Particle Production in Two-Photon Collisions at Belle

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We report recent measurements of the $\gamma\gamma \to \eta\eta$ process in the energy range, $1.096 \text{ GeV} < W < 3.8 \text{ GeV}$ and in scattering angle, $|\cos \theta^*| \leq 0.9 \text{ or } \leq 1.0$ depending on $W$, where $W$ is the energy of the two-photon center-of-mass system and $\theta^*$ is the $\eta$ scattering angle. In the lower energy region, we perform a partial wave analysis to the differential cross section and extract resonance parameters. In the higher energy region, (differential) cross section is compared with QCD predictions. We also present a study of $\eta_c(2S)$ production with 6-prong final states in two-photon collisions.

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Belle Two-Photon Results
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1. Introduction

Two-photon production of exclusive hadronic final states provides useful information about resonances and perturbative and nonperturbative QCD. From theoretical viewpoint, two-photon process is attractive because of the absence of strong interactions in the initial state and the possibility of calculating $gg \rightarrow q\bar{q}$ amplitudes. In addition, the quantum numbers of the final state are restricted to states of charge conjugation $C = +1$ with $J = 1$ forbidden.

We have measured production of charged meson pairs [1], neutral meson pairs [2], proton antiproton pair [3] and $D$-meson pair [4] in two-photon collisions. This paper reports recent measurements of $gg \rightarrow hh$ [5] and $gg \rightarrow h_c(2S) \rightarrow 6$ prong.

2. $gg \rightarrow \eta \eta$

The results are based on a 393 fb$^{-1}$ data sample collected with the Belle detector [6] at the KEKB $e^+e^-$ collider [7]. $\eta$ is reconstructed with a photon pair. This pure neutral final states are selected with energy sum and cluster counting triggers, both of which information are provided by a CsI(Tl) electromagnetic calorimeter. We subtract background by studying sideband events in two-dimensional $M_1(\gamma\gamma)-M_2(\gamma\gamma)$ distributions. Further background effects are studied using $|\vec{p}_t|$ distribution and taken into account as systematic errors. Fig. 1(Left) shows the total cross sections.

For the lower energy region $1.16 \text{ GeV} < W < 2.0 \text{ GeV}$, we apply a partial wave analysis to the differential cross section (Fig. 1(Right)). In addition to the known $f_2(1270)$ and $f'_2(1525)$, we introduce a tensor meson $f_2(X)$ to describe $D_2$ wave, which may correspond to $f_2(1810)$ state [8], and the mass, width and product of the two-photon decay width and branching fraction $\Gamma_{\gamma\gamma} B(\eta\eta)$ for $f_2(X)$ are obtained to be $1737 \pm 9 \text{ MeV/c}^2$, $228^{+21}_{-20} \text{ MeV}$ and $5.2^{+0.9}_{-0.8} \text{ eV}$, respectively. In the

Figure 1: Left: Cross section of the $\gamma\gamma \rightarrow \eta\eta$ process integrated over $|\cos \theta'| < 1$ ($W < 2.0 \text{ GeV}$) or $|\cos \theta'| < 0.9$ ($W > 2.0 \text{ GeV}$). Errors are statistical only. The dotted curve shows the size of the systematic uncertainty. Right: The total cross section ($|\cos \theta'| < 1$) and fitted curves. Dotted (dot-dashed) curves are $|S|^2$ ($|D|^2$) from the fit.
higher energy region $2.4 \text{ GeV} < W < 3.2 \text{ GeV}$ where effects from resonances are small, we compare the (differential) cross section with (perturbative) QCD ((p)QCD) predictions. In our previous studies for $\pi^+\pi^-$, $K^+K^-$, $\pi^0\pi^0$ and $\eta\pi^0$ modes, the angular dependence in $W \gtrsim 3.0 \text{ GeV}$ were consistent with $1/\sin^4 \theta^*$ while pQCD predicts $1/\sin^4 \theta^*$ only for charged meson pair. We find that the angular dependence of $\eta\eta$ is in better agreement with $1/\sin^4 \theta^*$ than $1/\sin^6 \theta^*$ (Fig. 2 (Left)). The total cross section is fitted with a power-low function, $W^{-n}$ and $n = 7.8 \pm 0.6 \pm 0.4$ is obtained (Fig. 2(a)). Fig. 2(b) shows the $W$ dependence of the ratio between the measured cross section integrated over $|\cos \theta^*| < 0.8$ of $\gamma\gamma \rightarrow \eta\eta$ to $\gamma\gamma \rightarrow \pi^0\pi^0$. The averaged value of $0.37 \pm 0.02 \pm 0.03$ can be compared with the (p)QCD predictions [9].

Figure 3: $\chi_0$, $\chi_2$ and $\eta_c(2S)$ peaks in (a)$6\pi$, (b)$4K2\pi$ and (c)$K_sK3\pi$ mass distributions. Curves are the best fit results.
**Table 1:** Fit results for $\eta_c(2S)$ parameters. Errors are statistical, systematics and effects from possible interference with continuum.

<table>
<thead>
<tr>
<th>Process</th>
<th>$M$ (MeV/c$^2$)</th>
<th>$\Gamma$ (MeV)</th>
<th>evts</th>
<th>signi. $\Gamma_{\gamma\gamma R}$ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$6\pi$</td>
<td>3638.9 ± 1.6 ± 2.3</td>
<td>10.7 ± 4.9</td>
<td>1485 ± 274</td>
<td>8.5$\sigma$ 20.1 ± 3.7 ± 3.2</td>
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<tr>
<td>$2K4\pi$</td>
<td>3634.7 ± 1.6 ± 2.8</td>
<td>1.4$^{+6.3}_{-1.4}$, 13(90%C.L.)</td>
<td>407 ± 91</td>
<td>6.2$\sigma$ 10.2 ± 2.3 ± 3.4</td>
</tr>
<tr>
<td>$K_SK3\pi$</td>
<td>3636.5 ± 1.8 ± 2.4</td>
<td>15.9 ± 5.7</td>
<td>563 ± 71</td>
<td>8.7$\sigma$ 30.7 ± 3.9 ± 3.7</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>3636.9 ± 1.1 ± 2.5 ± 5.0</td>
<td>9.9 ± 3.2 ± 2.6 ± 2.0</td>
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3. $\gamma\gamma \rightarrow \eta_c(2S)$

Motivated by the fact that $\eta_c(2S)$ was not seen in our result of four-prong final states [10], we study six-prong final states with four modes, $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ ($6\pi$), $K^+K^-\pi^+\pi^-\pi^+\pi^-$ ($2K4\pi$), $K^+K^-K^+K^-\pi^+\pi^-$ ($4K2\pi$) and $K_S^0K^+\pi^+\pi^-\pi^+\pi^-$ ($K_SK3\pi$), using a data sample of 923 fb$^{-1}$. $\chi_{0}$, $\chi_{2}$ and $\eta_c(2S)$ peaks are clearly seen in $6\pi$, $2K4\pi$ and $K_SK3\pi$ mass distributions (Fig. 4). They are the first observations except $\chi_{0} \rightarrow 4K2\pi$ mode. We do not take interference effect with continuum into account, which is estimated as systematic error independently. Fit results for the $\eta_c(2S)$ are summarized in Table 1.

References


