KLOE results on light meson spectroscopy and prospects for KLOE-2

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Abstract. The results obtained by the KLOE Collaboration on light meson spectroscopy are presented. The radiative decay $\phi \rightarrow \eta \gamma$ have been used to study several $\eta$ decay channels. The Dalitz plot distributions of the $\eta \rightarrow 3\pi$ decays, both in charged and neutral final states have been measured. The box anomaly contribution in $\eta \rightarrow \pi^+\pi^-\gamma$ has been investigated, and the rare decays $\eta \rightarrow \pi^0\gamma$, $\eta \rightarrow \pi^+\pi^-e^+e^-$ and $\eta \rightarrow e^+e^-e^+e^-$ have been measured. Also the strategy for the measurement of the transition form factor of $\phi \rightarrow \eta e^+e^-$ is described. The radiative process $\phi \rightarrow \eta' \gamma$ has been used to study the $\eta' \rightarrow \eta\pi\pi$ decay channels, obtaining a measurement of the pseudoscalar mixing angle, and finding an evidence for a gluonium content of $\eta'$. The decays $\phi \rightarrow PP\gamma$, where $P$ means a pseudoscalar meson, have been exploited to investigate the light scalar mesons, $f_0(980)$, $a_0(980)$, and $\sigma(600)$. The couplings of the scalar mesons to $K\bar{K}$, $\pi\pi$ or $\eta\pi^0$, and to the $\phi$ resonance have been measured. The prospects for the new KLOE-2 data-taking just started at the upgraded DAΦNE with an upgraded detector are described.

1. Introduction
The KLOE Collaboration took data from 2001 to 2006 at the Frascati $\phi$-factory DAΦNE, collecting about 2.5 fb$^{-1}$ at the peak of the $\phi(1020)$ resonance, and 250 pb$^{-1}$ off-peak, mainly at $\sqrt{s} = 1$ GeV. KLOE has covered several aspects of the light meson physics by exploiting all the main decay channels of the $\phi$ resonance:

(i) kaon physics: test of CKM unitarity and lepton universality, rare decays, tests of CPT violation and of quantum coherence by exploiting the kaon interferometry;
(ii) $\eta$, $\eta'$ decays: tests of Chiral Perturbation Theory (ChPT) and of Vector Meson Dominance (VMD) models, measurement of the pseudoscalar mixing angle;
(iii) study of the low mass scalar mesons, $f_0(980)$, $a_0(980)$ and $\sigma(600)$.
(iv) precision measurement of the hadronic cross-section using the process $e^+e^- \rightarrow \pi^+\pi^-\gamma$ when the photon is emitted by an initial lepton (Initial State Radiation), relevant to settle the hadronic contribution to the anomalous magnetic moment of the muon;
(v) hadron production in $\gamma\gamma$ collisions;

The results obtained in items (ii) and (iii) are reported in this paper, while items (iv,v) are covered by other talks in this Workshop[1][2].
In 2008 the Accelerator Division of the LNF tested a new interaction scheme for DAΦNE, aiming to reach an increase of a factor of three in luminosity with respect to the KLOE data taking.

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Following the success of this test, a new data-taking campaign of the KLOE experiment (KLOE-2 in the following) with an upgraded detector has been proposed[3], with the goal to collect 20 fb$^{-1}$ of data in the next three years. The detector upgrade is organized as a two step process:

(i) two tagger devices for scattered leptons in $\gamma\gamma$ processes have already been installed in view of the restarting of the data-taking in December 2011;

(ii) a major upgrade consisting in the insertion of an Inner Tracker (IT) and two small angle calorimeters is planned for Summer 2012.

2. The KLOE detector and the KLOE-2 upgrades

The KLOE detector is shown in fig.1. It consists of a large cylindrical drift chamber (DCH) surrounded by an electromagnetic calorimeter (EMC), both immersed in an axial magnetic field of 0.52 T produced by a superconducting solenoid.

The DCH[4], of internal radius 25 cm and external one of 2 m, has about 52000 wires, 12500 of which are sense wires, with all stereo geometry, and it is filled with a 90% He - 10% isobutane gas mixture. The momentum resolution is $\sigma_p/p \simeq 0.4\%$, and the space resolution is 150 $\mu$m in the transverse plane ($x,y$) and 2 mm along the DCH axis ($z$).

The EMC[5] has been designed to detect photons in the range 20 - 500 GeV with high efficiency, and with good energy and time resolutions. A fast response of the calorimeter is also an essential requirement since it is used as the main trigger of the experiment. The chosen solution has been a sampling calorimeter made of scintillating fibers, of 1 mm diameter, embedded in groved lead foils 0.5 mm thick, forming a composite with fiber:lead:glue ratio of 48:42:10. The total thickness of 23 cm corresponds to about 15 $X_0$. The energy and time resolutions are $\sigma_E/E = 5.7\%/\sqrt{E(\text{GeV})}$ and $\sigma_t = 55 \text{ ps}/\sqrt{E(\text{GeV})} \oplus 140 \text{ ps}$, respectively.

2.1. Present upgrade

For the forthcoming data-taking a tagger system to detect the scattered leptons from the $\gamma\gamma$ processes $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^*$ has been installed. It consists of two different devices:

(i) a Low Energy Tagger (LET), made of two small calorimeters of LYSO crystals, readout by SiPM, to detect leptons with energy between 130 and 300 MeV; they are placed near the

Figure 1. Vertical cross-section of the KLOE detector.
Interaction Point (IP), inside the main KLOE detector and the required energy resolution is $\sigma_{E}/E < 10\%$ for $E > 150$ MeV;

(ii) a High Energy Tagger (HET) to detect leptons with $E > 400$ MeV, consisting in two scintillator hodoscopes readout by PMT’s, placed after the first bending dipoles of DAΦNE, about 11 m far from the IP; given the energy-position correlation the 5 mm pitch corresponds to an energy resolution of 2.5 MeV.

2.2. Future upgrade
A major upgrade is planned for Summer 2012:

(i) an Inner Tracker (IT) made of four layers of cylindrical triple GEM will be installed between the beam-pipe and the DCH, to improve the acceptance for low momentum tracks;

(ii) two Crystal Calorimeters (CCALT) will cover the low polar angle regions to increase the acceptance for photons and $e^{\pm}$ down to $10^{\circ}$;

(iii) the focusing quadrupoles will be instrumented with sampling calorimeters (QCALT), made of tungsten and scintillator tiles.

