Light Hadron Spectroscopy and Charmonium

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During the last few years there has been a renaissance in charm and charmonium spectroscopy with higher precision measurements at the $\psi'$ and $\psi(3770)$ coming from BESII and CLEOc and many new discoveries coming from B-factories. In this paper, I review some new results on “classical” charmonium and $e^+e^- \rightarrow$ hadrons using B-factory Initial State Radiation and two photon events.

I. INTRODUCTION

In recent years, there has been tremendous progress in charm and charmonium spectroscopy with many new results from Belle, BaBar, CDF, D0, BES and CLEOc. I will review recent results on “classical” charmonium; Galina Pakhlova (see her paper in these proceedings) covers exotic charmonium states: X, Y, Z, etc.

Charmonium provides detailed information on QCD in the perturbative and non-perturbative regimes, as well as providing a laboratory for precision tests of lattice QCD and effective field theory [1].

Charmonium may be produced by $e^+e^-$ annihilation, $B$ decays, $e^+e^-$ annihilation where one or both electrons loses energy by Initial State Radiation (ISR), and two photon processes. The very high luminosity of B-factories allow the use of the latter two even though their cross sections are suppressed. Only $J^{PC}=1^{--}$ charmonium states can be produced directly in $e^+e^-$ annihilation. However states below the $\psi(2S)$ may be produced by $\psi(2S)$ radiative and hadronic transitions, a technique which has been used extensively by BES and recently by CLEOc.

I will also cover some light hadron spectroscopy results, including the $Y(2175)$ and $\phi(1680)$, two photon results at Belle, and ISR results at BaBar, and I will report the status of BEPCII and BESIII. I apologize to everyone whose results I do not cover because of lack of time and space. Please see the references for details.

II. CHARMONIUM RESULTS

Recently CLEOc obtained 27 million $\psi(2S)$ events and has reported many new high precision results using this sample. This is the world’s largest $\psi(2S)$ sample produced in $e^+e^-$ collisions.

A. $\psi(2S) \to J/\psi$ transitions

CLEOc has studied $\psi(2S) \to J/\psi$ transitions using $J/\psi \to e^+e^-$ and $\mu^+\mu^-$ decays to identify the $J/\psi$ [2]. A summary of their branching fraction results is shown in Table I, along with those of the Particle Data Group (PDG). Using the product $\chi_c$ branching fractions and $B(\psi(2S) \to \gamma \chi_cJ) = (9.4 \pm 0.4)\%$, $(8.8 \pm 0.04)\%$, and $(8.3 \pm 0.4)\%$ [3] for $J=0, 1, 2$, respectively, the $B(\chi_cJ \to \gamma J/\psi)$ radiative branching fractions are obtained and also listed in Table I. Precision branching fractions are important since $\psi(2S)$ production and decay is a primary means of producing $\chi_c$ states, and $\psi(2S)$ production in many experiments is measured by the narrow mass peak recoiling against the $\pi^+\pi^-$ in $\psi(2S) \to \pi^+\pi^- J/\psi$ decay.

B. $J/\psi$ and $\psi(2S) \to \gamma \eta_c$

The precise determination of the $\eta_c$ mass provides information on the hyperfine splitting of the $\eta_c$ and $J/\psi$. However, although there have been many measurements of the $\eta_c$ mass and width, the measurements do not agree very well, and the fitted masses and widths in the PDG [3] have very low confidence levels: 0.002 for the mass and < 0.0001 for the width. Further, the masses obtained from $J/\psi$ and $\psi(2S)$ decays are about 5.3 MeV/c$^2$ or 3$\sigma$.
lower than those obtained from $\gamma\gamma$ fusion and $p\bar{p}$ annihilation. Another problem is that the branching fraction for $J/\psi \rightarrow \eta_c$, $B(J/\psi \rightarrow \eta_c) = 1.3 \pm 0.4\%$ [3], is very low compared to recent Lattice QCD results, $B(J/\psi \rightarrow \eta_c) = 2.1 \pm 0.1 \pm 0.4\%$ [4].

Studying $J/\psi \rightarrow \eta_c$ and $\psi(2S) \rightarrow \eta_c$ is very important since these are magnetic dipole (M1) transitions, and their branching fractions are necessary for normalizing $\eta_c$ branching fractions.

