Expression of Interest

for

Expanded U.S. Participation

in the

Charm Physics Program of BES III

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Abstract

We argue for the physics reach of a program in open charm physics at BES III, and for new opportunities afforded by an expanded US participation. These opportunities are based on the proponents' experience in such physics with the CLEO and CLEO-c experiments at CESR. Specific contributions of this US group are based on a framework of physicists with a long track record of a coherent, mutually beneficial working relationship. Key aspects include Monte Carlo simulations using the Minnesota computing farm; analysis tools developed specifically for D and D_s production near threshold; long experience with reduction of systematic error in such measurements; and physics interests that are largely complementary to those of the current BES III collaboration membership. Future upgrade opportunities are also outlined. We further argue that we can pursue these opportunities by naturally transferring existing resources from CLEO to BES III, insofar as the operating expenses of the individual groups are involved.

I. INTRODUCTION

This expression of interest describes a developing plan for a subset of the CLEO collaboration to participate in the BES III experiment. In the spring of 2008, BES III will take first data at the high-luminosity BEPC II storage ring at the Institute for High Energy Physics (IHEP) in Beijing, China. The focus will be the physics of the charm-threshold region, $\sqrt{s} \simeq 3 - 4.5$ GeV, including both charmonium and open-charm states. This physics has been dominated in recent years by the CLEO-c experiment [2] at Cornell, which will cease data-taking on March 31, 2008. We believe that there remain many open questions in the charm sector and that BES III is the right facility to take the next step. In this document we describe our assessment of the opportunities to achieve greater precision in determining key Standard Model parameters and to make uniquely rigorous tests of strong-interaction theory. We lay out a plan for expanding U.S. participation in BES III that will allow us to meet our commitments to other programs while continuing to produce new results in quark-flavor physics and applying expertise and tools developed for CLEO in support of the HEP program of an important international partner.

A. Background

Investigations of e^+e^- annihilations in the charm-threshold region have provided some of the most important and most precise measurements of the properties of charmonium and open-charm states, dating back to the discovery measurements of the 1970's [1]. The spectroscopy of hadrons composed of charm quarks helped to establish the framework of strong-interaction theory, and charmed-meson decays are now providing the most stringent tests of Lattice QCD. Direct and indirect impact on our understanding of the quark mixing (the CKM matrix) is considerable, and precision charm-decay measurements are essential engineering input for experimental measurements of B decays and the more massive particles that decay (or may decay) into B's.

The CLEO-c program at the Cornell Electron Storage Ring (CESR) was conceived as an opportunity to make a major step forward in understanding charm when the very successful asymmetric B factories at SLAC and KEK ended CESR's longstanding dominance of b-quark physics. CLEO-c has had many successes, with approximately 40 publications in Physical Review and Physical Review Letters so far. The program has produced, or will produce before completion, many first measurements and dramatic improvement in the knowledge of decay constants, semileptonic form factors and the most important branching fractions of D and D_s mesons. CLEO-c has also presented numerous results in charmonium spectroscopy and decay.

The full promise of the CLEO-c program has not been realized, however, because of the even-greater-than-anticipated challenges of achieving high luminosity with the single-ring CESR collider at energies that are far below the original $\sim$ 10-GeV design. CLEO-c running will end with less than one quarter of the integrated luminosity proposed for the program, and with many statistics-limited measurements.

Our CLEO-c experience has demonstrated the power of a state-of-the-art magnetic spectrometer to do charm physics in the clean environment of an e^+e^- storage ring operating at threshold. This is exactly what BES III offers, with the further advantage that BEPC II is a two-ring collider designed for optimum performance in the charm-threshold energy range.

BEPC II has been built and is already delivering synchrotron beams for materials research. When BES III begins operation next year it will be an almost unique outpost of precision physics in the era of the LHC. We believe that it should have major U.S. involvement and that past investments in CLEO can be leveraged to produce major impact with modest resources.

B. Status of BEPC II and BES III

First data collection with the BEPC II storage ring and BES III detector is scheduled for spring of 2008. While first beam was stored in November, 2006, and synchrotron-radiation running began shortly thereafter, the schedule for colliding-beam operation was delayed by problems with the cryogenic system for the superconducting quadrupole (SCQ) magnets. These have been corrected and the SCQs have successfully operated at full field.

First beam collisions have been achieved, with a stored beam current of 5 mA for 20 bunches and an instantaneous luminosity of 7×10^{29} cm^{-2}s^{-1}. Based on this performance, BEPC II accelerator physicists project an initial luminosity of $\sim 10^{32}$ cm^{-2}s^{-1} as soon as a full complement of 93 bunches is stored. The design luminosity of BEPC II is 10^{33} cm^{-2}s^{-1} at an optimal beam energy of 1.89 GeV. The ability of IHEP to deliver on this luminosity projection is the key ingredient for the success of the program. While the two-ring design and charm-optimized geometry of BEPC II helped convince us that the design luminosity is realistic, the initial operational successes provide much-needed reinforcement for the optimism.

While the schedule delay resulting from the SCQ problems was considerable, the effect on BES III start-up has been minimized, with a revised plan for the detector to move into the beam line in March, 2008. Some important items remain to be delivered, like the beryllium beam pipe, but all systems are currently on track for this installation schedule. The main drift chamber is complete, and has achieved a single-hit resolution of 120 μm in cosmic ray tests, approximately equal to the design. The most recent milestone is the completion of installation of the crystals of the electromagnetic calorimeter, which occurred on September 21, 2007. Additional details on BES III readiness appear later in this document. All point to a successful start-up next year.

C. The BES III Collaboration and Initial Discussions of Membership

The accomplishments described in the previous section represent extremely impressive achievements by the BES III collaboration, which by the standards of comparable detector projects is quite small. Its total membership of ~ 150 is dominated by a large IHEP group and numerous Chinese universities, with only a small number of international collaborators, including groups from Europe and Japan. The University of Hawaii group currently represents the only major U.S. commitment to the project. The laboratory's and collaboration's urgent desire to strengthen international ties with new collaborators from outside China, especially in the U.S., has been widely reported [3].

