Workshop on the
Tau-Charm Factory
in the Era of
B-Factories and CESR
August 15, 1994

Mixing-Induced CP Violation in the $D^0\bar{D}^0$ System

Joseph M. Izen
University of Texas at Dallas

- Motivation
- Previous τCF estimate for $e^+e^- \to \gamma D^0 \overline{D}^0$
- Choice of $\sqrt{s}$: 4.03 GeV *vs* 4.14 GeV
- $e^+e^- \to \gamma D^0 \overline{D}^0$
  $\to \gamma$(shared f.s.)(semileptonic decay)
- $e^+e^- \to \gamma D^0 \overline{D}^0$
  $\to \gamma$(shared f.s.)(hadronic decay)
- $e^+e^- \to \gamma D^0 \overline{D}^0$
  $\to \gamma$(shared f.s.)(inclusive K or lepton)

Mixing-Induced $\not{CP}$ in $D^0, \bar{D}^0$

(following Bigi, SLAC Report 343)

- For shared final states (sfs) of D^0 and $\overline{D}^0$
  e.g. K^+K^-, $\pi^+\pi^-$ (assuming $y << x << 1$)

  $$\text{rate}(D^0 \to sfs) \cong e^{-\Gamma t}\hat{\mathrm{T}}_{\mathrm{PP}}(1-\sqrt{2r_D}\frac{t}{\tau_D}\mathrm{A}_{\mathrm{PP}})$$

- Study $e^+e^- \to D^0\overline{D}^0 + \ldots \to$ sfs + *hadronic* +...
  $\to$ sfs + *semileptonic* +...
  $\to$ sfs + $l^{\pm}$X +...
  $\to$ sfs + $K^{\pm}$X +...

- Quantum coherence:

Reaction	<CP Asym>$_{\text{time}}$	C[$D^0\overline{D}^0$]
$e^+e^- \to D^0\overline{D}^0$	0	−
$e^+e^- \to D^0\overline{D}^0\gamma$ + c.c.	$2\sqrt{2r_D}\mathrm{A}_{\mathrm{PP}}$	+
$e^+e^- \to D^0\overline{D}^0\pi^0$ + c.c.	0	−

$$\mathrm{A}_{\mathrm{CP}} = \langle\text{CP Asym}\rangle_{\text{time}} \equiv \frac{\mathrm{N}[(l^-\mathrm{X})(sfs)] - \mathrm{N}[(l^+\mathrm{X})(sfs)]}{\mathrm{N}[(l^-\mathrm{X})(sfs)] + \mathrm{N}[(l^+\mathrm{X})(sfs)]}$$

- Current mixing limits permit A_{CP} ~few %
  Standard Model A_{CP} ~10^{-5}

- An oscillation-induced asymmetry sensitivity of $O(10^{-3})$ would probe physics beyond the Standard Model.

Previous Mixing-Induced $\not{CP}$ Study

(U. Karshon, SLAC Report 343)

