KLOE results on light mesons

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Abstract The KLOE collaboration has recently published new results concerning scalar and pseudoscalar mesons. Here the $\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$ decay analysis and the search for the $\phi \to K^0\overline{K^0}\gamma$ decay are discussed, together with the $\eta \to \pi^+\pi^-e^+e^-$ decay measurements annd the new results for the pseudoscalar mixing angle and gluonium content of the η' meson.

Key words KLOE, light mesons

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1 Introduction

At a ϕ-factory one can access many of the light mesons (scalars, pseudoscalars and vectors) via the radiative decay of the ϕ. These decay processes allow us the study of inner structures of the mesons, in particular their s-quark content via the coupling to the ϕ and to the kaons.

The KLOE experiment, operating at the e^+e^- Frascati ϕ-factory DAΦNE [1], is perfectly suited for studying the scalar mesons f_0 and a_0, together with the pseudoscalar η,η' mesons.

2 Experimental setup

The KLOE experiment is performed at the Frascati ϕ factory DAΦNE, an e^+e^- collider running at $\sqrt{s} \sim 1020$ MeV (ϕ mass). Beams collide with a crossing angle of $(\pi - 0.025)$ rad. From 2001 to 2005, the KLOE experiment has collected an integrated luminosity of 2.4 fb^{-1} The KLOE detector consists of a large-volume cylindrical drift chamber [2] (3.3 m length and 4 m diameter), surrounded by a sampling calorimeter [3] made of lead and scintillating fibres. The detector is inserted in a superconducting coil producing a solenoidal field B=0.52 T. Large-angle tracks from the origin ($\theta > 45^\circ$) are reconstructed with momentum resolution $\sigma_p/p = 0.4\%$. Photon energies and times are measured by the calorimeter with resolutions $\sigma_E/E = 5.7\%/\sqrt{E/\mathrm{GeV}}$ and $\sigma_t = 54$ ps$/\sqrt{E/\mathrm{GeV}} \oplus 50$ ps.

3 The $\phi \to \eta\pi^0\gamma$ analysis

The $\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$ decay is searched for in $e^+e^- \to \eta\pi^0\gamma$ events, selected in a sample of $\simeq$430 pb^{-1}. To extract the relevant $a_0(980)$ parameters, the $\eta\pi^0$ invariant mass spectrum is fit with both Kaon-Loop (KL) [4] and No-Structure (NS) [5] models. For the η meson, two final states are considered: $\eta \to \gamma\gamma$, and $\eta \to \pi^+\pi^-\pi^0$, the first resulting in a 5-γ final state, and the second in a 5-γ plus two $\pi^\pm$.

For the first final state considered, the main background sources are the $\phi \to \pi^0\pi^0\gamma$, the $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$, and the $\phi \to \eta\gamma$ decays; the last one could make $\eta \to 3\pi^0$ and $\eta \to \gamma\gamma$ decays: these are backgrounds since lost or split, and accidental or merged photon clusters, respectively, can be detected in the calorimeter, mimicking the 5-γ final state. These and other background sources are rejected by kinematic cuts and MC background evaluation.

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The second final state considered has less background sources, coming from $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$ and $e^+e^- \to K_S K_L \to \pi^+\pi^- 3\pi^0$, again with split or merged photon clusters.

The combined branching ratio we get from these two channels is [6]

$$BR(\phi \to \eta\pi^0\gamma) = (7.06 \pm 0.22) \cdot 10^{-5}.$$

By the fit of the $M_{\eta\pi^0}$ invariant mass we get the values of a_0 couplings. These values are listed in Table 1.

Table 1. Best estimates of the parameters for KL and NS model fit to $M_{\eta\pi^0}$.

parameter	KL	NS
m_{a_0}/MeV	$982.5 \pm 1.6 \pm 1.1$	982.5 fixed
$g_{a_0 K^+ K^-}$/GeV	$2.15 \pm 0.06 \pm 0.06$	$2.01 \pm 0.07 \pm 0.28$
$g_{a_0 \eta\pi}$/GeV	$2.82 \pm 0.03 \pm 0.04$	$2.46 \pm 0.08 \pm 0.11$

4 Search for the decay $\phi \to K^0\overline{K^0}\gamma$

We analysed 2.2 fb^{-1} of data collected at the ϕ peak; we also used our Monte Carlo (MC) to generate enriched samples to evaluate the background, which is mainly due to $\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ with the K_L decaying close to the IP and an additional ISR, FSR photon, and to $e^+e^- \to \pi^+\pi^-\pi^+\pi^-(\gamma)$ non-resonant process. Our simulation is generated on a run-by-run basis, using as input the real data taking conditions for both detector and collider. We have also generated a MC signal sample of $\sim 10^4$ times the expected signal events, to study the selection efficiency.