3. $\eta, \eta'$ decays
The dominant decay channels of the $\phi$ meson are $K\bar{K}$ pairs, however other interesting final states are produced with high rates. The radiative decays $\phi \rightarrow$ meson + $\gamma$ produce large samples of pseudoscalar and scalar mesons. Since $Br(\phi \rightarrow \eta\gamma) = 1.3\%$ we collected about 100 millions of $\eta$ mesons, that can be easily identified by their recoil against the photon of $E = 363$ MeV. In the KLOE data sample we have also about half a million $\eta'$ mesons ($Br(\phi \rightarrow \eta'\gamma) = 6.25 \times 10^{-5}$), identified through their decays into $\eta\pi^{+}\pi^{-}$ and $\eta\pi^{0}\pi^{0}$ and the subsequent $\eta$ decays.

3.1. $\eta \rightarrow 3\pi$
The $\eta \rightarrow 3\pi$ decay violates isospin symmetry, and it is mainly induced by a QCD Lagrangian term proportional to the $d$ and $u$ quark mass difference. Once the amplitude for this decay is known, the measurement of the decay rate is suitable for a precise determination of the ratio of the light quark masses

$$Q^2 = \frac{m_{s}^2 - \hat{m}^2}{m_{d}^2 - m_{u}^2}$$

where $\hat{m} = \frac{1}{2}(m_{d} + m_{u})$. At leading order in ChPT, $\Gamma_{LO}(\eta \rightarrow \pi^{+}\pi^{-}\pi^{0}) = 66$ eV[6], to be compared with the experimental value $\Gamma_{exp} = (295 \pm 16)$ eV; a one loop calculation gives $\Gamma_{NLO}(\eta \rightarrow \pi^{+}\pi^{-}\pi^{0}) = (176 \pm 50)$ eV[7]. Higher order corrections improve the calculation[8], but there is yet no agreement with the experimental value.

We measured the Dalitz plot of both the charged, $\eta \rightarrow \pi^{+}\pi^{-}\pi^{0}$, and the neutral decay, $\eta \rightarrow 3\pi^{0}$. $\eta \rightarrow \pi^{+}\pi^{-}\pi^{0}$. In a sample of 450 pb$^{-1}$ of data we selected about 1.3 millions of $\eta \rightarrow \pi^{+}\pi^{-}\pi^{0}$ events. The Dalitz plot(fig.2) is described in terms of the variables $X$ and $Y$ that are linear combinations of the pion energies:

$$X = \sqrt{3} \frac{E_{+} - E_{-}}{\Delta}$$

$$Y = 3 \frac{E_{0} - m_{0}}{\Delta} - 1$$

where $\Delta = m_{\eta} - 2m_{\pm} - m_{0}$. 

3
The Dalitz plot density is usually parametrized as a power expansion around the center \((X = Y = 0)\):

\[ |A(X,Y)|^2 = 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + \ldots \]  \hfill (2)

The parameters of the expansion are obtained from a fit to eq.(2) and are listed in tab.1.

**Table 1. Results of the Dalitz plot fit.**

| Parameter | Value |
|-----------|-------|
| \(a\)     | \(-1.090 \pm 0.005^{+0.008}_{-0.019}\) |
| \(b\)     | \(0.124 \pm 0.006 \pm 0.010\) |
| \(c\)     | \(0.002 \pm 0.003 \pm 0.001\) |
| \(d\)     | \(0.057 \pm 0.006^{+0.007}_{-0.005}\) |
| \(e\)     | \(-0.006 \pm 0.007^{+0.007}_{-0.003}\) |
| \(f\)     | \(0.14 \pm 0.01 \pm 0.02\) |

\(P(\chi^2)\) 73%

From the fit results the following points can be emphasized:

- the \(c\) and \(e\) parameters, that multiply the odd powers of \(X\), are compatible with zero as expected since their presence would be a signal of charge conjugation violation;
- the quadratic slope in \(Y\), \(b\), does not agree with the Current Algebra prediction \((b = a^2/4)\);
- a large cubic term in \(Y\) is needed to fit the Dalitz plot; if the fit is repeated by forcing \(f = 0\), the fit quality becomes very poor \((\chi^2\) probability of the order of \(10^{-6}\)).

The integrated asymmetries (see fig.3 for definitions) of the Dalitz plot are sensitive to charge conjugation violation. In particular the left-right asymmetry is a test the overall \(C\) conservation, like the \(c\) and \(e\) parameters of the fit, the quadrant asymmetry is sensitive to \(C\) violation in \(\Delta I = 2\) amplitudes, while the sextant asymmetry tests \(C\) violation with \(\Delta I = 1\).

All the measured values of the three asymmetries, reported in tab.2, turn out to be compatible with zero, and are the most stringent tests at present.
Table 2. Integrated asymmetries of the $\eta \to \pi^+\pi^-\pi^0$ Dalitz plot.

|        | ($\text{units } 10^{-4}$) |
|--------|---------------------------|
| $A_{RL}$ | $9 \pm 10^{+9}_{-14}$   |
| $A_Q$    | $-5 \pm 10^{+5}_{-3}$    |
| $A_S$    | $8 \pm 10^{+8}_{-13}$    |

$\eta \to 3\pi^0$ The Dalitz plot of the neutral decay is symmetric, and its density can be parametrized as:

$$|A|^2 \propto 1 + 2\alpha Z + ...$$

where $Z$ is the distance from the Dalitz plot center normalized to its maximum.

$$Z = \frac{2}{3} \sum_{i=1}^{3} \left( \frac{3E_i - m_\eta}{m_\eta - 3m_\pi} \right)^2$$

In the same data-set analyzed for the charged channel we selected a clean sample of about $6.5 \times 10^5$ fully neutral events. The fit result is shown in fig.4, and from this fit we get the slope:

$$\alpha = -0.0301 \pm 0.0035^{+0.0022}_{-0.0036}$$

Figure 4. Fit of the $Z$ distribution for $\eta \to 3\pi^0$, the arrow indicates the fit range ($0 \div 0.7$).

Figure 5. Slope of the $\eta \to 3\pi^0$ Dalitz plot: comparison of the experimental results and some theoretical predictions.

