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Azimuthal correlations in $\gamma\gamma \rightarrow \pi^0\pi^0$ at DAΦNE

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Abstract

An investigation of azimuthal correlations in double-tag experiment $\gamma\gamma \rightarrow \pi^0\pi^0$ at DAΦNE, provides an interesting test of chiral pertubation theory up to $O(p^6)$.

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Contribution to the "Second DAΦNE Physics Handbook"

1 Introduction

At DAΦNE, with KLOE [1] and a somewhat large angle of electron tagging, it is possible to measure the azimuthal correlations of the $\pi\pi$ production by quasi-real photon collisions [2]. It had been shown [3, 4] that, in such a case, those correlations can be used to check dynamical models.

The process $\gamma\gamma \to \pi^0\pi^0$, in the framework of Chiral Perturbation Theory (CHPT) up to $O(p^4)$, involves a finite one-loop contribution [5, 6]. Comparing with the presently available data from Crystal Ball [7], this prediction lies below the data within 2σ. The study of azimuthal correlations provides a complementary test of the CHPT prediction and can be controlled by Monte Carlo simulation [8, 9, 10].

Recently, the amplitude to two loops in CHPT has been evaluated [11]. The cross section prediction agrees rather well with the available data. The purpose of the present work is to show how the two-loop correction experimentally affects the azimuthal correlations. Notice that the $O(p^6)$ correction due to the exchange of the ρ and ω resonances in the t-channel with both photons off-shell was calculated in [12].

2 General principle

The general formula describing the helicity structure of the completely differentiated cross section of a collision process $ee' \to ee'\, AA'$ can be written (accounting for parity conservation, rotational invariance and time invariance) as [13]:

$$\begin{aligned} \frac{d\sigma}{dLips} &= K[\, I_{++,++} + I_{++,--} - 2\varepsilon\, \mathcal{R}e\, I_{++,+-} \cos 2\phi \\ &- 2\,\varepsilon'\, \mathcal{R}e\, I_{+-,++} \cos 2\phi' + \varepsilon\varepsilon'\, \mathcal{R}e\, I_{+-,+-} \cos 2(\phi + \phi') \\ &+ \varepsilon\varepsilon'\, \mathcal{R}e\, I_{+-,-+} \cos 2(\phi - \phi')] + longitudinal\ \ terms\ , \end{aligned} \tag{2.1}$$

where the helicity terms $I_{m\bar{m},n\bar{n}}$ are defined as $I_{m\bar{m},n\bar{n}} = \sum_{aa'} M^{aa'}_{mn} M^{aa'*}_{\bar{m}\bar{n}}$. Here we call $M^{aa'}_{mn}$ ($M^{aa'}_{\bar{m}\bar{n}}$) the helicity amplitudes of the process $\gamma\gamma \to AA'$, and we denote by $m(\bar{m})$ and $n(\bar{n})$ the helicities of the two photons and by a, a' those of A, A'.
We call "longitudinal terms" all terms with at least one "0" helicity subscript (their explicit form can be found in Ref. [14]).

dLips is the Lorentz-invariant phase space, while the factor K is defined in Ref. [4]. ϕ and ϕ' are azimuthal angles in the $\gamma\gamma$ c.m. frame, between one of the particles produced (either A or A') and the two outgoing electrons ; ε, ε' are the polarization parameters of the photons.

In the particular kinematical situation of quasi-real photons (i.e. $Q, Q' \ll W$), we can use the 5-term formula (i.e. formula (2.1), neglecting longitudinal terms). On the other hand, for the two-pion production, the helicity terms are derived from the amplitudes M_{++} and M_{+-}. One has:

$$\begin{aligned} d\sigma &\propto (\mid M_{++} \mid^2 + \mid M_{+-} \mid^2) - 2\varepsilon \mathcal{R}e(M_{++}M_{+-}^*)cos2\phi - 2\varepsilon' \mathcal{R}e(M_{++}M_{+-}^*)cos2\phi' \\ &+ \varepsilon\varepsilon'(\mid M_{++} \mid^2 cos2(\phi+\phi') + \mid M_{+-} \mid^2 cos2(\phi-\phi')) \end{aligned} \tag{2.2}$$

We notice that $\phi + \phi'$ is, in the $\gamma\gamma$ c.m. frame, the azimuthal angle between the two electrons, while $\phi - \phi'$ is twice the angle between the bisectrix of the transverse momenta of the outgoing electrons and the transverse momentum of the pion.

3 Amplitudes to 2-loops in the framework of CHPT

The Lorentz and gauge invariant form of the amplitude is taken as in Eq. (2.1). Following [11] and assuming quasi-real photons, the CHPT prediction, including the 2-loop corrections, in the double-tag measurements reads

$$\begin{aligned} M_{++} &= 2\pi\alpha W^2(A - 2\beta^2 W^2 B) \ , \\ M_{+-} &= 4\pi\alpha\beta^2 W^4 B \sin\theta^2 \ , \\ \beta &= \sqrt{1 - \frac{4M_\pi^2}{W^2}} \ , \end{aligned} \tag{3.1}$$

with the two-loop amplitudes A and B obtained in [11]

$$\begin{aligned} A &= \frac{4\bar{G}_\pi(W^2)}{W^2F_\pi^2}(W^2 - M_\pi^2) + U_A + P_A \ , \\ B &= U_B + P_B \ . \end{aligned} \tag{3.2}$$

Let us notice that the leading term is generated by one-loop diagrams which result in [5, 6]

$$\begin{aligned} A_1 &= \frac{4\bar{G}_\pi(W^2)}{W^2F_\pi^2}(W^2 - M_\pi^2) \ , \\ B_1 &= 0 \ . \end{aligned} \tag{3.3}$$

All the terms of (3.2) are computed and explicitly expressed in Ref. [11].

