PROCEEDINGS OF SCIENCE

Recent Results on Two-photon Physics at BABAR

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Recent BABAR results on two-photon processes are presented. A high statistics study of the two-photon production of the charmonium states η_c and $\eta_c(2S)$ is performed. The mass and width of η_c and $\eta_c(2S)$ are measured; the ratio of the decay probabilities to $K_S K^+\pi^-$ and $K^+K^-\pi^+\pi^-\pi^0$ are determined. The latter mode is studied for the first time. The reactions $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-+$ pseudoscalar meson are studied in the single-tag mode for π^0, η, η', and η_c. From the measured differential cross sections the Q^2 dependencies of the photon-meson transition form factors are extracted. From these measurements we conclude that the pion distribution amplitude strongly differs from the distribution amplitudes of η and η' mesons.

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1. Introduction

Two-photon production of a resonance R is studied at e^+e^- colliders in the process $e^+e^- \to e^+e^-R$. The electrons in this process are scattered predominantly at small angles. For the pseudoscalar meson production, the effect of strong interactions is described by only one form factor $F(q_1^2, q_2^2)$ depending on the squared momentum transfers to the electrons.

Two-photon processes are usually studied in so called no-tag mode with both final electrons undetected. In this case the virtual photons emitted by electrons are practically real, the momentum transfers squared are close to zero. In no-tag mode the meson-photon transition form factor at zero q^2's and the meson two-photon width are measured.

In the single tag-mode one of the final electrons is detected. The corresponding virtual photon is highly off-shell. From the measurement of the cross section richer information is extracted: the dependence of the meson form factor on $Q^2 = -q_1^2$.

In this report we present results of no-tag and single-tag measurements performed with the BABAR detector at the PEP-II e^+e^- collider. The results are based on data with integrated luminosity of about 500 fb^{-1} collected at the center-of-mass energy of 10.6 GeV.

No-tag two-photon events are selected by the requirement that the transverse momentum of detected hadron system is low. The single-tag events are selected with the detected and identified electron and with the fully reconstructed pseudoscalar meson, π^0, η, η', or η_c. It is required that the transverse momentum of the electron-plus-meson system be low and the missing mass in an event be close to zero.

2. Measurement of η_c and $\eta_c(2S)$ parameters in the no-tag mode

The $K_S K^\pm \pi^\mp$ mass spectrum for no-tag events is shown in Fig. 1(a). The η_c, J/ψ, and $\eta_c(2S)$ peaks are clearly seen over a non-resonant smooth background. The J/ψ's are produced in the initial state radiation process $e^+e^- \to J/\psi\gamma$. An evidence for the $\chi_{c2} \to K_S K^\pm \pi^\mp$ decay is also seen in Fig. 1b. From the fit to the mass spectrum the following η_c parameters are determined [1]:

$$m = 2982.2 \pm 0.4 \pm 1.5 \text{ MeV}/c^2,\ \Gamma = 31.7 \pm 1.2 \pm 0.8 \text{ MeV}, \tag{2.1}$$

$$\Gamma(\eta_c \to \gamma\gamma)B(\eta_c \to K\bar{K}\pi) = 0.379 \pm 0.009 \pm 0.031 \text{ keV}. \tag{2.2}$$

These are the most precise measurements of the η_c mass and width to date. The obtained value of $\Gamma(\eta_c \to \gamma\gamma)B(\eta_c \to K\bar{K}\pi)$ agrees with the CLEO measurement $0.407 \pm 0.022 \pm 0.028$ keV [2].

From the fit to the $K_S K^\pm \pi^\mp$ mass spectrum in the vicinity of the $\eta_c(2S)$ resonance the following values of the $\eta_c(2S)$ mass and width are obtained:

$$m = 3638.3 \pm 1.5 \pm 0.6 \text{ MeV}/c^2,\ \Gamma = 14.2 \pm 4.4 \pm 2.5 \text{ MeV}. \tag{2.3}$$

These results are preliminary. They are in reasonable agreement with the previous BABAR measurements [3]: $m = 3630.8 \pm 3.4 \pm 1.0$ MeV/c^2 and $\Gamma = 17.0 \pm 8.3 \pm 2.5$ MeV, obtained using 88 fb^{-1} data. The current PDG values for these parameters are $m = 3637 \pm 4$ MeV/c^2 and $\Gamma = 14 \pm 7$ MeV [4]. The measured value of the $\eta_c(2S)$ width is also in good agreement with an estimation based on a quark model: $\Gamma(\eta_c(2S) \to gg) \approx \Gamma(\eta_c(1S) \to gg)\Gamma(\psi(2S) \to ee)/\Gamma(\psi(1S) \to ee) = 12.1 \pm 1.0$ MeV.