- Reconstruct $e^+e^- \to D^0\overline{D}^0\gamma$

  $\to$ (CP eigenstate)($Ke\nu$, $K\mu\nu$, $\pi e\nu$, $\pi\mu\nu$)γ

$\sqrt{s} = 4.14$ GeV

$\sigma(e^+e^- \to D^0\overline{D}^{*0} + c.c.) = 0.9$ nb

$B(D^{*0} \to \gamma D^0) = 0.37$

One 5000 hour year

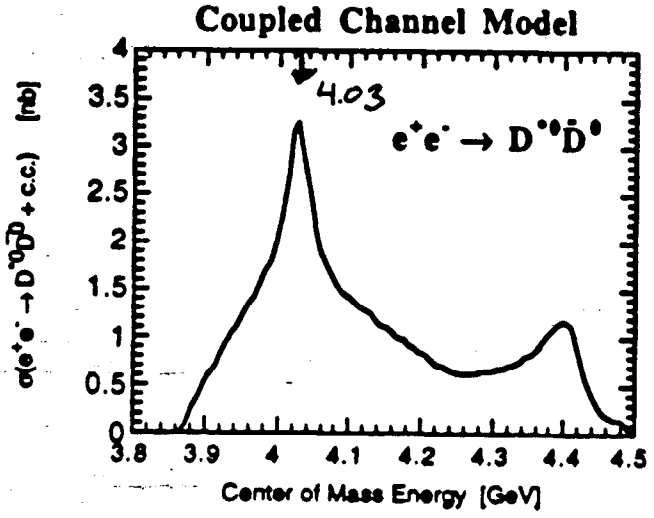
$L = 10^{33}$

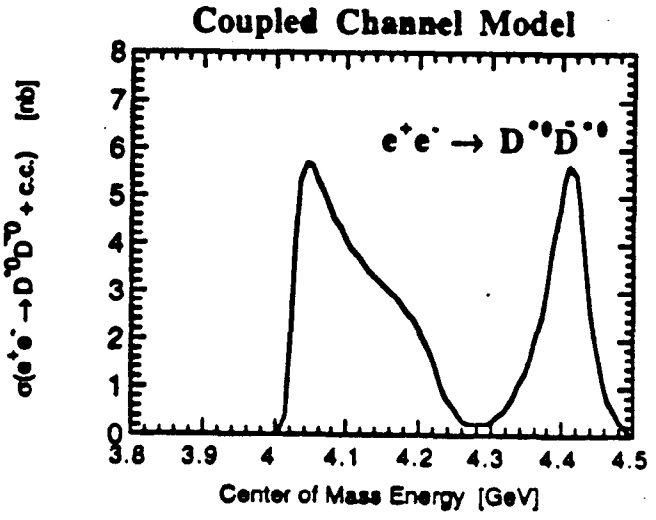
Channel	Br	efficiency	$\gamma D^0\overline{D}^0$ Events
$K_S\rho^0$	0.0027	0.42	460
$K_S\eta$	0.006	0.12	290
$K_S\phi$	0.0029	0.05	60
$K_S\pi^0$	0.0073	0.26	770
$K_S\omega$	0.013	0.06	320
$\rho^0\pi^0$	too high 0.011	0.7	3140
$\pi\pi$	0.0014	0.8	460
KK	0.0051	0.5	1040
K_SK_S	0.0003	0.26	30
SUM			6600

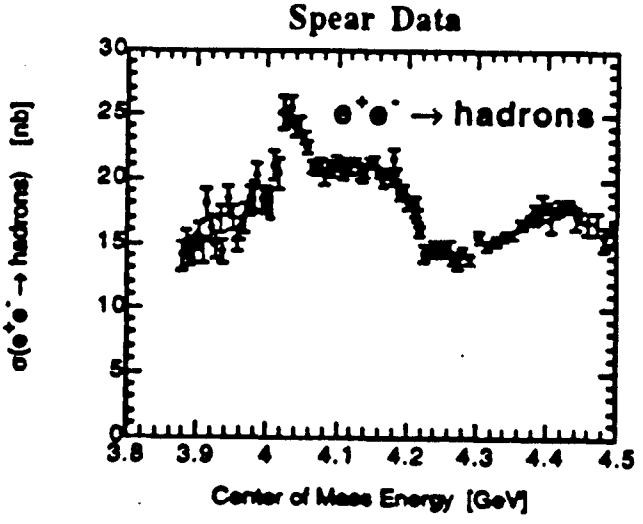
- $\Delta(A_{CP}) = 1.2 \times 10^{-2}$

CM Energy: 4.03 *vs.* 4.14 GeV

- BES measurment at $\sqrt{s} = 4.03$ GeV:
  $\sigma(e^+e^- \to D^0\overline{D}^{*0} + c.c.) = (2.55 \pm 0.12 \pm 0.25)$ nb
- Prediction: $\sigma(e^+e^- \to D^0\overline{D}^{*0} + c.c.)$ maximum at 4.03:







- Kinematic Rejection of $D^*\overline{D}^*$ events at $\sqrt{s} = 4.03$ GeV
  4.03 GeV: $D^*\overline{D}^*$ $p_{D^0} < 0.310$, $D\overline{D}^*$ $p_{D^0} > 0.380$
- 4.14 GeV: $D^*\overline{D}^*$ $p_{D^0} < 0.620$, $D\overline{D}^*$ $p_{D^0} > 0.530$

p_{D^0} from $D\overline{D}^*$ and $D^*\overline{D}^*$ overlaps at $\sqrt{s} = 4.14$ GeV.

Tagging Summary

- Final states shared by D^0 and $\overline{D}^0$.

Channel	PDG'94 Br	Br error	efficiency	Br * efficiency
$K_s\pi^0$	0.0103	0.0013	0.26	0.0027
$K_s\rho^0$	0.0055	0.0009	0.42	0.0023
KK	0.0045	0.0003	0.50	0.0023
$\pi\pi$	0.0016	0.0001	0.80	0.0013
$K_s\omega$	0.0100	0.0020	0.13	0.0013
$\rho\pi^0$	0.0020	←est.	0.38	0.0008
$K_s\eta$	0.0034	0.0006	0.12	0.0004
$K_s\phi$	0.0043	0.0006	0.05	0.0002
K_sK_s	0.0003	0.0001	0.26	0.0001
SUM				0.0114

