmless Hadronic Decays

◦ $B \to \eta' K^+$ @41.8 fb^{-1}, ηK^* @29.4 fb^{-1}

- Unexpectedly large $\mathcal{B}$ could be caused by new physics contribution.

— $b \to s$ penguin dominance $\to$ small $\mathcal{A}_{CP}$.

— new physics contribution $\to$ large $\mathcal{A}_{CP}$.

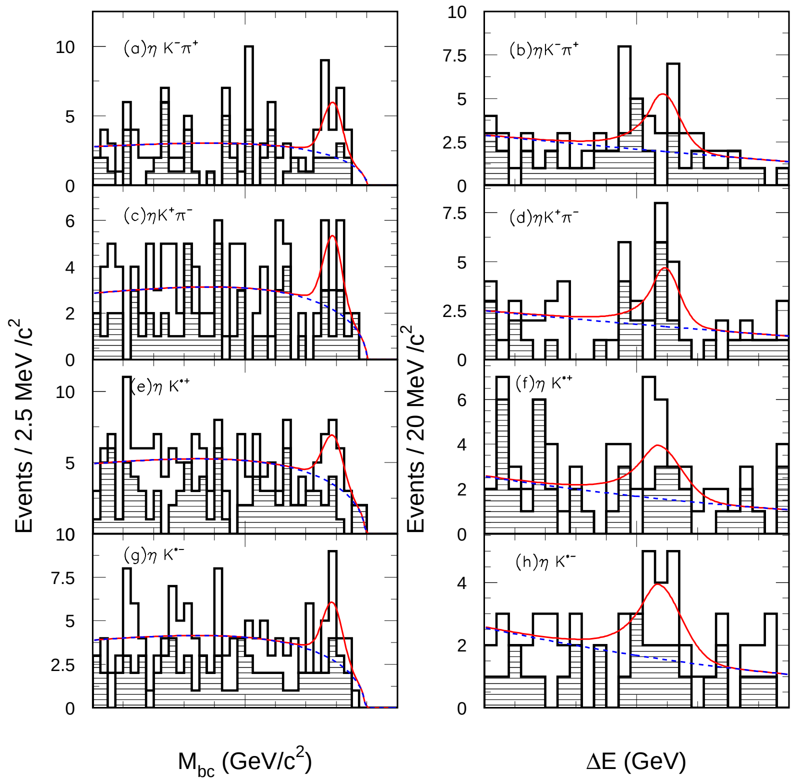
- $\eta' \to \eta\pi^+\pi^-$, $\rho^0\gamma$ / $\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$
- $K^{*0} \to K^-\pi^+$ / $K^{*+} \to K^+\pi^0$, $\overline{K}^0\pi^+$
- Unbinned 2D-ML fit

◦ $B^+ \to \omega K^+$ @29.4 fb^{-1}

- Belle result shows $\mathcal{B}(\omega K^+) > \mathcal{B}(\omega\pi^+)$.

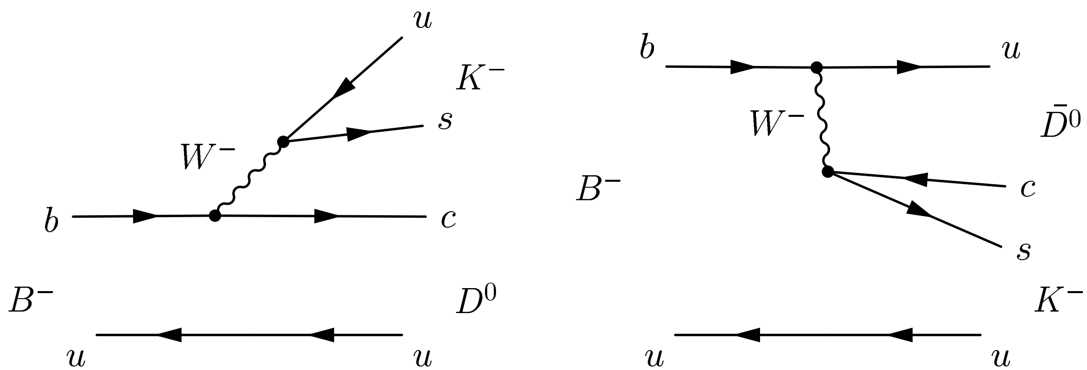
— sizable $\mathcal{A}_{CP}$ can be expected.