CLEOc studied these decays using 24.5 million $\psi(2S)$ events [5]. They obtained the branching fractions by fitting the $\gamma$ energy spectrum using three samples, (1) $\psi(2S) \rightarrow \gamma \eta_c$, inclusive, (2) $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow \eta_c$, $\eta_c \rightarrow X_i$, and (3) $\psi(2S) \rightarrow \gamma \eta_c$, $\eta_c \rightarrow X_i$, where $X_i$ denotes 12 exclusive $\eta_c$ hadronic decays. Sample (2) was used to determine the $\gamma$ line shape, shown in Fig. 1. Interestingly, they find that the line shape can not be fitted by a simple Breit-Wigner plus a resolution function, and an empirical shape was used. Their branching fraction results compared with the PDG are shown in Table II. The values are very different than the PDG and will affect all $\eta_c$ branching fractions. Their $B(J/\psi \rightarrow \eta_c)$ agrees much better with the Lattice QCD prediction above.

### TABLE I: Branching fractions for $\psi(2S) \rightarrow J/\psi$ transitions from CLEOc [2]. $B(\psi(2S) \rightarrow \gamma \chi_{cJ})$ values from Ref. [3] are used to obtain the CLEOc $\chi_c \rightarrow \gamma J/\psi$ radiative branching fractions, and the last error for them is from this branching fraction.

| Channel                  | B(%) CLEOc       | B(%) PDG08 [3]     |
|--------------------------|------------------|--------------------|
| $\pi^+\pi^- J/\psi$      | 35.04 ± 0.07 ± 0.77 | 32.6 ± 0.5       |
| $\pi^0\pi^0 J/\psi$      | 17.69 ± 0.08 ± 0.53 | 16.84 ± 0.33     |
| $\eta J/\psi$            | 3.43 ± 0.04 ± 0.09 | 3.16 ± 0.07       |
| $\pi^+ J/\psi$           | 0.133 ± 0.008 ± 0.003 | 0.126 ± 0.013   |
| $\gamma \chi_{c0} (\chi_{c0} \rightarrow J/\psi)$ | 0.125 ± 0.007 ± 0.013 | 0.120 ± 0.010   |
| $\gamma \chi_{c1} (\chi_{c1} \rightarrow J/\psi)$ | 3.56 ± 0.03 ± 0.12 | 3.15 ± 0.08     |
| $\gamma \chi_{c2} (\chi_{c2} \rightarrow J/\psi)$ | 1.95 ± 0.02 ± 0.07 | 1.66 ± 0.04     |
| anything $J/\psi$        | 62.54 ± 0.16 ± 1.55 | 57.4 ± 0.9       |
| $\chi_{c0} \rightarrow \gamma J/\psi$ | 1.32 ± 0.07 ± 0.14 ± 0.06 | 1.28 ± 0.11   |
| $\chi_{c1} \rightarrow \gamma J/\psi$ | 40.5 ± 0.3 ± 1.4 ± 1.8 | 36.0 ± 1.9     |
| $\chi_{c2} \rightarrow \gamma J/\psi$ | 23.5 ± 0.2 ± 0.8 ± 1.1 | 20.0 ± 1.0     |

If they fit the three samples with an unmodified Breit-Wigner, they obtain a mass $m(\eta_c) = 2976.7 \pm 0.6$ MeV/c$^2$ (stat. error), compared to $m(\eta_c) = 2982.2 \pm 0.6$ MeV/c$^2$ with their empirical line shape. The first mass is consistent with other determinations from $J/\psi$ and $\psi(2S)$ decay, while the second is consistent with those coming from $\gamma\gamma$
fission and $p\bar{p}$ annihilation. As examples of recent $2\gamma$ production $m(\eta_c)$ measurements, Belle determined $m(\eta_c) = 2986.1 \pm 1.0 \pm 2.5$ MeV/c$^2$ in $\eta_c \to$ four body decays [6] and $m(\eta_c) = 2981.4 \pm 0.5 \pm 0.4$ MeV/c$^2$ using $\eta_c \to K_SK\pi$ [7].

The line shape problem may explain the $3\sigma$ mass difference with $\gamma\gamma$ fusion and $p\bar{p}$ annihilation, but the uncertainty in how to deal with the line shape, according to the authors, prohibits the precise determinations of the $\eta_c$ mass and width. The authors point out that understanding the energy dependence of the $\psi(1S,2S) - \gamma\eta_c$ matrix element is crucial for understanding radiative decays.

