On the Case for a Super $\tau$-Charm Factory

David M. Asner

Carleton University, 1125 Colonel By Drive, Ottawa, Ontario, Canada, K1S 5B6

Abstract

Design studies for a Super Flavor Factory (SFF), an asymmetric energy $e^+e^-$ collider utilizing International Linear Collider (ILC) techniques and technology, are in progress. The capability to run at $\sqrt{s} = 3.770$ GeV could be included in the initial design. This report discusses the physics that can be probed with luminosity of $10^{35}$ cm$^{-2}$s$^{-1}$ near $\tau$-charm threshold.

1 Introduction

Design studies for a Super Flavor Factory (SFF), an asymmetric energy $e^+e^-$ collider utilizing International Linear Collider (ILC) techniques and technology, are in progress. Energy flexibility is an important component of the design. Luminosities of $10^{36}$ cm$^{-2}$s$^{-1}$ at the $\Upsilon(4S)$ and $10^{35}$ cm$^{-2}$s$^{-1}$ at the $\psi(3770)$
are expected. This report summarizes the physics that can be probed at a τ-charm threshold. The physics case for a Super τ-charm Factory \(10^{35} \text{cm}^{-2} \text{s}^{-1}\) or equivalently the case for designing the SFF with the capability to run at energies near \(D\bar{D}\) threshold must be evaluated relative to the physics reach with the enormous \(\tau\) and charm samples available from \(\sqrt{s} = 10.58\) GeV running as well as anticipated data samples from CLEO-c \(^2\) and BESIII \(^3\). The physics to be probed generally falls into two categories: (1) Probes of QCD to enhance or validate the theoretical control over QCD. This program will likely be completed with CLEO-c and BESIII (except for charm baryon studies). (2) Searches for physics beyond the Standard Model. This program will not be completed by CLEO-c and BESIII.

The two existing asymmetric \(B\)-factories, BABAR at PEP-II and Belle at KEKB, have operated since 1999. PEP-II is running with peak luminosity of \(10.0 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}\) and KEKB with peak luminosity of \(15.8 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}\) both at the \(\Upsilon(4S)\). The total integrated luminosity recorded by BABAR, 330 fb\(^{-1}\), and Belle, 500 fb\(^{-1}\), includes nearly \(10^9 B\bar{B}\) pairs. Also included in this data sample are nearly \(10^9\) \(\tau\)-pairs and \(4 \times 10^9\) charm mesons.

CLEO-c at CESR has been accumulating data in the charm threshold region since 2003. CESR is running with a peak luminosity of \(7 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}\). Data samples of 30 million \(\psi(2S)\), 750 pb\(^{-1}\) at \(\psi(3770)\), and 750 pb\(^{-1}\) at \(\sqrt{s} = 4170\) MeV are anticipated before shutdown in 2008. This corresponds to a sample of 2.7 million \(D^0\bar{D}^0\) pairs and 2.1 million \(D^+D^-\) from \(\psi(3770)\). The higher energy data sample includes a comparable number of \(D\) mesons plus 700,000 \(D_s^+D_s^- + D_s^+D_s^-\). BESIII at BEPCII expects first \(e^+e^-\) collisions at the end of 2007 and design luminosity, \(0.6 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}\) at the \(J/\psi\), by the end of 2008. Large charmonium samples, \(10 \times 10^9\) \(J/\psi\) and \(3 \times 10^9\) \(\psi(2S)\), are anticipated, however the \(\tau\) and charm meson samples will still be much smaller than those from existing \(B\)-factories.

The physics output of a Super Flavor Factory may be maximized by including energy flexibility in the design of both the accelerator and the detector. Assuming the facility is optimized for asymmetric collisions at \(\Upsilon(4S)\), little performance degradation is expected for center-of-mass energies ranging from \(\Upsilon(1S)\) to \(\Upsilon(5S)\). Including in the initial design the flexibility to run at energies in the \(\tau\)-charm threshold region requires further study. Some open questions include: (1) Should low energy running be symmetric or asymmetric? (2) Is...
the low energy physics reach compromised by a detector optimized for high energy running? (3) Is there a physics need for the low energy data given the enormous $\tau$ and charm samples produces at $\sqrt{s} = 10.58$ GeV?

2 The Advantages of Threshold Production

The production rate of charm during threshold running at a Super Flavor Factory and $\Upsilon(4S)$ running is comparable. Although the luminosity for charm threshold running is expected to be an order of magnitude lower, the production cross section is 3 times higher than at $\sqrt{s} = 10.58$ GeV. Charm threshold data has distinct and powerful advantages over continuum and $b \rightarrow c$ charm production data accumulated above $B$ production threshold.

**Charm Events at Threshold are Extremely Clean:** The charged and neutral multiplicities in $\psi(3770)$ events are only 5.0 and 2.4 - approximately $1/2$ the multiplicity of continuum charm production at $\sqrt{s} = 10.58$ GeV.

