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Testing Terazawa's soft pion predictions for $\gamma\gamma\to\pi\pi$ at soft pion momenta

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Terazawa has recently claimed that soft pion predictions for the $\gamma\gamma\to\pi\pi$ differential cross section are applicable at $\pi\pi$ masses as high as 4.5 GeV. Here we consider whether soft pion predictions are applicable at soft pion momenta. Experimental tests that DAΦNE, the Frascati ϕ factory, can check are detailed.

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With the dramatic increase in statistics on hadron production in $e^+e^-\to e^+e^-X$ [1], the process $\gamma\gamma\to\pi\pi$ has come under close scrutiny [2,3]. At low energies it is the one-pion exchange Born amplitude that provides the natural template with which to compare the predictions and measurements of $\gamma\gamma\to\pi^+\pi^-$. First low energy measurements by PLUTO [4] and DM1/2 [5] indicated an event rate perhaps up to a factor of 2 larger than the Born cross section. Subsequent dispersive calculations showed that without "new physics" final state interactions could not modify the Born cross section by more than 10% close to threshold [6,7]. This theoretical expectation was confirmed by the Mark II measurements [8] of the cross section down to a $\pi\pi$ mass of 350 MeV, though with the limited angular acceptance common to two photon experiments. In chiral perturbation theory the one-loop corrections to the Born cross section have also been computed [9] and in their region of applicability below 500 MeV they are in accord with dispersive calculations [3]. Subsequently, this dispersive framework [10,11], which embodies the constraints of analyticity, crossing and unitarity as well as the low energy theorems of QED and PCAC (partial conservation of axial-vector current), was developed into a whole amplitude analysis package [11,12]. Applying this to $\gamma\gamma\to\pi\pi$ measurements from Mark II [8] and Crystal Ball [13] allows the extraction of the radiative widths of scalar and tensor resonances from experiments [12,14]—widths that are an important guide to their quark structure [15].

However, there is a key alternative approach. Very recently Terazawa [16] has illustrated how his 20 year old soft pion result [17] for $\gamma\gamma\to\pi^+\pi^-$ is in good agreement with dimeson cross sections measured by Mark II [18] and TPC/Two Gamma [19] at the SLAC e^+e^- storage ring PEP and by CLEO [20] at the Cornell Electron Storage Ring (CESR) for $\pi\pi$ masses from 1.3 to 4.5 GeV. At high enough energies we expect the mechanisms calculable in perturbative QCD as pioneered by Brodsky and Lepage [21] to describe experiment. Nevertheless below 4 GeV, Terazawa [16] shows that his soft pion result provides a far better description. However, his being a prediction based on soft pion techniques, it must surely be applicable at low $\pi\pi$ masses. It is on this region that this note focuses.

Using PCAC and soft pion techniques, Terazawa has deduced that the $\gamma\gamma\to\pi^+\pi^-$ differential cross section at a c.m. energy $\sqrt{s}$ and scattering angle θ is given by

$$\frac{d\sigma}{d\cos\theta}=\pi\alpha^2\frac{\beta}{s}[f_\pi(s)]^2, \tag{1}$$

where $\beta=(1-4m_\pi^2/s)^{1/2}$. $f_\pi(s)$ is a pion structure function, which can be computed from the spectral functions of the vector and axial-vector currents. Using vector meson dominance, $f_\pi(s)$ can be approximated by one average vector meson of mass m_V, so that

$$f_\pi(s)\simeq\frac{8m_V^4}{(s+2m_V^2)(s+4m_V^2)}. \tag{2}$$

Terazawa [16] claims that $m_V\simeq 1.4$ GeV gives the best fit to the dimeson cross sections for $1.3<\sqrt{s}<4.5$ GeV. Here we

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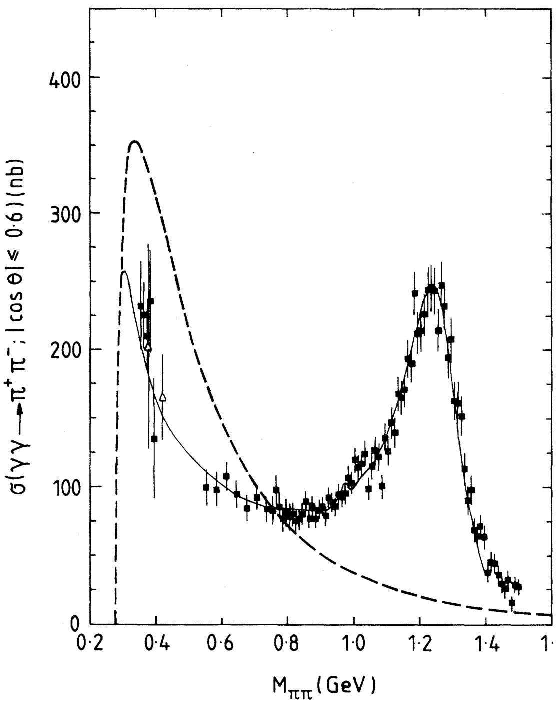

FIG. 1. $\gamma\gamma \to \pi^+\pi^-$ cross section for $|\cos\theta| \leq 0.6$ from Mark II [8] and PLUTO [4] as a function of $\pi\pi$ mass. The PLUTO results are only shown at low $\pi\pi$ mass where the experimental results on $d\sigma/d|\cos\theta|$ at $\cos\theta=0$ can be scaled to give σ for $|\cos\theta| \leq 0.6$ assuming a flat distribution in this region. The dashed line is the prediction using Terazawa's soft pion results of Eqs. (1) and (2) for this integrated cross section. The solid line is the Amplitude Analysis fit of Ref. [12].

