PROCEEDINGS OF SCIENCE

Hadron Spectroscopy in Two-Photon Collisions at Belle

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We present recent measurement in two-photon collision, $\gamma\gamma \to K_S K_S$ from the Belle experiment. In lower energy region, we perform partial wave analysis and extract parameters for f_J and a_J resonances. In higher energy region, we update our previous measurement and make comparison with QCD predictions.

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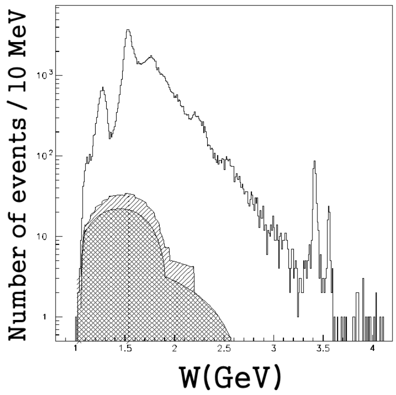

Figure 1: W distribution of signal candidates in $|\cos\theta^*| < 0.8$. Crosshatched and hatched histograms are non-exclusive background and four-pion background, respectively.

1. Introduction

The Belle experiment has measured exclusive meson-pair productions in two-photon collision, $\gamma\gamma \to \pi^+\pi^-$ [1, 2], $\pi^0\pi^0$ [3], K^+K^- [2, 4], $KsKs$ [5], $\eta\pi^0$ [6], $\eta\eta$ [7], and $D\bar{D}$ [8]. These measurements are based on no-tag method where e^+e^- beam particles escape through beam pipe and thus must not be detected to make sure almost-zero virtuality of colliding photons. In this configuration total transverse momentum of the final state hadron system in e^+e^- frame, $\sum \vec{p}_t^*$, balances, and photon-photon colliding axis, which cannot be determined, is well approximated with the e^+e^- colliding axis. Because energy of photons emitted from e^+e^- beams are not constant we obtain spectrum of cross section as a function of two-photon invariant mass W that is determined as invariant mass of final state hadron system.

The differential cross section is calculated as

$$\frac{d\sigma}{d|\cos\theta^*|}(W,|\cos\theta^*|) = \frac{\Delta N(W,|\cos\theta^*|)}{\Delta W \Delta|\cos\theta^*| \frac{dL_{\gamma\gamma}}{dW}\, \varepsilon(W,|\cos\theta^*|) \int \mathscr{L} dt}, \tag{1.1}$$

where θ^* is the scattering angle of the final state meson with respect to photon-photon axis in two-photon center-of-mass system, $\frac{dL_{\gamma\gamma}}{dW}$ is the luminosity function, ε is total efficiency including branching fractions, and $\int \mathscr{L} dt$ is the integrated luminosity.

We present measurement of K_S pair production in two-photon collisions using a data sample of 972 fb^{-1}. This study is published as Ref [9]. This process has been measured by various experiments [10] with at most 1 fb^{-1} of data. Although these experiments operated at higher e^+e^- c.m. energies, the cross section in two-photon processes depends on the e^+e^- c.m. energy only logarithmically.

2. Study of f_J and a_J resonances

Figure 1 shows signal candidate distribution, where in addition to well known resonances, structures around 1.7, 2.2 and 2.5 GeV are seen. We perform fits to $W < 2.0$ GeV and $2.0 < W <$

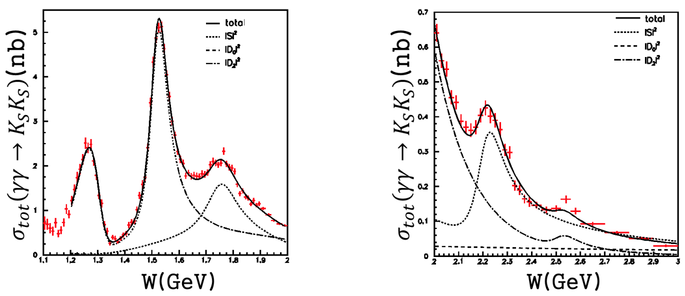

Figure 2: Measured cross sections and fit results for $W < 2.0$ GeV (left) and $2.0 < W < 3.0$ GeV (right). Dotted, dashed, and dot-dashed curves are $|S|^2$, $|D_0|^2$, and $|D_2|^2$ partial waves, respectively.

