EPJ Web of Conferences **73**, 03001 (2014)
DOI: 10.1051/epjconf/20147303001

Hadron physics at KLOE and KLOE-2

Simona Giovannella[a] on behalf of the KLOE and KLOE-2 Collaborations

Laboratori Nazionali di Frascati dell'INFN, Frascati, Italy

Abstract. The KLOE experiment at the Frascati ϕ-factory collected large samples of light mesons, providing precise knowledge of their decay dynamics. The $\eta \to \pi^+\pi^-\gamma$ decay has been studied to search for a possible contribution from chiral anomaly, while a new preliminary high statistics Dalitz plot analysis of the $\eta \to \pi^+\pi^-\pi^0$ will increase the accuracy of the light quark mass ratio. Pseudoscalar production associated to internal conversion of the photon into a lepton pair allows the measurement of the form factor $F_P(q_1^2 = M_\phi^2, q_2^2 > 0)$ in the kinematical region of interest for the VMD model. Detailed study of such decays has been performed both for $\phi \to \eta e^+e^-$ and $\phi \to \pi^0 e^+e^-$ processes. Moreover, data collected at $\sqrt{s} = 1$ GeV have been used to study hadron production in $\gamma\gamma$ interactions, providing the most precise measurement of the $\Gamma(\eta \to \gamma\gamma)$ partial width.

1. Introduction

The KLOE experiment at the Frascati ϕ-factory, DAΦNE, has collected 2.5 fb^{-1} of e^+e^- collisions at the ϕ peak and 240 pb^{-1} at $\sqrt{s} = 1$ GeV. These data provide high statistics samples of light mesons, allowing detailed studies of their decay dynamics and transition form factors. A new data taking is planned in years 2014–2015, aiming to collect 5 fb^{-1} with the upgraded KLOE-2 detector. A detailed description of the extended experimental physics program can be found in Ref. [1].

2. Dynamics of the $\eta \to \pi^+\pi^-\gamma$ decay

The $\eta \to \pi^+\pi^-\gamma$ decay provides a good tool to investigate the box anomaly, which is a higher term of the ChPT Lagrangian describing the direct coupling of three pseudoscalar mesons with the photon, both through the measurement of the partial width and the study of the invariant mass of the di-pion system [2]. Recently, the CLEO experiment has measured the ratio $\Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0)$ [3], providing an evidence in favor of the box anomaly.

The analysis of $\eta \to \pi^+\pi^-\gamma$ has been performed at KLOE using 558 pb^{-1}, where about $25 \times 10^6 \eta$'s are produced together with a monochromatic recoil photon ($E_{\gamma_\phi} = 363$ MeV) through the radiative decay $\phi \to \eta\gamma$. After preselection cuts used to clean up the data sample, signal events are selected exploiting the $\phi \to \eta\gamma$ two body decay kinematics. We find $N(\eta \to \pi^+\pi^-\gamma) = 204950 \pm 450$, with a 10% background contamination from $\phi \to \pi^+\pi^-\pi^0$ events (Fig. 1). The process $\phi \to \eta\gamma, \eta \to \pi^+\pi^-\pi^0$,

[a]e-mail: simona.giovannella@lnf.infn.it

Table 1. Fit results for $\eta \to \pi^+\pi^-\pi^0$ Dalitz plot analysis.

	a	b	d	f
KLOE08	$-1.090 \pm 0.005^{+0.008}_{-0.019}$	$0.124 \pm 0.006 \pm 0.010$	$0.057 \pm 0.006^{+0.007}_{-0.016}$	$0.14 \pm 0.01 \pm 0.02$
KLOE prel.	-1.104 ± 0.003	0.144 ± 0.003	0.073 ± 0.003	0.155 ± 0.006

