The Proposed CLEO-C Program and R Measurement Prospects [*]

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The proposed experimental program (CLEO-c) for a charm factory based on a modification of the Cornell Electron Storage Ring is summarized. The prospects for R measurements over the range $3\,\text{GeV} \leq \sqrt{s} \leq 7\,\text{GeV}$ are examined in detail.

1. CLEO-C PROGRAM OVERVIEW

The CLEO collaboration is proposing a focused three-year program of charm and QCD physics with the CLEO detector operating in the range $\sqrt{s} = 3 - 5$ GeV. The CLEO-c physics program includes a set of measurements that will substantially advance our understanding of important Standard Model processes and set the stage for understanding the larger theory in which we imagine the Standard Model to be embedded.

Much of this program revolves around the strong interactions and the pressing need to develop sufficiently powerful tools to deal with an intrinsically non-perturbative theory. At the present time, and for the last twenty years, progress in weak interaction physics and the study of heavy flavor physics has been achieved primarily by seeking those few probes of weak-scale physics that successfully evade or minimize the role of strong interaction physics. The preeminence of the mode $B \rightarrow J/\psi K_S$ in measuring $\sin 2\beta$ stems almost entirely from the absence of complications due to the strong interactions. Similarly, the discovery of a previously unrecognized symmetry in QCD, which led to Heavy Quark Effective Theory (HQET), created an opportunity in heavy-to-heavy quark decays where strong interaction effects are minimized. HQET's identification of the zero-recoil limit as the optimal kinematic point at which to measure $b \rightarrow c\ell\nu$ decays now dominates the extractions of $|V_{cb}|$ in B physics—not because it is experimentally optimal (quite the opposite!) but because it offers a way to minimize the complications of strong interactions. If we had similar strategies that would allow us to extract $|V_{ub}|$ from $b \rightarrow u\ell\nu$ measurements without form factor uncertainties, $|V_{td}|$ from B_d mixing measurements without decay constant and bag parameter uncertainties, or $|V_{ts}|$ from B_s mixing measurements (or limits) without its corresponding decay constant and bag parameter uncertainties, we would be well on our way to understanding the CKM matrix at the few percent level.

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In the current state of the field this is an unrealized dream. Across the spectrum of heavy flavor physics the study of weak-scale phenomena and the extraction of quark mixing matrix (CKM) parameters remain fundamentally limited by our restricted capacity to deal with the strong interaction dynamics.

Moreover, as we look to the future beyond the Standard Model, and beyond the realm of today's heavy flavor physics, we anticipate that the larger theory in which the Standard Model lives will certainly be either strongly coupled or will have strongly coupled sectors. Both Technicolor, which is modeled on QCD and is *ab initio* strongly coupled, and Supersymmetry, which needs strongly coupled sectors to break the supersymmetry, are prime examples of candidates for physics beyond the Standard Model. Strong coupling is a phenomenon to be *expected*: weak coupling is the exception in field theory, not the norm. Nevertheless our ability to compute reliably in a strongly coupled theory is far from developed, as evidenced by the careful identification and exploitation of golden modes in heavy quark physics. Techniques such as lattice gauge theory that deal squarely with strongly coupled theories will eventually determine our progress on all fronts of particle physics. At the present time absence of adequate theoretical tools significantly limits the physics we can obtain from heavy quark experiments.

Recent advances in Lattice QCD (LQCD), however, may offer hope. Algorithmic advances, and, to a lesser extent, improved computing hardware have produced a wide variety of nonperturbative results with accuracies of order 10–20%. This is particularly true for analyses of systems involving heavy quarks, such as B and D mesons or the Υ and ψ quarkonia. First-generation unquenched calculations have been completed for decay constants and semileptonic form factors, for mixing and for spectra. There is strong interest within the LQCD community in pursuing much higher precision, and the techniques needed to reduce errors to a few percent exist. A small number of calculations have achieved errors of 5% or less, including calculations of heavy-quark masses and the strong coupling constant; much more is possible within the next few years. But the push towards high precision is hampered by a lack of sufficiently accurate data against which to

test and calibrate the new theoretical techniques.

