Measurements of the Branching Fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$, and the Resonance Parameters of $\psi(3770)$ and $\psi(2S)$

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We measure the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$, and non-$D\bar{D}$ to be $(46.7 \pm 4.7 \pm 2.3)\%$, $(36.9 \pm 3.7 \pm 2.8)\%$, $(83.6 \pm 7.3 \pm 4.2)\%$, and $(16.4 \pm 7.3 \pm 4.2)\%$, respectively. The resonance parameters of $\psi(3770)$ and $\psi(2S)$ are measured to be $M_{\psi(3770)} = 3772.2 \pm 0.7 \pm 0.3$ MeV, $\Gamma^{\rm tot}_{\psi(3770)} = 26.9 \pm 2.4 \pm 0.3$ MeV, and $\Gamma^{ee}_{\psi(3770)} = 251 \pm 26 \pm 11$ eV; $M_{\psi(2S)} = 3685.5 \pm 0.0 \pm 0.3$ MeV, $\Gamma^{\rm tot}_{\psi(2S)} = 331 \pm 58 \pm 2$ keV, and $\Gamma^{ee}_{\psi(2S)} = 2.330 \pm 0.036 \pm 0.110$ keV. We also measure the light hadron R value to be $R_{\rm uds} = 2.262 \pm 0.054 \pm 0.109$ in the energy region from 3.660 to 3.872 GeV.

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The $\psi(3770)$ resonance was discovered 29 years ago [1]. Since its mass is above the open charm-pair threshold and its width is 2 orders of magnitude larger than that of the $\psi(2S)$, it is thought to decay almost entirely to pure $D\bar{D}$ [2]. However, there is a long-standing puzzle in understanding of $\psi(3770)$ production and decays. Historically published data indicate that about 38% of $\psi(3770)$ does not decay into $D\bar{D}$ [3]. The observed cross section $\sigma^{\rm obs}_{\psi(3770)}$ for

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$\psi(3770)$ production in e^+e^- annihilation can be obtained from $\psi(3770)$ resonance parameters [4] accounting for radiative corrections [5], which yield $\sigma^{\rm obs}_{\psi(3770)} = 7.53 \pm 1.44$ nb at the center-of-mass (c.m.) energy $E_{\rm cm} = 3.773$ GeV. Using the observed cross section for $D\bar{D}$ production in e^+e^- annihilation, $\sigma^{\rm obs}_{D\bar{D}} = 6.39 \pm 0.16$ nb measured by CLEO [6] and $\sigma^{\rm obs}_{D\bar{D}} = 5.93 \pm 0.58$ nb measured by BES [7] recently, one obtains the weighted average of the cross sections to be $\bar{\sigma}^{\rm obs}_{D\bar{D}} = 6.36 \pm 0.15$ nb. Comparing the $\sigma^{\rm obs}_{\psi(3770)}$ and $\bar{\sigma}^{\rm obs}_{D\bar{D}}$ one finds that $(16 \pm 16)\%$ of $\psi(3770)$ does not decay into $D\bar{D}$, where the large error is dominated by the uncertainties in the resonance parameters of $\psi(3770)$.

A better way to measure the branching fraction for $\psi(3770) \to D\bar{D}$ is to analyze the energy-dependent cross sections for the inclusive hadron, $D^0\bar{D}^0$ and D^+D^- event production in the energy range covering both the $\psi(2S)$ and $\psi(3770)$ resonances, simultaneously. In this way one can also more accurately measure the parameters of the two resonances, since they are correlated to each other in the analysis of the cross section scan data.

In this Letter, we report measurements of the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$ as well as for $\psi(3770) \to$ non-$D\bar{D}$ for the first time, and measurements of the resonance parameters of $\psi(3770)$ and $\psi(2S)$ with improved precision on $\psi(3770)$ resonance parameters. We also report a measurement of the $R_{\rm uds}$, which is the ratio of the lowest order continuum light hadron production cross section over the lowest order cross section for $e^+e^- \to \mu^+\mu^-$, in the energy region from 3.660 to 3.872 GeV. The data samples used in the analysis were taken with the BES-II detector [8] at the BEPC Collider in March 2003.

