$D^0 - \bar{D}^0$ Mixing and CP Violation: Experimental Projections for a τ-Charm Factory†

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† This work was supported in part by the U. S. Department of Energy, under contract DE-AC02-76ER01195

Introduction

This report presents the results of a set of feasability studies for observing $D^{\circ} - \bar{D}^{\circ}$ mixing and CP violation in the proposed high luminosity τ-charm factory. These studies are not yet complete, but clear general conclusions can already be drawn. In particular, a year of running with 10^{33} luminosity would allow observation of $D^{\circ} - \bar{D}^{\circ}$ mixing at the level of 10^{-4} to 10^{-5}, consistent with standard model expectations, while CP violation in the D system could be probed at the 10^{-2} level.

$D^{\circ} - \bar{D}^{\circ}$ Mixing

The usual problem encountered in the attempt to measure $D^{\circ} - \bar{D}^{\circ}$ mixing is that one is forced to choose between two experimental signatures: *(i)* the unambiguous signature presented by the observation of semileptonic decays such as $D^{\circ} \rightarrow Xe^{-}\nu$ which are usually complicated by the lack of a definite mass peak in the presence of plentiful backgrounds , or *(ii)* the ambiguous signature provided by hadronic decays such as $D^{\circ} \rightarrow K^{+}\pi^{-}$ in which the mass peak provides a clean identifiable signal, but potential mixing must be distinguished from the expected doubly Cabibbo suppressed decays (DCSD). Unfortunately the DCSD are expected to occur at a rate , relative to the corresponding Cabibbo favored mode of the order of $tan^4\theta_c \approx 3 \times 10^{-3}$, which is larger than the rate for $D^{\circ} - \bar{D}^{\circ}$ mixing expected from the standard model[1]

Fermilab experiment E-691[2] chose to search for $D^{\circ} - \bar{D}^{\circ}$ mixing by measuring the hadronic modes $D^{\circ} \rightarrow K^{-}\pi^{+}$ or $D^{\circ} \rightarrow K^{-}\pi^{+}\pi^{+}\pi^{-}$. They distinguish the mixing and DCSD components to these decays by measuring the time evolution of the process. For example, the time dependence for the rate for $D^0 \rightarrow K^{+}\pi^{-}$ is given by:

$$\text{Rate }(D^{\circ}(t) \rightarrow K^{+}\pi^{-}) \approx e^{-\Gamma t} \left\{ \begin{array}{r} \left(\frac{\Gamma t}{2}\right)^2 (x^2+y^2) \; + \; |\,\bar{\rho}_{K\pi}\,|^2 \;\tan^4\theta_c \\ + \, y\,\Gamma t \;\tan^2\theta_c \;\; Re\,\left(\frac{1+\epsilon}{1-\epsilon}\,\bar{\rho}_{K\pi}\right) \\ - \, x\,\Gamma t \;\tan^2\theta_c \;\; Im\,\left(\frac{1+\epsilon}{1-\epsilon}\,\bar{\rho}_{K\pi}\right) \end{array} \right\}$$

where the DCSD amplitude is contained in the factor $\bar{\rho}_{K\pi}$ defined as:

$$\bar{\rho}_{K\pi} = \frac{A(D^0 \rightarrow K^{+}\pi^{-})}{A(D^0 \rightarrow K^{-}\pi^{+})} \times \frac{1.0}{tan^2\theta_c}$$

and the mixing is characterized by x and y which are defined in terms of the mass and width differences of the flavor and mass eigenstates of the D° as follows:

$$x \equiv \frac{\Delta m}{\Gamma}$$

$$y \equiv \frac{\Delta \Gamma}{2\Gamma}$$

It is seen from the above that the ratio of $D^{\circ} - \bar{D}^{\circ}$ mixing rate to that from DCSD is proportional to t^2, leading to a relative enhancement of mixing at large decay times.

