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Non-$D\overline{D}$ decays of $\psi(3770)$ at BESIII

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Based on the data samples collected with the BESIII detector at the BEPCII storage ring, non-$D\overline{D}$ decays of $\psi(3770)$ have been searched for. The searches cover two aspects. This first one is the search for baryonic decays, including $\psi(3770) \to \Lambda\overline{\Lambda}\pi^+\pi^-$, $\Lambda\overline{\Lambda}\pi^0$, $\Lambda\overline{\Lambda}\eta$, $\Sigma^+\overline{\Sigma}^-$, $\Sigma\overline{\Sigma}^0$, $\Xi^-\overline{\Xi}^+$ and $\Xi^0\overline{\Xi}^0$. The other is the search for radiative transitions, including $\psi(3770) \to \gamma\chi_{cJ}(J=0,1,2)$ and $\psi(3770 \to \gamma\eta_c(\gamma\eta_c(2S))$. These measurements provide more information on the non-$D\overline{D}$ decays of $\psi(3770)$.

VIII International Workshop On Charm Physics
5-9 September, 2016
Bologna, Italy

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[†]I would like to thank for the support of the Ministry of Science and Technology of China (973 by MOST) under Contracts No. 2015CB856700.

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1. Introduction

The $\psi(3770)$ resonance is the lowest-mass $c\bar{c}$ resonance above the $D\overline{D}$ threshold. It is a long-standing puzzle to understand the nature of $\psi(3770)$. The potential model expects that more than 99%[3] of $\psi(3770)$ decay into $D\overline{D}$ final states. However, the BES Collaboration measured $\mathrm{Br}[\psi(3770) \to \text{non-}D\overline{D}] = (15 \pm 5)\%$ by using four different methods [4] under the hypothesis that only one simple $\psi(3770)$ resonance exists in the energy region from 3.70 to 3.87 GeV. The CLEO Collaboraion obtained $\mathrm{Br}[\psi(3770) \to \text{non-}D\overline{D}] = (-3.3 \pm 1.4^{+6.6}_{-4.8})\%$ which corresponds to $\mathrm{Br}[\psi(3770) \to \text{non-}D\overline{D}] < 9\%$ at the 90% confidence level [5]. The large non-$D\overline{D}$ component conflicts with theoretical prediction, which motivates the search for exclusive non-$D\overline{D}$ decay channels.

In 2003, the BES Collaboartion observed $\psi(3770) \to J/\psi\pi^+\pi^-$[6], which is the first non-$D\overline{D}$ decay of the particle laying above $D\overline{D}$ threshold. The CLEO Collaboration confirmed the same decay and searched for many other non-$D\overline{D}$ decay channels, such as $J/\psi\pi^0\pi^0$, $J/\psi\eta$[7], $\gamma\chi_{cJ}(J=0,1)$[8] and $\phi\eta$[9]. However, the total non-$D\overline{D}$ branching fraction of those decay channels is less than 2%. To better understand the nature of $\psi(3770)$, BESIII have searched for some exclusive non-$D\overline{D}$ decay channels of $\psi(3770)$.

2. Baryonic decays of $\psi(3770)$

Using the data sample of 2.92 fb^{-1} collected at $\sqrt{s} = 3.773$ GeV, the baryonic decays of $\psi(3770)$, including $\Lambda\overline{\Lambda}\pi^+\pi^-$, $\Lambda\overline{\Lambda}\pi^0$, $\Lambda\overline{\Lambda}\eta$, $\Sigma^+\overline{\Sigma}^-$, $\Sigma^0\overline{\Sigma}^0$, $\Xi^-\overline{\Xi}^+$ and $\Xi^0\overline{\Xi}^0$, are studied[10]. Those decay modes are unambiguous evidence for non-$D\overline{D}$ decays of $\psi(3770)$ since D mesons are not massive enough to decay to baryon pairs.