Let us note that the $O(p^6)$ low energy constants entering Eqs. (3.2) through the polynomials $P_{A,B}$ have been estimated from resonance saturation in [11], including the contributions of (axial-)vector, scalar, and $f_2(1270)$ resonances.

In a recent calculation [15] the low energy constants have been determined using the Extended Nambu Jona-Lasinio Model. These values agree within the uncertainties with those taken in [11].

4 Monte Carlo results and Conclusion

We display in Figs. 1-2 the different azimuthal correlations for one-loop (grey histograms) and two-loops (open histograms) in the $\gamma\gamma$ and e^+e^- c.m. frames. The Monte Carlo program was run assuming the following conditions:

$$|\cos\theta_\gamma| \leq 0.99 \;\;,\;\; 60\; mrad \leq \theta_{e,e'} \leq 150\; mrad, \;\;,\;\; W \leq 600 \text{ MeV}.$$

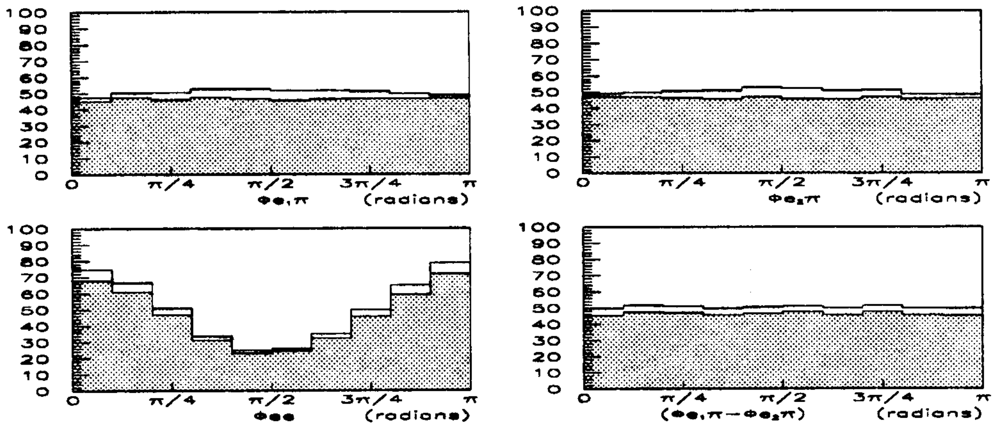

Figure 1: Azimuthal correlations in the $\gamma\gamma$ system

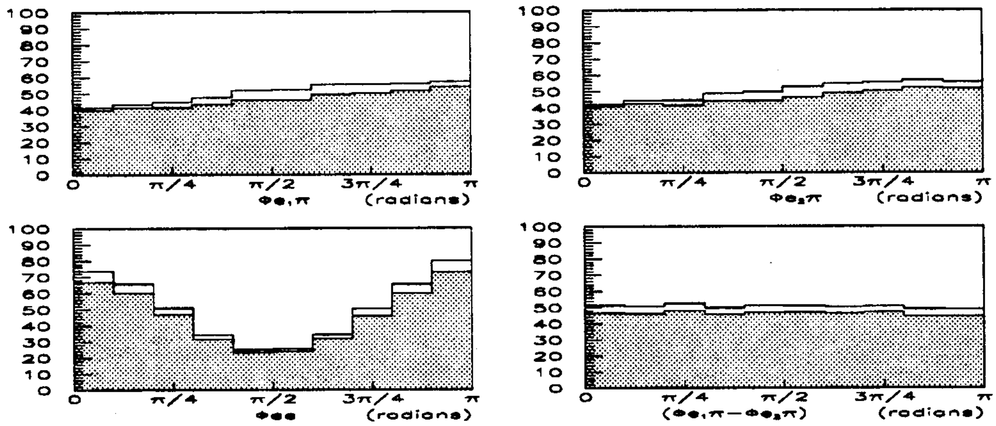

Figure 2: Azimuthal correlations in the e^+e^- system

At one-loop, only M_{++} contributes, while $M_{+-} = 0$. One expects, in the $\gamma\gamma$ c.m. frame, a flat distribution for ϕ, ϕ', $\phi - \phi'$ and a sharp azimuthal distribution for $\phi + \phi'$. The two-loop contribution affects substantially M_{++}, but one still has $M_{+-} \ll M_{++}$. This fact results in a quite similar shape of the azimuthal correlations for the one-loop and two-loop cases.

Any significant deviation from these predictions can be interpreted as probably due to another mechanism of $\pi^0\pi^0$ production in $\gamma\gamma$ reactions involving a larger contribution of $J \neq 0$ spin states. Let us notice that in the single tag mode, one azimuthal correlation (ϕ or ϕ') can be measured and still used to check the theoretical predictions.

Acknowledgements

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