The observed hadronic cross section is determined by

$$\sigma^{\rm obs}_{\rm had} = \frac{N^{\rm obs}_{\rm had}}{L\epsilon_{\rm had}\epsilon^{\rm trig}_{\rm had}}, \quad (1)$$

where $N^{\rm obs}_{\rm had}$ is the number of the observed hadronic events, L is the integrated luminosity, $\epsilon_{\rm had}$ is the efficiency for the detection of inclusive hadronic events and $\epsilon^{\rm trig}_{\rm had}$ is the trigger efficiency for collecting hadronic events in the online data acquisition system.

The hadronic events are required to have more than 2 good charged tracks. Each of the charged tracks is required to have well-measured momenta and to satisfy selection criteria as described in Ref. [9]. To separate some beam-gas associated background events and cosmic rays background events from the hadronic events we calculated the event vertex in the beam line direction. Figure 1(a) shows the distribution of the event vertex of the accepted events. Using a Gaussian function to describe the hadronic events plus a second order polynomial for the background to fit the distribution, we obtain the number, $N^{\rm zfit}_{\rm had}$, of the candidates for the hadronic events. This number of candidates for hadronic events contains contaminations from

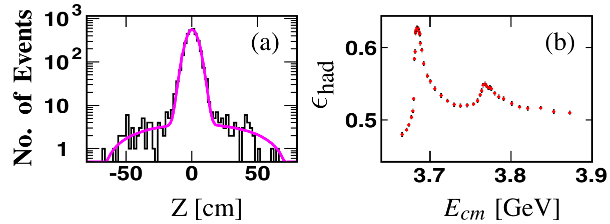

FIG. 1 (color online). (a) The distribution of the event vertex in z; (b) the efficiencies versus the nominal c.m. energies.

some background sources such as $e^+e^- \to \tau^+\tau^-$, $e^+e^- \to (\gamma)e^+e^-$, $e^+e^- \to (\gamma)\mu^+\mu^-$, and two-photon processes. The number of background events, N_b, due to these processes can be estimated by means of a Monte Carlo simulation [9]. Subtracting N_b from $N^{\rm zfit}_{\rm had}$ yields the number of the observed hadronic events, $N^{\rm obs}_{\rm had}$. The systematic uncertainty in measuring the produced hadronic events due to the hadronic event selection criteria is estimated to be $\sim$2.5% [9].

The integrated luminosities of the data sets are determined using large-angle Bhabha scattering events as described in Ref. [9]. The systematic uncertainty in the measured luminosities is estimated to be $\sim$1.8% [9].

The detection efficiency for hadronic events is determined via a special Monte Carlo generator [10] in which the radiative corrections to α^2 order are taken into account. These generated events are simulated with the GEANT3-based Monte Carlo simulation package [11]. The systematic uncertainty in the efficiencies due to the generator is estimated to be $\sim$2.0% ($\sim$ 0.7%) [9] for reconstruction of the hadronic events from $\psi(3770)$ and $\psi(2S)$ decays (from continuum hadrons). Figure 1(b) shows the Monte Carlo efficiencies for the detection of hadronic events produced at the different nominal c.m. energies.

The trigger efficiencies are measured to be $\epsilon_{\rm trig} = (100.0^{+0.0}_{-0.5})\%$ for both the $e^+e^- \to (\gamma)e^+e^-$ and $e^+e^- \to$ hadrons events [9].