To estimate the QED backgrounds, the data samples taken at $\sqrt{s}$=3.542, 3.554, 3.561, 3.600 and 3.650 GeV are also analyzed. A scale factor is used to normalize the continuum products to $\psi(3770)$ data. The factor is determined by the integrated luminosities of the data sets corrected for an assumed $1/s$ dependence of the cross section, and accounts for the small difference in efficiency between the $\psi(3770)$ data and continuum data. The backgrounds from the initial state radiation (ISR), such as $e^+e^- \to \gamma\psi(3686)$ and $e^+e^- \to \gamma J/\psi$, and the misidentified $\psi(3770)$ decays are estimated using Monte Carlo samples generated at the center-of-mass energy of 3.773 GeV. When subtracting backgrounds, the interference between continuum and resonance decay to the same final state is ignored. In this work, using the same method, we have also reported the branching fraction of $\psi(4040)$ to those final states based on the 482 pb^{-1} data taken at 4.009 GeV. Figure 1 shows the 2-dimensional invariant mass distribution for kinds of intermediate states.

After the subtraction of backgrounds, no significant signals are observed. The upper limits at the 90% confidence level are set to be $4.7(2.9), 0.7(0.9), 1.9(3.0), 1.0(1.3), 0.4(0.7), 1.5(1.6)$ and 1.4(1.8) ($\times 10^{-4}$) for $\psi(3770)(\psi(4040)) \to \Lambda\overline{\Lambda}\pi^+\pi^-$, $\Lambda\overline{\Lambda}\pi^0$, $\Lambda\overline{\Lambda}\eta$, $\Sigma^+\overline{\Sigma}^-$, $\Sigma^0\overline{\Sigma}^0$, $\Xi^-\overline{\Xi}^+$ and $\Xi^0\overline{\Xi}^0$, respectively. These results provide useful information to understand the nature of $\psi(3770)$. Most of those measurements are the first searches.

3. $\psi(3770) \to \gamma\chi_{cJ}$

The $\psi(3770)$ resonance is thought to be predominantly the 1^3D_1 $c\bar{c}$ state mixed with a small

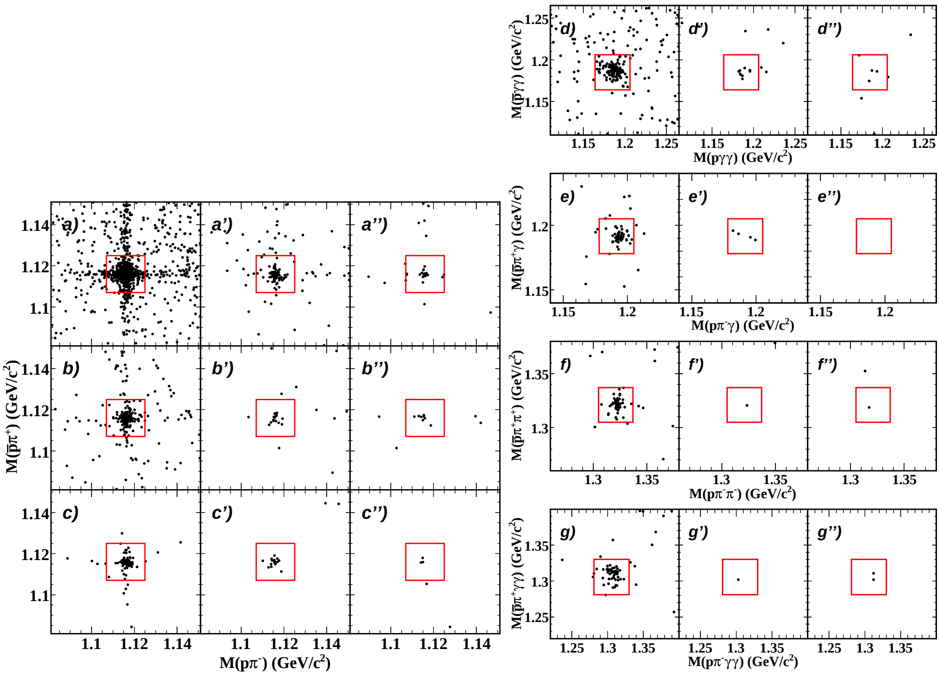

Figure 1: Invariant mass spectrum of intermediate states. The rectanglar regions indicate signal regions. The figures on the left (middle, right) side are the data at $\sqrt{(s)} = 3.773$ [4.009, continuum (3.542, 3.554, 3.561, 3.600 and 3.650)] GeV.

fraction of the 2^3S_1 state in the S-D mixing model. Under this assumption, the predictions of the partial widths of $\psi(3770)$ $E1$ radiative transitions are with large uncertainties [14]. As a result, precision measurements of partial widths of the $\psi(3770) \to \gamma\chi_{c0,1,2}$ processes plays an important role in testing teoretical models, as well as in finding out the origin of the non-$D\overline{D}$ decays of the $\psi(3770)$.