Table 1: Obtained parameters for $f_2'(1525)$, $f_0(1710)$, $f_2(2200)$, and $f_0(2500)$.

	mass (MeV/c^2)	width (MeV)	$\Gamma_{\gamma\gamma}\mathscr{B}(K\bar{K})$ (eV), (J,λ)
$f_2'(1525)$	$1525.3^{+1.2+3.7}_{-1.4-2.1}$	$82.9^{+2.1+3.3}_{-2.2-2.0}$	$48^{+67+108}_{-8-12}$
$f_0(1710)$	1750^{+6+29}_{-7-18}	139^{+11+96}_{-12-50}	12^{+3+227}_{-2-8}
$f_2(2200)$	2243^{+7+3}_{-6-29}	$145 \pm 12^{+27}_{-34}$	$3.2^{+0.5+1.3}_{-0.4-2.2}$
$f_0(2500)$	$2539 \pm 14^{+38}_{-14}$	$274^{+77+126}_{-61-163}$	40^{+9+17}_{-7-40}

3.0 GeV regions separately, assuming $f_2(1270)$, $a_2(1320)$, and $f_2'(1525)$ states in the lower region and $f_J(1710)$, $f_J(2200)$, and $f_J(2500)$ states in the higher region, using

$$\frac{d\sigma(\gamma\gamma \to K_S K_S)}{d\Omega} = \left|S\,Y_0^0 + D_0\,Y_2^0\right|^2 + \left|D_2\,Y_2^2\right|^2 , \tag{2.1}$$

where Y_J^λ are the spherical harmonics and S and D_λ are, respectively, helicity-λ components of S and D amplitudes that consist of Breit-Wigner for resonance and polynomial functions for background components. Figure 2 shows the differential cross sections and fit results for the two energy regions. The relative phase between $a_2(1320)$ and $f_2(1270)$ is measured to be $\left(172.6^{+6.0+12.2}_{-0.7-7.0}\right)^\circ$, hence destructive interference suggested by Ref. [11] is confirmed as measured by previous measurements [10]. The $f_2'(1525)$ parameters are measured taking inteference effect into account for the first time. Spin-0 is favored over Spin-2 for $f_J(1710)$. We found that the assignment of $f_2(2220)$ and $f_0(2500)$ gives the best solution over the second best with 3.4 σ. Measured parameters for these resonances are summarized in Table 1. $f_0(1710)$ and $f_2(2200)$ are unlikely to be glueballs because their total widths and $\Gamma_{\gamma\gamma}\mathscr{B}(K\bar{K})$ values are much larger than those expected for a pure glueball state.

3. Study of QCD in $W > 2.6$ GeV

In this energy region, we update our previous measurement [5]. The handbag model predicts $1/\sin^4\theta^*$ dependence of the differential cross section [12]. Figure 3 (left) shows measured differential cross section and fits to $1/\sin^\alpha\theta^*$. α increases with W in $W < 2.7$ GeV and does not approach 4 (Fig. 3 (right,top)). The slope parameter n that indicates W dependence of the cross