The observed cross section for $D^0\bar{D}^0$ (or D^+D^-) production is determined by

$$\sigma^{\rm obs}_{D^0\bar{D}^0({\rm or}\ D^+D^-)} = \frac{N_{D^0_{\rm tag}}({\rm or}\ N_{D^+_{\rm tag}})}{2 \times L \times B \times \epsilon}, \quad (2)$$

where $N_{D^0_{\rm tag}}$ (or $N_{D^+_{\rm tag}}$) is the reconstructed D^0 (or D^+) events obtained by analyzing the invariant mass spectra of $K^\mp\pi^\pm$ and $K^\mp\pi^\pm\pi^\pm\pi^\mp$ (or $K^\mp\pi^\pm\pi^\pm$) as discussed in detail in Ref. [12]; B is the branching fraction for the decay mode in question, and ϵ is the efficiency for reconstruction of this decay mode.

Figure 2 shows the observed cross sections (points with error) for inclusive hadronic event production, while Fig. 3(b) and 3(c), respectively, display the observed cross sections (circles with error) for $D^0\bar{D}^0$ and D^+D^- production. The error bars represent the combined statistical and point-to-point systematic uncertainties including the sta-

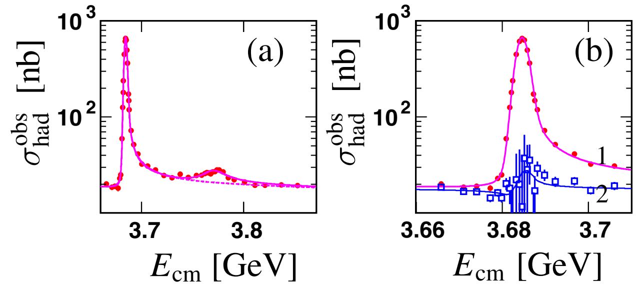

FIG. 2 (color online). The hadronic cross sections versus the nominal c.m. energies (see text).

tistical uncertainties in the luminosity and the efficiencies for the detection of Bhabha events, hadronic events, and singly tagged D events.

The determination of the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, and $D\bar{D}$ is accomplished by simultaneously fitting the observed cross sections for $\psi(2S)$, $\psi(3770)$, $D^0\bar{D}^0$, and D^+D^- to functions that describe the combined $\psi(2S)$, $\psi(3770)$ resonance shapes, the tail of J/ψ resonance, and the nonresonant hadronic background, as well as the partial $\psi(3770)$ resonance shapes for $\psi(3770) \to D^0\bar{D}^0$ and $\psi(3770) \to D^+D^-$. The functions are corrected for the radiative corrections [5,13].

For J/ψ and $\psi(2S)$, we take the Breit-Wigner function

$$\sigma^B(s') = \frac{12\pi\Gamma^{ee}\Gamma^h}{(s' - M^2)^2 + (\Gamma^{\rm tot}M)^2}, \quad (3)$$

to describe their production for $s' = s(1-x)$, where x is a parameter related to the total energy of the emitted photons and $\sqrt{s}$ is the nominal c.m. energy; M and $\Gamma^{\rm tot}$ are, respectively, the masses and total widths of the resonances, and Γ^{ee} and Γ^h are the partial widths to the e^+e^- final state and to the inclusive hadronic final states, respectively. Assuming that there are no other new structures and effects, we use a pure p-wave Born order Breit-Wigner function with energy-dependent total widths to describe the $\psi(3770)$ production and the $D\bar{D}$ ($D^0\bar{D}^0$ and D^+D^-) production from the $\psi(3770)$ decays. The $\psi(3770)$ resonance shape is taken as

$$\sigma^B_{\psi(3770)}(s') = \frac{12\pi\Gamma^{ee}_{\psi(3770)}\Gamma^{\rm tot}_{\psi(3770)}(s')}{(s' - M^2_{\psi(3770)})^2 + [M_{\psi(3770)}\Gamma^{\rm tot}_{\psi(3770)}(s')]^2}, \quad (4)$$

