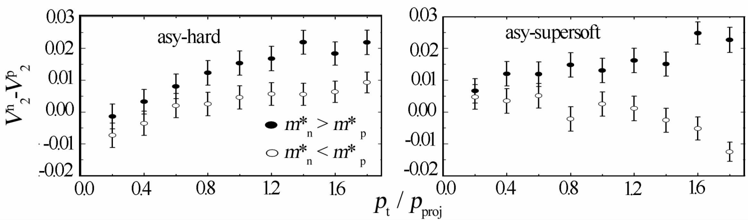

Fig. 3 Comparison of the difference between neutron and proton elliptic flows with the rapidity bin $|y/y_{proj}|<0.25$ for the different mass splitting in the semi-central ^{197}Au+^{197}Au collisions.

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1 - 6 Two Charged Strangeonium-like Structures Observable in Y(2175)→ϕ(1020)$\pi^+\pi^-$ Process

Chen Dianyong

As one of the newly observed XYZ states, Y(2175) was first reported by the BaBar Collaboration, where an enhancement structure with mass M=2175±10±15 MeV and width Γ=58±16±20 MeV was observed in the $\phi f_0(980)$ invariant mass spectrum of $e^+e^-\to\phi(1020)f_0(980)$ via the initial state radiation (ISR) mechanism[1]. Furthermore, Y(2175) was confirmed by BES-II in $J/\psi\to\eta\phi f_0(980)$[2] and by Belle in the $e^+e^-\to\phi(1020)\pi^+\pi^-$ and $e^+e^-\to\phi f_0(980)$ processes[3]. The observation of Y(2175) have stimulated theorists' interest in revealing its underlying structures. By a relativized quark model with chromodynamics, Godfrey and Isgur predicted the masses of $2\,^3D_1$ and $3\,^3S_1$ states close to the mass of Y(2175), which seems to support Y(2175) as a vector strangeonium. However, vector strangeonium assignment with $3\,^3S_1$ can be fully excluded since the calculated total width of this state is about 380 MeV, which is far larger than the width of Y(2175). Right after the observation of Y(2175), Ding and Yan studied the decay behavior of Y(2175) assuming it as a $2\,^3D_1$ strangeonium state[4] and calculated the total width of Y(2175) to be 167.21 MeV by the $^3P_0$ model or 211.9 MeV by the flux tube model, which are larger than the width of Y(2175) to some extent.

The observation of Y(2175) is tempting us to relate it to the observed Y(4260) and Υ(10860) due to some common peculiarities existing in the experiments of Y(2175), Y(4260) and Υ(10860). Before observing Y(2175), the BaBar Collaboration once reported an enhancement named as Y(4260) in the $J/\psi\pi^+\pi^-$ invariant mass spectrum of $e^+e^-\to J/\psi\pi^+\pi^-$[5]. In 2007, the Belle Collaboration found anomalous partial width of Υ(10860)→Υ(1S,2S)$\pi^+\pi^-$, which is 2~3 orders larger than those of Υ(nS)→Υ(mS) $\pi^+\pi^-$ (n=2,3,4 and $m<n$)[6]. Comparing the experimental phenomena of Y(2175), Y(4260) and Υ(10860), we notice the similarities among these particles. Y(2175), Y(4260) and Υ(10860). Firstly, Y(2175), Y(4260) and Υ(10860) are produced from the e^+e^- collision, which indicates that their quantum numbers are $J^{PC}=1^{--}$. Secondly, the dipion transitions of Y(2175), Y(4260) and Υ(10860) were observed. Thirdly, there exist some anomalous phenomena in the e^+e^- collisions at several typical energies 2175 MeV, 4260 MeV and 10860 MeV, which correspond to the relevant observations of Y(2175), Y(4260) and Υ(10860). These properties seem to show a complete series of flavors. Thus, the ideas that arise when studying Y(2175), Y(4260) and Υ(10860) can be shared with each other, which provides new insight into these peaks and further reveals the properties of Y(2175), Y(4260) and Υ(10860).

