Report of the 2004 BESIII and CLEO-c Workshop

Summary of the BESIII and CLEO-c Workshop
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1 Introduction

In early January 2004 ninety nine physicists, twenty nine of whom where from outside of China, including eleven from CLEO-c, met at the Institute of High Energy Physics of the Chinese Academy of Sciences in Beijing, to discuss the status and physics goals of the CLEO-c experiment at the Cornell Electron Storage Ring (CESR) and the BESIII experiment at the Beijing Electron Positron Collider (BEPCII). As BESIII expects to begin taking data at about the time the CLEO-c program is completed, a major goal of the workshop was to help refine the BESIII physics program. This workshop also provided an excellent opportunity for many young Chinese physicists – graduate students as well postdoctoral researchers – to learn more about the physics opportunities in the charm threshold region and to become acquainted with physicists working in this field from other countries.

Thirty four informative talks were given at the workshop. The agenda, a list of participants, and electronic copies of all of the talks are available from the workshop home page. http://bes.ihep.ac.cn/conference/wksp04/

At the time the workshop was held CLEO-c had recently been approved by the National Science Board of the National Science Foundation and had taken a pilot run with a single prototype wiggler magnet installed in CESR. The BESIII detector and BEPCII accelerator were under construction.

Three days of open and excellent discussions both during and after the talks, and at a special discussion session revealed many areas of common physics interest. At the midpoint of the workshop Jim Alexander (Cornell University and a former CLEO Co-Spokesperson) lead a discussion in which he asked the participants: “How can we optimize the physics output of BESIII/CLEO-c?” The ensuing discussion captured the spirit of the workshop and so we have summarized it here. The letter “c” stands for charm, and appropriately, five areas where optimization was possible that begin with that letter were discussed at length. The five areas were:

- *Complementarity:* CLEO-c has a higher accessible $\sqrt{s}$ than BESIII, but will accumulate a smaller integrated luminosity. The CLEO-c lifetime is brief, the BESIII lifetime is open-ended. CLEO-c is starting now, while BESIII starts later. CLEO-c has no muon identification while BESIII does.
- *Cooperation:* Physics workshops (such as this one), technical workshops, for example dedicated to the interaction region, visiting physicist programs and development of common software tools.
- *Community:* The formation of joint working groups for certain physics topics and a common approach to conference organizers to maximize CLEO-c/BESIII impact during the period when both experiments are producing results.
- *Competition:* is healthy, it leads to more efficient production of results, raises standards and drives new ideas.
- *Confirmation:* BESIII is the only experiment that will be able to confirm, and eventually exceed the precision of, decay constant and form factor measurements made by CLEO-c. If glueballs or exotica are observed at CLEO-c confirmation by BESIII will be crucial to acceptance of these objects by the community.

2 The Physics of CLEO-c and BESIII

The first session of the workshop was devoted to an overview of the physics program and the status of CLEO-c and BESIII. Ian Shipsey (Purdue University and a CLEO Co-Spokesperson) reviewed the CLEO-c physics program, Stephen Gray (Cornell University and a CLEO Run Operations Manager) reviewed the design and status of the CLEO-c detector and David Rubin (a professor of accelerator physics at Cornell University) reported on the status of CESR-c. The CLEO-c/CESR-c presentations were followed by excellent talks on the status of BESIII/BEPCII project by Weiguo Li (IHEP and Co-Spokesperson of BESIII), on the BESIII detector construction by Yifang Wang (BESIII Detector Project Leader) and an authoritative and broad overview of the theory of charm flavor physics by Ikaros Bigi (University of Notre Dame). This suite of talks laid out the CLEO-c and BESIII program. A summary of the content of the overview talks appears below.

2.1 The Big Questions in Quark Flavor Physics

The big questions in quark flavor physics are:

- "What is the dynamics of flavor?"
  The gauge forces of the standard model (SM) do not distinguish between fermions in different generations. The electron, muon and tau all have the same electric charge, quarks of different generations have the same color charge. Why generations? Why three?
- "What is the origin of baryogenesis?"
  Sakharov gave three criteria, one is CP violation [1]. There are only three known examples of CP violation: the Universe, and the beauty and kaon sectors. However, SM CP violation is too small, by many orders of magnitude, to give rise to the baryon asymmetry of the Universe. Additional sources of CP violation are needed.

- "What is the connection between flavor physics and electroweak symmetry breaking?" Extensions of the SM, for example supersymmetry, contain flavor and CP violating couplings that should show up at some level in flavor physics, but precision measurements and precision theory are required to detect the new physics.

Weak interaction measurements in the charm threshold region can shed light on these questions. Those measurements and others in the charmonium sector can contribute to our understanding of QCD, which is necessary to address these questions in other sectors of elementary particle physics.

2.2 The role of charm in CKM physics

This is the decade of precision flavor physics. In the "$\sin(2\beta)$ era", the goal is to over-constrain the CKM matrix with a range of measurements in the quark flavor changing sector of the SM at the per cent level. If inconsistencies are found between, for example, measurements of the sides and angles of the CKM unitarity triangle, it will be evidence for new physics. Many experiments will contribute including BaBar and Belle, CDF, DØ, and BTeV at Fermilab, ATLAS, CMS, and LHC-b at the LHC, BESIII, CLEO-c, and experiments studying rare kaon decays. BESIII and CLEO-c can play a special role in providing measurements of the CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$, as well as indirectly aiding the measurements of the other CKM matrix elements at these other facilities.

However, the study of weak interaction phenomena, and the extraction of quark mixing matrix parameters remain limited by our capacity to deal with non-perturbative strong interaction dynamics. Current constraints on the CKM matrix, except that of $\sin(2\beta)$, are dominated by uncertainties in the calculation of hadronic matrix elements. Techniques such as Lattice QCD (LQCD) directly address strongly coupled theories and have the potential to determine our progress in many areas of particle physics. Recent advances in Lattice QCD have produced calculations of non-perturbative quantities such as f_π, f_K, and heavy quarkonia mass splittings that agree with experiment [2]. Several per cent precision in charm and beauty decay constants and semileptonic form factors is hoped for, but the path to higher precision is hampered by the absence of accurate charm data against which to test lattice techniques. This is beginning to change with the BESII run at the $\psi(3770)$ (ongoing at the time of the workshop) and the start of data taking at the charm and QCD facility, CESR-c/CLEO-c [3]. Later in the decade BESIII at the new double ring accelerator BEPCII will also turn on. Beginning September 2004 CLEO-c will obtain charm data samples one order of magnitude or more larger than any previous experiment, and the BESIII data set is expected to be approximately a factor of five greater than the CLEO-c design. These data sets have the potential to provide unique and crucial tests of LQCD, and other QCD technologies such as QCD sum rules and chiral theory, with accuracies, at BESIII, of 1-2%.

If LQCD passes the charm factory tests, the elementary particle physics community will have much greater confidence in LQCD calculations of decay constants and semileptonic form factors in beauty physics. When these calculations are combined with 500 fb^{-1} of B factory data, and improvement in the direct measurement of $|V_{tb}|$ expected from the Tevatron experiments [4], they will allow a significant reduction in the size of the errors on the quark couplings $|V_{ub}|, |V_{cb}|, |V_{td}|$ and $|V_{ts}|$, quantitatively and qualitatively transforming knowledge of the CKM unitarity triangle, and thereby maximizing the sensitivity of heavy quark physics to new physics.

Of equal importance, LQCD combined with charm factory data allows a significant advance in understanding and control over strongly-coupled, non-perturbative quantum field theories in general. Field theory is generic, but weak coupling is not. Two of the three known interactions are strongly coupled: QCD and gravity (string theory). An understanding of strongly coupled theories may well be a crucial element in helping to interpret new phenomena at the high energy frontier.

2.3 New physics searches with charm

In the early part of the 20th Century table top nuclear β decay experiments conducted at the MeV mass scale probed the W at the 100 GeV mass scale. In an analogous way can we find violations of the Standard Model originating at high mass scales by studying low energy processes such as charm meson decays? The existence of multiple fermion generations appears to originate at very high mass scales and so can only be studied indirectly. Mixing, CP violation, and rare decays may investigate the new physics at these scales through intermediate particles entering loops. Why is charm a good place to look? In the charm sector, the SM contributions to these effects are small, in other words, a background free search for new physics is possible. Typically $D^0 - \bar{D}^0$ mixing $\mathcal{O}(< 10^{-2})$, CP asymmetry $\mathcal{O}(< 10^{-3})$ and rare decays $\mathcal{O}(< 10^{-6})$. In addition, charm is a unique probe of the up-type quark sector (down quarks in the loop). The sensitivity of searches for new physics in charm depends on high statistics rather than high energy and so will be a particular strength of the BESIII program.

3 A Detailed Look at the Physics Program

The remainder of the workshop was devoted to the essential task of examining in closer detail the ideas and goals sketched in the outline.

3.1 Charm Meson and Baryon Physics

Jim Alexander (Cornell University) reminded us how poorly we know charm hadronic branching ratios. Charm leptonic decays measure decay constants, and charm semileptonic decays measure form factors; absolute branching fractions are essential for both of these kinds of measurements. The absolute hadronic branching ratios $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$, $\mathcal{B}(D^0 \to K^-\pi^+)$, and $\mathcal{B}(D_s^+ \to \phi\pi^+)$ are also important as, currently, all other D^+, D^0 and D_s^+ branching ratios are determined from ratios to one or the other of these branching fractions [5]. In consequence, nearly all branching fractions in the B and D sectors depend on these reference modes.

There are decisive advantages to running at charm threshold. As $\psi \to D\bar{D}$, the technique is to fully reconstruct one D meson in a hadronic final state, which is referred to as the tag, and then to analyze the decay of the second D meson in the event to extract inclusive or exclusive properties. Charm mesons have many large branching ratios to low multiplicity final states. In consequence the tagging efficiency is very high, about 25%, this should be compared to much less than 1% for B tagging at a B factory. Tagging creates a single D meson beam of known momentum. This is a particularly favorable experimental situation.

Jim Alexander showed that with a 3 fb^{-1} data sample sub percent precision could be reached for $\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$, $\mathcal{B}(D^0 \to K^-\pi^+)$, and about 2% for $\mathcal{B}(D_s^+ \to \phi\pi^+)$.

Kanglin He (IHEP) reviewed the charm physics reach of BESIII. The measurement of the leptonic decay $D^+ \to \mu^+\nu_\mu$ benefits from the fully tagged D^- at the $\psi(3770)$. One observes a single charged track recoiling against the tag that is consistent with a muon of the correct sign. Energetic electromagnetic showers un-associated with the tag are not allowed. The missing mass $MM^2 = m_\nu^2$ is computed; it peaks at zero for a decay where only a neutrino is unobserved. The clear definition of the initial state, the cleanliness of the tag reconstruction, and the absence of additional fragmentation tracks make this measurement straightforward and nearly background-free. With 3 fb^{-1} a 3% error for f_{D^+} is expected, a dramatic improvement as the quantity was unmeasured at the time of the workshop. Similar precision is expected for $f_{D_s^+}$ at $\sqrt{s} = 4140$ MeV, again the improvement is dramatic as the quantity is currently known to 35% (January, 2004).

Shoji Hashimoto (KEK) reported on the status of precision Lattice QCD calculations. He started by noting that brute force LQCD calculations that reproduce the real world require 10^{10}Tflops $\cdot$ year, and so theoretical and algorithmic improvements are essential. He outlined the program of the HPQCD-UKQCD-MILC-Fermilab group which is designed to achieve the goal of 1% accuracy for decay constants and semileptonic form factor calculations. He concluded the goal was reachable.

Jim Wiss (University of Illinois) discussed leptonic and semileptonic charm decays with CLEO-c. The measurement of semileptonic decay absolute branching ratios and absolute form factors is also based on the use of tagged events. The analysis procedure, using $D^0 \to \pi^-e^+\nu_e$ as an example is as follows. A positron and a hadronic track are identified recoiling against the tag. The quantity $U = E_{miss} - P_{miss}$ is calculated, where E_{miss} and P_{miss} are the missing energy and missing momentum in the event. U peaks at zero if only a neutrino is missing. In previous studies at B Factories and fixed target experiments the background was larger than the signal but this is not the case at threshold. With 3 fb^{-1} a charm factory will make a very significant improvement in the precision with which each absolute charm semileptonic branching ratio is known.

The q^2 resolution at a charm factory is about 0.025 GeV^2, which is more than a factor of 10 better than CLEO III which achieved a resolution of 0.4 GeV^2 [6] This huge improvement is due to the unique kinematics at the $\psi(3770)$ resonance, i.e. that the D mesons are produced almost at rest and the D momentum vector is known. The combination of large statistics, and excellent kinematics will enable the absolute magnitudes and shapes of the form factors in every charm semileptonic decay to be measured, in many cases a precision of a few per cent may be achievable This is a stringent test of LQCD.

By taking ratios of semileptonic and leptonic rates, CKM factors can be eliminated. Two such ratios are $\Gamma(D^+ \to \pi^0 e^+\nu_e)/\Gamma(D^+ \to \mu\nu_\mu)$ and the corresponding ratio in the D_s sector: $\Gamma(D_s^+ \to (\eta \text{ or } \phi)e^+\nu_e)/\Gamma(D_s^+ \to \mu\nu_\mu)$. These ratios depend purely on hadronic matrix elements, and it is estimated that they can be determined to 4% and so will test amplitudes at the 2% level. This is an exceptionally stringent test of LQCD. Successfully passing the experimental tests will also allow the charm factories to use LQCD calculations of the charm semileptonic form factors to directly measure $|V_{cd}|$ and $|V_{cs}|$, currently known by direct measurements to 7% and 11% [5], with a greatly improved precision of better than 2% for each element. This in turn allows new unitarity tests of the CKM matrix.

Pakhlov Pavel (ITEP, Moscow) of the Belle Collaboration reported on the broad charm physics program of the B factories. In charm searches for new physics the B factory program is complementary to charm factory studies. Alex Bondar (BINP, Novosibirsk) of the Belle collaboration discussed how charm factory data plays a crucial role in enabling the B factories to determine ϕ_3/γ. The angle ϕ_3/γ can be determined from the interference between $b \to c$ and $b \to u$ tree decays to a common final state. There are a variety of methods on the market that require knowledge of the strong interaction phase difference between Cabibbo allowed and doubly Cabibbo suppressed charm hadronic two body decays, or the Dalitz plot model for multi-body decays. The phase differences and Dalitz plot models can be measured at a charm factory by exploiting quantum correlations. These measurements and also studies of CP violation and rare decays were reviewed by David Asner (University of Pittsburgh), Jianping Ma (ITP, CAS) and Ikaros Bigi (University of Notre Dame.)

John Yelton (University of Florida) reviewed the status of our knowledge of charm baryons. The absolute scale of charm baryon decays is not well-established due to a paucity of data at charm baryon threshold. A 1 fb^{-1} run at threshold would allow a measurement of $\mathcal{B}(\Lambda_c \to pK\pi)$ to better than 5% precision. While the workshop participants agreed that this physics is interesting, the Λ_c pair threshold is beyond the range of energies at which BEPCII can operate and a Λ_c run is not part of the CLEO-c base program.

3.2 Charmonium Physics

Ted Barnes (ORNL and University of Tennessee) described how measurements in the charmonium ($c\bar{c}$) sector can shed light on open questions in nonperturbative QCD. Useful information can be obtained from the properties and transitions of $c\bar{c}$ states above the open charm threshold, as well as the more conventional studies of transitions among the bound $c\bar{c}$ states. He emphasized that many features of QCD can be treated as perturbations to the simple non-relativistic potential model picture of the $c\bar{c}$ system. Electromagnetic transitions can reveal otherwise hidden features. For example, a significant width (as much as 100 keV) for $\psi(3770) \to \gamma\chi_{c2}$ would reveal a substantial S-wave admixture in the predominantly D-wave $\psi(3770)$ state. Measured leptonic widths of charmonium are often not in agreement with potential model predictions, so they can provide stringent tests of QCD corrections. Furthermore, measurements of strong decays of charmonium states above the open charm ($D\bar{D}$ threshold) may be able to distinguish between two quite different models of these strong decays.

Roberto Mussa (INFN Torino), Kamal Seth (Northwestern University), and Changzheng Yuan (IHEP) reviewed the status of measurements in the charmonium sector and the questions remaining. Although much has been learned in the 30 years since the discovery of the J/ψ and $\psi(2S)$, there are still many significant open questions. These include discovery of the elusive h_c and measurement of its properties, further exploration of the little-known η_c and η_c' spin singlet states, precise determination of branching fractions to challenge theoretical calculations, observing or confirming hadronic transitions with π^0 or η emission, and measurements of M2 photon transitions interfering with dominant E1 transitions. Many of these transitions are also possible between $c\bar{c}$ states above the open charm threshold and $c\bar{c}$ bound states, but have not been observed, providing fertile ground for new discoveries. One of the mysteries in charmonium physics is the $\rho\pi$ or 12% puzzle observed by the BES collaboration. The ratio of the branching fractions for $\psi(2S)$ decays to hadronic final states to those of J/ψ decays to the same final states should be approximately 12%. Many branching ratios, notably those to $\rho\pi$, differ significantly from this prediction. Investigation of many different final states and cataloging the agreement with and deviations from the 12% rule will be required in order to gain the insight to solve the puzzle.

3.3 Glueball Searches

Colin Morningstar (Carnegie Mellon University) described progress in predicting the masses of glueball states in LQCD. Technical progress on several fronts have contributed to greater understanding of the glueball spectrum and confidence in the results. However, realistic inclusion of light-quark loops in calculations remains to be achieved. The proposed glueball searches in the CLEO-c and BESIII programs provide strong motivation for concerted effort to address the quark-loop problem in order to improve determination of the spectrum of low-lying glueballs.

Jim Napolitano (Rensselaer Polytechnic Institute) described the current status of glueball searches in other experiments and the prospects for the CLEO-c and BESIII programs to resolve the open questions. One feature of previous glueball candidates is the overpopulation of mesons in the mass region below about 2 GeV/c^2. One possible candidate is the $f_0(1500)$ which is seen in $\bar{p}p$ annihilation and pp collisions, but has not been firmly established in $J/\psi \to f_0(1500)$. Therefore, searching for this state and establishing that it is a glueball (if it is) will require a large data sample and sophisticated partial wave analysis to determine its properties in the face of mixing with nearby $q\bar{q}$ states. Double radiative decays, in which an f_0 that is produced via radiative J/ψ decay, itself decays to a photon and a ρ or ϕ are a promising avenue for separating the $q\bar{q}$ and glueball components.

Xiaoyan Shen (IHEP) emphasized the special role that the enormous number of J/ψ events expected at at BESIII/BEPCII can play in the studies of conventional light hadrons, as well as the search for glueballs. With the luminosity of 10^{33} cm^{-2}s^{-1} expected at BEPCII, BESIII can accumulate as many as 10^{10} J/ψ decays per year. Even larger data samples can enable useful searches for new physics in highly suppressed decays such as $J/\psi \to D_s^+ K^-$.

3.4 Tau Physics

Tau physics theory was covered by Antonio Pich (IFIC, Universitat de València), We-Fu Chang (TRIUMF), and Kuang-Ta Chao (Peking University), while tau experimental prospects were discussed by Jean DuBoscq (Cornell University). The tau is the heaviest lepton, and by virtue of its mass the properties of the tau provide crucial input to a number of important measurements in particle physics. Studies of tau leptonic decays probe lepton universality and Lorentz structure. Semi-hadronic decays of taus allow tests of QCD and provide important input to the determination of the strange quark mass and V_{us}. The threshold production of tau pairs at BESIII or CLEO-c would allow a precision determination of the tau mass, a short run using the analysis technique developed by BES [7] would be sufficient to measure the tau mass to 0.1 MeV (a factor of three improvement on the world average [5].) In addition, threshold production offers kinematic advantages in searches for exotic decays, including searches for non-Standard Model physics through forbidden processes such as lepton flavor violation, second class currents and $CP-$violation in allowed decays.

3.5 Measurements of R

The measurement of R was discussed at this workshop in talks by Dong Su (SLAC), Steve Dytman (University of Pittsburgh), and Haming Hu (IHEP). The former discussed the measurement of R using initial state radiation at BaBar and KLOE, while the latter two concentrated on the measurements at CLEO-c and BESIII. Testing the consistency of the Standard Model requires a variety of measurements for which radiative corrections play a crucial role. An important example is the interpretation of the BNL $g_\mu - 2$ experiment [8] [9]. In order to compute physical quantities we must include radiative corrections which renormalize charges, masses, and magnetic moments. Although the electroweak radiative corrections are calculable, the hadronic ones are not. However the lowest-order hadronic radiative corrections can be obtained from $e^+e^- \rightarrow hadrons$ using dispersion relations and unitarity. R is the hadronic cross-section, corrected for initial state radiation and normalized to the lowest order QED cross section of the reaction $e^+e^- \rightarrow \mu^+\mu^-$. In addition to their importance for $g_\mu - 2$, R measurements can be utilized to measure α_s and to test perturbative QCD [10]. R provides information on the value of the running fine structure constant $\alpha(s)$, particularly its magnitude at the Z-pole, which is important for global electroweak fits. The current accuracy is limited by the systematic uncertainty of the low energy R measurements, including the region accessible by BESIII and CLEO-c. High precision measurements of R with an accuracy of 2-5% in the 3-5 GeV energy window, which spans the range achievable by both experiments, will have a large impact on many precision tests of the Standard Model. ISR measurements of R have different systematic uncertainties from the fixed CM measurements, and both techniques may be needed to obtain a complete and precise picture of R in this crucial energy region.

3.6 Contributions from $\bar{p}p$ Annihilation

Klaus Peters (Ruhr Universität, Bochum) described the largely complementary contributions that experiments with the $\overline{\mathsf{P}}\mathsf{ANDA}$ detector could make to the physics program discussed in the workshop. The $\bar{p}p$ initial state can be a copious source of charmonium states, glueballs, and hybrids. Using $\bar{p}p$ formation, precision measurements of masses, widths, and branching fractions of charmonium states are possible. High statistics creation and detection of charmed hybrids with masses in the 3–5 GeV/c^2 region is possible, and the $\overline{\mathsf{P}}\mathsf{ANDA}$ detector will provide the data required for sophisticated spin-parity analyses of the decay products. High-mass glueballs with exotic quantum numbers (such as the $J^{PC} = 2^{+-}$ glueball predicted at a mass of 4.3 GeV/c^2) are also accessible in the experiment.

4 Summary

David Cassel (Cornell University and a CLEO Co-Spokesperson) reviewed the essential details of the thirty three previous talks ta the workshop in his summary talk. He concluded that the combination of LQCD with CLEO-c and BESIII data is the missing piece in the puzzle of the origin of CP violation and quark mixing. LQCD and CLEO-c/BESIII have the potential to enable the particle physics community to draw back the curtain of hadronic uncertainty that has blocked the view for 40 years, and see clearly through the heavy quark window to the new physics that lies beyond the SM. The possibility of observing charm meson mixing, CP violation and rare decays, and glueballs and exotica add a discovery element to the program.

The consensus of the participants was that the workshop was an educational and very valuable experience. It is clear that experiments in the charm threshold region can address many critical physics issues that will have broad impact on the international elementary particle physics program.

Acknowledgments

As representatives of visitors from other countries, D.G.C. and I.P.J.S. wish to point out that the workshop was superbly organized by our very hospitable and gracious Chinese hosts, and we are delighted to express our appreciation for the outstanding hospitality. Travel funds for most of the participants from other countries were provided by a special grant from the National Science Foundation. Further support for the authors of this summary and for the workshop was provided by the Chinese Academy of Sciences, the Chinese Center for Advanced Study, the National Science Foundation, and the U.S. Department Of Energy.

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The CLEO-c Detector

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Abstract: The CLEO-c detector, built on the foundation of CLEO's third generation detector, CLEO III is described. It is the marriage of quality tracking and precision electromagnetic calorimetry with full spectrum particle identification in a single detector. Its inner tracking, trigger and data acquisition system have been adapted to the Charm Physics regime. It is a state of the art detector, understood at a precision level, now taking data at the $\psi(3770)$.

1 Introduction

Both BES and CLEO have a great tradition in the Physics of Heavy Quarks. Both groups have been the beneficiaries of the tremendous new opportunities of unprecedented high luminosity in the charm resonance region from their accelerator partners making it now possible to reach new physics previously inaccessible. This is a start of a new era. This new era will place new demands on each of their detectors.

One of the most important advances in modern detectors for heavy quark physics, crucial to both experiments, is the marriage of quality tracking and precision electromagnetic calorimetry in a single detector. New high luminosities will transform past measurements into precision, high statistics experiments limited by systematics. Detectors will need hermeticity to improve efficiency, reduce feed-down backgrounds, and reduce extrapolations and model dependencies. Full range particle identification will be needed to keep fake and combinatorial backgrounds small. Low mass detectors and supports are needed to preserve precious resolution and to keep acceptances simple and smooth. Luminosity will also provide increased sensitivity to rare decays. Here hermeticity and particle identification can be crucial to getting a signal out of the background. In this generation, the detector and the accelerator merge into each other and their designs must be fully integrated to provide the greatest opportunity for luminosity and to protect the detector from destructive backgrounds. It is crucial to fully model new detector performance with Monte Carlo simulations of the physics being investigated.

The CLEO-c detector [1] (See Figure 1) is built on the foundation of CLEO's third generation detector, CLEO III.

2 Tracking

As CLEO moves from the realm of Beauty to the world of Charm the momentum spectrum softens and particle multiplicity falls. The reduced multiplicities make tracking easier and triggering harder. The softer momenta mean that multiple scattering and tracks curling up become more important. To address the tracking environment CLEO-c lowered the magnetic field to 1.0 Tesla and exchanged its silicon detector for a new, low mass, inner gas drift chamber, called the ZD [1].

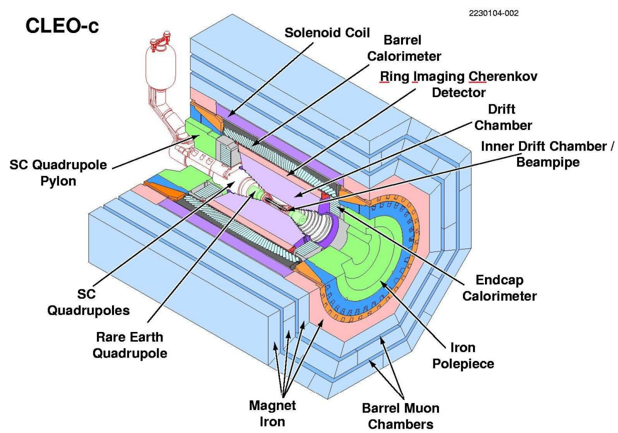

FIGURE 1. The CLEO-c Detector.

The existing CLEO III central drift chamber, DR3 [2], covers about 93 % of the solid angle; it has ∼9800 wires in 16 inner axial layers (∼85 micron average residuals) and 31 outer stereo layers with a very thin inner wall. The 60:40 helium-propane gas mixture and aluminum field wires also help keep scattering to a minimum. Outer cathode pads give a Z measurement at the outer radius. DR3 also provides ionization measurements with dE/dx resolution of 5.7 % at 1 GeV/c, allowing πK separation at low momenta.