while the $D\bar{D}$ resonance shapes are taken as

$$\sigma^B_{D\bar{D}}(s') = \frac{12\pi\Gamma^{ee}_{\psi(3770)}\Gamma_{D\bar{D}}(s')}{(s' - M^2_{\psi(3770)})^2 + [M_{\psi(3770)}\Gamma^{\rm tot}_{\psi(3770)}(s')]^2}, \quad (5)$$

where $M_{\psi(3770)}$ and $\Gamma^{ee}_{\psi(3770)}$ are the mass and leptonic width of the $\psi(3770)$ resonance, respectively; $\Gamma_{D\bar{D}}$ is the partial width of $\psi(3770)$ decay into $D\bar{D}$; $\Gamma^{\rm tot}_{\psi(3770)}(s')$ and $\Gamma_{D\bar{D}}(s')$ are chosen to be energy dependent, defined as

$$\Gamma^{\rm tot}_{\psi(3770)}(s') = \Gamma_{D^0\bar{D}^0}(s') + \Gamma_{D^+D^-}(s') + \Gamma_{{\rm non}\text{-}D\bar{D}}(s'), \quad (6)$$

where [14]

$$\Gamma_{D^0\bar{D}^0}(s') = \Gamma_0\theta_{00}\frac{(p_{D^0})^3}{(p^0_{D^0})^3}\frac{1 + (rp^0_{D^0})^2}{1 + (rp_{D^0})^2}B_{00}, \quad (7)$$

$$\Gamma_{D^+D^-}(s') = \Gamma_0\theta_{+-}\frac{(p_{D^+})^3}{(p^0_{D^+})^3}\frac{1 + (rp^0_{D^+})^2}{1 + (rp_{D^+})^2}B_{+-}, \quad (8)$$

and

$$\Gamma_{{\rm non}\text{-}D\bar{D}}(s') = \Gamma_0[1 - B_{00} - B_{+-}], \quad (9)$$

where p^0_D and p_D are the momenta of the D mesons produced at the peak of $\psi(3770)$ and at the actual c.m. energy $\sqrt{s'}$, respectively; Γ_0 is the total width of the $\psi(3770)$ at its peak, $B_{00} = B(\psi(3770) \to D^0\bar{D}^0)$ and $B_{+-} = B(\psi(3770) \to D^+D^-)$ are the branching fractions for $\psi(3770) \to D^0\bar{D}^0$ and $\psi(3770) \to D^+D^-$, respectively, r is the interaction radius of the $c\bar{c}$, θ_{00} and θ_{+-} are the step functions to account for the thresholds of the $D^0\bar{D}^0$ and D^+D^- production, respectively. In the fit we take Γ_0, B_{00}, B_{+-}, and r as free parameters.

The nonresonant background shape is taken as

$$\sigma^{\rm nrsnt}_h(s) = \int_0^\infty ds'' G(s, s'') \times \int_0^1 dx \frac{R_{\rm uds}(s')\sigma^B_{\mu^+\mu^-}(s')}{|1 - \Pi(s')|^2}F(x, s) + f_{D\bar{D}}\left[\left(\frac{p_{D^0}}{E_{D^0}}\right)^3\theta_{00} + \left(\frac{p_{D^+}}{E_{D^+}}\right)^3\theta_{+-}\right]\sigma^B_{\mu^+\mu^-}(s), \quad (10)$$

where $F(x, s)$ is the sampling function [5], $1/|1 - \Pi(s(1-x))|^2$ is the vacuum polarization correction func-

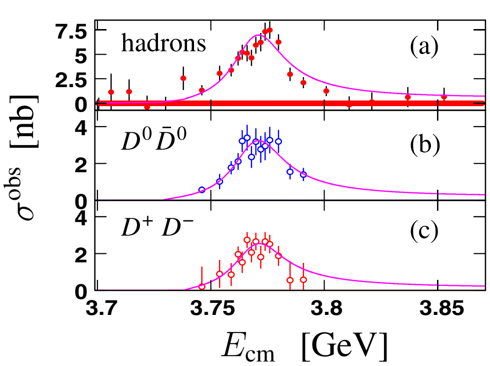

FIG. 3 (color online). The observed cross sections versus the nominal c.m. energies.

