Hadronic physics at KLOE

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Abstract. New KLOE results on scalar mesons, $\gamma\gamma$ physics and $\eta$ physics are presented.

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1. SCALAR PHYSICS

The structure of the scalars below 1 GeV needs to be further clarified. Several models have been proposed to describe them (e.g. $q\bar{q}$, four quarks, $K\bar{K}$ molecules, etc.). The decay of the scalars into two pseudoscalars ($S \rightarrow PP'$) can be used to investigate their nature because the branching ratios and the invariant mass of the two pseudoscalars are sensitive to the scalar structure.

$f \rightarrow a_0(980) \gamma \rightarrow \eta \pi^0 \gamma$ decay [1]. For this measurement about 400 pb$^{-1}$ of KLOE collected data have been used. The analysis has been performed for two different $h$ final states, i.e. $h \rightarrow gg$ and $h \rightarrow p^+ p^- p^0$. A kinematic fit has been performed imposing the four momentum conservation, the photon velocity and the invariant masses of both $h$ and $p^0$. The $\eta \pi^0$ invariant mass distribution has been fitted with the “no-structure”[2] and the “kaon loop”[3] models after background subtraction. The results of the fit are shown in table 1. It is interesting to note that both models give a large coupling of the $a_0(980)$ with the $f$ meson, indicating a sizable strange quark content in the $a_0(980)$.

The branching ratio obtained for the two different decay chains are in agreement: $BR( f \rightarrow hp^0 g ) = (7.01 \pm 0.10_{\text{stat}} \pm 0.20_{\text{syst}}) \times 10^{-5}$ for the $\eta \rightarrow \gamma \gamma$ final state and $BR( f \rightarrow hp^0 g ) = (7.12 \pm 0.13_{\text{stat}} \pm 0.22_{\text{syst}}) \times 10^{-5}$ for the $\eta \rightarrow \pi^+ \pi^- \pi^0$ final state.

$f \rightarrow K^0 \bar{K}^0 \gamma$ decay [4]. This decay allegedly proceeds through the intermediate $f_0(980)$ (I=0) and $a_0(980)$ (I=1) scalar mesons: $f \rightarrow (f_0 + a_0) \gamma \rightarrow K^0 \bar{K}^0 \gamma$. The kaon pair is produced in a $J^{PC} = 0^{++}$ state, so the two kaons are both $K_S$ or $K_L$. We have searched for a final state with a $K_S K_S$, with both $K_S^*$ decaying to $\pi^+ \pi^-$. This request

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TABLE 1. Output of the fit to the $\eta\pi^0$ invariant mass with two different models: kaon loop and no structure.

|                 | Kaon loop          | No structure         |
|-----------------|--------------------|----------------------|
| $M_{\eta\pi^0}$ [MeV] | 982.5 ± 1.6 ± 1.1 | 982.5 (Fixed)        |
| $g_{0K^+K^-}$ [GeV]  | 2.15 ± 0.06 ± 0.06 | 2.01 ± 0.07 ± 0.28   |
| $g_{0\pi^0\pi^0}$ [GeV] | 2.82 ± 0.03 ± 0.04 | 2.46 ± 0.08 ± 0.11   |
| $g_{\phi\eta\pi}$ [GeV$^{-1}$] | 1.58 ± 0.10 ± 0.16* | 1.83 ± 0.03 ± 0.08   |
| BR($\phi \to \rho\pi \to \eta\pi\pi\gamma$) | (0.92 ± 0.40 ± 0.15) $\cdot$ 10^{-6} | (0.05 ± 4 ± 0.07) $\cdot$ 10^{-6} |
| BR($\eta \to \gamma\gamma$)/BR($\eta \to \pi^+\pi^-\pi^0$) | 1.70 ± 0.04 ± 0.03 | 1.70 ± 0.03 ± 0.01   |
| $\chi^2$ probability | 0.104              | 0.309                |

* Not a free parameter of the fit in this model. Calculated from other fit outputs.

reduces the probability of observation to $\sim 22\%$, but selects a class of event with a clear signature: four tracks and a low energy photon coming from the interaction point. In this analysis the whole KLOE dataset, $\sim 2.2$ fb$^{-1}$, has been used. At the end of which we have observed 5 events in the data, while we were expecting $3.2\pm0.7$ background events from MC. A Cousin-Feldman approach has been used [5] and a 90% confidence level upper limit on the branching ratio has been obtained: $BR(\phi \to K^0\bar{K}^0\gamma) < 1.9 \times 10^{-8}$. This measurement excludes some of the theoretical predictions and is in agreement with expectations from other KLOE measurements (see figure 1 left, reference [4] and references therein).