**Charm Events at Threshold are pure $D\overline{D}$:** No additional fragmentation particles are produced. The same is true for $\sqrt{s} = 4170$ MeV production of $D\overline{D}$, $D^+_sD^-_s$, and $D^+_sD^{*-}_s$. This allows use of kinematic constraints, such as total candidate energy and beam constrained mass, and permits effective use of missing mass methods and neutrino reconstruction. The crisp definition of the initial state is a uniquely powerful advantage of threshold production that is absent in continuum charm production.

**Double Tag Studies are Pristine:** The pure production of $D\overline{D}$ states, together with low multiplicity and large branching ratios characteristic of many $D$ decays permits effective use of double-tag studies in which one $D$ meson is fully reconstructed and the rest of the event is examined without bias but with substantial kinematic knowledge. The techniques pioneered by Mark III and extended by CLEO-c $^4$ allow precise absolute branching fraction determination. Backgrounds under these conditions are heavily suppressed which minimizes both statistical errors and systematic uncertainties.

**Signal/Background is Optimum at Threshold:** The cross section for the signal $\psi(3770) \rightarrow D\overline{D}$ is about $1/2$ the cross section for the underlying continuum $e^+e^- \rightarrow$ hadrons background. By contrast, for $c\overline{c}$ production at $\sqrt{s} = 10.58$ GeV the signal is only $1/4$ of the total hadronic cross section.

**Neutrino Reconstruction:** The undetected energy and momentum is interpreted as the neutrino four-vector. For leptonic and semileptonic charm decays...
the signal is observed in missing mass squared distributions and for double-tagged events these measurements have low backgrounds. The missing mass resolution is about one pion mass. For semileptonic decays the $q^2$ resolution is excellent, about 3 times better than in continuum charm reconstruction at $\sqrt{s} = 10.58$ GeV. Neutrino reconstruction at threshold is clean.

**Quantum Coherence:** The production of $D$ and $\bar{D}$ in a coherent $C = -1$ state from $\psi(3770)$ decay is of central importance for the subsequent evolution and decay of these particles. The same is true for $D\bar{D}(n)\pi^0(m)\gamma$ produced at $\sqrt{s} \sim 4$ GeV where $C = -1$ for even $m$ and $C = +1$ for odd $m$. The coherence of the two initial state $D$ mesons allows both simple and sophisticated methods to measure $D\bar{D}$ mixing parameters, strong phases, $CP$ eigenstate branching fractions, and $CP$ violation.

3 Physics Reach of Low Energy Running

The low energy data at a Super Flavor Factory can be used to improve our knowledge of QCD, the Standard Model (SM), and search for New Physics (NP) with the study of the $\tau$ lepton, charmonia, total hadronic cross section, charm mesons, and charm baryons.

3.1 $\tau$ Studies

Studies of the $\tau$ lepton include measurement of absolute branching fractions, precision determination of $\tau$ properties - mass, lifetime, and dipole moment - to probe $CPT$ and $CP$ violation, lepton universality, measurements of hadronic currents - to probe QCD, measure $V_{us}$ and $m_s$, searches for $CP$ violation in weak $\tau$ decays, and searches for rare or Standard Model forbidden decays such as lepton flavor violation. The $\tau$ mass determination benefits from the constrained kinematics of threshold production but will likely be limited by knowledge of the beam energy to $\pm 0.1$ MeV at BESIII. This precision can be compared with the statistical error expected in 100 ab$^{-1}$ of $\pm 0.023$ MeV. Improved constraints on the $\tau$ neutrino mass in the range of 1-5 MeV might be attainable at threshold. The $\tau$ lifetime cannot be measured in symmetric collisions at threshold. The choice of energy for the rest of the $\tau$ program is driven by the need for large statistics. The $\tau$-pair production cross section is 0.89 nb at $\Upsilon(4S)$ and 1.2 nb at threshold. Combined with the expected luminosities there is no compelling reason to run at $\tau$ threshold.
3.2 Charmonium Physics at the $J/\psi$ Resonance

The design luminosity at a Super Flavor Factory at the $J/\psi$ resonance could exceed the design luminosity at BESIII by an order of magnitude. The BESIII samples will be orders of magnitude larger than current BES samples. It is challenging to predict quantitatively the sensitivities that can be achieved with the $10^{12} J/\psi$ sample that might be accumulated at the Super Flavor Factory. Below are described some of the physics topics that can be elucidated.

$J/\psi \rightarrow V S$ Transitions: The primary motivation for acquiring a large $J/\psi$ sample is the study of glueballs. More generally, it is the study of scalar ($J^{PC} = 0^{++}$) and tensor ($J^{PC} = 2^{++}$) mesons produced in radiative $J/\psi$ decay. The Particle Data Group lists three light isoscalar mesons, the $f_{0}(1370)$, $f_{0}(1500)$, and $f_{0}(1710)$ while the quark model predicts two in this mass region. There is a strong bias that one of the $f_{0}$ is the glueball or that the three observed $f_{0}$ mesons are mixtures of the glueball and the two $q\bar{q}$ states. The double radiative decay $J/\psi \rightarrow \gamma f_{0}$ followed by $f_{0} \rightarrow \gamma \rho, \gamma \phi$ and the decay $J/\psi \rightarrow V f_{0}$ may elucidate the glueball content of the $f_{0}$ mesons.