In this experiment, D°'s from the decay of D^*'s are observed via the reaction:

$$\begin{array}{llll} \gamma + Be \longrightarrow & D^{*+} + X & & \\ & \quad \hookrightarrow D^{\circ}\pi^{+} & & \\ & \qquad \hookrightarrow K^-\pi^+, K^-\pi^+\pi^-\pi^-\pi^+ & & \text{(right sign)} \\ & \qquad \hookrightarrow K^+\pi^-, K^+\pi^-\pi^+\pi^- & & \text{(wrong sign)} \end{array}$$

The charge of the pion from the D^* decay tags the charm of the D at the time of production while the time of the decay of the D is determined from the spatial measurement of the vertex provided by their silicon microstrip vertex detector. They observe a total of ≈ 1000 D^0 decays and find no evidence for $D^{\circ} - \bar{D}^{\circ}$ mixing. They are able to quote an upper limit at the 90% confidence level for $r_D \equiv \frac{(x^2+y^2)}{2}$ of :

$$r_D < 3.7 \times 10^{-3}.$$

The MarkIII experiment[3] at SPEAR searches for $D^{\circ} - \bar{D}^{\circ}$ mixing by observing both the hadronic and semileptonic modes of D°'s coming from the decay of the ψ'' via the reaction:

$$\begin{array}{l} e^+e^- \rightarrow \psi'' \longrightarrow D^{\circ}\ \bar{D}^{\circ} \\ \qquad\qquad\qquad \hookrightarrow \begin{pmatrix} K\pi,\ K\pi\pi\pi,\ K\pi\pi^{\circ} \\ Ke\nu,\ K\mu\nu \end{pmatrix} \\ \qquad\qquad \hookrightarrow \begin{pmatrix} K\pi,\ K\pi\pi\pi,\ K\pi\pi^{\circ} \\ Ke\nu,\ K\mu\nu \end{pmatrix} \end{array}$$

The events are kinematically fit to the hypothesis:

$$e^+e^- \longrightarrow X\,(M) \quad \overline{X}\,(M)$$
$$X(M) \hookrightarrow \text{mode 1} \qquad \overline{X}(M) \hookrightarrow \text{mode 2}$$

where M is a parameter of the fit; the hadronic modes fit are $K\pi$, $K\pi\pi\pi$, and $K\pi\pi^0$, and the semileptonic modes fit are $Ke\nu$ and $K\mu\nu$. A total of 224 events are observed in strangeness S=0 final states, while 3 events are observed in strangeness S=±2 final states. Unfortunately, MarkIII is unable to determine whether these 3 events should be attributed to DCSD or to $D^0 - \bar{D}^0$ mixing. Assuming all 3 events to be due to $D^0 - \bar{D}^0$ mixing leads to a mixing rate $r_D = 12 \pm 6 \times 10^{-3}$. Given the limit from E-691, it appears that DCSD must be present in these events at some level, leaving the mixture of these processes totally unknown at this time. Fortunately, these ambiguities can be completely removed at the proposed τ-charm factory.

Unambiguous evidence for $D^0 - \bar{D}^0$ mixing can be searched for at the τ- charm factory using the following three reactions:

$$(i)\quad e^+e^- \to \psi'' \longrightarrow D^0\ \bar{D}^0$$
$$\bar{D}^0 \hookrightarrow K^-\pi^+$$
$$D^0 \hookrightarrow K^-\pi^+$$

$$(ii)\quad e^+e^- \to \psi'' \longrightarrow D^0\ \bar{D}^0$$
$$\bar{D}^0 \hookrightarrow K^-e^+\nu$$
$$D^0 \hookrightarrow K^-e^+\nu$$

$$(iii)\quad e^+e^- \to D^-\ D^{*+}$$
$$D^{*+} \hookrightarrow \pi^+D^0$$
$$D^0 \hookrightarrow K^+e^-\nu$$
$$D^- \hookrightarrow K^+\pi^-\pi^-$$

The observation of Reaction *(i)* would be definite evidence for the existence of $D^0 - \bar{D}^0$ mixing since the final state $(K^-\pi^+K^-\pi^+)$ cannot be produced from DCSD due to a quantum statistics argument[4]. In particular, the initial $D^0 - \bar{D}^0$ pair is in an odd eigenstate of C which will preclude, in the absence of mixing between the D^0 and $\bar{D}^0$ over time, the formation of the symmetric state required by Bose statistics if the decays are to be to the same final state ($K^-\pi^+$). Reactions *(ii)* and *(iii)* offer unambiguous evidence for mixing in that the mixing is searched for in the semileptonic decays for which there are no DCSD. Of course since the time evolution is not measured, observation of Reactions *(ii)* or *(iii)* actually would indicate the violation of the selection rule relating the change in charm to the change in leptonic charge which must hold true in the standard model[1].