In fig.5 the KLOE results is compared to the other measurements and to some theoretical prediction. All the calculations based on ChPT predict positive values for the slope $\alpha$. A better agreement is found by the authors of ref.[9] in the framework of the U(3)ChPT in combination with a coupled-channels method, including final state interactions through the Bethe-Salpeter equation. Also the calculation performed within the framework of the modified Non-Relativistic Effective Field Theory (NREFT)[10] gives a value $\alpha = -0.025 \pm 0.005$ in good agreement with the world average, however in this calculation there are large discrepancies for what concerns the parameters of $\eta \to \pi^+\pi^-\pi^0$. Recently, dispersive approaches to the calculation of the $\eta \to 3\pi$ amplitudes have been proposed[11][12] that, using the experimental information of the charged
decay, are able to reproduce the negative slope of the neutral one. In both cases the authors
derive the $Q$ ratio, $21.31 \pm 0.59$ and $23.1 \pm 0.7$, respectively, different from the value expected
in the Dashen limit, $Q_{Dashen} = 24.2$

A new analysis of the charged channel on the full KLOE data-set is in progress with the aim
to reduce the systematic uncertainties, by using a different analysis scheme and an improved
MC simulation.

Also the decay $\eta' \rightarrow \pi^+\pi^−\pi^0$ can be related to the $d$ and $u$ quark mass difference; at present
only the measurement by CLEO exists[13], based on 24 events detected; at KLOE-2 with 5 fb$^{-1}$
of integrated luminosity we expect to collect about 8000 of such events.

3.2. $\eta, \eta' \rightarrow \pi^+\pi^−\gamma$

The decays $\eta, \eta' \rightarrow \pi^+\pi^−\gamma$ in principle proceed through two different contributions: a resonant
one dominated by the exchange of the $\rho$ meson and a non-resonant one described by a contact
term, the box anomaly which is a higher term of the Wess-Zumino-Witten Lagrangian. Both
the total decay rate and the shape of the invariant mass distribution of the two pions in the
final state are sensitive to the presence of such a contact term.

Previous measurements of $\eta \rightarrow \pi^+\pi^−\gamma$ date back to the 70's[14][15] and the analysis of these
two data-sets show some contradictions[16]. Moreover there is a 2 - 3 standard deviations dis-
crepancy between these old results and the more recent one by the CLEO Collaboration[17], as
shown in tab.3.

| Author          | Year | Events | Value       |
|-----------------|------|--------|-------------|
| CLEO Coll.[17]  | 2007 | 859    | 0.175 ± 0.007 ± 0.006 |
| Thaler et al. [15] | 1973 | 18000 | 0.209 ± 0.004 |
| Gormley et al.[14] | 1970 | 7250  | 0.201 ± 0.006 |
| PDG average     |      |        | 0.203 ± 0.008 |

Using a sample of about 560 pb$^{-1}$ of data, we measured the branching fraction of $\eta \rightarrow \pi^+\pi^−\gamma$
normalized to $\eta \rightarrow \pi^+\pi^−\pi^0$[18]. We extracted $2 \times 10^5$ signal events from the fit of the distribution
of $E - p$ (fig.6), where $E$ and $p$ are the energy and momentum of the photon from the $\eta$ decay,
reconstructed from all the other particles in the event ($p^\mu = p^\mu_\phi - p^\mu_\pi^+ - p^\mu_\pi^- - p^\mu_\gamma$). The main
background comes from $\phi \rightarrow \pi^+\pi^-\pi^0$.

Concerning the normalization sample(fig.7), we selected about $1.2 \times 10^6$ events, corresponding
to a $Br(\eta \rightarrow \pi^+\pi^-\pi^0) = (22.41 \pm 0.03 \pm 0.35)\%$, in very good agreement with the PDG value,
(22.74 ± 0.28)%[19].

The resulting ratio of branching ratios is in agreement with the recent CLEO measurement,
favouring a sizeable contribution of the contact term[16]:

$$\frac{\Gamma(\eta \rightarrow \pi^+\pi^-\gamma)}{\Gamma(\eta \rightarrow \pi^+\pi^-\pi^0)} = 0.1838 \pm 0.0005 \pm 0.0030$$
Figure 6. $E - p$ distribution; being $E$ and $p$ the energy and momentum of the photon from the $\eta$ decay, the signal is peaked at zero.

Figure 7. Recoiling mass against $\pi^+\pi^-\gamma$: the normalization sample ($\eta \rightarrow \pi^+\pi^-\pi^0$) is peaked at the $\pi^0$ mass.

Figure 8. Dipion invariant mass distribution after background subtraction, the red histogram is the fit result.

In fig.8 is shown the $\pi^+\pi^-$ invariant mass distribution after background subtraction, and with superimposed a fit according to the parametrization of ref.[20].

Also the $\eta'$ meson data show some contradictions: in 1997 the Crystal Barrel Collaboration claimed the evidence of the box anomaly in the two pion invariant mass distribution[21], while in 1998 the data by L3 were well described in terms of resonant contribution only[22]. Then it is important to measure with high statistics this decay in order to shed light on the contribution of the box anomaly. At KLOE-2, with 5 fb$^{-1}$, about $10^3$ $\eta' \rightarrow \pi^+\pi^-\gamma$ events are expected, including an overall analysis efficiency of 20%, evaluated on a subsample of KLOE data.
3.3. $\eta \rightarrow \pi^+\pi^-e^+e^-$

The predictions for the $Br(\eta \rightarrow \pi^+\pi^-e^+e^-)$ based on ChPT and on VMD are in the range $26 \div 36 \times 10^{-5}$. Before KLOE only two low statistics measurements were available, based on 4 events by CMD-2[23] and on 16 events by WASA@CELSIUS[24]. This process can be used as a probe of physics beyond the SM since an asymmetry in the angle $\phi$ between the decay planes of the two pions and of the two leptons(see fig.9), would be signal of CP violation. Such an asymmetry is originated by the interference of the electric transition amplitude, CP violating, with the CP conserving magnetic one, as observed for the $K_L \rightarrow \pi^+\pi^-e^+e^-$ decay[25][26].

Figure 9. $\phi$ is the angle between the decay planes of the two pions and of the two leptons.

\[
A_{CP} = \frac{N(\sin \phi \cos \phi > 0) - N(\sin \phi \cos \phi < 0)}{N(\sin \phi \cos \phi > 0) + N(\sin \phi \cos \phi < 0)}
\]

This asymmetry is constrained in the SM by the $\eta \rightarrow \pi^+\pi^-$ decay: from the experimental limit on the branching fraction by KLOE[27], one can expect $A_{CP} < 10^{-4}$, while according to theory $A_{CP} < 10^{-15}$. However a non-CKM mechanism has been proposed[28] that could raise the asymmetry up to 2% level.

We analyzed 1.7 fb$^{-1}$ of data, and we used the four track invariant mass distribution to extract the signal(fig.10).

