KLOE results on light meson properties

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A review of the recent results obtained by the KLOE experiment at DAFNE concerning the physics of low mass mesons is presented.

1. OVERVIEW OF THE KLOE EXPERIMENT AT DAFNE

The KLOE experiment has been working at the $e^+e^-$ collider DAFNE, the $\phi$-factory of the Frascati Laboratories, running at a centre of mass energy around 1.02 GeV (the $\phi$ resonance peak) with a luminosity peak value of $1.5 \times 10^{32}$ cm$^{-2}$s$^{-1}$. KLOE has collected about 2.7 fb$^{-1}$ total integrated luminosity mostly at the $\phi$ peak (2.5 fb$^{-1}$ corresponding to about $8 \times 10^9 \phi$ decays). The other data have been taken around the $\phi$ between 1.00 and 1.03 GeV.

The main mission of the $\phi$-factory is the study of kaon physics, 83% of $\phi$ decays being in kaon pairs. However, the $\phi$-factory is a copious source of mesons with mass below 1 GeV, especially through radiative decays.

In the following, results are presented concerning the physics of the lowest mass scalar mesons (the $f_0(980)$, the $a_0(980)$ and the $f_0(600)$) of the $\eta$-$\eta'$ mesons and of vector mesons. An update is given also of the measurement of the $e^+e^- \rightarrow \pi^+\pi^-$ cross-section for centre of mass energy below 1 GeV done by KLOE using the radiative return method. Finally the prospects of KLOE and DAFNE are briefly discussed.

2. RESULTS

2.1. Scalar Mesons

The lowest mass scalar mesons are accessible at DAFNE through $\phi \rightarrow \pi\pi\gamma$ (sensitive to the isospin 0 scalar mesons $f_0(980)$ and $f_0(600)$, the “controversial” $\sigma$ meson) and $\phi \rightarrow \eta\pi\gamma$ final states (sensitive to the isospin 1 $a_0(980)$). On the other hand, both isospin 0 and 1 mesons contribute to $\phi \rightarrow K\bar{K}\gamma$.

The study of the aforementioned decays essentially allows to measure the coupling of the scalar mesons to the $\phi$ meson, to kaon pairs and to $\pi\pi$ or $\eta\pi$. These couplings are strictly related to the quark composition of the mesons. Moreover the study of the $\pi\pi\gamma$ decay dynamics allows to look for effects due to the $\sigma$ meson.

KLOE has published results concerning $\pi^0\pi^0\gamma$ [1, 2], $\pi^+\pi^-\gamma$ [3] and $\eta\pi^0\gamma$ [4]. Here we present the final results of a new analysis of $\eta\pi^0\gamma$ corresponding to a statistics 20 times larger than the previous one [4], and the preliminary result of a direct search of $K^0\bar{K}^0\gamma$.

Two samples of $\eta\pi^0\gamma$ events are selected from a data set of about 450 pb$^{-1}$: one with $\eta \rightarrow \gamma\gamma$ and one with $\eta \rightarrow \pi^+\pi^-\pi^0$. The first sample is fully neutral (5 photons final state) and is characterised by large statistics (about 20000 events are selected) but also by large reducible background mostly coming from $\phi \rightarrow \eta\gamma$ with $\eta \rightarrow 3\pi^0$. The second sample (about 4000 events selected) gives rise to a final state of 2 tracks and 5 photons with lower background. After background subtraction we combine the two samples to get the measurement of the branching ratio:

$$B.R.(\phi \rightarrow \eta\pi^0\gamma) = (7.05 \pm 0.08_{\text{stat}} \pm 0.21_{\text{syst}}) \times 10^{-5}$$ (1)
A combined fit of the two $\eta\pi$ invariant mass spectra is done to extract the shape and the parameters of the $\phi \to a_0\gamma$ decay amplitude that dominates the $\phi \to \eta\pi\gamma$ decay. The fit (see Fig.1) is done using the kaon loop model to describe the scalar amplitude. The values of the couplings, $g_{a_0\eta\pi}$ and $g_{a_0KK}$ can be compared to the predictions of several models. In particular they fit quite well a recently proposed model based on instanton interactions.

To search for the rare $\phi \to K^0\bar{K}^0\gamma$ decay we look for events $K_S\bar{K}_S\gamma$ where both $K_S$ promptly decay to $\pi^+\pi^-\pi^0$. The background is strongly reduced by the request of two kaon vertexes with missing momentum matching a low energy photon in the calorimeter. Out of a $1.4 \, fb^{-1}$ sample, we find 1 event in the data and no events in a Montecarlo sample of the same size that includes all possible backgrounds. From these data we set a 90% C.L. upper limit:

$$B.R.(\phi \to K^0\bar{K}^0\gamma) < 1.8 \times 10^{-8}$$ (2)

that can be also compared to the predictions of several models concerning the structure of the scalar mesons.