We look for two K_S decaying into charged pions, by requiring the presence of two vertices close to the interaction point, inside a fiducial volume defined as a cylinder of 3 cm radius in the transverse plane, and ± 8 cm along the beam line, centered on the Interaction Point. Each vertex should have two charged tracks attached to.

For each vertex, the two-track reconstructed mass, $M_{2\pi}$, is built in the pion hypothesys. For the signal, the event density in the $M_{2\pi}(1)$, $M_{2\pi}(2)$ plane is well contained inside a circle of few MeV radius centered on the K_S mass. We require the events to satisfy a 4 MeV cut on this radius. With the reconstructed masses and momenta of the two K_S candidates we calculate the invariant mass of the kaon pair: this must be lower than 1010 MeV, as expected by the signal simulation. The quantity $|M_\gamma^2| = |E_{\rm miss}^2 - P_{\rm miss}^2|$, which is expected to be ≈ 0 for the signal, is requested to be $\leqslant 500$ MeV^2.

Events that survive all these cuts are searched for the presence of one photon, by requiring the presence of one cluster in the calorimeter not associated with any charged track, matching missing momentum direction, in time with the observed event.

All the above-mentioned cuts have been tuned upon an U.L. maximization based on MC samples, and checks for systematic errors have been performed. We estimate an efficiency of 24.8% for the signal.

By fitting the enriched MC background contributions to data distributions, using control samples, we obtain the scale factors used to reduce the residual background events to the number expected in our data sample. The expected background events are 3.2±0.7 . When looking at data we observe 5 residual events.

The following limit on the branching ratio is obtained [7]:

$$BR(\phi \to K_0\overline{K_0}\gamma) < 1.9 \cdot 10^{-8}, \qquad (1)$$

at 90%C.L. In Fig.1 the upper limit is compared with the theoretical predictions of Refs. [8–17]. Most of them are excluded by our result.

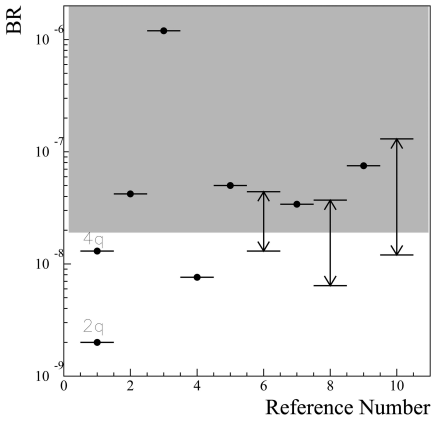

Fig. 1. Comparison between the obtained result on the Upper Limit of $B.R.(\phi \to K^0\bar{K}^0\gamma)$ and the present theoretical estimates in the region around $BR = 1 \times 10^{-8}$. The numbers in abscissa correspond to Refs. [8–17]. The hatched area corresponds to the excluded region.

5 The $\eta \to \pi^+\pi^- e^+e^-$ analysis

The branching ratio for internal conversion decay of the η meson, $\eta \to \pi^+\pi^- e^+e^-$, has been computed with different approaches, but until recently both the theoretical and the experimental results were affected by large uncertainties. The first calculation, based on pure QED, is 40 years old, while recently an approach based on the chiral effective Lagrangian including $\pi\pi$ interactions has obtained a more precise result: $BR = (2.99^{+0.06}_{-0.09}) \times 10^{-4}$ [18].

