The CLEO III detector upgrade and physics goals

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Representing the CLEO collaboration

Abstract

The CLEO III upgrade and physics plans are reviewed. Currently the CLEO II detector has accumulated over 4 fb^{-1} on the $\Upsilon(4S)$ with instantaneous luminosities as high as 2.5×10^{32} $\mathrm{cm}^{-2}\mathrm{sec}{-1}$. The planned upgrade will include a new drift chamber ,a four layer silicon vertex detector, and particle identification. In parallel the accelerator, CESR, will be upgraded with superconducting RF with a goal of reaching luminosities of 3.0×10^{33}.

1. CLEO-III DETECTOR UPGRADE

The CLEO collaboration has been the acknowledged leader in b-quark physics since it discovered the B meson in 1980 [1]. The CLEO-II detector was the first to achieve better than 2% resolution simultaneously in charged particle momentum and electronic shower energy for GeV particles.

In January 1995 there will be an upgrade of the CLEO detector to replace the present inner five-layer straw-tube drift chamber by a three-layer silicon drift chamber.

For Phase III a much more extensive upgrade of the detector is required. The detailed plan for the CLEO-III upgrade is contained in a design report issued in late 1993 [2] and a separate document on the CESR/CLEO upgrade plans [3]. The existing superconducting coil (B= 1.5 T, r = 1.5m , l = 3m), the magnet iron, the muon detection system, and the 7800 CsI calorimeter will be kept. The tracking system will be replaced with one of equal performance to the current chamber but allowing 20 cm of radial space for the installation of advanced particle identification devices for good K/π separation up to 2.8 GeV/c, the highest momentum possible in decays of B mesons produced at the $\Upsilon(4S)$ resonance. This system will consist of a four layer silicon vertex detector with layers at 2.5, 3.75, 7.5, and 10.0cm, comprised of 452 identical double sided pieces followed by a drift chamber to a radius of 80cm. A particle identification system will be installed in the 20cm of free space with two technologies being considered. The first

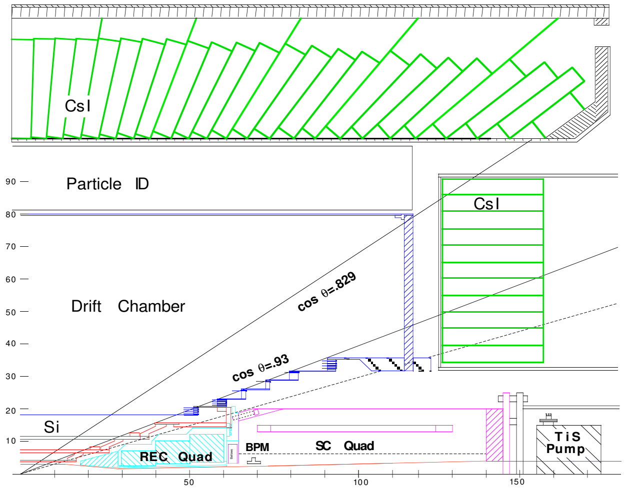

Figure 1. Quarter section view of the CLEO-III detector. The outer portions of the iron flux return and the muon chambers are not shown.

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is a fast RICH where beam tests have been completed at CERN and a full scale prototype is under construction. The second is high pressure tubes with a single threshold and these are also in the prototype stage. In addition as with the current detector dE/dx with an r.m.s of about 6 % will be used in the drift chamber. A quarter section of the CLEO-III detector is shown in Fig. 1. Angular coverage is defined by the interaction region quadrupole stay-clear line at $\theta = 300$ mrad. The active volume of the tracking system extends down to $\theta = 330$ mrad (93% of 4π steradians) with the remaining volume for cables and mechanical support.

2. PHYSICS GOALS

2.1. *Luminosity Expectations*

The peak luminosity goals for Phase II and Phase III of the CESR upgrade are shown in the table.

Phase	II	III	∞
Installation date	1994	1997	2000?
Peak luminosity, 10^{32} cm^{-2}s^{-1}	6	10	30
Average luminosity, fb^{-1}/yr	6	10	30

The last column shows what might optimistically be the asymptotic performance several years after the Phase III upgrade installation, when extensive experience with the new operating conditions will have enabled us to get the maximum out of the upgrade. In the other columns the Phase II and Phase III luminosity figures probably apply about a year after the corresponding installation date.

