$\eta \to \pi^0\gamma\gamma$, η/η' mixing angle and status of η mass measurement at KLOE.

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Here we present preliminary results from the KLOE experiment for the measurement of the Br($\eta \to \pi^0\gamma\gamma$), the ratio of the two branching fractions $Br(\phi \to \eta'\gamma)/Br(\phi \to \eta\gamma)$ with the $\pi^+\pi^-7\gamma$ final state and a preliminary measurement of the η mass using the decay $\phi \to \eta\gamma$, $\eta \to \gamma\gamma$.

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1 Introduction

The KLOE experiment is performed on the Frascati ϕ factory DAΦNE. It is an e^+e^- collider working at $\sqrt{s} \sim 1020$ MeV, corresponding to the ϕ mass. Among other physical goals KLOE performs measurements of η, η' decays and η mass with good accuracy and in the clean environment typical of the e^+e^- machines. The η is produced through the electromagnetic decay of the ϕ meson: $\phi \to \eta\gamma$.
The analysis described here have been performed using data collected during the years 2001 and 2002 (450 pb^{-1}), corresponding to ~ 19 millions of η mesons.
The KLOE detector is composed of two main detectors:

- a large cylindrical drift chamber with a stereo-wires configurations, used to detect the tracks left by charged particles, and used for charged vertex determination, momentum measurement and charge determination. It is embedded in a cylindrical superconducting solenoid that produces a magnetic field of ~ 5 KGauss. The Drift Chamber momentum resolution is $\sigma_{p_T}/p_T \sim 0.4\%$ [1].

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[2] F.Ambrosino, A.Antonelli, M.Antonelli, C.Bacci, P. Beltrame, G.Bencivenni, S.Bertolucci, C.Bini, C.Bloise, V.Bocci, F.Bossi, D.Bowring, P.Branchini, R.Caloi, P.Campana, G.Capon , T.Capussela, F.Ceradini, S.Chi, G.Chiefari, P.Ciambrone, S.Conetti, E.De Lucia, P.De Simone, G.De Zorzi, S.Dell'Agnello, A.Denig, A.Di Domenico, C.Di Donato, S.Di Falco, B.Di Micco, A.Doria, M.Dreucci, G.Felici, A.Ferrari, M.L.Ferrer, G.Finocchiaro, C.Forti, P.Franzini, C.Gatti, P.Gauzzi, S.Giovannella, E.Gorini, E.Graziani, M.Incagli, W.Kluge, V.Kulikov, F.Lacava, G.Lanfranchi, J.Lee-Franzini, D.Leone, M.Martini, P.Massarotti, W.Mei, S.Meola, S.Miscetti, M.Moulson, S.Müller, F.Murtas, M.Napolitano, F.Nguyen, M.Palutan, E.Pasqualucci, A.Passeri, V.Patera, F.Perfetto, L.Pontecorvo, M.Primavera, P.Santangelo, E.Santovetti, G.Saracino, B.Sciascia, A.Sciubba, F.Scuri, I.Sfiligoi, T.Spadaro, M.Testa, L.Tortora, P.Valente, B.Valeriani, G.Venanzoni, S.Veneziano, A.Ventura, R.Versaci, G.Xu.

- an electromagnetic calorimeter built with a sampling of lead and scintillating fibers. The light produced by the scintillating fibers is collected at both ends of the modules and it is used to determine time and energy of the produced clusters. The time resolution is $\sigma_t \sim 54/\sqrt{E(GeV)} \oplus 140$ ps and the energy resolution is $\sigma_E/E \sim 5.7\%/\sqrt{E(GeV)}$ [2].