Christine Davies showed a comparison of Lattice QCD (2007 HPQCD/MILC/FNAL) results with experiment [8]. One of the biggest discrepancies was in the $m(J/\psi) - m(\eta_c)$ comparison. Assuming from the CLEOc mass measurements with and without using the empirical line shape that the average $\eta_c$ mass might shift upwards by roughly 3 MeV/c$^2$, the agreement between LQCD prediction and experiment for $m(J/\psi) - m(\eta_c)$ would be considerably improved.

| Channel | CLEOc | PDG08 [3] |
|---------|-------|-----------|
| $\psi(2S) \to \gamma\eta_c$ | $(4.32 \pm 0.16 \pm 0.60) \times 10^{-3}$ | $(3.0 \pm 0.5) \times 10^{-3}$ |
| $J/\psi \to \gamma\eta_c$ | $(1.98 \pm 0.009 \pm 0.30)\%$ | $(1.3 \pm 0.4)\%$ |

C. $h_c(^1P_1)$

In 2005, E835 [9] and CLEO [10] reported measurements of the mass of the $h_c(^1P_1)$. CLEO used $e^+e^- \to \psi(2S) \to \pi^0 h_c$, and determined the $h_c$ mass by measuring the mass recoiling against the $\pi^0$ using both $h_c \to \gamma\eta_c$ inclusive events and exclusive $\eta_c$ decays. They have repeated their analysis using the 25 million $\psi(2S)$ sample [11]. They find excellent agreement between the inclusive and exclusive results and obtain a combined result of $m(h_c) = 3525.28 \pm 0.19 \pm 0.12$ MeV/c$^2$. Combining with their 2005 result, they obtain $m(h_c)_{AVG} = 3525.2 \pm 0.18 \pm 0.12$ MeV/c$^2$ and a product branching fraction, $(B_1 \times B_2)_{AVG} = (4.16 \pm 0.30 \pm 0.37) \times 10^{-4}$. A precise determination of the mass is important to learn about the hyperfine (spin-spin) interaction of the $P$ wave states. Using the spin weighted centroid of the $^3P_J$ states, $<m(^3P_J)>$, to represent $m(^3P_J)$, they obtain $\Delta m_{hf}(1P) = <m(^3P_J)> - m(^1P_1) = +0.08 \pm 0.18 \pm 0.12$ MeV/c$^2$. This is consistent with the lowest order expectation of zero.

D. $\chi_{cJ} \to \gamma\gamma$

$\chi_{cJ}(^3P_J) \to \gamma\gamma$ decays (QCD) are analogous to triplet decays of positronium (QED). For $R = \Gamma(^3P_2 \to \gamma\gamma)/\Gamma(^3P_0 \to \gamma\gamma)$, even the differences due to different masses and wave functions cancel, and for both $R = 4/15 \sim 0.27$ [12]. Departures from this are from strong radiative corrections and relativistic effects.

CLEOc has studied this process using $\psi(2S) \to \gamma_1 \chi_{cJ}, \chi_{cJ} \to \gamma_2 \gamma_3$ with their 25 million event sample [13]. The $\gamma_1$ energy spectrum is shown in Fig. 2, where clear peaks corresponding to $\chi_{c0}$ and $\chi_{c2}$ are seen. $\chi_{c1}$ is forbidden by the Landau-Yang Theorem [14]. Results are listed in Table III. Averaging the value of $R$ with those from previous experiments, $< R > = 0.20 \pm 0.02$ is obtained. The theoretical first order pQCD prediction for $R$ is $R_{Th} = (4/15)[1 - 1.76\alpha_S] [15]$, and for $\alpha_S = 0.32$,

$$R_{Th} = 0.12.$$ 

The disagreement with the experimental result confirms the inadequacy of the first order radiative corrections.

Belle has also determined $R$ using a number of exclusive decays of the $\chi_c$’s produced in $\gamma\gamma \to \chi_{c0,2}$ [6]. They measure $\Gamma_{\gamma\gamma} \times B(\chi_{c0,2} \to X)$, where $X$ is an exclusive decay, and divide by the known branching fraction to obtain $\Gamma_{\gamma\gamma}$. The results are also listed in Table III, and their $R$ values agree very well with $< R >$ determined by CLEOc.
TABLE III: $\chi_{cJ} \rightarrow \gamma \gamma$ widths and $R = \Gamma(^3P_2 \rightarrow \gamma \gamma)/\Gamma(^3P_0 \rightarrow \gamma \gamma)$ from CLEOc [13] for $\chi_{cJ} \rightarrow \gamma \gamma$ and Belle [6] for $\gamma \gamma \rightarrow \chi_{cJ}$, with $\chi_{cJ} \rightarrow$ exclusive hadronic decays. The CLEOc result is the first result; their last error is the contribution from $B(\psi(2S) \rightarrow \gamma \chi_{cJ})$ [3].