tion [13] including the contributions from all 1^{--} resonances, the QED continuum hadron spectrum as well as the contributions from the lepton pairs (e^+e^-, $\mu^+\mu^-$, and $\tau^+\tau^-$) [10]; $\sigma^B_{\mu^+\mu^-}(s)$ is the Born cross section for $e^+e^- \to \mu^+\mu^-$, E_{D^0}, and E_{D^+} are the energies of D^0 and D^+ mesons produced at the nominal energy $\sqrt{s}$, $f_{D\bar{D}}$ is a parameter to be fitted, and $R_{\rm uds}(s')$ is the R value for the light hadron production through one photon annihilation directly. In the fit we take $R_{\rm uds}(s')$ as a free parameter, assuming that the value is independent of the energy; we fix the J/ψ resonance parameters at the values given by PDG [4]. We also consider the effects of the BEPC energy spread on the calculation of the expected cross sections in the fit. $G(s, s'')$ in Eq. (10) is the Gaussian function to describe the c.m. energy distribution of the BEPC machine.

Figure 2(a) shows the observed cross sections with the fit to the data, where the solid line shows the fit to the data and the dashed line represents the contributions from J/ψ, $\psi(2S)$ and continuum hadron production. To examine the contribution from the vacuum polarization corrections to the Born hadronic cross section due to one photon annihilation directly, we subtract the contributions of $\psi(2S)$ and $\psi(3770)$ as well as J/ψ from the observed cross sections to yield the expected cross sections of the continuum hadron production corrected with the radiative effects, which is given by Eq. (10). The squares with error in Fig. 2(b) show the yielded-expected cross sections, where the errors are the originally absolute errors of the totally observed cross sections as shown in Fig. 2(a). The blue line (line 2) in Fig. 2(b) shows the fit to the expected cross sections of the continuum hadron production corrected for the radiative effects as given in Eq. (10). Figure 3(a) shows the observed cross sections for the inclusive hadronic event production, where the contributions from J/ψ and $\psi(2S)$ radiative tails as well as the continuum hadron production are removed. Figure 3(b) and 3(c) display the observed cross sections for $D^0\bar{D}^0$ and D^+D^- production with the fits to the data, respectively. The fit gives $\chi^2/\text{n.o.f} = 65.4/64 = 1.02$. In the data reduction, the number of the singly tagged D^0 (or D^+) events are removed from the inclusive hadronic event samples before calculating the hadronic cross section and its error based on Eq. (1). These make the hadronic event samples and the singly tagged D samples be independent.

The results from this fit are summarized in Table I, where the first error is statistical and second systematic arising from uncanceled systematic uncertainties in the measured $\sigma^{\rm obs}_{\rm had}$ ($\sim 2.8\%$) including the uncertainty in Monte Carlo efficiency, the uncanceled uncertainty in hadronic event selection and the uncanceled uncertainty in tracking, in $\sigma^{\rm obs}_{D^0\bar{D}^0}$ ($\sim 4.1\%$) including the uncertainty in particle identification, the uncertainty in singly tagged D^0 events due to fitting the invariant spectrum and the uncertainty in branching fractions for $D^0 \to K^-\pi^+$ and for $D^0 \to K^-\pi^+\pi^+\pi^-$, and in $\sigma^{\rm obs}_{D^+D^-}$ ($\sim 7.0\%$) including the uncertainty in particle identification, the uncertainty in singly tagged D^+ events due to fitting the invariant spectrum and the uncertainty in branching fraction for $D^+ \to K^-\pi^+\pi^+$. In estimation of the errors for the measurements of $B(\psi(3770) \to D\bar{D})$ and $B(\psi(3770) \to \text{non-}D\bar{D})$ we consider the correlation between the B_{00} and B_{+-} obtained from the fit. The fit gives the BEPC machine energy spread $\sigma_{E_{\rm BEPC}} = (1.343 \pm 0.029)$ MeV which is consistent with the expected energy spread $\sim$1.3 MeV in this energy region. From the fit we obtain the $R_{\rm uds}$ in the region between 3.660 and 3.872 GeV to be