From a fit with signal and background shapes evaluated by MC we found $1555 \pm 52$ signal events with 368 background ones. This corresponds to

\[
Br(\eta \rightarrow \pi^+\pi^-e^+e^-(\gamma)) = (26.8 \pm 0.9 \pm 0.7) \times 10^{-5}
\]

inclusive of radiative effects. From the distribution of $\sin \phi \cos \phi$ (fig.11) we could produce the first measurement of the asymmetry, consistent with zero at 3% level:

\[
A_{CP} = (-0.6 \pm 2.5 \pm 1.8) \times 10^{-2}
\]

The insertion of the IT in the second phase of KLOE-2, will allow to increase the efficiency and to reduce the background. With a sample of 20 fb$^{-1}$ we could reduce the total uncertainty in the branching fraction to 1.4%, and we could also improve the sensitivity to the asymmetry by a factor of at least two.

Figure 10. Invariant mass of the four charged tracks for $\eta \rightarrow \pi^+\pi^-e^+e^-$ candidate events.

\[
A_{CP} = \frac{N(\sin \phi \cos \phi > 0) - N(\sin \phi \cos \phi < 0)}{N(\sin \phi \cos \phi > 0) + N(\sin \phi \cos \phi < 0)}
\]
3.4. $\eta \to e^+e^-e^+e^-$

The double Dalitz decays in principle can be used to study the internal structure of the $\eta$ meson, by measuring the 4-momenta of the virtual photons via the invariant mass of the lepton pairs. The theoretical predictions for the branching fraction lay in the range $2.4 \div 2.6 \times 10^{-5}$ and only two experimental upper limits at 90% C.L. existed before the KLOE analysis, $Br(\eta \to e^+e^-e^+e^-) < 6.9 \times 10^{-5}$ (CMD-2)\cite{23} and $Br(\eta \to e^+e^-e^+e^-) < 9.7 \times 10^{-5}$ (WASA)\cite{24}.

In the same data sample analyzed for $\eta \to \pi^+\pi^-e^+e^-$, we observed for the first time this decay as shown in fig.12, obtaining $362 \pm 29 \ eta \to e^+e^-e^+e^-$ events, that correspond to

$$Br(\eta \to e^+e^-e^+e^-) = (2.4 \pm 0.2 \pm 0.1) \times 10^{-5}$$

fully inclusive of final state radiation.

3.5. $\eta \to \pi^0\gamma\gamma$

The decay $\eta \to \pi^0\gamma\gamma$ is a unique test of ChPT, since the lowest order amplitude, $O(p^2)$, is vanishing for neutral particles as well as the tree level amplitude at $O(p^4)$; the loop contributions at $O(p^4)$ are suppressed by G-parity and by the large kaon mass, thus the dominant terms are $O(p^6)$.

From the experimental point of view, several measurements have been published since '70s, with branching fraction decreasing with time by some order of magnitude. The most recent measurements are from GAMS-2000\cite{29}, $Br(\eta \to \pi^0\gamma\gamma) = (7.2 \pm 1.4) \times 10^{-4}$, Crystal Ball@AGS, $Br(\eta \to \pi^0\gamma\gamma) = (2.21 \pm 0.24 \pm 0.47) \times 10^{-4}$\cite{30}, and Crystal Ball@MAMI, $Br(\eta \to \pi^0\gamma\gamma) = (2.25 \pm 0.46 \pm 0.17) \times 10^{-4}$\cite{31}.

We analyzed the fully neutral decay with five prompt photons in the final state, $\phi \to \eta\gamma$ with $\eta \to \pi^0\gamma\gamma$. There is a large irreducible background coming from the other, more abundant, five prompt photons processes (see Sect.4), and from $\phi \to \eta\gamma$ with $\eta \to 3\pi^0$, with lost photons or merged clusters in the EMC. The four photon invariant mass distribution is reported in fig.13; after the subtraction of the residual background our preliminary result is\cite{32}

$$Br(\eta \to \pi^0\gamma\gamma) = (8.4 \pm 2.7 \pm 1.4) \times 10^{-5}$$
about two standard deviations lower than the Crystal Ball measurements and the ChPT predictions. From the first period of KLOE-2 data taking, with about 10 fb$^{-1}$ of data, we should be able to measure the branching fraction at 3% level, and to provide the $\gamma\gamma$ invariant mass spectrum with sufficient accuracy to solve the ambiguity connected to the sign of the interference term between the scalar amplitude, dominated by the exchange of the $a_0(980)$, and the VMD one(fig.13).

3.6. Transition form factor of $\phi \rightarrow \eta e^+e^-$

The Dalitz decays, like $A \rightarrow B\ell^+\ell^-$, can be used to study the internal electromagnetic structure of the decaying meson. For non point-like mesons the vertex $A \rightarrow B$ is described in terms of a transition form factor (FF), which is a function of the four momentum squared $q^2$ of the virtual photon (invariant mass of the $\ell^+\ell^-$ pair). Usually a pole parametrization is used for the FFs:

$$F(q^2) = \frac{1}{1 - \frac{q^2}{\Lambda^2}}$$

The $\Lambda$ parameter is a characteristic mass, that according to VMD can be roughly identified with the mass of the nearest vector meson. The dilepton invariant mass distributions of $\eta \rightarrow e^+e^-\gamma$ and $\eta \rightarrow \mu^+\mu^-\gamma$, recently measured by NA60 [33] and Crystall Ball@MAMI[34] are described by $\Lambda_\eta^{-2} = 1.92 \pm 1.95$ GeV$^{-2}$ in agreement with the VMD predictions $\Lambda_\eta^{-2} = 1.88$ GeV$^{-2}$. On the other hand there is a discrepancy between the dilepton spectrum of $\omega \rightarrow \pi^0\mu^+\mu^-$, with $\Lambda_\omega^{-2} = 2.24$ GeV$^{-2}$ also measured by NA60, and the VMD expectations 1.68 GeV$^{-2}$.

Concerning $\phi \rightarrow \eta e^+e^-$, there is only one low statistics measurement of the FF, by SND, $\Lambda_\phi^{-2} = (3.8 \pm 1.8)$ GeV$^{-2}$[?], to be compared with the VMD expectation, $\Lambda_\phi^{-2} \simeq m_\phi^{-2} \simeq 1$ GeV$^{-2}$.

We analyzed 1.5 fb$^{-1}$ of data looking for $\phi \rightarrow \eta e^+e^-$ with $\eta \rightarrow \pi^+\pi^-\pi^0$. In fig.15 is shown the recoiling mass against $e^+e^-$; by applying a tight cut around the $\eta$ peak, we selected abut 14000 candidate events, whose $e^+e^-$ invariant mass spectrum is shown in fig.16.