CLEO-c proposes to address this challenge by confronting it in the charm system at threshold where the experimental conditions are optimal. With high statistics data obtained from the decays of charmed mesons and charmonium, we will provide unprecedentedly precise data to confront theory. We will supplement the charmonium data with $\sim 4\text{fb}^{-1}$ of bottomonium data to be taken by CLEO III in the year prior to conversion to CLEO-c. Decay constants, form factors, spectroscopy of open and hidden charm and hidden bottom, and an immense variety of absolute branching ratio determinations will be provided with accuracies at the level of 1–2%. Precision measurements will demand precision theory.

The measurements proposed below are therefore an essential and integral part of the global program in heavy flavor physics of this decade and the larger program of the as yet unknown physics of the next decade. By exploiting capabilities which are unique to the charm sector and the charm energy region, and programmatic opportunities that are unique to CESR and CLEO, our measurements will explore a large set of critical weak and strong interaction phenomena. These in turn will drive theoretical advances that will both extend and enable the full program of flavor physics targeted by BaBar, Belle, CDF, D0, BTeV, LHCb, ATLAS, and CMS, and will lay the foundation for strong interaction theory to meet the requirements of future physics beyond the Standard Model.

1.1.   Run Plan and Datasets

The CESR accelerator will be operated at center-of-mass energies corresponding to $\sqrt{s} \sim 4140$, $\sqrt{s} \sim 3770(\psi'')$, and $\sqrt{s} \sim 3100(J/\psi)$ for approximately one calendar year each. Taking into account the anticipated luminosity which will range from 5×10^{32} cm^{-2}s^{-1} down to about 1×10^{32} cm^{-2}s^{-1} over this energy range, the proposed run plan will yield 3fb^{-1} each at the ψ'' and at $\sqrt{s} \sim 4140$ above $D_s\overline{D_s}$ threshold, and 1fb^{-1} at the J/ψ. These integrated luminosities correspond to samples of 1.5 million $D_s\overline{D_s}$ pairs, 30 million $D\overline{D}$ pairs, and one billion ψ decays. As a point of reference, note that these datasets will exceed those of the Mark III experiment by factors of 480, 310, and 170, respectively. If time and luminosity allow, modest additional data samples will be obtained at the $\Lambda_c\overline{\Lambda_c}$ threshold region, the $\tau^+\tau^-$ threshold region, the $\psi(3684)$, and over a set of scan points for an R versus $\sqrt{s}$ determination

In addition, prior to the conversion to low energy operation, we plan to take ~ 4 fb^{-1} spread over the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ resonances to launch the QCD part of the program. These datasets will increase the available $b\bar{b}$ bound state data by more than an order of magnitude.

1.2.   Hardware Requirements

The conversion of the CESR accelerator for low energy operation will require the addition of 18 meters of wiggler magnets to enhance transverse cooling of the beam at low energies. In the CLEO III detector the solenoidal field will be reduced to 1.0 T, and the silicon vertex detector may be replaced with a small, low mass inner drift chamber.

No other changes are needed to carry out the proposed program.

1.3.   Measurements

The principal measurement targets include:

1. **Leptonic charm decays:** $D^- \to \ell^-\overline{\nu}$ and $D_s^- \to \ell^-\overline{\nu}$. From the muonic decays alone the decay constants f_D and f_{D_s} can be determined to a precision of about 2%. The decay constants measure the nonperturbative wave function of the meson at zero inter-quark separation and appear in all processes where constituent quarks must approach each other at distances small compared to the meson size. Note that while f_π and f_K are known to 0.3% and 0.9% respectively, f_{D_s} and f_D are only known to about 35% and 100% respectively, and f_B and f_{B_s} are unlikely to be measured to any useful precision in this decade.