Exclusive $J/\psi$ Branching Fractions: Models of charmonium make definite predictions for the $\psi(2S)$ branching fractions based on $J/\psi$ decay rates. Exclusive branching fractions are not well measured. A systematic program of precision $J/\psi$ branching ratio measurements is desirable to test and improve our understanding of charmonium. Hadronic decays to charmless final states account for 87% of $J/\psi$ decay - only 40% of that is measured exclusively.

Leptonic $J/\psi$ Decays: The $J/\psi$ is commonly identified through its decay to leptons. The relative branching ratios of $J/\psi$ to leptons are known to 1% and do not pose a precision barrier to other measurements. The only exception is in the determination of $\Gamma_{ee}(J/\psi)$ through ISR.

Threshold Enhancements: BES reported an enhancement in the $M(p\bar{p})$ spectrum in $J/\psi \rightarrow \gamma p\bar{p}$ decays which they attribute to a sub-threshold resonance, the mass (1859 MeV) and width ($\Gamma < 30$ MeV at 90% C.L.) of which are not consistent with any known particle hence it is called the $X(1860)$. An enhancement observed by BES in the $\pi^{+}\pi^{-}\eta'$ spectrum in $J/\psi \rightarrow \gamma \pi^{+}\pi^{-}\eta'$ may confirm this observation. However, the enhancement is not observed in $J/\psi \rightarrow \pi^{0}p\bar{p}$ decays at BES or in $\Upsilon(1S) \rightarrow \gamma p\bar{p}$ decay at CLEO. BES has observed additional threshold enhancements. BESIII will accumulate a significant $J/\psi$ data sample which may clarify the situation.
3.3 Charmonium Physics at the $\psi(2S)$ Resonance

The design luminosity at a Super Flavor Factory at the $\psi(2S)$ resonance could exceed the design luminosity at BESIII by an order of magnitude. The BESIII samples will be orders of magnitude larger than current BES (58 million) and anticipated CLEO-c (30 million) samples. It is challenging to predict the physics issues to be addressed with $10^{12} \psi(2S)$ sample accumulated at the SFF.

**Radiative $\psi(2S)$ Transitions:** The $\eta_c$, the charmonium ground state, is of particular interest since its bottomonium counterpart is unobserved experimentally. The $\eta_c$ mass and width have been determined utilizing multiple production mechanisms but without good agreement. Additionally, the exclusive decay modes measured account for about 25% of the total with substantial uncertainties. Relating the $\eta_c$ branching fractions to the corresponding measurements on the $\eta'_c$ tests our models of charmonium. Although $\eta_c$ production rate is greater from radiative $J/\psi$ decay, data accumulated at the $\psi(2S)$ allows for both $\psi(2S) \to \gamma \eta_c$ and $\psi(2S) \to \gamma \eta'_c$ processes.

**Exclusive $\psi(2S)$ Branching Fractions:** Models of charmonium make definite predictions for the $\psi(2S)$ based on $J/\psi$ decay rates. Exclusive branching fractions are not well measured. A systematic program of precision $\psi(2S)$ branching ratio measurements at CLEO-c and BESIII will test our understanding of charmonium.

**Properties of $h_c(1^1P_1)$:** In 2005, CLEO reported first observation of the $h_c$ $^{22,23}$. The $h_c$ is the last of the eight bound states of charmonium expected to lie beneath open charm threshold. Precision determination of the properties of the $h_c$, mass, width, branching fractions will improve our understanding of the QCD potential – in particular, measuring $M(h_c)$ relative to the center of gravity of the $\chi_{cj}$ states. Predictions using a number of theoretical models $^{24,25}$ span a wide range of values and therefore precise measurements of the hyperfine splitting can distinguish among models. A precision of better than 0.1 MeV on $M(h_c)$ and 0.2 MeV on $\Gamma(h_c)$ is expected from a sample of 300 million $\psi(2S)$ - 10% of the sample anticipated in one year at BESIII.

**$J/\psi$ Sample from $\psi(2S)$:** A large $J/\psi$ sample can be obtained through the cascade production from $\psi(2S)$ decays to $\pi^+\pi^-J/\psi$ with $\mathcal{B} = 33.5\%$. This reduces and perhaps eliminates the need for running at the $J/\psi$.