- $\omega \to \pi^+\pi^-\pi^0$
- Unbinned 2D-ML fit



Decay Mode	$N(\overline{B})$	$N(B)$	$\mathcal{A}_{CP}$	90% C.L.
$B^+ \to \eta' K^+$	$139.7\ ^{+14.3}_{-13.5}$	$144.0\ ^{+14.6}_{-13.8}$	$-0.015 \pm 0.070 \pm 0.009$	[-0.13, 0.10]
$B^0 \to \eta K^{*0}$	$11.6\ ^{+5.4}_{-4.3}$	$14.6\ ^{+6.0}_{-4.8}$	$0.17\ ^{+0.28}_{-0.25} \pm 0.01$	[-0.24, 0.70]
$B^+ \to \eta K^{*+}$	$12.5\ ^{+6.1}_{-4.2}$	$13.1\ ^{+6.1}_{-4.6}$	$-0.05\ ^{+0.25}_{-0.30} \pm 0.01$	[-0.72, 0.38]
$B^+ \to \omega K^+$	7.3 ± 3.5	11.2 ± 3.7	$-0.21 \pm 0.28 \pm 0.03$	[-0.70, 0.28]

2.3 $B^+ \to D^0_{CP} K^+$ @29.1 fb^{-1}



- Interference between $b \to u$ and $b \to c$ trees.
- Theoretically clean mode for ϕ_3 constraint.

$$\mathcal{A}_{1,2} = \frac{2r \sin\delta' \sin\phi_3}{R_{1,2}}$$

$$r = \left| \frac{\mathcal{A}(B^- \to \overline{D}^0 K^-)}{\mathcal{A}(B^- \to D^0 K^-)} \right| \sim 0.1, \qquad \begin{array}{rcll} \delta' & = & \delta & (\text{ for } CP = +1) \\ & = & \delta + \pi & (\text{ for } CP = -1) \end{array}$$

$$\begin{array}{rcl} R_{1,2} & = & 1 + r^2 + 2r\cos\delta' \cos\phi_3 \\ & = & R(D_{1,2})/R(D_f) \end{array}, \qquad R(D_i) = \frac{\mathcal{B}(B^- \to D_i K^-)}{\mathcal{B}(B^- \to D_i \pi^-)}$$

- D^0 decay categories

— flavor-specific: $D_f \to K^-\pi^+$

— $CP = +1$: $D_1 \to K^-K^+$, $\pi^-\pi^+$

— $CP = -1$: $D_2 \to K^0_S\pi^0$, $K^0_S\eta$, $K^0_S\eta'$, $K^0_S\omega$, $K^0_S\phi$

- Other subdecay modes

— $\eta \to \gamma\gamma$ / $\eta' \to \eta\pi^+\pi^-$

— $\omega \to \pi^+\pi^-\pi^0$ / $\phi \to K^+K^-$

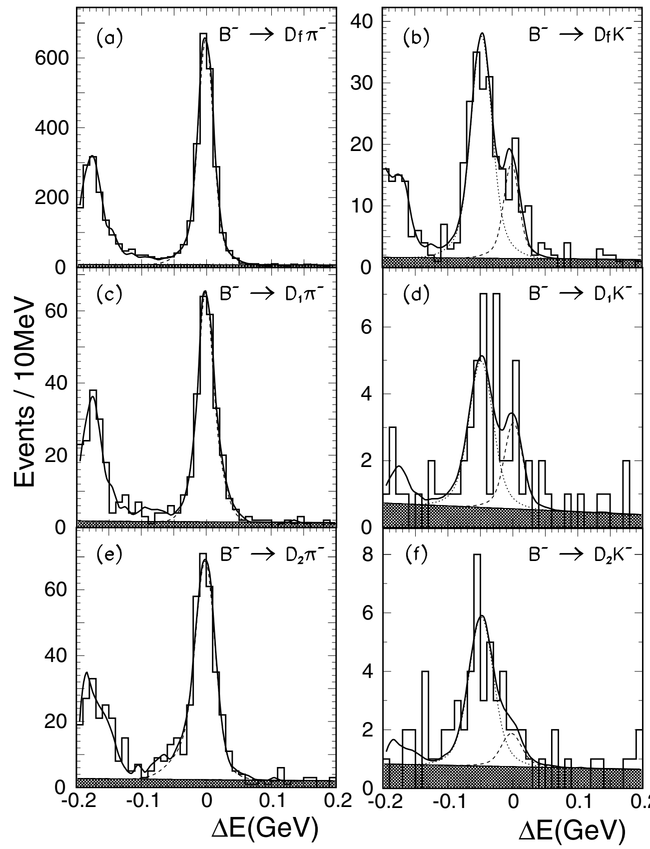
- Vetoes for B decay backgrounds

— $m_{h\pi}$ ($\sim m_{D^0}, m_{J/\psi}$) cut for $B^- \to D^0\pi^-$, $J/\psi K^-$ bg. in $B^- \to D_1(\pi^+\pi^-)h^-$