These three reactions have been studied using a parametric Monte Carlo in which the simulation of the detector has been assumed to be that of the standard "minimalist " version of the τ-charm detector in which the momentum resolution is given by:

$$(\frac{\sigma_p}{p})^2 = [0.4\% p(GeV/c)]^2 + [\frac{0.3\%}{\beta}]^2$$

and the time-of-flight resolution (important for background rejection for these reactions) is taken to have $\sigma_{TOF} = 120$ ps. The resolution of the electromagnetic shower detector does not play an important role in these studies, but the existence of some kind of hadronic calorimeter to detect the existence of K_L's in the event will be shown to be crucial.

For Reaction *(i)*, good accceptance and background rejection can be obtained with the following straight-forward requirements:

$$2K, 2\pi \text{ identified by TOF}$$

$$\text{BCMass} = 1864 \pm 4MeV$$

$$\Delta\text{Mass} \equiv \text{BCMass} - \text{InvariantMass} = 0 \pm 20MeV$$

where the beam-constrained mass (BC Mass) is defined to be the mass of the $K\pi$ pair obtained when the momentum of the pair is combined with the known beam energy. With these requirements, the acceptance for detecting the complete final state ($K\pi K\pi$) is 42.5%. Assuming one year (5000 hours) of running with a luminosity of 10^{33}, a total of 88200

$K^-\pi^+K^+\pi^-$ events will be produced, of which 37500 will be totally reconstructed and pass all the above requirements. This sample represents an increase of a factor of 2000 over the current MarkIII data sample for this final state. We now turn to a brief survey of possible backgrounds which could give rise to an apparent mixing final state ($K^-\pi^+K^-\pi^+$).

We claim the dominant background comes from a *double* particle misidentification of $K^-\pi^+K^+\pi^-$ events. While it is true that a single misidentification of $(K^-\pi^+)(K^+K^-)$ or $(K^-\pi^+)(\pi^+\pi^-)$ will give rise to an apparent mixing final state, these candidates are easily removed by the ΔMass requirement as is shown in Figure 1. In fact, a total of 538000 $K\pi$ vs "D^0 model" events (containing 22000 $K^-\pi^+K^+\pi^-$ events) were generated to look for potential backgrounds to the mixing final state $(K^-\pi^+K^-\pi^+)$. The only apparent mixing candidates (*i.e.* a final state with total strangeness S $= \pm 2$) in this sample came from events generated as $(K^-\pi^+)(K^+\pi^-)$. Consequently we now focus our attention only on backgrounds arising from double misidentification of the $(K^-\pi^+)(K^+\pi^-)$ events.

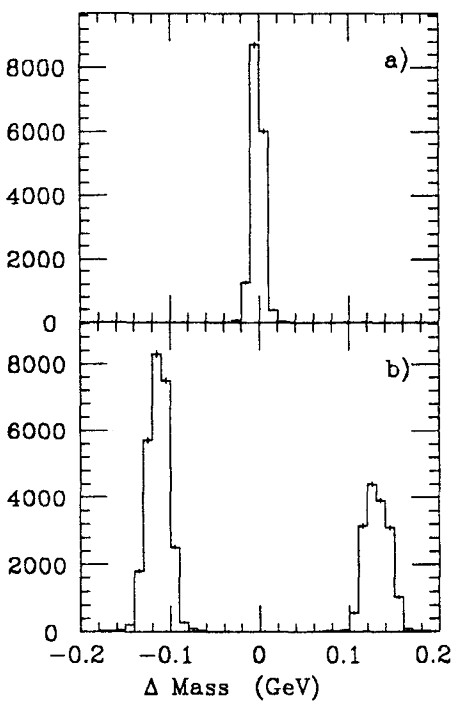

Figure 1. ΔMass distributions for (a) $D^0 \to K\pi$ and (b) $D^0 \to KK$(right peak) and $D^0 \to \pi\pi$ (left peak).

The probability that a $(K^-\pi^+)(K^+\pi^-)$ event gets misidentified as a $(K^-\pi^+)(K^-\pi^+)$ event is small and its calculation is believable since it is the result of two independent misidentifications. Figure 2 shows the TOF distributions for pions and kaons having the extreme values of momentum (0.7 GeV/c → 1.0 GeV/c) expected in the decay $D^0 \rightarrow K\pi$ as observed at the ψ'' resonance. The pion's flight time is seen to shorten by about 200ps at the highest momentum.