The $\eta \to \pi^+\pi^-e^+e^-$ decay has been first observed by the CMD-2 experiment [19], giving $BR = (3.7^{+2.5}_{-1.8} \pm 3.0) \times 10^{-4}$, and has afterwards been confirmed by the CELSIUS-WASA experiment [20, 21]: $BR = (4.3^{+2.0}_{-1.6} \pm 0.4) \times 10^{-4}$. The precision of these results does not allow to test different models.

The $\eta \to \pi^+\pi^-e^+e^-(\gamma)$ analysis has been performed using 1733 pb^{-1} from the 2004-2005 dataset, 242 pb^{-1} from the 2006 off-peak ($\sqrt{s}$=1000 MeV) data, 3447 pb^{-1} of Monte Carlo (MC) simulating all ϕ decays, 50506 pb^{-1} of signal Monte Carlo. Effects of Final State Radiation (FSR) have been taken into account in all MC productions. In a sample of $\sim 72 \times 10^6 \eta$s a preselection is performed requiring at least four tracks (two positive and two negative) coming from the Interaction Point. For each charge, the two tracks with the highest momenta are selected. Mass assignment for each track is performed by either identifying a pion decay from a kink in the track, or using the Time Of Flight (TOF) of the particles. To improve the energy and momentum resolution, a kinematic fit is performed imposing the four-momentum conservation and the TOF of the photon.

Two sources of background have to be taken into account. The first is mainly due to $\phi \to \pi^+\pi^-\pi^0$ events (with π^0 Dalitz decay) and to $\phi \to \eta\gamma$ events either with $\eta \to \pi^+\pi^-\pi^0$ (with π^0 Dalitz decay) or with $\eta \to \pi^+\pi^-\gamma$ (with photon conversion on the beam pipe). The second comes from $e^+e^- \to e^+e^-(\gamma)$ events with photon conversions, split tracks or interactions with some material in the region of DAΦNE quadrupoles inside KLOE, and has been studied using off-peak data taken at $\sqrt{s}$=1 GeV, where ϕ decays are negligible. In order to evaluate the background contribution, we perform a fit to the data distribution sidebands of the $\pi^+\pi^-e^+e^-$ invariant mass after the cuts on the momenta, using the background shapes only. For the signal estimate we limit ourselves to the region 535$\sim$555 MeV and perform the event counting after background subtraction: we find 1555 (368) signal (background) events. Data-MC comparisons show a very good agreement for all considered variables, as shown in Fig. 2.

Taking the total systematic error into account, the measurement of the branching ratio is [22]:

$$BR(\eta \to \pi^+\pi^-e^+e^-(\gamma)) = (26.8 \pm 0.9_{\text{Stat.}} \pm 0.7_{\text{Syst.}}) \times 10^{-5}. \quad (2)$$

Our measurement has 4% accuracy, ten times more precise than the previous best measurement [19–21], and is about 2σ smaller than theoretical predictions [18, 23, 24], while is in agreement ($\sim 1\sigma$) with the calculations of the ratio of the branching fractions $BR(\eta \to \pi^+\pi^-e^+e^-)/\text{BR}(\eta \to \pi^+\pi^-\gamma)$ in references [18, 25] when the recent CLEO measurement of $BR(\eta \to \pi^+\pi^-\gamma)$ [26] is used as normalization.

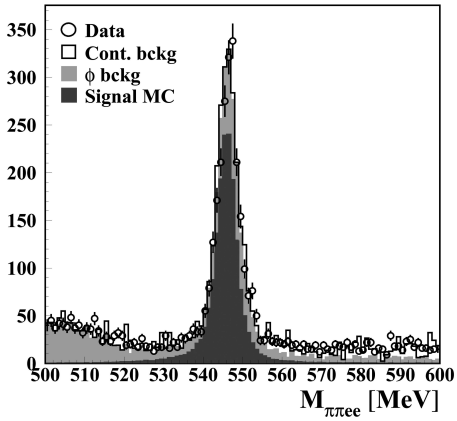

Fig. 2. $\pi^+\pi^-e^+e^-$ invariant mass spectrum zoomed around the η mass. Dots: data. The black histogram is the expected distribution, i.e. signal MC (dark grey), ϕ background (light grey) and continuum background (white).

