MENU 2007
11th International Conference
on Meson-Nucleon Physics and
the Structure of the Nucleon
September10-14, 2007
IKP, Forschungzentrum Jülich, Germany

RECENT KLOE RESULTS ON HADRON PHYSICS

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Abstract

The KLOE experiment at the e^+e^- collider DAFNE of the Frascati Laboratories has collected about 8×10^9 decays of the ϕ meson. From the study of the radiative decays in non-strange pseudoscalar and scalar mesons several informations have been obtained concerning the structure of the lowest mass mesons. A review of the most significant results is presented.

1 Introduction

The main physics motivation of an e^+e^- collider centred at the ϕ meson mass, a ϕ-factory, is the study of kaon physics, 83% of ϕ decays being in kaon pairs. However a ϕ-factory is also a copious source of other low mass mesons, essentially through the radiative decays in one or more pseudoscalar mesons. Hence it is a laboratory for the study of the properties of all the lowest mass mesons.

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Along the years KLOE has published several results concerning the properties of the low mass mesons. Here a review of the most recent results is given. After a brief description of the KLOE experiment (sect.2) the results are presented in Sect.3 and 4.

2 The KLOE experiment

DAFNE is an e^+e^- collider running at a center of mass energy of 1.02 GeV at the Frascati Laboratories of INFN with a luminosity that has reached a peak value of $1.5 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$, the maximum luminosity ever reached at this energy. KLOE has taken data in 4 years up to 2006 and has collected about 2.7 fb^{-1} total integrated luminosity. Most of these data (2.5 fb^{-1} corresponding to about 8×10^9 ϕ decays) have been taken at the ϕ peak, the others have been taken off-peak.

The KLOE detector is conceptually very simple. It consists of a large volume drift chamber [2] in full stereo geometry filled with a He-IsoButane gas mixture, for the measurement of charged tracks, and a lead scintillating fibers calorimeter [3] surrounding it for the measurement of neutral particles (essentially photons and K_L) and for the identification of the charged particles through time of flight. A superconducting coil provides a 0.52 T solenoidal magnetic field. The KLOE physics program includes kaon physics [4], hadron physics (see next sections) and the measurement of the $e^+e^- \to \pi^+\pi^-$ cross-section [5] for the hadronic corrections to $g_\mu - 2$. The prospects for a possible KLOE continuation are discussed in Ref. [6].

3 Results on Pseudoscalar mesons

The lowest mass pseudoscalar meson nonet consists of the pions, the kaons, the η and the η'. All these particles are well established since long time. However the high statistics of η and η' accumulated by KLOE allows to perform precision measurements of the properties of these particles (some are still controversial) and to improve the knowledge of some decays. In the following I review the main KLOE results on η and η'.

3.1 Precision measurement of the η mass

In the last years the precision on the measurement of the η mass has significantly improved. Few experiments, based on completely different experimental methods have pushed the uncertainty well below 100 keV. GEM at Juelich [7] and NA48 at CERN [8] reported 2 measurements in bad disagreement between each other. More recently CLEO has reported a further measurement [9] in agreement with the NA48 value and in disagreement with the GEM value.

In KLOE the η mass is measured using the decay channel $\phi \to \eta\gamma$ with the subsequent decay $\eta \to \gamma\gamma$, resulting in a fully neutral 3-photon final state. The excellent space and time resolutions of the calorimeter allow, through a kinematic fit constrained, to obtain a background free η sample with a well defined mass peak. The absolute calibration of the mass scale is provided by the measurement of the center of mass energy that, in turn, is normalised to the ϕ mass precisely measured by CMD-2 [10]. The result is:

$$m(\eta) = 547.873 \pm 0.007 \pm 0.048 \text{ MeV} \tag{1}$$

and is compared to the other measurements in fig.1.