| Channel       | $\Gamma_{\gamma \gamma}(\chi_{c0})$ (keV) | $\Gamma_{\gamma \gamma}(\chi_{c2})$ (keV) | $R$                      |
|---------------|------------------------------------------|------------------------------------------|--------------------------|
| $\chi_{cJ} \rightarrow \gamma \gamma$ | 2.53 ± 0.37 ± 0.11 ± 0.24 keV | 0.60 ± 0.06 ± 0.03 ± 0.05 keV | 0.237 ± 0.043 ± 0.015 ± 0.031 |
| $\rightarrow K_S K_S$                | 2.53 ± 0.23 ± 0.40 keV                   | 0.46 ± 0.08 ± 0.09 keV                   | 0.18 ± 0.03 ± 0.04       |
| $\rightarrow 4\pi$                  | 1.84 ± 0.15 ± 0.27 keV                   | 0.40 ± 0.04 ± 0.07 keV                   | 0.22 ± 0.03 ± 0.05       |
| $\rightarrow 2K^*2\pi$              | 2.07 ± 0.20 ± 0.40 keV                   | 0.44 ± 0.04 ± 0.16 keV                   | 0.21 ± 0.03 ± 0.09       |
| $\rightarrow 4K$                    | 2.88 ± 0.47 ± 0.53 keV                   | 0.62 ± 0.12 ± 0.12 keV                   | 0.21 ± 0.06 ± 0.06       |

E. Anomalous line shape of $\sigma(e^+e^- \rightarrow hadrons)$ in the $\psi(3770)$ energy region

BESII has accumulated more than 30 pb$^{-1}$ of data in the region of the $\psi(3770)$ from 3.650 to 3.872 GeV, while CLEOc has 818 pb$^{-1}$ at the $\psi(3770)$. These samples have provided precision measurements of $D$ meson decays using the very clean $\psi(3770) \rightarrow D\bar{D}$ events, as well as vastly improved knowledge about the $\psi(3770)$. However, there has been a puzzle concerning the amount of non-$D\bar{D}$ decay of the $\psi(3770)$. The $\psi(3770)$ is just above threshold for $D\bar{D}$ production and is expected to decay into $D\bar{D}$ pairs with a branching fraction greater than 98%. Surprisingly, BES measured the branching fraction of $\psi(3770)$ decays to $D\bar{D}$ to be $B(\psi(3770) \rightarrow D\bar{D}) = (85.3)\%$ [3, 16, 17] and directly measured $B(\psi(3770) \rightarrow non-D\bar{D}) = (13.4 \pm 5.0 \pm 3.6)\%$ [18] and $B(\psi(3770) \rightarrow non-D\bar{D}) = (15.1 \pm 5.6 \pm 1.8)\%$ [19]. However, BES and CLEOc have searched for exclusive non-$D\bar{D}$ decays of the $\psi(3770)$, and the summed non-$D\bar{D}$ branching fractions measured by each of the collaborations are less than 2% [20, 21].

In the inclusive measurements, BES assumed a single resonance in the energy region between 3.7 and 3.872 GeV. To understand the discrepancy between the inclusive and exclusive measurements, BES has reanalyzed the fine $R$-scan ($R = \frac{\epsilon^+e^- \rightarrow hadrons}{\epsilon^+e^- \rightarrow \mu^+\mu^-}$) in this region and finds that the fit to a single resonance is very poor and that allowing two non-interfering or two interfering resonances gives a much better fit, as seen in Fig. 3 [22]. The large non-$D\bar{D}$ inclusive branching fractions measured by BES may be due partially to the assumption of only one simple resonance in this region. This cross section anomaly must be confirmed, and this will be a high priority for BEPCII and BESIII (see below).
III. Y(2175) AND φ(1680)

A structure at 2175 MeV in the φf0(980) mass was observed by BaBar in the ISR process $e^+e^- \rightarrow \gamma_{ISR}\phi f_0(980)$; the mass and width are $m(Y(2175)) = 2175 \pm 10 \pm 15$ MeV/c$^2$ and $\Gamma(Y(2175)) = 58 \pm 16 \pm 20$ MeV/c$^2$ [23]. BaBar speculated that the $Y(2175)$ is the $s\bar{s}$ version of the $Y(4260)$ [24] since it is also a $1^{--}$ and has somewhat similar decay properties [23].