Recently, it has been proposed that a novel CP violating mechanism (CPV) could induce interference between electric and magnetic decay amplitudes. Such CPV effect could be tested in the decays of the pseudoscalar mesons by measuring the polarization of the virtual photon and would result in an asymmetry in the angle ϕ between the planes containing the e^+e^- and the $\pi^+\pi^-$ pairs in the meson rest frame, defined as:

$$\mathcal{A}_\phi = \left(\int_0^{\pi/2} \frac{d\Gamma}{d\phi} d\phi - \int_{\pi/2}^{\pi} \frac{d\Gamma}{d\phi} d\phi\right) \Big/ \left(\int_0^{\pi/2} \frac{d\Gamma}{d\phi} d\phi + \int_{\pi/2}^{\pi} \frac{d\Gamma}{d\phi} d\phi\right) \sim \mathcal{O}(10^{-2}).$$

The decay plane asymmetry is calculated starting from the momenta of the four particles and is expressed as function of ϕ, the angle between the pion and the electron planes in the η rest frame:

$$\mathcal{A}_\phi = \frac{N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}}{N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}}. \quad (3)$$

The final sample of 1555 signal events allows us to perform the first measurement of the CP-violating asymmetry $\mathcal{A}_\phi$ [22]:

$$\mathcal{A}_\phi = (-0.6 \pm 2.5_{\text{Stat.}} \pm 1.8_{\text{Syst.}}) \times 10^{-2}. \quad (4)$$

which is consistent with zero at the 3% percent precision level.

6 Pseudoscalar mixing angle and gluonium content of the η' meson.

The η' meson, being almost a pure $SU(3)_{\rm flavour}$ singlet, is considered a good candidate to host a gluon condensate. The question of a gluonium component in the η' meson has been extensively investigated in the past but it is still without a definitive conclusion [27]. KLOE already published results on the $\eta-\eta'$ mixing angle and η' gluonium content [28]. These results have been now updated by the KLOE collaboration, as described in the following.

We extract the η' gluonium content and the η-η' mixing angle in the constituent quark model according to the Rosner approach [29] with some modifications [30]. We use the same method as Escribano and Nadal [31], inntroducing in addition the $\pi^0\to\gamma\gamma$ and $\eta'\to\gamma\gamma$ branching fractions in the fit [32]. This method relates our measurement of the ratio $\phi\to\eta'\gamma$ and $\phi\to\eta\gamma$ branching ratio (BR), $R_\phi = BR(\phi\to\eta'\gamma)/BR(\phi\to\eta\gamma)$ [28], to the η' gluonium content and to the η, η' mixing angle. The same quantities were extracted in our previous analysis [28] with some assumptions, giving rise to some objections [31, 33]. We repeated the fit taking into account these comments, and we also repeated the fit with recently updated experimental results, to see their impact on our measurements. Our results are shown in Table 2.

Table 2. KLOE previous and new fit results for the η, η' parameters.

parameter	previous	update	with PDG'08
$Z_{\rm G}^2$	0.14 ± 0.04	0.105 ± 0.037	0.115 ± 0.036
$\psi_{\rm P}$	(39.7 ± 0.7)°	(40.7 ± 0.7)°	(40.4±0.6)°
$Z_{\rm q}$	0.91 ± 0.05	0.866 ± 0.025	0.936 ± 0.025
$Z_{\rm s}$	0.89 ± 0.07	0.79 ± 0.05	0.83 ± 0.05
$\psi_{\rm V}$	3.2°	(3.15 ± 0.10)°	(3.32 ± 0.09)°
$m_{\rm s}/\bar{m}$	1.24 ± 0.07	1.24 ± 0.07	1.24 ± 0.07
$P(\chi^2)$	49%	17%	20%

In this table, the first column shows the results obtained in the previous KLOE fit [28]; the second table shows the new result, in which also $Z_{\rm q}$, $Z_{\rm s}$, $\psi_{\rm V}$ and $m_{\rm s}/\bar{m}$ parameters are left free. The third column shows the results when PDG 2008 data are used, together with the KLOE result for $\phi\to\omega\pi^0$ [34]. The new results show that the gluonium content of the η' meson is confirmed at 3-σ level. By using these results, one can interpret this guonium as a mixing with a glueball, with a mass of 1.41 ± 0.10 GeV [35].

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