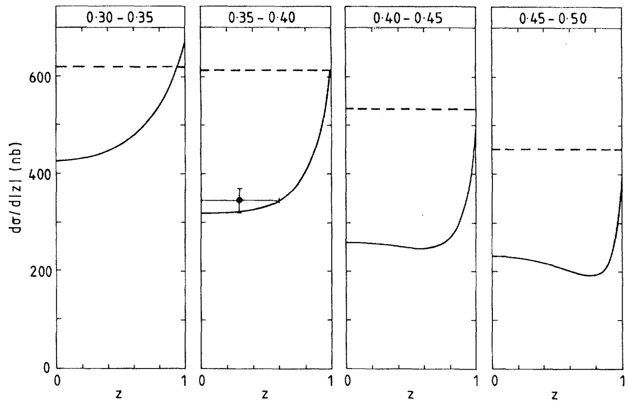

FIG. 2. $\gamma\gamma \to \pi^+\pi^-$ differential cross section, $d\sigma/dz$ where $z=\cos\theta$, in 50 MeV bins from 0.3 to 0.5 GeV. The dashed line shows the prediction of Terazawa's analysis of Eqs. (1) and (2), while the solid line is from the dispersive analysis of Refs. [12,3]. These lines correspond to the integrated cross sections similarly displayed in Fig. 1. The datum in the 0.35–0.40 GeV bin is from the Mark II results [8] also shown in Fig. 1.

consider the same predictions but below 1.4 GeV. This gives the integrated cross section presented in Fig. 1 and differential cross sections from 0.3 to 0.5 GeV in Fig. 2, shown as the dashed lines.

Figure 1 displays the cross section for $|\cos\theta| \leq 0.6$. Normalized experimental results come from Mark II [8] (with very similar cross sections from CELLO [22], not shown, above 0.8 GeV). Also displayed are very low energy results from PLUTO [4]. These are in fact for $d\sigma/d|\cos\theta|$ at $\theta=\pi/2$ and have been extrapolated to the angular coverage of Mark II assuming the cross section for $|\cos\theta|<0.6$ to be flat, which is a reasonable supposition below 400 MeV (see Fig. 2). Clearly, the soft pion prediction is *not* in accord with experiment. In contrast, the data are well understood within the dispersive framework with calculable final-state interactions, which give the solid lines. Not surprisingly, the soft pion analysis knows nothing of the $f_2(1270)$ resonance that is so important in the $\gamma\gamma \to \pi\pi$ channel. However, even far below this resonance, the Terazawa prediction does not do very well. It could be that some new choice of $f_\pi(s)$ may fare better. However, there is still another prediction of this approach that we now discuss.

The soft pion analysis is intrinsically a low energy treatment. Consequently, it approximates the angular dependence of the $\gamma\gamma \to \pi^+\pi^-$ cross section wholly by S waves, Eq. (1). In contrast, the dispersive analysis (like that of chiral perturbation theory, with which it agrees and extends) does more than incorporate the Thomson limit at $\gamma\pi$ threshold, but includes the one-pion exchange Born term [23]. In this S-matrix approach, the Born term controls the $\gamma\gamma \to \pi\pi$ amplitude even away from the $\gamma\pi$ threshold [10,11,13]. This is because the pion poles at $t=m_\pi^2$ and $u=m_\pi^2$ are in fact very near to the s-channel ($\gamma\gamma \to \pi\pi$) physical region. Thus at 500 MeV, for example, these poles are at $\cos\theta=\pm 1.2$, and the angular distribution is forced to peak in the forward and backward directions as shown in Fig. 2.

Figure 2 contrasts the flat differential cross section predicted by Terazawa with that given by the dispersive analysis in 50 MeV bins from 300 to 500 MeV. The integrated cross section from Mark II [8] is shown for orientation. Present experiments only yield detailed angular distributions above 550 MeV and then just for $|\cos\theta| \leq 0.6$. Fortunately, it is planned to incorporate taggers in the KLOE experiment at DAΦNE, the Frascati ϕ factory, to study two photon physics [24]. This will allow the low energy cross section to be measured over a larger angular region. Then this experiment should provide a definitive check of these rival approaches. DAΦNE will test whether Terazawa's soft pion result is only applicable at soft pion momenta close to $\gamma\pi$ threshold in a domain limited by the pion mass. This is what the S-matrix approach would suggest. In this case the agreement of Terazawa's result with data out to 20 GeV^2 ($\sim 1000 m_\pi^2$) would be a fortuitous accident, aided by the strong dependence of the prediction for the integrated cross section on the adjustable parameter m_V, Eq. (2). Or we will discover that its suppression of nearby pion poles tells us something new about the singularity structure of the $\gamma\gamma \to \pi\pi$ amplitude overturning the standard implementation of S-matrix principles through dispersion relations [10,6,7,11,2] or via chiral perturbation theory [9]. Figures 1 and 2 provide the basis for such tests. We await the experimental results with interest.

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