THE CLEO-C PROJECT - A NEW FRONTIER OF OCQ PHYSICS

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A proposal for a three-year program of charm and QCD physics with the CLEO detector operating in the range of $\sqrt{s}$ = 3 - 5 GeV is presented. The CLEO-c program will include studies of semileptonic and hadronic charm decays, as well as searches for gluonic matter in the area of nonpertubative QCD. In addition, spectroscopy of the Υ(1S), Υ(2S) and Υ(3S) resonances is being carried out prior to the CLEO-c program.

1 Introduction

In this article the hadronic and QCD part of the proposed CLEO-c physics program will be outlined. The proposal includes a broad program of measurements that will contribute to the understanding of important Standard Model processes as well as provide the opportunity to probe the physics that lies beyond the Standard Model. The dominant themes of this program are measurement of absolute branching ratios for charm mesons with the precision of the order of 1 - 2% (depending upon the mode), determination of charm meson decay constants and of the CKM matrix elements V_{cs} and V_{cd} at the 1 - 2% level and investigation of processes in charm and τ decays, that are expected to be highly suppressed within the Standard Model. Hence, a reconfigured CESR electron-positron collider operating at a center of mass energy range between 3 and 5 GeV together with the CLEO detector will give significant contributions to our understanding of fundamental Standard Model properties.

2 Run Plan and Data Sets

From the year 2003 to 2005 the CESR accelerator will be operated at center-of-mass energies corresponding to $\sqrt{s} \sim$ 4140 MeV, $\sqrt{s} \sim$ 3770 MeV (ψ") and $\sqrt{s} \sim$ 3100 MeV (J/ψ). 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 run plan will yield 3 fb^{-1} each at the ψ" and at $\sqrt{s} \sim$ 4140 MeV above $D_s\bar{D}_s$ threshold and 1 fb^{-1} at the J/ψ. These integrated luminosities correspond to samples of 1.5 million $D_s\bar{D}_s$ pairs, 30 million $D\bar{D}$ pairs and one billion J/ψ decays. As a point of reference, these datasets will exceed those of the Mark III experiment by factors of 480, 310 and 170, respectively.

In addition, prior to the conversion to low energy a total amount of 4 fb^{-1} spread over the Υ(1S), Υ(2S) and Υ(3S) resonances is taken to launch the QCD part of the program. These data sets will increase the available $b\bar{b}$ bound state data by more than an order of magnitude.

3 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 will be replaced with a small, low mass inner drift chamber. No other requirements are necessary.

4 Physics Program

The following sections will outline the proposed CLEO-c physics program. Section 4.1 will focus on the Ypsilon spectroscopy, section 4.2 will describe the charm decay program and finally section 4.3 will give an overview about the gluonic matter studies.

4.1 Ypsilon Spectroscopy

From fall 2001 to summer 2002 CLEO will collect data on the Υ resonances below the $\Upsilon(4S)$. During the resonance running CLEO anticipates in excess of 4 fb^{-1} of accumulated data.

So far, the only established states below $B\bar{B}$ threshold are the three vector singlet Υ resonances ($^3S_1$) and the six χ_b and χ_b' (two triplets of ^3P_J) that are accessible from these parent vectors via E1 radiative transitions. By collecting substantial data samples at the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$, CLEO will address a variety of outstanding physics issues.

- Discovery of η_b and Observation of h_b
  The η_b is the ground state of $b\bar{b}$. Most present theories indicate the best approach would be the hindered M1 transition from the $\Upsilon(3S)$, with which CLEO might have a signal of 5 σ significance in 1 fb^{-1} of data. In the case of the h_b, CLEO established an upper limit of $\mathcal{B}(\Upsilon(3S)\rightarrow \pi^+\pi^- h_b) < 0.18\%$ at 90% confidence level[1]. This result, based on $\sim 110\ pb^{-1}$, already tests the theoretical predictions[2] for this transition which range from 0.1 - 1.0%. The resonance run program will measure the mass of the h_b, assuming the predictions are valid, to ~ 5 MeV.
- Observation of 1^3D_J states
  The $b\bar{b}$ system is unique as it has states with L = 2 that lie below the open-flavor threshold. These states have been of considerable theoretical interest, as indicated by many predictions of the center-of-gravity of the triplet. Based on both theoretical estimates and previous CLEO data samples, CLEO should see 20 - 40 events in the four-photon cascade $\Upsilon(3S)\rightarrow \gamma_1\chi_b' \rightarrow \gamma_1\gamma_2(^3D_J) \rightarrow \gamma_1\gamma_2\gamma_3\chi_b \rightarrow \gamma_1\gamma_2\gamma_3\gamma_4\ell^+\ell^-$
- Search for glueball candidates in radiative $\Upsilon(1S)$ decays
  The BES collaboration has reported signals for a glueball candidate[3] in radiative J/ψ decay - a glue-rich environment. Naively one would expect the exclusive radiative decay to be suppressed in Υ decay by a factor of roughly 40, which implies product branching fractions for Υ radiative decay of $\sim 10^{-6}$. With 1 fb^{-1} of data and efficiencies of around 30% one can expect $\sim$ 10 events in each of the exclusive channels, which would be an important confirmation of the J/ψ studies.

4.2 Charm Decays

The observable properties of the charm mesons are determined by the strong and weak interactions. As a result, charm mesons can be used as a laboratory for the studies of these two fundamental forces. Threshold charm experiments permit a series of measurements that enable direct study of the weak interactions of the charm quark as well as tests of our theoretical technology for handling the strong interactions.