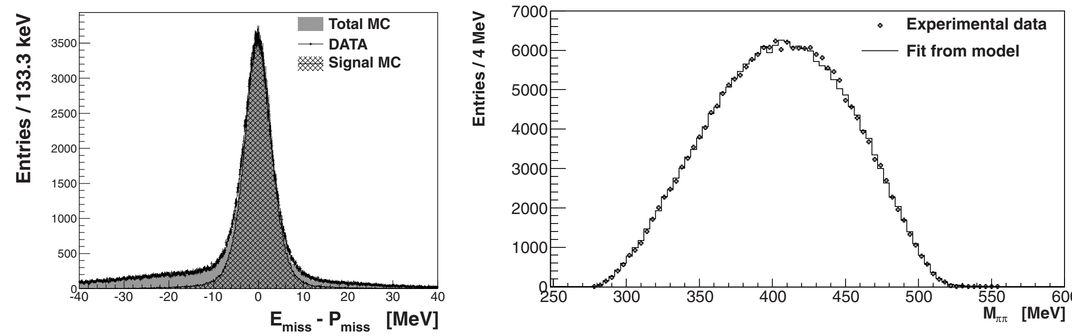

Figure 1. Left: data-MC comparison for $\eta \to \pi^+\pi^-\gamma$ events. Right: fit to the $\pi^+\pi^-$ invariant mass.

with similar event topology and negligible background contamination, has been used as normalization sample. The ratio of the partial decay widths is [4]:

$$\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.1856 \pm 0.0005_{\text{stat}} \pm 0.0028_{\text{syst}}, \tag{1}$$

consistent with CLEO result and with a factor three improved precision, pointing for a sizeable contribution of the direct term to the total width.

The $M_{\pi^+\pi^-}$ dependence of the $\eta \to \pi^+\pi^-\gamma$ decay width has been parameterized with the model independent approach of Ref. [5], providing $\alpha = (1.32 \pm 0.08_{\text{stat}}\ {}^{+0.10}_{-0.09}{}_{\text{syst}} \pm 0.02_{\text{theo}})\ \text{GeV}^{-2}$, in agreement with the WASA-at-COSY measurement [6] and with a factor five improved precision. Fit results are reported in Fig. 1 left.

3. Dynamics of the $\eta \to \pi^+\pi^-\pi^0$ decay

The $\eta \to \pi^+\pi^-\pi^0$ process is an isospin violating decay, sensitive to light quark mass difference [7]. Dalitz plot analysis, based on 450 pb^{-1}, has been performed at KLOE in 2008 [8] and has been used in dispersive analysis to extract the quark mass ratio [9, 10].

A new analysis is in progress with an independent and larger (1.7 fb^{-1}) data set, using a new analysis scheme and improved Monte Carlo (MC) simulation. Details can be found in Ref. [11]. The Dalitz plot density has been fitted with the polinomial expansion: $1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y$, where the X and Y variables are built by means of the kinetic energies of pions. Preliminary fit results are in agreement with previous KLOE measurement (Table 1). Evaluation of systematics is in progress.

4. Transition form factors from ϕ meson decays

The di-lepton invariant mass shape of the $\omega \to \pi^0\ell^+\ell^-$ Dalitz decay, measured by the NA60 collaboration [12], is not well described by the Vector Meson Dominance (VMD) model. New measurements

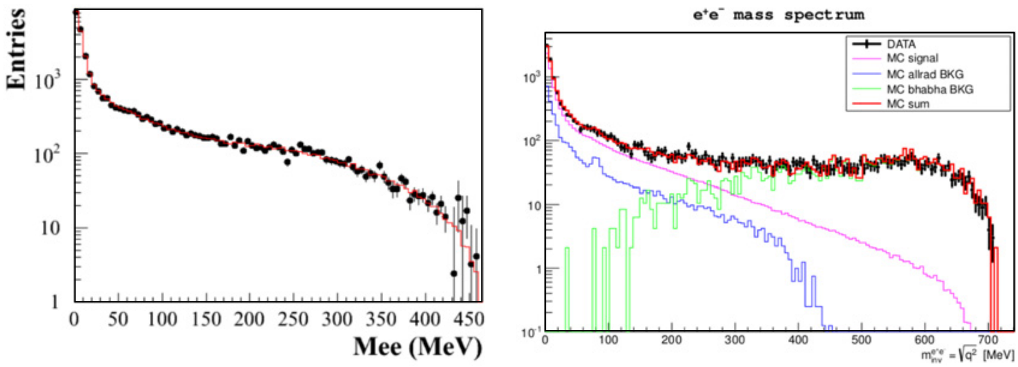

Figure 2. Left: fit to the M_{ee} spectrum for the Dalitz decay $\phi \to \eta e^+e^-$, with $\eta \to \pi^0\pi^0\pi^0$. Right: data-MC comparison of the M_{ee} distribution after all analysis cuts for $\phi \to \pi^0 e^+e^-$ events.