**$\chi_{cj}$ Sample from $\psi(2S)$:** The $\psi(2S)$ is a factory for producing $\chi_{cj}$ through $\psi(2S) \to \gamma \chi_{cj}$. The branching ratios are around 9% and photon detection
efficiencies (after $\pi^0$ suppression) are about 50% so that one detectable each of $\chi_{c0}$, $\chi_{c1}$ and $\chi_{c2}$ are produced for every 20 $\psi(2S)$. Hadronic decay of the $\chi_{cj}$ offer a number of interesting measurements (1) study of mesons with manifestly exotic quantum numbers through the Dalitz plot analysis of $\chi_{cj} \rightarrow \eta \pi \pi$ (2) study of the quark content of the three isoscalar mesons, $f_0(1370)$, $f_0(1500)$, and $f_0(1710)$. Since $f_2(1270)$ is nearly entirely $u\bar{u}, d\bar{d}$ and the $f'_2(1525)$ is nearly entirely $s\bar{s}$, these two narrow resonances can be used to tag the flavor of the $f_0$. Therefore comparing the relative rates of $\chi_{c2} \rightarrow f_2(1270)f_0$ and $\chi_{c2} \rightarrow f'_2(1525)f_0$ can shed light on the quark content of the $f_0$ in question. (3) Multibody charmonium decays access most of the kinematic range accessible to $B$ decays. Improved modeling of $\pi\pi$, $K\pi$, $KK$ S-wave in charmonium samples, such as $\chi_{c0} \rightarrow \pi^+\pi^-K^+K^-$ \cite{20}, will enable precision measurements of CKM angles $\alpha$, $\beta$, and $\gamma$. Specifically, understanding the $\pi\pi$ S-wave is important for the determination of $\alpha$ ($B^0 \rightarrow \pi^+\pi^-\pi^0$) and $\gamma$ ($B^- \rightarrow DK^-, D \rightarrow K_S^0\pi^+\pi^-$), understanding the $K\pi$ S-wave is important for the determination of $\gamma$ ($B^- \rightarrow DK^-, D \rightarrow K_S^0K\pi$), and the understanding of the $KK$ S-wave is important of the determination of $\beta$ using $b \rightarrow s$ penguin processes ($B \rightarrow K_S^0K^+K^-$).

The $M2/E1$ Ratio for $\chi_{cj} \rightarrow \gamma J/\psi$: The transitions $\chi_{c1} \rightarrow \gamma J/\psi$ and $\chi_{c2} \rightarrow \gamma J/\psi$ can each proceed through either an $E1$ or $M2$ transition. Current measurements are at odds with theoretical expectations \cite{27} \cite{28}. The BESIII sample of $\psi(2S)$ will be sufficient to conclusively measure this multipole ratio.

3.3.1 Using $\psi(2S)$ Running as Calibration Data

Data taken at the $\psi(2S)$ has a utilitarian value. The processes $\psi(2S) \rightarrow \pi^+\pi^-J/\psi$, $\pi^0\pi^0J/\psi$, and $\gamma\chi_{cj}$ are particularly useful. They provide hadron and photon spectra of known momenta that are useful for measuring reconstruction efficiencies in data, Monte Carlo tuning, and detector calibration. Such data, taken at intervals interspersed between higher energy running, can be used for monitoring software and detector performance, leading to better control of systematic uncertainties for studies of $\tau$ and charm at threshold.

3.4 Charmonium Physics above $c\bar{c}$ Threshold

The total $e^+e^-$ cross section and $R$ measurement: The BES measurements of the total cross section of $e^+e^-$ annihilation to hadrons or $R$ scan from 85 energy points between 2 and 5 GeV have an average statistical error of
6.6% and a systematic uncertainty of 3.3% using about 70 nb$^{-1}$ per point\cite{30}. The CLEO measurement of $R$ with an accuracy of 2% in the vicinity of the $\Upsilon(4S)$\cite{31} and recent progress in the calculation of radiative corrections together with the hermeticity of the BESIII detector allows one to expect a systematic uncertainty of about 1% below and 2-4% above open charm threshold.

A second approach to measuring $R$ in the 2-5 GeV range uses initial state radiation (ISR) from 10.58 GeV\cite{32}. This approach should be competitive with results from the $R$ scan. Existing data samples from BABAR and Belle are expected to be limited by systematic uncertainties to a precision of a few percent. If further advances in the calculation of radiative corrections enable $R$ measurements with sub-percent precision the ISR data from the $\Upsilon(4S)$ running of a SFF will have more than sufficient statistics for the $R$ measurement.

**c$\bar{c}$ Hybrids, $Y(4260)$ and Other Resonances:** The region at center-of-mass energies above open charm production threshold is of great interest to theory due to its richness of $c\bar{c}$ states, the properties of which are not well-understood. Prominent structures in the hadronic cross section are the $\psi(3770)$, $\psi(4040)$, and $\psi(4160)$. A dedicated scan, 1 fb$^{-1}$/per energy point at 100 energy points, to search for hybrid $c\bar{c}$ mesons coupling directly to $e^+e^-$ through a virtual photon or produced in decay products of charmonia represented by the structure in the hadronic cross section would require 100 days of SFF running.

Recently, observations of new charmonium-like states decaying to open-charm have been reported in this energy region. Additionally, an enhancement, the $Y(4260)$, in the invariant mass spectrum of $\pi^+\pi^-J/\psi$ has been observed by BABAR in ISR\cite{32}, and in $B \to K(\pi^+\pi^-J/\psi)$\cite{33}. This observation was confirmed by CLEO is both ISR ($\pi^+\pi^-J/\psi$)\cite{34} and in $e^+e^-$ collision at $\sqrt{s} = 4260$ MeV ($\pi^+\pi^-J/\psi$, $\pi^0\pi^0J/\psi$, $K^+K^-J/\psi$)\cite{35}. These observation help distinguish among the many models predicting properties of the $Y(4260)$.