$$R_{\rm uds} = 2.262 \pm 0.054 \pm 0.109,$$

where the first error is statistical and the second systematic arising from the uncertainty in the measured $\sigma^{\rm obs}_{\rm had}$ ($\sim 4.8\%$) [9], $\sigma^{\rm obs}_{D^0\bar{D}^0}$ ($\sim 0.4\%$), and $\sigma^{\rm obs}_{D^+D^-}$ ($\sim 0.2\%$). The fit also gives the resonance parameters of $\psi(3770)$ and $\psi(2S)$ as summarized in Table II, where the first error is statistical and the second systematic arising from the uncertainties in the measured $\sigma^{\rm obs}_{\rm had}$ ($\sim 4.4\%$), in $\sigma^{\rm obs}_{D^0\bar{D}^0}$ ($\sim 4.5\%$), and in $\sigma^{\rm obs}_{D^+D^-}$ ($\sim 7.4\%$). These uncertainties include the contributions from sources discussed above and the uncertainty of the luminosity.

The measured $\psi(3770)$ parameters yield the cross section for $\psi(3770)$ production at its peak to be $\sigma^{\rm prd}_{\psi(3770)} = 9.63 \pm 0.66 \pm 0.35$ nb, corresponding $\sigma^{\rm obs}_{\psi(3770)} = 6.94 \pm 0.48 \pm 0.28$ nb, which is consistent within error with $\sigma^{\rm obs}_{\psi(3770)} = 8.12 \pm 1.56$ nb at $\psi(3770)$ peak obtained from the PDG [4] $\psi(3770)$ parameters. The resonances branching fractions and widths yield

$$\Gamma_{D^0\bar{D}^0}/\Gamma_{D^+D^-} = 1.27 \pm 0.12 \pm 0.08,$$

which is in good agreement with $1.41 \pm 0.23 \pm 0.11$ measured by BES [7], and yield

$$B(\psi(3770) \to e^+e^-) = (0.93 \pm 0.06 \pm 0.03) \times 10^{-5},$$

and

$$B(\psi(2S) \to e^+e^-) = (0.704 \pm 0.122 \pm 0.033)\%.$$

We find that the continuum background shape affects the measured total and leptonic widths of the resonances from the line shape analysis. If we take

TABLE I. The measured branching fractions of $\psi(3770)$.

$\psi(3770) \to$	B (%)	$\psi(3770) \to$	B (%)
$D^0\bar{D}^0$	$46.7 \pm 4.7 \pm 2.3$	$D\bar{D}$	$83.6 \pm 7.3 \pm 4.2$
D^+D^-	$36.9 \pm 3.7 \pm 2.8$	non-$D\bar{D}$	$16.4 \pm 7.3 \pm 4.2$

TABLE II. The measured $\psi(3770)$ and $\psi(2S)$ parameters, where M is the mass, $\Gamma^{\rm tot}$ the total width [$\Gamma^{\rm tot} = \Gamma_0$ for $\psi(3770)$], Γ^{ee} the partial leptonic width, and ΔM the measured mass difference of the $\psi(3770)$ and the $\psi(2S)$.