2. $\gamma\gamma$ PHYSICS

KLOE has been making a pilot study for the search $\gamma\gamma \rightarrow \sigma(600) \rightarrow \pi^0\pi^0$ using 11 pb$^{-1}$ from the 240 pb$^{-1}$ taken at $\sqrt{s} = 1000$ MeV [6]. At this energy the background

![Figure 1](https://example.com/figure1.png)

**FIGURE 1.** Left: comparison between theoretical predictions for the $\phi \to K^0\bar{K}^0\gamma$ branching ratio and KLOE upper limit. The grey area represents the expected range for the branching ratio using other KLOE results on scalar mesons. Right: search for $\gamma\gamma \rightarrow \sigma(600) \rightarrow \pi^0\pi^0$; fit to the invariant mass of the four photons, $M_{\gamma\gamma}$, with MC shapes of expected source of background. Dots: data; atched yellow: total background; red: $\phi \to \eta\gamma \rightarrow \pi^0\pi^0\pi^0\gamma$; blue: $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\pi^0\gamma$; green: $\phi \rightarrow K_\delta K_L$; cyan: $\phi \rightarrow f_0\gamma$; magenta: $e^+e^- \rightarrow \gamma\gamma$. 

TABLE 2. Output of the fit imposing or not the gluonium content to be zero.

| Gluonium content forced to be zero | Gluonium content free |
|-----------------------------------|-----------------------|
| $Z_G^2$                           | fixed 0               |
| $\phi$                            | $(41.4 \pm 0.5)^\circ$|
| $Z_q$                             | $0.93 \pm 0.02$       |
| $Z_s$                             | $0.82 \pm 0.05$       |
| $\phi_q$                          | $(3.34 \pm 0.09)^\circ$|
| $m_s/\bar{m}$                     | $1.24 \pm 0.07$       |
| $\chi^2$ / dof                    | $14.7/4$              |
| $P(\chi^2)$                       | $0.005$               |

from $\phi$ decays is very small. We have performed a fit to the four photons invariant mass ($M_{4\gamma}$), using the shapes of the known sources, see figure [1], right. The result of the fit is very poor $\chi^2$/dof $= 441/94$, showing an excess of events in the expected $\sigma(600)$ region, compared to what expected from MC, therefore pointing towards a search for the signal in the $240 \text{ pb}^{-1}$.

3. PSEUDOSCALAR PHYSICS

The $\phi$ meson decays about 1.3% of times into $\eta \gamma$, this implies DAΦNE is an $\eta$-factory. KLOE has collected one of the largest sample of $\eta$ mesons in the world, about $10^{8}$.

$\eta - \eta'$ mixing and $\eta'$ gluonium content [7]. The KLOE paper on $\eta - \eta'$ mixing [7], suggesting for a $3\sigma$ evidence of gluonium content in the $\eta'$ meson, has triggered a large amount of discussion among theoreticians. Therefore we have decided to perform a new and more detailed study of this topic. We have considered $\eta$ and $\eta'$ in the quark mixing base as described in [8] ($|\eta' > = X_{\eta'}|q\bar{q} > + Y_{\eta'}|s\bar{s} > + Z_G|G >$). The new fit we have performed has more constraints thus allowing an independent determination of more free parameters. We use the BR values from PDG 2008 [9] and the new KLOE results on the $\omega$ meson [10]. The fit has been performed both imposing the gluonium content to be zero or allowing it free. The results are shown in table 2: gluonium content of the $\eta'$ is confirmed at $3\sigma$ level.

$\eta$ decays into four charged particles [11]. KLOE has started to study the decays of the $\eta$ into four charged particles, using $1.7 \text{ fb}^{-1}$ of data. This decay is interesting because it allows us to probe the $\eta$ internal structure exploiting the conversion of the virtual photon into a lepton pair [12]. It is also interesting because a non-CKM CP violating mechanism has been suggest to be present in this decay [13], and should manifest as an angular asymmetry $A_\phi$, between the pion and the electron decay planes in the $\eta$ rest frame. After background rejection a fit of the sidebands of the four tracks invariant distribution has been performed to obtain the background scale factors. Most of the background is due to $\phi$ decays, but there is still a non-negligible contribution from continuum events. Signal events have been counted in the $\eta$ mass region, giving $BR(\eta \rightarrow$
FIGURE 2. Left and center: $\eta \rightarrow \pi^+\pi^-e^+e^-$ analysis; $\pi^+\pi^-e^+e^-$ invariant mass and angular asymmetry distributions. Dots: data. The black histogram is the expected distribution, i.e. signal MC (dark grey), $\phi$ background (light grey) and continuum background (white). Right: $\eta \rightarrow e^+e^-e^+e^-$ analysis; fit of the four electron invariant mass, $M_{eeee}$.

$\pi_{eeee} = (26.8 \pm 0.9_{\text{Stat.}} \pm 0.7_{\text{Syst.}}) \times 10^{-5}$ and $A_{\phi} = (-0.6 \pm 2.5_{\text{Stat.}} \pm 1.8_{\text{Syst.}}) \times 10^{-2}$ [11], see figure 2 left and center.

More recently KLOE has started studying the $\eta \rightarrow e^+e^-e^+e^-$ decay. This decay, together with the $\eta \rightarrow \mu^+\mu^-e^+e^-$, is interesting for the $\eta$ meson form factor because there are only leptons in the final state. The analysis strategy is similar to the $\pi_{eeee}$ one. Most of the background comes from continuum events and a small contribution is due to $\phi$ decays. The latter is subtracted from data using the MC shape. The number of events is obtained fitting the data distribution of the 4 electron invariant mass, $M_{eeee}$, with signal and background shapes (figure 2 right). From the fit we obtain 413 events. This constitutes the first observation of this decay.

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