

Letter

Measurement of the η mass at KLOE*

B. Di Micco^a

On behalf of the KLOE Collaboration^b

Università degli Studi di Roma Tre, INFN sezione di Roma Tre, Roma, Italy

Received: 11 April 2008 / Revised: 6 August 2008

Published online: 7 October 2008 – © Società Italiana di Fisica / Springer-Verlag 2008

Communicated by Haiyan Gao

Abstract. In this report the measurement of the η mass is presented. The analysis has been performed on 450 pb^{-1} of data collected in the years 2001 and 2002. The measured value is $m_\eta = (547.874 \pm 0.07_{\text{stat}} \pm 0.029_{\text{syst}}) \text{ MeV}$.

PACS. 14.40.Aq π , K , and η mesons

1 Introduction

In this paper we describe the measurement of the η mass from the KLOE experiment [1] operating at the Frascati ϕ factory DAΦNE.

The value of the η -meson mass has been poorly determined for many years and today the picture is still not fully clarified. The first measurements date back to about 40 years ago studying η decays in bubble chamber experiments [2] with a mass resolution of $\sim 1 \text{ MeV}$; these resulted in mass values clustered around 548.5 MeV . A lower value with better precision was obtained in 1974 measuring the missing-mass spectrum of $\pi^- p \rightarrow Xn$ close to threshold, $m_\eta = (547.45 \pm 0.25) \text{ MeV}$ [3]. This result was confirmed by other experiments studying the production of η at threshold in pd [4] and γp [5] reactions. More recently, the mass was measured precisely by the GEM experiment using the reaction $dp \rightarrow \eta \text{ } ^3\text{He}$ at threshold:

$m_\eta = (547.311 \pm 0.028 \pm 0.032) \text{ MeV}$ [6]. Thus, all the experiments at threshold give consistent results.

However, this value of η mass is highly inconsistent with the one measured by the NA48 experiment studying the decay $\eta \rightarrow \pi^0 \pi^0 \pi^0$: $m_\eta = (547.843 \pm 0.030_{\text{stat}} \pm 0.041_{\text{syst}}) \text{ MeV}$ [7], the difference being about eight standard deviations. This discrepancy between threshold and decay experiments has been confirmed by the preliminary η mass measurement carried out by the KLOE experiment [8] $m_\eta = (547.822 \pm 0.005_{\text{stat}} \pm 0.069_{\text{syst}}) \text{ MeV}$. A recent result from the CLEO-c Collaboration gives $m_\eta = (547.785 \pm 0.017 \pm 0.057) \text{ MeV}$ [9] using $\psi(2S) \rightarrow \eta J/\psi$ decays and combining different η decay modes. In this paper, we report the best measurement of the η mass to date, using the $\phi(1020) \rightarrow \eta \gamma$ decay. This decay chain, assuming the $\phi(1020)$ -meson at rest, is a source of monochromatic η -mesons of $362.792 \text{ MeV}/c$, recoiling against a photon of the same momentum. The detection of such a photon signals the presence of an η -meson. Photons from $\eta \rightarrow \gamma \gamma$ cover a continuum flat spectrum between $147 < E_\gamma < 510 \text{ MeV}$ in the laboratory reference frame. The photon energies are measured in KLOE, but for 3γ events the main accuracy is ultimately from accurate measurements of the photon emission angles. Together with the stability of the continuously calibrated detector and the very large sample of η -mesons collected, we have been able to obtain a very accurate measurement of the η mass [10].

Events are selected requiring at least three energy clusters in the barrel calorimeter with polar angle $50^\circ < \theta_\gamma < 130^\circ$. Being r the distance between a photon cluster position and the interaction point, the time of the cluster must be such that the $|t - r/c| < 3\sigma_t$, with σ_t the calorimeter time resolution parametrized as $\sigma_t = \sqrt{(54 \text{ ps})^2 \times 1 \text{ GeV}/E + (140 \text{ ps})^2}$. A kinematic fit imposing energy momentum conservation is performed.

* Original article based on material presented at HADRON 2007.

