acta physica slovaca vol. 56 No. 3, 403 – 409 June 2006

THE $\eta \to \pi^0\gamma\gamma$ DECAY, THE η/η' MIXING ANGLE AND THE η MASS MEASUREMENT AT KLOE[1]

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Received 14 November 2005, in final form 16 February 2006, accepted 6 March 2006

We present preliminary results from the KLOE experiment on 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 $\phi \to \eta\gamma$, $\eta \to \gamma\gamma$.

PACS: 02.50.+s, 05.60.+w, 72.15.-v

[1]Presented at the Workshop on Production and Decay of η and η' Mesons (ETA05), Cracow, 15–18 September 2005.
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1 Introduction

The KLOE experiment is performed at the Frascati ϕ factory DAΦNE, an e^+e^- collider working at $\sqrt{s} \sim 1020$ MeV, corresponding to the ϕ mass. Among other physics goals, KLOE [1, 2] performs measurements of η decays, η' decays, and the η mass with good accuracy and in the clean environment typical of e^+e^- machines. The η is produced through the electromagnetic decay of the ϕ meson: $\phi \to \eta\gamma$.

The analyses described here have been performed using data collected during the years 2001 and 2002 (450 pb^{-1}), corresponding to ~ 19 million η mesons.

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

The ratio of the branching fractions $R = Br(\phi \to \eta'\gamma)/Br(\phi \to \eta\gamma)$ is related to the η-η' 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 produced in 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 to isolate signal events:

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

A kinematic fit is performed with energy-momentum conservation imposed, and the resulting χ^2 is used as a selection variable.

At the end of the selection procedure 3750 events are identified. The background has been estimated using a Monte Carlo simulation of all physical processes that can be identified as signal together with the full simulation of the detector response. The main background channels are

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

The first two processes emulate the signal if an additional cluster is present, either from machine background or from cluster splitting in the calorimeter. The total number of estimated background events is 345. The number of signal events N_{signal} is then

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

The systematic error comes from the variation of the estimated background contribution when the assumed rate of accidental clusters in the detector is varied.

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 ratios is calculated using the following formula

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

where

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

The factor K_ρ is a correction 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%), which will be measured with KLOE using the data collected in the years 2004 and 2005 [5].

Using the expression for R we obtain the preliminary result

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

and the pseudoscalar mixing angle $\varphi_P = (41.3^{+2.0}_{-0.6})^\circ$, calculated using the procedure described in Ref. 6.

3 Measurement of the branching fraction $\eta \to \pi^0\gamma\gamma$ in Ref. 11

The $\eta \to \pi^0\gamma\gamma$ decay has been measured by several experiments in the past. The experimental value of this branching fraction has decreased with time, in step with the increase in machine luminosities and in the available statistics of the η-meson samples produced, showing that the main issue in the measurement of this branching fraction is the correct background estimate. The 2004 Review of Particle Physics [7] lists only the measurement from the GAMS experiment [8], $(7.2 \pm 1.4) \times 10^{-4}$. Recently, two more measurements have been published by the Crystal Ball collaboration. These two measurements are different analyses of the same data sample; they find the values $(3.5 \pm 0.7_{stat.} \pm 0.6_{syst.}) \times 10^{-4}$ [9] and $(2.7 \pm 0.9_{stat.} \pm 0.5_{syst.}) \times 10^{-4}$ [10].

At KLOE the decay $\eta \to \pi^0\gamma\gamma$ proceeds through the chain:

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

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

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

The composition of the background in the data sample is determined at an early stage of the analysis at which the signal contribution is negligible, by fitting the spectrum of the invariant