The possibility of involving current CLEO collaborators in BES III was first suggested in early 2006. With encouragement and support from NSF through Cornell, a number of CLEO collaborators visited IHEP, participated in the CHARM 2006 conference in June, 2006, and consulted with BES III management, including Dr. Yifang Wang of IHEP (BES III

Spokesperson) and Prof. Fred Harris of the University of Hawaii (BES III Co-Spokesperson). It was a very warm reception, and an opportunity to see firsthand that the BES III project is ambitious, well designed, and in the hands of a capable team that needs additional experienced collaborators.

All of the senior representatives of CLEO groups have been impressed with the lab and the opportunity, but all have major commitments to other experiments, both the completion of CLEO-c and future programs at the LHC and elsewhere. In November, 2006, Moishe Pripstein organized a meeting at NSF for the purpose of discussing expanded U.S. involvement in BES III. While there was much enthusiasm for the physics, there were no commitments of resources from DOE and NSF and no commitments from the research groups to do more than conduct further explorations.

Since last fall several of us have made additional trips to Beijing. These visits and other discussions have affirmed our feeling that the BES III collaboration has specific need for the expertise that we have developed in CLEO-c research. Furthermore, our focused interest in charm physics complements the existing concentration of the BES III collaboration on topics in charmonium physics and other areas that have been emphasized in the earlier BEPC program. We are convinced that many data-starved CLEO-c charm analyses can easily be extended to BES III data, and that specific analysis tools developed for CLEO-c will transfer very readily to BES III, including utilities for calibration and other analysis tasks.

These conclusions are the motivation for this EOI, which presents our plan to form a coordinated effort to pursue charm physics with BES III. Preliminary drafts of this document have been shared with BES III management and discussed with CLEO-c senior investigators. The listed signers intend to function as a coherent US effort, requesting resources from their universities and funding agencies to transfer established CLEO-c research programs to BESIII. Each of us plans to apply for membership in the BES III collaboration in January 2008, with the contingencies that our ramp-up to full activity will occur as our CLEO-c research concludes and that we receive the support of our respective funding agencies.

D. Organization of this Document

The remainder of this document is divided into four parts. Section II gives an overview of the charm-physics opportunities of BES III. Section III describes contributions we propose to make to the operation of BES III. Section IV describes our assessment of the BES III detector as designed and some very preliminary thinking about how we might contribute to future upgrades. Section V provides the outline of a model for how we propose to organize our research within the BES III collaboration.

II. BES III PHYSICS OPPORTUNITIES

A. Introduction: Physics Goals of a BES III Charm Program

The CLEO-c phase of CLEO's three decades of heavy flavor physics has led us to two general conclusions:

- The center-of-mass energy region near $D\overline{D}$ threshold can be used *very* effectively for studying important aspects of charm decays.
- There will still be important things to be learned that will be best learned in this energy range after CLEO's data collection ends on March 31, 2008.

We feel that BES III is the natural vehicle for continuing the charm threshold program. That effort will benefit greatly from the addition of CLEO expertise.

The BES III design luminosity is 10^{33} cm^{-2}s^{-1}. Scaling from our CLEO-c experience (runs beginning at 6×10^{31} cm^{-2}s^{-1}, yielding 100 pb^{-1} per month), one can expect 10-fb^{-1} data samples in six months of data collection. Thus we can safely anticipate order-of-magnitude increases in sample size, compared to CLEO-c's probable 750 pb^{-1} samples at center-of-mass energies of 3770 MeV (for D^0 and D^+ studies) and 4170 MeV (for D_s). In what follows we assume 10-fb^{-1} data samples at the same two energy points, and scale from CLEO-c results. We do not discuss J/ψ and ψ' data samples, but these will be massive and will also provide interesting results.

1. *D Leptonic Decays*

The leptonic decays of D mesons, $D^+ \to \mu^+\nu$, $D_s^+ \to \mu^+\nu$,and $D_s^+ \to \tau^+\nu$ provide the opportunity for sensitive tests of lattice gauge theory (LQCD). The ability of LQCD to predict hadronic aspects of $B^0 - \overline{B}^0$ mixing and $B_s - \overline{B}_s$ mixing, thereby enabling extraction of V_{td}, is tested by these D decays. Results from CLEO-c will represent a major step in this direction, but will still leave substantial room for improvement.

$D^+ \to \mu^+\nu$

The present CLEO-c result of $\mathcal{B}(D^+ \to \mu^+\nu) = \left(4.40 \pm 0.66^{+0.09}_{-0.12}\right) \times 10^{-4}$ is based on 281 pb^{-1} of 3770 data. Taking 800 pb^{-1} as today's best guess of CLEO-c's ultimate sample, that leads to a statistical error of ±8.9%. Assuming no reduction in systematic error, that would be ±2.4%.

It is reasonable to expect that the systematic error can be reduced substantially below the 2.4%. For CLEO, there is no need to do this. For BES III, with a 10-fb^{-1} sample, giving a statistical error or ±2.5%, it *will* be necessary. BES III will have an additional tool not available to CLEO, namely muon identification functioning in the relevant momentum range. We can safely assume that a 10-fb^{-1} BES III sample would lead to a $D^+ \to \mu^+\nu$ branching fraction known to ∼3% precision.

$D_s^+ \to \mu^+\nu$ and $D_s^+ \to \tau^+\nu$

In CLEO-c, we have studied $D_s^+ \to \tau\nu$ via two different τ^+ decay modes: $\tau^+ \to \pi^+\nu$ and $\tau^+ \to e^+\nu\overline{\nu}$. The process $D_s^+ \to \tau^+\nu$, $\tau^+ \to \pi^+\nu$ represents a background to $D_s^+ \to \mu^+\nu$, which in turn represents a background to $D_s^+ \to \tau^+\nu$, $\tau^+ \to \pi^+\nu$. Consequently, we have taken two approaches.

In the first, we have assumed the validity of the Standard Model's prediction of the ratio of branching fractions for $D_s^+ \to \tau^+\nu$ to $D_s^+ \to \mu^+\nu$. We then combine $D_s^+ \to \mu^+\nu$ and $D_s^+ \to \tau^+\nu$, $\tau^+ \to \pi^+\nu$ signals, obtaining an "effective" $D_s^+ \to \mu^+\nu$ branching fraction.