A preliminary evaluation of the branching fraction has been performed

$$Br(\phi \rightarrow \eta e^+e^-) = (1.070 \pm 0.012) \times 10^{-4}$$
in good agreement with the PDG average \((1.15 \pm 0.10) \times 10^{-4}\)[19]. The quoted uncertainty is only statistics, the evaluation of the systematics is in progress. The extraction of the FF parameter is still in progress, however the collected statistics will allow to reach an accuracy of about 3% on \(\Lambda_\phi\).

This process is also suitable for the search of a possible low mass gauge boson, mediator of dark forces, as discussed by F. Bossi in this Workshop[35][36].

### 3.7. Precise \(\eta\) mass measurement

KLOE has performed the most precise determination to date of the \(\eta\) mass. Before that measurement there was an eight standard deviation discrepancy between the value measured in \(p + d \rightarrow ^3He + \eta\) at threshold by GEM@COSY[37], and the values obtained by looking at \(\eta\) decays by NA48[38] and CLEO[39].

We used the \(\phi \rightarrow \eta \gamma\) decay, with \(\eta \rightarrow \gamma \gamma\), by looking for three prompt photon events. In the Dalitz plot of fig.17 three bands are clearly visible: a low mass band given by the \(\phi \rightarrow \pi^0 \gamma\) decay, process used to check of the whole procedure, and the other two bands from \(\phi \rightarrow \eta \gamma\). In order to select pure \(\eta\) and \(\pi^0 \rightarrow \gamma \gamma\) samples we apply a cut by retaining the events below the black line of fig.17. The projection (fig.18) is fitted to extract the mass value. We found:

\[
m_\eta = (574.874 \pm 0.007 \pm 0.031)\text{MeV}
\]

\[
m_{\pi^0} = (134.906 \pm 0.012 \pm 0.048)\text{MeV}
\]

The \(\pi^0\) mass is in agreement within 1.4 standard deviations with the world average[19]. The \(\eta\) mass agrees with the measurements by NA48 and CLEO, and is the most accurate one up to now.
Figure 17. Dalitz plot of the selected 3γ events \((E_{\gamma_1} < E_{\gamma_2} < E_{\gamma_3})\).

Figure 18. Invariant mass of the \(\gamma_1 - \gamma_2\) pair after the cut indicated in fig.17.

Recently a preliminary result has been presented by the ANKE Collaboration at COSY, based on the kinematics of the reaction \(p + d \rightarrow ^3He + \eta\), in agreement with our value, \(m_\eta = (574.869 \pm 0.007 \pm 0.040)\) MeV[40].

3.8. \(\eta - \eta'\) mixing

The \(\eta - \eta'\) system can be parametrized in terms of only one mixing angle in the quark-flavour basis.

\[
|\eta > = \cos \varphi_P |q\bar{q} > - \sin \varphi_P |s\bar{s} > \\
|\eta' > = \sin \varphi_P |q\bar{q} > + \cos \varphi_P |s\bar{s} >
\]

where \(|q\bar{q} > = \frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d} >\). The ratio of branching fractions \(R = Br(\phi \rightarrow \eta'\gamma)/Br(\phi \rightarrow \eta\gamma)\), can be related to the pseudoscalar mixing angle \(\varphi_P[41]\):

\[
R = \cot^2 \varphi_P \left( 1 - \frac{m_S}{m} \frac{C_{NS}}{C_S} \frac{\tan \varphi_V}{\sin 2\varphi_P} \right)^2 \left( \frac{p_{\eta'}}{p_{\eta}} \right)^3
\]

where \(\varphi_V = 3.2^\circ\) is the vector mixing angle, \(p_{\eta(\eta')}\) is the \(\eta(\eta')\) momentum in the \(\phi\) center of mass, and \(C_{NS} = 0.91 \pm 0.05\) and \(C_S = 0.89 \pm 0.07\) represent the effect of the OZI-rule which reduces the vector and pseudoscalar wave-function overlap, and finally \(m_S/m = 1.24 \pm 0.07[41]\). We selected \(\phi \rightarrow \eta'\gamma\) with either \(\eta' \rightarrow \eta\pi^+\pi^-\), \(\eta \rightarrow 3\pi^0\), and \(\eta' \rightarrow \eta\pi^0\pi^0\), \(\eta \rightarrow \pi^+\pi^-\pi^0\), both corresponding to the \(\pi^+\pi^-\pi^0\) prompt photon final state. We used the \(\phi \rightarrow \eta\gamma\) decay where \(\eta \rightarrow \pi^+\pi^-\pi^0\), which is background free, as the normalization process. In a sample of 427 pb\(^{-1}\) we selected 3407 \(\eta'\gamma\)(fig.19) and about \(1.7 \times 10^7\ \eta\gamma\) events, and we obtained

\[
R = (4.77 \pm 0.09 \pm 0.19) \times 10^{-3}
\]

from which we derive

\[
Br(\phi \rightarrow \eta'\gamma) = (6.20 \pm 0.11 \pm 0.25) \times 10^{-5}
\]

where the systematic uncertainty is dominated by the knowledge of the \(\eta' \rightarrow \eta\pi\pi\) branching fractions.
Figure 19. Invariant mass of 6 out of 7 photons, after the combinatorial background subtraction.

Figure 20. $\varphi_P$, $Z_{\eta'}^2$ plane; the black ellipse is the 68% C.L. region of the fit.

From eq.5, we extracted the mixing angle

$$\varphi_P = (41.4 \pm 0.3 \pm 0.9)^\circ$$

that in the singlet-octet basis becomes: $\vartheta_P = (-13.3 \pm 0.3 \pm 0.9)^\circ$.

The $\eta'$ meson, being an almost pure $SU(3)_F$ singlet, is considered a good candidate to host a gluon condensate. Allowing for a $\eta'$ gluonium content ($|G|$), eq.(4) should be modified[42]

$$|\eta' > = X_{\eta'}|q\bar{q} > + Y_{\eta'}|s\bar{s} > + Z_{\eta'}|G >$$

where a non-zero value of $Z_{\eta'}^2$ is a signal of gluonium content of $\eta'$,

$$X_{\eta'} = \sin \varphi_P \cos \varphi_G$$
$$Y_{\eta'} = \cos \varphi_P \cos \varphi_G$$
$$Z_{\eta'} = \sin \varphi_G$$

and eq.(5) becomes

$$R = \cot^2 \varphi_P \cos^2 \varphi_G \left(1 - \frac{m_S C_{NS}}{m} \frac{C_S \tan \varphi_V}{\sin 2\varphi_P} \right) \left(\frac{p_{\eta'}}{p_{\eta}}\right)^3$$

We performed a fit by combining our $R$ measurement with other experimental constraints[43]; the fit parameters are listed in tab.4, and the result is shown graphically in fig.20. We then estimate a gluonium content of $\eta'$, different from zero at three standard deviation level.