2 Measurement of the ratio $Br(\phi \to \eta'\gamma)/Br(\phi \to \eta\gamma)$.

The ratio of the branching ratios $R = Br(\phi \to \eta'\gamma)/Br(\phi \to \eta\gamma)$ is related to the $\eta - \eta'$ mixing angle. The value of this angle is related to the presence of a valence gluon content in the η' meson [4]. Here we describe a preliminary KLOE measurement of this ratio by using the final state $\pi^+\pi^-7\gamma$.
The final state $\pi^+\pi^-7\gamma$ can be given by two different decay chains:

$$\phi \to \eta'\gamma, \eta' \to \pi^+\pi^-\eta, \eta \to 3\pi^0 \qquad \phi \to \eta'\gamma, \eta' \to \pi^0\pi^0\eta, \eta \to \pi^+\pi^-\pi^0$$

The following requirements are used for the signal searching:

- 1 charged vertex in a cylinder with a 4 cm radius and a 16 cm length around the interaction point;
- 7 clusters in the calorimeter with time $|t - r/c| < 5\sigma_t$ where (σ_t is the calorimeter time resolution) and angle $\theta_\gamma > 21°$ respect to the beam direction. The angular cut is used to reject machine background that produces accidental clusters in the lower angular region of the calorimeter;
- all the events identified as a K_S, K_L pair are rejected.

A kinematic fit is performed imposing energy-momentum conservation and the χ^2 of the kinematic fit is used as a selection variable.
At the end of the selection 3750 events are identified. The background has been estimated using a Monte Carlo simulation of the all physical processes that can be identified as signal together with the full simulation of the detector response. The main background channels are:

$$K_S \to \pi^+\pi^-, K_L \to 3\pi^0 \qquad K_S \to \pi^0\pi^0, K_L \to \pi^+\pi^-\pi^0$$
$$K_S \to \pi^+\pi^-\gamma, K_L \to \pi^0\pi^0\pi^0$$

the first 2 processes emulates the signal if a cluster is added by the machine background or there is a splitting of a cluster in the calorimeter.
The total number of estimated background events is 345, that gives a number of signal events N_{signal}:

$$N_{signal} = N_{observed} - N_{estimatedbackground} = 3405 \pm 65_{stat.} \pm 28_{syst.}$$

The systematic error comes from the variation of the background estimate as a function of the rate of accidental clusters in the detector.

The number of $\phi \to \eta\gamma$ decays is determined by counting the number of $\eta \to 3\pi^0$ decays ($N_{\eta\to 3\pi^0} = 1665000 \pm 1300$). The ratio of the two branching fractions is extracted using the following formula:

$$R = \frac{Br(\phi \to \eta'\gamma)}{Br(\phi \to \eta\gamma)} = \frac{N(\eta' \to \pi^+\pi^-7\gamma)}{N(\eta \to 3\pi^0)} \frac{\epsilon_{\eta\to 3\pi^0} Br(\eta \to 3\pi^0)}{Br_{charged}\epsilon_{charged} + Br_{neutral}\epsilon_{neutral}} K_\rho$$

where:

$$Br_{charged} = Br(\eta' \to \pi^+\pi^-\eta) \cdot Br(\eta \to 3\pi^0)$$
$$Br_{neutral} = Br(\eta' \to \pi^0\pi^0\eta) \cdot Br(\eta \to \pi^+\pi^-\pi^0).$$

The factor $K_\rho = 0.95$ is a correction factor to the observed decay rate due to the interference between $\phi \to \eta(\eta')\gamma$ and $\rho \to \eta(\eta')\gamma$ [3]. The evaluation of the systematic error is still under refinement. The main source of systematic error comes from the uncertainty on the $\eta' \to \pi^+\pi^-\eta$ and $\eta' \to \pi^0\pi^0\eta$ branching ratios (3%) that will be measured with KLOE using the data collected in the years 2004 and 2005 [5].
Using this formula we obtain the preliminary result:

$$R = (4.76 \pm 0.08_{stat.} \pm 0.20_{syst.}) \cdot 10^{-3} \qquad (1)$$

and the pseudo-scalar mixing angle $\varphi_P = (41.3^{+2.0}_{-0.6})^\circ$, obtained using the procedure described in [6].