Res.	M (MeV)	$\Gamma^{\rm tot}$ (MeV)	Γ^{ee} (eV)	ΔM (MeV)
$\psi(3770)$	$3772.2 \pm 0.7 \pm 0.3$	$26.9 \pm 2.4 \pm 0.3$	$251 \pm 26 \pm 11$	
$\psi(2S)$	$3685.5 \pm 0.0 \pm 0.3$	$0.331 \pm 0.058 \pm 0.002$	$2330 \pm 36 \pm 110$	86.7 ± 0.7

$$\sigma_h^{\rm nrsnt}(s) = h\sigma^B_{\mu^+\mu^-}(s) + f_{D\bar{D}}\left[\left(\frac{p_{D^0}}{E_{D^0}}\right)^3\theta_{00} + \left(\frac{p_{D^+}}{E_{D^+}}\right)^3\theta_{+-}\right]\sigma^B_{\mu^+\mu^-}(s), \quad (11)$$

in fitting the data (where h is a free parameter in the fit), we would obtain $\Gamma^{\rm tot}_{\psi(2S)} = 290 \pm 59 \pm 5$ keV, $\Gamma^{ee}_{\psi(2S)} = 2.378 \pm 0.036 \pm 0.103$ keV, $\Gamma^{\rm tot}_{\psi(3770)} = 27.3 \pm 2.5 \pm 1.1$ MeV, and $\Gamma^{ee}_{\psi(3770)} = 256 \pm 27 \pm 13$ eV, and almost unchanged measurements of the resonance masses. This fit yields $\chi^2/{\rm n.o.f} = 75.3/64 = 1.18$. This indicates that the vacuum polarization corrections to the Born order cross sections for the continuum hadron production cannot be ignored when precisely measuring the resonance parameters of the narrow resonances like J/ψ and $\psi(2S)$ as well as $\Upsilon(1S)$, etc., in e^+e^- cross section scan experiments. Ignoring the effects of the vacuum polarization corrections on the continuum hadron production cross sections in the analysis of the cross section scan data taken in the $\psi(2S)$ resonance region would decrease the $\psi(2S)$ total width by about 40 keV.

In summary, we measured the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, and $\psi(3770) \to$ non-$D\bar{D}$ for the first time and measured the resonance parameters of $\psi(3770)$ and $\psi(2S)$ with improved precision on $\psi(3770)$ parameters and with a comparable precision to the current PDG [4] world averages on $\Gamma^{ee}_{\psi(2S)}$. With the same data samples, we also measured the $R_{\rm uds}$ with a precision of about $\pm 5\%$. From this analysis we observed the effects of the vacuum polarization on the observed cross sections of the continuum hadron production in the neighborhood of the $\psi(2S)$ resonance for the first time directly.

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[1] P. A. Rapidis *et al.* (MARK-I Collaboration), Phys. Rev. Lett. **39**, 526 (1977).
[2] W. Bacino *et al.* (DELCO Collaboration), Phys. Rev. Lett. **40**, 671 (1978).
[3] G. Rong, D. H. Zhang, and J. C. Chen, hep-ex/0506051.
[4] S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004).
[5] E. A. Kuraev and V. S. Fadin, Yad. Fiz. **41**, 377 (1985).
[6] Q. He *et al.* (CLEO Collaboration), Phys. Rev. Lett. **95**, 121801 (2005).
[7] M. Ablikim *et al.* (BES Collaboration), Nucl. Phys. **B727**, 395 (2005).
[8] J. Z. Bai *et al.* (BES Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **458**, 627 (2001).
[9] M. Ablikim *et al.* (BES Collaboration), Phys. Lett. B **641**, 145 (2006).
[10] D. H. Zhang, G. Rong, and J. C. Chen, Phys. Rev. D **74** 054012 (2006).
[11] M. Ablikim *et al.* (BES Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **552**, 344 (2005).
[12] M. Ablikim *et al.* (BES Collaboration), Phys. Lett. B **603**, 130 (2004).
[13] F. A. Berends and G. J. Komen, Phys. Lett. B **63**, 432 (1976); Andrej B. Arbuzov and Eduard A. Kuraev *et al.*, J. High Energy Phys. 10 (1997) 006.
[14] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, New York, Chapman & Hall, London, 1952); R. H. Schindler *et al.* (MARK-II Collaboration), Phys. Rev. D **21**, 2716 (1980).