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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.

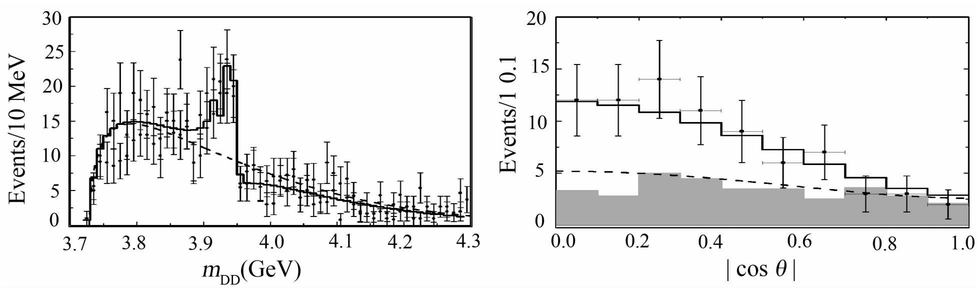

Fig. 1 Best fit to the $D\bar{D}$ invariant mass spectrum and $\cos\theta$ distribution of $\gamma\gamma \to D\bar{D}$.

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 masses of $\chi_{c0}(3415)$ and $\chi_{c2}(3556)$ are far away from the energy range discussed here, the high-mass tail of these resonances only provide one of the backgrounds to the $D\bar{D}$ invariant mass spectrum in the energy range (>3.7 GeV). The amplitudes are in the form,

$$M_{\mathrm{NOR}} = g_{\mathrm{NOR}}\varepsilon_1^{\mu}\varepsilon_2^{\nu}(T^0_{\mu\nu} + c_{02}T^2_{\mu\nu})F(s),$$
$$M_{\chi_{c0}(2P)} = \frac{ig_{\chi_{c0}(2P)\gamma\gamma}\varepsilon_1^{\mu}\varepsilon_2^{\nu}T_{\mu\nu}g_{\chi_{c0}(2P)D\bar{D}}}{s - m^2_{\chi_{c0}(2P)} + im_{\chi_{c0}(2P)}\Gamma_{\chi_{c0}(2P)}},$$
$$M_{\chi_{c2}(2P)} = \frac{ig_{\chi_{c2}(2P)\gamma\gamma}\varepsilon_1^{\mu}\varepsilon_2^{\nu}\varepsilon_{\mu\nu\alpha\beta}p^{\alpha\beta\rho\lambda}}{s - m^2_{\chi_{c0}(2P)} + im_{\chi_{c0}(2P)}\Gamma_{\chi_{c0}(2P)}}(-g_{\chi_{c2}(2P)D\bar{D}}ip_{1\rho}ip_{2\lambda}).$$

Thus the total amplitude is,

$$M_{\mathrm{Total}} = M_{\mathrm{NOR}} + \mathrm{e}^{i\phi_0}M_{\chi_{c0}(2P)} + \mathrm{e}^{i\phi_2}M_{\chi_{c2}(2P)}.$$

With above amplitudes, we can obtain the differential cross sections of $\gamma(k_1)\gamma(k_2)\to D(p_1)\bar{D}(p_2)$. By fitting the experimental data of $D\bar{D}$ invariant mass spectrum and $\cos\theta$ distribution, we can fix the free parameters in the amplitudes. In Fig. 1, we present our best to the $D\bar{D}$ invariant mass spectrum and $\cos\theta$ distribution. From the figure we can conclude that one can include $\chi_{c0}(2P)$ and $\chi_{c2}(2P)$ in present data of $\gamma\gamma\to D\bar{D}$[4].

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1 - 8 Neutrino Production based on Proton Linear Accelerator

Yong Gaochan

We investigated proton- and ^{3}He-induced reactions on a ^{197}Au target at beam energies of 2.8, 5, 10, and 16.587 GeV/u, and found that compared with proton-induced reactions, ^{3}He-induced reactions give larger cross sections of pion production, about 5 times those of the proton-induced reactions. And more importantly, pion production from ^{3}He-induced reaction is more inclined to low-angle emission. Neutrino production via positively charged pion is also discussed accordingly.

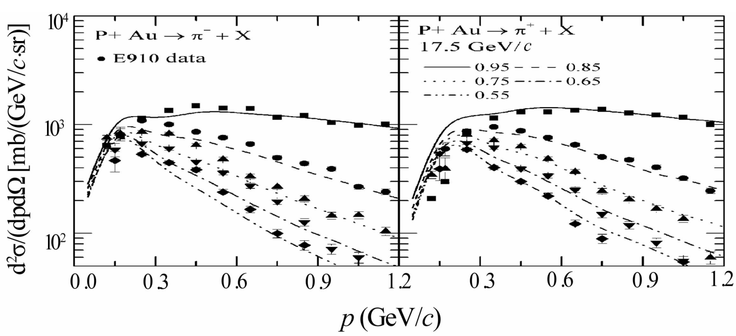

Fig. 1 Production cross sections of π^- (left panel) and π^+ (right panel) from p + Au at the incident beam momentum of 17.5 GeV/c ($E_{\mathrm{beam}}\approx$16.587 GeV/u) shown in bins of $\cos\theta$ (relative to beam direction). Numbers in the legend refer to the center of each bin, taken from Ref. [1].