By analyzing 2.92 fb^{-1} of data collected at $\sqrt{s} = 3.773$ GeV and 106.41×10^6 $\psi(3686)$ decays taken at $\sqrt{s} = 3.686$ GeV, the branching fraction and partial width of $\psi(3770) \to \gamma\chi_{c0}$ are obtained[15]. The χ_{c0} candidates are reconstructed with the decay chain of $\chi_{c0} \to 2(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$, $3(\pi^+\pi^-)$ and K^+K^-. To avoid the dependence on the large uncertainties in χ_{c0} decay branching fractions, the results of our measurements are obtained by taking the relative strength with respect to the well-known $\psi(3686)$ radiative $E1$ transition. Figure 2 shows the invariant mass spectra of those hadronic final states selected from data sample taken at 3.773 GeV, in which clear peaks can be observed for the χ_{c0} decays. The background events from the process of $e^+e^- \to \gamma\psi(3686)$ have the same event topologies as that of $\psi(3770)$ decays. When fitting to these invariant mass spectra, the size and line-shape of such backgrounds are fixed according to MC simulations. Then R_{c0}, the ratio of the branching fraction for $\psi(3770) \to \gamma\chi_{c0}$ divided by the branching fraction for $\psi(3686) \to \gamma\chi_{c0}$, is determined channel by channel. Multiplying the statistical-weighted average ratio $\overline{R}_{c0}$ by the branching fraction $\mathscr{B}(\psi(3686) \to \gamma\chi_{c0})$ (and the total width $\Gamma^{tot}_{\psi(3770)}$) taken from PDG, the branching fraction and partial decay width are measured to be $\mathscr{B}(\psi(3770) \to \gamma\chi_{c0}) = (6.88 \pm 0.28 \pm 0.67) \times 10^{-3}$ and $\Gamma[\psi(3770) \to \gamma\chi_{c0}] = (187 \pm 8 \pm 19)$ keV. These are the most precise measurements to date.

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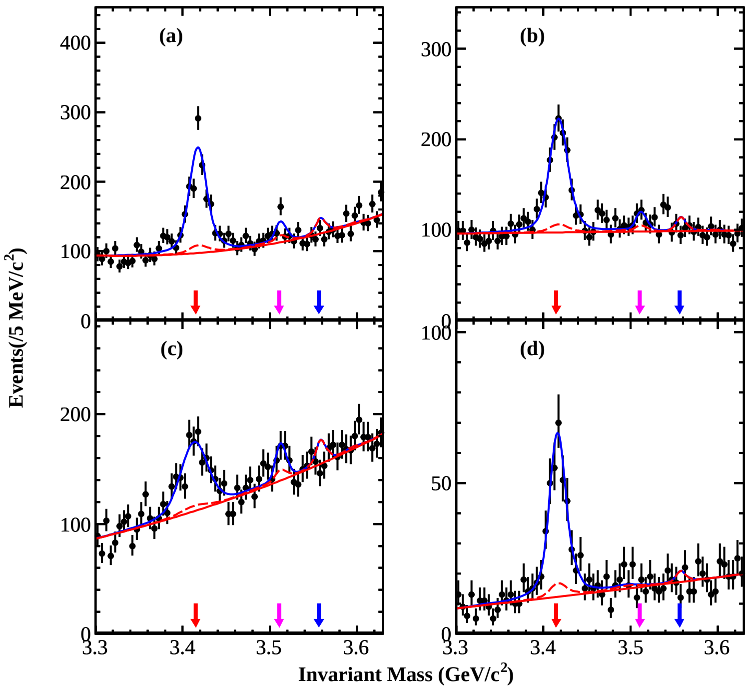

Figure 2: Invariant mass spectrum of the hadronic combinations selected from data take at 3.773 GeV.