The inner drift chamber, designed to complement the existing central drift chamber, has 6 stereo layers to give good Z measurement at small radius. Together, the two drift chambers in a 1.0 Tesla field measure momentum to about 0.33 % up to about 1 GeV/c and to about 0.5 % at 2 GeV/c and Z at the origin to 700-800 microns. The system resolution is similar to silicon in most mass measurements.

3 RICH Detector

The Ring Imaging CHerenkov counter combined with the dE/dx information from the drift chamber provide CLEO with particle identification over the entire momentum range in 83% of its solid angle. The RICH [3] uses ultra violet photons generated as Cherenkov light by high velocity particles passing through lithium fluoride crystal radiators. The "ring images" (the actual images look more like "smiles" because part of the ring is captured in the radiator by total internal reflection) develop in a drift space of very pure nitrogen and the photons are detected in multiwire chambers operating with methane doped with TEA. Some of the radiators have a "sawtooth" surface to prevent total internal reflection of all the light. The RICH uses only 20 cm of radial space and is about 12 % of a radiation length.

CLEO evaluated the RICH performance using $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ events during CLEO III B-physics running. The RICH provided >90 % Kaon efficiency with a fake rate from pions of 1 % or less up to 1.5 GeV/c (less than 2 % at 2 GeV/c, beyond the kinematic limit of most of our Charm running). We measured an 8:1 background suppression in $D^0 \to K^-\pi^+$ from our CLEO III B-physics data.

4 CsI Calorimetry

The Cesium Iodide electromagnetic calorimeter, introduced as part of CLEO II [4], consists of about 7800 16 X_o CsI(Tl) crystals each read out by 4 photodiodes, arranged in a barrel structure with two endcaps. The photodiodes and preamps have worked well; a few percent of the diodes were turned off for noise. Noise per crystal is ∼0.5 MeV incoherent and ∼0.2 MeV coherent. The energy resolution is ∼5 % at 100 MeV and ∼2.5 % at 1 GeV. The corresponding angular resolutions are 10 milliradians and 5 milliradians.

As part of the CLEO III upgrade the endcap crystal arrangement and support were modified. An important part of that upgrade was the great reduction of material in front of the endcaps with the new drift chamber (thinner endplates and less electronics mass). Material in front of the calorimeter causes a loss in efficiency at lower energies. During the rebuilding of the endcaps we found that a mysterious light loss of up to 20 % from some crystals was because the glue joint had broken in those counters. The damaged counters in the endcap were repaired. Light losses in the crystals during operation were completely accounted for by regular calibration.

5 Muon System

No upgrades to the Muon System are planned for CLEO-c. Although the present system cut-off of about 1 GeV/c limits its usefulness in the charm region, it has already proved useful in getting clean J/Ψ signals quickly and in understanding our cosmic ray rejection. It may also prove useful in some Tau and 2-photon analyses.

6 Trigger

The CLEO-c trigger uses field programmable gate arrays to create a pipe-lined trigger with no intrinsic deadtime. The trigger creates tracking and calorimeter crystal primitives which can be combined to form more complex triggers such as 2 tracks and low energy shower. The CLEO trigger is more than 99 % efficient for hadronic events.

For CLEO-c we reduced the trigger thresholds for low and medium energy showers and added several new all-neutrals trigger lines. We also implemented a ”Tile-Sharing” feature, a way of clustering shower energy from a larger number of crystals together to form the shower primitives. This created some additional low-threshold triggers from the noise from the larger number of crystals.

7 Data Acquisition

CLEO-c reads ∼300,000 channels in ∼25 microseconds [1]. The data acquisition hardware uses VME based PowerPC boards (Motorola VxWorks) boards in the crates connected to the Level 3 Trigger and the Event Builder on a 2 CPU Sun UltraSparc III Workstation by 100 MB/s Ethernet.

The challenge is to bring it up to the 250 Hertz performance required for J/Ψ running expected in 2004-5. Originally designed for a trigger rate of 1000 Hertz and a bandwidth of 4 MB/s, we have upgraded one Workstation and parts of the software. It has been tested to 500 Hz and 6 MB/s with a couple more upgrades planned this spring.

8 Summary

New era of high luminosity makes new demands on the detector. CLEO has met this challenge by evolving the CLEO III detector. CLEO started with a foundation of high resolution tracking, precision electromagnetic calorimetry, and particle identification over the full momentum range in a nearly hermetic detector. Changing the inner tracker and the magnetic field, adding new trigger capabilities, and upgrading the data acquisition system were the path to making it the CLEO-c Detector.

The CLEO-c Detector is state of the art, understood at a precision level, and now taking data in the charm region.

Acknowledgments

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CESR-c

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Abstract: CESR-c is a single ring, symmetric energy collider, that operates with center of mass energy just above the charm threshold. Superconducting wigglers are employed to increase the radiation damping rate and horizontal emittance. At beam energies of 1.89 GeV we measure a peak luminosity of $6 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and a daily integrated luminosity of about $3.1\mathrm{pb}^{-1}$.

1 Introduction

In the summer of 2001, the energy reach of CESR was extended with the upgrade of final focus. The 1.5 m long vertically focusing quadrupole was replaced with a superconducting doublet. The new, Phase III interaction region, enabled operation of the storage ring over the beam energy range of 1.5 GeV to 5.6 GeV. In order to maintain a high radiation damping rate and horizontal emittance in low energy operation, 12, 1.3 m long, high field superconducting wigglers were designed, manufactured, tested and installed. Beam based measurements indicate that the damping rate, emittance, energy spread, and multibunch instability thresholds in the now wiggler dominated storage ring are consistent with theoretical expectations. Measured wiggler field nonlinearities are in good agreement with our model. At beam energies of 1.89 GeV we have achieved a peak luminosity of $6 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ on the ψ_{2S} resonance with 70 mA per beam.

2 CESR Phase III Interaction Region

CESR operates with trains of bunches spaced 14 ns apart. Beams collide with a small horizontal crossing angle ($\theta \sim \pm 3$mrad). The trajectories of the counterrotating beams are separated horizontally at the parasitic crossing points. The electrons and positrons share a common vacuum chamber and the crossing angle and separated orbits are generated by 4 horizontal electrostatic separators. The closed orbits of the electrons and positrons are indicated in Fig. 1. The phase III interaction region was originally conceived as an upgrade for operation at 5.3GeV beam energy[1]. Our goal was to reduce β_v at the interaction point, and also to reduce the vertical β-function at the parasitic crossing point nearest the IP, (at 2.1m) so that bunch current would not be limited by the associated long range beam beam interaction. Both goals are achieved by placing strong final focus quadrupoles very near to the IP.

The final focus is a hybrid of permanent magnet and superconducting magnet quadrupoles. The placement of the final focus quadrupoles is indicated in Fig. 2. The Neodymium Iron Boron vertically focusing permanent magnet is 18.6cm long with gradient of 31.193 T/m. Its near end is 42.9 cm from the interaction point. A pair of 66cm long, vertically and horizontally focusing superconducting quads that share a common cryostat begin 84cm, and 1.75 m from the IP respectively. The 3.51 m long experimental solenoid is centered at the

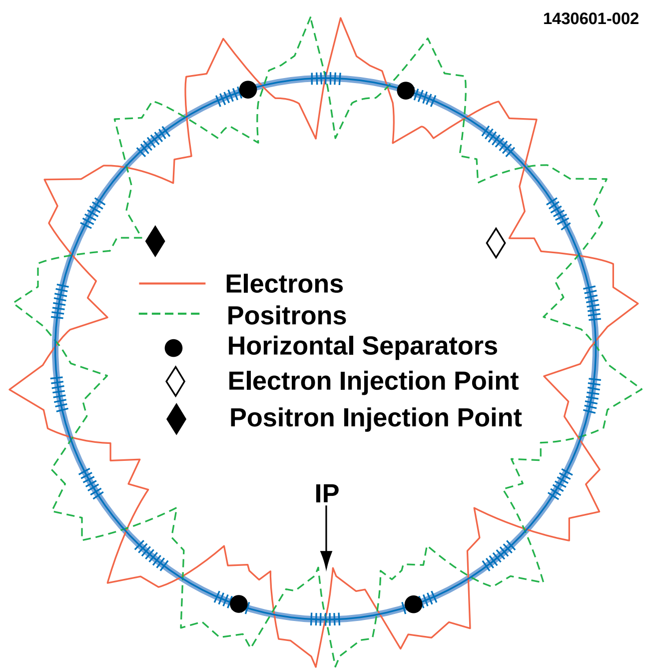

FIGURE 1. Electron and positron closed orbits compatible with nine 5-bunch trains in each beam. At the crossing point diametrically opposite the IP, beams are separated by a half wave electrostatic vertical bump.

interaction point. There are skew quad windings superimposed on the main windings of the superconducting quads. The quadrupole package is rotated 4.5° about the beam axis to compensate the transverse coupling introduced by the experimental solenoid. The skew quads are used to trim the coupling correction.

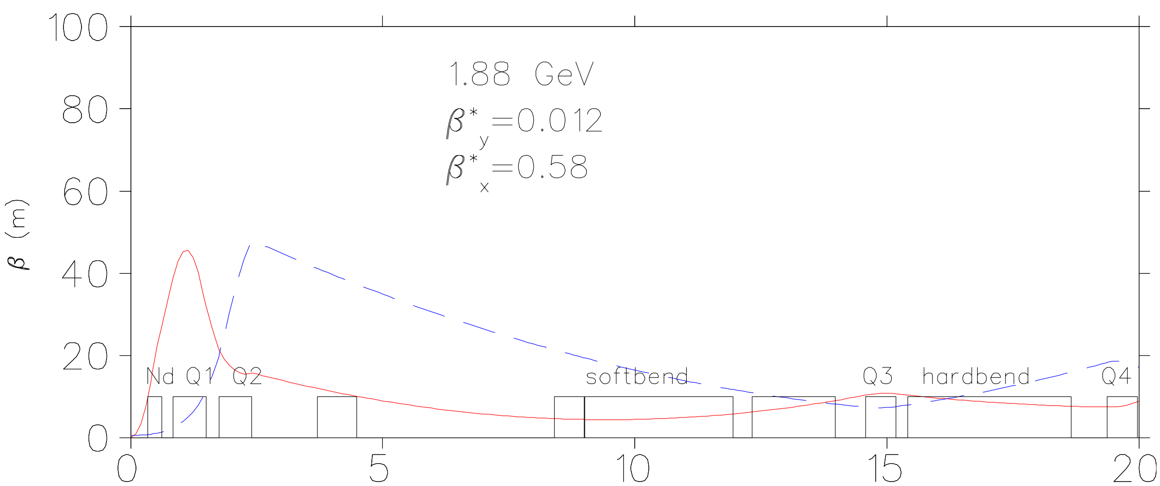

FIGURE 2. CESR-c interaction region. The scale along the horizontal axis is meters

3 Energy Dependence

The radiation damping time of a circulating electron beam in the CESR collider is about 25 ms at 5.3GeV and the energy spread is about 0.06%. The integer part of the horizontal tune is dictated by the requirement that nine equally spaced 5 bunch trains of counterrotating electrons and positrons be horizontally separated at the 89 parasitic crossing points as shown in Fig. 1. The corresponding horizontal emittance at 5.3GeV is about 0.2 mm-mrad.

The radiation damping time is proportional to the time to radiate away all of the energy in the beam, $\tau \sim E_{beam}/P$ where P is the average synchrotron radiated power. The synchrotron radiation power $P_{synch} \sim E^2B^2$ and in a machine with fixed bending radius, ρ, $P_{synch} \sim E^4/\rho$. Then $1/\tau \sim P/E \sim E^3$. At a beam energy of 1.89 GeV (ψ''), the damping time in CESR is increased to 500 ms. The longer damping time implies less tolerance to beam-beam forces and a reduction in the beam-beam limiting tune shift and current. There is a similar reduction in tolerance to the long range beam-beam effect at the parasitic crossings of the beams. and multibunch instability thresholds decrease. The injection repetition rate also scales with damping rate.

Beam emittance scales as the square of the beam energy in the fixed bend machine. The luminosity

$$L \sim \frac{I_B^2}{\sigma_x\sigma_y} = \frac{I_B^2}{(\epsilon_x\epsilon_y\beta_x\beta_y)^{\frac{1}{2}}}$$

where $\sigma_{(x/y)} = \sqrt{\beta_{(x/y)}\epsilon_{(x/y)}}$. We assume that the source of vertical emittance is coupling from the horizontal so we write $\epsilon_y = k\epsilon_x$. And we know that the horizontal beam-beam tune shift scales as $\xi_h \sim I_B/\epsilon_x$. Then the luminosity can be written in terms of horizontal tune shift parameter ξ_h which is a fundamental limit, and the emittance,

$$L \sim \frac{\epsilon_x(\xi_h)^2}{(k\beta_x\beta_y)^{\frac{1}{2}}}$$

Evidently, the beam-beam limiting current and the luminosity scale linearly with horizontal emittance.

Insofar as the emittance scales as the square of the beam energy, if we simply ramp CESR beam energy from 5.3GeV to 1.9 GeV the low energy emittance will shrink to $\sim$ 15% of the high energy value.

4 Damping and Emittance Wigglers

We have installed 12, 1.3 m long superconducting wigglers in CESR-c to increase the radiation damping rate and control horizontal emittance. The 8 pole wigglers have a long (40cm) period, to minimize the inherent vertical cubic nonlinearity. The width of the poles is chosen so that the field is uniform over a full horizontal aperture of 9cm.

Operating at a peak field of 2.1 T, CESR is a wiggler dominated storage ring. More than 90% of the synchrotron radiation emitted over the 768 m circumference of the machine comes from the 15.6 m length of wigglers. (The maximum field in the bending magnets is only 0.2 T)

In a wiggler dominated ring, beam emittance, energy spread and damping rate depend only on strength and total length of wiggler, and are very nearly independent of the configuration of the guide field magnets. The dependence on wiggler parameters is summarized as follows:

$$\begin{aligned}
\frac{1}{\tau} &\sim B_w^2 L_w^2 \\
\epsilon_x &\sim B_w L_w \\
\frac{\sigma_E}{E} &\sim \sqrt{B_w}
\end{aligned}$$

The 15.6 m of wiggler with $B_w = 2.1$T at beam energy of 1.9 GeV, yields a radiation damping time of 50 ms, emittance $\epsilon_x \sim 150$nm, and a fractional energy spread $\sigma_E/E \sim 8 \times 10^{-4}$.

5 Optical Effects of Wigglers

The integrated magnetic field along a particle trajectory in the midplane of the ideal wiggler is zero. An ideal wiggler has infinitely wide poles so that there is no dependence of magnetic field on horizontal displacement. But even in the ideal wiggler, vertical and longitudinal magnetic fields vary with vertical displacement. As the trajectory oscillates back and forth in the horizontal plane, the interaction with the longitudinal field component gives a vertical kick to the beam. If the vertical component of magnetic field varies sinusoidally with longitudinal position, then the longitudinal field is given by

$$B_s \sim -B_0 \sinh k_z y \sin k_z z \tag{1}$$

where B_0 is the peak vertical field, and $k_z = 2\pi/\lambda_z$ where λ_z is the wiggler period. The horizontal angle of the beam is of order

$$\theta \sim \frac{ceB_0}{E_0}\frac{\lambda_w}{2\pi}$$

and the vertical kick is

$$\Delta y' \sim \theta B_s \sim \frac{B_0^2 L}{2(E_0/ce)^2}\left(y + \frac{2}{3}\left(\frac{2\pi}{\lambda}\right)^2 y^3 + ...\right)$$

where we have expanded $B_s(y)$ to order 3. The term linear in y corresponds to vertical focusing and depends only on the length and peak field of the wiggler. The wiggler focusing ($\Delta Q_y \sim 0.1$/wiggler) is readily compensated in the CESR lattice by adjustment of nearby quadrupoles. The cubic term gives an amplitude dependent focusing and scales inversely with the square of the wiggler period. In order to minimize the amplitude dependent tune shift the period of the CESR-c wiggler is relatively long at 40cm.

Finally, the width of the poles is finite, and there is a nonuniformity of the fields in the horizontal midplane. A 3 dimensional table of wiggler field values is computed based on the detailed geometry of iron and conductor, using a finite element code. Bench measurements of the wiggler fields and beam based measurements[2], (dependence of horizontal and vertical tune on displacement) are in good agreement with the field model[3]. The sextupole component of the wigglers, associated with the finite width poles, is compensated in the ring sextupole distribution.

6 Measurements of Lattice Characteristics

The installation of 12 superconducting damping wigglers was completed in the spring of 2004. With the wigglers operating at a field of 2.1 T we stored beam and measured and corrected betatron phase. Our optical model of the wiggler is consistent with beam based measurements.

We observe the anticipated decrease in radiation damping time from 500 ms to 50 ms and a corresponding 10-fold increase in injection rate in the 12 wiggler machine. The feedback off multibunch instability threshold is increased to over 35 mA from less that 8 mA total beam current.

7 CESR-c parameters

The CESR-c lattice parameters are summarized in Table 1. Typical of electron-positron colliders, the horizontal tune is just above the half integer. Because of the relatively large energy spread, a high accelerating voltage is required to ensure that the bunch length is no greater than β_v^*. The high synchrotron tune is a further consequence of the large energy spread.

TABLE 1. Lattice parameters

β_v^*[mm]	12
β_h^*[m]	0.56
Crossing angle[mrad]	3.8
Q_x	9.59
Q_y	10.52
Q_s	0.089
ϵ_x[mm-mrad]	0.14
Bunch length[mm]	12
σ_E/E	8.4×10^{-4}

The permanent magnet vertically focusing quadrupole is very near to the interaction point and the peak values of β-function in the IR quads is modest (< 41m). The natural chromaticities are $Q'_x = -15.3$, $Q'_y = -23.6$.

Arc quadrupoles and sextupoles are all independently powered in CESR affording considerable optical flexibility. The linear optics are designed to minimize the long range interaction of counterrotating bunches at the parasitic crossing points, as well as to achieve the parameters summarized in the table. The sextupole distribution is chosen to minimize:

1. Energy dependence of β-function throughout the arcs
2. Amplitude dependence of β-function and tune
3. Mirror symmetry of β, and η for electrons and positrons (CESR has approximate mirror symmetry about the diameter through the IP. The pretzel is antisymmetric and β-functions for are mirror symmetric only by design of the sextupole distribution.)

and to establish near unity chromaticity.

8 CESR-c solenoid compensation

The transverse coupling introduced by the CLEO 1.0 T experimental solenoid is compensated by three antisymmetric pairs of skew elements. There are skew quadrupole magnets superimposed on both the vertically (Q1) and horizontally (Q2) focusing superconducting IR quadrupoles, and there is a third skew quadrupole about 9 m from the IP and adjacent to the first arc bending magnet, (soft bend). See Fig. 2. The permanent magnet (Nd) is at a fixed rotation of 4.5° about its axis. The skew quadrupole values are adjusted so that three of the four coupling matrix elements at the interaction point are zero (c_{11}, c_{12} and c_{22}) and so that the IR insert is block diagonal. Beam based measurement of relative phase and amplitude of coupling at each of the 100 beam position monitors in CESR provides for fine tuning of the coupling correction.

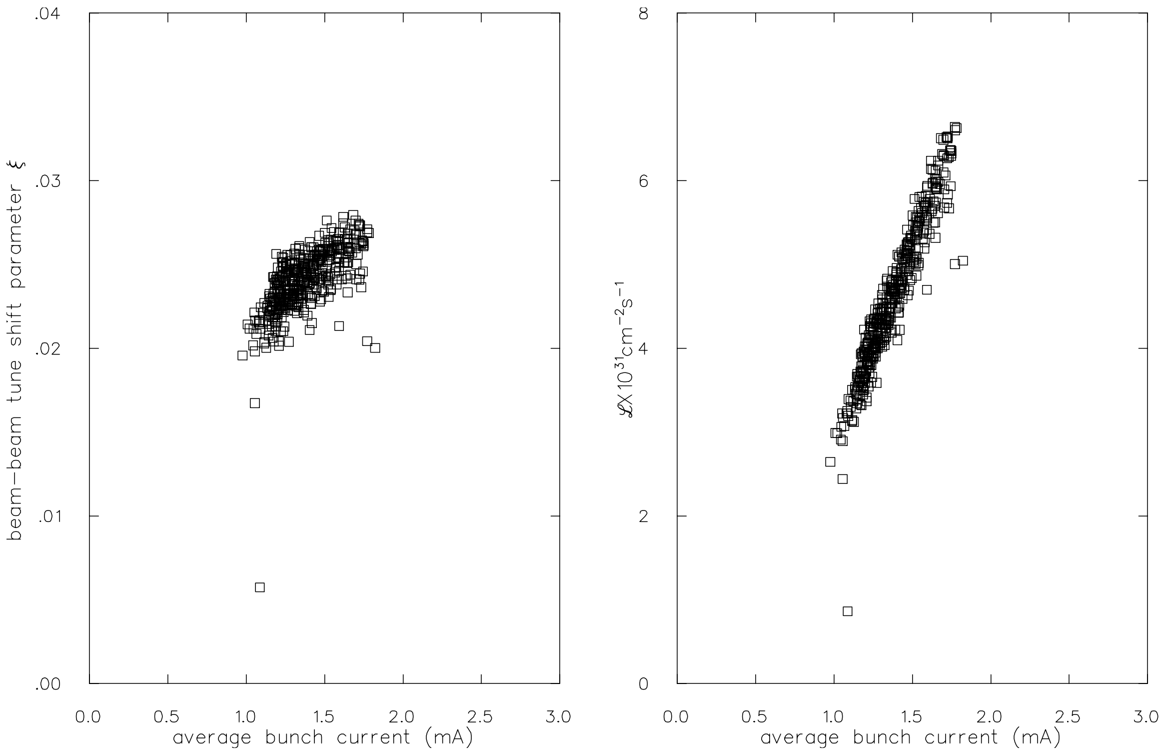

FIGURE 3. Dependence of luminosity and tune shift parameter on bunch current. Luminosity and tune shift are measured once/minute over a 24 hour period.

9 Beam beam performance

Our best performance is in a configuration of 8 trains of bunches with 5 bunches/train. The empty ninth train serves as an ion clearing gap. Dependence of luminosity and beam-beam tuneshift parameter on bunch current is shown in Fig. 3. The measured tuneshift parameter is less than 0.03. Our design goal is 0.04. The average bunch current is limited to about 1.9 mA, again well short of the design goal of 4 mA/bunch. We have circulated over 4 mA/bunch in each of 45 bunches in a single beam. The two beam bunch current is limited by the beam

beam interaction at the interaction point and at the 79 parasitic crossing points associated with the pretzel separation scheme.

10 Modeling and Simulation

We have developed a sophisticated model of the CESR-c guide field and that model is the basis of extensive simulation. The model includes all of the nonlinear elements in the machine. The damping wigglers are represented by a third order map[4]. The parasitic beam beam kicks are modeled as 2-dimensional gaussian distributions. Radiation damping and excitation is treated locally, so that dynamics that may arise from the discrete nature of the synchrotron radiation pattern in CESR-c are accurately modeled. In the interaction region quadrupoles, the guide field is a superposition of tilted quadruple, skew quadrupole and solenoidal fields.

We compute luminosity with a self-consistent weak-strong beam-beam simulation [5]. There is good agreement between calculated and measured luminosity as shown in Fig. 4 In particular, the low beam beam tune shift limit that we measure is reproduced by the simulation.

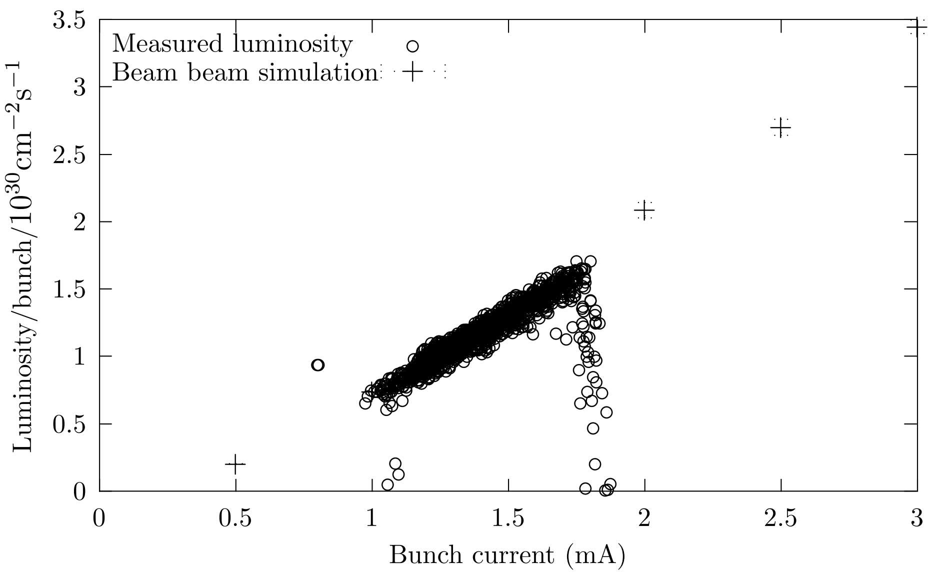

FIGURE 4. The luminosity is measured once per minute over the course of a 24 hour period. The luminosity calculated by simulation at 1 and 1.5 mA are hidden by the measured data.

We have determined that the vertical emittance is diluted by the relatively large energy spread in the beam and the chromaticity of the solenoid compensation optics. In simulations in which the field of the CLEO experimental solenoid, and the tilts of the IR quads are set to zero, the beam beam tune shift is increased by in excess of 50%. We have further determined, that if a compensating solenoid is used in conjunction with the skew quadrupole trims to compensate the coupling of the CLEO solenoid, that the energy dependence of the coupling correction is significantly reduced and, at least in simulation, the higher specific luminosity is realized. The computed luminosity in optics with; 1 T CLEO solenoid and compensation with skew quads, 0 T CLEO solenoid and no skew quads, and 1 T CLEO solenoid and compensating solenoids, appears in Fig. 5. The effect of the chromaticity of the solenoid compensation on specific luminosity is most evident at low current. Note that at 1 mA/bunch, the specific luminosity, and therefore the vertical tune shift parameter, is doubled if the solenoid field is set to zero. Half of the lost tune shift is recovered if a compensating solenoid is incorporated. We are studying the possibility of building compensating solenoids for CESR-c.

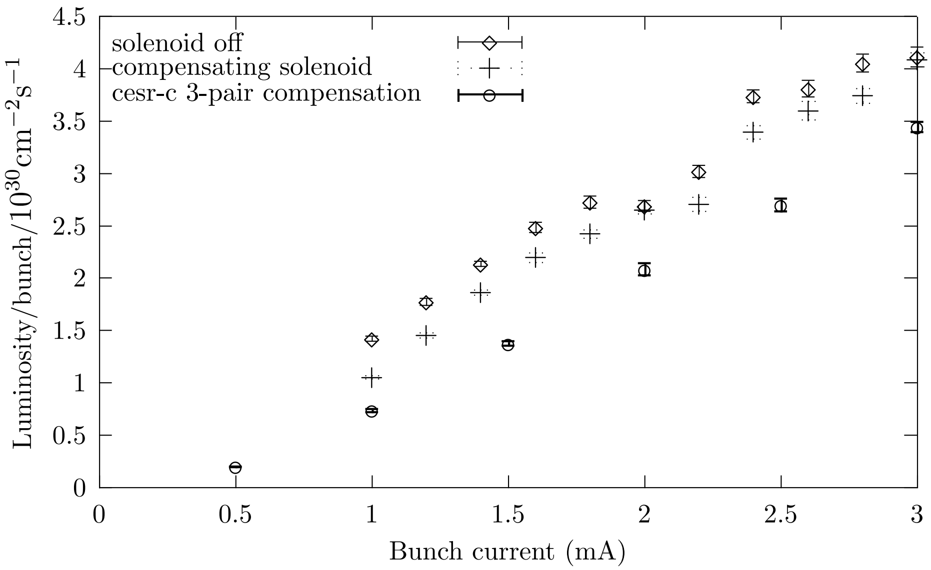

FIGURE 5. Current dependence of the luminosity for interaction region optics with; (a) CLEO solenoid off, (b) compensating solenoid, and (c) cesr-c 3 pair compensation.