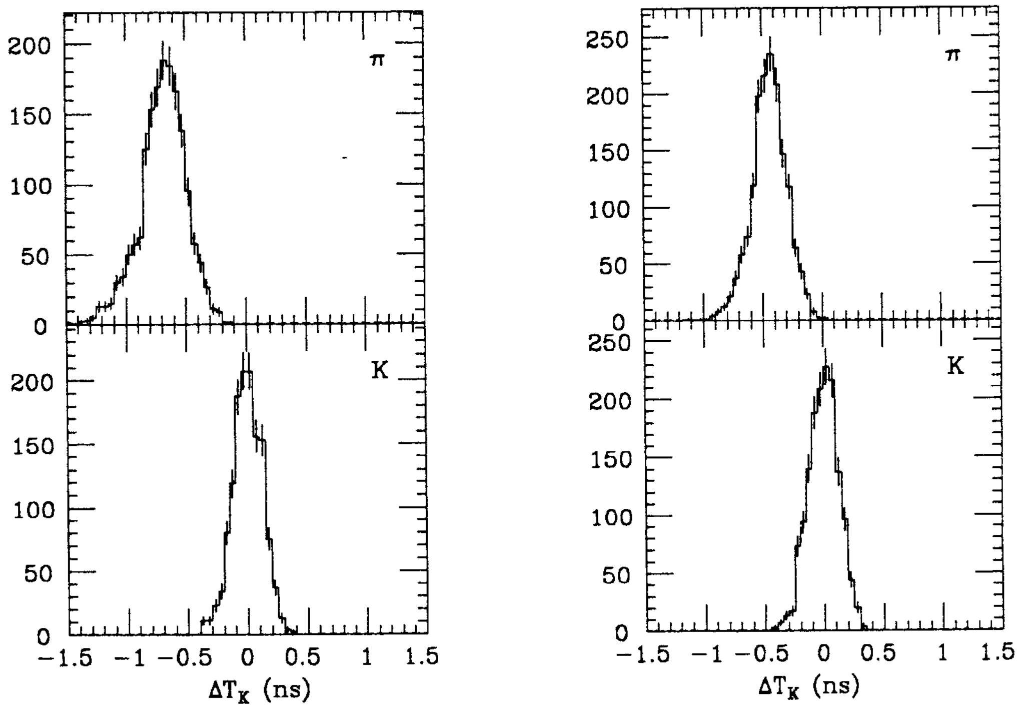

Figure 2. TOF Distributions for pions(top) and kaons(bottom) for p = 750-850 MeV/c(left) and p = 950-1000 MeV/c(right).

In order to make quantitative assessments of the background, the variable PID_{min}, defined by:

$$PID_{min} = \ min\ (PID\ (mode\,1),\, PID\ (mode\,2)$$

where

$$PID\ (mode\,i) = \max\ (\delta_K,\ \delta_\pi)$$

$$\delta_K = TOF_{obs} - \frac{1}{2}\ (TOF^{K}_{pred}\ +\ TOF^{\pi}_{pred}) \quad \text{for kaon track}$$

$$\delta_\pi = \frac{1}{2}\ (TOF^{K}_{pred}\ +\ TOF^{\pi}_{pred})\ -\ TOF_{obs} \qquad \text{for pion track}$$

is calculated for each event. PID_{min} is meant to represent the minimum TOF displacement required to reclassify a S=±2 event as a S=0 event. Figure 3 shows the PID_{min} distributions for both the correctly identified events and the doubly misidentified events from the same $(K^-\pi^+)(K^+\pi^-)$ data set. A total of 33792 events are correctly identified, while 15 events are doubly misidentified. However, as the distributions are quite different, a further requirement that $PID_{min} > 100$ps, for example, would result in a loss of efficiency of only 2% while the background events would be reduced from 15 to 3. Clearly, the dominant background for the mixed final state $(K^-\pi^+)(K^-\pi^+)$ can be kept to the level of an event or less for a year's running which would produce about 35000 observed events of the type $(K^-\pi^+)(K^+\pi^-)$. It should be noted that maintaining the excellent 120ps TOF resolution is essential for background rejection; if the TOF resolution were to be equal to that of the MarkIII experiment (180ps), the number of background events would increase by an order of magnitude while the signal efficiency would decrease by about 20%.

