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Recent results in charmonium spectroscopy at BaBar

P. Biassoni on behalf of the BaBar Collaboration
Università degli Studi and INFN, Sezione di Milano - Via Celoria 16, I-20133 Milano, Italy

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Summary. — We present the measurement of the mass and width of the $\eta_c(2S)$ meson in the $\gamma\gamma \to K^0_S K^\pm \pi^\mp$ process, and $\eta_c(2S)$ first observation in the $\gamma\gamma \to K^+K^-\pi^+\pi^-\pi^0$ process. The $\chi_{c2}(2P)$ resonance is searched, but no significant signal is found.

PACS 13.25.Gv – Decays of J/ψ, Υ, and other quarkonia.
PACS 14.40.Pq – Heavy quarkonia.

1. – Introduction

Charmonium spectroscopy above the open-charm threshold received renewed attention after the discovery of the $X(3872)$ [1]. Among the many new states established to date [2-4], the $Z(3930)$ resonance has been observed in the $\gamma\gamma \to D\overline{D}$ process [3, 4] and its interpretation as the $\chi_{c2}(2P)$ state is commonly accepted [5]. The first radial excitation $\eta_c(2S)$ of the $\eta_c(1S)$ charmonium ground state was observed at B-factories [6]. To date only the exclusive decay to $K\overline{K}\pi$ has been observed [5]. Precise determination of the $\eta_c(2S)$ mass may discriminate among models that predict the $\psi(2S)$-$\eta_c(2S)$ mass splitting [7].

In this paper, we report the results of the study of the two-photon process $e^+e^- \to \gamma\gamma e^+e^- \to fe^+e^-$, where $f = K^0_S K^\pm\pi^\mp$ or $K^+K^-\pi^+\pi^-\pi^0$, and the interacting photons are quasi-real [8]. The results are based on about $520\,\text{fb}^{-1}$ of data collected at energies near the $\Upsilon(nS)$ $(n = 2, 3, 4)$ resonances with the BABAR detector [9].

2. – Analysis technique

An event candidate is selected by requiring the total number of charged tracks to be equal to four. We reject events with a large number of reconstructed neutral particles [8].

Background arises mainly from random combinations of particles from e^+e^- annihilation, other two-photon collisions, and initial state radiation (ISR) processes. The value of the missing mass squared $M^2_{\text{miss}} = (p_{e^+e^-} - p_{\text{rec}})^2$, where $p_{e^+e^-}$ (p_{rec}) is the four-momentum of the initial state (reconstructed final state), is expected to be large for well-reconstructed $\gamma\gamma$ signal events and ~ 0 $(\mathrm{GeV}/c^2)^2$ for ISR events. Two-photon events are expected to have low transverse momentum (p_T) with respect to the collision axis. We require $M^2_{\mathrm{miss}} > 2$ $(\mathrm{GeV}/c^2)^2$ and $p_T < 0.15\,\mathrm{GeV}/c$.

The number of peaking background events originating from $\psi = J/\psi\,, \psi(2S)$ radiative decays are estimated from the number of ψ events observed in data and the ratios of branching fractions ($\mathcal{B}$) [5] and Monte Carlo (MC) efficiencies for the different decay modes. The number of non-ISR peaking-background events is estimated by fitting the signal yield distributions as a function of p_T using the signal p_T shape from signal MC events plus a flat background.