3 Measurement of the branching fraction $\eta \to \pi^0\gamma\gamma$ [7].

The $\eta \to \pi^0\gamma\gamma$ decay has been measured by several experiments in the past. The experimental value of this branching fraction decreased with time with the increasing of the luminosity of the machine and of the statistic of the η meson produced sample, showing that the main problem of this measurement is the correct estimate of the background. In the PDG2004 [8] is reported the measurement of the GAMS experiment [9], whose value is $(7.2\pm1.4)\times10^{-4}$. Recently other two measurements have been published by the Crystal Ball collaboration. These two measurements come from two different analysis of the same data sample, they find the values: $(3.5 \pm 0.7_{stat.} \pm 0.6_{syst.}) \times 10^{-4}$ [10] and $(2.7 \pm 0.9_{stat.} \pm 0.5_{syst.}) \times 10^{-4}$ [11].
At KLOE the $\eta \to \pi^0\gamma\gamma$ proceeds through the decay chain:

$$\phi \to \gamma\eta, \eta \to \pi^0\gamma\gamma, \pi^0 \to \gamma\gamma$$

Therefore there are 5 γ in the final state. The main background processes are:

$$\phi \to \gamma f_0, f_0 \to \pi^0\pi^0, \pi^0 \to \gamma\gamma \qquad \phi \to \gamma a_0, a_0 \to \eta\pi^0, \eta \to \gamma\gamma, \pi^0 \to \gamma\gamma$$
$$e^+e^- \to \pi^0\omega, \omega \to \pi^0\gamma, \pi^0 \to \gamma\gamma \qquad \phi \to \eta\gamma, \eta \to 3\pi^0, \pi^0 \to \gamma\gamma$$

The background composition in the DATA sample is determined at an early stage of the analysis where the signal contribution is negligible, by fitting the spectrum of the invariant mass of all pairs of photons ($m_{\gamma\gamma}$) reported in Fig. 1.
Then, further analysis criteria are used to reject background coming from the $\eta \to 3\pi^0$ channel

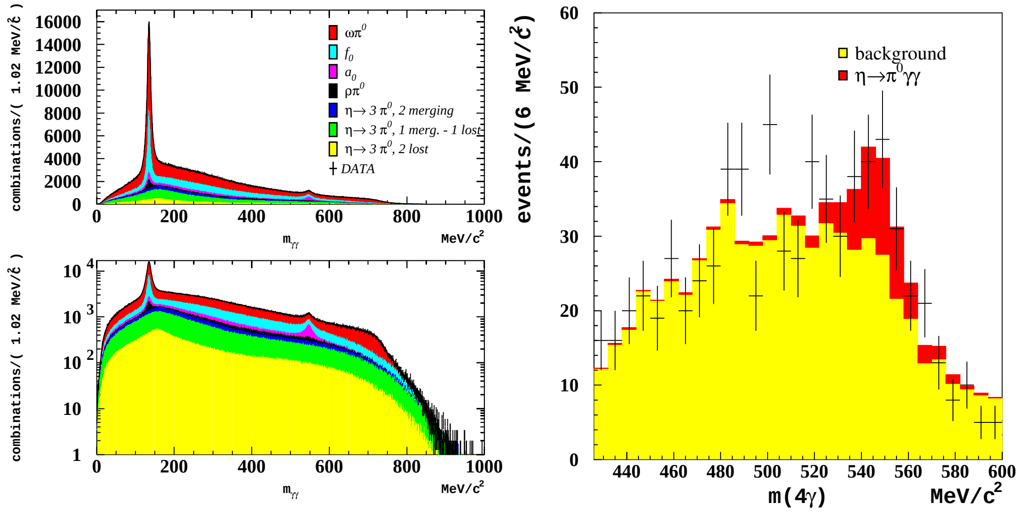

Fig. 1. **(left)** $m_{\gamma\gamma}$ distribution used to determine the background content; **(right)** $m_{4\gamma}$ distribution: DATA, dots with error bars, MC signal and MC background are normalised according the fit result.