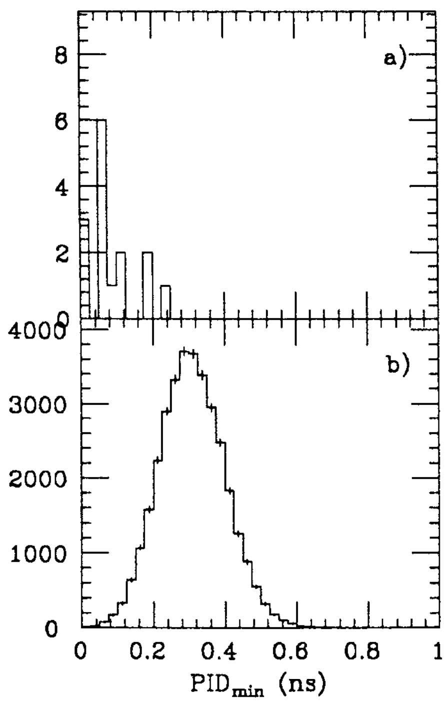

Figure 3. PID_{min} distributions for (a) background events and (b) signal events.

For Reaction *(ii)*, the double semileptonic decays of D^0, good accceptance can be obtained with the following straight-forward requirements:

2K identified by TOF

2e identified by TOF and EM calorimeter

PMISS > 100 MeV/c

EMISS > 300 MeV/c

where PMISS and EMISS are the missing momentum and energy (due to the 2 missing neutrinos) observed in the event. With these requirements, the acceptance for detecting the complete final state ($KeKe$) is 37.3%. Assuming one year (5000 hours) of running with a luminosity of 10^{33}, a total of 57800 $(K^-e^+\nu)(K^+e^-\nu)$ events will be produced, of which 21600 will be detected, passing all the above requirements. Therefore, a comparable number of events will be observed for Reaction *(ii)* as for Reaction *(i)*. The major question now remaining is the level of background to the double semileptonic events. We expect the background to be potentially larger than the background to the $(K^-\pi^+)(K^+\pi^-)$ events since there is no mass peak observed for Reaction *(ii)*.

To study these potential backgrounds, a total of 850000 "D° model" vs "$\bar{D}^\circ$ model" events, 500000 "D^+ model" vs "D^-model" events, and 250000 LUND events were generated. The background from the LUND events was found to be quite small and was not considered further. All background events from the D^+ vs D^- generation satisfied the EMISS and PMISS requirements by virtue of K_L's which were produced in the event. Consequently, this background can be eliminated by demanding that the τ-charm detector have a hadronic calorimeter which is able to induce and observe K_L interactions.

The background from the D° vs $\bar{D}^\circ$ events were dominated by events in which one semileptonic decay ($D^\circ \rightarrow K^-e^+\nu$) was correctly identified while the remaining D decay was misidentified. To study this dominant background in more detail, we generated a total of 300000 $D^\circ \rightarrow Ke\nu$ vs "D° model" events. Note this sample contains 10200 $(K^-e^+\nu)(K^+e^-\nu)$ events, of which a total of about 4000 will pass the above requirements (about 20% of the expected sample in a year's run).

A total of 65 events in this sample satisfied the standard requirements for a double semileptonic mixing signature. Most of these events can be eliminated by further requiring that no extra hadronic or electromagnetic energy is observed in the event. In particular, if we add the requirements:

$$E_{had} < 50MeV$$

$$E_{em} < 50MeV$$

we find only 14 of the background events remain. Half of these remaining events are due to kaon decays which can easily be eliminated by cutting on the distance of closest approach to the interaction point. For example, the reaction:

$$
\begin{aligned}
&e^+e^- \to \psi'' \longrightarrow D^0\bar{D}^0\\
&\qquad \bar{D}^0 \hookrightarrow K^-K^+\\
&\qquad\qquad K^+ \hookrightarrow \mu^+\nu\\
&\qquad D^0 \hookrightarrow K^-e^+\nu
\end{aligned}
$$

can give rise to the mixing signature if the muon is misidentified as an electron. Of the remaining 7 background events, 6 come from the reaction:

$$
\begin{aligned}
&e^+e^- \to \psi'' \longrightarrow D^0\bar{D}^0\\
&\qquad \bar{D}^0 \hookrightarrow K^-K^+\\
&\qquad D^0 \hookrightarrow K^-e^+\nu
\end{aligned}
$$

where the K^+ is misidentified as a positron. These events can also be easily eliminated at a cost of $< 1\%$ in efficiency by requiring that the mass of each Ke pair, calculated as a KK pair, must be different from the D^0 mass by more than 10 MeV. The remaining background event comes from the reaction:

$$
\begin{aligned}
&e^+e^- \to \psi'' \longrightarrow D^0\bar{D}^0\\
&\qquad \bar{D}^0 \hookrightarrow K^+\pi^-\\
&\qquad D^0 \hookrightarrow K^-e^+\nu
\end{aligned}
$$

where the K^+ is misidentified as a positron and the π^- is misidentified as a K^-. This event can be eliminated at the expense of a small loss of efficiency by making a slightly more stringent TOF requirement (as in the $K^-\pi^+K^-\pi^+$ case) or by requiring that the estimate of the neutrino energy for each Ke pair be somewhat larger than 0 (say 100 MeV).