11 Conclusions

CESR-c has begun operation with the installation of 12 superconducting damping wigglers at 1.89 GeV beam energy. With the wigglers the radiation damping time is reduced by a factor of 10. The optical effects of the wigglers, both linear and nonlinear are well understood and beam based measurements are consistent with our computer model. The 20/s damping rate permits 60 Hz injection and the anticipated increase in the single beam instability thresholds. We have achieved a peak luminosity of $\sim 6 \times 10^{31}\text{cm}^{-2}\text{s}^{-1}$ with 8 5-bunch trains in each beam. Single bunch current is limited by the beam beam and parasitic beam-beam interactions. The beam beam tune shift parameter is limited by the energy dependence of the solenoid compensation along with the relatively large energy spread generated by the wigglers.

Acknowledgments

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Status of BEPCII/BESIII

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1 The milestones of the project approvals

The project went through three major reviews the government required for its final approval: the project proposal, the feasibility study, the engineer design. The Chinese State Leading Group of the Science, Tech. and Education agreed to upgrade plan of BEPC to BEPCII in July 2000 with a single ring design which was estimated to cost 400 M RMB (1US$ = 8.3 RMB). And Institute of High energy Physics (IHEP) started the design and R&D work. The project was upgraded to a double ring design to compete with CESR-c in 2001, and negotiated on a funding increasing to 640 M RMB. In March of 2002, Chinese Academy of Sciences(CAS) reviewed the BEPCII proposal, and in June of 2002, Chinese Government agreed in principle to provide 540 M RMB to BEPCII. The rest 100 M RMB will be the contribution from CAS and International collaboration. In Sept. of 2002, the State Planning Committee(SPC) reviewed the BEPCII proposal, The State Council meeting approved the BEPCII proposal on Feb. 10, 2003. CAS reviewed BEPCII feasibility study report in March 2003. In June of 2003, State Development and Reform Committee(SDRC, formal SPC) reviewed Feasibility Study Report, and the State Council meeting approved the BEPCII Feasibility Study Report on Sept. 26, 2003. The SDRC agreed to allocate 100M RMB for BEPCII in 2003. In Nov of 2003, CAS reviewed the Preliminary Design Report of BEPCII project, and CAS gave the green light for construction on Dec. 30, 2003, and 100 M RMB is delivered. The project is approved to be finished in 5 years with a budget of 640 M RMB.

2 The Design of BEPCII and its Status

BEPCII is to be installed in the current tunnel. Its beam energy is designed to be in the energy range of 1 to 2.1 GeV, and it is optimized at the beam energy of 1.89 GeV with a luminosity of 10^{33} cm^{-2}s^{-1}. The linac needs to be upgraded to increase its positron inject rate to 50 mA per minute, its highest inject energy will be 1.89 GeV for top off injection. The machine will still be used for synchrotron radiation facility with its energy of 2.5 GeV and beam current of 250 mA. To achieve the goal of reaching the luminosity of 10^{33} cm^{-2}s^{-1}, the main measures are to increase the total current in each ring by installing multi-beam bunches, and to reduce the beam size by micro-beta technique. The main machine parameters are listed in Table 1. The main systems: linac upgrade; RF system; Injection system; Magnet system; Power supply system; Vacuum system; Beam diagnosis; Interaction region have been worked on, their design are more or less final. For example, RF cavity will be built in Japan, its structure is similar to the cavity used at KEK. And the super-conducting micro-beta quadruple magnets will be built at Brookhaven. Contracts for a lot of the hardware are already signed.

The designed luminosity at 1.89 GeV is $10^{33} cm^{-2}s^{-1}$, and at 1.5 GeV and 2.1 GeV, the luminosity will be $6 \times 10^{32} cm^{-2}s^{-1}$. So the expected yield each calendar year will be 10^{10}

TABLE 1. This Main Parameters of BEPCII

Energy E(GeV)	1.89	Energy spread $(10^{-4})\sigma_e$	5.16
Circumference C(m)	237.53	Emittance ϵ_x/ϵ_y(nm)	144/2.2
Harmonic number h	396	Momentum compact α_p	0.0235
RF frequency f_{rf}(MHz)	499.8	β_x^*/β_y^*(m)	1/0.015
RF voltage V_{rf}(MV)	1.5	Tunes $\nu_x/\nu_y/\nu_z$	6.57/7.6/0.034
Energy loss/turn U_0(KeV)	121	Chromaticities ν'_x/ν'_y	-11.9/-25.4
Damping time $\tau_x/\tau_y/\tau_z$(ms)	25/25/12.5	Natural bunch length σ_{z0}(cm)	1.3
Total current/beam I(A)	0.91	Crossing angle ϕ(mrad)	± 11
SR power P(kW)	110	Piwinski angle Φ(rad)	0.435
Bunch number N_b	93	Bunch spacing S_b(m)	2.4
Bunch current I_b(mA)	9.8	Beam-beam parameter ξ_x/ξ_y	0.04/0.04
Particle number N_t	4.5×10^{12}	Luminosity$(10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1})L_0$	1.0

J/ψ events, or 2×10^9 $\psi(2S)$ events, or running on $\psi(3770)$ to produce 2.3×10^7 D^0 plus 1.7×10^7 $D^\pm$ events.

The detector will be upgraded from BESII to BESIII. The main features of BESIII are as follows: From inside out, there is a main drift chamber(MDC), which adopts a small-cell structure with a full cell width of about 16 mm, it uses Al field wires and He based gas to reduce the material. In a magnetic field of 1 tesla, the momentum resolution for 1 GeV charged particle is about 0.5%. The DE/dx resolution from 43 layers of sense wires will be about 6%. Outside of MDC, there is a time of flight (TOF) arrays composed of 88 scintillator pieces at barrel region and 48 pieces at each side of the endcap, the barrel will have one or two layers of counters, and in the endcap, the TOF will have one layer. The expected intrinsic time resolution of the TOF system will be about 80 ps for barrel and 90 ps for endcap. Outside of TOF, an EM calorimeter composed of about 6K CsI crystals with an energy resolution of 2.5% for 1 GeV photons, taking into account the effect of dead material inside of calorimeter. Outside of EM calorimeter there is a super-conducting magnet with a central field of 1 tesla. Further out, there is a sandwich structure with alternative muon chambers and the magnet yoke steel layers. The muon detector is RPC chamber with a readout strip width of about 4 cm. Because the large cross-section at J/ψ, the expected maximum event rate for DAQ system will be about 4 KHz, which needs to be dealt with by pipe-line readout electronics, and a complicated trigger system with a latency of 6.4 μ s to read the events out. The maximum event rate on tape will be about 3 KHz after online event filter. Physics simulations were performed to study the expected physics reaches for D, $J/\psi, \psi(2S)$ studies. Some of the study can be found in other sections of this report.

Right now, the design optimization of machine and detector is completed, R&D works are in good progress, Many prototypes were done. Most of important decisions were made already, and the preliminary design report finished. Bidding of most of key systems and devices were done. The project management system has been improving, to insure the project moves forward as in the CPM plan, to control the project budget and to build up a quality control system.

A few items are on critical path for BESIII construction: The schedule for mechanical support and yoke; the mechanical support of Barrel EMC; crystal production; the superconducting Magnet; offline software. Backgrounds will be a serious issue when data taking starts; to achieve the design goal for the major detector components are very challenging.

The project is expected to finish in 5 years with a budget of 640 M RMB. So it will become operational at a time when CLEO-c will finish its scheduled physics programs, to continue the physics study in this energy region. BES collaboration welcomes more groups to join BESIII project.

The BESIII Detector

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Since its completion in 1989, the Beijing electron-positron collider (BEPC) and its detector, the Beijing Spectrometer (BES), have been in operation successfully for 13 years. There has been an upgrade in 1996 for both the machine (still called BEPC afterwards) and the detector (called BESII afterwards), leading to a significant improvement of performance. A variety of important physics results from J/ψ, ψ', τ, D, and D_s data were obtained and more than 50 papers were published on world-class journals.

The rich physics program of the BES experiment includes light hadron spectroscopy, charmonium spectrum, charm meson decay properties, QCD, tau physics, rare decays, search of glueball and other non-pure quark states, etc. These results played an important role towards our understanding of the Standard Model, and they are unique at the boundary between the perturbative and non-perturbative regime of QCD.

BEPCII is a high luminosity, multi-bunch collider, which requires a comparable high quality detector with the modern detector technology. On the one hand, the existing BESII detector is facing severe aging problems, and its electronics and data acquisition system do not support the multi-bunch mode; on the other hand, a factor of 100 increases of statistics requires a corresponding reduction of systematic errors. Therefore a modern detector, BESIII, has to be built to meet the following requirements:

- Very good photon energy resolution, good angle resolution for photon measurement. Crystal calorimeter, such as CsI, is one of the best choice.
- Accurate 4-momenta measurement of low momentum charged particles. A drift chamber based on He gas is one of the best choice.
- Good hadron identification capabilities. Both Cherenkov detector and Time-of-Flight system can meet our requirements.
- A modern data acquisition system and the front-end electronics system based on the pipeline technique, which can accommodate multi-bunch mode.

The choice of the detector components is based on physics requirements, existing experience in the collaboration, budgetary and schedule constraints, etc. Figure 1 shows the BESIII detector, which consists of the following components:

- A He gas based drift chamber with a single wire resolution better than 130 μm;
- A CsI calorimeter with an energy resolution better than 2.5% @ 1 GeV;
- A Time-of-Flight system with a time resolution better than 100 ps;
- A super-conducting solenoid magnet with a field of 1.0 Tesla;
- A RPC based muon chamber system.

Table 1 shows the comparison of the BESII and BESIII detector.

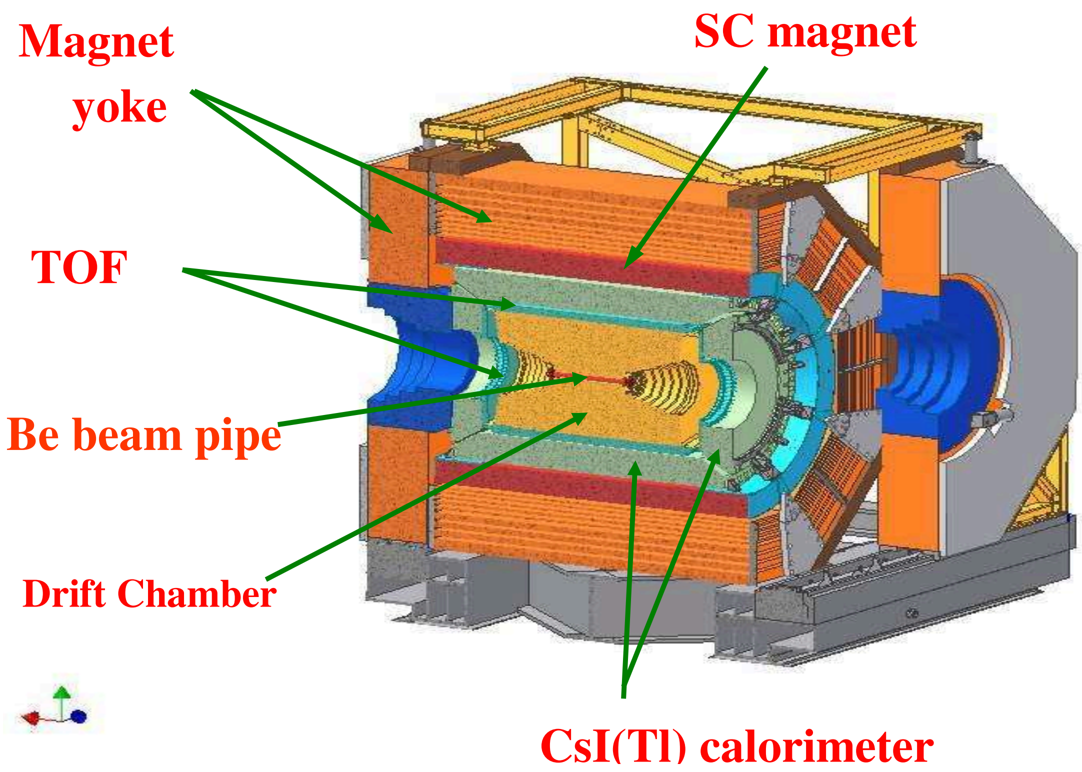

FIGURE 1. The BESIII detector.

TABLE 1. Detector parameters comparison.

Sub-system	BESIII	BESII
MDC	$\sigma_{xy} = 130\ \mu$m	250 μm
	$\Delta P/P = 0.5\%$ @ 1 GeV SC magnet	2.4% @ 1 GeV
	$\sigma_{dE/dx} = (6-7)\%$	8.5%
EM Calorimeter	$\Delta E/E = 2.5\%$ @ 1 GeV $\sigma_z = 0.6$ cm @ 1 GeV	20% @ 1 GeV 3 cm @ 1 GeV
TOF Detector	$\sigma_T =$ 100 ps barrel 110 ps endcap	180 ps barrel 350 ps endcap
μ Counters	9 layers	3 layers
Magnet	1.0 Tesla	0.4 Tesla

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A Case for Continuing Studies of Charm Dynamics

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While the discovery of charm quarks was crucial for the evolution as well as acceptance of the Standard Model, charm dynamics is far from a closed chapter. It is full of challenges that should properly be seen as promises. There is a triple and interrelated motivation for further *dedicated* studies [1]:

- They will provide novel insights into the nonperturbative dynamics of QCD and hopefully establish theoretical control over it.
- It will calibrate the theoretical tools for treating B decays.
- Certain charm transitions open a novel window onto New Dynamics.

1 Theoretical Tools

The accuracy of the theoretical description is of essential importance in three items listed above. While we do not have a theory *of* charm – i.e. why charm is the way it is – we do have several theoretical tools *for* charm – i.e. for treating charm dynamics. Its mass scale puts it somewhere between the worlds of bona fide heavy and light flavours. The accumulated evidence is that charm is 'somewhat' heavy as naively expected. Quark models are still a useful tool for training our intuition and diagnosing results from lattice QCD (LQCD), but not reliable enough for final answers. Heavy quark expansions (HQE) based on expansions in powers of $1/m_c$ for describing *inclusive* transitions like lifetimes turn out to work surprisingly well – unlike light cone sum rules for *exclusive* semileptonic decays, which fail. This could be due to the fact that the leading nonperturbative contributions to the former start in order $1/m_c^2$ involving local operators only, while the latter contain $\mathcal{O}(1/m_c)$ terms with *non*local correlators. LQCD is the only existing framework holding out the promise for a truly quantitative treatment of charm *hadrons* that can be improved *systematically* [4]. Hopefully charm will emerge as a firm 'bridge' between the treatment of heavy and light flavours.

2 Lessons on QCD from Open Charm Hadrons

It is no longer adequate to talk about the mass of the charm quark *per se* and identify it with the parameter that appears in a quark *model*. A clean definition that can pass muster by field theory has to be given. For the $\overline{MS}$ mass $\bar{m}_c(m_c)$ one finds 1.19 ± 0.11, 1.30 ± 0.03 and 1.14 ± 0.1 GeV, where the first two values come from different charmonium sum rules and the last one from moments of semileptonic B decays. The fact that these numbers coming from systematically so different observables agree so well is one piece of evidence that charm quarks can be treated as heavy. The other one comes from the lifetimes of charm hadrons. The weak lifetimes of seven $C = 1$ hadrons have been measured; they cover a factor ~ 20

between the longest and shortest lifetimes. While a priori the HQE treatment might be expected to fail even on the semiquantitative level since m_c exceeds typical hadronic scales by merely a moderate amount, it works surprisingly well in describing the lifetime ratios even for baryons, except for $\tau(\Xi_c^+)$ being about 50 % longer than predicted.

Another highly nontrivial HQE prediction is that the full semileptonic widths of charm *baryons* are *far from universal* – unlike for charm *mesons*. The semileptonic branching ratios of baryons thus do not reflect their lifetimes. It would be highly desirable to measure $\mathrm{BR}_{SL}(\Lambda_c)$ and even better $\mathrm{BR}_{SL}(\Xi_c^{0,+})$ – something that can be done only at a tau-charm factory. While $\Gamma_{SL}(D)$ is ill-suited to determine $|V(cs)|$ precisely, it is an interesting challenge to infer $|V(cd)/V(cs)|$ from the shape of inclusive lepton spectra in $D^0/D^+/D_s^+ \to \ell\nu X_{s,d}$.

As far as *exclusive* decays are concerned, theoretical tools exist only for semileptonic [nonleptonic] modes with one [two] hadron[s]/resonance[s] in the final states. Since the amplitudes for $D \to \ell\nu K[\pi]$ etc. depend on $|V(cs)[V(cd)]f_+^{K[\pi]}(q^2)$, there is a dual motivation to analyze them very carefully. One can accept the values of $V(cs)$ and $V(cd)$ inferred from other processes or from three-family unitarity and extract the formfactor, which can then be compared in its normalization as well as q^2 dependence with LQCD results; or one can employ the latter's prediction to infer the size of $V(cs)$ and $V(cd)$. For that purpose the level of accuracy has to be high to make it competitive. The theoretical prediction for the formfactor can of course be cross checked through its q^2 dependence. Yet that require very precise data since the range in q^2 is quite limited. It will be essential to do such an analysis for D^0, D^+ and D_s^+ Cabibbo allowed as well as suppressed modes and find consistent values for $V(cs)$ and $V(cd)$ before they can be accepted.

Measuring $D^+/D_s^+ \to \ell\nu\eta/\eta'$ can give us novel information of the wavefunctions of η and η'; one can also search for glueball candidates G in $D^+/D_s^+ \to \ell\nu G$.

The treatment of two-body nonleptonic decays poses a formidable theoretical challenge. It would make hardly any sense to rely on *pQCD*; the framework of *QCD factorization* should be tried, although it might fail due to its $\mathcal{O}(1/m_c)$ contributions, which could be beyond theoretical control. The pioneering Blok-Shifman analysis based on QCD sum rules should be updated and refined by including $SU(3)_{Fl}$ breaking. A meaningful LQCD analysis has to be fully unquenched. In conclusion: the only tools available at present are quark models; yet their findings have to be taken with quite a rock of salt. One ambitious motivation for such studies is that one wants to harness searches for direct CP violation in these nonleptonic channels as a *probe for new physics* as described later. For a model description of nonleptonic charm decays to claim reliability, it has to succeed on the Cabibbo allowed as well as singly or doubly Cabibbo suppressed levels, including resonant final states with more than one neutral hadron.

Establishing theoretical control over QCD's dynamics will teach us also important lessons about nonperturbative dynamics in general, as is relevant for New Physics models based on technicolour to cite but one example.

3 'Tooling up' for B Studies

Lack of precise values for the branching ratios of charm hadrons is increasingly becoming a bottle neck for analyses of B decays. Yet the connections go further than that. One should note that the *leading nonperturbative* contributions to the *exclusive* modes $B \to \ell\nu D^{(*)}$ are controlled by the scale m_c rather than m_b. As mentioned above extracting $V(cd)/V(cs)$ from different distributions in *inclusive* semileptonic D^0, D^+ and D_s^+ decays can provide us with a test ground for extracting $V(ub)/V(cb)$ from semileptonic B decays.

There is a novel motivation for understanding the spectroscopy of charm hadrons based on three points: (i) Obtaining $\Gamma_{SL}(B)$ accurately from data with cuts and non-universal efficiencies requires a good understanding of the hadronic charm systems in $B \to \ell\nu X_c$. (ii) Extracting $B \to \ell\nu D^{(*)}$ involves estimating the amount of feed-down from higher charm resonances. (iii) The spectroscopy of $C = 1$ resonances has an important impact on the OPE treatment of $B \to \ell\nu X_c$. For there is a set of exact sum rules relating the relevant heavy quark parameters with $B \to \ell\nu D^{*\cdots}$ amplitudes; e.g., $M_B - m_b(\mu) = 2\left(\sum_n \epsilon_n |\tau_{1/2}^{(n)}|^2 + 2\sum_m \epsilon_m |\tau_{1/2}^{(m)}|^2\right)$, where $\tau_{1/2[3/2]}$ is the transition amplitude for $B \to \ell\nu D(s_q = 1/2[3/2])$ with s_q denoting the angular momentum carried by the *light* degrees of freedom inside the charm meson; the sum runs over all resonances n with excitation energy $\epsilon_n \leq \mu$. The exact size of $M_B - m_b$ is of obvious importance, since $\Gamma_{SL}(B) \propto m_b^5$. There were candidates for the expected broad P wave states; yet their mass above 2400 MeV was quite inconsistent with the sum rules constraints, which would have grave consequences for the OPE treatment. In the spring '03 a new twist emerged due to BABAR's discovery of $D_s(2317)$, which is significantly lower in mass than previous quark model predictions. This suggested that its nonstrange counterparts are around the same mass or even somewhat lower consistent with the sum rules constraint.

The lesson here is that we need to understand $C = 1$ spectroscopy beyond the ground states D and D^* really well not only for its intrinsic value, but also as an input for our theoretical description of B decays and on how reliably we can determine $V(cb)$.

4 Searching for New Physics

The basic contention is that charm transitions represent a unique portal allowing a novel access to the flavour problem, where the experimental situation is a priori favourable – except for the leading charm decays being Cabibbo allowed: charm production rates are sizeable; the branching ratios into interesting modes – e.g., CP eigenstates – are large; the decay $D^* \to D\pi$ provides a powerful tool to flavour tag the D meson; there are the two layers of singly and doubly Cabibbo suppressed modes, where New Physics is more likely to surface; final state interactions are certainly virulent, which is good for inducing CP asymmetries, though not for predicting them; the effective weak phase is unusually small in the CKM description. On top of that we should remember that charm is the only *up*-type quark allowing the full range of probes of flavour couplings, including flavour changing neutral currents. For the π^0 decays electromagnetically and – being its own antiparticle – cannot exhibit oscillations. Top quarks on the other hand decay before they hadronize thus preventing $T^0 - \bar{T}^0$ oscillations; observable CP asymmetries are highly reduced due to a lack of coherence.

It has been stated many times that with the 'dull' SM weak phenomenology for charm – slow $D^0 - \bar{D}^0$ oscillations, small CP asymmetries – it allows almost 'zero-background' searches for New Physics. Yet this statement has to be updated carefully since experiments over the last ten years have bounded the oscillation parameters x_D, y_D to fall below very few % and direct CP asymmetries below several %.

4.1 Rare Decays

There are rare decays that would unequivocally signal New Physics, namely (i) $D^0 \to e^\pm\mu^\mp$; (ii) $D \to e^\pm\mu^\mp X$; (iii) D decays into a charged hadron and a *familon*. For the first channel with its clean signatures an upper bound has been established – $\mathrm{BR}(D^0 \to e^\pm\mu^\mp) \leq 8.1\times10^{-6}$ –, and it can be searched for at hadronic colliders; likewise for $D \to e^\pm\mu^\mp X$. No bound has been established yet for $D^\pm \to h^\pm$+*familon* and a tau-charm factory might be competitive here.

Other modes *could* be signals of New Physics – depending on their rates and progress in their theoretical interpretation. These are radiative channels – $D \to \gamma V$, $V = K^*, \rho, \omega, \phi$ – of which the first one has been seen by BELLE with $\mathrm{BR}(D^0 \to \gamma\phi) = (2.6^{+0.70+0.15}_{-0.61-0.17}) \times 10^{-5}$ – consistent with rough SM predictions. The motivation here is two-fold, namely to learn about long distance dynamics – which then can be applied to $B \to \gamma V$ – and to probe for New Physics; for the latter purpose one can calibrate the SM contributions by $D^0 \to \gamma\phi$, $\gamma\bar{K}^{*0}$ which are unlikely to be affected by New Physics.

For the rarest of the rare the SM predicts $\mathrm{BR}(D^0 \to \mu^+\mu^-) \sim 3\times10^{-13}$. This rate can be greatly enhanced by New Physics up to the present bound of $\mathrm{BR}(D^0 \to \mu^+\mu^-) < 4.1\times10^{-6}$, which will presumably be decreased significantly by hadronic collider experiments.

4.2 Oscillations

$D^0 - \bar{D}^0$ oscillations, while representing an ambiguous probe for New Physics, can have a significant impact on extracting the angle ϕ_3/γ from $B^\pm \to DK^\pm$ [2] and form an important ingredient for using CP studies as an unequivocal probe for New Physics. A conservative bound on oscillations can be expressed by $x_D = \Delta m_D/\Gamma_D$, $y_D = \Delta\Gamma_D/(2\Gamma_D) \leq \mathcal{O}(0.01)$. Comparing it with the present bounds [3] – $x_D \leq 0.03$, $y_D = 0.01\pm0.005$ – one sees that the 'hunt has just begun'. A careful OPE analysis yields $x_D|_{SM}$, $y_D|_{SM} \sim \mathcal{O}(10^{-3})$ and makes it unlikely that the theoretical uncertainties can be reduced significantly.

4.3 CP Violation

Several facts make charm decays an intriguing place to search for CP violation due to New Physics: strong phase shifts are in general large as are the branching ratios into relevant modes large; yet within the SM the effective weak phase is highly diluted in charm transitions, namely $\sim \mathcal{O}(\lambda^4)$, and it can arise only in singly Cabibbo suppressed transitions, where one expects them to reach the 0.1 % level; significantly larger value would signal New Physics. *Any* asymmetry in Cabibbo allowed or doubly suppressed channels requires the intervention of New Physics – except for $D^\pm \to K_S\pi^\pm$, where the CP impurity in K_S induces an asymmetry of 3.3×10^{-3}. We also know that the baryon number of the Universe implies New Physics generating CP violation; finally CP asymmetries can be linear in New Physics amplitudes. *Final state distributions like Dalitz plots* offer great opportunities for revealing CP asymmetries as discussed by Asner [3].

CP violation involving $D^0 - \bar{D}^0$ oscillations can be searched for in final states common to D^0 and $\bar{D}^0$ decays like CP eigenstates – $D^0 \to K_S\pi^0$, $K_S\phi$, K^+K^-, $\pi^+\pi^-$ – or doubly Cabibbo suppressed modes – $D^0 \to K^+\pi^-$. The CP asymmetry is controlled by $\sin(\Delta m_D t)\mathrm{Im}\,(q/p)\bar{\rho}(D \to f)$; within the SM both factors are small, namely $\sim \mathcal{O}(10^{-3})$, making such an asymmetry unobservably tiny – unless there is New Physics! One should note that this observable is linear in the quantity x_D rather than quadratic as for CP insensitive quantities. $D^0 - \bar{D}^0$ oscillations, CP violation and New Physics might thus be discovered simultaneously in a transition.