CESR now delivers between 1.2 and 1.5 fb^{-1} of integrated luminosity per year. In discussing the future physics potential it is useful to think of the integrated luminosity in units of 10 fb^{-1}. We can hope that by late 1998, as a result of the Phase II and III luminosity upgrades, CESR will have delivered two 10 fb^{-1} units and will be running at a rate of one unit per year. The goal for the PEP-II B Factory is 3 units per year. Ultimately, that rate may be possible also with the upgraded CESR.

2.2. *Rare B Decays*

Since its partner t quark is heavier, the b quark can decay only through mixing of quark families. The amplitudes are proportional to off-diagonal elements, V_{cb} and V_{ub}, of the Kobayashi-Maskawa matrix [6] that governs the flavor changing weak decays. Since V_{cb} is about 0.04, rare decays can compete and are a sensitive probe for new physics beyond the Standard Model.

2.2.1. b to u decays Lowest order tree diagram decays of the b quark occur through two possible W emission graphs, $b \to cW$ and $b \to uW$. The charmless amplitude is suppressed relative to the charmed decay amplitude by the factor

$$|V_{ub}/V_{cb}| = \lambda|\rho - i\eta| = 0.08 \pm 0.02,$$

where λ, ρ, and η are three of the four Wolfenstein parameters [7] in terms of which the nine KM matrix elements can be expressed. Hence, in spite of the relative phase space advantage of the charmless final states, the b to u modes are rare, with an inclusive branching ratio of about 2%.

The b to u decay is of special interest, because

- the amplitude involves V_{ub}, a basic constant of the Standard Model,
- the particular combination of CKM parameters, $\sqrt{\rho^2 + \eta^2}$, is not accessible in any other measurement,
- the measurement fixes the length of one side of the unitarity triangle, whose area determines the degree of CP violation in B meson decay,
- CP violating asymmetries are expected to be measurably large in exclusive hadronic b to u decay modes, such as $B \to \pi^+\pi^-$.

Our present information on $|V_{ub}/V_{cb}|$ comes from the observation of semileptonic B decays with lepton momenta beyond the end point for $B \to D\ell\nu$ [8]. Independent checks on $|V_{ub}/V_{cb}|$ can come from the measurement of branching ratios for exclusive charmless hadronic decay channels. A first observation of such decays has already been reported by CLEO [9]. The present CLEO detector can distinguish individual $B \to \pi^+\pi^-$ events from $B \to K^+\pi^-$ only at the 2.5 standard deviation level, by combining dE/dx (1.8 s.d. K/π separation) and kinematics (1.7 s.d. shift in reconstructed m_B). So the sum of the two branching ratios,

$$\mathcal{B}(B \to K^+\pi^-) + \mathcal{B}(B \to \pi^+\pi^-) = (2.4 \pm 0.8) \times 10^{5},$$

is better measured than the $\pi^+\pi^-$ branching ratio, $(1.3 \pm 0.8) \times 10^{-5}$. The number of events will increase with the upgraded CESR luminosity and the reliability of the signal will improve with the new CLEO particle identification. We can expect $\pi^+\pi^-$ and other hadronic b to u decay modes to show up at the level of a hundred or more detected events per 10 fb^{-1} unit of integrated luminosity. A study of the pattern of branching ratios in the various modes will be necessary for the detailed understanding of the mechanisms responsible for these decays, which in turn will be essential for the interpretation of CP violating asymmetries.

