Light meson spectroscopy with the KLOE experiment.

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Abstract

In this paper we describe the status of the analyses in progress on light meson spectroscopy in the KLOE experiment. We present the analyses of φ decays into f_0(980)γ and a_0(980)γ, the Dalitz plot analysis of the η → π^+π^−π^0 decay, the branching ratio measurement of η → π^0γγ, the upper limits on Br(η → 3γ) and Br(η → π^+π^−), the measurement of the ratio Br(φ → ηγ)/Br(φ → γγ) and φ lepton width measurements.

1 Introduction

The KLOE detector [1], operates at the Frascati e^+e^- collider DAΦNE [2], which runs at a CM energy W equal to the φ-meson mass, W≈1019.5 MeV. The analyses presented here are based on data collected in the years 2001 and 2002 for an integrated luminosity of ~ 450 pb^-1 corresponding to 1.5 billions of φ and 20 millions of η mesons [Br(φ → γγ) ~ 1.3% [3]]. This means that KLOE can also study η physics in a clean environment with high statistic.
2 Search for $\phi \rightarrow f_0\gamma$ in $\pi^+\pi^-\gamma$ events.

The $\phi$ radiative decays to scalar mesons, $\phi \rightarrow S\gamma$, give significant insight in the assessment of the nature of lower mass scalar mesons [4]. With the KLOE experiment the decays $\phi \rightarrow f_0(980)\gamma$ and $\phi \rightarrow a_0(980)\gamma$ are searched for in $\pi^0\pi^0\gamma$ and $\eta\pi^0\gamma$ [5,6] final states respectively. Moreover the $f_0(980)$ signal is also searched for in $\pi^+\pi^-\gamma$ events with a photon at large angle. The search for this signal is characterized by the presence of a huge irreducible background due to the initial state radiation (ISR), to $e^+e^- \rightarrow \pi^+\pi^-\gamma$ (FSR) and $\phi \rightarrow \rho^\pm (\rightarrow \pi^\pm\gamma)\pi^\pm$. The $f_0$ events are searched for in the large photon angle region $45^\circ < \theta < 135^\circ$ to reduce ISR background. The $f_0$ signal appears as a bump in the $\pi^+\pi^-$ invariant mass $M_{\pi\pi}$ spectrum around 980 MeV. Fig.1 (top) shows the spectrum obtained at $\sqrt{s} = M_{\phi}$.

An overall fit to the spectrum has been done by applying the following formula:

$$
\frac{dN}{dM_{\pi\pi}} = \left[ \frac{d\sigma}{dM_{\pi\pi}} \right]_{ISR} + \left[ \frac{d\sigma}{dM_{\pi\pi}} \right]_{FSR+f_0} + \left[ \frac{d\sigma}{dM_{\pi\pi}} \right]_{\rho\pi} \times L \times \epsilon(M_{\pi\pi})
$$

with $L$ the integrated luminosity and $\epsilon(M_{\pi\pi})$ the selection efficiency as a function of $M_{\pi\pi}$. The $f_0$ amplitude is taken from the kaon-loop approach [7]. 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 between FSR and ISR[8]. Fig.1 (bottom) shows the asymmetry as a function of $M_{\pi\pi}$ compared to the prediction based on the ISR-FSR interference alone. A significant deviation from the prediction is observed in the high mass region clearly due to the $f_0$ contribution.

![Figure 1](image-url)
tion has been fitted as: \(|A(X,Y)|^2 \simeq (1+aY+bY^2+cX+dX^2+eXY+...)|.
C-parity conservation prevents odd powers in \(X\) being present in the expansion: thus parameters \(c\) and \(e\) should be zero as confirmed by our fit. The results of the fit are shown in table 3. Efficiency is \(\sim 36\%\) over the whole Dalitz plot. The evaluation of systematic effects is under completion.

### Table 1

| \(a\) | \(b\) | \(c\) |
|------|------|------|
| \(-1.075 \pm 0.008\) | \(-1.18 \pm 0.009\) | \(-0.005 \pm 0.004\) |
| \(d\) | \(e\) | \(f\) |
| \(-0.049 \pm 0.008\) | \(-0.004 \pm 0.01\) | \(-0.13 \pm 0.02\) |

4 Rare and forbidden \(\eta\) decays

\((\eta \to \pi^0\gamma\gamma, \eta \to \pi^+\pi^-, \eta \to \gamma\gamma\gamma)\)

The \(\eta \to \pi^0\gamma\gamma\) decay is interesting to test the Chiral Perturbation Theory prediction for the branching ratio and \(m_{\gamma\gamma}\) spectrum[9,10]. The most accurate measurement for the branching ratio[11] is, in fact, far from any theoretical prediction for this decay based on ChPT. Recently a new measurement has been performed[12] giving a much lower value than the previous one, with a larger error. All previous experiments were done at hadron machines, using mainly \(\pi^-p \to \eta n\), and are largely dominated by \(\pi^0\pi^0\) background and geometrical acceptance. KLOE performs a measurement of competitive precision in a cleaner environment. Furthermore, it has different background topologies and experimental systematics. The signal is searched for by looking for a \(\pi^0\gamma\gamma\gamma\) topology, where the further \(\gamma\) comes from \(\phi \to \eta\gamma\). Five prompt clusters are required and an overall kinematic fit requiring \(\pi^0\) mass is performed. The clusters energy must be \(>30\) MeV and azimuthal angle \(>21^\circ\) to reject fake clusters coming from machine background. The dominant background channel is \(\eta \to 3\pi^0\) that had been reduced with several topological cuts. With this selection we obtain an efficiency of \(5.7\%\). To give an idea of the sensitivity, in fig. 2 we compare the \(M(4\gamma)\) data spectrum with MC based predictions of signal and background in two hypothesys for the size of signal: one based on PDG value[11] and one based on the recent CB result[12]. It is evident that our data are incompatible with [11] and are marginally in agreement with [12]. The background simulation and the efficiency for the signal is still under study.