— Helicity angle cut for non-D_{CP} bg. in $D \to VP$

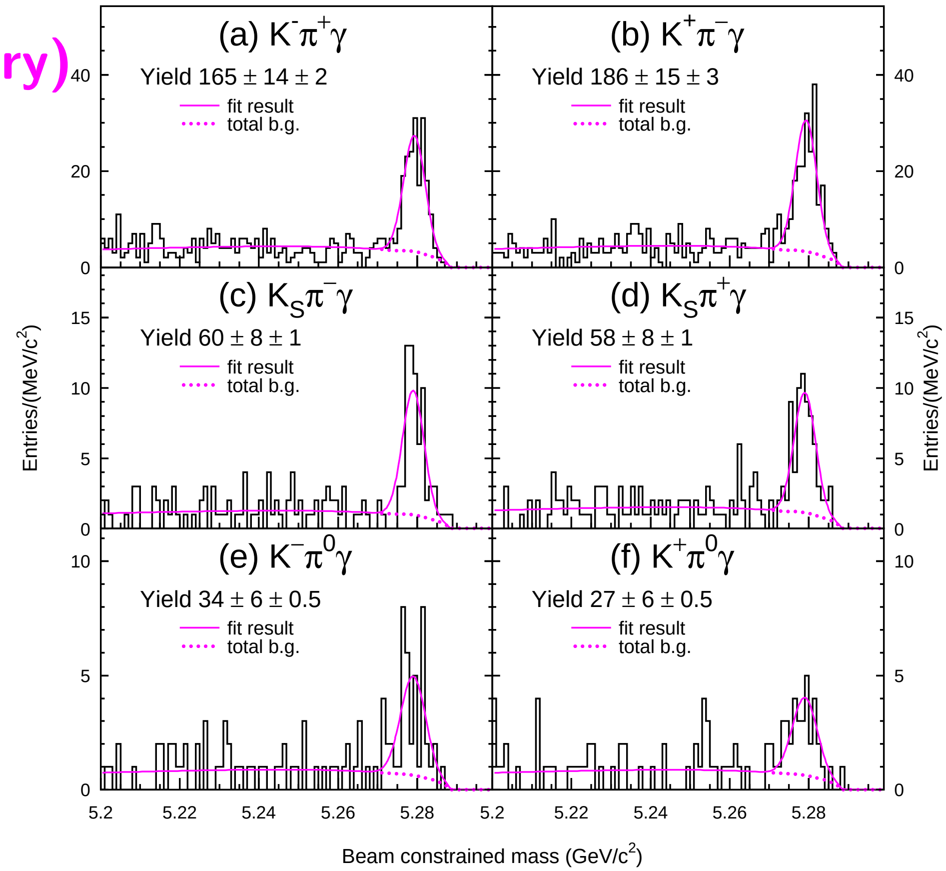
— $m_{K^*(\to K^0_S\pi)}$ cut for $D^0 \to K^{*-}\rho^+$ bg. in $D \to K^0_S\omega$

- High momentum PID for D^0K^- / $D^0\pi^-$ separation.



Decay Mode	$N(\overline{B})$	$N(B)$	$\mathcal{A}_{CP}$	90% C.L.
$B^+ \to D_fK^+$	81.1 ± 10.4	80.6 ± 10.1	$0.003 \pm 0.089 \pm 0.037$	[-0.15, 0.16]
$B^+ \to D_1K^+$	14.7 ± 4.6	8.1 ± 3.9	$0.29 \pm 0.26 \pm 0.05$	[-0.14, 0.73]
$B^+ \to D_2K^+$	10.6 ± 4.2	16.4 ± 5.5	$-0.22 \pm 0.24 \pm 0.04$	[-0.62, 0.18]

2.4 $B \to K^* \gamma$ @60 fb^{-1} (Preliminary)



- SM predicts $\mathcal{A}_{CP}(K^* \gamma) < 1\%$.
- — Large asymmetry would be an indication of new physics.
- $K^{*0} \to K^+\pi^-$ / $K^{*+} \to K^0_S\pi^+$, $K^+\pi^0$
- — Dilution of double mis-PID is corrected in $K^{*0} \to K^+\pi^-$ mode $(w = 0.90\%)$.
- Possible detecotr/reconstruction bias is studied with an inclusive K^* sample.
- — $\mathcal{A}(K^{*0} \to K^+\pi^-) = (-0.46 \pm 0.59)\%$
- — $\mathcal{A}(K^{*+} \to K^0_S\pi^+) = (-0.93 \pm 0.63)\%$
- — $\mathcal{A}(K^{*+} \to K^+\pi^0) = (-0.21 \pm 1.23)\%$

Decay Mode	$N(\overline{B})$	$N(B)$	$\mathcal{A}_{CP}$	90% C.L.
$K^{*0} \to K^+\pi^-$	$165 \pm 14 \pm 2$	$186 \pm 15 \pm 3$	$-0.061 \pm 0.061 \pm 0.022$	
$K^{*+} \to K^0_S\pi^+$	$61 \pm 8 \pm 1$	$58 \pm 8 \pm 1$	$-0.018 \pm 0.101 \pm 0.017$	
$K^{*+} \to K^+\pi^0$	$34 \pm 6 \pm 0.5$	$27 \pm 6 \pm 0.5$	$0.121 \pm 0.146 \pm 0.001$	
combined K^{*+}			$0.053 \pm 0.083 \pm 0.016$	
combined K^*			$-0.022 \pm 0.048 \pm 0.017$	[-0.106, 0.062]

3 Summary

- Belle DCPV results show null consistent asymmetries in decay rates.

— Using time-integrated analysis.

— Based on $29 - 78$ fb$^{-}1$.

— Previously observed large asymmetry in $B^+ \to K^0_S\pi^+$ has disappeared.

- Statistical precisions have reached below 10% level in several decays.

— Much more interesting informations can be expected in a few years.

ϕ_3, strong phase, new physics . . .