Two-photon reactions with KLOE detector at DAΦNE

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Abstract

We reexamine the feasibility of two-photon reactions at DAΦNE with the KLOE detector excluding the small angle tagging system. Event-rate predictions of interesting channels : $\gamma\gamma \to \pi^0$, η and $\gamma\gamma \to \pi^+\pi^-$, $\pi^0\pi^0$ are discussed.

I. INTRODUCTION

The physical interest of $\gamma\gamma$ collisions at DAΦNE has first been pointed out by A. Courau [1]. He has shown that the photons remain quasi-real up to a relatively large angle (a few hundreds of mrad.) of the scattered electrons. The counting rate of a double-tag measurement [2] remains relatively important (Fig. 1) in contrast with that of a similar measurement at a high energy machine (LEP) [3].

It has been shown that there is an overwhelming background the ϕ-meson production through annihilation process. Therefore a study of precision measurements of two-photon reactions with the KLOE detector [4] using the small angle tagging

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system has been performed [5]. For $\gamma\gamma \to \pi^0\pi^0$, a transverse-momentum cut allows one to isolate the signal from the background due to $\phi \to K_S K_L \to \pi^0\pi^0 \ + \ X$ (undetected).

The KLOE detector allows for a minimal tagging angle of the electrons of about 200 mrad, which is a rather large angle. In this context, we reexamine the feasibility of the two-photon reactions at DAΦNE with this constraint. Realistic event-rate predictions of interesting channels (pseudoscalar meson and pion-pair productions) are shown in sections II and III.

II. PSEUDOSCALAR MESON PRODUCTION

For pseudoscalar meson production by $\gamma\gamma^*$ collisions, there has been considerable theoretical and experimental activity to predict and measure the pion-photon transition form factor $F_{\pi\gamma}(Q^2)$. Previous pQCD predictions [6-9], using the asymptotic distribution amplitude, have been found to be consistent with the CELLO [10] and CLEO II data [11] up to $Q^2 = 8.$ GeV^2. The leading order (LO) prediction of the pion-photon transition form factor, in the framework of the hard scattering approach [12], reads :

$$F_{\pi\gamma}(Q^2) = \frac{2 f_\pi}{Q^2} \qquad\qquad \text{as} \qquad Q^2 \to \infty \tag{1}$$

where $f_\pi \simeq 93$ MeV is the pion decay constant.

Interpolating between this asymptotic expression and the current-algebra prediction at $Q^2 \to 0$, Brodsky and Lepage (BL) have proposed a simple-pole formula [6] :

$$F_{\pi\gamma}(Q^2) = \frac{1}{4\pi^2 f_\pi} \, \frac{1}{(1 + Q^2/\Lambda_\pi^2)} \tag{2}$$

with $\Lambda_\pi^2 = 8\pi^2 f_\pi^2$; one gets, for the mass-scale parameter, $\Lambda_\pi \simeq 826$ MeV. However, this formula is compatible as well with the prediction based on vector-meson dominance model (VMD) with $\Lambda_\pi = m_\rho$.
CLEO Collaboration [11] has reported the pole mass fit of the pion-photon transition form factor. They obtain $\Lambda_{\pi^0} = 766 \pm 10 \pm 12 \pm 16$ MeV, a value close to the mass of the ρ-meson.

Recently a full calculation, assuming the asymptotic distribution amplitude and including a QCD radiative correction [13], has been performed [14]. Formula (1) is modified, taking the following form

$$F_{\pi\gamma}(Q^2) = \frac{2f_\pi}{Q^2}\left(1 - \frac{5\alpha_V(e^{-3/2}Q)}{3\pi}\right) \tag{3}$$

Assuming $\alpha_V(e^{-3/2}Q)/\pi \simeq 0.12$, the magnitude of $Q^2 F_{\pi\gamma}(Q^2)$ is remarquably consistent with the CLEO data (see Fig. 2). One can also fit the data by using the interpolation formula (2) with a new mass scale $\Lambda_\pi \simeq 739$ MeV. So it is very hard to discriminate between the BL model and the VMD.