We can construct loop diagrams for processes $b \to s\gamma$ or $b \to sg$, called "penguin" modes. The intermediate loop contains a W boson and either a u, c, or t quark, with the heaviest particle dominating the amplitude. Although the theoretical predictions [10] for the inclusive radiative decays,

$$\mathcal{B}(b \to s\gamma) = 4 \times 10^{-4} \left|\frac{V_{ts}}{0.046}\right|^2 \left(\frac{m_t}{150 \text{ GeV}}\right)^{0.5},$$

are subject to large QCD corrections, they are considered reliable, within $\pm 10\%$ uncertainties coming from Λ_{QCD}. CLEO has detected $b \to s\gamma$ in the exclusive channels $\overline{B} \to K^{*0}\gamma$ and $B^- \to K^{*-}\gamma$, the first experimental observation of penguin decays. The measured average branching ratio is $(4.5 \pm 1.5 \pm 0.9) \times 10^{-5}$ [11]. The inclusive rate has now been measured [12] and is $(2.32 \pm 0.51 \pm 0.2 \pm 0.32) \times 10^{-4}$. As an indication of the importance of these modes this measurement sets a limit on the Higgs mass in the two Higgs doublet model.

2.2.2. Other B Physics With data samples of tens of fb^{-1} a wide variety of unique physics can be probed some of these are:

- Purely leptonic decays such as $B \to \tau\nu$.
- B decay to baryons and the detailed decay mechanisms.
- Forbidden dilepton decays such as $B \to \mu e$.
- Precision measurements of semileptonic decays and form factors.
- Precision measurements of CKM elements such as V_{ub} and V_{cb}.
- Measurement of exclusive $b \to u$ semileptonic decays.
- Using events with one fully reconstructed B decay to study in detail the decay of the other B and to separate cleanly B^0 from B^- decays.

2.3. CP Asymmetries in B Decays without Tagging

In 1964 we learned that CP symmetry is violated in about 0.2% of the weak decays of neutral kaons [14]. The phenomenon of CP violation may be the basis for the striking asymmetry in the occurrence of matter and antimatter in the universe. In 1973, before the discovery of the charmed quark, Kobayashi and Maskawa [6] realized that the most general 3×3 quark doublet rotation matrix for six quarks can contain an imaginary piece (the $i\eta$ in the Wolfenstein parametrization [7]) that can give rise to CP violation at the level observed in kaon decay.

CP violation effects in B decays [15] are accessible to experiments carried out at a symmetric-energy e^+e^- collider operating near the $b\bar{b}$ threshold and in general require measuring rate differences.

A particular example is the decay $B^{\mp} \to K^{\mp}\pi^0$ since the decay $B^- \to K^-\pi^0$ can proceed through either the spectator diagram, with $b \to u + s\overline{u}$ or through the penguin loop process with $b \to s + u\overline{u}$.

Starting with a sample of equal numbers of B^+ and B^-, one looks for an asymmetry in the occurrence of $K^+\pi^0$ and $K^-\pi^0$ final states. In terms of the Wolfenstein parameters, the asymmetry is

$$A = \frac{\Gamma - \overline{\Gamma}}{\Gamma + \overline{\Gamma}} = \frac{2sp\eta \sin(\delta_s - \delta_p)}{s^2\lambda^2(\rho^2 + \eta^2) + p^2\lambda^{-2} + 2sp\rho\cos(\delta_s - \delta_p)}.$$

There are many such possible decay modes that can be used and these searches can be carried out in any experiment in which B and $\overline{B}$ are produced in equal numbers. One simply compares the total numbers of observed B and $\overline{B}$ decays to the chosen CP-conjugate modes. Tagging and decay length measurements are not needed. Many of the favorable modes are charmless modes which do not suffer from the low detection efficiencies typical of charmed final states.

The total number of produced $B\overline{B}$ pairs required to get an asymmetry A with significance s standard deviations is $N(B\overline{B}) = s^2/\mathcal{B}A^2\epsilon$. Provided that there is at least one mode or summable set of modes with branching ratio times efficiency $\mathcal{B}\epsilon > 10^{-5}$ and asymmetry $A > 10\%$, then 1.6×10^8 events would be sufficient to establish CP violation to 4 standard deviations. That would correspond to a run of 150 fb^{-1} integrated luminosity.

Gronau and Wyler [17] have pointed out a class of decay modes that could in principle be used to extract the angle ϕ_s in the unitarity triangle, and for which the asymmetry is independent of hadronic matrix elements. The decays that they consider are $B^- \to D^0K^-$, $B^- \to \overline{D}^0K^-$, $B^- \to D^0_{CP}K^-$, and their charge conjugates. (Both the K^- and the D^0 can be replaced by similar final state particles of the same quark content, for example K^{*-} or D^{*0}.) Interference can occur between the first two amplitudes if the D^0 decay is into a non-flavor-specific final state such as K^+K^-. CP violation may be observable in these modes if the branching ratio for $B^- \to D^{(*)0}K^{(*)-}$, summed over modes, is greater than 5.4×10^{-6} [18]. Otherwise, the background may swamp the signal.