- Flavor-tagging D^0 hadronic decays

Channel	PDG'94 Br	Br error	efficiency	Br * efficiency
$K\pi$	0.0410	0.0014	0.64	0.0264
$K\pi\pi^0$	0.1380	0.0100	0.23	0.0318
$K\pi\pi\pi$	0.0810	0.0050	0.36	0.0294
$K\pi\pi^0\pi^0$	0.1500	0.0500	0.08	0.0121
SUM				0.0997

- Flavor-tagging D^0 semileptonic decays

Channel	PDG'94 Br	Br error	efficiency	Br * efficiency
$Ke\nu$	0.0368	0.0021	0.71	0.0261
$K\mu\nu$	0.0368	0.0021	0.57	0.0210
$\pi e\nu$	0.0039	0.0016	0.71	0.0028
$\pi\mu\nu$	0.0039	0.0016	0.57	0.0022
SUM				0.0521

Semileptonic Flavor Tagging

- $e^+e^- \rightarrow D^0\overline{D}^0\gamma \rightarrow$(sfs)(*semileptonic*)$\gamma$ at 4.03 GeV

- Reconstruct γ: Photons from both
  $D^{*0} \rightarrow D^0\gamma$ (0.10 GeV $< p_\gamma <$ 0.18 GeV) and
  $D^{*0} \rightarrow D^0\pi^0 \rightarrow D^0\gamma\gamma$ (0.04 GeV $< p_\gamma <$ 0.12 GeV)
  are easily seen by CsI calorimeter.
  (*efficiency* ~ 0.7)

- Require missing mass ~ 0, *i.e.* consistent with a ν.

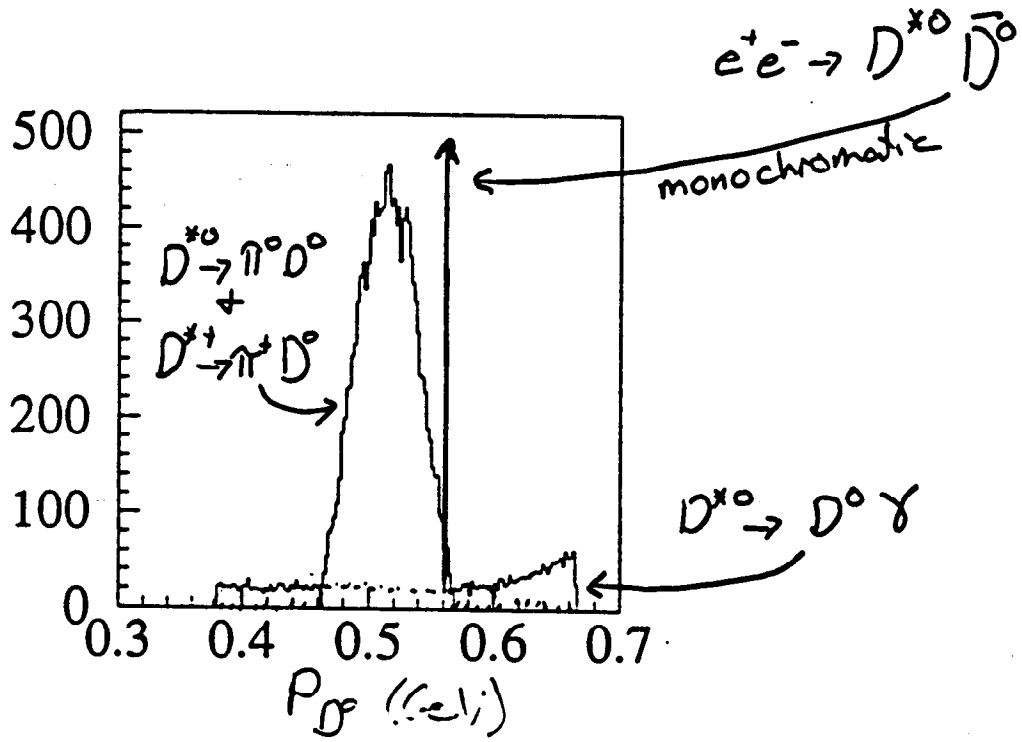
- Require: 1 'monochromatic D' plus
  1 D consistent with $D^{*0} \rightarrow D^0\gamma$

- $N_{events}[e^+e^- \rightarrow D^0\overline{D}^0\gamma \rightarrow$(sfs)(*semileptonic*)$\gamma]$
  $= 13 \times 10^3$/yr

- $\Delta(A_{CP}) = 8.6 \times 10^{-3}$

Hadronic Flavor Tagging

- $e^+e^- \to D^0\overline{D}^0\gamma \to$(sfs)(*hadronic*)$\gamma$
- At 4.03 GeV, can distinguish $e^+e^- \to D^{*0}\overline{D}^0 \to D^0\overline{D}^0\gamma$ and reject $e^+e^- \to D^{*0}\overline{D}^0 \to D^0\overline{D}^0\pi^0$ kinematically! (*efficiency* ~ 0.74)



- Require: 1 'monochromatic D' plus
  1 D having p inconsistent with $D^{*0} \to D^0\pi^0$
- Alternatively, reconstruct γ with efficiency ~0.7.