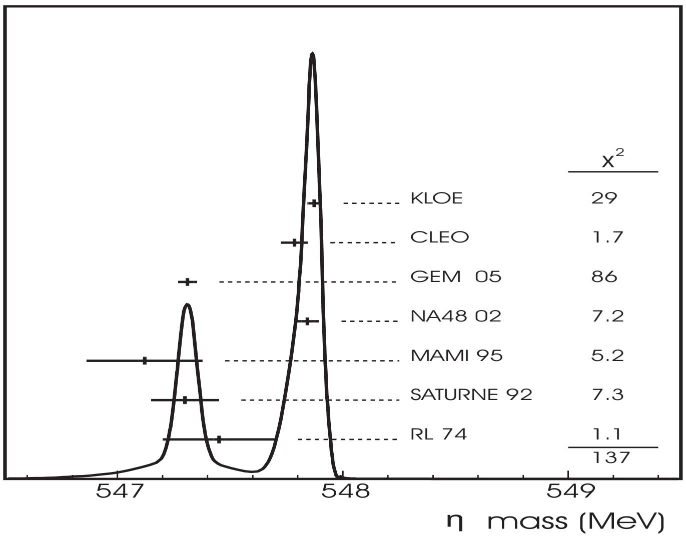

Figure 1: Review of all the measurements of the η mass available now. The curve shown and the χ^2 values are obtained according to the prescriptions of PDG [1].

3.2 η-η' mixing and the gluon content of the η'

Since the ϕ meson is essentially a pure $s\bar{s}$ state, the ratio of branching ratios

$$R = \frac{B.R.(\phi \to \eta'\gamma)}{B.R.(\phi \to \eta\gamma)} \tag{2}$$

is directly related to the pseudoscalar mixing angle ϕ_P in the flavour basis, assuming no gluonium contribution in the η and η' wave-functions [11].

KLOE has measured the ratio R using 2 different data sets and 2 different final states [12,13]. The results are in agreement between each other and the best estimate of the mixing angle is:

$$\phi_P = (41.4 \pm 0.3 \pm 0.9)^o \tag{3}$$

where the systematic uncertainty is dominated by the knowledge of the intermediate η and η' branching ratios entering in the evaluation of R.

If we allow a gluonium contribution in the η' wave function, the ratio R gives a band in the ϕ_P-$Z^2_{\eta'}$ plane, $Z_{\eta'}$ being the size normalized to 1 of the gluonium content. The band is shown in fig.2. Other bands can be put in the same plot following the analyses of refs. [14–16]. The intersection between the bands define the allowed region. According to the KLOE analysis [13] the allowed region is about 3 standard deviation away from $Z_{\eta'} = 0$. More recently a different analysis [17] using different constraints and also a different set of free parameters obtain a result compatible with 0.

Notice that a significant improvement for this combined analysis can be obtained by pushing the measurements of η and η' widths and branching ratios down to 1% level.

3.3 Dynamic of the decay $\eta \to 3\pi$

The η decays in 3 pions are isospin violating decays. In fact a 3 pion system with 0 angular momentum can be only in a I=0 isospin state. Since the η meson cannot decay to 2 pions due to P and CP invariance in strong interactions, the η in 3 pion is the most frequent hadronic η decay with a very small electromagnetic contribution. Models inspired to chiral perturbation theory allow to evaluate the decay widths and the dynamics [18] of both $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^0\pi^0\pi^0$.

KLOE detects both decays with a large statistics and a completely negligible background. We give here the final result for the study of $\eta \to \pi^+\pi^-\pi^0$ and a preliminary result concerning $\eta \to \pi^0\pi^0\pi^0$.

The $\eta \to \pi^+\pi^-\pi^0$ Dalitz plot has been fit using the following expansion of the amplitude A:

$$|A(X,Y)|^2 = 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 \tag{4}$$

where the Dalitz plot variables are defined as usual:

$$X = \sqrt{3}\frac{T_+ - T_-}{Q_\eta}; Y = \frac{3T_0}{Q_\eta} \tag{5}$$

with $T_{+,-,0}$ the kinetic energies of the three pions and $Q_\eta = m_\eta - 2m_{\pi^\pm} - m_{\pi^0}$. The results of the fit, based on a sample of 1.34 million of events are shown in Tab.1. The following comments can be done on these results:

- the odd terms in X (c and e) are compatible with 0, so that no C violation is observed;
- the quadratic term in X (d) is unambiguously different from 0;
- the cubic term in Y (f) is needed to get an acceptable fit;
- the $b = a^2/2$ rule expected based on current algebra is largely violated.