2.2. $\eta$-$\eta'$ physics

$\eta$ and $\eta'$ mesons are copiously produced through the radiative decays $\phi \to \eta\gamma$ (B.R.=1.2%) and $\phi \to \eta'\gamma$ (B.R.=6.2 $\times 10^{-5}$). In both cases the monochromatic radiated photon allows to tag the event giving almost background-free $\eta$ samples and good $\eta'$ samples.

Among the measurements carried out in this field we mention the precision measurement of the $\eta$ mass, of the $\eta$-$\eta'$ mixing, of the dynamics of the 3 pion $\eta$ decays and the observation and measurement of the branching ratios of the rare decays $\eta \to \pi^+\pi^-e^+e^-$, $\eta \to e^+e^-e^+e^-$ and $\eta \to \pi^0\gamma\gamma$.

2.3. Measurement of $\phi \to \omega\pi^0$

The decay $\phi \to \omega\pi^0$ is a OZI and G-parity violating process. To detect it at KLOE, we measure the cross-section of the processes $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ and $e^+e^- \to \pi^0\pi^0\gamma$, both dominated by the $\omega\pi^0$ intermediate state as a function of the centre of mass energy $\sqrt{s}$ (see Fig.2). For this analysis we use the energy scan around the $\phi$ peak between 1000 and 1030 MeV. From the fit shown in Fig.2 we extract the quantities:

$$B.R.(\phi \to \omega\pi^0) = (4.4 \pm 0.6) \times 10^{-5}$$ (3)

$$\Gamma(\omega \to \pi^0\gamma)/\Gamma(\omega \to \pi^+\pi^-\pi^0) = 0.0897 \pm 0.0016$$ (4)
Using unitarity and the PDG values \[12\] for the rare $\omega$ decays we get \(^1\):

\[
B.R.(\omega \rightarrow \pi^+\pi^-\pi^0) = (90.24 \pm 0.19)\% \tag{5}
\]

\[
B.R.(\omega \rightarrow \pi^0\gamma) = (8.09 \pm 0.14)\% \tag{6}
\]

significantly shifted with respect to current PDG values (respectively (89.1\(\pm\)0.7)\% and (8.90\(\pm\)0.27)\%).

### 2.4. Update of hadronic cross-section measurement

The $e^+e^- \rightarrow \pi^+\pi^-$ cross-section for centre of mass energies between the $\pi\pi$ threshold and 1 GeV is the main ingredient for the theoretical evaluation of the hadronic contribution to the muon $g-2$ \[14\]. KLOE has measured this cross-section in the $q^2$ region $0.35 < q^2 < 0.95$ GeV\(^2\) ($q^2 = s$) using the ISR method \[15\]. A first result has been published based on a data sample of about 100 pb\(^{-1}\) \[16\]. Here we present the result of a new analysis on an independent data sample twice in statistics with reduced systematic and theoretical errors. Fig.\ref{fig:cross_section} shows the new KLOE results for the pion form factor compared to the results obtained by the Novosibirsk experiments CMD-2 and SND at VEPP-2M \[17\] that use the energy scan. From the measured cross-section we obtain for the muon magnetic anomaly $a_\mu = (g - 2)/2$:

\[
a_\mu(0.35 < q^2 < 0.95) = (388.2 \pm 0.6_{stat} \pm 3.3_{syst} \pm 2.0_{lh}) \times 10^{-10} \tag{7}
\]

in agreement with the previous measured value and with the CMD-2 and SND values in the same $q^2$ region. This result confirms the 3 $\sigma$ discrepancy between the experimental value of $g - 2$ and the theoretical expectation \[14\].

\(^1\)Notice that due to the method used to extract the two B.R.s, a significant correlation is present between the two values (see discussion in \[13\]).
3. OUTLOOK

DAFNE is testing now a new machine scheme to increase luminosity. The first results are encouraging and KLOE will start a new run in summer 2009. The KLOE2 physics program is based on an integrated luminosity exceeding 20 fb$^{-1}$ and on some substantial upgrades of the detector. Among the physics items, other than several items in kaon physics, we mention $\gamma\gamma$ physics, improved measurements in the $\eta$-$\eta'$ sector and observation of $K\bar{K}\gamma$ final states.

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