2. **Semileptonic charm decays:** $D \to (K, K^*)\ell\nu$, $D \to (\pi, \rho, \omega)\ell\nu$, $D_s \to (\eta, \phi)\ell\nu$, $D_s \to (K, K^*)\ell\nu$, and $\Lambda_c \to \Lambda\ell\nu$.
   Absolute branching ratios in critically interesting modes like $D \to \pi\ell\nu$ and $D \to K\ell\nu$ will be measured to $\sim 1\%$, and form factor slopes to $\sim 4\%$. Form factors in all modes can be measured across the full range of q^2 with excellent resolution. Semileptonic decays are the primary source of data for the CKM elements $|V_{ub}|$, $|V_{cb}|$, $|V_{cd}|$, and $|V_{cs}|$, but these CKM elements cannot be extracted without accurate knowledge of form factors. Currently, semileptonic branching ratios are known with uncertainties that range from 5% to 73%—in the cases where they are known at all—and form factor measurements are limited by resolution and background. Inclusive semileptonic decays such as $D \to eX$, $D_s \to eX$, and $\Lambda_c \to eX$ will also be examined and branching ratios will be measured to a precision of 1–5%. Currently, such quantities are known with uncertainties that range from 4% to 63%.

3. **Hadronic decays of charmed mesons.**
   The rate for the critical normalizing modes $D \to K\pi$, $D^+ \to K\pi\pi$, and $D_s \to \phi\pi$ will be established to a precision of order 1–2%. Currently these are known with uncertainties that range up to 25% and are even larger for other hadronic decays of interest. Many important B meson branching ratios are normalized with respect to these subsidiary charm modes.

4. **Rare decays, $D\overline{D}$ mixing, and CP violating decays.**
   CLEO-c can search for rare decays with a typical sensitivity of 10^{-6}, study mixing with a sensitivity to $x = \Delta M/M$ and $y = \Delta\Gamma/2\Gamma$ of under 1%, and detect any CP violating asymmetries that may be present

with a sensitivity of better than 1%. CLEO-c will also search for evidence of new physics within τ decays.

5. **Quarkonia and QCD.**
With approximately one billion J/ψ's produced, CLEO-c will exploit the natural glue factory, $\psi \rightarrow \gamma gg \rightarrow \gamma X$, to search for "glueballs" and other glue-rich states. The region of $1 < M_X < 3 \,\text{GeV}/c^2$ will be explored with partial wave analyses for evidence of scalar or tensor glueballs, glueball-$q\bar{q}$ mixtures, exotic quantum numbers, quark-glue hybrids, and other evidence for new forms of matter predicted by QCD but not yet cleanly observed.

   (a) Masses, widths, spin-parity quantum numbers, decay modes, and production mechanisms will be established for any states that are identified.

   (b) Reported glueball candidates such as the tensor candidate $f_J(2220)$, and the scalar states $f_0(1710)$, $f_0(1500)$, and $f_0(1370)$ will be explored in detail and spin-parity assignments clarified.

   (c) The inclusive photon spectrum in $J/\psi \rightarrow \gamma X$ will be examined with < 20 MeV photon energy resolution. States with up to 100 MeV width and inclusive branching ratios above 1×10^{-4} will be identified.

The $\sim 4 \,\text{fb}^{-1}$ of CLEO $b\bar{b}$ resonance data (to be taken prior to conversion to low energy operation) will also be exploited to survey the physics of the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$, resonances. We will measure leptonic widths (related to decay constants of mesons with open flavor) and photonic transition matrix elements (related to form factors in semileptonic decays of open flavor mesons). Comparing experimental results with LQCD predictions for the Υ (and ψ) spectra, leptonic widths and form factors test both the heavy-quark action that is used for LQCD simulations of B's and D's, and the specific techniques used to analyze B and D decay constants and form factors in LQCD. CLEO-c will also make spectroscopic searches for new states of the $b\bar{b}$ system and for exotic hybrid states such as $cg\bar{c}$ and perhaps $bg\bar{b}$. Analysis of $\Upsilon(1S) \rightarrow \gamma X$ will play an important role in establishing or debunking any glueball candidates found in the J/ψ data.