Consequently, we see that approximately 20000 $(K^-e^+\nu)(K^+e^-\nu)$ events should be observed in a year's running at the τ-charm factory with a small (<5? events) background for the mixing signature. Potentially, there is an extra factor of 3 in rate to be gained by including the $(K^-e^+\nu)(K^-\mu^+\nu)$ events and the $(K^-\mu^+\nu)(K^-\mu^+\nu)$ events. The difficulty here is providing good muon identification at low momentum. Quantitative estimates must await further study; however, it seems likely that a CRID placed after the electromagnetic calorimeter should do the job nicely.

Reaction *(iii)* was studied by Constantine Simopolous and is presented in more detail in his contribution to these proceedings[5]. Several general comments are in order here, however. First, since the D^- tag ($K\pi\pi$ in this case) is observed, its well-defined mass peak should give excellent background rejection. Further, particle identification is not even critical for this tag since it is the charge of the tag which tags the charm of the opposite D^0. Finally, the rates for this process are quite high; for example a year's running at an energy of 4.14 GeV with a luminosity of 10^{33} will produce approximately 44000 events of the type:

$$e^+e^- \to D^- \; D^{*+}$$
$$D^{*+} \to \pi^+ D^0, \quad D^0 \to K^+e^-\nu$$
$$D^- \to K^+\pi^-\pi^-$$

Estimates[5] indicate that the efficiency for observing the above final state will be about 30%, which leads to a total of 13000 measured events. Once again Monte Carlo studies show the background level to be at the one event or less level. This rate estimate should also be increased to account for the possibility of adding the semimuonic decay $D^0 \to K^-\mu^+\nu$ and other D^- decay modes to the list of detected final states. Quantitative estimates for this increase have yet to be done, but factors of 2-3 seem reasonable to expect.

CP Violation

Searching for CP violation in the charm system may be the only way to probe the CP violation properties of an up-quark system. In the standard model, CP violation in the charm sector is predicted to be quite small, much beyond the capabilities of the proposed τ-charm factory to explore. However, there are currently no experimental limits on CP violation in the charm sector. Any observation of CP violation at the τ-charm factory would require an explanation based on new physics.

CP violation in the charm sector can occur either through mixing or directly through a difference in the decay amplitude to a final state for the particle and its anti-particle[1]. We look first at CP violation induced by $D^0 - \bar{D}^0$ mixing.

To simplify the following, we assume for now that the decay amplitudes themselves conserve CP. If direct CP violation is present as well, the observed effects will be larger, but the interpretation will be more difficult. CP violation induced by mixing can be studied at a τ-charm factory by once again exploiting the quantum coherence of the initial state. For example, if the $D^0 - \bar{D}^0$ pair is produced with a photon [as in $\psi'' \rightarrow D^{0*}\bar{D}^0 \rightarrow (D^0\gamma)(\bar{D}^0)$] the time-integrated CP asymmetry is proportional to x (rather than x^2), while if the $D^0 - \bar{D}^0$ pair is produced by itself (ie at the ψ'') or with a single π^0, the CP asymmetry is 0 (in the absence of direct CP violation) ! Consequently in a single sample of $D^{0*}\bar{D}^0$ events, we should see a CP asymmetry for those D^* decays to a γ while any detector induced asymmetries can be accounted for by observing the expected 0 signal in those D^* decays to a π^0. For example, in the reaction:

$$e^+e^- \rightarrow \bar{D}^0 \; D^{*0}$$

$D^{*0} \rightarrow \gamma D^0$, with $D^0 \rightarrow K^+K^-$

$\bar{D}^0 \rightarrow K^+e^-\nu$

the CP asymmetry is defined as:

$$a_{CP} \equiv \frac{N[(K^+e^-\nu)(K^+K^-)] - N[(K^-e^+\nu)(K^+K^-)]}{N[(K^+e^-\nu)(K^+K^-)] + N[(K^-e^+\nu)(K^+K^-)]}.$$