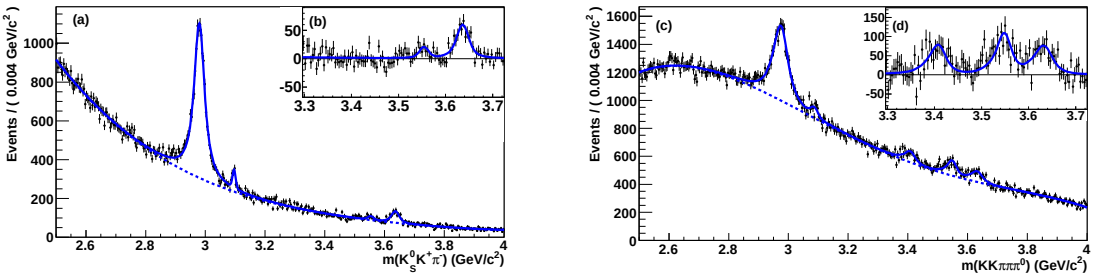

Figure 1: The $K_SK^{\pm}\pi^{\mp}$ (a) and $K^+K^-\pi^+\pi^-\pi^0$ (c) mass spectra. The solid line is the fit result. The dashed line represents non-resonant background. The plots (b) and (d) show background subtracted spectra for the mass range 3.3–3.7 GeV/c^2.

The mass spectrum for $K^+K^-\pi^+\pi^-\pi^0$ two-photon events is shown in Fig. 1(c). The signals from η_c, χ_{c0}, χ_{c2}, and $\eta_c(2S)$ are seen. This is a first observation of the $K^+K^-\pi^+\pi^-\pi^0$ decay for these resonances. The $\eta_c(2S)$ meson was previously observed in only $K_SK\pi$ decay mode. We have determined the ratios of the branching fractions into the two decay modes for η_c and $\eta_c(2S)$:

$$B(\eta_c \to K^+K^-\pi^+\pi^-\pi^0)/B(\eta_c \to K_SK^{\pm}\pi^{\mp}) = 1.42 \pm 0.06 \pm 0.26, \quad (2.4)$$

$$B(\eta_c(2S) \to K^+K^-\pi^+\pi^-\pi^0)/B(\eta_c(2S) \to K_SK^{\pm}\pi^{\mp}) = 2.1 \pm 0.4 \pm 0.5. \quad (2.5)$$

These results are preliminary.

3. Measurement of meson-photon transition form factors

In perturbative QCD, at large Q^2, the meson-photon transition form factor can be represented as a convolution of a calculable amplitude for $\gamma\gamma^* \to q\bar{q}$ with a nonperturbative meson distribution amplitude (DA) [5]. The latter describes the transition of the meson into two quarks.

Due to the relatively large c-quark mass, the η_c form factor is rather insensitive to the shape of the η_c distribution amplitude. Its Q^2 dependence is expected to be described by a monopole function with a pole parameter $\Lambda \sim 10$ GeV^2 [6]. This value is close to the VDM prediction: $\Lambda = m^2_{J/\psi} = 9.6$ GeV^2.

The BABAR data on the Q^2 dependence of the normalized $\gamma\gamma^* \to \eta_c$ transition form factor [1] is fitted well by a monopole function. The found pole parameter $\Lambda = 8.5 \pm 0.6 \pm 0.7$ GeV^2 is in agreement with both VDM and QCD predictions, and with the result of the lattice QCD calculation: $\Lambda = 8.4 \pm 0.4$ GeV^2 [7].

For light pseudoscalars, the form factor depends strongly on the shape of the meson DA. Experimental data can be used to test different DA models. The BABAR results [8] on the scaled (multiplied by Q^2) $\gamma\gamma^* \to \pi^0$ transition form factor is shown in Fig. 2(a) together with CLEO and CELLO data [9, 10]. The horizontal dashed line indicates the asymptotic limit for the scaled form factor ($Q^2F(Q^2) = \sqrt{2}f_\pi \approx 0.185$ GeV) predicted by pQCD [5]. The measured form factor exceeds the asymptotic limit at $Q^2 > 10$ GeV^2. This means that the pion DA is significantly wider than the asymptotic DA. The models with wide or very wide, flat DA's were proposed (see, for example, Refs. [11, 12, 13, 14, 15, 16, 17]) to describe the Q^2 dependence of the pion form factor observed by BABAR.