6. **Spot checks of R.**
The ratio $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ will be measured at various values of $\sqrt{s}$ with a precision of 2% per point. The R measurements are critical to interpretation of precision electroweak data and the $g - 2$ experiment.

1.4. Unique Features of the CLEO-c Program

Many of the measurements described above have been done or attempted by other experiments such as Mark III and BES,

and many are accessible to the B-factory experiments operating at the $\Upsilon(4S)$. What makes CLEO-c unique?

Compared to the Mark III and BES experiments which have taken data on the same ψ resonances as we propose here, CLEO-c will have:

1. **Vastly more data.**
As noted above the CLEO-c data sample will be $\sim$200–500 times larger than the corresponding Mark III datasets. Compared to BES, CLEO-c will have 270 times as much D and D_s data, and 20 times as many $\psi(3100)$ decays. One order of magnitude opens new vistas; two orders of magnitude can change a field.

2. **A modern detector.**
Mark III was built twenty years ago, and BES was modeled on Mark III. Detectors have gone through several generations of development since then. In every resolution and performance parameter—hit resolution, momentum and energy resolution, mass resolution, particle ID capability, solid angle coverage—CLEO III is superior to these other detectors by substantial margins. Photon energy resolution, for example, is factors of 10–20 times better (depending on E_γ); charged particle momentum resolution is 2–3 times better (depending on p_T). Particle identification with the RICH detector, augmented by energy loss (dE/dx) measurements in the drift chamber, give tens to hundreds of sigma $K\pi$ separation across the full kinematic range. A 25% increase of solid angle coverage relative to BES gives CLEO-c a huge advantage in analyses such as double-tag measurements that require every particle to be reconstructed. The gains go as 1.25^n where n is the total track and photon multiplicity of the event. This implies a typical effective luminosity gain of 8 in such analyses. For studies that involve partial wave analysis, the increase in solid angle coverage means angular distributions can be measured across the full angular range without large variations in efficiency. This translates to substantial gains in the reliability and precision with which J^{PC} can be measured for a given state.

On the other hand, CLEO-c will *not* have any advantage in statistics or in detector performance when compared to BaBar and Belle. The three detectors are all similar, and with an anticipated 400fb^{-1} of $\Upsilon(4S)$ data, BaBar and Belle will each have about 500 million continuum $e^+e^- \rightarrow c\bar{c}$ events. Yet the data CLEO-c takes at charm threshold has distinct and powerful advantages over continuum charm production data taken at the B-factories, which we list here:

1. **Charm events produced at threshold are extremely clean.**
The charged and neutral multiplicities in $\psi(3770)$ events are 5.0 and 2.4, compared with 11.0 and 5.6 in $\Upsilon(4S)$ events. This alone substantially reduces combinatorics, but in addition the $\psi(3770)$ decays are spherical, distributing decay products uniformly in the detector solid angle. Low multiplicity in CLEO-c translates to high efficiency and low systematic error.

2. **Charm events produced at threshold are pure $D\bar{D}$.**
   No additional fragmentation particles are produced. The same is true for $\psi(4140)$ decaying to $D\bar{D}^*$, $D_s\bar{D}_s$ and $D_s\bar{D}_s^*$, and also for threshold production of $\Lambda_c\bar{\Lambda}_c$. This allows the use of kinematic constraints such as total candidate energy and beam constrained mass, and also permits effective use of missing mass methods and neutrino reconstruction. The crisp definition of the initial state is a uniquely powerful advantage of threshold charm production that is absent in continuum charm production.

3. **Double-tag studies are pristine.**
   The pure production of $D\bar{D}$ states, together with the low multiplicity and high branching ratios characteristic of typical 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. These techniques, pioneered by Mark III many years ago allow one to make *absolute* branching ratio determinations. Backgrounds under these conditions are heavily suppressed. Very low background conditions minimize both statistical and systematic errors.