The fit result is driven by the measurement of $\Gamma(\eta' \rightarrow \gamma\gamma)/\Gamma(\pi^0 \rightarrow \gamma\gamma)$. Since the theoretical frameworks in which the $\eta' \rightarrow \gamma\gamma$ and the $P \rightarrow V\gamma$ decays are described are slightly different[44], it would be very important to obtain a sensitivity to gluonium fraction independent from
Table 4. Result of the fit to the gluonium content of $\eta'$.  

| Parameter | Value |
|-----------|-------|
| $Z_{\eta'}^2$ | 0.12 ± 0.04 |
| $\phi_P$ | (40.4 ± 0.6)$^\circ$ |
| $C_{NS}$ | 0.94 ± 0.03 |
| $C_S$ | 0.83 ± 0.05 |
| $\phi_V$ | (3.32 ± 0.10)$^\circ$ |
| $m_s/\bar{m}$ | 1.24 ± 0.07 |
| $\chi^2/\text{ndf}$ | 4.6/3 |
| $P(\chi^2)$ | 20% |

$\eta' \rightarrow \gamma \gamma$. It can be shown[43] that this could be achieved at KLOE-2 if we will be able to measure the main $\eta'$ branching fractions at 1% level, in that case the sensitivity to $Z_{\eta'}^2$ would increase to four $\sigma$ level. A further improvement in the gluonium determination could be obtained by measuring the also the $\eta'$ decay width at 1% through the measurement of $\sigma(e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^-\eta')$; however this would require to run DAΦNE at least at $\sqrt{s} \approx 1.2$ GeV.

4. Light scalar mesons

The problem of the classification of the scalar mesons of mass below 1 GeV is still open. It is controversial whether they are ordinary $q\bar{q}$ mesons[45], compact $qq\bar{q}\bar{q}$ states[46], or bound states of a $K$ and a $\bar{K}$[47].

In KLOE we studied the radiative decays $\phi(1020) \rightarrow PP\gamma$, where $P$ means a pseudoscalar meson, as they are dominated by the exchange of a scalar meson $S$ in the intermediate state ($\phi \rightarrow S\gamma$, and $S \rightarrow PP$), and then they are suitable processes to study the light scalars, since the branching ratios and also the $PP$ invariant mass shapes are expected to depend on their structure.

The $f_0(980)$ has been searched for in the dipion final states: $f_0(980) \rightarrow \pi^+\pi^-$ has been observed as a deviation from the expected Initial State Radiation plus Final State Radiation contributions in $e^+e^- \rightarrow \pi^+\pi^-\gamma$, while the Dalitz plot of the reaction $e^+e^- \rightarrow \pi^0\pi^0\gamma$ has been used to study the $f_0(980) \rightarrow \pi^0\pi^0$ decay, looking also for a possible signal of the $\sigma(600)$. The $a_0(980)$ has been studied by exploiting the decay chains $\phi \rightarrow \eta\pi^0\gamma$ with $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$.

In order to discriminate between models, data have been fit to different theoretical approaches. For each of them the $a_0(980)/f_0(980)$ masses and the couplings to $KK$, $\pi\pi$ or $\eta\pi^0$ and to the $\phi$ have been extracted. The decay $\phi \rightarrow (a_0/f_0) \rightarrow K^0\bar{K}^0\gamma$ has also been searched for.

4.1. $e^+e^- \rightarrow \pi^0\pi^0\gamma$

The analyzed data sample consists of 450 pb$^{-1}$. This sample has been analyzed by grouping all runs in center of mass energy bins of 100 keV; only those runs belonging to the bin with the highest statistics have been used for the fit of the Dalitz plot. This subsample corresponds to 145 pb$^{-1}$ collected at $\sqrt{s} = 1019.7 - 1019.8$ MeV.

The data analysis consists of four steps: (i) events with five prompt photons have been selected; (ii) a kinematic fit with the constraint of the total 4-momentum conservation has been performed; (iii) a pairing algorithm of photons to $\pi^0$'s is applied; (iv) a second kinematic fit has been performed with the further constraints of the $\pi^0$ masses, according to the chosen photon pairing. The residual background mainly comes from $\phi \rightarrow \eta\pi^0\gamma$, same final state of the signal, and from $\phi \rightarrow \eta\gamma$ with $\eta \rightarrow \pi^0\pi^0\pi^0$, that can mimic the signal when there are lost or merged photons. It
has been evaluated by MC and then subtracted. The Dalitz plot after the background subtraction is shown in fig.21: there are two entries per event, corresponding to the two possible $\pi^0\gamma$ combinations. The two bands in the region $M_{\pi\pi} < 700$ MeV are due to the non resonant process $e^+e^- \rightarrow \omega\pi^0$, with $\omega \rightarrow \pi^0\pi^0$, while the region of high $M_{\pi\pi}$ is dominated by the $f_0$.

The Dalitz plot has been fitted using the parametrization of the scalar amplitude according to the Kaon Loop (KL) model in which the $\phi$ is coupled to the scalar meson through a loop of charged kaons[48]; all the formulae can be found in ref.[49]. The fit function includes also the contribution of the charged kaons[48]; all the formulae can be found in ref.[49]. The fit function includes also the contribution of the $\sigma(600)$; the free parameters or the $f_0$ are its mass and the couplings $g_{f_0K^+K^-}$ and $g_{f_0\pi^+\pi^-} (= \sqrt{2}g_{f_0\pi^0\pi^0})$. The vector part ($e^+e^- \rightarrow \omega\pi^0$ and $\phi \rightarrow \rho^0\pi^0$, with $\rho^0 \rightarrow \pi^0\gamma$) plus the interference one are described by seven free parameters. The $\sigma(600)$ parameters have been fixed to the values of the best fit of ref.[48].

The relevant parameters of the fit are reported in tab.5. If we perform a fit by excluding the $\sigma(600)$ contribution, the fit quality becomes very poor.