KLOE has also analysed a sample of 0.6×10^6 $\eta \to \pi^0\pi^0\pi^0$. In this case the fit is done on the 1-dimensional Z distribution:

$$|A(Z)|^2 = 1 + 2\alpha Z \tag{6}$$

where Z is

$$Z = \frac{2}{3}\sum_{i=1}^{3}\Big(\frac{3E_i - m_\eta}{m_\eta - 3m_{\pi^0}}\Big)^2 \tag{7}$$

The fit of the Z spectrum divided by the simulated spectrum with a pure phase-space distribution gives the value of the slope α:

$$\alpha = -0.027 \pm 0.004 \pm 0.005 \tag{8}$$

in good agreement with Crystal Ball result [19]

4 Results on Scalar mesons

The lowest mass scalar nonet is not well established. On one side the two lowest mass states, the I=0 $\sigma(600)$ and the I=1/2 $\kappa(800)$ are both controversial; on the other side for what concern the two highest mass states, the I=0 $f_0(980)$ and the I=1 $a_0(980)$, although they are firmly established states, several different interpretations of their structure have been proposed.

KLOE contributes in the understanding of the scalar mesons in two ways: in the assessment of the $\sigma(600)$ looking at the $\pi\pi$ low energy mass spectra and by measuring the couplings of the $f_0(980)$ and the $a_0(980)$ to the ϕ and to the KK, $\pi\pi$ and $\eta\pi$ final states. The analysis of the radiative ϕ decays in $\pi\pi\gamma$, $\eta\pi\gamma$ and $K\overline{K}\gamma$ allows to carry on this program. In the following I give the most recent results concerning the analysis of these decay channels.

4.1 Analysis of $\pi\pi\gamma$: the $\mathbf{f}_0(980)$ and the $\sigma(600)$.

The final states $\pi^+\pi^-\gamma$ and to $\pi^0\pi^0\gamma$ receives contributions from the radiative decays $\phi \rightarrow$f$_0$(980)γ and $\phi \rightarrow \sigma(600)\gamma$, but also from other processes that give rise to large unreducible backgrounds. By fitting the mass spectra of $\pi^+\pi^-\gamma$ [21] and $\pi^0\pi^0\gamma$ [22,23] final states KLOE has extracted the scalar part of the amplitude and has obtained relevant informations on the isoscalar scalar low mass $\pi\pi$ amplitude concerning in particular the couplings. Summarising the fit results the following statements can be done:

- the Kaon-Loop prescription [20] for the coupling of the ϕ meson to the scalar provides a good description of the data;

- the f$_0$(980) meson is strongly coupled to the ϕ and coupled to the KK system more than to the $\pi\pi$ system;

- the scalar amplitude has a low mass tail ($m_{\pi\pi}$ lower than 600 MeV) that can be interpreted as due to the σ meson.

A combined fit of the two spectra with an improved parametrisation of the scalar amplitude is in progress and will be presented soon.

4.2 Analysis of $\eta\pi\gamma$: the $\mathbf{a}_0(980)$

The $\eta\pi$ system is a I=1 state, so that is dominated by the radiative decay $\pi \rightarrow$ a$_0$(980)γ. In this case the possible unreducible backgrounds are much less than in the case of the $\pi\pi$ state.

KLOE has selected these final states in two ways: looking for $\eta\pi\gamma$ with $\eta \rightarrow \gamma\gamma$ (decay 1 in the following) and looking for the same final state but with $\eta \rightarrow \pi^+\pi^-\pi^0$ (decay 2). The two decay channels are characterized by different systematic effects and reducible backgrounds that can affect the measurement. Two branching ratios are obtained independently:

$$BR(\phi \rightarrow \eta\pi\gamma)(1) = (6.92 \pm 0.10_{stat} \pm 0.20_{syst}) \times 10^{-5}$$

$$BR(\phi \rightarrow \eta\pi\gamma)(2) = (7.19 \pm 0.17_{stat} \pm 0.24_{syst}) \times 10^{-5}$$

in good agreement between each other. The uncertainty is improved from 9% of the previous KLOE measurement [24] to 3%.

The two mass spectra are fitted simultaneously with the Kaon-Loop model. The result for the parameters are given in tab.2.