\(\eta \to 3\gamma\) decay is \(C\) violating. It is a sensitive test of \(C\) violation in the strong and electromagnetic interactions. For the details of this analysis see ref.[13]. The KLOE result for the branching ratio is: \(Br(\eta \to \gamma\gamma\gamma) \leq 1.6 \times 10^{-5}\) @90 \% C.L. This limit is the best experimental limit for this decay. The expected branching ratio from the Standard Model is \(\leq 10^{-12}\) [14], so any discovery of a larger decay rate would be a clear signal of Standard Model deviation.
$\eta \rightarrow \pi^+\pi^-$ decay is P and CP violating. This decay is allowed as a weak direct CP violating decay with a very low branching ratio: $BR(\eta \rightarrow \pi^+\pi^-) \sim 10^{-27}$ [15]. Therefore the detection of this decay at an accessible level would be a signal of P and CP violation not explainable in the Standard Model framework. The latest published [16] direct search of this decay has given the following 90% C.L. upper limit: $BR(\eta \rightarrow \pi^+\pi^-) < 3.3 \times 10^{-4}$. In KLOE the signal is searched for the $M(\eta)$ region of the $\pi^+\pi^-$ invariant mass spectrum of $\pi^+\pi^-$ events selected according to the $f_0(980) \rightarrow \pi^+\pi^-$ analysis described before (see fig. 1). The signal efficiency is: $\epsilon_s=16.6\%$. The expected signal has a Gaussian shape with a mass resolution of 1.33 MeV. No signal is observed. The background is determined by fitting the theoretical model for $\pi^+\pi^-\gamma$ sample to the full spectrum. In order to determine an upper limit, we have added to this background a Gaussian function representing the signal multiplied by a constant $N_s$. We obtain: $N_s = -8 \pm 24$. The 90% confidence level upper limit on the number of events is obtained using the tables in [17]: $N_s < 33$. The branching ratio is $BR(\eta \rightarrow \pi^+\pi^-) = \frac{N_s}{\epsilon_s N_\eta}$ with $N_\eta$ the number of $\eta$ in the sample ($1.55 \times 10^7$). The 90% C.L. upper limit is: $BR(\eta \rightarrow \pi^+\pi^-) < 1.3 \times 10^{-5}$. It improves by a factor $\sim 30$ the current PDG limit.

5 \textit{$\eta$ - $\eta'$ mixing}

Here we present the $R = \frac{\Gamma(\phi \rightarrow \eta'\gamma)}{\Gamma(\phi \rightarrow \eta\gamma)}$ measurement. The $\eta'$ is identified via the decays: $\phi \rightarrow \eta'\gamma$; $\eta' \rightarrow \pi^+\pi^-\eta$; $\eta \rightarrow \pi^0\pi^0\pi^0$ and the decays $\phi \rightarrow \eta'\gamma$; $\eta' \rightarrow \pi^0\pi^0\eta$; $\eta \rightarrow \pi^+\pi^-\pi^0$. The final state is thus characterized by two charged pions and seven photons, and has no physics background with the same topology in KLOE. After background subtraction we observe $3405 \pm 61 \pm 31 \phi \rightarrow \eta'\gamma$ events. We normalize to the number of observed $\eta \rightarrow \pi^0\pi^0\pi^0$ decays in the same runs to obtain a preliminary measurement of the ratio of BR’s: $R = (4.9 \pm 0.1_{\text{stat}} \pm 0.2_{\text{syst}}) \times 10^{-3}$. 

Fig. 2. $M(4\gamma)$, the spectra expected from the GAMS[11] and Crystal Ball[12] measurement are shown. In the lower plot we show also the expected spectrum for a $Br \sim 1/2$ of C.B. result.
This result compares favourably with our previous estimate [18] (which already dominates the world average [3]) but with considerably improved accuracy.

6 A new measurement of the $\phi$ leptonic width.

KLOE has performed a new measurement of the $\phi$ leptonic widths $\Gamma_l$ with $l = e, \mu$ [19], using the two data samples taken below ($\sqrt{s} = 1017$ MeV) and above ($\sqrt{s} = 1022$ MeV) the $\phi$ peak together with the data taken at the $\phi$ peak. The dependences on $\sqrt{s}$ of the forward-backward asymmetry of Bhabha events $A_{FB}$ and of the $e^+e^- \rightarrow \mu^+\mu^-$ cross-section $\sigma(\mu\mu)$ around the $\phi$ peak are sensitive to the value of $\Gamma_{ee}$ and $\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}$ respectively. We measure the $\phi$ mass $M_\phi$, the forward-backward asymmetry at $W = M_\phi A_{FB}^0$, and finally $\Gamma_{ee}$. The result for $\Gamma_{ee}$ is: $\Gamma_{ee} = 1.32 \pm 0.05_{stat} \pm 0.03_{syst}$ MeV The result for $\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}$ is: $\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}} = 1.320 \pm 0.018_{stat} \pm 0.017_{syst}$ MeV. The two results are in good agreement consistently with lepton universality. Combining them we get: $\Gamma_{ll} = 1.320 \pm 0.017_{stat} \pm 0.015_{syst}$ MeV with a total uncertainty below 2 %. We point out that the value of $\Gamma_{ee}$ is necessary for $\phi$ decay branching ratio measurements, and play also a role in the evaluation of the hadronic contribution to vacuum polarization [20].

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