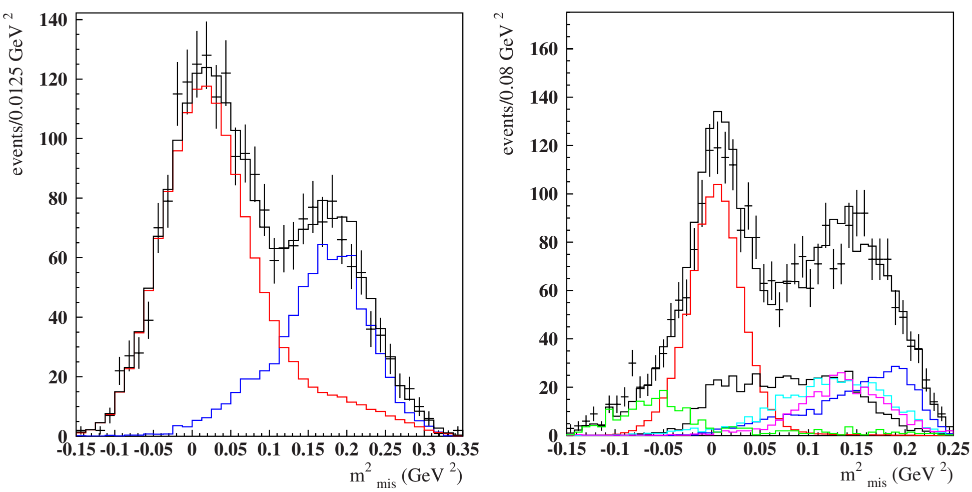

Figure 3. $\gamma\gamma \to \eta$: M^2_{miss} distribution for $\eta \to \pi^0\pi^0\pi^0$ (left) and $\eta \to \pi^+\pi^-\pi^0$ (right) events. Points with error bars are data, black solid histogram is fit result. The main components are signal (blue) and $\phi \to \eta\gamma$ (red).

of other $V \to P\gamma^*$ transitions are therefore needed to confirm this evidence. The only other existing experimental result come from the SND experiment, which has measured the M_{ee} invariant mass distribution of the $\phi \to \eta e^+e^-$ decay on the basis of 213 events [13]. The same process has been studied at KLOE with 1.7 fb^{-1}, using the $\eta \to \pi^0\pi^0\pi^0$ final state. After loose preselection cuts, residual background contamination, due to $\phi \to \eta\gamma$ events with photon conversion and multi-pion events from $\phi \to K\bar{K}/\pi^+\pi^-\pi^0$ are rejected tracking back to conversion surfaces the two e^+, e^- candidates and using time-of-flight to the calorimeter, respectively. About 30,000 $\phi \to \eta e^+e^-$, $\eta \to \pi^0\pi^0\pi^0$ candidates are present in the analyzed data set, with a residual background contamination below 3%. The resulting branching fraction of the process is: $\text{BR}(\phi \to \eta e^+e^-) = (1.131 \pm 0.032_{\text{stat+norm}}\,{}^{+0.011}_{-0.006}{}_{\text{syst}}) \times 10^{-4}$. The resulting electron-positron invariant mass shape, M_{ee}, has been fitted, taking into account bin-by-bin analysis efficiency and using the decay parametrization from Ref. [14]. Fit results are reported in Fig. 2 left. The preliminary value obtained for the slope of the transition form factor in the whole KLOE data set is: $b_{\phi\eta} = (1.17 \pm 0.11_{\text{stat}}\,{}^{+0.09}_{-0.08}{}_{\text{syst}})$ GeV^{-2}, in agreement with VMD predictions.