Uri Karshon in his contribution to these Proceedings[6] provides detailed estimates for the number of events of the type $[(D^0 \rightarrow \text{semileptonic mode})(\gamma, \bar{D}^0 \rightarrow \text{CP eigenstate})]$ which can be used to measure any CP violation asymmetry which might exist. He finds that the separation of $D^0\bar{D}^0\gamma$ events from $D^0\bar{D}^0\pi^0$ events can be readily accomplished with the detectors being contemplated for the τ-charm factory. Table I is taken directly from his paper and indicates that a total of approximately 6600 events would be observed in a year's running

Table I Estimate of the number of fully reconstructed semileptonic tagged events with CP eigenstates in a one year running time				
Eigenstate	CP	BR(%)	Efficiency	$\gamma D^o \overline{D}^o$ Events
$K_s^o \rho^o$	-1	0.27 ± 0.17	0.42	460
$K_s^o \eta$	-1	0.60 ± 0.32	0.12	290
$K_s^o \Phi$	-1	0.29 ± 0.18	0.05	60
$K_s^o \pi^o$	-1	0.73 ± 0.24	0.26	770
$K_s^o \omega$	-1	1.3 ± 0.7	0.06	320
$\rho^o \pi^o$	+1	1.1 ± 0.4	0.70	3140
$\pi^+ \pi^-$	+1	0.14 ± 0.05	0.80	460
$K^+ K^-$	+1	0.51 ± 0.11	0.50	1040
$K_s^o K_s^o$	+1	0.03 ± 0.01	0.26	30

at a luminosity of 10^{33}. Consequently, the observed CP asymmetry could be measured with an accuracy of 1.2% in a year's time.

We turn now to consider the case of direct CP violation, *i.e.* the case when the amplitude for the particle to decay into final state f is not equal to the amplitude for the antiparticle to decay into the same state f. For now, we assume no mixing; a non-zero value of mixing generally increases the size of the effect, at the cost of some confusion in interpretation.

We can search for direct CP violation either in asymmetries as in the mixing case, or directly in the rate. Both these searches are most effectively carried out at the ψ''. The asymmetry is measured, once again, in events in which the charm of one D is tagged by a semileptonic decay, while the other D is observed in a decay mode which can be reached by both particle and antiparticle. If we define $\bar{\rho}$ as the ratio of the amplitudes and assume that the CP violation is small, we can write:

$$\bar{\rho}(f) \equiv \frac{T(\bar{D}^o \to f)}{T(D^o \to f)} \Rightarrow |\bar{\rho}(f)| \approx 1 - \frac{1}{2}\Delta$$

$$\Rightarrow a_{CP} = |\bar{\rho}(f)|^2 = 1 - \Delta$$

where the dimensionless parameter Δ measures the CP violation in the amplitude. The experimental asymmetry then is just equal to Δ. Table II gives estimates for the number of events which can be seen in a year's running at a luminosity of 10^{33}.

Table II Rates for Direct CP Violation Asymmetries $\psi'' \rightarrow (Kl\nu)$(CP Eigenstate)	
CP Eigenstate	Number of Events
K^+K^-	15000
$\pi^+\pi^-$	10000
K_SK_S	4000
$\rho^0\pi^0$	5000

This total of $\approx$ 35000 observed events then gives rise to a sensitivity in Δ on the order of $\frac{1}{2}$%.

CP violation can also be searched for directly in the rate, since the initial state , ψ'', is an eigenstate of CP with eigenvalue +1. Consequently, any observation of the $D^\circ \bar{D}^\circ$ into 2 states of the same CP will constitute an unambiguous sign of CP violation. Table 3 gives estimates for the total number of events that would be observed if CP were completely violated.

Table III Rates for Direct CP Violation $\psi'' \rightarrow$(CP Eigenstate1)(CP Eigenstate2)		
CP Eigenstate1	CP Eigenstate2	No. of Events for 100% CP Violation
K^+K^-	$\pi^+\pi^-$	300
K^+K^-	$K_L\pi^0$	3000
$\pi^+\pi^-$	$K_L\pi^0$	1000