4.4 EPR Correlations

For proper interpretation it is essential to understand whether one has observed direct CP violation or one involving oscillations. The latter's telling time dependence can be probed through EPR correlations: (i) One can compare the observed signal for $e^+e^- \to D^0\bar{D}^0 \to (l^\pm X)_D f_D$ – where the $D^0\bar{D}^0$ pair forms a C *odd* configuration – with $e^+e^- \to D^{*0}\bar{D}^0 \to D^0\bar{D}^0\gamma \to (l^\pm X)_D f_D\gamma$, where it is C *even.* (ii) One searches for $e^+e^- \to D^0\bar{D}^0 \to f_1 f_2$ where $f_{1,2}$ denotes final states with the same CP parity. Here it is the existence of such a reaction that establishes CP violation rather than an asymmetry.

4.5 Benchmarks

For definitive measurements one wants to reach the level at which SM effects are likely to emerge, namely down to x_D, $y_D \sim \mathcal{O}(10^{-3})$, time-*dependent* CP asymmetries in $D^0 \to K_S\phi$, K^+K^-, $\pi^+\pi^-$ $[K^+\pi^-]$ down to 10^{-5} $[10^{-4}]$ and *direct* CP asymmetries in partial widths and Dalitz plots down to 10^{-3}.

5 On a Menu for a τ-Charm Factory

A key advantage of a τ-charm factory is that it allows impressively clean and model-independent analyses. Yet it comes at a price: different measurements often require running at different energies. Central menu items are: (i) $e^+e^- \to \tau^+\tau^-$ *below* $\psi(3770)$ allow the cleanest study of τ decays; (ii) $e^+e^- \to \psi(3770) \to D\bar{D}$ for accurate data on inclusive as well as exclusive D decays; (iii) $e^+e^- \to D^{*0}\bar{D}^0 \to D^0\bar{D}^0\gamma$ to search for intrinsic signals of $D^0 - \bar{D}^0$ oscillations with or without CP violation; (iv) $e^+e^- \to D_s^+D_s^-$ for a comprehensive study of D_s decays; (v) $e^+e^- \to D_1D_2X$ to study higher charm meson resonances; (vi) $e^+e^- \to \Lambda_c\bar{\Lambda}_c$ and (vii) $e^+e^- \to \Xi_c\bar{\Xi}_c$ to reduce our considerable ignorance about charm baryon decays. The program could hardly be called complete without items (i) - (vi).

Considering this rich and challenging menu one needs the highest luminosity possible as well as flexibility – and one has to watch the competition.

6 The 'Pantheon List'

Any *unequivocal* signal for New Physics is a *sure bet* to make HEP's Pantheon list: establishing indirect CP violation or direct CP violation in Cabibbo allowed or doubly suppressed channels are such *sure bets*. *Likely* candidates are the observation of direct CP violation in singly Cabibbo suppressed channels and measuring the decay constants f_D and f_{D_s} within 1-2% accuracy and in full agreement with lattice QCD predictions. Establishing the existence of $D^0 - \bar{D}^0$ oscillations or of glueball or hybrid states would be *on the bubble*: their admission to the Pantheon would depend on the signal and the reliability of its theoretical interpretation. In summary: a dedicated τ-charm physics program has the potential to impact HEP fundamentally.

7 The Big Picture

Powerful theoretical arguments suggest that New Physics around the 1 TeV scale drive the electroweak phase transition. It is the goal of the LHC to uncover and survey this New Physics. The task of the *linear collider* is to provide a more surgical probe. While this New Physics cannot be expected to elucidate the origin of the flavour pattern, flavour transitions can in turn act as sensitive indirect probes distinguishing between variants of New Physics, in particular variants of SUSY. Like the linear collider B factories should be viewed as legitimate daughters of the LHC – as do τ-charm factories, with the latter being quite frugal!

Acknowledgments:

I thank the organizers for creating such a fine workshop that was appealing in several aspects and acknowledge interesting exchanges with D. Asner. This work was supported in part by the NSF under grant number PHY-0087419.

References

1. For a very detailed presentation of my views and a comprehensive list of references to the original literature, see: S. Bianco, F. Fabbri, D. Benson, I.Bigi, hep-ex/0309021, to appear in Rivista di Nuovo Cimento.
2. A. Bondar, talk given at the CLEO-c/BESIII Joint Workshop, Beijing, Jan. 2004.
3. D. Asner, ibidem.
4. S. Hashimoto, ibidem.

Fully Leptonic and Semileptonic Physics at the $\psi(3770)$

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Two measurements where threshold $\psi(3770)$ running has dramatic advantages have particularly important significance: the fully leptonic process $D^+ \to \ell\nu$ and the semileptonic process $D^0 \to \pi^+\ell\nu$. When combined with B^o mixing data and the $B \to \pi^+\ell\nu$ branching fraction, they can dramatically improve information on the two uncertain legs of the unitarity triangle V_{ub} and V_{td}. Validation of the hadronic current factors required to extract these CKM elements would dramatically improve knowledge on ρ and η and make the $\sin 2\beta$ measurements from processes such as $B^0 \to J/\psi K_s$ a much more incisive test of the standard model as shown in Figure 1. Threshold charm production is ideally suited for measurement of $D^+ \to \ell\nu$ branching fraction using the tagging technique. Combining the branching fraction with the known D^+ lifetime produces a measurement of the leptonic width which is in turn proportional to the square of the D^+ decay constant times a CKM matrix element. Because the leptonic decay constant is proportional to the square of the lepton mass, one is essentially limited to the D^+ and D_s^+ decays into $\mu^+\nu$ or $\tau^+\nu$. The relevant CKM matrix elements V_{cs} or V_{cd} are known to $\approx \pm 0.1\%$ and $\approx \pm 1\%$ respectively assuming 3 generation unitarity. Hence a measurement of the leptonic branching fraction basically serves as a measurement of $|f_D|^2$ with a fractional error equal to the fractional error on the tagged event yield. In 3 fb^{-1} of threshold running it is estimated that the leptonic decay fraction can be measured to about 2% precision for the $D^+ \to \mu\nu$ as well as in $D_s^+ \to \mu\nu$ and $D_s^+ \to \tau\nu$ with substantial components of the error due to CKM and/or charm lifetime uncertainties. At present, the oscillation frequency for $B_o \leftrightarrow \bar{B}_o$ mixing serves as the best measurement of V_{td} The oscillation frequency which is proportional $|V_{td}|^2$ is currently known to 1.2 % precision. The major uncertainty in V_{td} is due to the uncertainties in the hadronic matrix element which can be factorized into a bag parameter and the B leptonic decay constant (f_B) which presently carries an estimated 15% error thus dominating the uncertainty in V_{td}. Although f_B carries substantial systematic uncertainties, uncertainties in f_B/f_D are much smaller. Hence a 2% measurement of f_D should substantially reduce the systematic error on the Δm_d band shown in Figure 1.

A similar argument holds for determination of V_{ub}. In principle V_{ub} can be determined from measurements of $\Gamma(B \to \pi\mu\nu)$. However this determination relies on calculation of both the scale and q^2 dependence of form factor ($f_+(q^2)$). The same basic LQCD calculation is required for predicting $f_+(q^2)$ for the process $D^0 \to \pi^-\ell\nu$ decay. In 3 fb^{-1} of threshold running, one should reconstruct $\approx 12,000$ clean, tagged, and reconstructed $D^0 \to \pi^- e^+\nu$ decays that would allow one to measure $\Gamma(B \to \pi\mu\nu)$ to about 1% level rather than the current 25% precision. Studying $D^0 \to \pi^-\ell\nu$ decays at the $\psi(3770)$ provides precision width measurements that do not require previously obtained values of charm absolute branching fractions. The ability to close the neutrino kinematics using beam energy and recoil tagging information, allows one both kinematically distinguish the $D^0 \to \pi^-\ell\nu$ from the much more copious $D^0 \to K^-\ell\nu$ misidentification background as well as providing excellent q^2 resolution. A 4% measurement of the q^2 slope at low q^2 should be possible in a 3 fb^{-1} sample. Hence both the (LQCD) predicted scale and q^2 dependence $f_+(q^2)$ can be incisively tested for the first time. Past data on $D^0 \to \pi^- \ell\nu$ and $D^0 \to K^- \ell\nu$ relied on either a pole dominance or ISGW exponential q^2 model to bridge the gap between the high rate, low q^2 region where the data lies and the high q^2 region where theoretical systematics are most under control. The pole dominance and ISGW model can be easily distinguished experimentally with such a sample for the first time. It is remarkable that LQCD is just now able to compute $f_+(q^2)$ over a wide range of q^2 rather than just $q^2_{\rm max}$ with good systematic control while simultaneously gaining systematic control by eliminating the need for the *quenched* approximation.

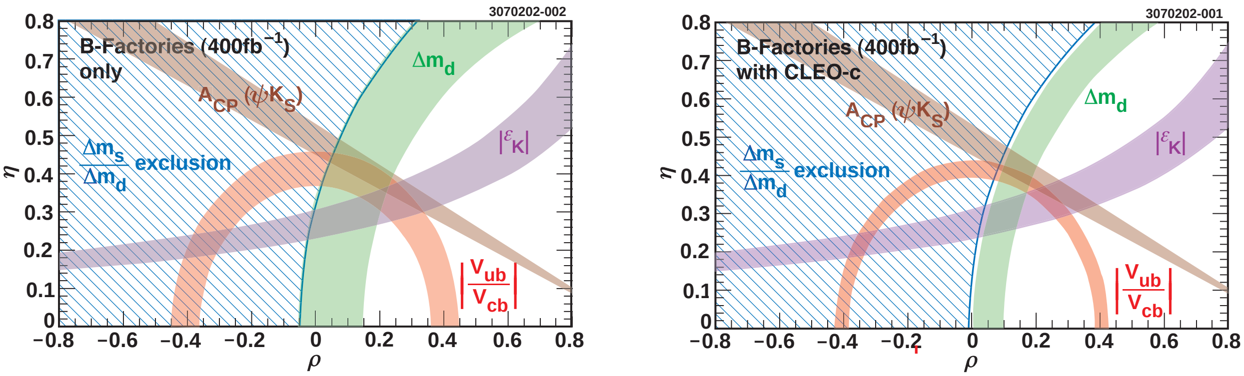

FIGURE 1. Projected allowed regions in the $\rho - \eta$ plot after B-factory accumulate 400 fb^{-1} with present theoretical uncertainties (left) and with the reduced LQCD uncertainties made possible by the fully leptonic and semileptonic charm decay samples obtainable in 3 fb^{-1} run at the $\psi(3770)$ (right).

The LQCD calculational techniques are presently better developed for charm decays into pseudoscalar $\ell\nu$ than for vector $\ell\nu$ decays such as $D \to \bar{K}^* \ell\nu$ or $\rho\ell\nu$. In addition, recently the FOCUS collaboration found evidence that the $D \to \bar{K}^* \ell\nu$ process was further complicated by the presence of an interfering $D \to K\pi\ell\nu$ s-wave contribution. At present there are two important experimental enigmas that could be easily resolved in the nearly background free environment of $D\bar{D}$ produced at the $\psi(3770)$ or $D_s^+ D_s^-$ produced at the $\psi(4140)$. There is a problem in understanding the ratio $\Gamma(D \to \bar{K}^* \ell\nu)/\Gamma(D \to \bar{K}\ell\nu)$ which is roughly 1/2 of the value predicted in quark models. In 2002, the CLEO collaboration published new data that tended to resolve this discrepancy, while a month later FOCUS published a new measurement that tended to restore it. There has been a long standing problem with a (3.3 σ) consistency between the form factors measured for $D_s^+ \to \phi\ell\nu$ and those measured for $D^+ \to \bar{K}{*}\ell\nu$. One would expect the form factors to be the same within present experimental errors owing to SU(3) symmetry. FOCUS recently obtained consistent form factors for the D^+ and D_s^+ decays thus casting doubt on this old experimental inconsistency. It will be important to understand the $D_s^+ \to \phi\ell\nu$ process since $\Gamma(D_s+ \to \phi\ell\nu)/\Gamma(D_s+ \to \ell\nu)$ is independent of V_{cs} and thus serves as a pure "calibrator" of LQCD calculations which if successful can test the unitarity relation $|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 1$ at the few percent level compared to present tests of this relation at the $\approx 20\%$ level. In addition, measuring vector $\ell\nu$ decays at threshold, would allow one to make precise measurements of the q^2 dependence of the relevant form factors for the first time.

Charmonium at BES and CLEO-c

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Abstract: This note summarizes topics in charmonium which we discussed in a presentation at the BES/CLEO-c Workshop. These included the spectroscopy of charmonium states, radiative transitions, e^+e^- widths, two-photon widths, hadron loop effects and open-charm strong decays. A reference has been made available as a preprint which discusses these results in more detail.

1 Introduction

Charmonium has been called the "hydrogen atom of QCD", since many of the most characteristic and interesting aspects of QCD can be inferred from studies of the spectrum of charmonium states and their decays and interactions. Charmonium is a useful system for the study of forces between quarks in QCD, especially the poorly understood, nonperturbative confining interaction. This system is of special interest because the dynamics are only quasirelativistic, and the quark-gluon coupling at this mass scale is intermediate in strength; for this reason the more unusual features of QCD, such as relativistic corrections to the properties of bound states, spin-dependent forces from quark motion, virtual meson decay loops and various other effects may be only moderately large "controlled" corrections to a simple nonrelativistic potential model picture. Thus in charmonium we have a laboratory in which various novel dynamical effects may simultaneously be large enough to be clearly identified, and small enough so that they can be treated as perturbations of a familiar quantum mechanical model.

In our (expanded) contribution to the BES/CLEO-c Workshop, which is available elsewhere as an hep-ph preprint [1], we discussed some aspects of charmonium that can be studied most easily at BES, CLEO-c and other e^+e^- facilities. These included the spectrum of states, electromagnetic transitions between charmonium states, leptonic widths, two-photon widths (not relevant for charmonium at BES and CLEO-c energies) and strong decays. In this short summary we will only discuss radiative transitions, leptonic widths and strong decays, and refer to the longer preprint for discussions of the other topics.

Electromagnetic transitions between charmonia (Table 1) are interesting in part because they allow one to reach states beyond the 1^{--} levels produced in e^+e^- annihilation. The dominant transitions are E1, and these have been observed clearly only in the series 2S→1P and 1P→1S (from the ψ' to the χ_J states and thence to the J/ψ). We noted that measurements of the E1 transition rates from the nominally D-wave state $\psi(3770)$ would be very interesting, especially to $\gamma\chi_2$; for a pure D-wave $\psi(3770)$ this should be quite weak (only a few keV), but with a significant S-wave admixture a width of 10s to 100 keV becomes plausible. This mixing has been predicted by models of the effect of virtual D-meson loops on charmonium states [2,3]. M1 transitions, especially $J/\psi \to \gamma\eta_c$, would also be very interesting to measure more accurately, since the $c\bar{c}$ model predictions involve only m_c, and yet are about a factor of 2-3 larger than experiment.

The leptonic widths of charmonia are (relatively) straightforward to measure, and it is of great interest that they are clearly in disagreement with potential model predictions (see Table 1). The table shows the theoretical predictions of the VanRoyen-Weisskopf formula [4], which assumes heavy quarks and an annihilation amplitude proportional to the wavefunction at contact, $\psi_{c\bar{c}}(0)$ ($\psi''_{c\bar{c}}(0)$ for the D-wave states). Evidently there is a large discrepancy between theory and experiment. This has been attributed to QCD radiative corrections [5], although this is not a satisfactory resolution because the pQCD effects are prescription dependent and hence rather uncertain, and in addition the observed discrepancies appear to be strongly state-dependent. The nominally D-wave states $\psi(3770)$ and $\psi(4159)$ are especially interesting because they have surprisingly large leptonic widths, which may be due to S-D mixing. A more accurate determination of the leptonic widths, especially of the $\psi(3770)$ and $\psi(4159)$, would be very useful in testing models of these effects.

One novel aspect of the physics of charmonium which BES and CLEO-c can explore is open-flavor (here, open-charm) strong decays. Although these processes are the dominant strong decay amplitudes (when allowed), the underlying QCD decay mechanism remains poorly understood. Theoretical models of these decays typically use a potential model formalism with a phenomenological $q\bar{q}$ pair production amplitude. Two very different assumptions regarding this amplitude may be found in the literature: One is the "$^3P_0$ model" of Micu *et al.* [6], which assumes decay through pair production with vacuum (0^{++}) quantum numbers. This is a standard approach for the description of light hadron decays [7]. In contrast, the well known charmonium papers of Eichten *et al.* [8] assume a very different decay model, with $q\bar{q}$ pair production from the linear confining potential, treated as a timelike vector (γ_0) interaction.

The new round of charmonium experiments may be able to distinguish between these different models of the open-flavor strong decay mechanism. As an example, in Table 2 we give $^3P_0$ model predictions for the strong decay amplitudes and branching fractions of the four easily accessible 1^{--} states with open-charm modes. (These results are abstracted from a larger work, which is currently in preparation [9]. The corresponding amplitudes in the Cornell decay model are currently being evaluated [10].) A simple measurement of these branching fractions, which are predicted to be strongly state-dependent (compare $\psi(4040)$ and $\psi(4159)$), would be extremely useful for comparison with the predictions of different decay models. A determination of the D^*D^* amplitude ratios in the decays of the $\psi(4040)$ and the $\psi(4159)$ might be the most useful measurement for theorists, since previous studies have shown that amplitude ratios are very sensitive to the quantum numbers assumed for $q\bar{q}$ pair production.

A careful study of these decay amplitudes would also be very useful as an indication of the limits of quenched lattice QCD. In the quenched approximation the effects of loops of open-charm mesons on charmonium states are ignored. Since these loops are second-order virtual decay processes, a better understanding of these strong decay amplitudes can be used to improve estimates of the effect of meson loops on the spectrum and couplings of charmonium states.

Finally, we note that the strong decays of higher-mass charmonium states may provide access to some of the interesting recent discoveries. For example, the new $D^*_{sJ}(2317)$ and $D_{s1}(2457)$ states can both be made in S-wave from the "high-mass tail" of the $\psi(4415)$, through $\psi(4415) \to D^*_s D^*_{sJ}(2317)$ and $D_s D_{s1}(2457)$. Since the predicted branching fractions to these final states are not especially small [9], running on the high-mass tail of the $\psi(4415)$ could produce a large sample of $D^*_{sJ}(2317)$ and $D_{s1}(2457)$ events.

Acknowledgments

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TABLE 1. Theoretical [9] and experimental [11] E1, M1 and e^+e^- partial widths of the easily accessible 1^{--} states, as well as some interesting additional cases (see text).

Initial state	Final state	$\Gamma_{thy.}$ (keV)	$\Gamma_{expt.}$ (keV)
χ_2	$\gamma \mathrm{J}/\psi$	424	426 ± 48
χ_1	$\gamma \mathrm{J}/\psi$	320	288 ± 51
χ_0	$\gamma \mathrm{J}/\psi$	155	119 ± 17
h_c	$\gamma \eta_c$	494	
ψ'	$\gamma \chi_2$	38	18.0 ± 2.0
	$\gamma \chi_1$	54	23.6 ± 2.7
	$\gamma \chi_0$	62	24.2 ± 2.5
$\eta_c{}'$	γh_c	49	
$\psi(3^3\mathrm{S}_1)(4040)$	$\gamma \chi_2$	0.5	
	$\gamma \chi_1$	0.4	
	$\gamma \chi_0$	0.2	
	$\gamma \chi_2(2^3\mathrm{P}_2)$	14	
	$\gamma \chi_1(2^3\mathrm{P}_1)$	39	
	$\gamma \chi_0(2^3\mathrm{P}_0)$	54	
$\psi(^3\mathrm{D}_1)(3770)$	$\gamma \chi_2$	4.9	≤ 330 (90% c.l.) [3]
	$\gamma \chi_1$	126	280 ± 100 [3]
	$\gamma \chi_0$	405	320 ± 100 [3]
$\psi(2^3\mathrm{D}_1)(4159)$	$\gamma \chi_2$	0.8	
	$\gamma \chi_1$	14	
	$\gamma \chi_0$	27	
	$\gamma \chi_2(2^3\mathrm{P}_2)$	5.9	
	$\gamma \chi_1(2^3\mathrm{P}_1)$	168	
	$\gamma \chi_0(2^3\mathrm{P}_0)$	485	
	$\gamma \chi_2(^3\mathrm{F}_2)$	51	
J/ψ	$\gamma \eta_c$	2.9	1.2 ± 0.3
ψ'	$\gamma \eta_c{}'$	0.21	
ψ'	$\gamma \eta_c$	4.6	0.8 ± 0.2
$\eta_c{}'$	$\gamma \mathrm{J}/\psi$	7.9	
J/ψ $(1\,^3\mathrm{S}_1)$	e^+e^-	12.13	5.40 ± 0.17
ψ' $(2\,^3\mathrm{S}_1)$	e^+e^-	5.03	2.12 ± 0.12
$\psi(3770)$ $(1^3\mathrm{D}_1)$	e^+e^-	0.056	0.26 ± 0.04
$\psi(4040)$ $(3\,^3\mathrm{S}_1)$	e^+e^-	3.48	0.75 ± 0.15
$\psi(4159)$ $(2^3\mathrm{D}_1)$	e^+e^-	0.096	0.77 ± 0.23
$\psi(4415)$ $(4\,^3\mathrm{S}_1)$	e^+e^-	2.63	0.47 ± 0.10

TABLE 2. Open-charm strong decay modes of the 1^{--} states accessible at BES and CLEO-c. A reaction-dependent factor has been removed from the decay subamplitudes in the final column of the table, so only the amplitude ratios are physically meaningful.

State	Mode	$\Gamma_{expt.}$ (MeV) [11]	$\Gamma_{thy.}$ (MeV) [9]	Subamps.
$\psi(3770)$ ($^3\mathrm{D}_1$)	DD		43.	
	all	23.6 ± 2.7	43.	
$\psi(4040)$ ($3\,^3\mathrm{S}_1$)	DD		0.1	
	DD*		33.	
	$\mathrm{D}_s\mathrm{D}_s$		8.	
	D*D*		33.	$^1\mathrm{P}_1 = +0.056$
				$^5\mathrm{P}_1 = -0.251$
				$^5\mathrm{F}_1 = 0$
	all	52 ± 10	74.	
$\psi(4159)$ ($2\,^3\mathrm{D}_1$)	DD		16.	
	DD*		0.4	
	D*D*		35.	$^1\mathrm{P}_1 = +0.081$
				$^5\mathrm{P}_1 = -0.036$
				$^5\mathrm{F}_1 = -0.141$
	$\mathrm{D}_s\mathrm{D}_s$		8.	
	all	78 ± 20	73.	
$\psi(4415)$ ($4\,^3\mathrm{S}_1$)	DD		0.4	
	DD*		2.3	
	D*D*		16.	$^1\mathrm{P}_1 = -0.018$
				$^5\mathrm{P}_1 = +0.081$
				$^5\mathrm{F}_1 = 0$
	$\mathrm{D}_s\mathrm{D}_s$		1.3	
	$\mathrm{D}_s\mathrm{D}_s{}^*$		2.6	
	$\mathrm{D}_s{}^*\mathrm{D}_s{}^*$		0.7	$^1\mathrm{P}_1 = +0.006$
				$^5\mathrm{P}_1 = -0.028$
				$^5\mathrm{F}_1 = 0$
	S+P modes [9]			
	all	52 ± 10		

Challenges and Opportunities for Charmonium Physics at CLEO-c

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Abstract: A review of the present status of charmonium spectroscopy is presented and its unique place in understanding the strong interaction and QCD is emphasized. Experimental and theoretical challenges are noted, and the prospects of addressing them at CLEO-c are described.

1 Introduction

I strongly believe that precision spectroscopy is the most important means of unraveling the mysteries of any interaction, and that the strong interaction is still the most challenging interaction, with some of its basic properties, like confinement, not yet understood. This talk is dedicated to the pursuit of the strong interaction physics for its own sake, not as a contaminating nuisance to weak interaction physics whose enthusiasts believe that it will lead them to the promised land beyond the standard model.

Although the QCD interaction is independent of quark flavors, it is difficult to study it conveniently and transparently in the light quark (u,d,s) sector which is characterized by a high density of overlapping $q\bar{q}$ states (In the 1.25–2.25 GeV region, typical level spacing $\approx$ 14 MeV, typical width $\approx$ 150 MeV). In contrast, the heavy quarks, charm (c) and beauty (b), form mesons with well resolved masses, and have the additional advantage of having not too large a strong coupling constant, and being comparatively free from relativistic complications. From a theoretical point of view, the $b\bar{b}$ bottomonium system, with more bound states and even less of these problems than the $c\bar{c}$ charmonium, is the better system to work on, but practical considerations like larger formation cross sections, larger level spacings, and accessibility via $p\bar{p}$ annihilation, make charmonium an odds-on favorite.

2 Charmonium

In my presentation at the BES/CLEO workshop I used forty transparencies relating to charmonium, and skipped ten relating to QCD exotics, glueballs, and hybrids. Clearly, here I can not go even into all of what I managed to talk about. So, in the following I present a summary, which will be unavoidably cryptic at times.

2.1 The Experimental Status

Table 1 summarizes the current status of our knowledge of charmonium [1]. Notice that for states other than J/ψ and ψ' very little is known. Few decays have been studied, and even fewer branching ratios have better than $\pm$30% precision. No radials have been observed, and essentially nothing is known about states above the $D\bar{D}$ threshold at 3.73 GeV, except that they are broad and decay mainly into $D\bar{D}$. So, obviously lots remains to be done.

TABLE 1. Current status of charmonium decays. [1]

$\|c\bar{c}>$ Resonance $R(n^S L_J)$	Number of Decay Channels: Total	Error $< 15\%$	Error $15\% - 30\%$	Upper Limit or Error or $\geq 30\%$	Fraction of hadronic BR seen (%)
$\eta_c(1^1S_0)$	21			21	26.1
$\eta_c'(2^1S_0)$	4			4	seen
$J/\psi(1^3S_1)$	134	39	39	56	51.6
$\psi'(2^3S_1)$	62	14	17	31	59.1
$\chi_{c0}(1^3P_0)$	17	4	6	7	13.1
$\chi_{c1}(1^3P_1)$	13	1	4	8	7.7
$\chi_{c2}(1^3P_2)$	19	3	7	9	8.3
$h_c(1^1P_1)$	3			3	(seen)
$\psi(3770)$	2		1	1	$D\bar{D}$ domin.
$\psi(4040)$	6		1	5	seen
$\psi(4160)$	1			1	
$\psi(4415)$	2			2	domin.

Let me use the spin singlet states of charmonium to illustrate both the present situation and the future promise, the challenge and the opportunity, in charmonium physics.

Consider the spin-singlet ground state of charmonium, $\eta_c(1^1S_0)$. The pyramid of excited states of any composite system is built on the foundation of its ground state, which is therefore the most important state to study and understand. So what do we know about η_c? Regrettably, very little!

Prior to 2003, the world total of η_c decays detected was ≈1600 events spread over 20 decay channels, with the result that not a single branching ratio had been measured with less than ±30% error. η_c must decay 100% by $c\bar{c}$ annihilation, and the data barely accounted for $(26 \pm 8)\%$ of it. Measurements of its width ranged from ∼10 MeV to 25 MeV, and PDG averages did not mean much. To repeat, obviously much remained to be done.