### Table 5. Parameters of the $f_0(980)$.

| Parameter                  | $f_0 \rightarrow \pi^0\pi^0$ | $f_0 \rightarrow \pi^+\pi^-$ |
|----------------------------|---------------------------------|-------------------------------|
| $M_{f_0}$ (MeV)            | 984.7                           | 983.7                         |
| $g_{f_0K^+K^-}$ (GeV)      | 3.97                            | 4.74                          |
| $g_{f_0\pi^+\pi^-}$ (GeV) | -1.82                           | -2.22                         |
| $R_{f_0} = (g_{f_0K^+K^-}/g_{f_0\pi^+\pi^-})^2$ | 4.8    | 4.6                           |

We tried also an alternative parametrization of the amplitude in which a point-like coupling of the scalar to the $\phi$ meson is assumed, then this model is called “No Structure” (NS)[50]. The NS model does not include explicitly the $\sigma(600)$ contribution. In this case the coupling of the $\phi$ to the $f_0$ can be determined directly from the fit, and we obtain $g_{\phi f_0\gamma} = 2.61 \pm 0.31$ GeV$^{-1}$. From the integral of the scalar contribution only, the following branching ratio can be extracted[49]:

$$Br(\phi \rightarrow S\gamma \rightarrow \pi^0\pi^0\gamma) = (1.07^{+0.01}_{-0.03} (fit)) \times 10^{-4} \times 10^{-4}$$

(6)

where the third uncertainty is systematic and it is due to the model formulation.

4.2. $e^+e^- \rightarrow \pi^+\pi^-\gamma$

Only a small fraction of $\pi^+\pi^-\gamma$ events originates from $\phi \rightarrow f_0\gamma$ with $f_0 \rightarrow \pi^+\pi^-$. The main contribution is given by $e^+e^- \rightarrow \pi^+\pi^-\gamma$ in which the photon is produced by either an initial state (ISR) or a final state (FSR) radiation. A small amount of events is expected also from the decay $\phi \rightarrow \rho\pi\pi$ with $\rho \rightarrow \pi^+\pi^-\gamma$.

Events with one vertex close to the interaction region and two tracks of opposite charge, emitted at polar angles $\vartheta_{\pi\pi} > 45^\circ$, have been selected. The ISR component, that is dominant for small photon polar angles, is suppressed by requiring the polar angle of the missing momentum $\vartheta_{\pi\pi} > 45^\circ$. Furthermore the presence of a photon in the calorimeter matching the missing energy and momentum is required to reduce the residual $\pi^+\pi^-\pi^0$ background.

The $\pi^+\pi^-$ invariant mass distribution (fig.22) has been fitted to the differential cross-section ($m = M_{\pi^+\pi^-}$):
Figure 21. Dalitz plot of $e^+e^- \rightarrow \pi^0\pi^0\gamma$.

Figure 22. $M_{\pi^+\pi^-}$: upper plot - full spectrum; lower plot - only scalar.

The analytic expressions for the first two terms as well as for the $\rho\pi$ term are taken from ref.[51]. The scalar contribution is parametrized according to the KL model, and the last term $d\sigma_{scal} \otimes FSR/dm$ can be added (constructive interference between $f_0$ and FSR) or subtracted (destructive interference). The relevant parameters of the fit are listed in tab.5, and are in good agreement with the parameters from the fit of the Dalitz plot of the neutral channel. A destructive interference between $f_0$ and FSR is preferred by the fit. Due to the huge irreducible background, the charged channel is not sensitive to the presence of the $\sigma(600)$. By integrating the $f_0$ term of the fit function, the following range for the branching ratio can be derived[52]:

$$Br(\phi \rightarrow f_0\gamma \rightarrow \pi^+\pi^-\gamma) = 2.1 \times 10^{-4} - 2.4 \times 10^{-4}$$

As expected this branching ratio is about twice the value of eq.(6).

4.3. $e^+e^- \rightarrow \eta\pi^0\gamma$

To study the $a_0(980)$, the decay $\phi \rightarrow \eta\pi^0\gamma$ has been exploited, by looking for the two final states corresponding to $\eta \rightarrow \gamma\gamma$ ($Br = 39.31\%$) and $\eta \rightarrow \pi^+\pi^-\pi^0$ ($Br = 22.74\%$). The fully neutral final state is characterized by five photons originating from the DAΦNE interaction point, then the selection and the analysis scheme are very similar to those of $\pi^0\pi^0\gamma$. The main backgrounds come from the other five photon final states, $\phi \rightarrow f_0(980)\gamma \rightarrow \pi^0\pi^0\gamma$ and $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$, while the seven photon process, $\phi \rightarrow \eta\gamma$ with $\eta \rightarrow 3\pi^0$, can mimic five photon events due to either loss or merging of photons. Also the three photon final states, $\phi \rightarrow \eta(\pi^0)\gamma$ with $\eta(\pi^0) \rightarrow \gamma\gamma$, give a small contribution to the selected sample, due to either photon splittings or accidental coincidence with machine background. Other background processes are negligible. In the analyzed sample of 450 pb$^{-1}$, 29061 events have been selected. The expected irreducible background amounts to about 50% of the final sample, and has been evaluated by MC and checked on data with control samples largely dominated by background. After the background subtraction, the sample consists of 13269 ± 192 events. By normalizing to the number of $\phi$ mesons produced in the analyzed data set, the following branching ratio is obtained[53]:

$$Br(\phi \rightarrow \eta\pi^0\gamma) = (7.01 \pm 0.10 \pm 0.20) \times 10^{-5}$$ (7)
The decay chain with $\eta \to \pi^+\pi^-\pi^0$ is characterized by two opposite charge pions and five prompt photons. With respect to the fully neutral final state, it provides a lower statistics since the branching ratio of $\eta \to \pi^+\pi^-\pi^0$ is about half of the $\eta \to \gamma\gamma$ one. However in this case the background is in principle less relevant since no other final state with two tracks and five photons is expected to have a significant branching ratio from the $\phi$.

Thus the main sources of background are due to abundant final states with two tracks and either four or six photons. At the end of the analysis chain 4181 events are selected with a total background of 15%. By normalizing to the produced $\phi$'s[53]:

$$Br(\phi \to \eta \pi^0\gamma) = (7.12 \pm 0.13 \pm 0.22 \times 10^{-5})$$

in good agreement with eq.(7) within the uncertainties. By combining the two results and taking into account the common normalization error, $Br(\phi \to \eta \pi^0\gamma) = (7.06 \pm 0.22) \times 10^{-5}$ is obtained, where the uncertainty is both statistic and systematic.

A combined fit, with the same set of free parameters, has been performed on the two $\eta \pi^0$ invariant mass distributions, to both KL and NS models. The free parameters of the fit are: $M_{a_0}$, $g_{a_0K^+K^-}$, $g_{a_0\pi^0\gamma}$, the branching ratio of the vector contribution, and, as a relative normalization between the two different final states, the ratio $R_\eta = Br(\eta \to \gamma\gamma)/Br(\eta \to \pi^+\pi^-\pi^0)$. For what concerns the NS fit also the $g_{\phi a_0\gamma}$ coupling is left free. The fit results are shown in fig.23, and the parameters are listed in tab.6.