BES searched for the $Y(2175)$ in $J/\psi \rightarrow \eta \phi f_0(980)$, $\eta \rightarrow \gamma \gamma$, $\phi \rightarrow K^+K^-$, $f_0(980) \rightarrow \pi^+\pi^-$ using 58 million $J/\psi$ events and found a peak in the $\phi f_0(980)$ mass around 2175 MeV/c$^2$ [25]. Fig. 4 shows the simultaneous fit to signal and sideband events with a Breit-Wigner to represent the signal and a third order polynomial for the background. The peak has a significance of about 5 $\sigma$, and the mass and width obtained are $m(Y(2175)) = 2186 \pm 10 \pm 6$ MeV/c$^2$ and $\Gamma(Y(2175)) = 65 \pm 23 \pm 17$ MeV/c$^2$, in good agreement with BaBar. Fitting also the smaller $\sim 2\sigma$ peak at around 2460 MeV/c$^2$, also seen by BaBar, does not change the mass and width of the first peak. The product branching fraction is $B(J/\psi \rightarrow \eta Y(2175)) \cdot B(Y(2175) \rightarrow \phi f_0(980)) \cdot B(f_0(980) \rightarrow \pi^+\pi^-) = (3.23 \pm 0.75 \pm 0.73) \times 10^{-4}$.

Belle has also searched for the $Y(2175)$ in $e^+e^- \rightarrow \gamma_{ISR}\phi f_0(980)$ using 673 fb$^{-1}$ of data at the $\Upsilon(4S)$ [26]. They find a peak in the $e^+e^- \rightarrow \phi f_0(980)$ cross section and fit it with one Breit-Wigner interfering with a non-resident background (see Fig. 5 b), as in the BaBar analysis, and also with two Breit-Wigner functions. They also see a peak in $e^+e^- \rightarrow \gamma_{ISR}\phi \pi^+\pi^-$ (see Fig. 5 a) and fit it. For their final results, they take a simple average of their fits and
enlarge errors to cover the spread. They find \( m(Y(2175)) = 2133^{+69}_{-115} \text{ MeV/c}^2 \) and \( \Gamma(Y(2175)) = 169^{+105}_{-92} \text{ MeV/c}^2 \), where the Belle errors include both statistical and systematic errors.

Belle also finds for the first time in \( e^+e^- \rightarrow \gamma_{ISR}\phi\pi^\mp\pi^- \) a clear \( \phi(1680) \) (see Fig. 5 a), which was first seen by DM1 25 years ago [27]. Belle determines \( m(\phi(1680)) = 1687 \pm 21 \text{ MeV/c}^2 \) and \( \Gamma(\phi(1680)) = 212 \pm 29 \text{ MeV/c}^2 \). BaBar also recently reported the \( \phi(1680) \) in \( e^+e^- \rightarrow \gamma_{ISR}\phi\eta \) and \( \gamma_{ISR}K^*K \) [28]. The masses and widths are summarized in Table IV along with the PDG [3] \( \phi(1680) \) values. The Belle results are preliminary.

### Table IV: Summary of masses and widths of \( Y(2175) \) and \( \phi(1680) \).

| Experiment | Channel | Mass (MeV/c²) | Width (MeV/c²) |
|------------|---------|---------------|----------------|
| BaBar [23] | \( Y(2175) \rightarrow \phi f_0(980) \) | 2175 \pm 10 \pm 15 | 58 \pm 16 \pm 20 |
| BES [25]   | \( Y(2175) \rightarrow \phi f_0(980) \) | 2186 \pm 10 \pm 6 | 65 \pm 23 \pm 17 |
| Belle [26] | \( Y(2175) \rightarrow \phi\pi^\mp\pi^- \), \( \phi f_0(980) \) | 2133^{+69}_{-115} | 169^{+105}_{-92} |
| Belle [26] | \( \phi(1680) \rightarrow \phi\pi^\mp\pi^- \) | 1687 \pm 21 | 212 \pm 29 |
| BaBar [28] | \( \phi(1680) \rightarrow K^*K \) and \( \phi\eta \) | 1709 \pm 20 \pm 43 | 322 \pm 77 \pm 160 |
| PDG [3]    | \( \phi(1680) \) | 1680 \pm 20 | 150 \pm 50 |

