KLOE RESULTS ON $f_0(980)$, $a_0(980)$ SCALARS AND $\eta$ DECAYS

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The KLOE experiment running at the $\phi$-factory DAΦNE has collected $\sim 450$ pb$^{-1}$ in the 2001–2002 data taking. We report preliminary results on light meson spectroscopy based on this data sample; particles are all produced through $\phi$ radiative decays. The nature of $f_0(980)$ and $a_0(980)$ is investigated by studying the shape of the resulting mass spectra, which is sensitive to their structure. A detailed study of the $\eta \to \pi\pi\pi$ dynamics through a Dalitz plot analysis gives the possibility to extract information on the quark mass difference. Finally, the branching ratio for the $\eta \to \pi^0\gamma\gamma$ decay is compared with previous measurements and with the expectations from Chiral Perturbation Theory.
1 Introduction

The KLOE experiment\(^{\text{11}}\) operates at DAΦNE,\(^{\text{2}}\) the Frascati \(e^+e^-\) collider, whose center of mass energy is equal to the \(\phi\) mass. Data collected in 2001-2002, corresponding to \(\sim 450\) pb\(^{-1}\), are used to study light scalar and pseudoscalar mesons produced through \(\phi\) radiative decays.

2 Light Scalar Mesons: \(f_0(980)\) and \(a_0(980)\)

A complete study of the radiative decay of the \(\phi\) to the scalar mesons \(f_0(980)\) and \(a_0(980)\) is in progress, involving the decays \(f_0 \to \pi^+\pi^-/\pi^0\pi^0\) and \(a_0 \to \eta\pi^0\), with \(\eta \to \gamma\gamma\) and \(\eta \to \pi^+\pi^-\pi^0\). Since the mass spectra are sensitive to the nature of such mesons\(^{\text{8,4,5,6}}\) which are still puzzling,\(^{\text{4,5,6}}\) the data are compared with two different theoretical models. In the first one the scalar amplitude is described by the kaon-loop model\(^{\text{7}}\) while in the second one a point-like approach is followed. In both cases, the interference with the background with the same final state is taken into account in the fit procedure.

For the \(\pi^+\pi^-\gamma\) final state there is a huge irreducible background of \(e^+e^- \to \pi^+\pi^-\) with an additional photon due to initial state (ISR) or final state radiation (FSR). However, requiring two tracks and a large angle photon a clean signal appears in the \(M_{\pi\pi}\) region above 850 MeV (see Fig. \text{1}\text{.}left). Moreover, a forward-backward asymmetry \(A = \frac{N_{\theta>90^\circ} - N_{\theta<90^\circ}}{N_{\theta>90^\circ} + N_{\theta<90^\circ}}\) is expected due to the interference of FSR and ISR.\(^{\text{8}}\) In Fig. \text{1}\text{.}right we show this asymmetry as a function of \(M_{\pi\pi}\), both for data and for theoretical predictions with ISR and FSR only. A clear discrepancy is observed in the \(f_0\) region and in the mass range below 700 MeV, thus adding a further evidence on the need of a scalar meson in the theoretical description.

In the case of the \(f_0 \to \pi^0\pi^0\) decay we instead deal with a non-resonant background with the same \(\pi^0\pi^0\gamma\) signature, produced through \(\omega\pi^0/\rho\pi^0\) intermediate states. The intensity of this background is twice the signal. In order to consider its interference with the scalar term we fit the Dalitz plot distribution. A smaller background contamination dominated by \(\phi \to \eta\gamma\), with \(\eta \to \pi^0\pi^0\pi^0\) and two lost or merged photons, is estimated by Monte Carlo and subtracted from the Dalitz plot. When using the kaon-loop model we cannot describe data without introducing a scalar term due to a \(\sigma(600)\) meson.

For the fully neutral search of \(\phi \to a_0\gamma\), the background with the same \(\eta\pi^0\gamma\) final state is
small and simplifies the fit procedure. On the other hand, having a yield ten times smaller than the \( f_0 \to \pi^0\pi^0 \), it is contaminated by a large non-interfering background with a five photon signature. The \( a_0 \) decay chain with \( \eta \to \pi^+\pi^-\pi^0 \) has instead a rate three times smaller than the neutral channel, but it is completely background free. A combined fit of the two channels is in progress to extract the \( a_0 \) parameters.

### 3 Dynamics of \( \eta \to \pi\pi\pi \)

The amplitude of \( \eta \to \pi\pi\pi \) is related to the d-u quark mass difference; a precise study of this decay can lead to a very accurate measurement of \( Q^2 = (m_s^2 - m_u^2)/(m_d^2 - m_u^2) \). Using the 17 millions \( \eta \) mesons produced in 2001/2002, the dynamics of both \( \pi^+\pi^-\pi^0 \) and \( \pi^0\pi^+\pi^0 \) final states has been studied through a Dalitz plot analysis. The \( \eta \) mesons are clearly tagged by detecting the monochromatic recoil photon of the \( \phi \to \eta\gamma \) decay (\( E_{\text{recoil}} = 363 \text{ MeV} \)); the background is at the level of few per mill.

