Sensitivity Reach for ϕ_3 (γ)

K. Abe
KEK

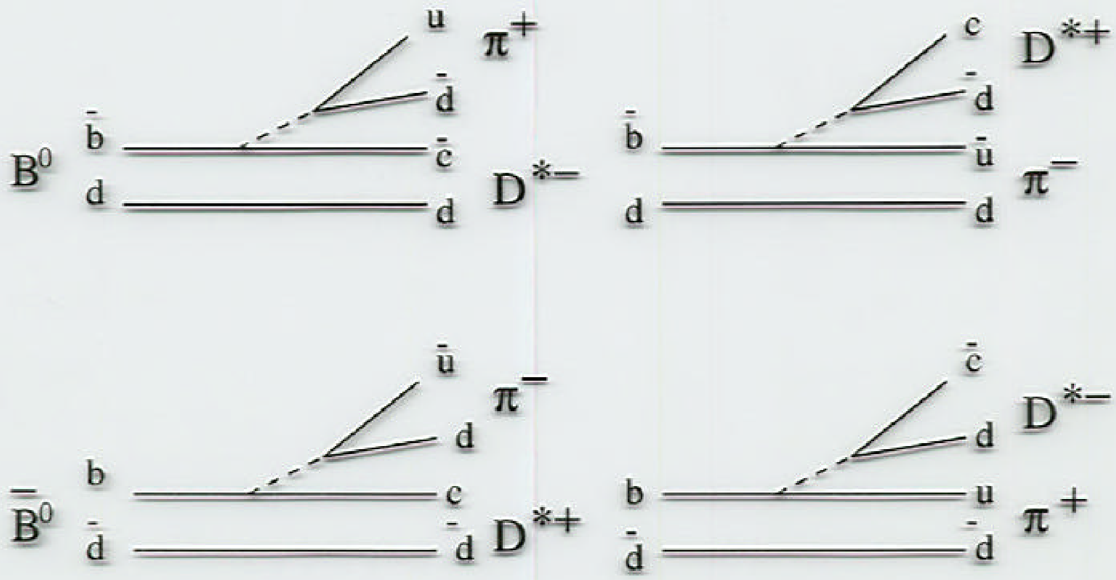
BCP4
February, 2001

contents

Possible Ways to Measure ϕ_3 (γ)
(listed as we will hear "result")

- $B \to K\pi, \pi\pi$, QCD factorization
  - Branching fractions. No tagging. No time analysis.
  - All branching ratios are of similar size.
  - Several theoretical problems.
- $B^0/\bar{B}^0 \to D^{*\mp}\pi^{\pm}$, Dunietz
  - Mixing assisted, need tagging and time analysis.
  - Theoretically clean.
  - Large event sample by partial reconstruction.
- $B^0/\bar{B}^0 \to D^{*\mp}\rho^{\pm}$, London-Sinha-Sinha
  - Same as $D^{*\mp}\pi^{\pm}$ except 3 helicity amplitutes.
  - Need angular analysis.
  - Redundant measurements might help resolving ambiguity.
- $B \to DK$, variations of Granou-London-Wyler
  - Original GLW faced difficulty:
    cannot distinguish $B^- \to \bar{D}^0(K^+\pi^-)K^-$ from $B^- \to D^0(K^+\pi^-)K^-$
  - $B \to DK \to$ (favored B decay) $\times$ (suppressed D decay),
    Atwood-Dunietz-Soni
  - other variations.
  - Use theoretical values of Br($B^- \to \bar{D}^0(K^+\pi^-)K^-$).
  - Small event samples.
- Measurements at B_s^0

$B^0(\bar{B}^0) \to D^{*\mp}\pi^{\pm}$



- No penguin.
- Large data sample with partial reconstruction.

$$
\begin{aligned}
a &\equiv A(B^0 \to D^{*-}\pi^+) = |\, a \,|\, e^{i\delta^a}, \qquad \bar{a} = |\, a \,|\, e^{i\delta^a} \\
b &\equiv A(B^0 \to D^{*+}\pi^-) = |\, b \,|\, e^{i\delta^b} e^{-i\phi_3}, \quad \bar{b} = |\, b \,|\, e^{i\delta^b} e^{+i\phi_3}
\end{aligned}
$$

Time-dependent amplitudes

$$
A_{B^0 \to D^{*-}\pi^+}(t) = e^{-\frac{\gamma}{2}t} a \left(\cos\frac{\Delta m\, t}{2} - \frac{q}{p}\frac{\bar{b}}{a} i \sin\frac{\Delta m\, t}{2} \right)
$$