^a e-mail: dimicco@fis.uniroma3.it

^b F. Ambrosino, A. Antonelli, M. Antonelli, F. Archilli, P. Beltrame, G. Bencivenni, S. Bertolucci, C. Bini, C. Bloise, S. Bocchetta, F. Bossi, P. Branchini, P. Campana, G. Capon, T. Capussela, F. Ceradini, S. Chi, P. Ciambrone, E. De Lucia, A. De Santis, P. De Simone, G. De Zorzi, A. Denig, A. Di Domenico, C. Di Donato, S. Di Falco, B. Di Micco, A. Doria, M. Dreucci, G. Felici, M.L. Ferrer, S. Fiore, C. Forti, P. Franzini, C. Gatti, P. Gauzzi, S. Giovannella, E. Graziani, W. Kluge, G. Lanfranchi, J. Lee-Franzini, D. Leone, M. Martini, P. Maszarotti, S. Meola, S. Miscetti, M. Moulson, S. Müller, F. Murtas, M. Napolitano, F. Nguyen, M. Palutan, E. Pasqualucci, A. Passeri, V. Pa tera, F. Peretto, P. Santangelo, B. Sciascia, A. Sciubba, A. Sibidanov, T. Spadaro, M. Testa, L. Tortora, P. Valente, G. Venanzoni, R. Versaci, G. Xu.

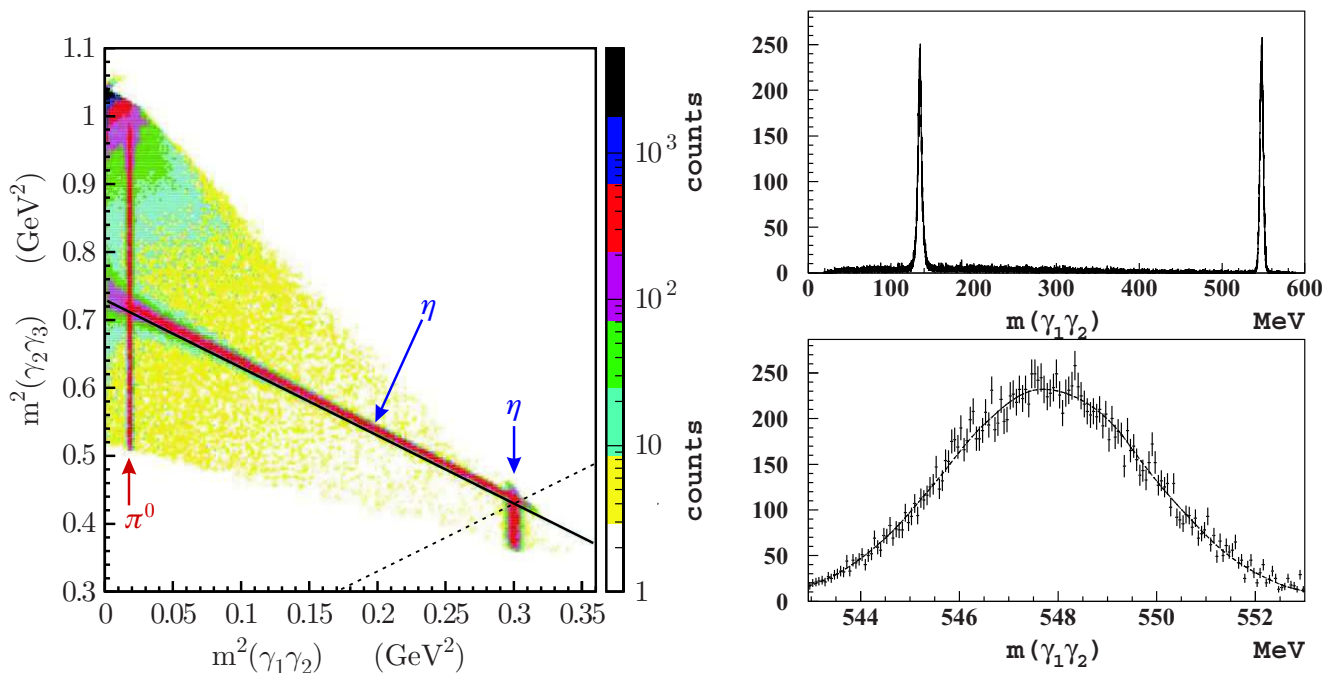


Fig. 1. Left: population in the invariant-mass-squared ($m_{\gamma_2\gamma_3}^2, m_{\gamma_1\gamma_2}^2$)-plane. The photon energies are ordered as $E_{\gamma_1} < E_{\gamma_2} < E_{\gamma_3}$. The η and π^0 signal are quite evident; right top: distribution of the invariant mass $m_{\gamma_1\gamma_2}$ for the events selected by the cut. Right bottom: distribution of the invariant mass $m_{\gamma_1\gamma_2}$ around the value of the η mass and the Gaussian fit.

The kinematic fit uses the value of the total energy, the $\phi(1020)$ transverse momentum and the average value of the beam-beam interaction point; these values are determined with good precision run by run by analyzing $e^+e^- \rightarrow e^+e^-$ elastic scattering events. The energy resolution gets greatly improved from the good calorimeter angular resolution. Moreover, a cut on the χ^2 of the kinematic fit is imposed in order to reject background events from $> 3\gamma$ final states: events with $\chi^2 < 35$ are retained.