3. – Mass and Width Measurement

The resonance signal yields, masses and widths are extracted using a binned extended maximum likelihood fit to the invariant $K^0_S K^\pm\pi^\mp$ and $K^+K^-\pi^+\pi^-\pi^0$ mass distributions (see fig. 2 of ref [8]). We parameterize each signal probability density function (PDF) as a convolution of a non-relativistic Breit-Wigner and the detector resolution function determined using MC events. The combinatorial background PDF is a fourth-order polynomial. The mass and width of the $\chi_{c0,2}(1P)$ states are fixed to their nominal values [5]. The $\eta_c(2S)$ decay to $K^+K^-\pi^+\pi^-\pi^0$ is observed for the first time with a significance (including systematic uncertainties) of 5.3 standard deviations. In the $K^0_S K^\pm\pi^\mp$ decay mode, we measure the $\eta_c(2S)$ mass $m(\eta_c(2S)) = (3638.5 \pm 1.5 \pm 0.8)\,\mathrm{MeV}/c^2$ and width $\Gamma(\eta_c(2S)) = (13.4 \pm 4.6 \pm 3.2)\,\mathrm{MeV}$, where the first (second) error is statistical (systematic).

We search for $\chi_{c2}(2P)$ by adding to the fit described above a component with the mass and width fixed to the values reported in ref. [4], but find no significant signal.

The main source of systematic uncertainty in the yield measurement is the parameterization of the combinatorial background. The main sources of systematic uncertainty in the mass and width measurement are the interference between signal and non-resonant background and the differences between the detector resolution in data and MC events.

4. – Two-photon width times branching fraction measurement

The ratios of the $\mathcal{B}$ of the two decay modes and the product between the two-photon coupling $\Gamma_{\gamma\gamma}$ and the resonance $\mathcal{B}$ to the final state are computed using the efficiency-weighted yields of each resonance. The efficiency-weighted yields are extracted using an unbinned maximum likelihood fit, where each event is given a weight proportional to the inverse of its detection efficiency. The detection efficiency is parameterized taking into account the $K^0_S K^\pm\pi^\mp$ and $K^+K^-\pi^+\pi^-\pi^0$ decay kinematics. We obtain:

$$\frac{\mathcal{B}(\eta_c(1S) \to K^+K^-\pi^+\pi^-\pi^0)}{\mathcal{B}(\eta_c(1S) \to K^0_S K^\pm\pi^\mp)} = 1.43 \pm 0.05 \pm 0.21, \tag{1}$$

$$\frac{\mathcal{B}(\eta_c(2S) \to K^+K^-\pi^+\pi^-\pi^0)}{\mathcal{B}(\eta_c(2S) \to K^0_S K^\pm\pi^\mp)} = 2.2 \pm 0.5 \pm 0.5, \tag{2}$$

$\Gamma_{\gamma\gamma} \times \mathcal{B}(\eta_c(1S) \to K\overline{K}\pi) = 0.386 \pm 0.008 \pm 0.021$, $\Gamma_{\gamma\gamma} \times \mathcal{B}(\eta_c(2S) \to K\overline{K}\pi) = 0.041 \pm 0.004 \pm 0.006$, $\Gamma_{\gamma\gamma} \times \mathcal{B}(\eta_c(1S) \to K^+K^-\pi^+\pi^-\pi^0) = 0.190 \pm 0.006 \pm 0.028$, and $\Gamma_{\gamma\gamma} \times \mathcal{B}(\eta_c(2S) \to K^+K^-\pi^+\pi^-\pi^0) = 0.030 \pm 0.006 \pm 0.005$. Since no $\chi_{c2}(2P)$ signal is observed, we compute a Bayesan upper limit $\Gamma_{\gamma\gamma} \times \mathcal{B}(\chi_{c2}(2P) \to K\overline{K}\pi) < 2.1 \times 10^{-3}$, and $\Gamma_{\gamma\gamma} \times \mathcal{B}(\chi_{c2}(2P) \to K^+K^-\pi^+\pi^-\pi^0) < 3.4 \times 10^{-3}$ at 90% confidence level.

5. – Conclusion

In conclusion, we observe for the first time the $\eta_c(2S)$ decay to $K^+K^-\pi^+\pi^-\pi^0$. This is the first observation of an exclusive hadronic decay of $\eta_c(2S)$ other than $K\overline{K}\pi$ [8]. The measurement of the $\eta_c(2S)$ mass and width in the $K^0_S K^\pm\pi^\mp$ decay is more precise than the current PDG average [5].

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