The good agreement of the ratio $R_\eta$ with the PDG value, $1.73 \pm 0.04$[19], indicates that the two samples are consistent with each other, and that the background subtraction has been correctly performed.

From the small vector background found one can conclude that the $\phi \to \eta \pi^0\gamma$ process is completely dominated by $\phi \to a_0(980)\gamma$.

4.4. $\phi \to K^0\bar{K}^0\gamma$

The $K^0\bar{K}^0$ pair is produced in a $J^{PC} = 0^{++}$ state, then the signature of this decay is provided by the presence of either two $K_S$ or two $K_L$ and a low energy photon ($E_\gamma < 23.8$ MeV). This decay is expected to be dominated by $\phi \to (f_0 + a_0)\gamma \to K^0\bar{K}^0\gamma$, and its branching ratio is
In order to summarize the results presented in this Section, the following statements can be made:

(i) the branching ratios of $\phi \to S\gamma$ are compatible, with much smaller uncertainties, with the previous measurements by the VEPP-2M experiments, SND and CMD-2 (fig.24);

(ii) the $f_0$ branching ratio and couplings are closer to the SU(3) predictions for the $qq\bar{q}q$ structure than for the $q\bar{q}$ one (see fig.24 and tab.7);

(iii) the $a_0$ branching ratio and couplings are in between the SU(3) predictions for $qq\bar{q}q$ and $q\bar{q}$ structures;

(iv) large $g_{\phi S\gamma}$ couplings have been found, pointing to a large strange quark contents of both $f_0$ and $a_0$, in fact both $g_{\phi f_0\gamma}, g_{\phi a_0\gamma} > g_{\phi s\gamma} = 0.75$ GeV$^{-1}$ ($\eta'$ has about 66% content of $s\bar{s}$);

(v) another indication of large strange quark content in the $a_0$ is that $Br(\phi \to a_0\gamma) \simeq Br(\phi \to \eta'\gamma)$;

(vi) concerning the $\sigma(600)$, there are indications of the need of such a broad, low mass scalar state to fit the Dalitz plot of $e^+e^- \to \pi^0\pi^0\gamma$.

Concerning the KLOE-2 data-taking, no big improvement is expected for the $e^+e^- \to \pi^0\pi^0\gamma$ and $e^+e^- \to \eta\pi^0\gamma$ processes, since the results of the fits are dominated by the model systematics. For $\phi \to K^0\bar{K}^0\gamma$ the insertion of the IT will increase the vertex resolution and then will improve the background rejection; with 20 fb$^{-1}$ the expected sensitivity to the branching

| Table 6. $a_0(980)$ parameters from the combined fit of $M_{\eta\pi\gamma}$. |
|-------------------------|--------------------------|--------------------------|
|                         | KL model                | NS model                |
| $M_{a_0}$ (MeV)         | 982.5±1.6±1.1           | 982.5 (fixed)           |
| $g_{a_0K^+K^-}$ (GeV)   | 2.15±0.06±0.06          | 2.01±0.07±0.28          |
| $g_{a_0\eta\pi}$ (GeV)  | 2.82±0.03±0.04          | 2.46±0.08±0.11          |
| $g_{\phi a_0\gamma}$ (GeV$^{-1}$) | -                      | 1.83±0.03±0.08          |
| $Br_{\gamma\gamma \times 10^6}$ | 0.92±0.40±0.15          | negligible              |
| $R_\eta = Br(\eta \to \gamma\gamma) / Br(\eta \to \pi^+\pi^-\pi^0)$ | 1.70±0.04±0.03          | 1.70±0.03±0.01          |
| $R_{a_0} = (g_{a_0K^+K^-} / g_{a_0\eta\pi})^2$ | 0.58±0.03±0.03          | 0.67±0.06±0.13          |
| $P(\chi^2)$             | 10.4%                   | 30.9%                   |
Table 7. Comparison of the couplings to the SU(3) predictions for $qq\bar{q}\bar{q}$ and $q\bar{q}$ structure of the scalars ($n$ means a non-strange quark).

|                  | Experimental values | $qq\bar{q}\bar{q}$ | $q\bar{q}$ |
|------------------|---------------------|---------------------|------------|
| $(g_{a_0}K^+K^-/g_{a_0}\pi^0)^2$ | 0.6 - 0.7           | 1.2 - 1.7           | ~0.4       |
| $(g_{f_0}K^+K^-/g_{f_0}\pi^0)^2$   | 4.6 - 4.8           | $>> 1$              | $>> 1$ ($f_0 = s\bar{s}$) 0.25 ($f_0 = n\bar{n}$) |
| $(g_{f_0}K^+K^-/g_{a_0}K^+K^-)^2$ | 4 - 5               | 1                   | 2 ($f_0 = s\bar{s}$) 1 ($f_0 = n\bar{n}$) |

Figure 24. $f_0$ (left and center plots), and $a_0$ (right) branching ratios, compared with the previous measurements and with the theoretical predictions.

fraction is about $0.5 \times 10^{-8}$, of the same order of magnitude of the theoretical predictions, thus the first observation of this decay will be possible.

Another piece of information about the light scalars, will be provided by the study of the decays $\eta' \rightarrow \eta \pi \pi$: a scalar contribution mediated by $\sigma(600)$, $a_0(980)$ and $f_0(980)$ is expected[54] in the decay amplitude; the golden channel for KLOE-2 is $\eta' \rightarrow \eta \pi^+ \pi^-$ with $\eta \rightarrow \gamma \gamma$, with 10 fb$^{-1}$ of integrated luminosity we expect about 70000 fully reconstructed events (including a 23% efficiency evaluated from the analysis of this channel for other studies).

Moreover the $\sigma(600)$ will be studied with the $\gamma \gamma$ process $e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0$[2].

5. Conclusions.
KLOE, with the 2.5 pb$^{-1}$ collected during the 2001-2006 data-taking, has given a relevant contribution to the study of the light pseudoscalar and scalar mesons. In 2008 has been shown that with a new interaction scheme DAΦNE could increase the luminosity by a factor of about three. A new data-taking campaign is now starting with the KLOE detector upgraded, at first with taggers for $\gamma \gamma$ physics, and then with an Inner Tracker and new small angle calorimeters. We plan to collect about 20 pb$^{-1}$ in the next three years, improving the precision on many of the performed measurements and studying new final states.

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