The task is difficult for both e^+e^- annihilation experiments in which η_c can only be reached by weak M1 radiative transitions from the vector states, J/ψ and ψ', which are the only ones directly formed, and the $p\bar{p}$ annihilation experiments in which huge hadronic backgrounds create difficult signal/background conditions. If things are so difficult with η_c, perhaps we should put it aside and concentrate on other things. No, we can not, for many important reasons for QCD physics. Of all the bound states of charmonium, η_c lies the deepest in the Coulombic region of the $q\bar{q}$ potential, just as its radial excitation η_c' lies almost the farthest in the confinement region. Spin-singlet $\eta_c(1^1S_0)$ is split from its triplet partner, $J/\psi(1^3S_1)$ purely by the spin-spin hyperfine interaction, there being no spin-orbit or tensor contribution. So, the S-wave hyperfine splitting $\Delta M_{hf} \equiv M(n^3S_1) - M(n^1S_0)$ offers the most direct insight into this part of the $q\bar{q}$ interaction, and its development from the Coloumbic to the confinement part of the QCD interaction. Further, precision measurements of the two-photon width and the total width ($\approx$ two-gluon width) of η_c should lead to excellent measurements of the strong coupling constant at the charm quark mass. So what is already being done about η_c and η_c'?

About $\eta_\mathbf{c}$: In 2003 new measurements on η_c have been reported by BES [2], Fermilab E835 [3], Belle [4], CLEO [5], and BaBar [6] (see Table 2). On the mass of η_c there is a near-consensus, with the weighted average of all five new measurements being $M(\eta_c) = 2981.0 \pm 0.8$ MeV, having been pulled down by 1.3 MeV from the average of the other four by the substantially lower BES result. The total width disagreements continue to be much more serious, ranging from $\Gamma(\eta_c) = 17.0 \pm 8.3$ MeV by BES [2] to $\Gamma(\eta_c) = 34.3 \pm 2.5$ MeV from BaBar [6]. A similar variation exists in $\Gamma_{\gamma\gamma}(\eta_c)$ between the CLEO and E835 results, although much of it can be attributed to the $\approx \pm 30\%$ errors in the different branching ratios from the literature used by the two measurements [1]. The differences between the measurements are all within their large errors, but that only emphasizes the real need for better measurements. As an aside, we note that even with the 58 million J/ψ in its arsenal, BES [2] is only able to determine η_c branching ratios with net uncertainties which range from $\pm 50\%$ to $\pm 33\%$. Far more statistics and far better capabilities in the detector are needed to resolve the present discrepancies, for example, in $\Gamma_{\gamma\gamma}(\eta_c)$.

TABLE 2. Summary of the latest results on η_c.

	$M(\eta_c)$ (MeV)	$\Gamma(\eta_c)$ (MeV)	$\Gamma_{\gamma\gamma}(\eta_c)$ keV	$M(\eta_c')$ (MeV)
BES [2]	2977.5 ± 1.6	17.0 ± 8.3	–	–
E835 [3]	2984.1 ± 2.3	$20.4^{+8.0}_{-7.0}$	$3.8^{+2.2}_{-1.4} \pm 1.3$ (br)	–
Belle [4]	2979.6 ± 2.8	29 ± 10	–	–
Belle [7,8]	–	–	–	3640.8 ± 7.7
CLEO [5]	2981.8 ± 2.0	24.8 ± 4.9	$7.4 \pm 0.6 \pm 2.3$ (br)	3642.9 ± 3.4
BaBar [6]	2982.5 ± 1.4	34.3 ± 2.5	–	3630.8 ± 3.5
Average	2981.0 ± 0.8	30.5 ± 2.0	$5.5^{+1.8}_{-1.5}$	3637.1 ± 2.3

About $\eta_\mathbf{c}'$: As mentioned earlier, it is necessary to identify $\eta_c'(2^1S_0)$ in order to trace the evolution of S-state hyperfine splitting as charmonium moves from the Coloumbic to the confinement region. We have $\Delta M_{hf}(1S) \equiv M(J/\psi) - M(\eta_c) = 116 \pm 1$ MeV. We need to identify η_c' and measure its mass to determine $\Delta M_{hf}(2S) \equiv M(\psi') - M(\eta_c')$. The old claim by Crystal Ball, $M(\eta_c') = 3594 \pm 5$ MeV has never been confirmed. So, it was very exciting when in two separate decays Belle announced the observation of η_c' last year. The two measurements resulted in rather different masses, $M(\eta_c') = 3654 \pm 10$ MeV [7], and 3622 ± 12 MeV [8], which average to 3640.8 ± 7.7 MeV, but they were clearly at variance with the CB claim. This has motivated CLEO and BaBar to search for η_c' in the two-photon fusion reaction

$$e^+e^- \to (e^+e^-)\gamma\gamma \quad , \quad \gamma\gamma \to \eta_c' \to K_S K\pi.$$

CLEO has successfully identified η_c' in separate analyses of its CLEO-II and CLEO-III data taken in the $\Upsilon(4S)$ region [5], and BaBar has also analyzed its $\Upsilon(4S)$ data [6]. We at CLEO report $M(\eta_c') = 3642.9 \pm 3.4$ MeV, and BaBar reports $M(\eta_c') = 3630.8 \pm 3.5$ MeV, which average to 3637 ± 2.4 MeV. The final result is that $\Delta_{hf}(2S) = 49 \pm 2$ MeV, i.e., a factor 2.4 smaller than $\Delta_{hf}(1S)$. While it is always possible to find some potential model or unquenched lattice calculation which gives this large a variation between 1S and 2S hyperfine splittings, it is fair to say that the present experimental result is rather unexpected, and it should catalyze some theoretical rethinking.

As exciting as it is to have identified η_c', much is still unknown about it. Only BaBar reports the total width, $\Gamma(\eta_c') = 17 \pm 9$; others only give large upper limits. Of course, no reliable decay branching ratios are obtained by anybody. With admittedly ad-hoc assumptions, CLEO reports $\Gamma_{\gamma\gamma}(\eta_c') = 1.3 \pm 0.6$ keV, i.e., about 1/5 that of η_c.

It is clear that to improve on the present scant knowledge of η_c' it must be identified with much higher statistics and precision.

About $\mathbf{h_c(1^1P_1)}$: The other spin-singlet state which has eluded all searches so far is the P-wave singlet, $h_c(1^1S_0)$ with $J^{PC} = 1^{+-}$. It can not be reached by radiative transition from any vector state ($J^{PC} = 1^{--}$) because of charge conjugation invariance. Its identification is extremely important to determine the Lorenz-structure, (scalar or vector) of the confinement interaction, which is generally *assumed* to be scalar. If that is indeed true, h_c should be located within a couple of MeV of the centroid of the $\chi_J(1^3P_J)$ states, which is known to be at 3525.3 ± 0.1 MeV. In 1992, Fermilab E760 $p\bar{p}$ annihilation experiment searched for h_c in the reaction $p\bar{p} \to (h_c) \to \pi^0 J/\psi$. They (and I was a part of it) observed a small enhancement at $M = 3526.2 \pm 0.2$ MeV and attributed it to h_c [9].

Since then the successor experiment, Fermilab E835, has attempted to confirm this identification with much large investment of luminosity. While there is no official E835 announcement of it so far, my student, D. Joffe, who has made the h_c search for his Ph. D. dissertation [10], finds no evidence for h_c excitation in the $h_c \to \pi^0 J/\psi$ decay, at levels considerably lower than the E760 'observation'. Other decay channels, e.g., $h_c \to \eta_c\gamma$ are still being investigated.

Again, what is clear is that in order to unambiguously identify h_c, and to make a precision determination of its mass, it will have to be searched for in a high statistics missing mass/invariant mass measurement like $\psi' \to \pi^0 h_c$. CLEO-c should be able to do that.

All this brings me to present in Table III what is expected at CLEO-c. The rates listed in Table III are based on 3.5×10^7s ($\approx 1/2$ productive year) of running at J/ψ and ψ' peak each, which is expected to yield luminosities, $\mathcal{L}(J/\psi) = 0.75\times10^{32}$ cm^{-2}s^{-1}, and $\mathcal{L}(\psi') = 2.1\times10^{32}$ cm^{-2}s^{-1}. Mass resolutions, $\Gamma_{exp}(J/\psi) = 3.5$ MeV, and $\Gamma_{exp}(\psi') = 4.2$ MeV are expected. It is obvious from this table that CLEO-c will be in a unique position to not only improve the precision in our knowledge of all the strong decays (Br $\sim$ %), but really yield definitive answers about the weak and very weak decays (Br $< 10^{-3}$) as well.

While Table III lists only charmonium decays, it is worthwhile mentioning that with its excellent detector, CLEO-c should be able to search for the QCD exotics, the (light and heavy quark) hybrids and glueballs, with unprecedented sensitivity. [11] Since by now I have used up most of the space given to me, I will only list the other topics I covered, and give references to other place where presentations about them may be found:

TABLE 3. Approximate expected rates per 0.5×10^7 sec (year) for charmonium decays at CLEO-c. The second column does not include the events detected by BES II. They tend to be factors of 2 to 3 larger than those listed, and are being gradually reported.

Particles and Decays	World Detected Events	Branching Ratios Assumed	CLEO Produced $\sim$ Events
ψ	26×10^6	Direct Formation	1900×10^6
$\psi \to \gamma\eta_c$	$\sim 1 \times 10^4$	1.3%	25×10^6
$\psi \to \gamma\gamma\gamma$	0	$< 5.5 \times 10^{-5}$	0.1×10^6
ψ'	4×10^6	Direct Formation	1400×10^6
$\psi' \to \gamma\eta_c$	$\sim 2.5 \times 10^3$	3.4×10^{-3}	4.8×10^6
$\psi' \to \gamma\eta'_c$	?	$< 10^{-3}$	$< 1.4\times10^6$
$\psi' \to \gamma\chi_{c0,1,2}$	$\sim 2 \times 10^5$ each	$\sim 9.3\%$ each	$\sim 130\times10^6$ each
$\psi' \to \pi^0 h_c$	0	$> 1 \times 10^{-4}$	0.14×10^6
$\psi' \to \pi^0 J/\psi$	30	$\sim 1 \times 10^{-3}$	1.4×10^6
$\psi' \to \eta J/\psi$	~ 500	$\sim 3\%$	42×10^6
η_c		From ψ	25×10^6
$\eta_c \to \gamma\gamma$	250	4.3×10^{-4}	0.01×10^6
$\eta_c \to p\bar{p}$	41	1.3×10^{-3}	0.03×10^6
$\eta_c \to \phi\phi$	104	2.6×10^{-3}	0.06×10^6
$\eta_c \to \omega\omega$	0	$< 3 \times 10^{-3}$	0.08×10^6
$\eta_c \to K^*\bar{K}^*$	23	8.5×10^{-3}	0.21×10^6
$\eta_c \to \rho\rho$	145	2.6%	0.65×10^6
$\eta_c \to \eta\pi\pi$	93	4.9%	1.22×10^6
$\eta_c \to \eta'\pi\pi$	14	4.1%	1.03×10^6
$\eta_c \to K\bar{K}\pi$	196	5.7%	1.43×10^6
$\eta_c \to 2(K^+K^-)$	~ 5	1.5%	0.04×10^6
$\eta_c \to 2(\pi^+\pi^-)$	162	1.2%	0.03×10^6
$\chi_{c0}, \chi_{c1}, \chi_{c2}$		From ψ'	130×10^6 each
$\chi_{c0} \to \gamma\gamma$	~ 100	$\sim 2.5 \times 10^{-4}$	0.03×10^6
$\chi_{c2} \to \gamma\gamma$	127	$\sim 2.5 \times 10^{-4}$	0.03×10^6
$\eta'_c \to \gamma\gamma$	0	$\sim 1.5 \times 10^{-4}$	0.02×10^6

1. Problems with $R = \sigma(e^+e^- \to h)/\sigma(e^+e^- \to \mu^+\mu^-)$ measurements and the higher vector states of charmonium. A new analysis gives quite different total and leptonic widths for $\psi(4S, 5S, 6S)$. [12].
2. CLEO has established limits on $X(3872)$ excitation in $\gamma\gamma$-fusion and ISR. [13]
3. Theoretical Challenges: So far little help from lattice calculations is available in the charmonium region. Experimental results can only be compared to pQCD and potential

model predictions. There is a large body of evidence that there are serious problems. I enumerate some of them.

(a) The Hadron Helicity Conservation (HHC) rule of pQCD is grossly violated; $p\bar{p} \to \eta_c$ and $p\bar{p} \to \chi_0$ are strongly populated. [1]

(b) The $\rho - \pi$ problem, or the fact that the pQCD expectation for the ratio between corresponding hadronic transitions of ψ' and J/ψ to be $\approx 13\%$ is quite often strongly violated. Our colleagues at BES have long worked on this problem [14], and recently CLEO-c has begun to contribute to it [15].

(c) Gluon radiative corrections are only available in the first order, and they are generally too large (up to 100%) to be believable. [16]

(d) Strong coupling constant, α_s, is difficult to obtain reliably even from well measured charmonium transitions, primarily due to the problem with the huge radiative corrections. There are special problems with determinations based on J/ψ (also $\Upsilon(1S)$). [17]

(e) The spin-structure of the $q\bar{q}$ potential is still not well understood. Neither the observed fine-structure splitting of the $\chi_J(1^3P_J)$ states [17], nor the hyperfine splitting of the 2S states is understood.

In closing, let me draw your attention to one very important physics capability, not related to charmonium, which CLEO-c will have, and will hopefully exploit. It is to measure with precision at large Q^2 (> 9 GeV^2) the timelike form factors of the proton (also Λ), pion, and kaon via $e^+e^- \to X\bar{X}$, where X is a baryon or meson. Almost no data exist for any of these (except for proton from the Fermilab E760/E835 experiments [18]), and they can be obtained anytime CLEO-c runs at energies away from the vectors, which it must if for no other reason than to get the required off-peak data.

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Charmonium Physics at BESIII/BEPCII

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Abstract: The BESIII program with large J/ψ, ψ' and ψ'' data samples expected will be extremely useful for the systematic study of the charmonium physics. In this report, the search for the $h_c(^1P_1)$ state, the study of the charmonium decay puzzle between J/ψ and ψ', and the data taking strategy for a high precision measurement in e^+e^- experiment are discussed. Examples are given for studying J/ψ decays with sample produced from $\psi' \to \pi^+\pi^- J/\psi$.

1 Charmonia data samples at BESIII

With the designed high luminosity of the BEPCII collider and the small energy spread, the J/ψ and ψ' data sample at BESIII in one year's running (assuming 10^7 s running time) can be 10×10^9 and 3×10^9 respectively. The samples of ψ'' and higher mass charmonium states such as $\psi(4040)$ and $\psi(4160)$, although will be much smaller than those of J/ψ and ψ' due to the small production cross sections, are still at the order of a few ten million in each year's running. Considering the data taking time for these states will be a few years for high precision D and D_s measurements, the data samples will also be large.

As for the other charmonium states which can not be produced directly in e^+e^- annihilation, ψ' decay is a very good source of the data sample, especially for the P-wave spin triplet states χ_{c0}, χ_{c1} and χ_{c2}.

With these large data samples, certainly there are lots of topics to be studied in the future, here we only list a few of them, which are well known and long standing questions.

2 Search for $h_c(^1P_1)$ state

After the discovery of the η_c' state recently [1], the only left charmonium state still missing below the $D\bar{D}$ threshold is the P-wave spin singlet state $h_c(^1P_1)$. From potential models, its mass is expected at the c.o.g of the χ_{cJ} states, which is 3526 MeV. Perturbative QCD (pQCD) and Non-Relativistic QCD (NRQCD) predict its width to be around 0.5 to 1.1 MeV, with $\gamma\eta_c$ the dominant decay mode of a branching ratio at 40 to 90% [2]. However, $h_c(^1P_1)$ production rate in the e^+e^- experiment is very small. The most promising way of searching for this state is in the ψ' isospin violated decay mode, $h_c(^1P_1)\pi^0$, with a branching ratio of $(2-30) \times 10^{-4}$ depends on the assumptions in the models [2].

Searching for $h_c(^1P_1)$ in ψ' exclusive decay mode, $\psi' \to h_c(^1P_1)\pi^0 \to \gamma\eta_c\pi^0$, with η_c decays into hadronic final states, such as $K_SK^\pm\pi^\mp$, $2(\pi^+\pi^-)$, $\pi^+\pi^-K^+K^-$, $2(K^+K^-)$, is possible with ψ' data sample taken in one year's running or less. The good particle ID capacity, as well as the good momentum resolution of the charged tracks and the energy resolution of the neutral tracks are important for achieving high efficiency and very low background [3].

We also studied the possibility of searching for $h_c(^1P_1)$ in inclusive π^0 momentum in ψ' decays, this will enable a measurement of the absolute production rate of $h_c(^1P_1)$ in ψ'

decays, as well as the absolute decay branching ratio of $h_c(^1P_1)$. The study is performed by generating a Monte Carlo sample of $\psi' \to h_c(^1P_1)\pi^0$ with different branching ratio, the background channels are generated with the lundcrm [4], which is a generator for inclusive ψ' decays with its decay branching ratios considered. To be efficient, only a small lundcrm sample is generated, after getting the inclusive π^0 momentum spectrum, it is parameterized and scaled to get the distribution in the full ψ' sample in one year's running. The number of events in each bin of the momentum spectrum is randomly distributed according to a Poisson distribution. By mixing the inclusive π^0 momentum spectrum and the signal channel events with different input branching ratio between $(2-30)\times 10^{-4}$, the momentum spectrum is fitted to get the number of signal events with a Gaussian for the signal and polynomial for the background in the vicinity of the signal region. In all the cases, the fit out signal has a statistical significance much higher than 5σ, although the signal peak is invisible by eyes (Fig. 1), when the input branching ratio is low. This means a search for the $h_c(^1P_1)$ state is feasible in inclusive π^0 momentum spectrum. However, as can be imagined, the shape of the background, the description of the momentum resolution of the signal may not be easy in real data, especially when the signal is faint. It certainly need more careful work after the real data sample is available.

To conclude, the search for the $h_c(^1P_1)$ state in ψ' decays is feasible both in exclusive and in inclusive modes, with a data sample of 3×10^9 events.

3 Hadronic decay dynamics and "$\rho\pi$ puzzle"

From pQCD, it is expected that both J/ψ and ψ' decaying into light hadrons are dominated by the annihilation of $c\bar{c}$ into three gluons, with widths proportional to the square of the wave function at the origin [5]. This yields the pQCD "12%" rule, that is

$$Q_h \;=\; \frac{\mathcal{B}_{\psi'\to h}}{\mathcal{B}_{J/\psi\to h}} = \frac{\mathcal{B}_{\psi'\to e^+e^-}}{\mathcal{B}_{J/\psi\to e^+e^-}} \approx 12\% \quad . \tag{1}$$

Following the first observation of its violation in $\rho\pi$ and $K^{*+}K^- + c.c.$ modes by Mark II [6], BES has measured many two-body modes of ψ' decays, among which some obey the 12% rule while others violate it [7]. There have been many theoretical efforts trying to solve the puzzle [8], however, none explains all the existing experimental data satisfactorily and naturally.

A most recent explanation of the "$\rho\pi$ puzzle" using the S- and D-wave charmonia mixing was proposed by Rosner [9]. In this scheme, the mixing of $\psi(2^3S_1)$ state and $\psi(1^3D_1)$ is in such a way which leads to almost complete cancellation of the decay amplitude of $\psi' \to \rho\pi$, and the missing $\rho\pi$ decay mode of ψ' shows up instead as enhanced decay mode of ψ''. A study on the measurement of $\psi'' \to \rho\pi$ in e^+e^- experiments shows that with the decay rate predicted by the S- and D-wave mixing, the interference between the three-gluon decay amplitude of the ψ'' resonance and the continuum one-photon amplitude is destructive so the observed cross section is very small [10], which is in agreement with the unpublished upper limit of the $\rho\pi$ cross section at the ψ'' peak by Mark III [11].

If the ψ' and ψ'' are indeed the S- and D-wave charmonia mixtures, not only the vector pseudoscalar (VP) [9] and the pseudoscalar pseudoscalar (PP) modes [12] will be affected, but all the other modes in ψ' decays will be affected as well, such as vector tensor (VT),

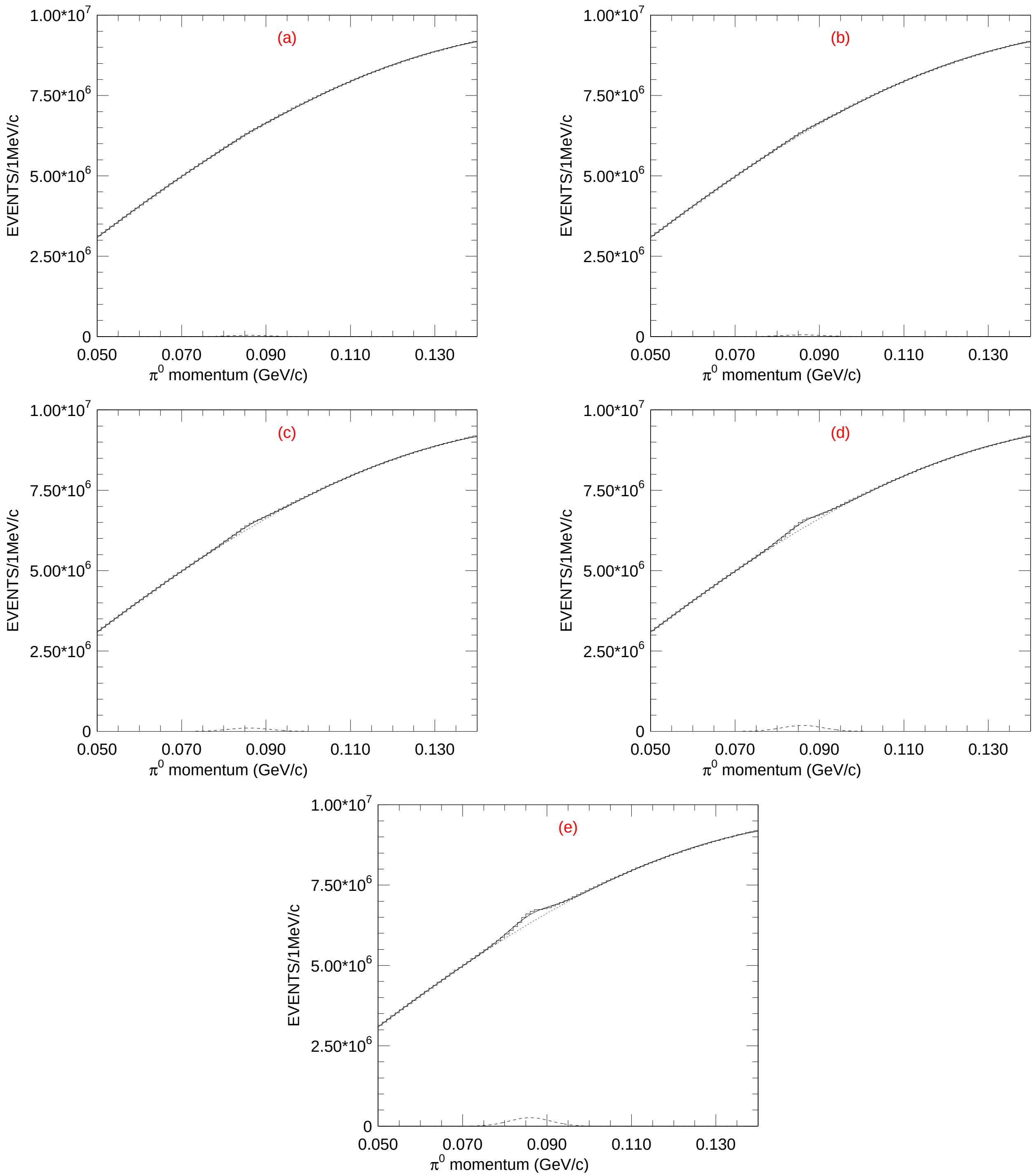

FIGURE 1. The inclusive π^0 momentum distribution of 3×10^9 produced ψ' events from the Lund charm Monte Carlo program, and with different input $\psi' \to h_c(^1P_1)\pi^0$ branching ratios. The branching ratios used in the calculation are (a) 2×10^{-4}, (b) 4×10^{-4}, (c) 10×10^{-4}, (d) 20×10^{-4} and (e) 30×10^{-4}. The curves are best fit to the spectrum.

axial-vector pseudoscalar (AP) and so forth. For the decay modes which have been measured both at ψ' and J/ψ, the corresponding branching ratio at ψ'' can be evaluated under the assumption of pQCD. Then the measurements at ψ'' provide a test for the mixing scheme, at the same time help to reveal the charmonium decay dynamics and the relation between J/ψ and ψ' decays.

The mixing scheme is a simple and natural model. If it is correct, it will provide a new angle of purview of understanding the $\rho\pi$ puzzle between J/ψ and ψ' decays, and the non-$D\bar{D}$ decay of ψ''.

Since the typical ψ' hadronic decay branching ratio is at the order of $10^{-5} - 10^{-4}$, the branching ratios of the channels suppressed relative to the 12% rule are even smaller, the big sample at ψ' is extremely necessary for the study. The high precision measurement of the J/ψ decay branching ratio will also be helpful. For the measurements of the non-$D\bar{D}$ decays of the ψ'', the statistics is even more important, since the branching ratio can be even smaller [12].

This is only an example for the study of the charmonium decay dynamics, in principle, the large data samples at J/ψ, ψ', ψ'', $\psi(4040)$ and $\psi(4160)$ will be helpful for any high precision test of the models for solving the $\rho\pi$ puzzle. They will shed light on the understanding of the charmonium decay dynamics.

4 Continuum amplitude and data taking strategy

It is well known that the e^+e^- experiments have lots of advantages in the study of the charmonium physics: large cross section, small background, and well-determined initial state (both four-momentum and quantum numbers). However, there is an inevitable amplitude - the continuum amplitude

$$e^+e^- \to \gamma^* \to hadrons$$

accompanied with the production of the resonances. This amplitude does not go through the resonance, but in general it can produce the same final hadronic states as charmonia do.

The experimentally observed cross sections in e^+e^- collision are modified by the initial state radiation. For the narrow resonances, the observed cross sections are also distorted by the energy spread of the collider. In general, different experiments have very different selection criteria and very different energy spreads, the contribution of the continuum amplitude is thus very different, considering the different energy dependence of the resonance and the continuum amplitudes. The proportion of the continuum amplitude contribution is also different for different mode, depending on the relative strength between strong and electromagnetic decay amplitudes of the resonance. However, even in the case that the continuum amplitude is relatively small, such as in ψ', certain values of the phase between the resonance and the continuum amplitudes possibly lead to non-negligible interference.

In principle, any experimental measurement should subtract the contribution of the continuum amplitude to get the physical quantity related to the resonance. Unfortunately, up to now, most of the experiments just neglect this contribution and the measured quantities are assumed to be purely from resonance decays for almost all the channels studied, at least at J/ψ and ψ'. As a consequence, the theoretical analyses and the experiments actually are talking about different things for the same quantity. On one hand, the theoretical analyses are based on pure contribution from the resonance, on the other hand, the experiments actually measure quantities with the contribution of the continuum amplitude included.