Time-dependent decay rates

$$\Gamma(B^0 \to D^{*-}\pi^+) = e^{-\gamma t}\frac{|\,a\,|^2}{2\gamma}$$
$$\Big[(1+r^2) + (1-r^2)\cos\Delta m t + 2r\sin(2\phi_1+\phi_3-\delta)\sin\Delta m t\Big]$$

$$\Gamma(\bar{B}^0 \to D^{*-}\pi^+) = e^{-\gamma t}\frac{|\,a\,|^2}{2\gamma}$$
$$\Big[(1+r^2) - (1-r^2)\cos\Delta m t - 2r\sin(2\phi_1+\phi_3-\delta)\sin\Delta m t\Big]$$

$$\Gamma(B^0 \to D^{*+}\pi^-) = e^{-\gamma t}\frac{|\,a\,|^2}{2\gamma}$$
$$\Big[(1+r^2) - (1-r^2)\cos\Delta m t + 2r\sin(2\phi_1+\phi_3+\delta)\sin\Delta m t\Big]$$

$$\Gamma(\bar{B}^0 \to D^{*+}\pi^-) = e^{-\gamma t}\frac{|\,a\,|^2}{2\gamma}$$
$$\Big[(1+r^2) + (1-r^2)\cos\Delta m t - 2r\sin(2\phi_1+\phi_3+\delta)\sin\Delta m t\Big]$$

$$\begin{aligned} \delta &\equiv \delta^b - \delta^a \\ r &= \left|\frac{V_{ub}^* V_{cd}}{V_{cb} V_{ud}^*}\right| \sim 0.4\lambda^2 \sim 0.02 \quad (\lambda \sim 0.22) \end{aligned}$$

Time-integrated decay rates

t>0 upper signs
t<0 lower signs

$$\Gamma(B^0 \to D^{*-}\pi^+) = \frac{|a|^2}{2\gamma}\left[(1+r^2) + \frac{1-r^2}{1+x^2} \pm \frac{2rx}{1+x^2}\sin(2\phi_1+\phi_3-\delta)\right]$$

$$\Gamma(\bar{B}^0 \to D^{*-}\pi^+) = \frac{|a|^2}{2\gamma}\left[(1+r^2) - \frac{1-r^2}{1+x^2} \mp \frac{2rx}{1+x^2}\sin(2\phi_1+\phi_3-\delta)\right]$$

$$\Gamma(B^0 \to D^{*+}\pi^-) = \frac{|a|^2}{2\gamma}\left[(1+r^2) - \frac{1-r^2}{1+x^2} \pm \frac{2rx}{1+x^2}\sin(2\phi_1+\phi_3+\delta)\right]$$

$$\Gamma(\bar{B}^0 \to D^{*+}\pi^-) = \frac{|a|^2}{2\Gamma}\left[(1+r^2) + \frac{1-r^2}{1+x^2} \mp \frac{2rx}{1+x^2}\sin(2\phi_1+\phi_3+\delta)\right]$$

$$x = \Delta m/\gamma = 0.73$$

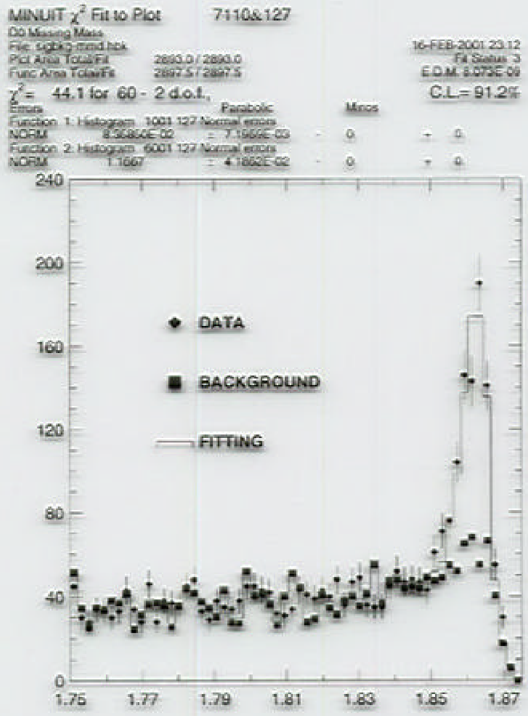
$N_{DCSD} \sim \frac{x^2}{2+x^2} \sim 1/5 \times N_{CFD}$. (not small because of Mixing)

$\sin(2\phi_1 + \phi_3)$ can be extracted from both time-integrated asymmetry and Δt fit.