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

In the decay $\phi \to K^0\overline{K^0}\gamma$ the KK pair is produced in a symmetric state with 0 angular momentum, so that either K_SK_S or K_LK_L pairs can be obtained with equal probability. KLOE has searched for the decay $\phi \to K_SK_S\gamma$ with both K_S decaying to the most frequent final state $\pi^+\pi^-$. The predictions for the branching ratio of this decay depend on the model used to describe the intermediate scalar states: the $f_0(980)$ for the I=0 part of the amplitude and the $a_0(980)$ for the I=1 part. Due to the very small available phase-space, very small branching ratios are predicted, all in the region between 10^{-9} and 10^{-7} as shown in fig.3. Notice that no experimental measurements are available for this decay.

KLOE has searched for this decays requiring: (i) 2 vertices both connected to 2 charged tracks near the e^+e^- interaction point (ii) kaon invariant masses for both vertices (iii) a combined two-kaon invariant mass well below the ϕ mass and finally (iv) a low energy photon. In the end only 1 event survives the selection while the estimate of the background based on the Montecarlo sample with the same luminosity of the data gives 0 expected events. Based on the numbers we set the upper limit:

$$B.R.(\phi \to K^0\overline{K^0}\gamma) < 1.8 \times 10^{-8} \quad (90\% C.L.) \tag{9}$$

that allows to exclude several among the proposed models (see fig.3).

References

[1] W.M.Yao et al., (Particle Data Group), Journ. of Phys. **G33** (2006) 1.

[2] M.Adinolfi et al., Nucl. Instr. and Meth. **A488**, (2002) 1.

[3] M.Adinolfi et al., Nucl. Instr. and Meth. **A482**, (2002) 364.

[4] M.Antonelli et al. (KLOE collaboration), talk given at Lepton-Photon 2007, Seoul;

[5] A.Aloisio et al. (KLOE collaboration), Phys. Lett. **B606**, (2005) 12.

[6] F.Ambrosino et al., Eur.Phys.J. **C50** (2007) 729;

[7] M.Abdel-Bary et al. (GEM collaboration), Phys. Lett. **B619** (2005) 281.

[8] A.Lai et al. (NA48 collaboration), Phys. Lett. **B533** (2002) 196.

[9] D.H.Miller et al. (CLEO collaboration), arXiv:0707.1810, submitted to Phys.Rev.Lett.;

[10] A.Akhmetshin et al., (CMD-2 collaboration), Phys. Lett.**B578** (2004) 285.

[11] A.Bramon et al., Eur. Phys. J. **C7** (1999) 24.

[12] A.Aloisio et al. (KLOE collaboration), Phys. Lett. **B541**, (2002) 45.

[13] F.Ambrosino et al. (KLOE collaboration), Phys. Lett. **B648**, (2007) 267.

[14] J.L.Rosner, Phys. Rev. **D27** (1983) 1101;

[15] A.Bramon et al., Phys. Lett. **B503**, (2001) 271.

[16] E.Kou, Phys. Rev. **D63** (2001) 54027;

[17] R.Escribano, J.Nadal, JHEP 0705 (2007) 006;

[18] B.Borasoy, R.Nissler, AIP Conf.Proc.796 (2005) 150;

[19] W.B.Tippens et al., (Crystal Ball collaboration), Phys. Rev. Lett. 87 (2001) 192001;

[20] N.N.Achasov and V.N.Ivanchenko, Nucl. Phys. **B315** (1989) 465.

[21] F.Ambrosino et al. (KLOE collaboration), Phys. Lett. **B634**, (2006) 148.

[22] A.Aloisio et al., (KLOE collaboration), Phys. Lett. **B537** (2002) 21.

[23] F.Ambrosino et al., (KLOE collaboration), Eur. Phys. J. **C49** (2006) 433;

[24] A.Aloisio et al. (KLOE collaboration), Phys. Lett. **B536**, (2002) 209.

[25] N.N.Achasov, V.V.Gubin, Phys.Rev.**D64** (2001) 094016;

[26] A.Bramon, A.Grau, G.Pancheri, Phys. Lett. **B289** (1992) 97;

[27] J.A.Oller, Phys. Lett. **B426**(1998) 7;

[28] R.Escribano, Eur. Phys. J. **A31** (2007) 454;

[29] A.Gokalp, C.S.Korkmaz, O.Yilmaz hep-ph/0702214.