Further, we include the (appropriately scaled) $D_s^+ \to \tau^+\nu$, $\tau^+ \to e^+\nu\overline{\nu}$ measured branching fraction in a final determination of the "effective" branching fraction. In this way, with the anticipated 630 pb^{-1} of 4170 data, CLEO-c will measure the effective branching fraction for $D_s^+ \to \mu^+\nu$ to a statistical precision of ±5.0%. The current systematic error is ±3.8%, for analyses using the present 4170 data sample of 318 pb^{-1}.

For BES III, with a 10-fb^{-1} 4170 sample, the statistical error on the effective $D_s^+ \to \mu\nu$ branching fraction will be ±1.3%, and it will be urgent to reduce the systematic error. Taking advantage of the BES III muon identification system, this should be possible, but it is likely that systematic errors will remain important. A combined statistical plus systematic error for the effective branching fraction for $D_s^+ \to \mu^+\nu$ of ~2% seems likely. This is to be compared with an ultimate measurement from CLEO-c of ~5.5%.

The second approach that we have taken in analyzing CLEO-c data is to separately measure the branching fractions for $D_s^+ \to \mu^+\nu$ and $D_s^+ \to \tau^+\nu$, taking the ratio of these two branching fractions as our goal. This ratio is firmly predicted by the Standard Model (SM), and many, but not all, extensions of the SM give the same result. So, this second approach is looking for evidence of non-SM behavior.

With the anticipated 630 pb^{-1} of CLEO-c 4170 data, the ratio will be determined to a statistical precision of ±10%. The systematic error, ±7% with current, preliminary analyses using the 318 pb^{-1} sample, can be expected to shrink, leading to a final CLEO-c combined error of ~11%.

BES III, with 10 fb^{-1} of 4170 data, will determine the ratio with a statistical precision of ±2.6%, so clearly reducing the systematic error will be essential. A factor-of-two reduction in systematic error seems plausible, leading to a combined error of ~4%.

Interpretation

The key numbers to extract from the $D \to \ell\nu$ measurements are $\mathcal{B}(D^+ \to \mu^+\nu)$ and $\mathcal{B}(D_s^+ \to \mu^+\nu)/\mathcal{B}(D^+ \to \mu^+\nu)$, which provide tests of LQCD, and $\mathcal{B}(D_s^+ \to \tau^+\nu)/\mathcal{B}(D_s^+ \to \mu^+\nu)$, which could reveal a breakdown of the Standard Model. Anticipated results from 10-fb^{-1} BES III data samples and final CLEO-c data samples are compared in Table I. BES III can achieve factor-of-three improvements over CLEO-c on these three quantities, severely challenging LQCD and hunting for a chink in the SM armor.

TABLE I: Predicted CLEO-c and BES III precision for charm-meson leptonic decay measurements.

	CLEO-c	BES III
$\mathcal{B}(D^+ \to \mu^+\nu)$	±9.0%	±3.0%
$\frac{\mathcal{B}(D_s^+ \to \mu^+\nu)}{\mathcal{B}(D^+ \to \mu^+\nu)}$	±10.5%	±3.6%
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu)}{\mathcal{B}(D_s^+ \to \mu^+\nu)}$	±11.0%	±4.0%

It should be noted that $\mathcal{B}(D^+ \to \mu^+\nu)$ is proportional to $|V_{cd}|^2$, and $\mathcal{B}(D_s^+ \to \mu\nu)$ is proportional to $|V_{cs}|^2$. So the LQCD tests must take these quantities from elsewhere, assuming unitarity of the 3×3 CKM matrix to get the required precision. (If one *trusted* LQCD, one could use the $D \to \ell\nu$ measurements to obtain $|V_{cd}|^2$, $|V_{cs}|^2$.) One can bypass the need to know the CKM matrix elements by taking ratios to semileptonic decay branching ratios, in particular

$$\frac{\mathcal{B}\,(D^+ \to \mu^+\nu)}{\mathcal{B}\,(D^0 \to \pi^- e^+\nu)} \quad \text{and} \quad \frac{\mathcal{B}\,(D_s^+ \to \mu^+\nu)}{\mathcal{B}\,(D^0 \to K^- e^+\nu)}\ .$$

Those ratios represent a pure challenge to LQCD. Semileptonic D decays are discussed in the next section.

2. D Semileptonic Decays

The exclusive semileptonic decays of D^0 and D^+ to pseudoscalars, for example $D \to Ke\nu$ and $D \to \pi e\nu$, are being extensively studied in CLEO-c, as are the decays to vectors, for example $D \to K^* e\nu$ and $D \to \rho e\nu$. Like the leptonic decays, these provide tests of Lattice QCD. In particular, the ability of LQCD to correctly describe $D \to \pi e\nu$ gives confidence in its ability to describe $B \to \pi e\nu$, and thus in the extraction of $|V_{ub}|$ from measurements of that decay. The CLEO-c analyses of $D \to Ke\nu$ will be systematics-limited, so this mode will probably not present an opportunity for BES III. The CLEO-c analyses of $D \to \pi e\nu$, with rates down by $|V_{cd}/V_{cs}|^2 \approx \frac{1}{20}$, will be far from systematic limits, however, particularly for the q^2 distributions, so this mode presents an excellent opportunity for BES III.

Studies of D_s exclusive semileptonic decays with CLEO-c data are at a very early stage. Even with the full CLEO-c 4170 data sample, all modes will have very limited statistics, and will be very far from any systematics limit. This is another great opportunity for BES III, although from the perspective of LQCD tests, it is not apparent that D_s decays offer any advantages over the more easily studied D^0 and D^+ decays. One exception to this statement is the weak annihilation contribution, with helicity suppression broken by soft gluon emission, i.e., $D_s^+ \to gge^+\nu$. Compared to $D^+ \to gge\nu$, this is enhanced by a factor $|V_{cs}/V_{cd}|^2 \approx 20$. It is important to understand this weak annihilation process, as it could contribute to high-momentum lepton production in B decays, affecting the extraction of $|V_{ub}|$ by measurements in the end-point region of the B-decay lepton spectrum. In $D_s^+ \to gge\nu$, the gluon pair might materialize as $\pi^+\pi^-$. Thus, a search for $D_s^+ \to \pi^+\pi^- e\nu$ is under way. While no evidence for the weak annihilation process has been seen, events resembling $D_s^+ \to f^0(980)e^+\nu$, $f^0(980) \to \pi^+\pi^-$ *have* been seen. The likely mechanism is f^0 produced because of its $s\overline{s}$ component, then decaying because of its $u\overline{u} + d\overline{d}$ component. This is a very clean environment in which to study $f^0(980)$, a rather poorly understood object.