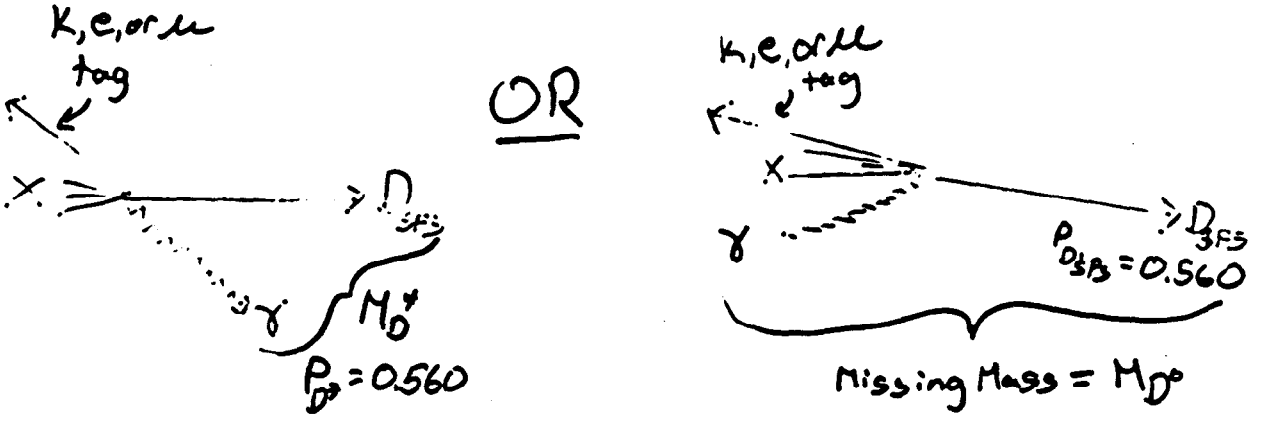
- $N_{events}[e^+e^- \to D^0\overline{D}^0\gamma \to$(sfs)(*hadronic*)$\gamma] = 27 \times 10^3$/yr
- $\Delta(A_{CP}) = 6.1 \times 10^{-3}$

Inclusive Flavor Tagging?

- Use same list of shared final states (sfs) for D^0 and $\overline{D}^0$.
- Inclusive D^0 flavor tags

Inclusive Channel	PDG'94 Br	efficiency	Br * efficiency
$K_{right\ sign}$	0.5300		
$K_{wrong\ sign}$	0.0340		
$K_{right\ -\ wrong}$	0.4960	0.80	0.40
lepton	0.1620	0.75	0.12
Correlated Sum			0.47

- Reconstruct transition γ from $e^+e^- \rightarrow D^{*0}\overline{D}^0 \rightarrow D^0\overline{D}^0\gamma$
  γ reconstruction efficiency ~ 0.7
- Require:



- $N_{events}[e^+e^- \rightarrow D^0\overline{D}^0\gamma \rightarrow (\text{sfs})(K^{\pm}X, l^{\pm}X)\gamma] = 120 \times 10^3/\text{yr}$
- $\Delta(A_{CP}) = 2.9 \times 10^{-3}$
- **A serious background study is required before this method can be taken seriously!**

Conclusions

- A τCF can measure a time-integrated, mixing-induced, CP asymmetry in the process
  $\sigma(e^+e^- \to D^0\overline{D}^{*0} + c.c. \to D^0\overline{D}^0\gamma$.

- The preferred $\sqrt{s}$ for this measurement is 4.03 GeV.

- In one τCF year (200 day year at L=10^{33}):

$$N_{events}[e^+e^- \to D^0\overline{D}^0\gamma \to (\text{sfs})(semileptonic)\gamma] = 13 \times 10^3/\text{yr}$$

$$N_{events}[e^+e^- \to D^0\overline{D}^0\gamma \to (\text{sfs})(hadronic)\gamma] = 27 \times 10^3/\text{yr}$$

- Both samples combined: $\Delta(A_{CP}) = 5.0 \times 10^{-3}$.

- "Interesting" sensitivity for new physics beyond the Standard Model.