when one or more pairs of photons merge in the calorimeter. A likelihood function has been built to identify merged clusters. At the last stage of the analysis the spectrum of the invariant mass $m_{4\gamma}$ is used to extract the number of signal events. The spectrum shown in Fig. 1 is fitted with the MC expected distributions of the background and of the signal. The number of signal events is $N_{sig} = 68 \pm 23$. To extract the branching fraction, we have counted the number of $\eta \to 3\pi^0$ events in the same data sample: $N_{\eta\to 3\pi^0} = 2288882$. The efficiency of the $\eta \to \pi^0\gamma\gamma$ analysis has been computed by MC, using a flat phase space assumption for the $\pi^0\gamma\gamma$ dynamic. It is $\epsilon_{\eta\to\pi^0\gamma\gamma} = 4.63 \pm 0.09\%$, while $\epsilon_{\eta\to 3\pi^0} = 0.378 \pm 0.08_{syst} \pm 0.01_{stat}$. Therefore we can write:

$$\frac{Br(\eta \to \pi^0\gamma\gamma)}{Br(\eta \to 3\pi^0)} = \frac{N(\eta \to \pi^0\gamma\gamma) \cdot \epsilon_{\eta\to 3\pi^0}}{N(\eta \to 3\pi^0) \cdot \epsilon_{\eta\to\pi^0\gamma\gamma}} = (2.43 \pm 0.82) \times 10^{-4} \tag{2}$$

Using the value of $Br(\eta \to 3\pi^0)$ reported in [8] we obtain the preliminary KLOE result:

$$Br(\eta \to \pi^0\gamma\gamma) = (8.4 \pm 2.7_{stat} \pm 1.4_{syst}) \times 10^{-5} \tag{3}$$

This value is lower than the previously published values and it is in agreement with ChPT prediction at order p^6 with VMD resonance saturation assumption for the $\mathcal{L}_6$ Lagrangian [12, 13].

4 η mass measurement.

Recently a new η mass measurement has been performed by the GEM collaboration [14] that measures a mass value that is half MeV below the previous NA48 measurement [15], but it is in

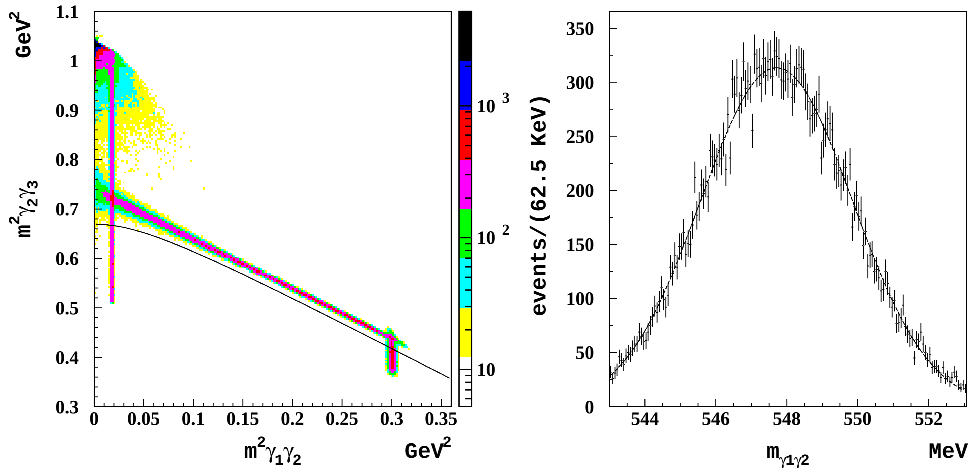

Fig. 2. **(left)** Dalitz plot of the 3γ final state, the cut chosen to reject background is shown, **(right)** $m_{\gamma\gamma}$ distribution.