CLEO-c has published studies of D^0 and D^+ inclusive semileptonic decays, and a study of D_s^+ inclusive semileptonic decays is at an early stage. The naive theoretical expectation is that the total semileptonic widths of D^0, D^+, and D_s^+ are equal. More sophisticated theoretical considerations [4] suggest that $D^0 - D_s^+$ widths might differ by as much as "several tens of percent," while the $D^0 - D^+$ widths difference would be $\sim |V_{cd}/V_{cs}|^2 = \frac{1}{20}$ as large. Voloshin urges a measurement of the D_s^+ semileptonic width, as being helpful in understanding B semileptonic decays and the extraction of $|V_{cb}|$.

D^0, D^+ Exclusive Semileptonic Decays

With 281 pb^{-1} of CLEO-c data, the systematic error on $D \to Ke\nu$ branching fraction is 1.2 times the statistical error. With the eventual CLEO-c sample of 800 pb^{-1}, $D \to Ke\nu$ will be very much systematics limited and not an opportunity for BES III.

With 281 pb^{-1} of CLEO-c data, the systematic error on $D \to \pi e\nu$ is one third of the statistical error, and so it is this mode that we are considering for BES III. In particular, for the q^2 distributions, the statistical errors will dominate. Binning the q^2 distribution in nine equal bins, errors per bin are typically ±10% with 281 pb^{-1}, ±6% with the full CLEO-c sample, and ±1.7% for 10 fb^{-1} with BES III. While with BES III we will certainly have to worry about q^2-dependent systematic errors, it is clear that we will be able to study the q^2 variation of the $D \to \pi e\nu$ form factor in great detail, far better than with CLEO-c data.

D_s Exclusive Semileptonic Decays

Table II presents *very* preliminary measurements of D_s exclusive semileptonic yields in 318 pb^{-1} of CLEO-c data at 4170 MeV, along with projected raw event numbers for the full CLEO-c and BES III samples. It is clear that we will be starved for statistics event with the full CLEO-c 4170 sample. With 10 fb^{-1} of BES III 4170 data, the situation is much better. In particular, the ∼500 $D_s^+ \to f^0 e\nu$ events should make studies of the features of $f^0(980)$ possible.

TABLE II: Raw numbers of exclusive semileptonic D_s decays for the current CLEO-c sample (300 pb^{-1}), projected CLEO-c sample (630 pb^{-1}) and projected BES III sample (10 fb^{-1}).

	300 pb^{-1}	630 pb^{-1}	10 fb^{-1}
$D_s^+ \to \phi e\nu$	65	137	2,200
$D_s^+ \to \eta e\nu$	77	410	2,600
$D_s^+ \to \eta' e\nu$	7	15	230
$D_s^+ \to K_s^0 e\nu$	11	23	370
$D_s^+ \to K^{*0} e\nu$	6	13	200
$D_s^+ \to f^0 e\nu$	16	34	530

Inclusive Semileptonic Decays of $D^0,\ D^+, D_s^+$

CLEO has published a study of D^0 and D^+ inclusive semileptonic decays based on 281 pb^{-1} of 3770 data. We find the ratio of the semileptonic widths to be consistent with 1.0, with a statistical error of ±2.8% and a systematic error of ±1.5%. Thus, a comparison of semileptonic total widths for D^0 and D^+ should be viewed as DONE, and not an objective for BES III. A comparison of the D^0 and D^+ *spectra* would benefit from more data, but the strongest argument for more statistics for inclusive semileptonic measurements is comparison of the D^0 and D_s^+ semileptonic widths.

An analysis of D_s^+ inclusive semileptonic decays is in its early stages. Reasonable projections of the statistical error on the inclusive semileptonic branching fraction and are ±4.7% with the full CLEO-c 4170 sample and ±1.2% with 10 fb^{-1} of BES III 4170 data. Clearly, systematic errors will be significant, and it will be necessary to remeasure the D^0 semileptonic width in BES III to achieve cancellation of some systematic errors. With the full CLEO-c data sample, the total error on the $D^0 - D_s$ semileptonic width difference is ±6% of the width. With a 10-fb^{-1} BES III sample at 4170 and 3770 it is likely that systematic errors will dominate. But a reduction in total error of at least a factor of 2 should be achievable. With an error of ±3%, it should be easy to see an effect of "several tens of percent." A comparison of the D^0 and D_s^+ lepton momentum spectra will also be possible, and here the systematic errors will be less important. It will be possible to show *where* any difference between D^0 and D_s^+ occurs. For example: is it the high momentum end, signalling a problem for $|V_{ub}|$ measurements via $B \to X\ell\nu$ endpoint analyses?

3. D Hadronic Decays

We consider three categories of D hadronic decay measurements. The first is determination of key reference decay modes to high precision. The second is "roughing out the terrain" – determining *lots* of decay modes, so that a large fraction of D decays are accounted for. The third is searching for, and obtaining measurements of, rare and forbidden D decays.

Precision Determination of a Few Reference Modes

For D^0 and D^+, this is considered to be *done*, with the 281 pb^{-1} 3770 data sample. It assuredly will be done, with the full 800 pb^{-1} CLEO-c sample. There is nothing for BES III to add here, other than verifying the CLEO-c results.

For D_s^+, the projection is that key reference modes $D_s^+ \to K^+K_s^0$, $D_s^+ \to K^+K^-\pi^+$, will be measured to a statistical precision of ±3.3%. Systematic errors are "guesstimated" at ±2.7%. So, while there will be room for improvement with BES III, it is unlikely to be the "factor of 3 improvement" we have seen for other topics.

Roughing Out the Terrain

The 281 pb^{-1} 3770 CLEO-c sample contains 1.0×10^6 $D^0\overline{D}^0$ events, and 0.81×10^6 D^+D^- events. With the full $\sim$ 800 pb^{-1} CLEO-c sample, there will be enough events to "rough out the terrain," even if we require a clean tag on one side. For example, $D^0 \to K^-\pi^+$, with a 4% branching fraction, should give ∼200K tagged D^0, with a similar number of cleanly tagged D^+ possible.