Though these numbers are not large, this method is important in that it alone is sensitive to the quantum mechanical phase of the amplitudes. The asymmetry is sensitive only to the absolute magnitude of $\bar{\rho}$, the ratio of the amplitudes. In particular, let $\bar{\rho}$ be defined in terms of a magnitude and a phase α_f as follows:[7]

$$\bar{\rho}(f) \equiv |\bar{\rho}(f)|e^{i\alpha_f}$$

Then, for simplicity, assume one amplitude (for final state f_a) is CP conserving and that the CP violating parts of the amplitude for the other state (f_b) are small, *i.e.*

$$|\bar{\rho}(f_\alpha)| = 1$$

$$|\bar{\rho}(f_\beta)| = 1 - \frac{1}{2}\Delta_b, \qquad \Delta_b \ll 1$$

$$\delta\alpha \equiv \alpha_b - \alpha_a \ll 1$$

Then , the rate for observing $\psi'' \to (D^\circ \to f_a)(\bar{D}^\circ \to f_b)$ is given by:

$$N(f_a, f_b) = N_{D^0\bar{D}^0} BR(D \to f_a) BR(D \to f_b)(\frac{1}{2}{\Delta_b}^2 + 2(\delta\alpha)^2)$$

Two remarks are in order here: first that the rate is proportional to Δ^2 rather than Δ as was the case for the asymmetry. Consequently this method is not competitive with that using asymmetries for determining the magnitude of Δ. However, the asymmetry method is totally insensitive to the phase difference $\delta\alpha$. If α were as large as 0.1, one would expect to see a handful of $KK\pi\pi$ events, for example. The observation of final states involving $K_L\pi^0$ does not of itself indicate CP violation in the charm sector since one has to include the known CP violation in the K^0 system. In fact, a few 10's of events of the type $\psi'' \to (D^\circ \to K^+K^-)(\bar{D}^\circ \to K_L\pi^0)$ should be observed in a year's running due to this effect.

Conclusions A high luminosity τ-charm factory offers the possibility of cleanly measuring $D^\circ - \bar{D}^\circ$ mixing at levels expected in the standard model as well as providing the first look at potential CP violation in the charm sector. Table 4 summarizes the results given in this paper.

$D^\circ - \bar{D}^\circ$ mixing can be studied unambiguously (*ie* without the complications of DCSD) in three independent modes, each capable of reaching sensitivities in r of the order of 10^{-4} or better. Furthermore, in all cases studied, the obvious backgrounds are calculated to be quite small. CP violation in the charm sector can also be probed by three independent methods which are separately sensitive to CP violation induced by mixing and to both the

Table IV

Rate Summary (1 year's run at L = 10^{33})

(a) $D^0 - \bar{D}^0$ Mixing

Reaction	Events (right sign)	r_D for 6 observed events
$\psi'' \rightarrow (K^-\pi^+)(K^-\pi^+)$	37500	1.6 $\times 10^{-4}$
$\psi'' \rightarrow (K^-e^+\nu)(K^-e^+\nu)$	21600	
$\psi'' \rightarrow (K^-e^+\nu)(K^-\mu^+\nu)$	40000*	7.4 $\times 10^{-5}$
$\psi'' \rightarrow (K^-\mu^+\nu)(K^-\mu^+\nu)$	20000*	
$D^{*+}D^- \rightarrow [\pi^+(K^+e^-\nu)(K^+\pi^-\pi^-)]$	19000	
$D^{*+}D^- \rightarrow [\pi^+(K^+\mu^-\nu)(K^+\pi^-\pi^-)]$	15000*	
$D^{*+}D^- \rightarrow [\pi^+(K^+e^-\nu)$(other D^- tag)]	15000*	9.4 $\times 10^{-5}$
$D^{*+}D^- \rightarrow [\pi^+(K^+\mu^-\nu)$(other D^- tag)]	15000*	

(b) CP Violation

Reaction	Events	Comment
$D^{*0}\bar{D}^0 \rightarrow [(\gamma$(semileptonic)][(CP eigenstate)] asymmetry measurement see Table I	6570	measures mixing-dependant CP violation asymmetry determined to 1.2%
$\psi'' \rightarrow$(semileptonic)(CP eigenstate) asymmetry measurement see Table II	34000*	measures magnitude of CP violating amplitude to 0.5%
$\psi'' \rightarrow$(CP eigenstate)(CP eigenstate) rate measurement see Table III	4000*	sensitive to phase of direct CP violating amplitude

* estimates based on scaling acceptances of similar processes

magnitude and phase of any direct CP violation in the decay amplitudes. Although the levels of CP violation which can be probed do not reach the standard model predictions, the τ-charm factory would provide the first look into potential CP violation in the up-quark sector. Perhaps there are surprises in store for us.

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7. In this exercise, I follow the argument of I. Bigi in these Proceedings.