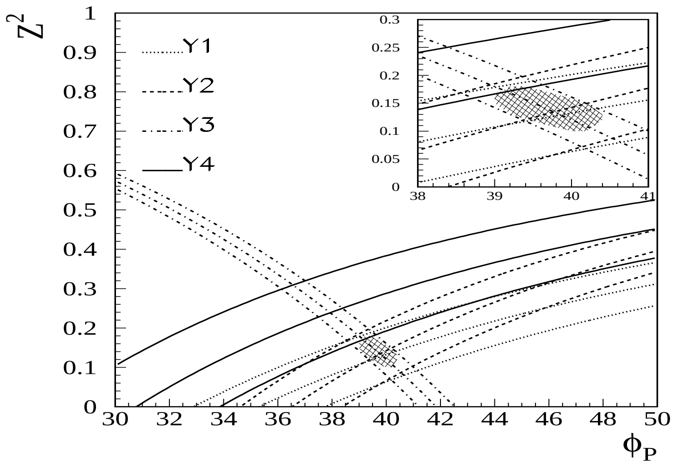

Figure 2: Analysis of the η' gluonium content. The four bands shown in the $Z^2_{\eta'}$-ϕ_P plane are: (Y1) from $\Gamma(\eta' \to \gamma\gamma)/\Gamma(\pi^0 \to \gamma\gamma)$, (Y2) from $\Gamma(\eta' \to \rho\gamma)/\Gamma(\omega \to \pi^0\gamma)$, (Y3) from the KLOE result (see text) and finally (Y4) from $\Gamma(\eta' \to \omega\gamma)/\Gamma(\omega \to \pi^0\gamma)$. A detailed view of the intersection region is shown in the box.

Table 1: In each line the result of a fit is reported with a different set of free parameters. Empty cells means that in that particular fit the parameter has been fixed to 0.

dof	p(χ^2)	10^3a	10^3b	10^3c	10^3d	10^3e	10^3f
147	73%	-1090±5	124±6	2±3	57±6	-6±7	140±10
149	74%	-1090±5	124±6		57±6		140±10
150	10^{-6}	-1069±5	104±5				130±10
150	10^{-8}	-1041±3	145±6		50±6		
151	10^{-6}	-1026±3	125±6				

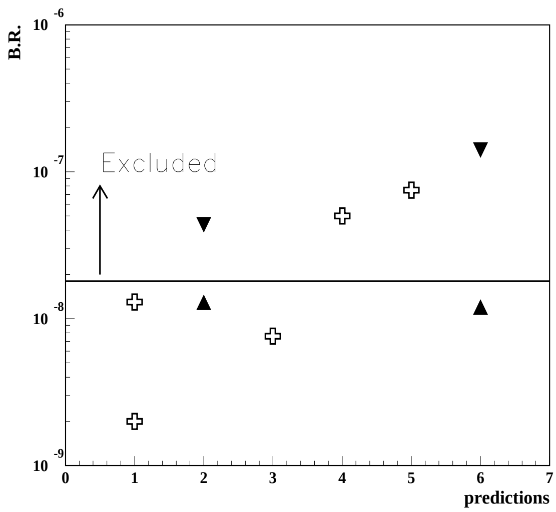

Figure 3: Published predictions on the branching ratio of the process $\phi \to K^0\overline{K^0}\gamma$ (abscissas 1-6 corresponds to refs. [20, 25–29]). The models above the horizontal line are ecluded by the data.

Table 2: Result of the $\eta\pi\gamma$ combined fit using the Kaon-Loop parametrisation for the scalar amplitude. Apart from the a_0 mass, free parameters are the couplings and the ratio R between the η branching ratios that is left free in the fit and results in agreement with the PDG value.

dof	p(χ^2)	M_a0 (MeV)	$g_{a0K^+K^-}$ (GeV)	$g_{a0\eta\pi}$ (GeV)	R
136	11%	983±1	2.16±0.04	2.8±0.1	1.69±0.04