A 195 pb^{-1} 4170 CLEO-c data sample contains ∼187K $D_s^{*+}D_s^-$ or $D_s^+D_s^{*-}$ events. With the ultimate CLEO-c 4170 sample of 630 pb^{-1}, we will therefore have ∼600K $D_s^+D_s^-$ pairs. Again, this should be enough to "rough out" the D_s terrain.

So, we believe ∼90% of the branching fraction for D^0, D^+, and D_s can be determined without BES III data.

Rare and Forbidden D^0, D^+, and D_s Decays

Here there is a clear need for more data. As an example, we consider an analysis measuring the ratio of Cabibbo-suppressed to Cabibbo-favored D_s decays. $\mathcal{B}(D_s^+ \to K^+\eta)/\mathcal{B}(D_s^+ \to \pi^+\eta)$, and similarly for $K^+\eta'/\pi^+\eta'$, $\pi^+K_s^0/K^+K_s^0$, and $K^+\pi^0/K^+K_s^0$. With the present CLEO-c 4170 sample of ∼300 pb^{-1}, we clearly see all four suppressed modes, and determine the ratios ($\sim |V_{cd}/V_{cs}|^2 = \frac{1}{20}$) with statistical errors ranging from 10% to 30%. With the full CLEO-c 4170 data sample, errors will go down, but results will still be statistics-limited.

In that analysis, a search is also being made for the isospin-forbidden decay $D_s^+ \to \pi^+\pi^0$. There is no evidence, but only a rather weak upper limit due to background from continuum events. With a larger sample, a double-tag technique could be used. A 10-fb^{-1}

BES III sample would likely result in an order-of-magnitude improvement over CLEO-c for background-dominated searches like this one.

Having noted that BES III will give an order-of-magnitude improvement in sensitivity for searches for very rare decays, we expect to identify other modes of interest in addition to $D_s^+ \to \pi^+\pi^0$.

4. Strong Phases, $D^0 - \overline{D}^0$ Mixing and CP Violation

There is an analysis, currently under way, that makes use of the quantum correlation between D^0 and $\overline{D}^0$ mesons produced at the 3770, i.e., $e^+e^- \to \gamma_{\rm virt} \to D^0\overline{D}^0$. Since the virtual photon is CP even, spin 1, the D^0 and $\overline{D}^0$ are in relative $\ell = 1$ state, and so must have opposite CP's. The analysis measures single-tag yields for $D^0 \to K^-\pi^+$ (a flavor-tag), $D^0 \to$ CP-odd, and $D^0 \to$ CP-even. It also measures double-tag yields for all pairs of the preceding, and also pairs consisting of each of the preceding with a semileptonic decay. The theoretical expressions for these yields contain, in addition to the individual branching fractions for a D^0 in isolation, three interesting quantities. One is the $D^0 - \overline{D}^0$ mixing parameter y. The other two are the magnitude and strong phase for the amplitude ratio $\langle K^-\pi^+|\overline{D}^0\rangle/\langle K^-\pi^+|D^0\rangle \equiv -r_{K\pi}e^{-i\delta_{K\pi}}$. The importance of knowing the strong phase $\delta_{K\pi}$ is that some of the experiments looking for $D^0 - \overline{D}^0$ mixing have measured $y' \equiv y\cos\delta_{K\pi} + x\sin\delta_{K\pi}$. A knowledge of $\delta_{K\pi}$ enables the y' and y measurements to be combined, therby improving the overall precision.

The current analysis, using just the information described above, is expected to measure y to a precision of ± 0.03 and $\cos\delta_{K\pi}$, near 1.0, to a precision of ± 0.10 with a CLEO-c $\psi(3770)$ sample of 800 pb^{-1}. This is useful information on the strong phase, but the measurement of y is not competitive. We are exploring adding $D^0 \to K_S^0\pi^+\pi^-$ and $D^0 \to K_L^0\pi^+\pi^-$ to the mix. These modes contain CP-odd and CP-even, as well as flavored components. Precision will be improved because of the increased total CP-odd and CP-even yields, and may be further improved by making use of phase information, interference between CP-odd, CP-even, and flavored components. With a 10 pb^{-1} BES III 3770 data sample, using the analysis in its present form, y can be determined to a precision of ± 0.01, mildly interesting, and of additional value because it gives y by a different technique. If the ideas for improved precision being explored come to fruition, then the measurement of y becomes quite interesting. Certainly one of our physics goals with BES III will be continuing to develop and carrying out analyses of this type.

Other schemes for investigating $D^0 - \overline{D}^0$ mixing with CLEO-c data are being explored. They involve studies of correlated pairs of Dalitz plots, e.g. $D^0 \to K_s^0\pi^+\pi^-$ vs. $\overline{D}^0 \to K_s^0\pi^+\pi^-$. Should such investigations show promise, their application to the much larger BES III data set will be compelling.

A firm, unambiguous prediction of the Standard Model is that CP violation in D decays is negligibly small. Thus, a search for CP violation is in order: comparing rates for D^0 and $\overline{D}^0$ decays to specific final states, ditto for D^+ and D^-, and for D_s^+ and D_s^-. To what precision can $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$ be compared? $D^+ \to K^-\pi^+\pi^+$ and $D^- \to K^+\pi^-\pi^-$? $D_s^+ \to K_s^0\pi^+$ and $D_s^- \to K_s^0\pi^-$? At this point, lacking firm theoretical guidance, a shotgun approach is in order: Cabibbo-favored decays; Cabibbo-singly-suppressed decays, Cabibbo-doubly-suppressed decays. While a study of Cabibbo-favored decays can be carried out with

CLEO-c data samples, the benefit from samples an order of magnitude larger is obvious, as they give access to Cabibbo-suppressed decays.

A word of warning is in order here. Because interaction rates in detector material for K^- and K^+ are not identical, and ditto for π^- and π^+, and because these effects are not perfectly modeled by available Monte Carlo simulations, care will be needed to distinguish between actual CP violation and differences in rates caused by differences in detection efficiency. The detection efficiency differences are of order 1%, and one would very much like sensitivities at the sub-1% level.

III. CONTRIBUTIONS TO BES III INFRASTRUCTURE AND OPERATIONS

The combination of our group's knowledge with that of the current BES III collaborators will be very powerful in laying a solid foundation for quality physics output. We will bring valuable experience, based on the excellent performance of the CLEO-c detector and many successful precision physics analyses.