### 3.5 $D^0$, $D^+$, and $D_s^+$ Decays

**Leptonic Charm Decays -** $D^+ \to \ell^+\nu$, $D^+_s \to \ell^+\nu$: For the muonic decays, CLEO-c and BESIII, will determine the decay constants $f_D$ and $f_{D_s}$, to precision of 1%. The decay constants measure the nonperturbative wave function of the meson at zero inter-quark separation. In the Standard Model the relative widths for $\tau^+\nu$, $\mu^+\nu$ and $e^+\nu$ are $2.65: 1: 2.3\times10^{-5}$. Comparison of electronic, muonic and tauonic rates\cite{36,37,38} tests for physics beyond the SM.
Exclusive Semileptonic Charm Decays - \( D \to (K, K^*, K\pi)\ell\nu \), \( D \to (\pi, \eta, \rho, \omega, \pi\pi)\ell\nu \), \( D_s \to (K, K^*, K\pi)\ell\nu \), and \( \Lambda_c \to \Lambda\ell\nu \): Absolute branching ratios, for the \( D \) and \( D_s \), will be measured to \( \sim 1\% \) and the form factor slopes to \( \sim 2\% \) by CLEO-c \(^{40}\text{41}\text{42}\) and BESIII. Threshold production enables form factor measurements with improved resolution over the full range of \( q^2 \). Semileptonic decay rates and accurate knowledge of form factors are required for CKM elements \( |V_{ub}| \), \( |V_{cb}| \), \( |V_{cd}| \), and \( |V_{cs}| \).

Inclusive Semileptonic Charm Decays - \( D \to \ell X \), \( D_s \to \ell X \), and \( \Lambda_c \to \ell X \): Inclusive branching ratios, for the \( D \) and \( D_s \), will be measured to \( \sim 1\% \) by CLEO-c \(^{29}\) and BESIII. Inclusive spectra have three advantages compared to semileptonic branching fractions as a probe of theory: (1) Theoretical interpretation is cleaner as spectra are independent of the hadronic width. (2) Spectra contain both shape and rate information. (3) Non-perturbative effects are pronounced in the lepton endpoint region. Low backgrounds associated with tagged events at threshold enable inclusive semileptonic studies. The theoretical description of semileptonic decays in the charm sector, coupled with heavy quark symmetry, will improve the description of semileptonic \( B \) decays and the determination of \( V_{ub} \) and \( V_{cb} \).

Hadronic Charm Decays: CLEO-c and BESIII will measure the branching fractions for the normalizing modes \( D^0 \to K\pi \), \( D^+ \to K^-\pi^+\pi^+ \), and \( D_s^+ \to K^+K^-\pi^+ \) to a precision of less than \( 1\% \) \(^{43}\). Sensitivity to Cabibbo suppressed modes, \( D \to (n)\pi(m)\pi^0 \), at \( 10^{-5} - 10^{-6} \) level \(^{44}\text{43}\) and independent measurements of \( D \to K^0\pi X \) and \( D \to K^0\pi X \) are possible at threshold due to low backgrounds and constrained kinematics with these data samples.

3.6 Impact on CKM physics

**Determination of \( V_{ub} \):** Limited by form factor calculations to \( \sim 13\% \). Improving form factor calculation methods in the charm decays \( D \to \pi\ell\nu \) and \( D \to \rho\ell\nu \) with data from CLEO-c will enable \( 5\% \) precision in \( |V_{ub}| \). Improved understanding of weak annihilation contributions to inclusive semileptonic charm decay will improve the extraction of \( V_{ub} \) from inclusive semileptonic \( B \) meson decay. Improvement will be possible with the BESIII data sample.

**Determination of \( V_{td} \) and \( V_{ts} \):** Limited by ignorance of \( f_{B}\sqrt{B_{b_{d}}} \) and \( f_{B_s}\sqrt{B_{b_{s}}} \). Determining \( |V_{td}| \) and \( |V_{ts}| \) from \( B \) mixing measurements requires improved determination of \( f_{B} \) and \( f_{B_s} \). Precision measurements of \( f_{D} \), \( f_{D_s} \), and...
$f_D/f_{D_s}$ at CLEO-c and BESIII will enable the necessary theoretical advances.

**Determination of $V_{cd}$ and $V_{cs}$:** Currently known to $\sim$10% level by direct measurement. CLEO-c is measuring absolute branching ratios of leptonic and semileptonic decays from which $|V_{td}|$ and $|V_{ts}|$ can be determined with few percent accuracy. Again form factor and decay constant calculations must achieve comparable precision for the few percent precision on CKM parameters to be realized. These measurements will enable Unitarity tests of the CKM matrix. Data from BESIII will enable additional improvement.

**Determination of $V_{cb}$:** Presently limited by several factors including theoretical control of form factors and experimental determination of $B(D \to K \pi)$. CLEO-c will drive form factor technology and will measure the normalizing hadronic charm branching ratios at the percent level. Precision of 3% in $V_{cb}$ is expected. Improved precision using BESIII data will require theoretical advances to better estimate corrections to form factors. The inclusive determination of $V_{cb}$ will benefit from better knowledge of the inclusive lepton spectra which refine modeling of the “cascade” decays $b \to c \to s \ell \nu$.