4. **Signal/Background is optimum at threshold.**
   The cross section for the signal $\psi(3770) \rightarrow D\bar{D}$ is equal to the cross section for the underlying continuum $e^+e^- \rightarrow$ hadrons background. By contrast, for $c\bar{c}$ production at $\sqrt{s} = 10.6$ GeV the signal is only 1/4 of the total hadronic cross section. In addition, the $c\bar{c}$ fragmentation distributes the final states among many charm hadron species.

5. **Neutrino reconstruction is clean.**
   For leptonic and semileptonic decays the lost neutrino can be treated as a missing mass problem and in the double tagged mode these measurements have low backgrounds. The missing mass resolution is under a pion mass. For semileptonic decays this also means that the resolution on q^2 is excellent, about 3 times better than is available in continuum charm reconstruction at $\sqrt{s} = 10.6$ GeV.

6. **Quantum coherence.**
   For D mixing and some CP violation studies, the fact that the D and $\bar{D}$ are produced in a coherent quantum state in $\psi(3770)$ decay is of central importance for the subsequent evolution and decay of these particles. The same is true for the CP = +1 mode $\psi(4140) \rightarrow \gamma D\bar{D}$. The coherence of the two initial-state particles allows simple methods to measure $D\bar{D}$ mixing parameters and check for direct CP violation.

In addition to the advantages of studying open-charm decays at threshold, the CLEO-c program includes the opportunity to use a huge charmonium data sample in searches for glueballs, hybrids, and exotic states. If found—or if *not* found—these states will present a powerful challenge to QCD calculations. Furthermore, CLEO will have the unique ability to compare results between both high statistics J/ψ and Υ data sets, and

further cross check with the 25fb^{-1} of existing two-photon data. These corroboratory measurements will be used to eliminate spurious glueball candidates. Theory, moreover, will be forced to confront precision data in both open- and hidden-flavor charm and bottom mesons simultaneously.

Taken together, these technical and programmatic features constitute formidable advantages for the CLEO-c proposal.

2. THE IMPACT OF CLEO-C

The measurements of leptonic decay constants and semileptonic form factors, together with the study of QCD spectroscopy both in the $c\bar{c}$ and $b\bar{b}$ quarkonium sectors will yield an extensive set of $1-2\%$ precision results that will rigorously constrain theoretical calculations. The calculations which survive these tests will be validated for use in a wide variety of areas where the interesting physics cannot be extracted without theoretical input. This broader impact of CLEO-c results extends beyond the borders of CLEO-c measurements and affects most of the core issues in heavy flavor physics. We list here some of the areas that will be most notable:

1. **Extraction of $|V_{ub}|$.**
   Currently limited by form factor calculations to an estimated 25% accuracy, and unlikely to improve beyond 10% in present-day extrapolations. Pinning down form factor technology in the closely related charm decays such as $D \rightarrow \pi\ell\nu$ and with $D \rightarrow \rho\ell\nu$, CLEO-c data will open the door to 5% or better precision in $|V_{ub}|$.

2. **Extraction of $|V_{td}|$ and $|V_{ts}|$.**
   Currently limited by ignorance of $f_B\sqrt{B_{B_d}}$ and $f_{B_s}\sqrt{B_{B_s}}$, our only prospect for separately extracting $|V_{td}|$ and $|V_{ts}|$ from B mixing measurements is through improving decay constant calculations to the percent level. Determinations of the charmed decay constants f_D and f_{D_s} will underwrite the required theoretical advances and open the door to $\sim 5\%$ determinations of $|V_{td}|$ and $|V_{ts}|$.

3. **Extraction of $|V_{cd}|$ and $|V_{cs}|$.**
   Currently known only at the $\sim 10\%$ level by direct measurement, CLEO-c will provide absolute branching ratio measurements of leptonic and semileptonic decays from which $|V_{cd}|$ and $|V_{cs}|$ can be extracted to $\sim 1\%$ accuracy. Here as elsewhere, form factor and decay constant calculations must be advanced to a comparable level of precision and validated by the entire range of CLEO-c measurements for CKM determinations at the percent level to be valid.