Monte Carlo Study

(with input from data analysis)

- Event Selection
  - Partial reconstruction:
    Use only π_s and π_f from $D^{*-}\pi^+ \to D^0\pi_s^-\pi_f^+$.
    ($\times 10$ gain w.r.t. full reconstruction)
  - Tagging by leptons only. (helps removing bkg)



- Belle 6.1 fb^{-1} (preliminary result from Y.H. Zheng, U.of Hawaii)

  signal: 559±48

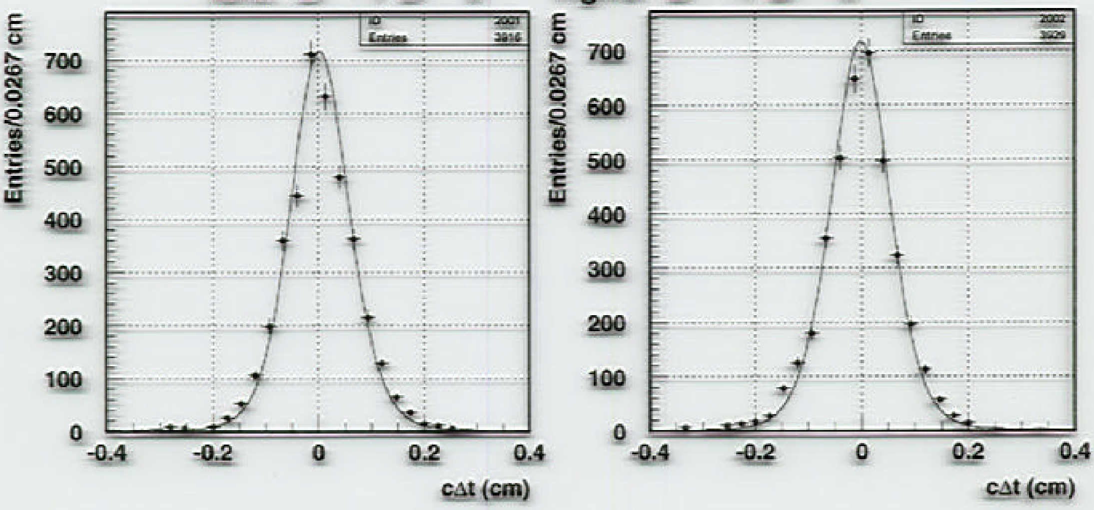
  bkg : 421±15

- Efficiency:

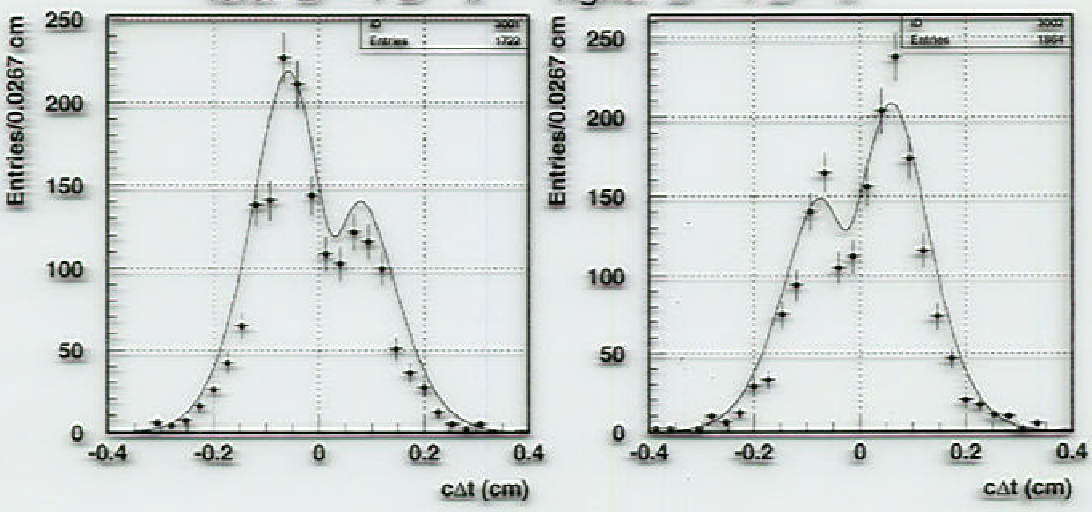
  N(signal)$/N(B^0 \to D^{*-}(D^0\pi^-)\pi^+)$
  $= e_{\mathrm{P.R.}} \times e_{\mathrm{tag}} = 0.43 \times 0.12 = 0.052$