Figure 1 shows the $m_{\gamma_2\gamma_3}^2, m_{\gamma_1\gamma_2}^2$ Dalitz plot population, with the energies ordered as $E_{\gamma_1} < E_{\gamma_2} < E_{\gamma_3}$. The $m_{\gamma_1\gamma_2}^2 \simeq m_{\pi^0}^2$, $m_{\gamma_1\gamma_2}^2 \simeq m_{\eta}^2$ and $m_{\gamma_1\gamma_3}^2 = m_{\eta}^2$ bands are clearly visible. We apply a cut $m_{\gamma_1\gamma_2}^2 + m_{\gamma_2\gamma_3}^2 \leq 0.73 \text{ GeV}^2$, “background-rejection cut” in the following, shown by the line in fig. 1. Events below the line are retained for the analysis. The resulting $m_{\gamma_1\gamma_2}$ distribution, for a data subsample, is shown in fig. 1, right-top panel. The background under the η peak is very small and flat, therefore the $m(\gamma_1\gamma_2)$ distribution in the 542.5 to 552.5 interval is well fitted with a single Gaussian with $\sigma = 2.0 \text{ MeV}$, neglecting the background contribution (fig. 1). The result of the fit is $m_{\eta} = 547.777 \pm 0.016 \text{ MeV}$ with $\chi^2/\text{n.d.f} = 168/161$. The Gaussian width is dominated mostly by the experimental resolution, as the decay width of the eta being $1.30 \pm 0.08 \text{ keV}$ [11] is well below the detector resolution.

Systematic uncertainties have been determined studying the effects of the detector response, alignment, event selection cuts, kinematic fit and beam energy calibration. The values of the systematic errors are shown in table 1.

The systematic uncertainties have been evaluated using several DATA control samples in order to estimate the error on the reconstructed quantities: photon entry points

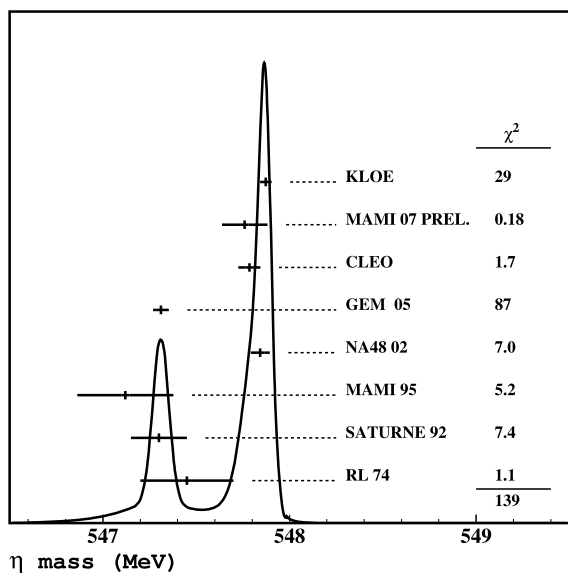
Table 1. Systematic errors evaluated for m_{η} , m_{π^0} and the ratio $R = m_{\eta}/m_{\pi^0}$.

Systematic effect	m_{η} (keV)	m_{π^0} (keV)	R ($\times 10^{-5}$)
Vertex position	4	6	19
Calorimeter energy scale	4	1	6
Calorimeter non-linearity	4	11	31
θ angular uniformity	10	44	120
ϕ angular uniformity	15	12	37
χ^2 cut	< 1	4	13
Background-rejection cut	12	4	18
ISR emission	8	9	28
\sqrt{s} calibration	16	3.4	–
Total	29	49	136

in the calorimeter, beam interaction point position, photon energies. A sample of $e^+e^- \rightarrow \pi^+\pi^-\gamma$ events has been used to estimate biases in the interaction point determination, by comparing the π^+ , π^- vertex to the reconstructed vertex from Bhabha events. The deviation from linearity and calibration was checked by comparing the photon energy reconstructed from the missing energy of the $\pi^+\pi^-$ tracks with the cluster energy. The energy scale was found to be correct at 1% level and linearity was better than 2%. Miscalibration at the level of the estimated uncertainty on both vertex and energy was applied event by event. The η mass has been recomputed, and the spread observed in the mass measurement is used as systematic error. The systematics due to the inhomogeneous response

Table 2. Measurements of the η mass. For consistency the averages are computed according the PDG prescription [11].