We anticipate that our group will be able to make significant contributions to the BES III infrastructure. There are two key aspects that should allow our impact to be more significant than our nominal group size. First, we have extensive experience with the CLEO-c detector systems, which are very similar to most components of the new BES III detector. Second, our physics interests (D and D_s physics) are complementary to the predominant interests of the existing BES III collaboration (charmonium). In addition, our own group is diverse in terms of both infrastructure and analysis expertise.

The areas in which we may contribute include the following items, to varying degrees: monitoring, calibration, reconstruction, simulation, analysis tools, and systematic studies. We now discuss each of these in turn. In all cases, we are interested in learning what is in place or planned, and providing suggestions. Clearly, in a few key places, we would plan to make significant direct contributions. Since we are not yet completely familiar with details of BES III needs, we present some CLEO-inspired philosophies of what is important, while highlighting some of the more natural possibilities for our focused contributions.

A. Online Monitoring

Though not a clean distinction, one can factorize online monitoring into two pieces. The first is to assure that the detector components are live and operational. A very large fraction of problems can be traced back to power supplies or data transfer. The second aspect is that information being read out is of the expected quality.

While we anticipate that such monitoring will be designed and implemented by BES detector experts, we are interested in reviewing these matters and offering ideas based on our experiences, both good and bad.

B. Calibration

In the evolution from CLEO II to CLEO-c, vast improvements were made in the turnaround time for calibration, which had been a bottleneck limiting physics output. While

BES III may not have direct competition for much of its program, it will clearly benefit from being able to achieve quality and speed in concert. One of us has already visited BES III to exchange ideas about drift chamber calibration, for both the tracking and dE/dx aspects of this detector.

Fast turnaround requires efficient skimming or tagging of calibration event samples both online and during data reconstruction. Error-free operation is made more likely by well-designed verification procedures and good tools for viewing constants. Playing a specific role within the scope of drift chamber calibration is one obvious possibility for our group.

C. Reconstruction

We anticipate that reconstruction software will be well under way by the time we arrive. Nonetheless, our experience may prove useful in cases where the detector has evolved significantly, e.g., calorimetry. Quality monitoring is also important during reconstruction.

D. Monte-Carlo Simulation

One of the strengths of CLEO-c, built up with years of software evolution as the detector components also evolved, is the quality of the Monte-Carlo simulation. We are also keenly aware of which aspects have proven difficult to tune well and the relative importance of various aspects of the simulation for physics output. One possibility would be drift chamber simulation, closely related to potential calibration work. Another is the calorimeter, where in addition to experience we might also be able to address remaining shortcomings in the CLEO simulation related to EM and hadronic shower-shape problems in GEANT.

We also have much experience and expertise in supporting the production of large Monte Carlo samples. In particular, the University of Minnesota has operated Monte Carlo farms for CLEO since the early 1990's, and has a current facility of approximately 50 rack-mounted dual-Xeon systems running Scientific Linux 4. It can generate and reconstruct approximately 9 million Geant-simulated events per day. Farm jobs are specified and monitored with a custom web interface (http://webusers.physics.umn.edu/˜ cleo3/) and the farm is managed with the University of Wisconsin Condor (http://www.cs.wisc.edu/condor/) system for high-throughput computing. Routine operation of the farm is provided by student labor, with faculty and postdoc oversight.

Because the CLEO-c Minnesota farm is so fast and the Condor management system is stable and efficient, Minnesota provides high-statistics samples very soon after data become available and can replace samples as needed when physics generators or detector simulations improve. The farm has produced and delivered one billion GEANT-simulated CLEO-c events, which have been used for every CLEO-c analysis.

We propose to transition the Minnesota farm to BES III Monte Carlo production. Because the capacity exceeds CLEO-c needs, this can begin immediately upon our joining the collaboration. This is further described in Sec. III, along with a proposal that we use this facility to support analysis of BES III data by U.S.-based members of the collaboration.

E. Analysis Tools

Based on a survey of BES III collaborators, we know that charmonium physics remains more popular than D physics. Thus, one area where we would almost certainly volunteer is creation and maintenance of D-tagging software. Some of us were intimately involved in this project at CLEO, and it is a place where we can contribute to the common infrastructure while also directly aiding our own physics goals.

We are also interested in applying D tagging tools to an improved scan of the region above $D\bar{D}$ threshold, similar to the CLEO-c scan that determined the optimal energy for D_s production. Finally, discussions inside CLEO have led us to ask if we might run at a different energy for D_s physics if luminosity was much larger. One could consider taking data at the peak of the $D_s^+ D_s^-$ rate, as opposed to the $D_s^{*+} D_s^- + c.c.$ rate, trading statistics for simplicity of analysis.

F. Systematic Studies

Much effort is needed to understand systematic effects at the level required by many of the precision physics measurements. Good results have their roots in quality calibration and simulation and their motivation in the precision physics. Hence, our contributions would likely be guided by drift chamber and possible calorimeter work, coupled with our D physics interests.

G. Infrastructure Summary

Some of us have already begun to share ideas informally with BES III. We would expect this sort of input to expand greatly after we become formal collaborators. However, our most significant contributions will come via projects where we assume a lead role.

The key items discussed above include:

- Drift-chamber calibration
- Monte Carlo tuning
- Monte Carlo production
- Development of D-tagging tools
- Selected systematic studies

This list would be made more specific as part of future negotiations to join BES III.

IV. POTENTIAL UPGRADE OPPORTUNITIES FOR BES III

As the expanded U.S. group matures, we would expect to begin contributing to upgrades of the BES III experiment itself. This section outlines potential opportunities for such upgrades.

A. Particle identification

The current particle identification (PID) system for BES III [5] consists primarily of plastic scintillator time-of-flight (TOF) counters, arranged around the outside of the barrel (but inside the CsI calorimeter) and along the endcaps. The barrel TOF counters are arranged in a double layer. The ultimate (rms) time resolution is expected to be 90 ps for the barrel system, and 110-120 ps for the endcaps. This leads to a K/π separation $\geq 2\sigma$ of $|\cos\theta| < 0.6$ for momenta below about 1 GeV/c.