Table 1: Proposed branching fractional errors for semileptonic decay modes

Decay Mode	BR fractional error %	
	PDG 2000	CLEO-c
$D^0 \to K\ell\nu$	5	1.6
$D^0 \to \pi\ell\nu$	16	1.7
$D^+ \to \pi\ell\nu$	48	1.8
$D_s \to \phi\ell\nu$	25	2.8

Semileptonic Charm Decays

The CLEO-c program will provide a large set of precision measurements in the charm sector against which the theoretical tools needed to extract CKM matrix information precisely from heavy quark decay measurements will be tested and honed.

CLEO-c will measure the branching ratios of many exclusive semileptonic modes, including $D^0 \to K^- e^+ \nu$, $D^0 \to \pi^- e^+ \nu$, $D^0 \to K^- e^+ \nu$, $D^+ \to \bar{K}^0 e^+ \nu$, $D^+ \to \pi^0 e^+ \nu$, $D^+ \to \bar{K}^{0*} e^+ \nu$, $D_s^+ \to \phi e^+ \nu$ and $D_s^+ \to \bar{K}^{0*} e^+ \nu$. The measurement in each case is based on the use of tagged events where the cleanliness of the environment provides nearly background-free signal samples, and will lead to the determination of the CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$ with a precision level of 1.6% and 1.7%, respectively. Measurements of the vector and axial vector form factors $V(q^2)$, $A_1(q^2)$ and $A_2(q^2)$ will also be possible at the $\sim$ 5% level. Table 1 summarizes the proposed branching fractional errors.

HQET provides a successful description of the lifetimes of charm hadrons and of the absolute semileptonic branching ratios of the D^0 and D_s [4]. Isospin invariances of the strong forces lead to corrections of $\Gamma_{SL}(D^0) \simeq \Gamma_{SL}(D^+)$ in the order of $\mathcal{O}(\tan^2\Theta_C) \simeq 0.05$. Likewise $SU(3)_{Fl}$ symmetry relates $\Gamma_{SL}(D^0)$ and $\Gamma_{SL}(D^+)$, but a priori would allow them to differ by as much as 30%. However, HQET suggests, that they should agree to within a few percent. A charm factory is the best place to measure absolute inclusive semileptonic charm branching ratios, in particular $\mathcal{B}(D_s \to X\ell\nu)$ and thus $\Gamma_{SL}(D_s)$.

Hadronic Charm Decays

Of the charm hadrons, the D^0 is the best known. The CLEO and ALEPH experiments provide by far the most precise measurements for the decay $D^0 \to K^-\pi^+$. They use the same technique, where they look at $D^{*+} \to \pi^+ D^0$ decays and take the ratio of the D^0 decays into $K^-\pi^+$ to the number of decays with only the π^+ from the D^{*+} decay detected. The dominant systematic uncertainty is the background level in the latter sample. In both experiments, the systematic errors exceed the statistical errors. By using $D^0\bar{D}^0$ decays and tagging both D mesons the background can be reduced to almost zero and the branching ratio fractional error can be improved significantly (see Table 2).

The D^+ absolute branching ratios are determined by using fully reconstructed D^{*+} decays, comparing π^0 D^+ with π^+ D^0 and using isotropic spin symmetry. Hence, this rate cannot be determined any better than the absolute D^0 decay rate using this technique. By using D^+D^- decays and a double tag technique the background can be reduced again to almost zero which leads to a significant improvement of the branching ratio fractional error (see Table 2).

4.3 Gluonic Matter

With approximately one billion J/ψ produced, CLEO-c will be the natural glue factory to search for glueballs and other glue-rich states using $J/\psi \to gg \to \gamma X$ decays. The region of

Table 2: Proposed branching fractional errors for hadronic decay modes

Decay Mode	BR fractional error %	
	PDG 2000	CLEO-c
$D^0 \to K\pi$	2.4	0.5
$D^+ \to KK\pi$	7.2	1.5
$D_s \to \phi\pi$	25	1.9

$1 < M_X < 3$ 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 new forms of matter predicted by QCD. This includes the establishment of masses, widths, spin-parity quantum numbers, decay modes and production mechanisms for any identified states, an in detail exploration of reported glueball candidates such as the tensor candidate $f_J(2220)$ and the scalar states $f_0(1370)$, $f_0(1500)$ and $f_J(1710)$, and the examination of the inclusive photon spectrum $J/\psi \to \gamma X$ with < 20 MeV photon resolution and identification of states with up to 100 MeV width and inclusive branching ratios above 1×10^{-4}. In addition spectroscopic searches for new states of the $b\bar{b}$ system and for exotic hybrid states such as $cg\bar{c}$ will be made using the 4 fb^{-1} $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ data sets. Analysis of $\Upsilon(1S) \to \gamma X$ will play an important role in verifying any glueball candidates found in the J/ψ data.

5 Summary

The high-precision charm and quarkonium data 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 unambigous determinations of physical quantities discussed above. CLEO-c will utilize a variety of tools, namely J/ψ radiative decays, two-photon collisions (using almost real, as well as highly virtual space-like photons), deep inelastic Coulomb scattering and continuum production via e^+e^- annihilation to obtain significant new information on the spectrum of hadrons, both normal and exotic, and their decay channels. A quantitative improvement can be expected not only from the large accumulated statistics, but also from combining the results obtained using all these tools together with the results from the Υ resonance runs. The significance of this is better sensitivity, reduced systematics and a better chance to obtain a coherent picture of the hadron sector.

Acknowledgments

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References

1. F. Butler *et al*, *Phys. Rev.* D **49**, 40 (1994).
2. Y.-P. Kuang and T.-M. Yan, *Phys. Rev.* D **24**, 2874 (1981).
3. BES Collaboration, J.Z. Bai *et al*, *Phys. Rev. Lett.* **76**, 3502 (1996).
4. I.I. Bigi in *Proceedings of BCP3*, ed. H.-Y. Cheng, W.-S. Hou (World Scientific, Singapore, 2000).