Recently, the effects of the continuum amplitude in the physics analyses are extensively examined in a series of papers [13]: it modifies the measurements of the $\pi^+\pi^-$ and $\omega\pi^0$ form factors at ψ' significantly; it changes the fitting of the relative phase between the strong and electromagnetic decay amplitudes of ψ' and implies a universal $-90°$ phase in all the hadronic decay modes and in all 1^{--} charmonium states, it sheds light on the understanding of the $\rho\pi$ puzzle, and it decreases the observed $\rho\pi$ cross section near the ψ'' resonance peak to a much smaller level than the expectation from either pure continuum contribution or estimation of the ψ'' non-$D\bar{D}$ decays.

The effect of this continuum amplitude will become more significant in the coming high luminosity experiments, such as CLEOc and BESIII, in this energy region. To achieve high precision to match the high statistics, the cross section of each mode understudy in the vicinity of the resonance should be measured. This implies an energy scan near the resonance peak at a few energy points with considerably large statistics to allow a reasonable subtraction of the continuum contribution via a fit to the line shape of the resonance [13].

The current physics analyses of the charmonium decays are all in the frame of Ref. [14], the validity of the parametrization of the hadronic decay amplitudes certainly needs high precision data to test, including both J/ψ and ψ' decays, even those from ψ'' and even higher mass charmonium states.

The data taking strategy should be carefully studied considering the relative strength of the strong and electromagnetic decay amplitudes, the relative phase between them, and the magnitude of the continuum amplitude. All these are being studied with a toy Monte Carlo, to determine how many data taking energy points, at what energies, and how to distribute the luminosity. However, no final result is available yet.

5 J/ψ study using ψ' data sample

Because of the large decay branching ratio of $\psi' \to \pi^+\pi^- J/\psi$, it is of great interest to investigate the possibility of doing J/ψ physics study with ψ' sample. We simulated two cases where ψ' sample is more suitable than J/ψ sample collected at J/ψ peak. One is the high precision measurement of the J/ψ decay branching ratio, and the other is the search for the J/ψ rare decays or forbidden decays. It is found that using 3×10^9 ψ' events, the branching ratio of $J/\psi \to \rho\pi$ can be measured to a precision at about 1% level, and the upper limit of the C-violating process $J/\psi \to \gamma\gamma$ can be determined at 10^{-7} sensitivity.

Since one of the most important topics using large J/ψ data sample is studying light hadron spectroscopy using partial wave analysis method, whether the J/ψ sample produced in ψ' decays can be used effectively needs more investigation.

6 Conclusions

At BESIII, large charmonium data samples will be accumulated, with these samples, $h_c(^1P_1)$ states can be searched for in a high sensitivity. The hadronic decays of the 1^{--} charmonia can be studied in high precision. It will supply more information for the testing and the development of the QCD at low energy, toward a final understanding of the charmonium decay dynamics. To achieve the high precision, the continuum amplitude should be considered in the experimental analyses, as well as in making the data taking plan.

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Open and Hidden Charm Physics with $\overline{\mathsf{P}}\mathsf{ANDA}$

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Abstract: Fundamental questions of hadron and nuclear physics will be studied in interactions of antiprotons with nucleons and nuclei, using the universal $\overline{\mathsf{P}}\mathsf{ANDA}$ detector. Gluonic excitations and the physics of strange and charm quarks will be accessible with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\overline{\mathsf{P}}\mathsf{ANDA}$ detector is a state-of-the-art internal target detector at the *HESR* at *GSI* covering almost the full solid angle.

1 Physics

Experimentally, studies of hadron structure can be performed with different probes such as electron, pion, kaon, proton or antiproton beams, each of which have its specific advantages. In antiproton-proton annihilation, particles with gluonic degrees of freedom as well as particle-antiparticle pairs are copiously produced, allowing spectroscopic studies with unprecedented statistics and precision. Antiprotons of 1–15 GeV/c will therefore be an excellent tool to address the open problems mentioned above. The following experiments are foreseen:

- Charmonium ($c\bar{c}$) spectroscopy: precision measurements of mass, width, decay branches of all charmonium states, especially for extracting information on the quark-confining potential. The unequaled resolution in the $\bar{\mathrm{p}}\mathrm{p}$ formation process and small systematic uncertainties give the unique opportunity to improve dramatically our knowledge which can not be achieved elsewhere.

- Firm establishment of the QCD-predicted gluonic excitations (charmed hybrids, glueballs) in the charmonium mass range (3–5 GeV/c^2) using high statistics in combination with sophisticated spin-parity analysis in fully exclusive measurements.

- Search for modifications of meson properties in the nuclear medium, and their possible relationship to the partial restoration of chiral symmetry for light quarks. Particular emphasis is placed on mesons with open and hidden-charm, which extends ongoing studies in the light quark sector to heavy quarks, and adds information on contributions of the gluon dynamics to hadron masses.

- Precision γ-ray spectroscopy of single and double hypernuclei for extracting information on their structure and on the hyperon-nucleon and hyperon-hyperon interaction.

As soon as the*HESR* facility reaches the full design luminosity further physics opportunities will open up like:

- Extraction of generalized parton distributions from $\bar{\mathrm{p}}\mathrm{p}$ annihilation,

- D meson decay spectroscopy (rare leptonic and hadronic decays), and
- Search for CP violation in the charm and strangeness sector (D meson decays, $\Lambda\overline{\Lambda}$ system).

Selected topics of the science case will be discussed in the following sections. For other topics not mentioned here, please refer to the $\overline{\mathsf{P}}$ANDA LoI [1] and the CDR [2] and previous work on the physics and a potential detector [3,4]. It is an important feature of the $\overline{\mathsf{P}}$ANDA detector that for a given antiproton momentum and target selection, different physics aspects can be studied simultaneously.

1.1 Charmonium

There are many open questions in terms of narrow charmonia and charmonia above the open charm threshold. Apart from this conventional spectrum also states with excited glue are expected (called hybrids) which are traced by the observation of exotic quantum numbers. $\overline{\mathrm{p}}\mathrm{p}$ formation experiments will generate charmonium and non-exotic charmonium hybrids with high cross sections, while production experiments would yield a charmonium hybrid together with another particle, such as a π or an η. In $\overline{\mathrm{p}}\mathrm{p}$ annihilation, production experiments are the only way to obtain charmonium hybrids with exotic quantum numbers. It is envisaged that the first step of exploring charmonium hybrids would consist of production measurements at the highest antiproton energy available ($\mathrm{E}_{\overline{\mathrm{p}}}$=15 GeV, $\sqrt{s}$=5.46 GeV/c^2), and studying all possible production channels available to cover exotics and non-exotic states. The next step would consist of formation measurements by scanning the antiproton energy in small steps in the regions in which promising hints of hybrids have been observed in the production measurements, thus having a second check on the static properties like the J^{PC} assignment as well as mass and width.

1.2 Glueballs

Glueballs with exotic quantum numbers are called oddballs. These cannot mix with normal mesons; as a consequence, they are predicted to be rather narrow and easy to identify experimentally [5]. Since the spin structure of an oddball is different [5], it is conceivable that comparing oddball properties with those of non-exotic glueballs will reveal deep insights into the so-far unknown glueball structure. The lightest oddball, with $\mathrm{J}^{\mathrm{PC}} = 2^{+-}$ and a predicted mass of 4.3 GeV/c^2, would be well within the range of the proposed experimental program. Like charmonium hybrids, glueballs can either be formed directly in the $\overline{\mathrm{p}}\mathrm{p}$-annihilation process, or produced together with another particle. In both cases, the glueball decay into final states like $\phi\phi$ or $\phi\eta$ would be the most favorable reaction below 3.6 GeV/c^2 while $J/\psi\eta$ and $J/\psi\phi$ are the first choice for the more massive states.

The indication for a tensor state around 2.2 GeV/c^2 was found in the experiment of *JETSET* collaboration at *LEAR* [6]. The acquired statistics was not large enough and the complimentary reactions were not measured. We plan to measure the $\overline{\mathrm{p}}\mathrm{p} \to \phi\phi$ channel with statistics of two orders of magnitude higher than in the previous experiments. Moreover, other reactions of two vector particle production, such as $\overline{\mathrm{p}}\mathrm{p} \to \omega\omega, K^*\overline{K^*}, \rho\rho$ will be measured.

1.3 Charmed Hadrons in Matter

The investigation of medium modifications of hadrons embedded in hadronic matter is one of the main research activities at *GSI* at present and in the near future. The main physics goal is to understand the origin of hadron masses in the context of spontaneous chiral symmetry breaking in QCD and their modification due to chiral dynamics and partial restoration of chiral symmetry in a hadronic environment.

Investigating the interaction of $c\bar{c}$ mesons with nucleons and nuclei is therefore a way to exploring fundamental aspects of gluon dynamics in QCD. For the low-lying charmonium states J/ψ and η_c recent calculations [7] indicate, however, only small in-medium mass reductions of the order of 5–10 MeV/c^2, but since this effect is expected to scale with the volume occupied by the $c\bar{c}$ pair, the situation may be different for excited charmonium states and is certainly different for open-charm states. For D mesons, the situation is different. Built of a heavy c quark and a light antiquark, the D meson is the QCD analogue to the hydrogen atom. Hence, D mesons provide the unique opportunity to study the in-medium dynamics of a system with a single light quark.

2 Detector

The rich experimental program being proposed in the previous section can only be pursued with a universal hermetic modular detector which is capable of detecting charged and neutral particles with nearly 4π solid angle coverage and high resolution. The basic elements are:

- Hidden-charm physics and the search for exotics require the concurrent detection of dilepton pairs as well as good kaon identification and high efficiency for open-charm final states. In addition the detection of low energy photons, either from radiative decays and/or background channels, is extremely important. Thus, muon detection capabilities and a highly-segmented low-threshold electromagnetic calorimeter are important to tag and precisely reconstruct hidden-charm and to reduce background. Good vertex recognition and particle identification for charged kaons from very low energies up to a few GeV/c is mandatory to reconstruct light hadronic and open-charm final states.

- The detector must withstand large radiation dosage from hadrons emitted from the spallation process when using nuclear targets. These spallation products include neutrons down to thermal energies, which contribute most.

- The specific demands for experiments with a secondary target require a good detection of antihyperons and low momentum K^+ in the forward region. A compact high-resolution solid state tracker for absorption and tracking of low momentum hyperons at large angles is certainly needed. The geometry of this secondary target is determined by the short mean life of the Ξ^- of only 0.164 ns. To measure the radiative transitions a high resolution and high-efficiency Ge-array for γ-ray detection is envisaged.

- Open-charm spectroscopy and electromagnetic reactions have similar demands as are envisaged in the hidden-charm and exotics programs. It is worthwhile to mention that the decay of a charmed hadron releases a rather high p_t (up to 1.5 GeV/c) as compared to light and even strange meson decays. This leads to large opening angles of the daughter particles in the laboratory reference frame.

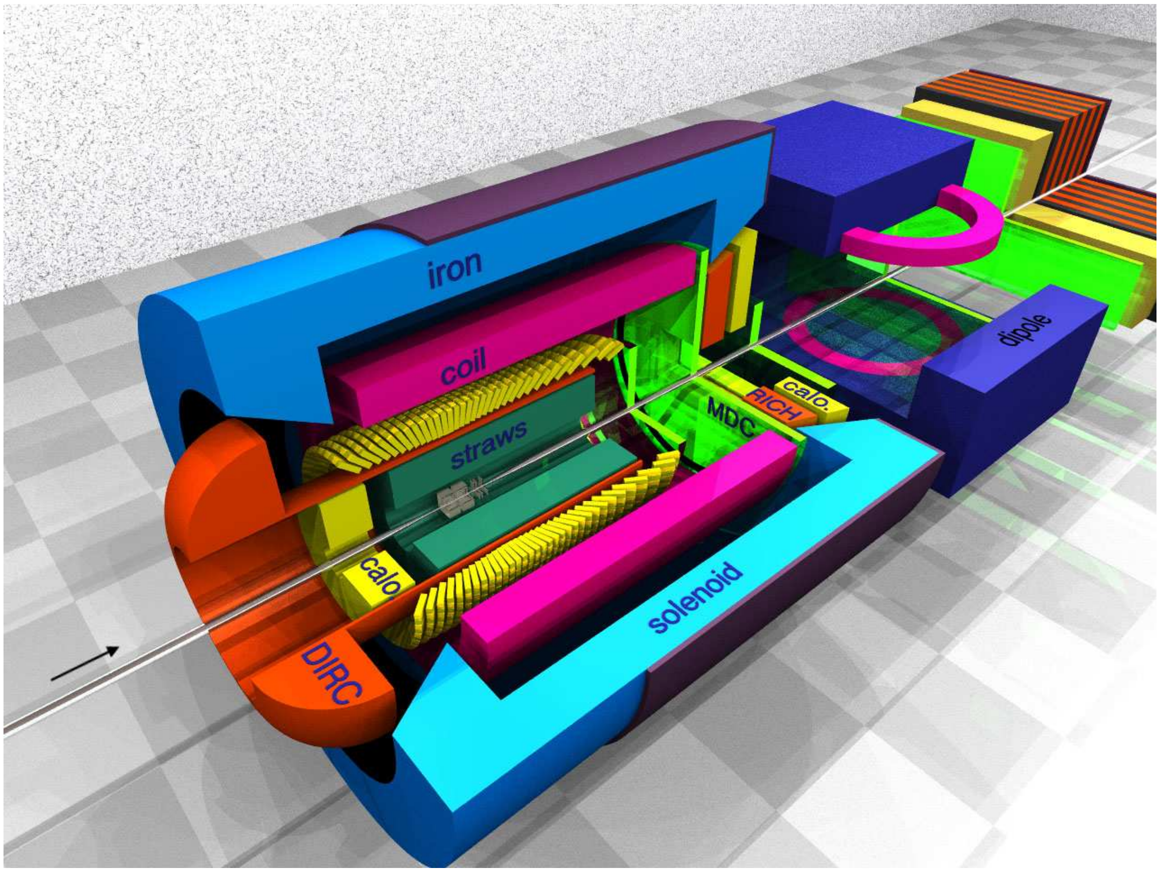

FIGURE 1. Artist's view of the $\overline{\mathsf{P}}\mathsf{ANDA}$ detector system for experiments at the internal target of the antiproton storage ring. It allows the detection and identification of neutral and charged particles generated within the relevant angular and energy range. This task will be shared by the combination of a central and a forward spectrometer of modular design which both are optimized for the specific kinematics of the antiproton-nucleon annihilation process.

For the envisaged experimental program a nearly full coverage of the solid angle together with good particle identification and high energy and angular resolutions for charged particles and photons are mandatory. The proposed detector is subdivided into the target spectrometer (TS) consisting of a solenoid around the interaction region and a forward spectrometer (FS) based on a dipole to momentum-analyze the forward-going particles. The combination of two spectrometers allows a full angular coverage, it takes into account the wide range of energies and it still has sufficient flexibility, so that individual components can be exchanged or added for specific experiments, e.g. for the experiments with hypernuclei or for the special needs of CP violation studies.

Particles emitted with laboratory polar angles larger than 5° are measured solely in the TS. Surrounding the interaction volume there will be 4 diamond or silicon start detectors (each $20\times30\,\mathrm{mm}^2$) followed by 5 layers of a silicon micro-vertex detector. Starting from a radial distance of 15 cm from the beam line, up to 42 cm, there will be 15 double-layers of crossed straw tubes, that extend from 40 cm upstream to 110 cm downstream of the target.

At a radial distance of 45 cm a cylindrical DIRC follows. The forward region will be covered by an aerogel Cherenkov detector using proximity focusing onto gas based photon detectors. These detectors are surrounded by an electromagnetic calorimeter consisting of $PbWO_4$ crystals that are read out with avalanche photodiodes. In the region between the calorimeter and the end-cap there will be two sets of mini drift chambers. The TS is contained in a 2.5 m long and 90 cm radius solenoid. Behind the return yoke there will be scintillating bars for muon identification.

Particles emitted with polar angles below $10°$ in the horizontal and $5°$ in the vertical direction are measured with the help of a 1 m gap FS-dipole. MDCs will be located before and behind the dipole for tracking. Particle identification will be obtained by a TOF-Stop detector and a dual-radiator RICH detector. Behind this there is a $3\,\mathrm{m}^2$ lead glass calorimeter and a hadronic calorimeter followed by a muon detection system.

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What Do We Know About Glueballs from Lattice QCD?

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Abstract: Our current knowledge of glueball from lattice QCD simulations is summarized.

Monte Carlo simulations of QCD regularized on a space-time lattice are an important tool for breeching the Great Wall separating the QCD Lagrangian from hadronic observables. Lattice simulations not only are useful for brute-force black-box computations of such quantities, but also can be judiciously applied to probe more subtle features of QCD. In this talk, efforts to compute the low-lying glueball spectrum are outlined.

Pure gauge methods are now entirely satisfactory. The combination of improved gauge actions, anisotropic lattices, local pseudo-heathbath/Creutz-overrelaxation updating, and sets of extended and smeared operators makes significant calculations of gluonic observables feasible using the commodity personal computers of today. In fact, the glueball spectrum in the pure Yang-Mills gauge theory is now well-known (see Fig. 1). This spectrum is not only a first step towards the computation of real-world glueballs (which must include the effects of interactions with quarks), but also a measuring rod with which models of confined gluons may be judged. Theoretical issues related to confinement may be probed using this spectrum. Recently [2], simulations using a new gauge action designed to ameliorate the well-known lattice-spacing artifacts in the scalar sector have been done, significantly reducing the systematic uncertainties in the excited scalar glueball mass.

However, the inclusion of quark loops is still problematic. Simulations which include quarks require the inversion of a huge matrix by the conjugate gradient method not only in the Monte Carlo updating, but also in the computation of the quark propagators needed to evaluate the hadron correlation functions. The inversions of the fermion matrix are extremely costly for realistically-light quark mass, so that many simulations resort to using much heavier quark masses. To further complicate matters, the necessary inclusion of multi-hadron states can also require all-to-all quark propagators which must be evaluated stochastically.

For this reason, computations of the glueball masses in the presence of realistically-light quarks has not yet been reliably achieved. However, the importance of such simulations is well recognized, and the U.S. Department of Energy has recently provided funding through a new program, known as the Scientific Discovery through Advanced Computing (SciDAC) initiative, to construct teraflop parallel computing clusters at Jefferson Lab and Fermilab. With such computing power, the push to compute the entire low-lying spectrum of QCD has intensified. Such efforts are now very timely given the Hall-D initiative at Jefferson Lab, the CLEO-c project at Cornell, the proposed BESIII upgrade in Beijing, and the resurgence of interest in spectroscopy due to the discovery of pentaquark states and mesons of exotic quantum numbers.

The glueball tale is still far from finished. The latest chapter in this story can be found in Ref. [3]. In this work, the scalar and tensor glueball masses were studied in two-flavor

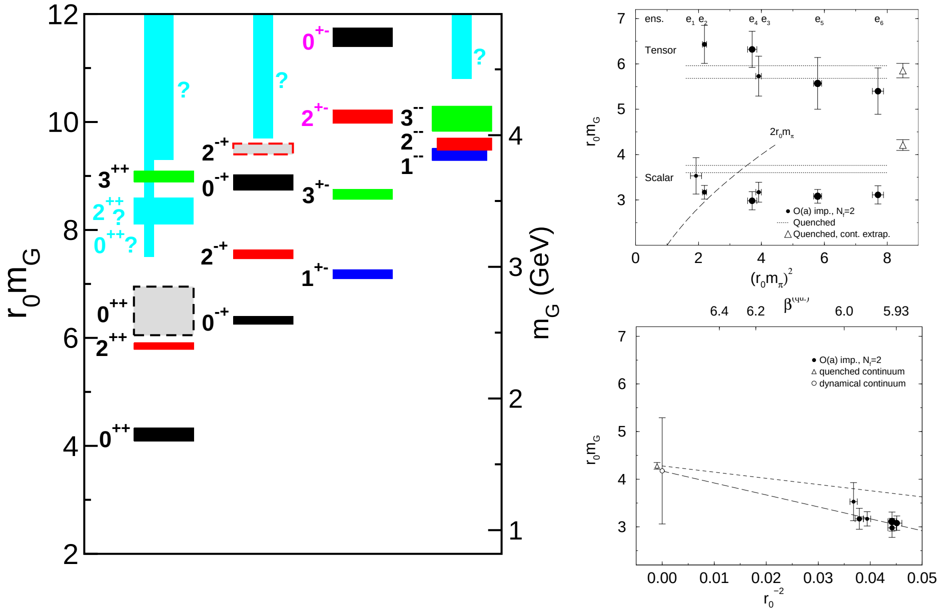

FIGURE 1. (Left) The mass spectrum of glueballs in the pure SU(3) gauge theory from Ref. [1] in terms of the hadronic scale $r_0^{-1} = 410(20)$ MeV. (Top right) The masses of the scalar and tensor glueballs against m_π^2 in the absence of quarks (horizontal bands) and in QCD with two quark flavors (symbols [3]). The dashed line is the threshold for decay to $\pi\pi$. (Bottom right) The continuum limit of the scalar glueball mass in the absence of quarks (triangle) and in QCD with two quark flavors (circle [3] with large error bar).

QCD simulations using the Wilson gauge action and the clover fermion action. Results at a lattice spacing $a \sim 0.1$ fm were obtained for a range of quark masses $m_q \geq \frac{1}{2}m_s$, where m_s is the mass of the strange quark. Little change in the tensor glueball mass was found, but a suppression of the scalar glueball mass was observed. At this lattice spacing, the scalar mass was found to be 0.85 that of the pure-gauge glueball. The authors were able to rule out finite volume as the cause of this mass decrease. Also, the decrease was found to be independent of the quark mass (see Fig. 1), suggesting an unphysical origin. These authors concluded that the most likely source of the mass decrease was the known lattice artifact responsible for the large discretization errors in the scalar glueball mass (an unphysical critical point in the fundamental/adjoint coupling plane). Given masses at a few different lattice spacings, the authors attempted a linear extrapolation to the continuum limit (see Fig. 1). The results are consistent with the pure-gauge mass, but the uncertainty in the extrapolated value is enormous. To date, the *tentative* conclusion is that mixing effects with quarkonia are small and do not appreciably change the scalar and tensor glueball masses.

Continued effort to include quark loops is needed. Other planned future work includes probing glueball structure with plaquette-based form factors [4] and on-going work to compute vacuum-glueball transition matrix elements [5].

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Glueball Searches: Experiment

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Abstract: We review the status of searches for glueballs, and opportunities to resolve current questions using CLEO-c and BESIII. This talk was given at the CLEO-c/BESIII workshop, 13-15 January 2004, at IHEP, Beijing.

1 History and Outstanding Puzzles

Glueballs represent the utter breakdown of the quark model. On the other hand, they should exist on the basis of QCD, and lattice gauge calculations predict their mass and quantum numbers [1]. Consequently, establishing their existence and properties is crucial to understanding the strong interactions.

A number of glueball candidates have presented themselves over the years [2]. One feature of these candidates is that they overpopulate the states predicted by the quark model. Two examples, observed in J/ψ radiative decay, are the $I = 0$ pseudoscalar mesons with mass near 1440 MeV, and the scalar mesons with masses between roughly 1400 MeV and 1700 MeV. As Lattice QCD predicts the lightest glueball to be a scalar with mass near 1700 MeV, we restrict this discussion to the latter.

There are three relatively well established scalar mesons in this mass region [3], the $f_0(1370)$, the $f_0(1500)$, and the $f_0(1710)$. The quark model, on the other hand, predicts only two, namely the $I = 0$, ${}^3P_0$ $|u\bar{u} + d\bar{d}\rangle \equiv |n\bar{n}\rangle$ and $|s\bar{s}\rangle$ combinations. Therefore, there is a widespread belief that these three mesons are mixtures of the two quark model states, and the lightest glueball. The mixing coefficients are not yet widely accepted, however. There is the additional complication that radially excited ${}^3P_0$ states are expected with masses near 1700 MeV [4].

One problem is that these three states are not each clearly observed in the same glue-rich production mechanism. In particular, only the $f_0(1370)$ and $f_0(1710)$ are seen in J/ψ radiative decay [5,6,7], whereas the evidence for $J/\psi \to \gamma f_0(1500)$ is marginal [6,8]. On the other hand, the copious production of $f_0(1500)$ in $\bar{p}p$ annihilation [9] and central pp collisions [10] argues that it has a large glueball component.

2 Opportunities in J/ψ Radiative Decay

An important goal for CLEO-c and CESR-c is to acquire $\approx 10^9$ events at the J/ψ peak. In addition to various rare decay processes, a prime focus will be to study gluonic excitations through radiative decay, i.e. $J/\psi \to \gamma X$. A vector resonance can decay to three (but not two) vector particles. If one of these decay products is a photon, then there is a fair probability that the remaining two are gluons. Hence, this process is expected to give rise to final state glueballs X [11].

Observation of the $J/\psi \to \gamma f_0(1500)$ is a high priority for CLEO-c. We will search for this decay mode in several final state decays of the $f_0(1500)$. High statistics will be critical, not only to observe a presumably small signal, but also in order to thoroughly understand the detector and analysis acceptance. Figure 1 gives some indication of the inherent difficulties. Although the discrimination in this case is clear, there is one dominant

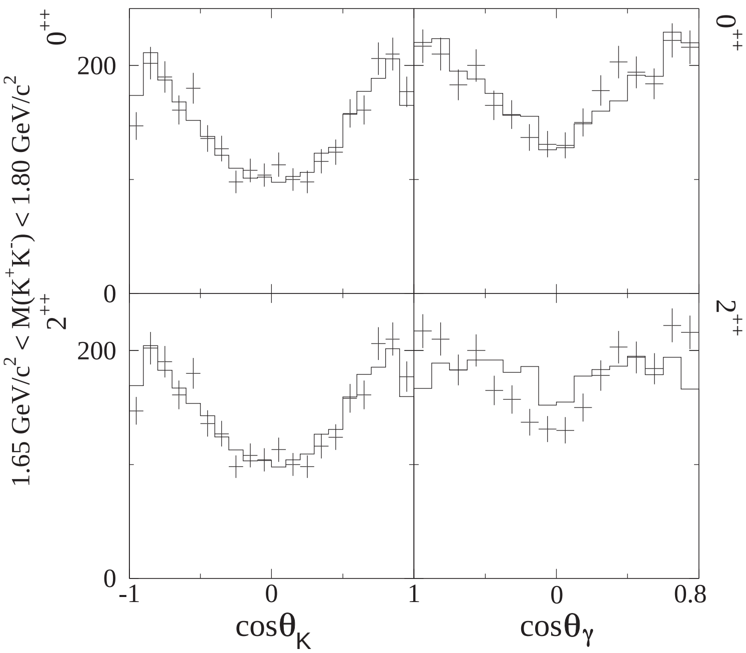

FIGURE 1. Partial wave analysis relies on subtle differences in the various angular distributions. This figure (from [6]) shows the difference between data and fit, for 0^{++} and 2^{++} hypotheses, for two angles used to describe the multiparticle correlations, in the mass region dominated by the $f_0(1710)$. High statistics, as well as good control over systematics, will be necessary to go far beyond the discrimination illustrated here, for example in the 1500 MeV/c^2 mass region.

structure (the $f_0(1710)$) in the indicated mass region (1.65 to 1.80 GeV/c^2). To search for the $f_0(1500)$, one needs to beat the signal against the dominant $f_2'(1525)$, and that will be a much more significant challenge.