- Signal MC events for $200 fb^{-1}$
  - $|r| = 0.1$ (instead of 0.02, but results quoted here are for this value)
  - $\sin(2\phi_1 + \phi_3) = 0.985$
  - $\delta = 0$
- $c\Delta t = \Delta z/\beta\gamma$ using π_f and tagging lepton.

left: $B^0 \to D^{*-}\pi^+$ right: $\bar{B}^0 \to D^{*+}\pi^-$



left: $\bar{B}^0 \to D^{*-}\pi^+$ right: $B^0 \to D^{*+}\pi^-$



Time-integrated asymmetry

$$A_{CFD} = \frac{2rx}{1+x^2}\sin(2\phi_1+\phi_3) \sim 0.012\sin(2\phi_1+\phi_3)$$
$$A_{DCSD} = \frac{2r}{x}\sin(2\phi_1+\phi_3) \sim 0.055\sin(2\phi_1+\phi_3)$$

- $A_{DCSD} \sim 5 \times A_{CDF}$ ($\sqrt{5}$ times more significance)

- Error of signal events reduces statistical power.

  $\sigma_A \to 1/\sqrt{N} \to 1/\sqrt{(N/\delta N)^2}$

  Assume this will improve in future: use $\sigma_A = 1/\sqrt{N}$.

$$A_{CFD} = 0.0055 \pm 0.016 \to \sin(2\phi_1+\phi_3) = 0.09 \pm 0.92$$
$$A_{DCSD} = 0.348 \pm 0.019 \to \sin(2\phi_1+\phi_3) = 1.26 \pm 0.44$$

Simultaneous Δt fit of all 4 modes

- Δm and r are fixed.

- Signal PDF is the theoretical decay rates convolved with double gaussion Δz resolution.

  Result of fit: $\sin(2\phi_1+\phi_3) = 0.86 \pm 0.30$

$B^0(\bar{B}^0) \to D^{*\mp}\rho^{\pm}$

a and b are replace by:

$$
\begin{aligned}
a_\lambda &\equiv A[B^0 \to (D^{*-}\rho^+)_\lambda] = \mid a_\lambda \mid e^{i\delta^a_\lambda}, \qquad \bar{a}_\lambda = \zeta_\lambda \mid e^{i\delta^a_\lambda} \\
b_\lambda &\equiv A[\bar{B}^0 \to (D^{*-}\rho^+)_\lambda] = \mid b_\lambda \mid e^{i\delta^b_\lambda} e^{-i\phi_3}, \quad \bar{b}_\lambda = \zeta_\lambda \mid b_\lambda \mid e^{i\delta^b_\lambda} e^{+i\phi_3}
\end{aligned}
$$

$\lambda = \parallel,\ 0,\ \perp,$

$(\zeta = +1$ for $\parallel$ and 0, -1 for $\perp)$

Time-dependent amplitude is now given by

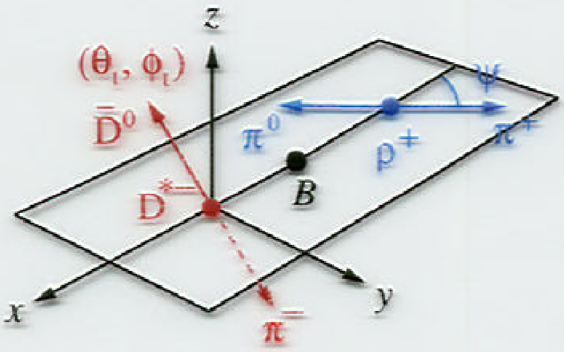
$$
A_{B^0 \to D^{*-}\rho^+}(\phi_{tr}, \theta_{tr}, \psi, \Delta t) = e^{-\frac{\gamma}{2}|\Delta t|} \sum_\lambda a_\lambda \left(\cos\frac{\Delta m\, \Delta t}{2} - \frac{q}{p}\frac{\bar{b}_\lambda}{a_\lambda} i \sin\frac{\Delta m\, \Delta t}{2} \right) g_\lambda
$$