4. **Extraction of $|V_{cb}|$.**
   Currently limited by a variety of both experimental and theoretical inputs. Prominent among these are the theoretical control of the form factors and the experimental determination of $\mathcal{B}(D \rightarrow K\pi)$. CLEO-c will drive form factor technology, and measure the normalizing branching ratios at the sub-percent level.

5. **Unitarity tests of CKM.**
Currently poorly satisfied by the first two rows of the CKM matrix, which fail both orthogonality and orthonormality conditions at the $2 - 3\sigma$ level. Unitarity conditions can be probed with 1% precision when $|V_{cd}|$ and $|V_{cs}|$ are provided at this level by CLEO-c.

6. **Over-constraining the Standard Unitarity Triangle.**
Provided $|V_{ub}|$ and $|V_{td}|$ have been determined at the 5% level, as discussed in items 1 and 2 above, the triangle sides will have been measured with precision comparable to the phase quantity $\sin 2\beta$—thereby allowing for the first time meaningful comparison of the sides of the unitarity triangle with one of the angles.

7. **New forms of matter.**
In the quarkonium studies new forms of gluonic matter may be identified. Current results in this field are murky and contradictory. The high statistics data sample, high resolution detector, and clean initial state will be an unprecedented combination in this field, and offer the best hope for incisive experimental results.

3. MEASUREMENTS OF *R*

CLEO-c can approach measurement of R in two ways. The first involves an explicit scan over $\sqrt{s}$ to measure R directly at different energies. The second involves the use of radiative returns to determine an average R over a range of energies below those accessible directly by CESR-c.

3.1. *R* scanning

A scan of the energy range between 3 and 5 GeV will clarify the energy dependence of R just below the open charm threshold, from J/ψ to $\psi(3770)$, and above it where several relatively broad $c\bar{c}$ resonances exist. A possible scenario is to scan this energy range with steps of 100 and 20 MeV, below and above $\psi(3770)$ respectively, collecting about 10^4 hadronic events per point. Such a scan will require an integrated luminosity of about 100 pb^{-1}. It will also serve as an introduction to a more detailed potential study of the $c\bar{c}$ resonances in this energy range as well as D^* and D_s mesons copiously produced in their decays

The previous experience of CLEO (which measured R with an accuracy of 2% in the vicinity of the $\Upsilon(4S)$ resonance [1]) and recent progress in the calculations of radiative corrections together with the hermeticity of the CLEO-III detector allows one to expect a systematic uncertainty of about 2%. After that a scan of the energy range from 5 to 7 GeV will be needed to solve the dramatic contradiction between the old measurement of MARK-I [2] and the unpublished results of Crystal Ball [3]. Here a scan in steps of 100 MeV with 10^4 events per point will be adequate, requiring an integrated luminosity of 50 pb^{-1}. At an average luminosity of 3×10^{32} cm^{-2}s^{-1} it will take one week of collection time to scan the entire energy range between 3 and 7 GeV.

3.2. Radiative returns

The second approach to measuring R at CLEO-c will be to use radiative return events [4, 5]. Such events would allow CLEO-c to measure R in the 1–3 GeV energy range which is of crucial importance to reduce the overall uncertainty in $\alpha(M_Z)$ and $(g - 2)_\mu$. Recent experience of BaBar confirms statistical feasibility of such R measurements [6]. While running at the $\psi(3770)$ one can expect $\sim 10^4$ fully contained radiative return events in the range 1–3 GeV per 1 fb^{-1} of data. However, it is still unclear whether systematic errors can be controlled well enough to make the radiative return measurements meaningful, that is, to reach an uncertainty of less than 5%.