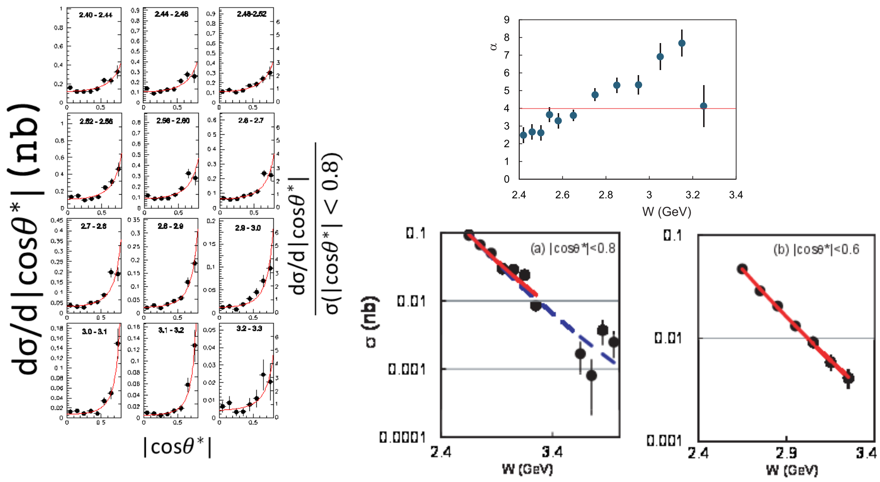

Figure 3: (left) Angular dependence of the differential cross section for different energy region. Points are data and curves are fit results to $1/\sin^{\alpha}\theta^{*}$. With right vertical scale, the differential cross sections are normalized to unity over this angular region. (right top) W dependence of the parameter α. The horizontal line at $\alpha = 4$ corresponds to the claim from non-perturbative calculation. (right bottom) Cross sections in $|\cos\theta^{*}| < 0.8$ (a) and in $|\cos\theta^{*}| < 0.6$ (b) and fits to W^{-n} in 2.6-4.0 GeV excluding charmonia region (dashed line) and in 2.6-3.3 GeV (solid line).

Table 2: Measured χ_{c0} and χ_{c2} parameters. Width of χ_{c2} is fixed to 2 MeV.

Interference	$\Gamma_{\gamma\gamma}\mathscr{B}(\chi_{c0})$ (eV)	$\Gamma_{\gamma\gamma}\mathscr{B}(\chi_{c2})$ (eV)	Mass(χ_{c0}) (MeV/c^2)	Width(χ_{c0}) (MeV)	Mass(χ_{c2}) (MeV/c^2)
Not included	$8.09 \pm 0.58 \pm 0.83$	$0.268^{+0.041}_{-0.037} \pm 0.028$	3414.8 ± 0.9	13.2 ± 2.1	3555.4 ± 1.3
Included	$8.7 \pm 1.7 \pm 0.9$	$0.27^{+0.07}_{-0.06} \pm 0.03$	3414.6 ± 1.1	13.2 ± 2.1	3555.4 ± 1.3

Table 3: Upper limits at 90% confidence level on charmonium productions.

R	$\Gamma_{\gamma\gamma}(R)\mathscr{B}(R \to K_S K_S)$ eV
$\chi_{c0}(2P)$	0.49
$\chi_{c2}(2P)$	0.064
η_c	1.6

section, $\sigma \sim W^{-n}$ is measured to be $n = 11.0 \pm 0.4 \pm 0.4$ ($|\cos\theta^{*}| < 0.8$, 2.6 - 4.0 GeV excluding charmonia region) and is in good agreement with perturbative QCD calculation [13].

4. Study of charmonia

Figure 4 is candidate events in $|\cos\theta^{*}| < 0.5$. χ_{c0} and χ_{c2} peaks are evident. We fit these peaks with and without interference. The results (Table 2) supersede the previous measurement [5]. We set upper limits at 90% confidence level on $\Gamma_{\gamma\gamma}\mathscr{B}(\to K_S K_S)$ for expected $\chi_{c0}(2P)$ and $\chi_{c2}(2P)$ mesons, and P- and CP-violating decay $\eta_c \to K_S K_S$ as summarized in Table.3.

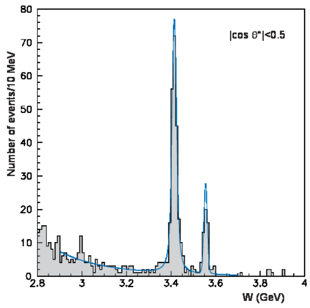

Figure 4: Measured cross sections and fit results for $W < 2.0$ GeV (left) and $2.0 < W < 3.0$ GeV (right). Dotted, dashed, and dot-dashed curves are $|S|^2$, $|D_0|^2$, and $|D_2|^2$ partial waves, respectively.

5. Conclusion

We perform partial wave analysis and extract parameters of a_J and f_J resonances in lower W region up to around 2.5 GeV, In higher energy region where resonance effect is small, we update our previous study [5], and evaluate QCD calculations by measuring differential cross section. We also measure parameters of χ_{c0} and χ_{c2}, and set upper limits on another charmonium productions.

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