Recently, the Belle Collaboration announced two charged bottomonium-like structures Z_b(10610) and Z_b(10650) observed in the Υ(1S,2S,3S)$\pi^\pm$ and h_b(1P,2P)$\pi^\pm$ invariant mass spectra of Υ(10860)→Υ(1S,2S,3S) $\pi^+\pi^-$, h_b(1P,2P) $\pi^+\pi^-$[7]. In Ref. [8], the Initial Single Pion Emission (ISPE) mechanism, a unique mechanism, was introduced in the Y(10860) hidden-bottom dipion decay. The ISPE mechanism can naturally explain why the $Z_b(10610)$ and $Z_b(10650)$ enhancements close to the BB^* and B^*B^* thresholds, respectively, appear in the $Y(1S,2S,3S)\pi^\pm$ and $h_b(1P,2P)\pi^\pm$ invariant mass spectra. Emphasized in Ref. [8], extending the ISPE mechanism to study the hidden-charm dipion decays of higher charmonia is also an interesting research topic. The similarity existing in Y(2175), Y(4260) and Y(10860) stimulates us to apply the ISPE mechanism to study the hidden-strange dipion decay of Y(2175), which can result in some novel phenomena in Y(2175). To some extent, carrying out the search for such phenomena will not only be an important and intriguing topic, but also provide useful test of the ISPE mechanism.

Fig. 1 The ISPE mechanism in $Y(2175)\to\phi(1020)\pi^+\pi^-$ decay process. Here, we only list two schematic diagrams by the initial π^+ and π^- emissions corresponding to diagrams (a) and (b).

We can employ the effective Lagrangian based on $SU(3)$ symmetry and the gauging of Wess-Zumino action. The coupling constants are estimated by the $SU(3)$ limit. With the effective Lagrangians, we can obtain the decay amplitudes corresponding diagram (a) in Fig. 1. By making replacement $p_{\pi^+}\leftrightarrow p_{\pi^-}$ one can obtain the decay amplitudes corresponding diagram (b) in Fig. 1. Thus, the differential decay width of Y (2175)$\to\phi(1020)\pi^+\pi^-$ read as,

$$d\Gamma=\frac{1}{(2\pi)^3 32m_Y^3}\ \overline{|A|}^2 dm^2_{\phi\pi^+}dm^2_{\pi^+\pi^-},$$

where A is the total decay amplitudes of $Y(2175)\to\phi(1020)\pi^+\pi^-$, m_Y denotes the mass of Y(2175) and $m_{\pi^+\pi^-}$ is the $\pi^+\pi^-$ invariant mass.

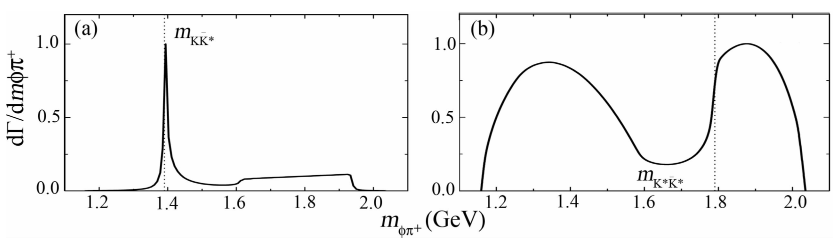

Fig. 2 The lineshape of the $\phi(1020)\pi^+$ invariant mass distribution for the differential cross section of $Y(2175)\to\phi(1020)\pi^+\pi^-$ with $K^*\bar{K}$ (a) and $K^*\bar{K}^*$ (b) as the intermediate states.

With above preparation, we can obtain the distributions of $\phi(1020)\pi^+$ invariant mass under ISPE mechanism with different strange meson pairs as the intermediate states. The lineshape of the $\phi(1020)\pi^+$ invariant distributions of the differential cross section are present in Fig. 2. For $K^*\bar{K}$ intermediate process (shown in diagram (a) of Fig. 2), the numerical result indicates there should exist a sharp peak near the threshold of $K^*\bar{K}$. In addition, we also notice that the change of the lineshape in the 1.6 to 1.9 GeV range becomes smooth, which is due to t he contribution from its reflection. For $K^*\bar{K}^*$ intermediate process (shown in Fig. 2(b)), our estimation indicates there should exist two broad structures. One is close to $K^*\bar{K}$ threshold and another corresponds to its reflection contribution[9].

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1 - 7 Does Enhancement Observed in $\gamma\gamma \to D\bar{D}$ Contain Two *P*-wave Higher Charmonia?