Let us notice that the slope predictions in the framework of chiral perturbation theory (CHPT) [15] are consistent with the pole mass fit of CLEO. It is very exciting that with this simple process a nice description of the form factor is reliable from $Q^2 = 0$ up to $Q^2 \to \infty$.

Kessler and Ong [16] have shown that pseudoscalar-meson production by two off-shell photons can be used to check the pQCD hard scattering approach. Notice that in this approach the transition form factor is $\sim Q^{-2}$ while the VMD predicts it to be $\sim Q^{-4}$. In the symmetric configuration $Q'^2 = Q^2$ where $Q^2 = -q^2$, $Q'^2 = -q'^2$ (q, q' are the four-momenta of the photons) the form factor becomes independent of the choice of the distribution amplitude; one obtains with the BL interpolation formula

$$F_{\pi\gamma^*}(Q^2,Q^2) = \frac{1}{4\pi^2 f_\pi}\,\frac{1}{(1+3Q^2/\Lambda_\pi^2)} \tag{4}$$

which is compared with the VMD prediction :

$$F_{\pi\gamma^*}(Q^2,Q^2) = \frac{1}{4\pi^2 f_\pi}\,\frac{1}{(1+Q^2/m_\rho^2)^2} \tag{5}$$

The measurement of this form factor at low Q^2 can be performed at DAΦNE with the KLOE detector. In the framework of CHPT, the slope prediction of $\pi^0 \to \gamma^*$ transition form factor is similar as well with the prediction based on the vector-meson dominance (VMD). The slope determination at $Q^2 \to 0$ of $F_{\pi\gamma^*}(Q^2,Q^2)$ should allow one to check the validity of the BL model vs the CHPT.

In order to check the feasibility of such measurements, we have computed the number of events for energy and luminosity planned at DAΦNE assuming the VMD form factor (see table 1).

III. PION PAIRS PRODUCTION

In a previous paper [19], we have shown that azimuthal correlations in single-tag measurements of photon-photon collisions can be used to check dynamic models We here extend our investigation to double-tag measurements.

The main contribution to $\gamma\gamma \to \pi^+\pi^-$ arises from the Born terms. The chiral loops give the next order contribution [17] and are consistent with the MARK II data [18]. It had been shown [19-21] that azimuthal correlations can be used to check dynamical models. At DAΦNE, with somewhat large angles of electron tagging, it should be possible to determine these correlations in double-tag measurements of photon-photon collisions.

In contrast with the charged-pion pair production, the process $\gamma\gamma \to \pi^0\pi^0$ involves no contribution from Born terms. A finite one-loop contribution up to $\mathcal{O}(p^4)$ in the framework of CHPT has been computed [22]. Comparing with the presently available data from Crystal Ball [23], this prediction lies below them within 2σ. Recently, the amplitude involving two loops has been evaluated [24]; the corresponding cross section prediction agrees rather well with the Crystal Ball data. However, another prediction [25] based on the dispersion relations has been found to be as well consistent with the data. We emphasize the importance of precise measurements of the azimuthal correlations at DAΦNE for this channel.

In double-tag measurements where both electrons are tagged at small angle ($Q,\ Q' \ll W/2$), we can use the 5-term formula [20,21]. Integrating the differential cross section over all variables other than ϕ_1 and ϕ_2, we obtain :

$$\frac{d\sigma}{d\phi_1 d\phi_2} = \sigma_0 + \sigma_1 \cos 2\phi_1 + \sigma_2 \cos 2\phi_2 + \sigma_3 \cos 2(\phi_1 + \phi_2) + \sigma_4 \cos 2(\phi_1 - \phi_2) \quad (6)$$

where ϕ_1 and ϕ_2 are the azimuthal angles, in the $\gamma^*\gamma^*$ c.m. frame, between one of the particles (pions) produced and the two outgoing electrons. The helicity terms $\sigma_0 \ldots \sigma_4$ can be determined from measurements of the integrated cross section and azimuthal correlations.