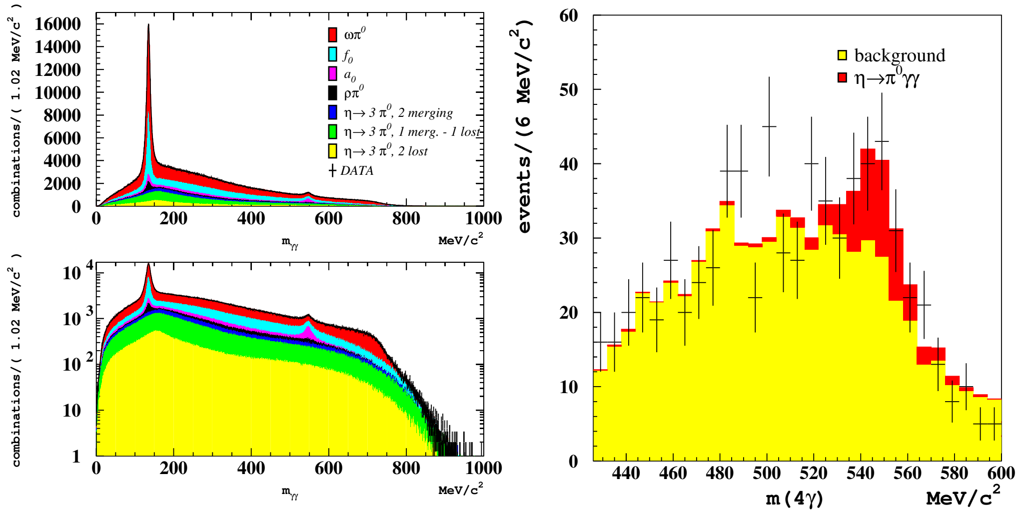

Fig. 1. (Left): the $m_{\gamma\gamma}$ distribution used to determine the background content; (right): the $m_{4\gamma}$ distribution: the dots with error bars show the data; MC signal and MC background are normalised according the fit result.

mass of all photon pairs ($m_{\gamma\gamma}$), as shown in Fig. 1. Further analysis criteria are used to reject background coming from the $\eta \to 3\pi^0$ channel when one or more photon pairs 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 right, is fitted with the MC expected distributions for signal and background. 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 $\pi^0\gamma\gamma$ dynamics. The efficiencies are $\epsilon_{\eta\to\pi^0\gamma\gamma} = 4.63 \pm 0.09\%$ and $\epsilon_{\eta\to 3\pi^0} = 0.378 \pm 0.08_{\mathrm{syst}} \pm 0.01_{\mathrm{stat}}$. 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 $Br(\eta \to 3\pi^0)$ from Ref. 7, we obtain the preliminary KLOE result

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

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

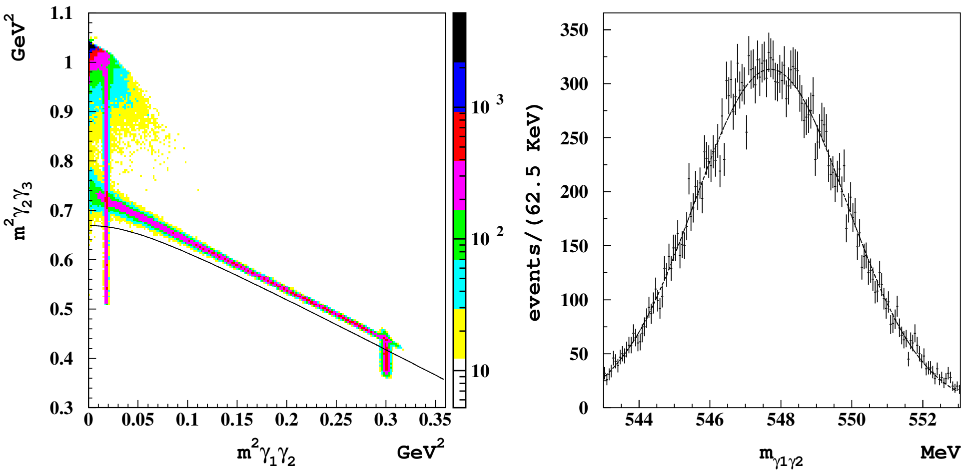

Fig. 2. (Left): Dalitz plot of the 3γ final state. The cut chosen to reject background is shown, the $m_{\gamma\gamma}$ distribution (right).

4 The η mass measurement

A new η mass measurement has recently been performed by the GEM collaboration [14]. The value for the mass is 0.5 MeV below that obtained by NA48 [15], but is in agreement with previous η mass measurements [7]. For this reason, KLOE is performing a new measurement of the η mass using a completely different approach. The mass is measured by studying the decay $\phi \to \eta\gamma, \eta \to \gamma\gamma$. To improve the energy response of the calorimeter, a kinematic fit is performed with constraints from energy-momentum conservation. A cut in the Dalitz plot of the 3γ final state is performed in order to reduce the background, which is mainly due to $e^+e^- \to \gamma\gamma$, $e^+e^- \to e^+e^-(\gamma)$, and $\phi \to \pi^0\gamma$ events (Fig. 2, left). A sharp peak at the η mass is found with negligible background ($\sigma_{\rm peak} \sim 2$ MeV), as seen in Fig. 2, right.