This would be good enough for many measurements, but let us consider a particularly difficult one, which is also particularly interesting, namely $D^0 \to K^+\pi^-$. Cleanly identifying this doubly Cabibbo suppressed rate is important for studies of $D^0 - \overline{D}^0$ mixing, and the branching ratio relative to the Cabibbo favored rate is just under 4×10^{-3}, which corresponds to a 2.7σ separation. The K/π momentum for this decay is 0.86 GeV/c (for D's decaying at rest), so something better than 2σ would generally be achieved, but the margin is slim, if not nonexistent.

Clearly, then, the case can be made for an upgraded PID system. For the available space (810 mm $\leq r \leq$ 925 mm, and little area on either side of the overall detector volume) three options are under consideration. One option is to use resistive plate counters (RPC's) configured for precise timing [6]. Space constraints would allow a four-gap device, and an rms time resolution of approximately 60 ps should be achievable.

The other two options are based on the detection of totally internally reflected Cherenkov light. The radiating medium would be a quartz bar, which fits into the available space in the barrel and which transmits light to the ends. Microchannel plate (MCP) photomultiplier tubes (PMT) could be used to detect this Cherenkov radiation, with good timing (perhaps $\leq$ 50 ps) and perhaps with some position resolution. Just measuring the time, referred to as Cherenkov Correlated Timing (CCT), should be able to achieve 95% K/π separation up to 1.2 GeV/c. Combining timing with position, referred to as Time of Propogation (TOP), should be able to provide outstanding K/π separation [7, 8], but the technique is still under study. There does not appear to be enough available room for a DIRC [9, 10], but this also requires more investigation.

Contributions of the U.S. group towards this direction would first be the simulation and evaluation of these different options, and might eventually include the prototyping, design, installation, and commissioning of the upgraded PID system.

B. Computing

The BES III data volume will be more than an order of magnitude larger than for CLEO-c. This not only includes colliding beam data written to storage, but also the Monte Carlo simulation data sample with several times the statistical precision. A large computing facility is under construction in Beijing, but additional computing resources are needed. There is much room for the U.S. group to contribute to the solution here, not only for our own analysis needs, but for the common use of the experiment.

Because we propose to support Monte Carlo simulation and the full BES III analysis system in the U.S., we will have the opportunity and expertise to contribute to overall upgrades of the analysis system. One possibility under consideration is extension of a streamlined ROOT-based analysis system developed at Minnesota for CLEO-c to BES III analysis. While it would not completely replace the standard analysis packages, it would allow high-speed data processing and analysis development. By parallelizing ROOT processing, PROOF or an extension of our locally developed procedures, it should be possible to reduce turn-around time for large analysis tasks by an order of magnitude or more, as has been achieved for CLEO-c.

C. Networking

Moving and analyzing large amounts of data in widely separated geographical regions presents a significant problem in modern particle physics. However, it is a problem that has been recognized for some time, and whose solution is being aggressively pursued. A set of different "data grid" approaches, namely the Grid Physics Network (GriPhyN) [11], the International Virtual Data Grid Laboratory (iVDGL) [12], and the Particle Physics Data Grid (PPDG) [13] have been developed over the past several years, and have provided data analysis frameworks in the U.S. and elsewhere for a number of experiments, including CMS and ATLAS at the LHC, and also LIGO.

These projects are now moving under the umbrella of the Open Science Grid (OSG) [14], which is funded for \$30M from 2006-2011. There are a large number of institutions already making use of OSG [15] and several institutions represented in this Expression of Interest are either already part of OSG, or are located nearby facilities that would allow connection to it. Furthermore, IHEP in Beijing (and other Chinese institutions) are collaborating on CMS, and there are several efforts to provide better bandwidth for research and education to China, for example GLORIAD [16].

Consequently, a "broader impact" of this expanded U.S. collaboration would be to make use of the Open Science Grid for data analysis efforts at BES III, and thereby extend the range of U.S./China collaboration in general. Specific details of the U.S. contribution have yet to be worked out, but contact has already been made with the OSG leadership.

D. Absolute beam energy calibration

Some measurements will benefit a great deal from a precise measurement of the beam energy resolution. One direct example is the τ mass measurement. However, since the beam energy is a constraint used on virtually all analyses that exploit $D_{(s)}\bar{D}_{(s)}$ production, understanding its value and how it changes with time, would be useful information for many physics results.

A precision beam energy measurement technique, based on Compton backscattering of laser light, has been successfully used at the VEPP-2M storage ring in Novosibirsk [17]. This technique, which should be straightforward to adapt to the BEPC II ring, a high power ($\sim$ 20 W) CO_2 laser ($\lambda = 10.591\ \mu$m) which is reflected at 180° from the incident stored electron or positron beam. These backscattered photons have a well-understood energy distribution, with a sharp cutoff at $\omega_{\max}$ from 4 to 7 MeV for a beam energy in the range of 1.5 to 2 GeV. These photons are detected in a high purity Germanium detector which provides excellent energy resolution and which is straightforward to calibrate. At VEPP-2M (during the running of the KEDR experiment) a resolution of 60 keV was achieved at these beam energies.

It appears to be straightforward to adapt this procedure to BEPC II. Besides procuring the laser and detectors and developing the calibration procedures, it is necessary to design and install the laser and electron/positron beam optics systems. However, a preliminary design has been worked out and a cost estimate (under $250K) has been produced.

V. PROPOSED ORGANIZATION OF OUR BES III EFFORT

Before deciding to develop this EOI the proponents carried out many consultations and investigations to assess whether BES III is the right facility to take the next step in charm physics beyond CLEO-c. As discussed earlier, luminosity is the most essential ingredient, and in this regard our confidence in the excellent BEPC II design is now fortified with encouraging initial colliding-beam experience.

The capability of the BES III detector is a second crucial issue. Overall BES III's capabilities are very comparable to CLEO-c's, with some areas of superiority (usable muon detection) and others where it is not as powerful (hadron identification). While future upgrades could address the shortcomings, we conclude that even the initial BES III configuration is well matched to our planned charm program. We we recognize, however, that it will take a great deal of effort to develop and customize calibrations and other analysis tools to the level that decades of CLEO research have achieved.