Belle finds a wider \( Y(2175) \) and notes that the widths of the \( Y(2175) \) and \( \phi(1680) \) are rather similar, which suggests the possibility that the \( Y(2175) \) may be an excited \( \phi \) state. So what is the \( Y(2175) \)? It could be a \( s\bar{s} \) analogue of the \( Y(4160) \), as suggested by BaBar; a \( s\bar{s}g \) hybrid [29]; a \( 2^D_1 \) \( s\bar{s} \) state [30]; a \( s\bar{s}s\bar{s} \) tetraquark state [31]; a \( \Lambda\bar{\Lambda} \) state [32]; or, as suggested, by Belle a conventional \( s\bar{s} \) state. More data are needed to understand the \( Y(2175) \).

**FIG. 5**: Belle \( Y(2175) \) and \( \phi(1680) \) fits. (a) Fit to \( \phi\pi^\mp\pi^- \) cross section in \( e^+e^- \rightarrow \gamma_{ISR}\phi\pi^\mp\pi^- \) and (b) fit to \( \phi f_0(980) \) cross section in \( e^+e^- \rightarrow \gamma_{ISR}\phi f_0(980) \) with one Breit-Wigner (dashed curve) interfering with a non-resonant contribution (lower smooth curve) [26].

### IV. BELLE 2γ PHYSICS

Two \( \gamma \) collisions provide valuable information on both light and heavy quark resonances, perturbative and non-perturbative Quantum Chromodynamics, and hadron production mechanisms. Some \( \gamma\gamma \) charmonium results have already been reported in Sections II B and II D. Recently Belle studied \( 2\gamma \) production of \( \pi^\mp\pi^- \) [33], and now has new high statistics results on \( 2\gamma \) production of \( \pi^0\pi^0 \) using 95 fb\(^{-1} \) of data [34].

Shown in Fig. 6 is a partial wave analysis fit of the differential cross section in the low mass energy region in terms of \( S \), \( D_0 \), and \( D_2 \) partial waves. The \( D_2 \) wave is dominated by the \( f_2(1270) \) while the \( S \) wave contribution includes at least one additional resonance (\( f_0(Y) \)) besides the \( f_0(980) \), which could be the \( f_0(1370) \) or the \( f_0(1500) \). The fit includes the \( f_0(980) \), another scalar, \( f_0(Y) \), \( f_2(1270) \), and \( f_2(1525) \). Known parameters are used for the \( f_2(1270) \) and the \( f_2(1525) \) in the fit. \( r_{02} \) is the ratio of helicity 0 to helicity 2 of the \( f_2(1270) \).
The fit results are reported in Table V. The fit with the $f_0(Y)$ included is strongly favored. BES studied $J/\psi \to \gamma \pi\pi$ using 58 million $J/\psi$ events and found a scalar with $m = 1466 \pm 6 \pm 20 \text{ MeV}/c^2$ and $\Gamma = 108_{-11}^{+14} \pm 25 \text{ MeV}/c^2$ [35], in good agreement with Belle’s result.

![Graph](image_url)

FIG. 6: Partial wave analysis fit of the $2\gamma$ to $\pi^0\pi^0$ differential cross section in the low CM energy ($W$) region in terms of $S$, $D_0$, and $D_2$ partial waves by Belle [34]. The contributions of the components are also shown.

| Parameter | Nominal | $r_{02} = 0$ | No $f_0(Y)$ | Units |
|-----------|---------|-------------|-------------|------|
| $m(f_0(980))$ | $982.2 \pm 1.0$ | $980.2 \pm 1.0$ | $983.7^{+1.5}_{-1.0}$ | MeV/c$^2$ |
| $\Gamma(f_0(980))$ | $285.5^{+18.2}_{-18.1}$ | $297.7^{+14.2}_{-13.7}$ | $370.5^{+20.2}_{-18.7}$ | eV |
| $m(f_0(Y))$ | $1469.7 \pm 4.7$ | $1466.8 \pm 0.6$ | -- | MeV/c$^2$ |
| $\Gamma(f_0(Y))$ | $89.7^{+8.1}_{-6.6}$ | $422.4^{+18.4}_{-19.8}$ | -- | MeV |
| $\Gamma_{\gamma\gamma}B(f_0(Y) \to \pi^0\pi^0)$ | $11.2^{+5.0}_{-4.0}$ | $6780.2^{+626.5}_{-574.7}$ | 0 (fixed) | eV |
| $r_{02}$ | $3.69^{+0.24}_{-0.29}$ | 0 (fixed) | $5.04^{+0.26}_{-0.24}$ | % |
| $B(f_2(1270) \to \gamma\gamma)$ | $1.57 \pm 0.01$ | $1.62^{+0.02}_{-0.01}$ | $1.52^{+0.13}_{-0.31} \times 10^{-5}$ | |
| $\chi^2(ndf)$ | 1010 (615) | 1206 (617) | 1253 (619) | |