Various dedicated experiments have recently been proposed to improve our knowledge of R in the crucial 1–3 GeV energy range [7]. If they are approved, the CLEO-c measurements would be most valuable as an independent check of the dedicated experiments.

A 2% measurement of R between 3 and 7 GeV will significantly reduce the uncertainty of the hadronic contribution to $(g - 2)_\mu$ and especially $\alpha(M_Z)$. If radiative return events can be utilized to reach the 5% accuracy between 1 and 3 GeV, remarkable improvement is expected. For example, the $\alpha(M_Z)$ uncertainty would be a factor of 2 smaller than it is at present.

3.3. 'Modern' *R* Measurements for Charm Spectroscopy Studies

Although $c\bar{c}$ states below strong decay threshold (3.7 GeV) were studied at e^+e^- machines some time ago, higher mass states are very poorly defined. Most quark model analyses [8] find 3 poorly defined L=2 states above a mass of 4 GeV based on low statistics R data from 30 years ago. A detailed study of the properties of these states will test the long-range $q\bar{q}$ potential in a controlled way. In addition, the mass region from 4–5 GeV is where lattice calculations have predicted charmed hybrids to be, as detailed in other sections of this document.

Thus, a means to study this spectroscopy with more detail than the previous experiments is required. CLEO-c proposes a study that will provide a direct look at the states through a scan of the mass region 3.7–5 GeV. Because very little is known about the states above $D\bar{D}$ threshold, a broad look is appropriate. However, the complexities of extraction above the inelastic threshold require more detailed information about the final state. The proposed study will be similar to the R measurement described above. However it will measure the final state whenever possible by reconstructing D mesons in that the dominant decay modes will be $D\bar{D}$, $D^*\bar{D}$, $D^*\bar{D}^*$, and $D^{**}\bar{D}$. Previous measurements of these decay rates are strongly in disagreement with quark model calculations [8], but the data is of poor quality.

Data would be collected with a loose trigger in the region 3.7–5 GeV. Similar to an R measurement, runs will be at closely spaced energies (steps of 20 MeV). However, the runs need to be much longer ($\sim$100,000 events) than is typical [9]. Although the BES data have higher statistics than the older SLAC experiments, no attempts have been made to analyze the composition of the final state because of detector limitations. With

the larger event samples and the acceptance of CLEO, one would be able to reconstruct at least one D meson in about 10% of the events. This would be sufficient to characterize the final state and measure the angular distribution. The overall efficiency (summed decay branching ratio times detection efficiency) is about 16% for D^0 mesons and 6% for D^+ mesons for prominent decay modes. At a luminosity of 3×10^{32} cm^{-2}s^{-1}, each step would require about 2 days of data taking.

Existing quark model calculations for charmed hybrid mesons [10] assume the quarks to have orbital angular momentum 1. For decay mechanisms normally used in quark models, decays to $D\bar{D}$ mesons will be suppressed. If this symmetry is correct, a state with very low decay rate to $D\bar{D}$ would signal the possibility of a hybrid. Total widths are about 10–30 MeV in these models, similar to the conventional $c\bar{c}$ states at the same mass.

This measurement is related to other CLEO-c measurements outlined in this document. It is closely related to the R measurement discussed in the previous section, but will require much larger statistics.

4. SUMMARY

The high-precision charm and quarkonium data we propose to take will permit a broad suite of studies of weak and strong interaction physics. In the threshold charm sector measurements are uniquely clean and make possible the unambiguous determinations of physical quantities discussed briefly above,

and at greater length in the chapters that follow. The advances in strong interaction calculations that we expect to drive will in turn underwrite advances in weak interaction physics not only in CLEO-c, but in all heavy quark endeavors and in future explorations of physics beyond the Standard Model.

CLEO-c stands to make a significant impact upon the R determination in 3–7 GeV range, with direct 2% measurements appearing feasible with a fairly detailed scan. In addition, the use of radiative returns may provide a useful crosscheck for direct low energy measurements at other facilities if the systematic uncertainties can be controlled at the 5% level.

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