2.4. Non-B Physics

Our normal pattern of running yields the following numbers of events per fb^{-1} of integrated luminosity.

$b\bar{b}$	650,000
$c\bar{c}$	1,000,000
$\tau^+\tau^-$	800,000

CESR will in fact be a "Tau-Charm Factory". Also, running at the $\Upsilon(3S)$ resonance one gets 4 million $\Upsilon(3S)$ decays per fb^{-1}, including a wealth of transitions to lower $b\bar{b}$ bound states: $\Upsilon(2S)$, $\Upsilon(1S)$, $\chi_b(2P_{0,1,2})$, $\chi_b(1P_{0,1,2})$, $\eta_b(1^1S_0)$, $\eta_b(1^1S_0)$, $h_b(2^1P_1)$, $h_b(1^1P_1)$, $\Upsilon(1D)$, *inter alia*.

CLEO has already demonstrated its capabilities in these fields. A survey of the publication record (up to the end of 1993) reveals the following numbers of non-B published papers.

Charmed mesons	29
Charmed baryons	9
Tau decays	14
Photon-photon physics	3
Upsilon bound states	28

Besides increasing the data sample size by at least an order of magnitude, the upgrade will improve our ability to identify charm and tau decays, by isolating the decay vertices and by separating secondary kaons and pions. There are a number of interesting topics for which the number of events now available is not sufficient for definitive study. Some examples are

- pushing down the upper limit on the tau neutrino mass, now about 30 MeV, or making a measurement if m_{ν_τ} is nonzero,
- second-class current decays of the tau, such as $\tau^- \to \pi^-\eta\nu_\tau$, expected at the level of 10^{-5} in the Standard Model,
- the search for forbidden tau decays, like $\tau^- \to e^-e^+e^-$, $\tau^- \to \mu^-e^+e^-$, $\tau^- \to e^-K^0$, and $\tau^- \to \mu^-\rho^0$,
- rare decays of the charmed mesons, D^+, D^0, D_s, particularly the rare and forbidden modes $D \to \mu e$ and $D \to X\ell^+\ell^-$,
- $D^0 - \overline{D^0}$ mixing, expected in the Standard Model at the level of 10^{-4},
- the decay modes of the charmed baryons, Λ_c^+, Σ_c^0, Σ_c^+, Σ_c^{++}, Ξ_c^0, Ξ_c^+, Ω_c^0,
- the spectroscopy of charmed mesons, D^{**} and D_s^{**}, and baryons, Λ_c^*, Σ_c^*, Ξ_c^*, and Ω_c^*,
- the spectroscopy of the $b\bar{b}$ bound states, especially, the so far undiscovered η_b and h_b singlet states and the Υ(D)'s,
- the search for new glueballs, $q\bar{q}g$ hybrids, 4-quark $q\bar{q}q\bar{q}$ states, and $C = +1$ $c\bar{c}$ states in two-photon processes.

As the statistical errors decrease with larger and larger data samples and as rarer and rarer processes become accessible, many incisive tests of the Standard Model become possible, increasing the likelihood of finding new physics beyond the Standard Model. A more detailed survey of the possibilities is given in reference [13], chapters 7-10.

3. CONCLUSIONS

The Standard Model of six quarks and six leptons interacting through the unified electroweak interaction and quantum chromodynamics is consistent with all we know from experiment but there are still many unanswered questions.

The CLEO III detector together with the upgraded CESR accelerator will clearly probe new regions that may contain answers to some of these questions and will be a major step forward in our understanding of quarks and leptons and the fundamental interactions. The sensitivity we will reach in rare B decays certainly opens a new window to observe physics beyond the standard model. This coupled with high precision measurements on b, c, and τ decays and the possibility of measuring CP violation will keep the experiment at the very forefront of discovery for the next decade and beyond.

4. References

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