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Hadronic physics with KLOE

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Summary. — The KLOE experiment has successfully completed its data taking in March 2006 with a total integrated luminosity of about 2.5 fb^{-1}. We report the newest results on hadronic physics, such as the parameter of scalar a_0, the first observation of the $\eta \to \pi^+\pi^-e^+e^-$ rare decay, the $\eta - \eta'$ mixing angle, and the measurement of the hadronic cross-section.

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1. – The KLOE experiment

The KLOE experiment [1] runs at the Frascati ϕ-factory DAΦNE, a high-luminosity e^+e^- collider working at $\sqrt{s} \simeq 1020$ MeV, corresponding to the ϕ meson mass.

The KLOE detector consists of a large cylindrical drift chamber (3.3 m length and 2 m radius), surrounded by a sampling lead-scintillating fiber electromagnetic calorimeter. Both detectors operate inside a uniform magnetic field of $\simeq 0.5$ T provided by a superconducting coil. Large angle tracks from the origin ($\theta > 45°$) are reconstructed with relative momentum resolution $\sigma_p/p = 0.4\%$. Photon energies and times are measured by the calorimeter with resolutions of $\sigma_E/E = 5.7\%/\sqrt{E(\mathrm{GeV})}$ and $\sigma_t = 57\,\mathrm{ps}/\sqrt{E(\mathrm{GeV})} \oplus 100\,\mathrm{ps}$.

In the whole data taking (2001–2006) KLOE has collected an integrated luminosity of 2.7 fb^{-1}: 2.5 fb^{-1} at the ϕ peak (corresponding to about $6 \times 10^9 \phi$ decays) and 0.2 fb^{-1} around the center-of-mass energy, $\sqrt{s} = 1$ GeV, out of the ϕ-resonance region.

2. – Scalar mesons

The still unresolved structure of these states is studied either through electric dipole transitions such as $\phi \to a_0(980)\gamma$ and looking at the mass spectrum of the scalar meson decay products, or with the search for processes like $\phi \to [a_0(980) + f_0(980)]\gamma \to K\bar{K}$.

(*) On behalf of the KLOE Collaboration.

TABLE I. – *Results from the two indepentent analyses.*

Channel features	$\eta \to \gamma\gamma$	$\eta \to \pi^+\pi^-\pi^0$
Signal efficiency	40%	20%
$B/(S+B)$	50%	14%
$BR(\phi \to \eta\pi^0\gamma) \times 10^5$	7.01(10)(20)	7.12(13)(22)

2˙1. $\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$. – Two independent analyses [2] using $\eta \to \gamma\gamma$ or $\eta \to \pi^+\pi^-\pi^0$ decays are performed from a sample of $410\,\mathrm{pb}^{-1}$. Both analyses share the requirement of five photons from the interaction point. The selection of also two tracks of opposite charge, while less efficient for $\eta \to \pi^+\pi^-\pi^0$ events, has a selected sample with smaller background than from the $\eta \to \gamma\gamma$ channel. Since the interfering $\phi \to \rho\pi^0 \to \eta\pi^0\gamma$ background is small, it is possible to extract the branching fraction (BR) directly from event counting after the residual background subtraction. Table I shows that the two samples lead to consistent branching ratio values, thus a combined fit of the two spectra is performed. The couplings, fitted according to the Kaon Loop [3] and the No Structure [4] models, point to a total width in the range 80–105 MeV and to a sizeable $s\bar{s}$ content of the $a_0(980)$.

2˙2. *Search for* $\phi \to [a_0(980) + f_0(980)]\gamma \to K\bar{K}$. – Using $2.2\,\mathrm{fb}^{-1}$ of the KLOE data, a search [5] for the decay $\phi \to K\bar{K}$ has been performed. In this decay the $K\bar{K}$ pair is produced with positive charge conjugation and a limited phase space due to the small mass difference between the ϕ and the production threshold of two neutral kaons (995 MeV). The signature of this decay is provided by the presence of either 2 K_S or 2 K_L and a low-energy photon. In the reported analysis, only the K_SK_S component has been used, looking for double $K_S \to \pi^+\pi^-$ decay vertex. The main background are the resonant $e^+e^- \to \phi\gamma \to K_SK_L\gamma$ and the continuum $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\gamma$ processes.

5 candidate events are found in data, whereas 3 events are expected from Monte Carlo background samples. This leads to: $BR(\phi \to K\bar{K}) < 1.9 \times 10^{-8}$ at the 90% CL.

Theory predictions for the BR spread over several orders of magnitude; several of them are ruled out by our result. Moreover the present upper limit is consistent with the $BR(\phi \to K\bar{K})$ prediction computed with $a_0(980)$ [2], $f_0(980)$ [6] couplings measured by KLOE.

3. – $\eta - \eta'$ mixing angle

We have measured the ratio $R_\phi = BR(\phi \to \eta'\gamma)/BR(\phi \to \eta\gamma)$ by looking for the radiative decays $\phi \to \eta'\gamma$ and $\phi \to \eta\gamma$ into the final states $\pi^+\pi^-7\gamma$ and 7γ, respectively, in a sample of $\simeq 1.4 \times 10^9 \phi$ mesons. We obtained [7] $R_\phi = (4.77 \pm 0.09 \pm 0.19) \times 10^{-3}$, from which we derive $BR(\phi \to \eta'\gamma) = (6.20 \pm 0.11 \pm 0.25) \times 10^{-5}$.