One particularly exciting possibility is flavor decomposition of the scalars (and other states) through their own radiative decay. It has been shown [12] that there is a good deal of sensitivity to the amount of $q\bar{q}$ substructure, in the radiative widths of these states. Their calculations are summarized in Table 1.

Here, "L", "M", and "H" ("light", "medium", and "heavy") refer to the mass of the pure glue state, relative to the two quark model states. The discrimination between mixing scenarios is excellent, but the relative branching ratios for the radiative decays are 10^{-3} or so. This may be the cleanest way of all to determine the $q\bar{q}$/glueball mixing. However, with

TABLE 1. An opportunity for CLEO-c and BESIII. High statistics studies of J/ψ radiative decay will make it possible to discriminate glueballs from $q\bar{q}$ states using double radiative decays. The table is from [12].

Radiative Decay Widths (keV)							Γ_{TOT}
	$f_0 \to \gamma\rho(770)$			$f_0 \to \gamma\phi(1020)$			(MeV)
State	L	M	H	L	M	H	
$f_0(1370)$	443	1121	1540	8	9	32	∼300
$f_0(1500)$	2519	1458	476	9	60	454	109
$f_0(1710)$	42	94	705	800	718	78	125

the net branching ratio for $J/\psi \to \gamma X \to \gamma\gamma Y$ on the order of 10^{-6}, a sample of 10^9 events will likely be needed to deconstruct the final states.

Other spectroscopic issues can be investigated with bearing on glueballs. For example, the pseudoscalar and axial vector mesons in the 1400 MeV/c^2 region (the "E/ι puzzle" [2]) remain somewhat controversial, and a new search for gluonic and $q\bar{q}$ states up to $J = 4$ for $M_X \geq 2$ GeV/c^2 should be carried out. High statistics samples will likely be needed to disentangle the various overlapping final states.

3 Conclusions

There is strong evidence that the lightest scalar glueball is a mixture of known states. The details of this mixture, including confirmation of a glueball component in at least one of them, is still unsettled, however. High statistics samples of J/ψ radiative decay from CLEO-c and BESIII should not only settle this question, but also provide us with new evidence for other glueball states.

Acknowledgments

I would like to thank our gracious hosts from IHEP Beijing for an exciting and useful symposium, as well as a delightful visit to Beijing and China. I would also like to thank Cornell University and the Wilson Synchrotron Laboratory for their hospitality during this academic year.

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J/ψ physics at BESIII/BEPCII

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Abstract: The J/ψ decays provide a good laboratory for the study of the hadron spectroscopy, as well as the glueballs and hybrids. In this talk, the main physics topics at BESIII/BEPCII are reported.

1 Introduction

Our present understanding of the strong interactions is based on a non-Abelian gauge field theory, Quantum Chromodynamics (QCD) [1], which describes the interactions of quarks and gluons and thus predicts the existence of other types of hadrons with explicit gluonic degrees of freedom – glueballs and hybrids. Therefore, the observation of glueballs and hybrids is a direct test of QCD. The systematic study of the hadron spectroscopy, as well as the glueball and hybrid spectroscopies will be a good laboratory for the study of the internal structure of mesons and baryons and so for the study of the strong interaction in the strongly coupled non-perturbative regime.

Many experiments have been dedicating to the study of the hadron spectroscopy. The hadronic peripheral production, K^-p reaction by LASS, π^-p experiments by E852, GAMS, VES, and the experiment at KEK provided many data on the light meson spectroscopy. The pp central production at CERN, and $p\bar{p}$ annihilation at CERN and FNAL contributed much to the meson spectroscopy too. Crystal Ball, MARKIII, DM2, BES collaborations at e^+e^- storage rings and two photon collision experiments at CLEO and LEP have played and will still play an important role in the study of the hadronic spectroscopy. These years, a new generation of experiments with electromagnetic probes (real photon and space-like virtual photon) has been started at new facilities such as Jefferson Lab, ELSA at Bonn, GRAAL at Grenoble and SPRING8 at KEK for the study of the excited baryons.

With the double-ring design, the luminosity of BEPCII will reach 10^{33}. Therefore, a large J/ψ data sample, e.g. 10^{10} can be obtained in one year. On the other hand, BESIII has a much improved photon detection capability, a good charged tracks' momentum resolution and a better particle identification. Therefore, BESIII is able to access the final states with all-neutral or multi-photon and multi-charged tracks.

2 Physics at BESIII/BEPCII

The main topics at BESIII/BEPCII will be the search for the non-$q\bar{q}$ states including glueballs, hybrids and multi-quark states, the systematic study of the meson and baryon spectroscopies and the precise measurements. The possible new physics can be probed as well. With a large sample of J/ψ data, a large amount of η_c can be obtained and therefore the η_c physics can be studied.

The Monte-Carlo simulations are performed for some of above topics.

2.1 Monte-Carlo simulation of possible 2^{++} *glueball in* $J/\psi \to \gamma\eta\eta'$

According to lattice QCD[2], the lowest glueball state is 0^{++} with the mass being in 1.5 - 1.7 GeV region and the next lightest glueball is 2^{++} with the mass around 2.4 GeV. As an example, we simulated $J/\psi \to \gamma\eta\eta'$, $\eta \to \gamma\gamma$ and $\eta' \to \gamma\rho$, $\rho \to \pi^+\pi^-$ to investigate the 2^{++} glueball candidate $\xi(2230)$, based on the design of BESIII. Some theoretical calculations predict that $\xi(2230)$ can be largely coupled to $\eta\eta'$ and $\eta'\eta'$, provide it exists and is a glueball. We assume $Br(J/\psi \to \gamma\xi(2230))Br(\xi(2230) \to \eta\eta') = 3 \times 10^{-6}$ and the total J/ψ number is 6×10^9. Fig. 1 shows the expected $\eta\eta'$ invariant mass spectrum of 6×10^9 J/ψ events passing through BESIII detector. In addition to $\xi(2230)$, the $f_0(1500)$, $X(1910)$ and $X(2150)$, as well as some background channels are included according to the results from other experiments. The $\xi(2230)$ can be clearly seen here and the mass resolution at this mass is around 12 MeV. Table 1 shows the input and output Breit-Wigner fit results for each components.

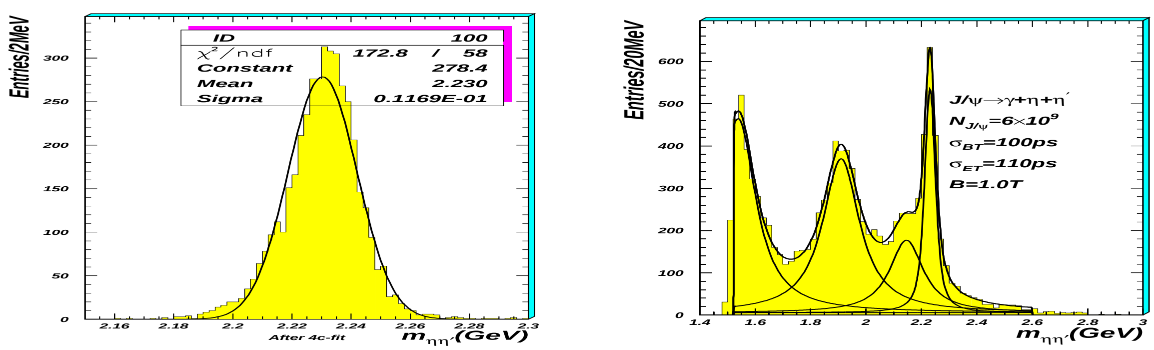

FIGURE 1. The $\eta\eta'$ invariant mass spectrum

TABLE 1. The results of Breit-Wigner fit

		Input	Output
	M(MeV)	1910.0	1909.4 ± 2.4
$X(1910)$	Γ MeV	150.0	153.9 ± 8.7
	$Br(\times 10^{-6}$	7.2	7.5 ± 0.3
	M(MeV)	2150.0	2152.2 ± 9.9
$X(2150)$	Γ MeV	157.0	167.1 ± 21.0
	$Br(\times 10^{-6}$	3.6	3.7 ± 0.3
	M(MeV)	2230.0	2231.2 ± 1.1
$\xi(2230)$	Γ MeV	25.0	30.2 ± 4.5
	$Br(\times 10^{-6}$	3.0	3.2 ± 0.3

2.2 *Separation of* 0^{++}, 2^{++} *and* 4^{++} *in* $J/\psi \to \gamma K^+K^-$

The structures in the $M_{K^+K^-}$ high mass region is very complicated. Therefore, distinguishing 0^{++}, 2^{++} and 4^{++} in this region is important.

We take the example of $\xi(2230)$ and $f_4(2050)$ to see whether these two states can be separated. The $J/\psi \to \gamma\xi(2230)$ and $\gamma f_4(2050)$ events with $\xi(2230)$ and $f_4(2050)$ decaying to K^+K^- are generated based on the design of BESIII, assuming we have 1×10^9 J/ψ data. The main background channel $J/\psi \to K^*(892)K$ is included in the Monte-Carlo sample. For $\xi(2230)$, we assume that it is a 2^{++} state and its helicity amplitude ratios x and y are 0.5. And we assume $f_4(2050)$ is a 4^{++} state with x and y being 0.5 too. The partial wave analysis (PWA) of this Monte-Carlo sample shows that the J^{PC} of $\xi(2230)$ and $f_4(2050)$ being 2^{++} and 4^{++} gives the best Log Likelihood value. Fig. 2 shows the generated Monte-Carlo data compared with the PWA fit projection. Two states can be separated clearly.

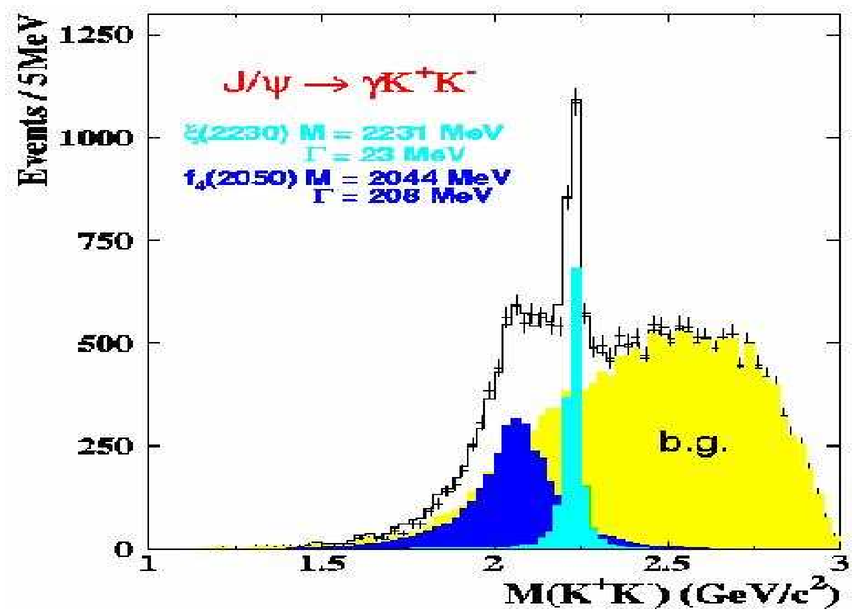

FIGURE 2. $M_{K^+K^-}$ mass spectrum. The crosses are generated Monte-Carlo data and the histogram is the PWA fit projection.

2.3 *Precise measurement of* $K^*(892)$ *mass splitting*

There is mass splitting between different isospin states $K^*(892)^\pm$ and $K^*(892)^0$. The different theoretical models give different mass splitting ΔM. A precise measurement of ΔM requires not only a large statistics but also a detector with good particle identification, good momentum resolution and energy resolution.

The ΔM can be measured from the decays of $J/\psi \to K^*(892)^0 K_s^0 + c.c.$ with $K^*(892)^0 \to K^\pm\pi^\mp, K_s^0 \to \pi^+\pi^-$ and $J/\psi \to K^*(892)^+K^- + c.c.$ with $K^*(892)^+ \to K_s^0\pi^+, K_s^0 \to \pi^+\pi^-$. About 685000 $J/\psi \to K^*(892)^\pm K^\mp$ and 575000 $J/\psi \to K^*(892)^0 K_s^0$ events out of a sample of 6×10^8 J/ψ data are generated according to their branching ratios. The backgrounds that are mainly from the channels listed in table 2, are added to the signals. The $K^*(892)^\pm$ and $K^*(892)^0$ signals are fitted by

$$BW = \frac{M_0\Gamma_0}{M_0^2 - M^2 - iM_0\Gamma_0}(\frac{p}{p_0})^3(\frac{q}{q_0})^3, \tag{1}$$

where, M is the invariant mass of $K_s^0\pi^\pm$ or $K^\pm\pi^\mp$, M_0 and Γ_0 are the mass and width of $K^*(892)^0$ or $K^*(892)^\pm$, p is the momentum of $K_s^0\pi^\pm$ or $K^\pm\pi^\mp$ in J/ψ system and q is the momentum of $K_s^0(K^\pm)$ in $K_s^0\pi^\pm$ ($K^\pm\pi^\mp$) center of mass system. The background is fitted by the 3rd. order polynomial. When the input ΔM is 6.0 MeV, we obtain the mass splitting as $5.8 \pm 0.2 \pm 0.1$ MeV, with the first error being the statistical error and the second being systematic. Therefore, we can precisely measure the mass splitting at BESIII/BEPCII.

TABLE 2. The background channels

Decay modes	Branching ratios	Events
$J/\psi \to K_1(1400)^\pm K^\mp \to K^*(892)^\pm\pi^0 K^\mp \to K_S^0\pi^\pm\pi^0 K^\mp$	2.7×10^{-4}	163380
$J/\psi \to K1(1400)^\pm K^\mp \to K^*(892)^0\pi^\pm K^\mp \to K_S^0\pi^0\pi^\pm K^\mp$	2.7×10^{-4}	163380
$J/\psi \to K1(1400)^\pm K^\mp \to K^*(892)^0\pi^\pm K^\mp \to K^\pm\pi^\mp\pi^\pm K^\mp$	1.6×10^{-3}	952800
$J/\psi \to K_S^0\bar{K}_2^*(1430)^0 \to K_S^0 K^\pm\pi^\mp$	2.3×10^{-4}	136920
$J/\psi \to K_S^0\bar{K}_2^*(1430)^0 \to K_S^0 K^*(892)^\pm\pi^\mp \to K_S^0 K^\pm\pi^0\pi^\mp$	3.8×10^{-5}	22593
$J/\psi \to K_S^0\bar{K}_2^*(1430)^0 \to K_S^0 K^*(892)^0\pi^0 \to K_S^0 K^\pm\pi^\mp\pi^0$	3.8×10^{-5}	22593
$J/\psi \to K_1(1270)^\pm K^\mp \to K_S^0\rho^\pm K^\mp \to K_S^0\pi^\pm\pi^0 K^\mp$	2.9×10^{-4}	172860
$J/\psi \to K_1(1270)^\pm K^\mp \to K^\pm\rho^0 K^\mp \to K^\pm\pi^\pm\pi^\mp K^\mp$	4.2×10^{-4}	252000
$J/\psi \to K_1(1270)^\pm K^\mp \to K^*(892)^\pm\pi^0 K^\mp \to K_S^0\pi^\pm\pi^0 K^\mp$	3.7×10^{-5}	21954
$J/\psi \to K_1(1270)^\pm K^\mp \to K^*(892)^0\pi^\pm K^\mp \to K^\pm\pi^\mp\pi^\pm K^\mp$	2.1×10^{-4}	127980
$J/\psi \to K_1(1270)^\pm K^\mp \to K^*(892)^0\pi^\pm K^\mp \to K_S^0\pi^0\pi^\pm K^\mp$	3.7×10^{-5}	21954
$J/\psi \to K^*(892)^0\bar{K}^*(892)^0 \to K^-\pi^+K^+\pi^-$	2.2×10^{-4}	133300
$J/\psi \to K^*(892)^0\bar{K}^*(892)^0 \to K^\pm\pi^\mp K_S^0\pi^0$	7.6×10^{-5}	45732

2.4 Simulation of $J/\psi \to D_s^+K^-$

In the standard model, the decay branching ratios of J/ψ to single D meson have typical values of $\sim 10^{-8}$ or smaller, and thus these processes are not easy to be observed. However, these processes can serve as a probe to the new physics. Recently, some theorists[3] have studied the possibility of searching for new flavor changing neutral current in the decay of J/ψ. We generated the decay of $J/\psi \to D_s^+K^-$ events based on a 10×10^{10} BESIII J/ψ data. The main background from $J/\psi \to \pi^+\pi^-K^+K^-$ is also simulated. If the branching ratio of $J/\psi \to D_s^+K^-$ is 1.0×10^{-6}, a clear D_s^+ signal can be seen in $K^+K^-\pi^+$ invariant mass from the simulation, as shown in the upper plot of Fig. 3, while if $Br(J/\psi \to D_s^+K^-) = 1.0\times10^{-7}$, an upper limit can be set as $Br(J/\psi \to D_s^+K^-) < 2.48\times10^{-7}$ at 90% $C.L.$.

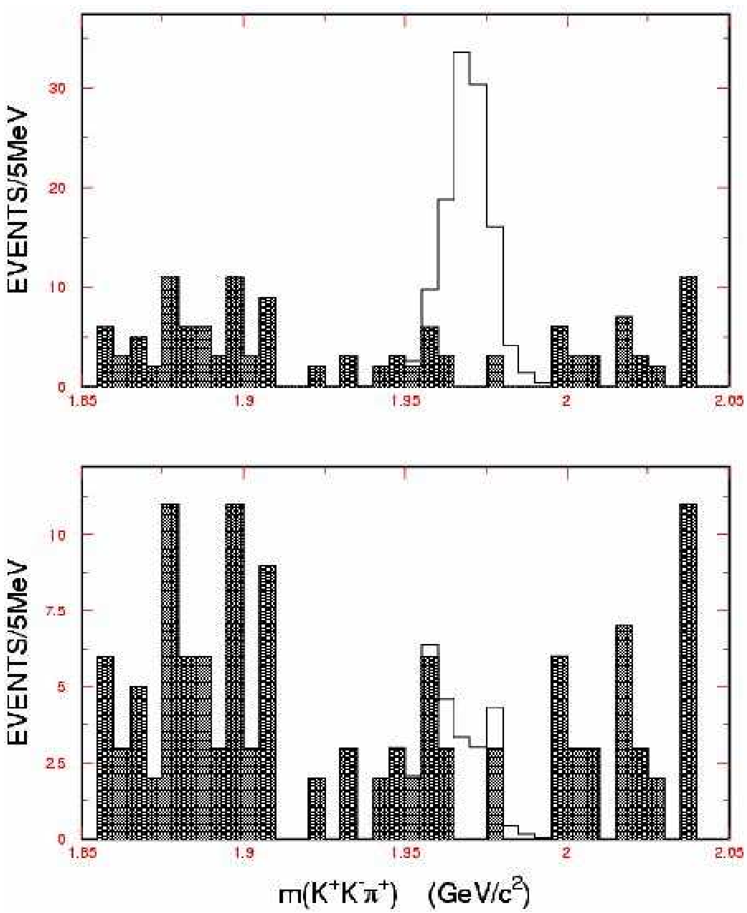

FIGURE 3. The $K^+K^-\pi^+$ invariant mass. Upper plot: $Br(J/\psi \to D_s^+K^-) = 1.0 \times 10^{-5}$, medium plot: $Br(J/\psi \to D_s^+K^-) = 1.0\times10^{-6}$, lower plot: $Br(J/\psi \to D_s^+K^-) = 1.0\times10^{-7}$

In summary, the search for non-$q\bar{q}$ states, the systematic study of the hadron spectroscopy, as well as the glueball and hybrid spectroscopies can be performed at BESIII/BEPCII. The J/ψ decays provide a good laboratory for the study of the strong interaction in the strongly coupled non-perturbative regime.

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Present and Future R measurements at CLEO

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Abstract: The CLEO collaboration has recently taken data for R at energies 7.0-11.3 GeV. These data are under analysis. Scans in the energy region 3.8-4.5 GeV are under active consideration for CLEO-c.

1 Introduction

Recognition of the importance of R is long-standing. As a total cross section, it gives a global view of particle physics at different energies.

$$R(s) = \frac{\sigma_{e^+e^- \to hadrons}(s)}{\sigma^{point}_{e^+e^- \to \mu^+\mu^-}(s)} \qquad (1)$$

This definition comes from theoretical significance rather than experimental convenience. The muon pair production cross section in the denominator is the point value, i.e. with all radiative corrections taken out. It is one of the small number of cross section tabulations maintained by PDG [1].

In modern times, it's a key component in a number of theoretical efforts to establish or predict fundamental quantities such as Higgs mass (M_H), running QED coupling constant ($\alpha_{QED}(M_Z)$), the strong coupling constant ($\alpha_S(M_Z)$), charm and bottom quark masses (m_c and m_b), and the muon anomalous magnetic moment ($(g-2)_\mu$). (See also talks by Haiming Hu and Su Dong at this workshop.) The hadronic corrections are the primary source of error in the electroweak predictions to $\alpha_{QED}(M_Z)$ and $(g-2)_\mu$. These corrections come from dispersion integrals over $R(s)$ weighted by $\sim s^{-1}$ and s^{-2}, respectively. Although lower energies are weighted more, the impact of a particular data set is a complicated function of the quality of the existing data and its interaction with other quantities in the electroweak calculations. Bolek Pietrzyk [2] finds that the electroweak prediction of M_H changes by $\sim$14 GeV when the *either* the existing data in the 1-2 GeV or 2-5 GeV regions are varied by 1 standard deviation of their quoted error bars. Therefore, data at CESR-c/BEPCII energies will have significant impact on M_H and $\alpha_{QED}(M_Z)$. In line with these important underlying physics goals, we need to measure R with $\leq$2% accuracy at these energies. There is also significant interest in the resonance structure at $\sqrt{s}$ >4.0 GeV. All reported knowledge [1] of $\psi(4S), (5S)$, and $(6S)$ comes from Breit-Wigner fits to total cross section data at least 20 years old [11]. Recent BES data [12] provided important new constraints of the Higgs mass prediction and caused doubt about the existing interpretation of the higher mass $\psi(4S), (5S)$, and $(6S)$.

Interest in the energy range of 7.0$\leq \sqrt{s} \leq$11.3 GeV is more phenomenological. The data in this region is important for determination of the bottom quark mass using the methods of Kuhn and Steinhauser [3]. We also provide a test of perturbative QCD (pQCD) predictions.

Various researchers put different value on these predictions. At one extreme, an older work of Davier and Hocker [4] use pQCD values down to $\sqrt{s}$ =1.8 GeV. With more data available, Burkhardt and Pietrzyk [5] take the more measured viewpoint that we should rely on data whenever possible, especially when the theory is unreliable. In addition, there is a long-standing doubt about the data for 5-7 GeV because of the disagreement between older Mark I [8] and Crystal Ball [9] data. Although the calculations are in good agreement with Crystal Ball and the recent Novosibrisk [7] data, most experts seek improved measurements of R to avoid any dependence on pQCD where it's uncertain.

2 CLEOIII R data

During the short period of time at energies below Υ(4S), data was taken for a potentially significant set of R values. Continuum data for Υ(1S), Υ(1S), and Υ(3S) were taken at $\sqrt{s}$ = 9.4, 10.0 and 10.33 GeV. Additional runs were taken across the Λ_b production threshold at 11.2 GeV and at lower energies (6.96, 7.38, and 8.38 GeV). Although the $\sqrt{s} \sim 11.2$ GeV data have somewhat lower statistics at a much tighter energy spacing, the other data sets have at least 10,000 hadronic events at each energy even with very tight cuts.

Data at energies below Υ(4S) are expected to be finalized in early 2005. Analysis at the higher energies is proceeding at a less rapid pace. It is presently clear that it is possible to have convincing measurements with systematic error of less than 2%.

3 R at CLEO-c energies

As discussed above, there is significantly more interest in data at lower energies. The priority of CLEO is now data-taking at Ψ(3770). Although direct R measurements are not possible in the near term, there is still a possibility of using radiative return for measurements down to low energies.

A scan of energies $3.8 \leq \sqrt{s} \leq 4.5$ GeV will require about 4-6 weeks of data-taking at projected CLEO-c luminosities. Time for energy changes has not been investigated yet, but will likely at least double the time. Time estimates assume 10 MeV steps in energy and 30,000 detected hadrons per step. Two major physics results can come from these data.

First, values of R with systematic errors of less than 2% will have a significant impact on the electroweak prediction of the Higgs' mass. With the experience at the Υ energies, similar systematic errors can be expected. The new LUNDAreaLaw generator which was written for BES data at the same energies should be appropriate with some adjustment of parameters. The estimated error on the Higgs' mass should decrease by about 10 MeV with these data. The BES data [12] also caused a significant shift in the value of the electroweak Higgs' mass because their data values were different than the previous values.

The second major study is the resonance structure in this energy region. Since the Ψ(4S), (5S) and (6S) states are above $D\overline{D}$ threshold, they have widths of ~40-80 MeV and sit on a continuum background. The parameters for these states come from Breit-Wigner fits to the older R values [11] assuming a non-interfering background. The energy dependence of the new BES data is quite different and the interpretation is less clear; BES declines to suggest a new interpretation of these states. We suggest that with the apparent complexity of interpreting the new data another experiment with more information is required. The CLEO detector can make accurate determination of the final state particles as $D\overline{D}$ and

$D^*\overline{D}$ with an efficiency of ∼0.36 (detecting one of the D's through a major decay channel) and of $D^*\overline{D^*}$ with an efficiency of ∼0.1 because a slow pion will have to be detected to uniquely define the final state. With an estimated fraction of 30% of the hadronic states populated by D's and assuming the final states to be equally populated, we estimate a sample of about 5000 events per energy where the hadronic content will be fully identified. That will allow a modern partial wave analysis (hence we call this a *modern R measurement*) to be done. The results of this analysis will provide parameters of the higher Ψ states with excellent accuracy.

Finally, there was an odd feature seen in the Mark I data [13] that has defied explanation for many years. They measured properties of the decays for the first time. The D_0 momentum spectrum measured at 4.028 GeV has peaks corresponding to the many decay paths by which it can be produced. Although they fit this spectrum to 8 Breit-Wigners, the most basic signature for D^*D^* is strong since it gives the lowest momentum D's. Despite being just 15 MeV above the threshold for this decay path, the ratio of phase space weighted $D^*D^* : DD$ is 640± ∼60% with theoretical estimates much smaller [14]. BES remeasured the D_0 momentum spectrum at the same energy [15] and it looks very similar to the older SLAC data.

The 2 physics goals unfortunately have somewhat different requirements. The Higgs' mass prediction requires an excellent systematic error on a total cross section. Spacing of the energy points in the scan can be looser than for the spectroscopy measurement. Although 10 MeV spacing is probably required to get good spectroscopy information, spacing of 15 MeV should work for the electroweak value. The spectroscopy measurement also requires better statistics because of the need to accurately define the final state. Assuming the time for the energy changes to dominate the calendar time, it makes sense to get the larger data samples required for the spectroscopy information. This trade-off can be varied depending on the priorities expressed.