What's more, based on the 2.92 fb^{-1} of data collected at $\sqrt{s} = 3.773$ GeV, the decay $\psi(3770) \to \gamma\chi_{c1,2}$ was searched for [16] through the decay channel of $\chi_{cJ} \to \gamma J/\psi$, $J/\psi \to l^+l^-(l = e$ or $\mu)$. The energy of the γ from the process of $\psi(3770) \to \gamma\chi_{cJ}$ $(J = 1,2)$ is lower than that of the γ from $\chi_{cJ} \to \gamma J/\psi$. So the invariant mass of $\gamma^H J/\psi$, where γ^H refers to the higher energetic photon in the final state $\gamma\gamma l^+l^-$, is analyzed to reconstruct the χ_{c1} and χ_{c2}. Figure 3 shows the invariant mass spectrum of the $\gamma^H J/\psi$. The decays to $\gamma\chi_{c1}$ are observed, the branching fraction is measured to be $\mathscr{B}(\psi(3770) \to \gamma\chi_{c1}) = (2.48 \pm 0.15 \pm 0.23) \times 10^{-3}$. No significant signal for the χ_{c2} is observed, an upper limit at 90% confidence level is set to be $\mathscr{B}(\psi(3770) \to \gamma\chi_{c2}) < 0.64 \times 10^{-3}$. This measured branching fraction for $\psi(3770) \to \gamma\chi_{c1}$ is consistent within error with $\mathscr{B}(\psi(3770) \to \gamma\chi_{c1}) = (2.8 \pm 0.5 \pm 0.4) \times 10^{-3}$ measured by CLEO-c [11], but the precision is improved by more than a factor of 2.

4. $\psi(3770) \to \gamma\eta_c(2S) \to \gamma K^0_S K\pi$

Under the assumption that the $\psi(3770)$ is predominantly the 1^3D_1 state, the radiative transitions of $\psi(3770) \to \gamma\eta_c(\eta_c(2S))$ are highly suppressed by selection rules. However, higher multipoles beyond the leading one could contribute to the partial width of these processes [12]. The partial widthes of those processes are predicted by considering the immediate meson loop calculation (IML) contributions. Experimental measurements of the branching fractions $\mathscr{B}(\psi(3770) \to \gamma\eta_c(\eta_c(2S))$ would help to test theoretical predictions.

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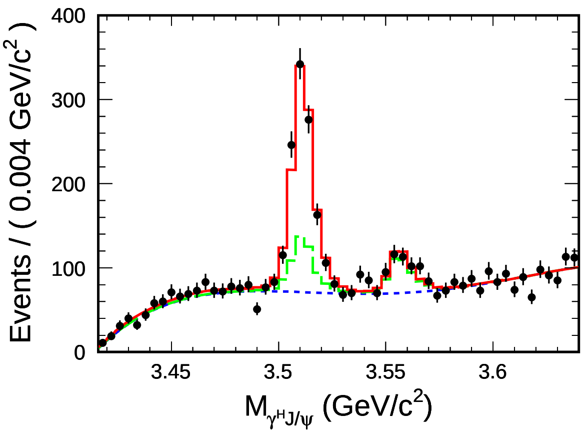

Figure 3: Invariant mass spectrum of the energetic photon and J/ψ combinations selected from data. The dots with error bars represent the data. The solid (red) line shows the fit. The dashed (blue) line shows the smooth background. The long-dashed (green) line is the sum of the smooth background and the contribution from $e^+e^- \to (\gamma_{\rm ISR})\psi(3686)$ production.