The value of R_ϕ can be related to the $\eta - \eta'$ mixing angle in the flavor basis. Using the approach [8] and [9], where the $SU(3)$ breaking is taken into account via constituent quark mass ratio $m_s/\bar{m}$, and the two parameters C_{NS} and C_S take into account the effect of the OZI rule, which reduce the VP wave function overlaps [10]:

$$(1) \qquad R = \frac{BR(\phi \to \eta' \gamma)}{BR(\phi \to \eta\gamma)} = \cot^2 \varphi_P \left(1 - \frac{m_s}{\bar{m}} \frac{C_{NS}}{C_S} \frac{\tan\varphi_V}{\sin 2\varphi_P}\right)^2 \left(\frac{p_{\eta'}}{p_\eta}\right)^3 .$$

From eq. (1) we obtained the following result: $\varphi_P = (41.4 \pm 0.3_{\text{stat.}} \pm 0.7_{\text{syst.}} \pm 0.6_{\text{th}})^\circ$.

The η' meson is a good candidate to have a sizeable gluonium content, we can have $|\eta'\rangle = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|\text{gluon}\rangle$ where the $Z_{\eta'}$ parameter takes into account a possible mixing with gluonium. The normalization implies $X^2_{\eta'} + Y^2_{\eta'} + Z^2_{\eta'} = 1$ with $X_{\eta'} = \cos\phi_G \sin\phi_P$, $Y_{\eta'} = \cos\phi_G \cos\phi_P$ and $Z_{\eta'} = \sin\phi_G$, where ϕ_G is the mixing angle for the gluonium contribution. Possible gluonium content of the η' meson corresponds to a non-zero value for $Z^2_{\eta'}$.

Introducing other constraints on $X_{\eta'}$ and $Y_{\eta'}$ [9-11], as: $\Gamma(\eta' \to \gamma\gamma)/\Gamma(\pi^0 \to \gamma\gamma)$; $\Gamma(\eta' \to \rho\gamma)/\Gamma(\omega \to \pi^0\gamma)$; $\Gamma(\eta' \to \omega\gamma)/\Gamma(\omega \to \pi^0\gamma)$, and allowing for gluonium, we minimized the χ^2, function of (ϕ_P, ϕ_G), to determine $Z^2_{\eta'}$ and ϕ_P. The updated values of the $\eta{-}\eta'$ mixing angle and η' gluonium content by fitting R_ϕ together with several vector meson radiative decays to pseudoscalars, pseudoscalar mesons radiative decays to vectors and the $\eta' \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$ widths, are consistent with those previously published by KLOE [7]. We extract from the fit a gluonium fraction of $Z^2_{\eta'} = 0.12 \pm 0.04$ and a mixng angle $\phi_P = (40.4 \pm 0.6)^\circ$. In the new fit [12], following the prescription from [13, 14], we do not fix the VP wave function overlap parameters, the vector-mixing angle and the quark mass ratio and we conclude that the origin of the difference between the KLOE result in [7] and the one by Escribano [13], is the use of the $\Gamma(\eta' \to \gamma\gamma)/\Gamma(\pi^0 \to \gamma\gamma)$ constraint.

4. – Branching ratio $\eta \to \pi^+\pi^-e^+e^-$

The study of $\eta \to \pi^+\pi^-e^+e^-$ decay allows to probe the internal structure of the η meson [15] and could be used to compare the predictions based on Vector Meson Dominance (VMD) and Chiral Perturbation Theory (ChPT) [16]. Moreover, it would be possible to study CP violation not predicted by the Standard Model by measuring the angular asymmetry between the decay planes of the electrons and of the pions in the η rest frame.

The $\eta \to \pi^+\pi^-e^+e^-$ analysis [17] is based on a sample of $1.7\,\text{fb}^{-1}$. The event selection consists of the requirement of one photon of $E > 250\,\text{MeV}$ energy, namely the monochromatic photon from $\phi \to \eta\gamma$, and four charged tracks coming from the interaction region. Mass assignment for each track is done using time of flight of the charged particles measured in the calorimeter. The contamination is evaluated by fitting the sidebands of the $M_{\pi\pi ee}$ data spectrum with background components after loose cuts on the kinematic fit χ^2 and on the sum of momenta of the charged particles. Signal events are computed after rejecting γ conversions, and from the fit the branching ratio is evaluated: $BR(\eta \to \pi^+\pi^-e^+e^-\gamma) = (26.8 \pm 0.9_{\text{stat.}} \pm 0.7_{\text{syst.}}) \times 10^{-5}$. The decay plane asymmetry is calculated starting from the momenta of the four particles and is expressed as a function of the angle ϕ between the pion and the electron planes in the η rest frame. It has been evaluated for the events in the signal region after background subtraction. The value obtained is: $\mathcal{A}_\phi = (-0.6 \pm 2.5_{\text{stat.}} \pm 1.8_{\text{syst.}}) \times 10^{-2}$ which is the first measurement of this asymmetry.