The readiness of the BES III detector is a third major concern. While much work remains, the collaboration has done extremely well in the construction phase in spite of personnel limitations. Much of the success has been achieved through flexibility and resourcefulness in adapting techniques and software from other experiments. This same flexibility will continue to be needed during final preparations, commissioning and operation of the detector, and is evident in the eagerness expressed by BES III collaboration management and rank-and-file members to incorporate CLEO-c expertise.

The fourth major area of concern that we have considered is the logistics and sociology of collaboration. The physics of BES III is familiar terrain for current CLEO-c physicists, but IHEP, Beijing and China are not. Among the most important questions for the proponents of this EOI has been whether effective participation in BES III is possible for small groups at U.S. universities that have limited resources and significant commitments to other projects. Clearly we will be very reliant on the support of the host laboratory, and IHEP is working hard to develop an infrastructure that can support a major international collaboration. On-site facilities are good and the lab provides an excellent working environment and affordable accommodations for visiting researchers.

Because the BES III collaboration has such a strong group from IHEP, concerns have been expressed about whether university physicists can and will have appropriate input into the management and scientific direction of the program. It is clear that the lab and collaboration are sensitive to this concern, and BES III has adopted policies and governance structures that are modeled after other major collaborations. Furthermore, the collaboration has shown sensitivity to these concerns by soliciting our opinions on organizational questions and incorporating some of those suggestions into their policies.

Because of limited resources and other commitments, we expect that the majority of our scientific personnel will be deployed at our home institutions, as they are for CLEO-c. Nevertheless, effective participation in the experiment and the education of our graduate students will require some on-site presence at IHEP. While details remain to be worked out, we expect that the proponents of this EOI will coordinate our on-site efforts at IHEP closely. Rather than every group maintaining a sizable on-site contingent, we will try to maintain a collective "critical mass," with postdocs or senior faculty on extended visits acting as points of contact for the entire group and providing needed oversight of graduate students. This will require us to coordinate and collaborate on analysis projects, which should be very practical because of our shared interest in charm physics. Frequent (probably weekly) audio/video conferences of the entire group will be essential in this regard, as they have been for our CLEO groups.

Coordination will also be needed to maintain effective analysis efforts at our home campuses. Our assumption is that BES III physics will complement activities in R&D and construction of future projects, just as CLEO-c physics does for many of us now. To be effective in this mode it is necessary to minimize the overhead for analysis activities. Almost all CLEO-c groups carry out analysis remotely on computers at Cornell, relieving the burden of maintaining code and data samples. Unfortunately, one aspect of IHEP infrastructure that currently does not measure up to other major laboratories is computer networking. Our experience so far demonstrates that it is not practical to carry out interactive computing on facilities at IHEP from our home institutions in the U.S., so the CLEO model is not viable. Our alternative is to set up U.S.-based computing facilities maintaining all BES III computer code and hosting the BES III data and Monte Carlo samples that we need for our analyses.

As was described in Sec. III, there is one exception to the remote-computing model of CLEO-c. The University of Minnesota operates a 100-CPU computing farm that generates all large Monte Carlo samples for the experiment, as well as supporting most of the analysis activities of the Minnesota group. We are proposing to implement BES III Monte Carlo on the Minnesota farm soon after joining the collaboration. Since this requires supporting the full analysis environment, we also propose to support data-analysis activities of other U.S.-based BES III groups. It is our judgment that this kind of shared computing resource, at Minnesota or elsewhere, is essential for our effective participation in BES III.

While the current farm configuration can provide sufficient capacity for BES III Monte Carlo production, at least initially, and sufficient CPU for analysis, its 6-TB disk array will require expansion. The required upgrades will be assessed during the initial startup of BES III work. Costs should be modest, and, like the original farm acquisition, matching funds from the University of Minnesota are expected.

Conclusion and Next Steps

In submitting this EOI the authors are signaling our intention to begin negotiations to join the BES III collaboration. While we propose to coordinate our efforts, we will apply as individual university groups and senior researchers. Likewise, we will apply to our respective funding agencies and universities for continuing support of productive research programs in heavy-flavor physics. We are enthuiastic about the potential of BES III and committed to the successful completion of CLEO-c. We expect to present a more detailed plan and schedule for our BES III transition at the time of this fall's U.S.-China collaboration meeting at Fermilab.

APPENDIX A: PROFESSIONAL STATUS OF PROPONENTS

Roy Briere (Carnegie Mellon University)

CLEO Collaborator since 1995. Funded as a co-PI from DOE/HEP. Anticipate becoming active on CMS very soon. CLEO Analysis Coordinator 1997-8; CLEO Co-spokesperson 2005-7. Extensive experience with drift chamber calibration. Physics interests at BES III include various aspects of open charm decays.

Dan Cronin-Hennessy (University of Minnesota)

CLEO Collaborator since 1999. CLEO Analysis coordinator 2004. CLEO Operations manager 2003. Funded by DOE/HEP. Current involvement in CLEO-c and Neutrinos (NOvA and MINOS). Physics interest in BESIII include leptonic, semileptonic and radiative D decays.

Jim Napolitano (Rensselaer Polytechnic Institute)

CLEO collaborator since 2003. Funded as Principle Investigator through Elementary Particle Physics program within NSF/PHY. Present research commitments beyond CLEO-c include Daya Bay Neutrino Oscillation Experiment (in collaboration also with IHEP Beijing). Physics interests for BES III include quantum correlations between $D^0\bar{D}^0$ pairs produced through $e^+e^- \to D\bar{D}$ and $e^+e^- \to D^*\bar{D}$.

Ron Poling (University of Minnesota)

CLEO collaborator since 1977. (His PhD thesis in 1981 was the first of more than 300 that have been based on CLEO data.) Served as CLEO spokesperson 1995-1997. Funded by DOE/HEP. Present research activities are CLEO-c and NOvA. Principal physics interests for BES III are semileptonic D and D_s decays.

Ed Thorndike (University of Rochester)

CLEO collaborator from the beginning. Funded as Principal Investigator through NSF/EPP. CLEO Spokesperson or Co-Spokesperson, off and on, for nine of CLEO's thirty years. No commitments beyond CLEO-c other than BES III. Physics interests for BES III include leptonic and semileptonic D decays, and searches for rare D decays.

John Yelton (University of Florida)

Member of CLEO since 1988. Funded by DOE/HEP. Active on CMS. Interests include open charm decays.

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