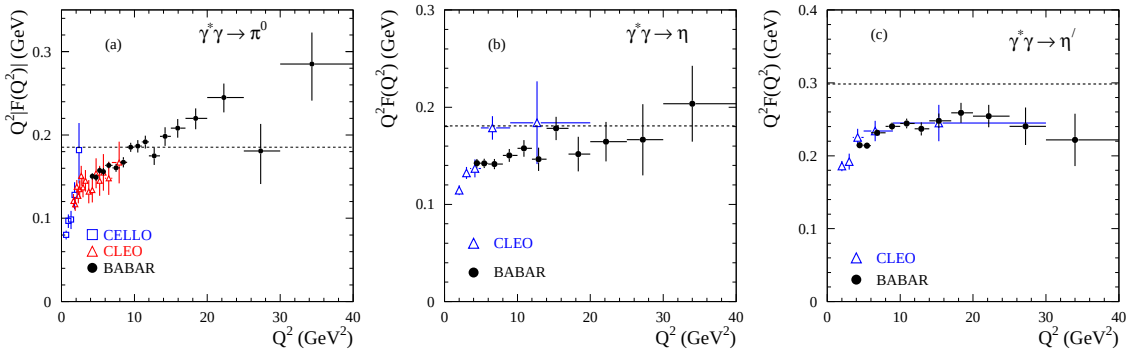

Figure 2: The scaled photon-meson transition form factors for π^0 (a), η (b), and η' (c) mesons. The dashed lines indicate the asymptotic limits for the scaled form factors.

The BABAR preliminary results on the scaled $\gamma\gamma^* \to \eta$ and η' transition form factors measured in the $e^+e^- \to e^+e^-\eta^{(\prime)}$ reactions are shown in Figs. 2(b) and (c) in comparison with previous CLEO measurements [10]. We significantly improve the precision and extend the Q^2 region for form factor measurements. For η' our results and CLEO measurements are in good agreement. For η the agreement is worse. The CLEO point at 7 GeV^2 lies higher than our data by about 3 sigmas.

The $e^+e^- \to \eta^{(\prime)}\gamma$ reactions also can be used to determine the transition form factors, but in the time-like region $q^2 = s > 0$. The time- and space-like form factors are expected to be close to each other at high Q^2. The form factors at $Q^2 = 14.2$ GeV^2

$$Q^2F_\eta(Q^2) = 0.187 \pm 0.030 \text{ GeV}, \; Q^2F_{\eta'}(Q^2) = 0.222 \pm 0.035 \text{ GeV} \tag{3.1}$$

are obtained from the values of the $e^+e^- \to \eta^{(\prime)}\gamma$ cross sections measured by CLEO [18] near the maximum of the $\psi(3770)$ resonance. The assumption is used that the contributions of the $\psi(3770) \to \eta^{(\prime)}\gamma$ decays to the $e^+e^- \to \eta^{(\prime)}\gamma$ cross sections are negligible. The time-like form factors at $Q^2 = 14.2$ GeV^2 are close to the corresponding space-like values. The BABAR measurements of the $e^+e^- \to \eta^{(\prime)}\gamma$ cross sections [19] near the maximum of the $\Upsilon(4S)$ resonance allows us to extend the Q^2 region for the η and η' form factor measurements up to 112 GeV^2. The time-like form-factor values at 112 GeV^2 are as follows:

$$Q^2F_\eta(Q^2) = 0.229 \pm 0.031 \text{ GeV}, \; Q^2F_{\eta'}(Q^2) = 0.251 \pm 0.021 \text{ GeV}. \tag{3.2}$$

The dashed lines in Figs. 2(b) and (c) indicate the asymptotic limits for the scaled η and η' form factors calculated in Ref. [20]. It is seen that Q^2 dependencies of the form factors for η and η' differ from that for π^0. We conclude that BABAR results on the meson-photon transition form factors for light pseudoscalars indicate that the pion DA is significantly wider than the DA's of η and η' mesons.

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