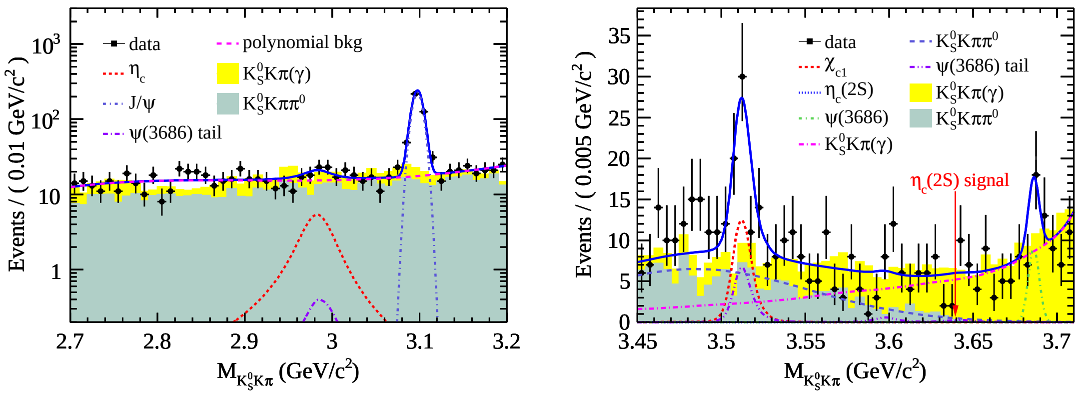

Figure 4: Invariant-mass spectrum for $K_S^0K^\pm\pi^\mp$ from data with the estimated backgrounds and best-fit results superimposed in the η_c and $\eta_c(2S)$ mass regions. Dots with error bars are data. The shaded histograms represent the background contributions. The solid lines show the total fit results.

Using the 2.92 fb^{-1} data sample taken at $\sqrt{s} = 3.773$ GeV, searches for the radiative transitions between the $\psi(3770)$ and the $\eta_c(2S)$ through the decay process $\psi(3770) \to \gamma K_S^0K^\pm\pi^\mp$ are performed [13]. Figure 4 shows the invariant mass distribution of $K_S^0K^\pm\pi^\mp$ for the selected candidates in the η_c and $\chi_{c1} - \eta_c(2S)$ mass regions. No significant η_c and $\eta_c(2S)$ signals are observed. Upper limits on the product branching fractions at a 90% confidence level are set to be $\mathscr{B}(\psi(3770)\to\gamma\eta_c)\times\mathscr{B}(\eta_c\to\gamma K_S^0K^\pm\pi^\mp) < 1.6\times10^{-5}$ and $\mathscr{B}(\psi(3770)\to\gamma\eta_c(2S))\times\mathscr{B}(\eta_c(2S)\to\gamma K_S^0K^\pm\pi^\mp) < 5.6\times10^{-6}$. Combining those results with the $\mathscr{B}(\eta_c(\eta_c(2S))\to\gamma K_S^0K^\pm\pi^\mp)$ quoted from PDG, the branching fractions upper limits are set to be $\mathscr{B}(\psi(3770)\to\gamma\eta_c) < 6.8\times10^{-4}$ and $\mathscr{B}(\psi(3770)\to\gamma\eta_c(2S)) < 2.0\times10^{-3}$ at a 90% confidence level.

The measured branching fractions correspond to the partial decay widthes $\Gamma(\psi(3770)\to\gamma\eta_c) < 19$ keV and $\Gamma(\psi(3770)\to\gamma\eta_c(2S)) < 55$ keV. The upper limit for $\Gamma(\psi(3770)\to\gamma\eta_c)$

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is just within the error range of the theoretical prediction of the IML [12] ($17.14^{+22.93}_{-12.03}$ keV). While the upper limit for $\Gamma(\psi(3770) \to \gamma\eta_c(2S))$ is much larger than the IML prediction [12] ($1.82^{+1.95}_{-1.19}$ keV). This is result is limited by statistics and the uncertainty in the branching fraction of $\eta_c(2S) \to K^0_S K^\pm \pi^\mp$.

5. Summary

Using $\psi(3770)$ data of 2.92 fb^{-1} integrated luminosity, many analyses are performed. Exclusively baryonic decays of the $\psi(3770)$ are searched for, but no significant signals are observed, and the upper limits for the branching fractions are set for these decays. For the radiative transition $\psi(3770) \to \gamma\chi_{cJ}$ and $\psi(3770) \to \gamma\eta_c(\eta_c(2S))$, we measure the branching fractions of $\psi(3770 \to \gamma\chi_{c0})$ and $\psi(3770 \to \gamma\chi_{c1})$, which are the most precise measurement to date. The upper limit on the braching fractions of $\psi(3770 \to \gamma\chi_{c2})$ and $\psi(3770 \to \gamma\eta_c(\gamma\eta_c(2S)))$at a 90% confidence level have been set. These measurements provide more information on the non-$D\overline{D}$ decays of $\psi(3770)$.

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