Concerning the \( \pi^+\pi^-\pi^0 \) final state, the conventional Dalitz variables are \( X \propto T_+ - T_- \) and \( Y \propto T_0 \), where \( T \) is the kinetic energy of the pions. The measured distribution is parametrized as: \( |A(X,Y)|^2 = 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 \). As expected from \( C \) parity conservation, the odd powers of \( X \) are consistent with zero (see Tab. 1). Using our fitted parameters, the value of \( Q \) can be extracted. For example, in Ref. 9 the value \( Q = 22.8 \pm 0.4 \) is obtained, the error being dominated by the \( \eta \to \pi^+\pi^-\pi^0 \) width. This value is in agreement with Chiral Perturbation Theory (\( \chi_{PT} \)) predictions \(^{10}\) and with other evaluations based on \( \eta \) decays, \(^{11,12}\) which have larger errors.

For the \( \eta \to \pi^0\pi^0 \) decay the Dalitz plot density is described by a single parameter \( \alpha \): \( |A|^2 \propto 1 + 2\alpha z \), where \( z \) is related to the three pion energies in the \( \eta \) rest frame. Photons are paired to \( \pi^0 \)’s after kinematically constraining the total 4-momentum to \( M_\phi \), thus improving the energy resolution. By fitting a sample with high purity on pairing (98.5%), corresponding to an analysis efficiency of 4.5%, we get:

\[
\alpha = -0.013 \pm 0.005_{\text{stat}} \pm 0.004_{\text{syst}}.
\] (1)

### 4 The \( \eta \to \pi^0\gamma\gamma \) Decay

The \( \eta \to \pi^0\gamma\gamma \) decay is an important test of \( \chi_{PT} \) because of its sensitivity to \( p^6 \) on both the branching ratio (BR) and the \( M_{\gamma\gamma} \) spectrum. \(^{13,14,15}\) The present experimental situation is not completely clear: the most accurate determination of the BR is far from theoretical predictions while a more recent measurement \(^{16}\) with a larger relative error, gives a significantly lower value. Moreover, all previous searches were done at hadron machines, using mainly \( \pi^-p \to \eta n \). The value of the BR has decreased by three orders of magnitude in the last 40 years, due to the improved separation of the \( \eta \to \pi^0\pi^0\pi^0 \) background.

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**Table 1: Fitted parameters of the \( \eta \to \pi^+\pi^-\pi^0 \) Dalitz plot.**

| \( N_{\text{ dof}} \) | \( \text{Prob}(\chi^2) \) (%) | \( a \) | \( b \) | \( c \) |
|---|---|---|---|---|
| 147 | 60 | \(-1.072 \pm 0.006^{+0.005}_{0.007} \) | \(0.117 \pm 0.006^{+0.004}_{0.006} \) | \(0.08 \pm 0.0025^{+0.003}_{0.0021} \) |
| 149 | 63 | \(-1.072 \pm 0.005^{+0.005}_{0.008} \) | \(0.117 \pm 0.006^{+0.004}_{0.006} \) | --- |

\( a \) is independent of the \( \eta \) value of \( \text{BR} \) has decreased by three orders of magnitude in the last 40 years, due to the improved separation of the \( \eta \to \pi^0\pi^0\pi^0 \) background.
KLOE searches for this decay in a much cleaner environment, with different background topologies and experimental systematics. The two orders of magnitude higher background with the same five photon final state ($e^+e^- \to \omega \pi^0 \to \pi^0\gamma\pi^0$, $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$, $\phi \to a_0\gamma \to \eta\pi^0\gamma$ with $\eta \to \gamma\gamma$) is reduced by vetoing the additional $\omega/\pi^0/\eta$ particles in the event. The remaining background is $\eta \to \gamma\gamma$ with additional clusters from shower fragmentation or machine background and $\eta \to \pi^0\pi^0\pi^0$ with merged/lost photons. We reject them with energy momentum conservation and a likelihood technique to identify merged clusters. The preliminary results obtained fitting the $\eta$ invariant mass spectrum (Fig. 2) gives a BR in agreement with $\mathcal{O}(p^6)\chi_{PT}$ calculations, with a central value which is three times smaller than the previous measurement:

$$BR(\eta \to \pi^0\gamma\gamma) = (8.4 \pm 2.7_{\text{stat}} \pm 1.4_{\text{syst}}) \times 10^{-5}.$$ (2)

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