agreement with the previous η mass measurements [8]. For this reason KLOE is performing a new measurement of the η mass using a completely different approach. The mass is measured studying the decay $\phi \to \eta\gamma, \eta \to \gamma\gamma$. To improve the energy response of the calorimeter a Kinematic fit is performed imposing energy-momentum conservation. A cut in the Dalitz plot of the 3γ final state is performed in order to reduce the background mainly due to $e^+e^- \to \gamma\gamma$, $e^+e^- \to e^+e^-(\gamma)$, $\phi \to \pi^0\gamma$, Fig. 2. A sharp peak around the η mass is found with negligible background ($\sigma_{peak} \sim 2$ MeV), Fig. 2. The 2001 + 2002 data taking has been divided into 8 periods, each corresponding to about 50 pb^{-1} of collected data. The systematic has been studied by studying the effect of energy, time, vertex position and $\sqrt{s}$ miscalibration on the measured value of the η mass. In Fig. 3 the measurements obtained in the 8 periods are reported and the systematic band is shown. All the measurement lie in the estimated systematic band. The statistical error has been computed by fitting the 8 measurement with a constant and evaluating the error on it. The preliminary result obtained is:

$$m_\eta = 547822 \pm 5_{stat} \pm 69_{syst} \text{ keV} \tag{4}$$

As a check of the method we have measured also the mass of the π^0 by using the decay $\phi \to \pi^0\gamma$ obtaining $m_{\pi^0} = 134990 \pm 6_{stat.} \pm 30_{syst.}$ keV, that is fully in agreement with the value reported in [8] $m_{\pi^0}^{PDG} = 134976.6 \pm 0.6$ keV.

This preliminary measurement is in agreement with NA48 measurement, 0.24 standard deviation away ($m_\eta^{NA48} = 547843 \pm 30_{stat.} \pm 41_{syst.}$ keV), and it disagrees with the GEM measurement ($m_\eta^{GEM} = 547311 \pm 28_{stat.} \pm 32_{syst.}$ keV).

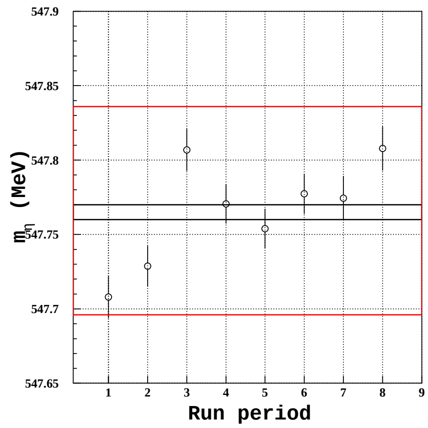

Fig. 3. η mass measurement in the several periods. The systematic band, red rectangle, is shown.

References

[1] M. Adinolfi et al.: *Nucl. Instr. Meth.* **A 488** (2002) 1

[2] M. Adinolfi et al.: *Nucl. Instr. Meth.* **A 492** (2002) 134

[3] R. R. Akhmestin et al.: *Phys. Lett.* **B 434** (1998) 426

[4] F. E. Close: *The DAΦNE physics handbook vol. II*, ed. L. Maiani, G. Pancheri and N. Paver, Frascati 1992

[5] C. Bloise et al.,*This Proceedings.*

[6] A. Bramon, R. Escribano, M. D. Scadron: *Eur. Phys. J.* **C 7** (1999) 271

[7] B. Di Micco: *Phd Thesis* **http://www.fis.uniroma3.it/∼dimicco** (2005) Rome

[8] S.Eidelman et al.: *Phys. Lett.* **B 592** (2004) 1

[9] Alde et al.: *Z. Phys.* **C 25** (1984) 225

[10] S. Prakhov et al.: *Phys. Rev.* **C 72** (2005) 025201

[11] Knecht et al.: *Phys. Lett.* **B 589** (2004) 14

[12] E. Oset,J. R. Pelaź,L. Roca: *Phys. Rev.* **D 67** (2003) 073013

[13] L. Ametller,J. Bijnens,A. Bramon,F. Cornet: *Phys. Lett.* **B 276** (1992) 185

[14] M. Abdel-Bary et al.: *Phys. Lett.* **B 619** (2005) 281

[15] A. Lai et al.: *Phys. Lett.* **B 533** (2002) 196