Experiment	η mass (MeV)
RL74	547.45 ± 0.25
SATURNE 92	547.30 ± 0.15
MAMI 95	$547.12 \pm 0.06_{\text{stat}} \pm 0.25_{\text{syst}}$
NA48 02	$547.843 \pm 0.030_{\text{stat}} \pm 0.041_{\text{syst}}$
GEM07	$547.311 \pm 0.028_{\text{stat}} \pm 0.032_{\text{syst}}$
PDG average	547.51 ± 0.18
KLOE 06 preliminary [8]	$547.822 \pm 0.005_{\text{stat}} \pm 0.069_{\text{syst}}$
MAMI 07 preliminary	$547.76 \pm 0.10_{\text{stat}} \pm 0.07_{\text{syst}}$
CLEO 07	$547.785 \pm 0.017_{\text{stat}} \pm 0.057_{\text{syst}}$
Updated average	547.61 ± 0.11
This result	$547.874 \pm 0.007_{\text{stat}} \pm 0.029_{\text{syst}}$
Average (excluding KLOE 06 preliminary)	547.71 ± 0.10
Average (excluding GEM07)	547.83 ± 0.04

**Fig. 2.** Comparison among the measurements of the η mass. The continuous line and the χ^2 contributions are obtained according the procedure described in ref. [11].

of the calorimeter in the 4π solid angle have been determined by dividing the data sample into subsamples with different photon solid angles. No systematic behaviour has been observed, and the rms of the points has been used as systematic error. The error coming from the background rejection cut was obtained by varying the slope and the intercept of the linear cut in the plot. The rms of the measurements obtained was used as the systematic error.

The initial-state radiation in the $e^+e^- \rightarrow \phi$ process affects the available center-of-mass energy in the decay $\phi \rightarrow \eta\gamma$. Correction due to this effect was estimated by MC. The systematic error has been computed evaluating the η mass as a function of the \sqrt{s} and comparing DATA with MC. The rms of the DATA-MC difference has been used as systematic error.

2 Results

The procedure described in the previous section has been applied to events $\phi(1020) \rightarrow \pi^0\gamma$, $\pi^0 \rightarrow \gamma\gamma$ in order to evaluate the π^0 mass and the ratio $R = m_\eta/m_{\pi^0}$. The values obtained are:

$$m_{\pi^0} = (134.906 \pm 0.012_{\text{stat}} \pm 0.049_{\text{syst}}) \text{ MeV}, \quad (1)$$

$$m_\eta = (547.874 \pm 0.007_{\text{stat}} \pm 0.029_{\text{syst}}) \text{ MeV}, \quad (2)$$

$$\frac{m_\eta}{m_{\pi^0}} = 4.0610 \pm 0.0004_{\text{stat}} \pm 0.0014_{\text{syst}}. \quad (3)$$

Our η mass measurement is the most precise result to date and is in good agreement with the recent measurements based on η decays shown in fig. 2. Averaging these measurements we obtain $m_\eta = 547.851 \pm 0.025$ MeV which differs by $\sim 10 \sigma$ from the average of the measurements done studying the production of the η -meson at threshold in nuclear reactions. In table 2 we show all η mass measurements starting from 1974.

References

1. M. Adinolfi *et al.*, Nucl. Instrum. Methods A **488**, 51 (2002); M. Adinolfi *et al.*, Nucl. Instrum. Methods A **482**, 364 (2002).
2. P. Bastien *et al.*, Phys. Rev. Lett. **8**, 114 (1962); C. Alff *et al.*, Phys. Rev. Lett. **9**, 322 (1962); H. Foelsche, H. Kraybill, Phys. Rev. **134**, B1138 (1964); M. Foster *et al.*, Phys. Rev. **138**, B652 (1965).
3. A. Duane *et al.*, Phys. Rev. Lett. **32**, 425 (1974).
4. F. Plouin *et al.*, Phys. Lett. B **276**, 526 (1992).
5. B. Krusche *et al.*, Z. Phys. A **351**, 237 (1995).
6. M. Abdel-Bary *et al.*, Phys. Lett. B **619**, 281 (2005).
7. A. Lai *et al.*, Phys. Lett. B **533**, 196 (2002).
8. The KLOE Collaboration (B. Di Micco *et al.*), Acta Phys. Slov. **56**, 403 (2006).
9. D.H. Miller *et al.*, Phys. Rev. Lett. **99**, 122002 (2007).
10. B. Di Micco, *Precise measurement of the η mass*, KLOE note 217 (<http://www.lnf.infn.it/kloe/>).
11. W.-M. Yao *et al.*, J. Phys. G **33**, 1 (2006).