We have also studied the decay $\phi \to \pi^0 e^+ e^-$, where no data are available on transition form factor. Dedicated analysis cuts strongly reduce the main background component of Bhabha scattering events to $\sim$20%, which dominates for $M_{ee} > 300\,\mathrm{MeV}$ (Fig. 2 right). The other relevant background contribution is from ϕ radiative decays. A sample of $\sim$9000 candidates is obtained from the analysis of $1.7\,\mathrm{fb}^{-1}$. Studies are in progress to refine the evaluation of background contamination and of analysis efficiencies.

5. $\gamma\gamma$ interactions

The gamma-gamma couplings and partial widths of mesons provide information about their structure and can be measured in the $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- X$ processes, where X is a generic $J^{PC} = 0^{\pm+}$, $2^{\pm+}$ final state. In the low-energy region accessible at DAΦNE, several existing measurements are affected by large uncertainties. At KLOE, where there is no tagging of the outgoing e^+e^-, $\gamma\gamma$ interactions have been studied using off-peak data ($240\,\mathrm{pb}^{-1}$ collected at $\sqrt{s} = 1\,\mathrm{GeV}$), where backgrounds from ϕ decays are suppressed.

The η partial width, $\Gamma(\eta \to \gamma\gamma)$, is extracted from the measurement of the $e^+e^- \to e^+e^-\eta$ cross section, using both neutral and charged $\eta \to \pi\pi\pi$ decay channels [15]. The main background is due to resonant $\phi \to \eta\gamma$ events, with an undetected recoil photon. After reducing background components with specific kinematical cuts, signal events are extracted by fitting with the expected Monte Carlo components the two-dimentional plot M^2_{miss}–$p_{L/T}$, where M^2_{miss} is the squared missing mass and $p_{L/T}$ is the η longitudinal/transverse momentum in the $\pi^0\pi^0\pi^0/\pi^+\pi^-\pi^0$ decay. Combining the two measurements, the extracted value for the production cross section is: $\sigma(e^+e^- \to e^+e^-\eta) = (32.7 \pm 1.3_{\mathrm{stat}} \pm 0.7_{\mathrm{syst}})\,\mathrm{pb}$ This value is used to extract the most ptecise measurement of the $\eta \to \gamma\gamma$ partial width:

$$\Gamma(\eta \to \gamma\gamma) = (520 \pm 20_{\mathrm{stat}} \pm 13_{\mathrm{syst}})\ \mathrm{eV}. \tag{2}$$

The KLOE-2 upgrade, with four tagging stations to detect electrons and positrons from the reaction $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- X$, will give the opportunity to investigate $\gamma\gamma$ physics also at the ϕ resonance [1].

References

[1] G. Amelino-Camelia et al., Eur. Phys. J. C **68**, 619 (2010)
[2] M. Benayoun et al., Eur. Phys. J. C **31**, 525 (2003)
[3] A. Lopez et al., Phys. Rev. Lett. **99**, 122001 (2007)
[4] D. Babusci et al., Phys. Lett. B **718**, 910 (2013)
[5] F. Stollenwerk et al., Phys. Lett. B **707**, 184 (2012)
[6] P. Adlarson et al., Phys. Lett. B **707**, 243 (2012)
[7] H. Leutwyler, Mod. Ph. Lett. A **28**, 1360014 (2013)
[8] F. Ambrosinoet al., JHEP **05**, 006 (2008)
[9] G. Colangelo et al., PoS(EPS-HEP2011)304
[10] K. Kampf et al., Phys. Rev. D **84**, 114015 (2011)
[11] Li Caldeira Balkestahl, these proceedings
[12] S. Damjanovic et al., Phys. Lett. B **677**, 260 (2009)
[13] M.N. Achasov et al., Phys. Lett. B **504**, 275 (2001)
[14] L.G. Landsberg, Phys. Rep. **128**, 301 (1985)
[15] D. Babusci et al., JHEP **01**, 199 (2013)