4 Conclusions

Data for R at the lower energies is very interesting to the world and deserves to be a priority with the CLEO and BES collaborations. However, the CLEO-c Yellow Book suggested data-taking at only a few selected energies for testing the absolute magnitude. If the CLEO collaboration decides to invest time in the energy scan briefly described here, two significant physics programs will be in hand. If CLEO is unable to make these measurements, it will be a great opportunity for an upgraded BES. The BES proposal weights this program correctly.

Acknowledgments

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Tau Physics

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Abstract: Precise measurements of the lepton properties provide stringent tests of the Standard Model structure and accurate determinations of its parameters. The tau–charm factory will allow an extensive programme of high–precision studies of the τ lepton to confront the current theoretical framework and explore the frontier of its possible extensions.

The known leptons are clean probes to perform very precise tests of the electroweak gauge structure. Moreover, the hadronic τ decays turn out to be a beautiful laboratory for studying strong interaction effects at low energies. Accurate determinations of the QCD coupling and the strange quark mass have been obtained with τ decay data [1]. Very recently, the first hints of new physics beyond the Standard Model have also emerged from the lepton sector. Convincing evidence of neutrino oscillations has been obtained by SNO and Super-Kamiokande. Combined with data from other neutrino experiments, it shows that $\nu_e \to \nu_{\mu,\tau}$ and $\nu_\mu \to \nu_\tau$ lepton-flavour-violating transitions do occur [2].

The large statistics and high precision of the tau–charm factory (τcF) should push the significance of the τ tests beyond the present few per cent level. The ability to control backgrounds and systematic errors makes the τcF an ideal experimental environment for τ physics. Among the extensive list of physics topics that the τcF can address, I would like to mention:

- **Universality.** The present data verify the universality of the leptonic charged–current couplings to the 0.2% level. In addition to a more precise measurement of the τ mass at CLEO-c or at the τcF, further improvements require a better determination of the leptonic branching fractions (present accuracy 0.35%) and the τ lifetime (present accuracy 0.31%). While the τcF could make precise measurements of the τ decay rates, a high–precision study of the τ lifetime should be attempted at the B factories.

- **Lorentz Structure.** The $V - A$ structure of the leptonic currents has been determined with good precision only in μ decays. The accuracy of the present τ data is still not good enough to provide strong constraints; nevertheless it shows that the Standard Model gives indeed the dominant contribution to the τ decay amplitudes. Present measurements of the τ polarization put a limit of 3.2% (90% CL) on the probability of having a (wrong) decay from a right–handed τ, but the polarization of the final lepton has never been measured. Large room for improvements appears to be possible.

- **Hadronic Decays.** The semileptonic τ decay modes probe the matrix element of the left–handed charged current between the vacuum and the final hadronic states. Precise measurements of the exclusive decay rates and kinematical distributions would provide important information [1,3] to improve our theoretical understanding of strong interactions in the non-perturbative regime (chiral dynamics, confinement, ...) and make better evaluations of the QCD corrections to quantities like the muon anomalous magnetic moment. The present τ Monte Carlo libraries should be updated to match the quality of the most recent theoretical developments,

- **QCD Tests.** The inclusive character of the total τ hadronic width renders possible an accurate calculation, using analyticity constraints and the Operator Product Expansion [4]. One can separately compute the contributions associated with specific quark currents (vector, axial, strange) and moments of their invariant mass distributions. High–precision data sets can be used to perform important perturbative (α_s) and non-perturbative (vacuum condensates, chiral sum rules, ...) tests of QCD [1].

- **Strange Quark Mass and $|V_{us}|$ Determination.** The separate measurement of the $|\Delta S| = 0$ and $|\Delta S| = 1$ τ decay widths allows us to pin down the SU(3) breaking effect induced by the strange quark mass. The present m_s determination [5] is based on the ALEPH analysis of Cabibbo suppressed decays, which has a rather low statistics. High–precision studies at the τcF and the B factories would improve the accuracy of the strange quark mass and could even lead to a determination of $|V_{us}|$ more precise than the current world average [6].

- **New Physics Searches.** The non-zero value of neutrino masses constitutes a clear indication of new physics beyond the Standard Model framework. The existence of lepton flavour violation opens a very interesting window to unknown phenomena. The present data on neutrino oscillations implies a lepton mixing structure very different from the one in the quark sector. The smallness of the neutrino masses suggests a strong suppression of neutrinoless lepton-flavour-violation processes, but this suppression can be avoided in models with other sources of lepton flavour violation not related to m_{ν_i}. An important question to be addressed in the future concerns the possibility of leptonic CP violation and its relevance for explaining the baryon asymmetry of our universe through a leptogenesis mechanism.

An extensive study of the τ properties should be an important priority of the τcF. In addition to probe the Standard Model to a much deeper level of sensitivity, it could allow to explore interesting and totally unknown phenomena.

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Opportunities for τ Physics at CLEO-c and BESIII

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Abstract: BESIII and CLEO-c offer a new regime in which to study the τ lepton with high statistic samples. I cover a few interesting studies and emphasize the added value that these programs represent relative to the high statistic samples available at the B Factories.

1 Overview of τ's at low energy

The lowest order τ pair production cross section via e^+e^- annihilation is given by:

$$\sigma_{\tau\tau}^{(0)} = \frac{4\pi\alpha^2}{3s}\frac{(3\beta - \beta^3)}{2} \tag{1}$$

This cross section is modified by radiative effects, beam energy width and tau pair electromagnetic corrections. This cross section turns on sharply at about 3.55 GeV, and rises to hit a maximum near 4.25 GeV after which the cross section falls like $1/s$. The CLEO-c running proposal, as detailed in [1], calls for 0.25 fb^{-1} a few MeV above threshold, and 3 fb^{-1} at each of the ψ'' and $D_s^+D_s^-$ production energies. This running proposal is not yet a guaranteed running plan. If data are taken at these energies, there will be a small low background sample of τ pairs near threshold ($\approx 10^5$), and a much larger sample ($\approx 10^7$) with a charm background. These samples are to be compared to the $\Upsilon(4s)$ CLEO sample of $\approx 1.5 \times 10^7$ and the B factory samples of over 10^8 τ pairs. Obviously, the key in such a program is to exploit interesting niches available at low energies to beat the relative statistical weakness of the sample. The BESIII running program is not yet firmly established, and has the advantage that it comes after CLEO-c and is open ended.

2 Event Kinematics

At e^+e^- colliders, τ's are produced in pairs, with perhaps an initial state radiation photon accompanying them. Each τ always has at least one neutrino in its decay, and thus a key indicator of τ pair production is the presence of missing energy and momentum. Near threshold, the momentum of the τ decay products is much less than that at the B Factory. Because of this, a hadronic τ decay, with only 1 missing ν, will have a sharp momentum distribution for any narrow hadronic state. This makes the possibility of using the $\tau \to \pi\nu$ and $\tau \to \rho\nu$ decays in addition to the usual lepton final state tags more useful than at the B Factories. The low energy of the τ's also ensures that the maximum energy of the decay products is always much less than that of the Bhabha and μ pair background, making them a negligible background compared to B-Factories. In addition, the low energy production near threshold makes initial state radiation (ISR) from the collider electrons and positrons and final state radiation (FSR) from the τ's less significant than at higher energies, resulting in more well defined τ production and decay energies, better τ^+ - τ^- pair spin correlations and cleaner events.

Unfortunately at low energies, the decay products from each τ are not as nicely separated into hemispheres as at higher energies. This will make disentangling the τ's from each other and from other backgrounds more difficult. Below charm threshold, the main background will be (uds) pair production. Understanding this background for Monte Carlo tuning purposes will require a sample of events taken below the τ. For the backgrounds due to charm at higher energy, the ultimate Monte Carlo tuning will likely be done by using tagged D samples from the data.

3 Tau Mass

The value of the τ mass is a fundamental parameter in the Standard Model and is also an input to precision studies and lepton universality studies. The current best measured value is from BES: $m_\tau = 1.776.96^{+0.18+0.25}_{-0.21-0.17}$ MeV. This was obtained by using a 5 pb^{-1} scan taken over two months at BEPC. Both CLEO-c and BESIII will be able to increase the sample size for such a measurement by a factor of at least 50, thus decreasing the statistical error dramatically. Most of the systematic error in the measurement comes from knowing the accelerator energy scale by scanning over the ψ and ψ' peak. It is believed that this systematic can be decreased sufficiently to bring the total error on m_τ to 0.1 MeV. This measurement cannot be done at any other facility.

4 Very Massive Neutrinos and Exotic Decays

The almost monochromatic momentum spectrum of charged particles in two body τ decays means that searches for displaced peaks due to massive unseen particles are much easier at low energy facilities than at B factories. For instance, one can rule out the existence of a ≈ 100 MeV neutrino in addition to the usual (almost) massless neutrino in the decay $\tau \to \pi\nu$ with branching ratios at the several per mil level and improve upon the current limit for an exotic unseen boson in the decay $\tau \to e^- X$ substantially. In more conventional physics, low energy running offers a unique laboratory near threshold for looking at radiative decays such as $\tau \to l\nu\nu\gamma$. Near threshold, the ISR and FSR diagrams no longer contribute, simplifying the background subtraction. At low energies, there is a greater separation between the lepton and the radiated photon than at B Factories allowing a finer scale angular discrimination. In addition, CLEO-c and BESIII have access to photons that are emitted opposite to the daughter lepton - this is an unexplorable regime at B Factories. The small threshold sample at CLEO-c should easily decrease the total error on the relative branching ratios by a factor of 10. BESIII's reach will easily surpass this.

5 Tau Atoms

In e^+e^- collisions just below the τ threshold, virtual $\tau^+\tau^-$ pairs should form bound states, just like positronium [2]. These bound states should decay either via direct τ decay or via $\tau^+\tau^-$ annihilation for pairs in an S state. The peak cross section for this is estimated to be 1 mb, although the width is quite narrow ($\approx 10^{-3}$eV). Convoluting with the expected beam energy spread at CLEO-c and BESIII, the production cross section for $\tau\tau$ atoms should be on the order of 0.1 nb. There is no hope of detecting the keV gamma rays in the transitions between different $\tau\tau$ atom excited states, and the direct τ decays would be indistinguishable from normal τ decays just at threshold. It is possible that one might be able to see the annihilation of τ pairs directly into μ pairs relative to the total Bhabha cross section by monitoring this quantity in a scan. Simple minded estimates indicate that 0.25 fb^{-1} might be sufficient for this purpose if muon ID systematics can be sufficiently well controlled. It might also be interesting to investigate the annihilation into 3 photons to see if this is visible.

6 Neutrinoless Decays

Current limits on 2 body neutrinoless tau decays are at the 10^{-5} to 10^{-6} level. It is likely that in many of these modes, B Factories will soon hit irreducible backgrounds and the limits will not decrease quickly. If one can get good enough particle ID discrimination between $e/\mu/\pi$ and K near 1 GeV, then it is quite conceivable that BESIII could explore the BR $\approx 10^{-7}$ regime.

7 Precision Branching fractions

Precision branching fractions for leptonic decay modes feed into lepton universality studies and measurements of the total relative semi leptonic branching fraction, R_τ, for QCD studies. For these, current measurements are systematically limited by luminosity and τ cross section systematics. For the hadronic final states π, ρ, K and K^*, the promise of CLEO-c and BESIII is in lowering the error in relative branching ratio measurements to the 1% level.

8 Michel Parameters

The Michel parameters describe the spectrum of leptonic decays of the τ:

$$\frac{d\Gamma}{dxd\cos\theta} \propto x^2[h_0(x) + \rho h_\rho(x) + \eta\frac{m_l}{m_\tau}h_\eta(x) + P_\tau\xi\cos\theta(h_\xi(x) + \delta h_\delta(x))]) \tag{2}$$

While the statistical power of the B factories is quite large, measurements at low $\sqrt{s}$ have a few interesting niches. The Michel parameter η, which is measurable only in $\tau \to \mu\nu\nu$ since it multiplies the lepton mass, should be measurable down to the level of $\eta \approx 0.05$, a factor of four below the current limit. The superior BESIII muon identification at lower energies compared to CLEO-c will give it a substantial advantage. The parameters ξ and δ are accessible at B factories through longitudinal spin correlations in leptonic decays recoiling against a spin analyzing decay such as $\tau \to \rho\nu$. These correlations are transverse near threshold and thus allow for a systematically different analysis. In addition, the lack of ISR/FSR near threshold will reduce the dilution of these spins correlations. Detailed studies however are needed to understand the potential gain due to this.

9 Hadronic Structures

The τ lepton decays mostly to hadrons and a neutrino. The simple initial state of these decays makes the τ an interesting laboratory for QCD. While the B factories will have much more statistical power than either CLEO-c or BESIII for these kinds of studies, the combination of sample purity and excellent detector resolution will make BESIII an important player in the study of the ρ line shape. This line shape is an important input to muon g-2 studies.

10 CP Violation

CP violation in τ decay is most sensitively studied by using spin correlations in between the two τ in an event. Since the spin correlations are transverse at low energies and longitudinal at higher energies, BESIII will be able to probe CP violation in a way that is different from what the B factories can do. Detailed simulations are required to understand the true reach.

11 Neutrino Mass

Current ν_τ mass limits, near 18 MeV, are obtained by looking at the endpoint of multi-pion τ decays in the hadronic energy versus mass plane. The dominant systematic error contributions are the understanding of the 2 dimensional detector resolution function, the accelerator energy scale and the underlying hadronic physics. The two dimensional method is quite sensitive to the presence of lucky events near the endpoint, rendering the meaning of an upper limit questionable. As $\sqrt{s}$ decreases, the roughly triangular allowed region collapses down to a line, making the systematics of the measurement different than at higher energies. At lower energies, it might be possible to use the lack of ISR/FSR near threshold to make the measurement more sensitive per event. BESIII and CLEO-c are also expected to have smaller error ellipses than the B-factories rendering each event observed even more sensitive. Below charm threshold, it will likely be possible to use looser cuts than at B-factories. This will also contribute to the sensitivity of low energy running. Previous estimates of prototype Tau Charm Factories reach indicate that a limit on the order of 10 MeV is quite possible [3].

12 Conclusions

In spite of the luminosity advantages of the B factories, it is clear that BESIII and CLEO-c will play an important role in tau physics. There are many unique niches at lower energies that make BESIII and CLEO-c key players. A run that includes a scan about the tau mass, a large sample just below charm threshold and a large sample near the tau cross section peak above charm threshold, in addition to a background normalization sample below tau threshold will allow for important contributions in all sectors of tau analysis.

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Λ_c^+ Physics at the Energy Threshold

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Abstract: This is a review of what we know, and what we do not know about the Λ_c^+, with an accent on what new knowledge can be gained but running with e^+e^- annihilations (just) above threshold.

1 Introduction

A Λ_c^+ is a *cud* quark combination in an iso-singlet configuration. The ground state Λ_c^+ is the lowest-lying of the charmed baryons; all higher Λ_c and Σ states decay into it, leaving it to decay weakly. Historically, most of the information we have on the Λ_c^+ comes from e^+e^- annihilations at B meson energies (in particular by CLEO), with notable contributions from fixed target experiments. There has only been one experiment investigating e^+e^- annihilations in the 4.5-5.5 GeV region (MARK II at SPEAR)[1]. They made a major contribution to our knowledge by making the first reliable measurement of the Λ_c^+ mass, and they are the only experiment with a cross-section measurement in the threshold region.

2 Mass Measurements

The Λ_c^+ mass is not measured as well as mass differences of charmed baryons. The most precise measurement was by CLEO I and was systematically limited by uncertainties in the amount of energy loss of particles traversing the material of the inner detector. At threshold, a beam-constrained mass can be calculated, minimizing these uncertainties, and the definitive measurement should be possible.

3 Hadronic Decay Measurements

The lifetime of the Λ_c^+ is now well measured by fixed target experiments, and in any case cannot be measured in a threshold experiment. Many branching ratios are known, and although there is more work to be done, the relative sizes of the three basic decay mechanisms (external W-decay, internal W-decay and W-exchange) can be estimated. However, only relative decay rates are well known. To convert these ratios into absolute branching fractions, it is usual to use $\Lambda_c^+ \to pK^-\pi^+$ as the "normalizing" mode. It is the largest mode, and generally the easiest to detect, although it is unfortunately a three-body decay with resonant sub-structure that affects the detector resolution. Without knowing an absolute branching fraction for a Λ_c^+ decay mode, we do not know how many charmed baryons are being produced in a reaction. This gap in our knowledge has wide-ranging ramifications, notably in B physics, where it limits the knowledge of the overall $b \to c$ decay rate.

All previous methods to meadure a Λ_c^+ absolute branching fraction are either flawed, or are limited by systematic uncertainties. The obvious, and almost fool-proof method is to run at an e^+e^- machine just above Λ_c^+ threshold, where Λ_c^+'s are produced in pairs. The optimum energy is unknown; the SLAC data shows rising baryon production in the threshold region, with no plateau until around 5.2 GeV center-of-mass. Ideally we would prefer to run *just* above threshold where no other particles can be produced, but probably the cross-section would not be high enough. As the energy increases, complications arise from Σ_c production, then Ξ_c production, but the biggest disadvantage of running at higher energy will be once pD production is possible (5.08 GeV). At that point, one Λ_c^+ in the event will not guarantee the existence of another. Clearly it would be ideal to first have a scan of the 5 GeV region to measure the $\Lambda_c^+ \to pK^-\pi^+$ rate before settling on a final run plan.

Mark II at SLAC measured $\sigma.B(\Lambda_c \to pK^-\pi^+)$ of 0.037 ± 0.012 nb. This implies that for 1 fb^{-1} of running, 37000 $\Lambda_c \to pK^-\pi^+$ decays will be produced. The efficiency should be high, maybe 50%[2], as the momentum spectra of the particles is convenient both for detection and species identification. Based upon these numbers, we can expect 500 clean, fully reconstructed $e^+e^- \to \Lambda_c^+\overline{\Lambda_c^+} \to pK^-\pi^+\overline{p}K^+\pi^-$ events per $1fb^{-1}$. This should yield a statistical uncertainty in the measurement of 4.5% of itself, and would be easily the definitive world measurement. Moreover, the measurement should be statistically limited, and free from the systematic uncertainties that plague measurements that could be made at the B factories.

4 Other Measurements

The large luminosities available at the B-factories make is possible to do many exclusive decay mode measurements. However *inclusive* measurements such as $\Lambda_c^+ \to \Lambda, \Sigma$ etc. can be better performed with a threshold experiment, and these are important "engineering" numbers that will be used in many experiments' Monte Carlo generators. More importantly from a theory standpoint will be the study of semi-leptonic decays. Although the decay $\Lambda_c^+ \to \Lambda l\nu$ is fairly well understood, there is almost no information of semi-leptonic decays that do not have an unaccompanied Λ as the hadron in the final state. A threshold experiment can easily make such studies possible.

5 Conclusions

Running an e^+e^- annihilation machine at $E \approx 5$GeV can yield the definitive measurement of the absolute branching fraction $B(\Lambda_c^+ \to pK^-\pi^-)$. There are large uncertainties in our knowledge of the cross-section, and also the analysis efficiency, however, we estimate a statistical uncertainty of 4.5% of itself is possible with an integrated luminosity of 1 fb^{-1}. Running at threshold will also yield the best measurements of the Λ_c^+ mass, inclusive decay rates, and semi-leptonic decay rates.

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$D^0-\bar{D}^0$ Mixing, CP Violation and Rare Decays

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Abstract: We review the prospects to study $D^0-\bar{D}^0$ mixing, CP violation and rare decays with charm produced near threshold at the CLEO-c and BESIII experiments.

CLEO-c[1] and BESIII[2] will have the opportunity to probe for physics beyond the Standard Model. Three highlights - $D^0-\bar{D}^0$-mixing and CP violation, rare charm decays - are discussed in the following sections.

1 $D^0\bar{D}^0$-Mixing

Neutral flavor oscillation in the D meson system is highly suppressed within the Standard Model. The time evolution of a particle produced as a D^0 or $\bar{D}^0$, in the limit of CP conservation, is governed by four parameters: $x = \Delta m/\Gamma$, $y = \Delta\Gamma/2\Gamma$ characterize the mixing matrix, δ the relative strong phase between Cabibbo favored (CF) and doubly-Cabibbo suppressed (DCS) amplitudes and R_D the DCS decay rate relative to the CF decay rate [3]. Standard Model based predictions for x and y, as well as a variety of non-Standard Model expectations, span several orders of magnitude [4]. The mass and width differences x and y can be measured in a variety of ways. The most precise limits are obtained by exploiting the time-dependence of D decays [3]. Time-dependent analyses are not feasible at CLEO-c and BESIII; however, the quantum-coherent $D^0\bar{D}^0$ state provides time-integrated sensitivity to x, y at $\mathcal{O}(1\%)$ level and $\cos\delta \sim 0.05$ [1,5]. These projected results compare favorably with current experimental results; see Fig. 1 in Ref. [3].

By tagging one of the mesons as a CP eigenstate, y can be determined by measuring the flavor specific branching ratios of the other meson. The flavor tag width is independent of the CP quantum number however the branching ratio is inversely proportional to the total width. Consequently, charm threshold experiments have time-integrated sensitivity to y.

The decay $D^0 \to K_S\pi^+\pi^-$ is measured with a Dalitz plot analysis to proceed through intermediate states that are $CP+$ eigenstates, such as $K_S f_0$, $CP-$ such as $K_S\rho$ and flavor eigenstates such as $K^{*-}\pi^+$ [3]. The presence of mixing through y would introduce an intensity modulation across the Dalitz plot as a function of the CP of the contributing amplitudes. Preliminary estimates suggests a limit of $y < 0.6\%$ @95% confidence level is attainable with the the CLEO-c data.

2 CP Violation

Standard Model predictions for the rate of CP violation in charm mesons are as large as 0.1% for D^0 decays and as large as 1% for certain D^+ and D_s^+ decays [6]. The production process $e^+e^- \to \psi(3770) \to D^0\bar{D}^0$ produces an eigenstate of $CP+$, in the first step, since the $\psi(3770)$ has J^{PC} equal to 1^{--}. Now consider the case where both the D^0 and the $\bar{D}^0$ decay into CP eigenstates. Then the decays $\psi(3770) \to f_+^i f_+^j$ *or* $f_-^i f_-^j$ are forbidden, where f_+ denotes a

$CP+$ eigenstate and f_- denotes a $CP-$ eigenstate. This is because $CP(f^i_\pm\ f^j_\pm) = (-1)^\ell = -1$ for the $\ell = 1$ $\psi(3770)$. Hence, if a final state such as $(K^+K^-)(\pi^+\pi^-)$ is observed, one immediately has evidence of CP violation. Moreover, all $CP+$ and $CP-$ eigenstates can be summed over for this measurement. The expected sensitivity to direct CP violation is $\sim 1\%$. This measurement can also be performed at higher energies where the final state $D^{*0}\bar{D^{*0}}$ is produced. When either D^* decays into a π^0 and a D^0, the situation is the same as above. When the decay is $D^{*0} \to \gamma D^0$ the CP parity is changed by a multiplicative factor of -1 and all decays $f^i_+ f^j_-$ violate CP [7]. Additionally, CP asymmetries in CP even initial states depend linearly on x allowing sensitivity to CP violation in mixing of $\sim 3\%$ [1].

A Dalitz plot analysis of multibody final states measures amplitudes and phases rather than the rates and so may provide greater sensitivity to CP violation. In the limit of CP conservation, charge conjugate decays will have the same Dalitz distribution. Although the D^+ and D^+_s decays are self-tagging, there have been no reported Dalitz analyses that search for CP violation with charged D's. The decay $D^0 \to K_S\pi^+\pi^-$ proceed through intermediate states that are $CP+$ eigenstates, such as $K_S f_0$, $CP-$ such as $K_S\rho$ and flavor eigenstates such as $K^{*-}\pi^+$ [8]. It is noteworthy that for uncorrelated D^0 the interference between $CP+$ and $CP-$ eigenstates integrates to zero across the Dalitz plot but for correlated D the interference between $CP+$ and $CP-$ eigenstates is locally zero. The Dalitz plots for $\psi(3770) \to D^0\bar{D}^0 \to f_+K_S\pi^+\pi^-$ and $\psi(3770) \to D^0\bar{D}^0 \to f_-K_S\pi^+\pi^-$ will be distinct, as illustrated in Fig. 1, and the Dalitz plot for the untagged sample $\psi(3770) \to D^0\bar{D}^0 \to XK_S\pi^+\pi^-$ will be distinct from that observed with uncorrelated D's from continuum production at ~ 10 GeV [3]. The sensitivity at CLEO-c to CP violation with Dalitz plot analyses has not yet been evaluated.

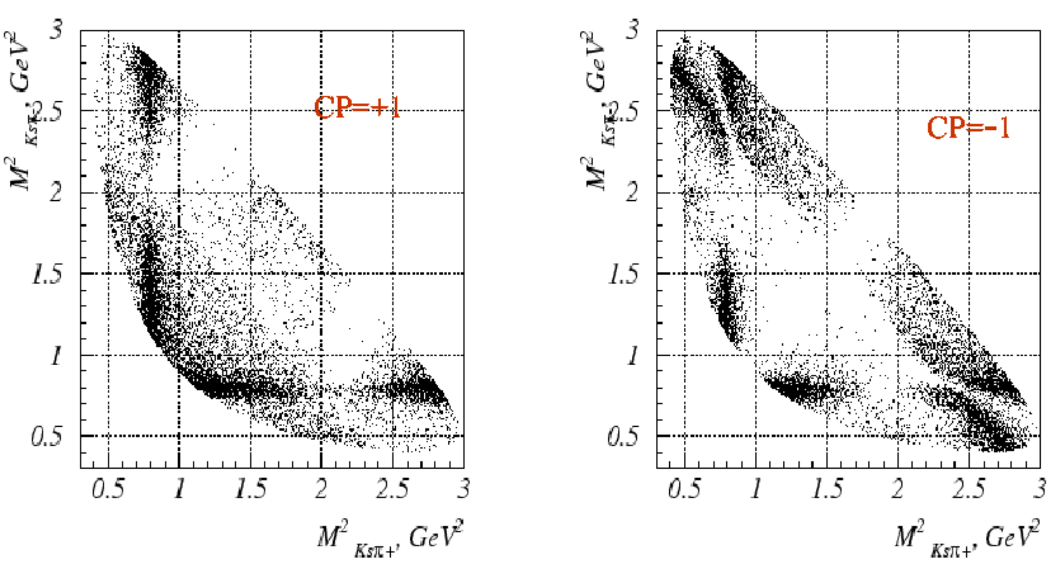

FIGURE 1. Monte Carlo Dalitz distributions for $D^0 \to K_S\pi^+\pi^-$ vs $CP\pm$ tag.

3 Rare Charm Decays

Rare decays of charmed mesons and baryons provide "background-free" probes of new physics effects. In the framework of the Standard Model (SM) these processes occur only at one loop level. SM predicts vanishingly small branching ratios for processes such as $D \to \pi/K^{(*)}\ell^+\ell^-$ due to the almost perfect GIM cancellation between the contributions of strange and down quarks. This causes the SM predictions for these transitions to be very uncertain. In addition, in many cases annihilation topologies also give sizable contribution. Several model-dependent estimates exist indicating that the SM predictions for these processes are still far below current experimental sensitivities [9,10].

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