**CKM Angle $\gamma/\phi_3$:** Measurement of the CKM angle $\gamma/\phi_3$ is challenging. Several methods have been proposed using $B^{\pm} \to DK^{\pm}$ decays: (1) the Gronau-London-Wyler (GLW) method where the $D$ decays to $CP$ eigenstates (2) the Atwood-Dunietz-Soni (ADS) method where the $D$ decays to flavor eigenstates and (3) the Dalitz-plot method where the $D$ decays to a three-body final state. Uncertainties due to charm contribute to each of these methods. A variety of charm measurements impact the determination of $\gamma/\phi_3$ from the $\Upsilon(4S)$: (1) Improved constraints on charm mixing amplitudes - important for GLW, (2) Measurement of the relative rate and relative strong phase $\delta$ between $D^0$ and $\bar{D}^0$ decay to $K^{+}\pi^{-}$ - important for ADS, and (3) studies of charm Dalitz plots tagged by hadronic flavor or $CP$ eigenstates. Charm threshold data is necessary for the measurement of $\delta$ and the study of $CP$ tagged Dalitz plots. Only 1 fb$^{-1}$ of charm threshold data is required to measure $\cos \delta$ to $\pm 0.1$ which will be accomplished by CLEO-c and BESIII. The CKM angle $\gamma/\phi_3$ will be measured to 1° (statistical) with 100 ab$^{-1}$ of SFF data. The sample of 30 fb$^{-1}$ at charm threshold - expected from BESIII - is needed to limit Dalitz-plot systematic uncertainties to 1°.
4  $D$ Mixing, CP Violation, and Rare Charm Processes

$D^0 - \bar{D}^0$ Mixing: Neutral flavor oscillation in the $D$ meson system is highly suppressed within the SM. The time evolution of a particle produced as a $D^0$ or $\bar{D}^0$, in the limit of CP conservation, is governed by four parameters: $x = \Delta m / \Gamma$, $y = \Delta \Gamma / 2 \Gamma$ characterize the mixing matrix, $\delta$ the relative strong phase between Cabibbo favored (CF) and doubly-Cabibbo suppressed (DCS) amplitudes and $R_D$ the DCS decay rate relative to the CF decay rate. The mass and width differences $x$ and $y$ can be measured in a variety of ways. The most precise limits are obtained by exploiting the time-dependence of $D$ decays. A time-dependent analysis of $D^0 \to K_S^0 \pi^+ \pi^-$ Dalitz plot allows simultaneous determination of $x$ and $y$ without phase or sign ambiguity but with $\sim 4\times$ less sensitivity relative to the time-dependent study of $D^0 \to K^+ \pi^-$. Time-dependent analyses are not feasible at CLEO-c and BESIII; however, the quantum-coherent $D^0 - \bar{D}^0$ state provides time-integrated sensitivity to $x$, $y$ at $O(1\%)$ level and $\cos \delta \sim 0.05$. Asymmetric collisions near $\sqrt{s} = 4$ GeV at a SFF could enable time-dependent measurements.

CP Violation: Standard Model CP violation is strongly suppressed in charm as the effective weak phase is rather small - $O(\lambda^4)$, arising only in singly-Cabibbo-suppressed transitions where expected CP asymmetries reach $O(0.1\%)$. Significantly larger values would indicate NP. Any asymmetry in CF or DCS decays requires new physics - except for $D^{\pm} \to K_S^0 \pi^{\pm}$, where the CP impurity due to the $K_S^0$ induces an asymmetry of $3.3 \times 10^{-3}$. At $\sqrt{s} = 10.58$ GeV, the decay channel $D^{*\pm} \to D\pi^{\pm}$ is used to provide a flavor tag for the $D$ meson. Threshold production provides a CP tag. CP conservation forbids certain final states from the decay of the $D^0 \bar{D}^0$ pair from correlated production. For $C = -1$ states produced from $\psi(3770) \to D\bar{D}$, the final state $f_+ f_+$, such as $(K^+ K^-)(\pi^+ \pi^-)$, is forbidden; For $C = +1$ states produced from $e^+ e^- (4170 \text{ MeV}) \to D\bar{D} \gamma$, the final state $f_+ f_-$, such as $(K^+ K^-)(K_S^0 \pi^0)$, is forbidden. The expected sensitivity to direct CP violation with tagged decays at CLEO-c and BESIII is $\sim 1\%$; at a SFF it is $\sim 0.1\%$. There are also methods to probe CP violation with untagged charm decays.