For numerical predictions, we assume the general experimental conditions for the double-tag case (see tables 2-3), as it is more interesting to study azimuthal correlations in double-tag measurements. One obtains different predictions (figs. 3-4) for $\pi^+\pi^-$ and $\pi^0\pi^0$.

A complete and exact Monte Carlo for $\gamma\gamma \to \mu^+\mu^-$ is also available [3]. It can be used to calibrate the measurement of these azimuthal correlations.

In conclusion, we are showing that, for two-pion production, some useful information may be provided by the study of azimuthal correlations. Also the possibility of a sizeable two-loop effect in the framework of CHPT or a one loop effect in GCHPT [26] has been discussed.

IV. CONCLUSION

We have shown that DAΦNE is a unique e^+e^- machine where a double-tag measurements of $\gamma^*\gamma^*$ collisions should be performed. It will be the first time that the $\pi^0 \to \gamma^*$ transition form factor at low Q^2 and the five structure functions in pion pairs production measurements should allow one to check dynamic models.

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TABLES

TABLE I. Number of events expected assuming $E_{beam} = 0.51$ GeV with integrated luminosity $L = 5.\ 10^{39}\ cm^{-2}$. Q^2_{min} is the minimal value of the four-momentum squared of the virtual photon.

$\gamma^*\gamma^* \to$	π^0	η
$Q^2_{min} = 0.$ GeV^2	$2.\ 10^6$	$5.\ 10^5$
$Q^2_{min} = 5.\ 10^{-3}$ GeV^2	$3.55\ 10^4$	$9.18\ 10^3$
$Q^2_{min} = 1.\ 10^{-2}$ GeV^2	$1.99\ 10^4$	$5.44\ 10^3$
$Q^2_{min} = 5.\ 10^{-2}$ GeV^2	$2.63\ 10^3$	$8.\ 10^2$

TABLE II. Number of events expected with $E_{beam} = 0.51$ GeV and the integrated luminosity $L = 5.\ 10^{39}\ cm^{-2}$. We assume the invariant mass $2m_\pi \leq W_{\gamma\gamma} \leq 700$ MeV and an acceptance cut $|\cos\theta| \leq 0.8$

$\gamma^*\gamma^* \to$	$\pi^+\pi^-$	$\pi^0\pi^0$
$0 \leq \theta_e \leq 300$ mrad	$9.54\ 10^5$	$7.58\ 10^3$
$200 \leq \theta_e \leq 300$ mrad	$4.82\ 10^3$	$4.5\ 10^1$
$250 \leq \theta_e \leq 300$ mrad	$9.25\ 10^2$	10

TABLE III. Same as Tab. II, but with $|\cos\theta| \leq 0.98$

$\gamma^*\gamma^* \to$	$\pi^+\pi^-$	$\pi^0\pi^0$
$0 \leq \theta_e \leq 300$ mrad	$2.11\ 10^6$	$4.\ 10^4$
$200 \leq \theta_e \leq 300$ mrad	$7.93\ 10^3$	$2.\ 10^2$
$250 \leq \theta_e \leq 300$ mrad	$1.45\ 10^3$	35

FIGURES

FIG. 1. Angular distribution of either scattered electron for $e^+ e^- \to e^+ e^- \pi^+\pi^-$ with $E_{beam} = 510$ MeV and an acceptance cut $|\cos\theta| \leq 0.8$

FIG. 2. Solid line : prediction of the $\pi\gamma$ transition form factor, including the QCD radiative correction and assuming the asymptotic distribution amplitude. Dash line : prediction with the interpolation formula assuming $\Lambda_\pi \simeq 739$ MeV. Data are taken from Ref.[10,11]

FIG. 3. Born-term predictions of azimuthal distributions with regard to (ϕ_1,ϕ_2, $\phi_1 + \phi_2$ and $\phi_1 - \phi_2$) for $e^+ e^- \to e^+ e^- \pi^+\pi^-$ with $E_{beam} = 510$ MeV and an acceptance cut $|\cos\theta| \leq 0.8$

FIG. 4. Same as Fig. 3 for $e^+ e^- \to e^+ e^- \pi^0\pi^0$ in Chiral Perturbation Theory