12 unknown quantities

$$
\mid a_0 \mid,\ \mid a_\parallel \mid,\ \mid a_\perp \mid,\ \mid b_0 \mid,\ \mid b_\parallel \mid,\ \mid b_\perp \mid
$$

$$
\delta^a_\parallel,\ \delta^a_\perp,\ \delta^b_0,\ \delta^b_\parallel,\ \delta^b_\perp
$$

$$
2\phi_1 + \phi_3
$$



$$g_\parallel = \frac{1}{\sqrt{2}} \sin\theta_{tr} \sin\phi_{tr} \sin\psi$$

$$g_0 = \sin\theta_{tr} \cos\phi_{tr} \cos\psi$$

$$g_\perp = \frac{i}{\sqrt{2}} \cos\theta_{tr} \sin\psi$$

Time-dependent Decay Rates

$$\Gamma[B^0 \to D^{*-}\rho^+(\phi_{tr}, \theta_{tr}, \psi, \Delta t)]$$
$$= e^{-\frac{\gamma}{2}|\Delta t|} \sum_{\lambda \leq \sigma} (\Lambda_{\lambda\sigma} + \Sigma_{\lambda\sigma} \cos \Delta m \Delta t - \rho_{\lambda\sigma} \sin \Delta m \Delta t)\, g_\lambda g_\sigma$$

- Λ's and Σ's contain δ^a_λ and δ^b_λ.
- ρ's contain $\phi \equiv (2\phi_1 + \phi_3)$.
(correspond to $r \sin(2\phi_1 + \phi_3 \pm \delta)$ for $D^*\pi$)
- Λ's, Σ's, ρ's contain a_λ and b_λ.

$$\begin{aligned}
\rho_{\lambda\lambda} &= \zeta_\lambda a_\lambda b_\lambda \sin(-\phi + \delta_\lambda), \quad (\zeta = -1 \text{ for } \perp) \\
\rho_{\perp 0} &= -a_\perp b_0 \cos(-\phi + \delta^b_0 - \delta^a_\perp) - a_0 b_\perp \cos(-\phi + \delta^b_\perp - \delta^a_0) \\
\rho_{\perp \parallel} &= -a_\perp b_\parallel \cos(-\phi + \delta^b_\parallel - \delta^a_\perp) - a_\parallel b_\perp \cos(-\phi + \delta^b_\perp - \delta^a_\parallel) \\
\rho_{\parallel 0} &= +a_\parallel b_0 \sin(-\phi + \delta^b_0 - \delta^a_\parallel) + a_0 b_\parallel \sin(-\phi + \delta^b_\parallel - \delta^a_0)
\end{aligned}$$

- Signs of ϕ, Λ, Σ, and ρ are different for different decay modes.

Event Rate

- Full reconstruction of $D^{*\mp}\rho^{\pm}$
  - Use $D^0 \to K^-\pi^+,\ K^-\pi^+\pi^0,\ K^-\pi^+\pi^+\pi^-$ modes.
  - Reconstruction efficiency: 1.15×10^{-2} (preliminary)
- Flavor-tagging and Δt measurement: Belle standard
- Expected signal events for $200 fb^{-1}$:

$$\begin{aligned} & N_{B\bar{B}} \times Br(B^0 \to D^{*-}\rho^+) \times \times Br(D^{*-} \to D^0\pi^-) \times e_{\text{recon}} \times e_{\text{tag}} \\ = \ & 2 \times 10^8 \times 6.8 \times 10^{-3} \times 0.677 \times 1.15 \times 10^{-2} \times 0.27 = 3000 \end{aligned}$$

(compared to 8000 for $D^*\pi$)

Guessing ϕ_3 Sensitivity

- A naive MC study of $D^*\pi$ with $200 fb^{-1}$ gives:

  $\delta \sin(2\phi_1 + \phi_3) = 0.44$ for A_{DCSD}

  $\delta \sin(2\phi_1 + \phi_3) = 0.30$ for Δt fit

  - DCSD to CFD ratio r, is assumed to be known from other methods.
  - Possible ambiguity of $2\phi_1 + \phi_3$ and δ ca be resolved by some clever methods.
  - Error of signal sample and background behaviour can be controled.

- Study of other methods should help on r and ambiguity.

- A wild guess: $\delta \sin(2\phi_1 + \phi_3) = 0.3$ for $200 fb^{-1}$

  (About 4 times bigger than $\delta \sin 2\phi_1$)

	$L_{\text{int.}}$ (fb^{-1})	$\delta \sin(2\phi_1 + \phi_3)$
summer 2002	110	~~0.3~~ 0.42
summer 2005	540	~~0.14~~ 0.20

Ambiguities, theoretical problems will begin to limit the measurement by 2005.