### V. BABAR ISR PHYSICS

Because of the very high luminosity at B factories, hadron spectroscopy has also benefited greatly from studies using ISR to reduce the CM energy below the $\Upsilon(4S)$ to study $e^+e^- \to \text{hadrons}$ from $1 < \sqrt{s} < 5$ GeV. The BaBar collaboration have used 232 fb$^{-1}$ at the $\Upsilon(4S)$ to study $e^+e^- \to K^+K^-\pi^0$ and $K_SK^-\pi^+\pi^0$ using this technique. They require that the ISR $\gamma$ be detected, which forces the hadrons to be within the fiducial volume of the detector, and fully reconstruct the hadronic final state. The Dalitz plots are dominated by $K^+K^*$ production. From a Dalitz plot analysis, they have separated the isoscalar and isovector components and measured their cross sections, as shown in Fig. 7. The channels are dominated by resonances that are consistent with the $\phi(1680)$ and $\rho(1450)$ [36].

BaBar has also studied $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ using ISR events [37]. Channels with four pions dominate the cross sections in the $1 < E_{CM} < 2$ GeV region, and are very important for determinations of the anomalous magnetic
moment, $\alpha_{\mu}$, and the fine structure constant evaluated at the Z-pole, $\alpha(m_Z^2)$. The cross section, shown in Figs. 8 a and b, is consistent with SND at low energy and is a huge improvement about 1.4 GeV, as shown in Fig. 8 b. The preliminary precision is 8%, and it is hoped that it will reach 5% over the peak region, which will help improve the precision of $\alpha_{\mu}$. This method will be used to improve the precision of $R$ values at low energy, which Marco Verzocchi pointed out at this conference could be a bottleneck to future tests of Electroweak physics.

Finally I report briefly the status of BEPCII and BESIII. BEPCII is a two-ring $e^+e^-$ collider that will run in the tau-charm energy region ($E_{CM} = 2.0 - 4.2$ GeV, but possibly as high as 4.6 GeV) with a design luminosity of $1 \times 10^{33}$ cm$^{-2}$s$^{-1}$ at a beam energy of 1.89 GeV, an improvement of a factor of 100 in luminosity with respect to the BEPC. This is accomplished mainly by using multi-bunches and micro-beta.

The BESIII detector consists of a beryllium beam pipe, a helium-based small-celled drift chamber, Time-Of-Flight counters (TOF) for particle identification, a CsI(Tl) crystal calorimeter, a superconducting solenoidal magnet with a field of 1 Tesla, and a muon identifier using the magnet yoke interleaved with Resistive Plate Counters. Fig. 9 shows the schematic view of the BESIII detector, including both the barrel and end cap portions.
The detector moved to the IP in the spring of this year and is shown in Fig. 10 at its final location in June 2008 with all beam magnets and vacuum pipes in place. Commissioning of the detector and collider together began in July, and the first hadronic event was obtained on July 19, 2008. Currently data at the $\psi(2S)$ is being taken for calibration purposes.

Clearly BESIII with a luminosity of $1 \times 10^{33}$ cm$^{-2}$ s$^{-1}$ will contribute greatly to precision flavor physics; $V_{cd}$ and $V_{cs}$ will be measured with a statistical accuracy of better than 1.0%. $D^0\bar{D}^0$ mixing will be studied, and CP violation will be searched for. Huge $J/\psi$ and $\psi(2S)$ samples will be obtained. The $\eta_c$, $\chi_{cJ}$, and $h_c$ can be studied with high statistics. The high statistics will allow searches for physics beyond the standard model. The future is very bright. More detail on BEPCII and BESIII may be found in Ref. [38].

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