Decays to final states with more than two pseudoscalars or one pseudoscalar and one vector meson contain more dynamical information than given by their widths. Distribution on Dalitz plots or $T$ odd moments can exhibit CP asymmetries considerably larger than those for the width. The Dalitz plots
for $\psi(3770) \to D^0 \bar{D}^0 \to f_+ K_S \pi^+ \pi^-$ and $\psi(3770) \to D^0 \bar{D}^0 \to f_- K_S \pi^+ \pi^-$ will be distinct and the Dalitz plot for the untagged sample $\psi(3770) \to D^0 \bar{D}^0 \to X K_S \pi^+ \pi^-$ will be distinct from that observed with uncorrelated $D$’s from continuum production at $\sim 10$ GeV [54]. The sensitivity at charm threshold to $CP$ violation with Dalitz plot analyses has not yet been evaluated. The sensitivity to $CP$ violation with flavor tagged $D^0 \to K^0_S \pi^+ \pi^-$ at $\sqrt{s} = 10.58$ GeV in 9 fb$^{-1}$ is in the range $(3.5$ to $28.4) \times 10^{-3}$ depending on the decay channel [55].

**Rare and Forbidden Charm Decays:** The Standard Model predicts vanishingly small branching ratios for processes such as $D \to \pi/K^{(*)} \ell^+ \ell^-$ which is GIM suppressed. Rare decays of charmed mesons and baryons provide “background-free” probes of new physics effects that enhance rare or allow forbidden processes such as lepton flavor violation ($D \to K e^+ \mu^-$) and lepton number violation ($D^+ \to K^- e^+ e^+$). Current limits are $\mathcal{O}(10^{-4})$ to $\mathcal{O}(10^{-6})$ and are limited by statistics. Limits from BESIII will improve to $\mathcal{O}(10^{-7})$ to $\mathcal{O}(10^{-8})$. It is noteworthy that long distance dynamics can generate some of these final states even within the SM such as $D^+ \to \phi \pi^+$, $\phi \to e^+ e^-, \mu^+ \mu^-$. In these cases distinguishing NP from SM contributions will be a challenge.

4.1 Charm Baryons

The absolute scale for charm baryon decays decays is not well determined. To date, the measurements of the charm baryon absolute rate are model dependent. The decay mode used to normalize all other decay rates is $\Lambda_c^+ \to p K^- \pi^+$ but it is only known to be $(5.0 \pm 1.3)\%$ [55]. Prospects for improving this situation are poor without data taken near $\Lambda_c \bar{\Lambda}_c$ threshold where a modest amount data, 20 fb$^{-1}$, could measure $\mathcal{B}(\Lambda_c)$ to within 1% of itself. Semileptonic decays of charm baryons are also of interest to test our theoretical understanding of form factors. Measuring $\Lambda_c$ is important for understanding of $b$ fragmentation and the study of $\Lambda_b$ which is usually studied in $\Lambda_b \to \Lambda_c X$, $\Lambda_c \to p K^- \pi^+$.

5 Summary

Current questions in $\tau$, open charm and charmonium have been summarized. For $\tau$ physics there is no compelling reason to run near threshold. Charmonium data samples will increase by several orders of magnitude before a 2011 as BESIII carries out its physics program. It is difficult to forecast what questions
will remain and new question arise in this area. Although ISR from $\sqrt{s} = 10.58$ GeV renders an $R$ scan unnecessary, the capability to study charm hybrids and charmonium above open charm threshold with direct production is desirable. Using open charm produced near threshold to improve the precision of CKM parameters determined by BABAR, Belle, CLEO-c and BESIII will require theoretical advances. Searches for $D$-mixing, $CP$ violation charm and rare charm decays are driven by statistics. The enormous $B$ and charm samples available at a Super Flavor Factory at $\sqrt{s} = 10.58$ GeV partially mitigate the need for charm threshold data. However, there are many advantages to running at threshold such as lower backgrounds, lower multiplicity, increased kinematical constraints and quantum coherence. Thus, it is prudent to design the Super Flavor Factory machine and detector with the flexibility to operate effectively with center-of-mass energies ranging from $J/\psi$ to $\Upsilon(5S)$. More work is required and is ongoing to determine whether the benefit of charm threshold running is worth the cost and effort.