5. – The measurement of the hadronic cross-section

At DAΦNE, it is possible to measure the differential spectrum of the $\pi^+\pi^-$ invariant mass, $M_{\pi\pi}$, from Initial State Radiation (ISR), $e^+e^- \to \pi^+\pi^-\gamma$ events with photon emission at small angle, and to extract the total cross-section $\sigma_{\pi\pi(\gamma)} = \sigma_{e^+e^-\to\pi^+\pi^-}$ using the following formula [18]:

$$M^2_{\pi\pi}\frac{\mathrm{d}\sigma_{\pi\pi\gamma}}{\mathrm{d}M^2_{\pi\pi}} = \sigma_{\pi\pi}(M^2_{\pi\pi})H(M^2_{\pi\pi}), \tag{2}$$

where H is the radiator function. This formula neglects Final State Radiation (FSR) terms. Using $240\,\mathrm{pb}^{-1}$ of data taken in 2002 the dipion contribution to the muon anomaly, $a_\mu^{\pi\pi}$, in the interval $0.592 < M_{\pi\pi} < 0.975\,\mathrm{GeV}$, has been measured [19] with a negligible statistical error and a 0.6% experimental systematic uncertainty. Radiative corrections increase the systematic uncertainty to 0.9%. Combining all errors we found

$$a_\mu^{\pi\pi}(0.592 < M_{\pi\pi} < 0.975\,\mathrm{GeV}) = (387.2 \pm 3.3) \times 10^{-10}.$$

This result represents an improvement of 30% on the systematic error with respect to our previously published value [20], and confirms the current disagreement between the standard model prediction for a_μ and the measured value. The spectrum of the pion form factor is also in very good agreement with recent results from SND and CMD2 experiments at Novosibirsk [21]. Independent analyses are in progress: to measure $\sigma_{\pi\pi(\gamma)}$ using detected photons emitted at large angle, improving knowledge of the FSR interference effects (in particular the $f_0(980)$ contribution); to measure the pion form factor directly from the ratio, bin-by-bin, of $\pi^+\pi^-\gamma$ to $\mu^+\mu^-\gamma$ spectra; and to extract the pion form factor from data taken at $\sqrt{s} = 1\,\mathrm{GeV}$, off the ϕ resonance, where $\pi^+\pi^-\pi^0$ background is negligible.

REFERENCES

[1] Adinolfi M. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **488** (2002) 51; **482** (2002) 364.
[2] Ambrosino F. *et al.* (KLOE Collaboration), *Phys. Lett. B*, **681** (2009) 5.
[3] Achasov N. N. and Gubin V. V., *Phys. Rev. D*, **56** (1997) 4084.
[4] Isidori G., Maiani L., Nicolaci M. and Pacetti S., *JHEP*, **0605** (2006) 049.
[5] Ambrosino F. *et al.* (KLOE Collaboration), *Phys. Lett. B*, **679** (2009) 1014.
[6] Ambrosino F. *et al.* (KLOE Collaboration), arXiv:0805.2521v1.
[7] Ambrosino F. *et al.* (KLOE Collaboration), *Phys. Rev. Lett. B*, **648** (2007) 267.
[8] Bramon A., Escribano R., and Scadron M. D., *Eur. Phys. J. C*, **7** (1999) 271.
[9] Rosner J. L., *Phys. Rev. D* , **27** (1983) 1101.
[10] Bramon A., Escribano R. and Scadron M. D., *Phys. Lett. B* , **503** (2001) 271.
[11] Kou E., *Phys. Rev. D*, **63** (2001) 54027.
[12] Ambrosino F. *et al.* (KLOE Collaboration), *JHEP*, **0907** (2009) 105.
[13] Escribano R. and Nadal J., *JHEP*, **0705** (2007) 006.
[14] Thomas C. E., *JHEP*, **0710** (2007) 026.
[15] Landsberg L. G., *Phys. Rep.*, **128** (1985) 301.
[16] Jarlskog C. and H. Pilkhun H., *Nucl. Phys. B*, **1** (1967) 264; Faessler A. *et al.*, *Phys. Rev. C*, **61** (2000) 035206; Picciotto C. and Richardson S., *Phys. Rev. D*, **48** (1993) 3395; Borasoy B. and Nissler R., hep-ph 07050954.
[17] Ambrosino F. *et al.* (KLOE Collaboration), *Phys. Lett. B*, **675** (2009) 283.

[18] Binner S., Kuhn H. and Melnikov K., *Phys. Lett. B*, **459** (1999) 279.
[19] Ambrosino F. *et al.* (KLOE Collaboration), *Phys. Lett. B*, **670** (2009) 285.
[20] Aloisio A. *et al.* (KLOE Collaboration), *Phys. Lett. B*, **606** (2005) 12.
[21] Akhmetshin R. R. *et al.* (CMD-2 Collaboration), *Phys. Lett. B*, **648** (2007) 28; Achasov M. N. *et al.* (SND Collaboration), *J. Exp. Theor. Phys.*, **103** (2006) 380.