Chen Dianyong

As the *P*-wave spin-triplet charmonium spectrum becomes more abundant, however, an urgent and crucial question emerges out of the study on the first radial excitation of *P*-wave charmonia. Very recently, the BaBar Collaboration[1] confirmed the observation of X(3915) in the $\gamma\gamma \to J/\pi\omega$ process and indicated that X(3915) is a $\chi_{c0}(2P)$ charmonium by a spin-parity analysis. This new observation is consistent with the prediction of the property of X(3915) given in Ref. [2]. Thus, these experimental measurements show that the mass of X(3915) as the first radial excitation of $\chi_{c0}(3415)$ is very close to that of $\chi_{c2}(2P)$ and above the $D\bar{D}$ threshold. Additionally, the decay behavior of $\chi_{c2}(2P)$ and $\chi_{c0}(2P)$ shows that both of them decay into $D\bar{D}$ via the *D*-wave and *S*-wave interactions, respectively, where $\chi_{c0}(2P) \to D\bar{D}$ is a dominant contribution to the total width[2]. Since Z(3930) was already observed in the $D\bar{D}$ invariant mass spectrum of the $\gamma\gamma \to D\bar{D}$ process[3], we believe that $\chi_{c0}(2P)$ should exist in the same data samples of the $D\bar{D}$ invariant mass spectrum, where $\chi_{c0}(2P)$ and Z(3930) are assumed to have the same spatial wave functions. However, the present experiment did not report any evidence of $\chi_{c0}(2P)$ in this process[3], which obviously contradicts the above general analysis. This is a new puzzle when studying the *P*-wave higher charmonia.

Due to the peculiarity of $\chi_{c0}(2P)$, we propose a novel conjecture to solve this puzzle, i. e., the enhancement structure observed in the $D\bar{D}$ invariant mass spectrum of the $\gamma\gamma \to D\bar{D}$ process should contain both $\chi_{c0}(2P)$ and $\chi_{c2}(2P)$ signals. To testify that this conjecture is reasonable, in the following analysis we shall construct a model depicting the $\gamma\gamma \to D\bar{D}$ process, where we will consider both $\chi_{c0}(2P)$ and $\chi_{c2}(2P)$ contributions to this process. Furthermore, by fitting the experimental data of the $D\bar{D}$ invariant mass spectrum, we will test this conjecture and extract the resonance parameters of $\chi_{c0}(2P)$ and $\chi_{c2}(2P)$, which are important properties of *P*-wave higher charmonia. What is more important is that we find a complete series of *P*-wave spin-triplet charmonia including the established ground states and their corresponding first radial excitations. Of course, this will inspire experimentalists' interest in studying these $\chi_{c0}(2P)$ and $\chi_{c2}(2P)$ in future experiment, too.

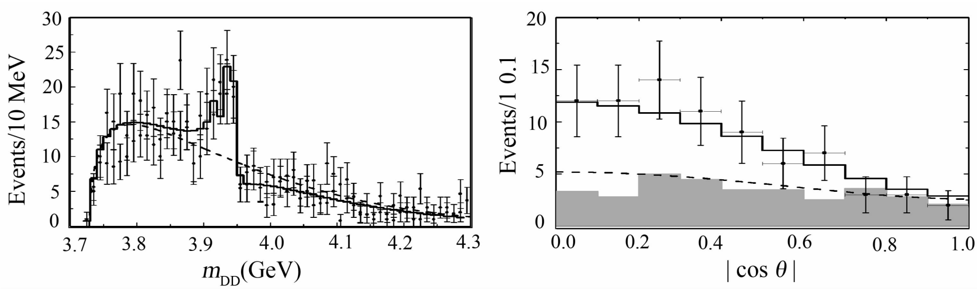

Fig. 1 Best fit to the $D\bar{D}$ invariant mass spectrum and $\cos\theta$ distribution of $\gamma\gamma \to D\bar{D}$.

In general, $\gamma(k_1)\gamma(k_2) \to D(p_1)\bar{D}(p_2)$ occurs via two different mechanisms. The first mechanism is the so-called direct process, which provides the background contribution when studying the $D\bar{D}$ invariant mass spectrum. The second mechanism is the intermediate resonance state contribution to this process, which is from the s-channel. The initial $\gamma\gamma$ and final $D\bar{D}$ are connected by the intermediate resonances with $J^P = 0^+, 2^+$, where the parity and total quantum number of the intermediate state are constrained by both the initial $\gamma\gamma$ and final $D\bar{D}$. When analyzing the data of Belle and BaBar, we select $\chi_{c0}(2P)$ and $\chi_{c2}(2P)$ as the intermediate states, which are the first radial excitations of $\chi_{c0}(3415)$ and $\chi_{c2}(3556)$, respectively. These ground states can also contribute to $\gamma\gamma \to D\bar{D}$ as the intermediate resonances. However, since the