References

1. J. Albert et al., INFN Roadmap Report, arXiv:physics/0512235.
2. R. A. Briere et al., Cornell University, CLNS 01/1742 (2001) (unpublished).
3. Internal Report, IHEP-BEPCII-SB-13 (unpublished).
4. Q. He et al. [CLEO Collab.], Phys. Rev. Lett. 95, 121801 (2005).
5. I. I. Y. Bigi, UND-HEP-89-BIG01 Given at Tau Charm Factory Workshop, Stanford, CA, May 23-27, 1989
6. D. M. Asner and W. M. Sun, Phys. Rev. D 73, 034024 (2006).
7. M. Gronau, Y. Grossman and J. L. Rosner, Phys. Lett. B 508, 37 (2001).
8. I. I. Y. Bigi and A. I. Sanda, Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. 9, 1 (2000).
9. S. Bianco et al., Riv. Nuovo Cim. 26N7, 1 (2003)
10. J. M. Roney, at the International Workshop on Discoveries in Flavour Physics at $e^+e^-$ Colliders (DIF 06), Frascati, Italy, 28 Feb - 3 Mar 2006.
11. F. E. Close and A. Kirk, Eur. Phys. J. C 21, 531 (2001).
12. F. E. Close and Q. Zhao, Phys. Rev. D 71, 094022 (2005).
13. M. Ablikim et al. [BES Collab.], Phys. Lett. B 607, 243 (2005).
14. M. Ablikim et al. [BES Collab.], Phys. Lett. B 603, 138 (2004).
15. Q. Zhao, B. s. Zou and Z. b. Ma, Phys. Lett. B 631, 22 (2005).
16. B. Aubert et al. [BABAR Collab.], Phys. Rev. D 69, 011103 (2004).
17. J. Z. Bai et al. [BES Collab.], Phys. Rev. Lett. 91, 022001 (2003).
18. M. Ablikim et al. [BES Collab.], Phys. Rev. Lett. 95, 262001 (2005).
19. S. B. Athar et al. [CLEO Collab.], Phys. Rev. D 73, 032001 (2006).
20. M. Ablikim et al. [BES Collab.], Phys. Rev. Lett. 96, 162002 (2006).
21. [BES Collab.], arXiv:hep-ex/0604045.
22. J. L. Rosner et al. [CLEO Collab.], Phys. Rev. Lett. 95, 102003 (2005).
23. P. Rubin et al. [CLEO Collab.], Phys. Rev. D 72, 092004 (2005).
24. T. Appelquist et al. Ann. Rev. Nucl. Part. Sci. 28, 387 (1978).
25. S. Godfrey and J. L. Rosner, Phys. Rev. D 66, 014012 (2002).
26. M. Ablikim et al. [BES Collab.], Phys. Rev. D 72, 092002 (2005).
27. T. A. Armstrong et al. [E760 Collab.], Phys. Rev. D 48, 3037 (1993).
28. M. Ambrogiani et al. [E835 Collab.], Phys. Rev. D 65, 052002 (2002).
29. N. E. Adam [CLEO Collab.], hep-ex/0604044 - submitted to PRL.
30. J. Z. Bai et al. [BES Collab.], Phys. Rev. Lett. 88, 101802 (2002).
31. R. Ammar et al. [CLEO Collab.], Phys. Rev. D 57, 1350 (1998).
32. F. Anulli [BABAR Collab.], arXiv:hep-ex/0406017.
33. B. Aubert et al. [BABAR Collab.], Phys. Rev. Lett. 95, 142001 (2005).
34. B. Aubert *et al.* [BABAR Collab.], Phys. Rev. D **73**, 011101 (2006).
35. M. R. Shepherd *et al.* [CLEO Collab.], to be submitted to Phys. Rev. D.
36. T. E. Coan *et al.* [CLEO Collab.], Phys. Rev. Lett. **96**, 162003 (2006).
37. G. Bonvicini *et al.* [CLEO Collab.], Phys. Rev. D **70**, 112004 (2004).
38. M. Artuso *et al.* [CLEO Collab.], Phys. Rev. Lett. **95**, 251801 (2005).
39. P. Rubin [CLEO Collab.], hep-ex/0604043, submitted to Phys. Rev. D.
40. T. E. Coan *et al.* [CLEO Collab.], Phys. Rev. Lett. **95**, 181802 (2005).
41. G. S. Huang *et al.* [CLEO Collab.], Phys. Rev. Lett. **95**, 181801 (2005).
42. M. Artuso, arXiv:hep-ex/0510052.
43. H. Li, “Charm Physics with BES-III at BEPC-II,” arXiv:hep-ex/0605004.
44. P. Rubin *et al.* [CLEO Collab.], Phys. Rev. Lett. **96**, 081802 (2006).
45. M. Gronau and D. Wyler, Phys. Lett. B **265**, 172 (1991);
   M. Gronau and D. London., Phys. Lett. B **253**, 483 (1991).
46. D. Atwood, I. Dunietz and A. Soni, Phys. Rev. Lett. **78**, 3257 (1997);
   D. Atwood, I. Dunietz and A. Soni, Phys. Rev. D **63**, 036005 (2001).
47. A. Giri *et al.*, Phys. Rev. D **68**, 054018 (2003).
48. A. Bondar and A. Poluektov, arXiv:hep-ph/0510246.
49. D. Asner, “$D^0 - \overline{D^0}$ Mixing”, Phys.Lett.B592: 1, 2004.
50. D. M. Asner *et al.* [CLEO Collab.], Phys. Rev. D **72**, 012001 (2005).
51. R. Godang *et al.* [CLEO Collab.], Phys. Rev. Lett. **84**, 5038 (2000).
52. F. Buccella, M. Lusignoli and A. Pugliese, Phys. Lett. B **379**, 249 (1996).
53. A. A. Petrov, Phys. Rev. D **69**, 111901 (2004).
54. H. Muramatsu *et al.* [CLEO Collab.], Phys. Rev. Lett. **89**, 251802 (2002).
55. D. M. Asner *et al.* [CLEO Collab.], Phys. Rev. D **70**, 091101 (2004).
56. P. R. Burchat, “$\Lambda_c^+$ Branching Fractions,” Phys.Lett.B592: 1, 2004.