The 2001–2002 data sample has been divided into 8 periods, each corresponding to about 50 pb^{-1} of collected data. In Fig. 3, the measurements obtained in each of the 8 periods are shown. The statistical error has been computed by fitting the 8 measurements with a constant. The fit gives the value $m_\eta = 547765 \pm 5_{stat.}$ keV. The systematic error has been determined by studying the effect of energy, time, vertex position and $\sqrt{s}$ miscalibration on the measured value of the η mass. Studying the line shape of the ϕ meson we find that the ϕ mass is 110 keV below the value reported by the CMD2 collaboration [16] showing a miscalibration of our $\sqrt{s}$ measurement. We apply a +110 keV correction to the $\sqrt{s}$ and, to be conservative, assume an error of 110 keV on this correction. This produces a correction of +57 keV on the value of the η mass, giving the prelimianry result

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

The relation between the measured η mass and the $\sqrt{s}$ is shown in Fig. 3 (right). The individ-

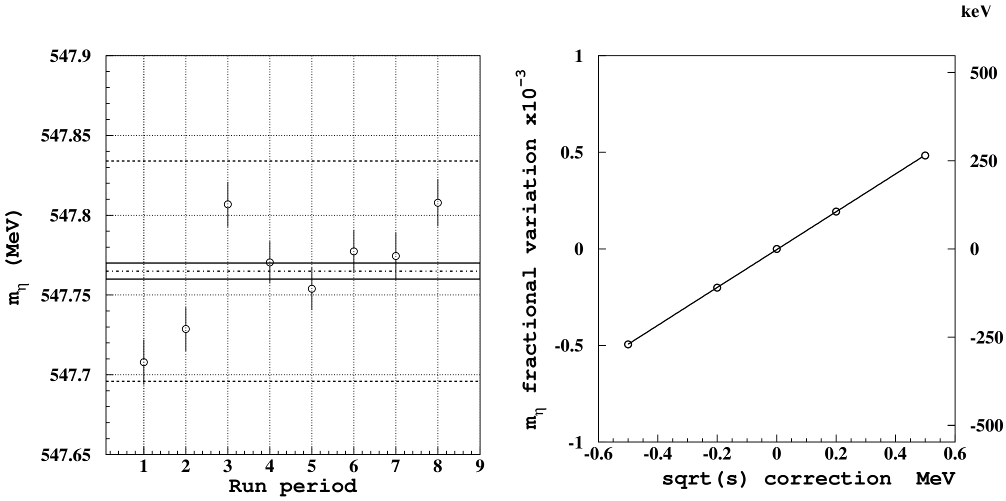

Fig. 3. (Left): the η mass measurement in several periods. The dashed-dotted line indicates the value obtained fitting the 8 points with a constant, the statistical error (continuous border box) and the systematic error (dashed border box) are shown. (Right): fractional correction to the η mass as a function of $\sqrt{s}$ shift.

ual contributions to the systematic error are reported in Table 1. All the measurements lie within the estimated systematic error band.

As a check of the method we have also measured the mass of the π^0 using the decay $\phi \to \pi^0\gamma$, obtaining $m_{\pi^0} = 134990 \pm 6_{stat.} \pm 30_{syst.}$ keV, which is fully in agreement with the value reported in Ref. 7, $m_{\pi^0}^{PDG} = 134976.6 \pm 0.6$ keV.

The preliminary measurement in eq.(4) differs from the NA48 measurement ($m_\eta^{NA48} = 547843 \pm 30_{stat.} \pm 41_{syst.}$ keV) by only 0.24 standard deviations. It disagrees with the GEM measurement ($m_\eta^{GEM} = 547311 \pm 28_{stat.} \pm 32_{syst.}$ keV) by 7 standard deviations.

Tab. 1. Systematic contributions to the error on the η mass measurement (preliminary).

Systematic source	error (keV)
Energy calibration	2
Energy abs. scale	3
time abs. scale	4
vertex position x,y	27
vertex position z	5
$\sqrt{s}$	57
overall	69

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