KLOE NOTE n$^o$173, March 2002

# The Upper Limit of $\eta \to\gamma\gamma\gamma$ Decay

**LU Feng**
*Institute of High Energy Physics,Beijing,China*
*KLOE Collaboration,LNF,INFN,Italy*

**Abstract**

The C-violating $\eta \to\gamma\gamma\gamma$ decay is searched by analysing the KLOE data sample of about $2.57 \times 10^6$ $\eta$ mesons.No signal events have been observed,the signal number is estimated as: $-1.16\pm13.57$ events by an unbinned maximum likelihood fit.The upper limit of $\eta \to\gamma\gamma\gamma$ is $5.5 \times 10^{-5}$ under 95% CL.

# 1 INTRODUCTION

Searching for the decays which violate the fundamental symmetries (C,P,T) is one kind of the most important goals for modern particle physics experiments,which will lead to new physics field. In Standard Model (SM),C-parity is strictly conserved in both strong and electromagnetic decays, but it could break in weak interaction,SM explains this kind of C violation by V-A coupling theory. Just like $\pi^0$,$\eta$ meson is an eigenstate of charge conjugation(C) operator with a positive eigenvalue,while a photon has a negative C eigenvalue,so $\eta$ mesons decay into any final state with odd number of photons are forbidden by charge conjugation(C) symmetry.Experimentally searching for $\eta \to \gamma\gamma\gamma$ decay, which breaks C-invariance only,is more sensitive test of C-invariance,because it is $(M_\eta/M_{\pi^0})^{12} \simeq 3.0 \times 10^7$ [1] better than $\pi^0 \to\gamma\gamma\gamma$ decay. The C-violating $\eta \to\gamma\gamma\gamma$ decay rate could be induced by a parity-violating CP-conserving interation,provided by usual weak interation:$Br(\eta \to \gamma\gamma\gamma) \simeq 3\times10^{-19\pm6}$ [2];An alternative mechanism could be an interaction which violates C and CP,the constraint from the present limit for the electric dipole moment of the neutron gives the limit:$Br(\eta \to \gamma\gamma\gamma)<10^{-10}$ [2].

The Frascati $\phi$-factory DA$\phi$NE,besides its the most important physical goal:the study on CP violation,could produce a great number of $\eta$ mesons by the radiative decay of $\phi$ mesons(at $10^7$ $\eta$ events level per year). $e^+e^-$ from DA$\phi$NE collide each other to produce $\phi$ mesons and about 1.298% $\phi$ mesons radiatively decay into $\eta$ mesons,the $\eta$ mesons decay fragments are measured by the KLOE $4\pi$-detector [3]. In PDG2001,$Br(\eta \to \gamma\gamma\gamma)<5\times10^{-4}$(95% CL), was measured by GAMS2000 in 1984,based upon $6 \times 10^5$ $\eta$ events [4].So far it still is only published formal measurement in the world.Crystal Ball collaboration(AGS/CB) had reported their preliminary upper limit as :$4.5\times10^{-5}$(95% CL) in 2000,based upon $18.9 \times 10^6$ $\eta$ events

[5].Both results are from fix target experiments where $\eta$ mesons are produced from the process $\pi^-$P$\rightarrow$ $\eta$n. If defining $N_\eta Br^2(\eta \rightarrow 3\gamma)$ as an equivalent experiment sensitivity,one could find AGS/CB's sensitivity is about 4 times of GAMS2000's,the most important reason is that AGS/CB's C.M. burst is much smaller than GAMS2000's: $P_{\pi^-}$=30GeV/c for GAMS2000; $P_{\pi^-}$=760MeV/c for AGS/ CB. However,it still has the serious problem of seperating $\gamma$ from $\pi^0$ which makes its systematic error be under control hardly,so $\eta \rightarrow 3\pi^0$ events still is dominant in its $\eta \rightarrow \gamma\gamma\gamma$ background.The upper limit measured by an $e^+e^-$ collider experiment with zero C.M. burst is still absent,while KLOE is just fit for this need.

# 2 ANALYSIS

Total integrated luminosity of $59.933pb^{-1}$ KLOE data,nearestly accumulated on 31/Oct. to 7/Dec. 2001, corresponding to about $2.57 \times 10^6$ $\eta$ events,has been analysed for searching $\eta \rightarrow\gamma\gamma\gamma$ decay;An $\eta \rightarrow\gamma\gamma\gamma$ MC generator of pure phase space is linked with KLOE $\phi \rightarrow \gamma\eta$ MC generator to create 30,000 $\phi \rightarrow \gamma\eta$, $\eta \rightarrow\gamma\gamma\gamma$ $\rightarrow 4\gamma$ MC signal sample.The critera of signal events selction are as follows:

1)After splitting clusters mergence and clusters' rejection of DC tracks association,exactly 4 clusters are in the time window.All 4 photons' clusters of the signal events come from the I.P.(interaction piont),which must obey the relation t-r/c=0 if omitting calorimeter time resolution:$\sigma_t$,where t is the arrival time of a photon's cluster on the calorimeter,r is the distance of the cluster from I.P. and c is the speed of light.The time window width is 5 times of $\sigma_t$=$\sqrt{0.15^2 + 0.054^2/E(GeV)}$ ns but no more than 2ns: $|t-r/c|$<min($5\sigma_t$,2ns),which rejects most machine accidental clusters and suppresses neutral final states without four photons largely. 2)The four clusters satisfy: Eclu> 30MeV and $|cos\theta|$<0.93.Cluster energy threshold could suppress fragments of survival cluster splitting,machine accidental clusters and the calorimeter electronic noise,which have a high peak in low energy region;The polar angle interval 21.6°-158.4° excludes the blind region around the beam-pipe. 3)$\theta_{\gamma\gamma}$>15°,$\theta_{\gamma\gamma}$ is minimal angle of the clusters' pairs,the cut suppresses $3\gamma$ final states which has a peak before 15° coming from the survival splitting clusters. 4) Etot>910MeV to reject $K_L K_S$ background.5) Ptot<110MeV to suppress $\eta \rightarrow 3\pi^0$,$\eta \rightarrow \pi^0\gamma\gamma$ and 5 photons backgrounds. 6) $|cos\theta|$<0.9,Tighten polar angle interval to 25.84°-154.16° in order to suppress QED background and reduce accidental clusters futher.

After above selection,there are 14057 events in MC signal sample and 10105 events in the DATA sample,MC efficiency is 46.9%. Then using a kinematic 3C-fit on these four photons events,which based on the Lagrange multipliers method to minimize the following $\chi^2$:

$$\chi^2 = \sum_i \frac{(x_i - \mu_i)^2}{\sigma_i^2} + \sum_j \lambda_j F_j(\{\mu\}) \tag{1}$$

with 4 free parameters ($\mu_i$=$E_i$): energies of 4 photons, $\sigma_i$=$\sigma_{E_i}$=$(5.7\%/\sqrt{E(GeV)}+0.6\%)E_i$ MeV while photons' momenta directions are fixed as calorimeter measure-

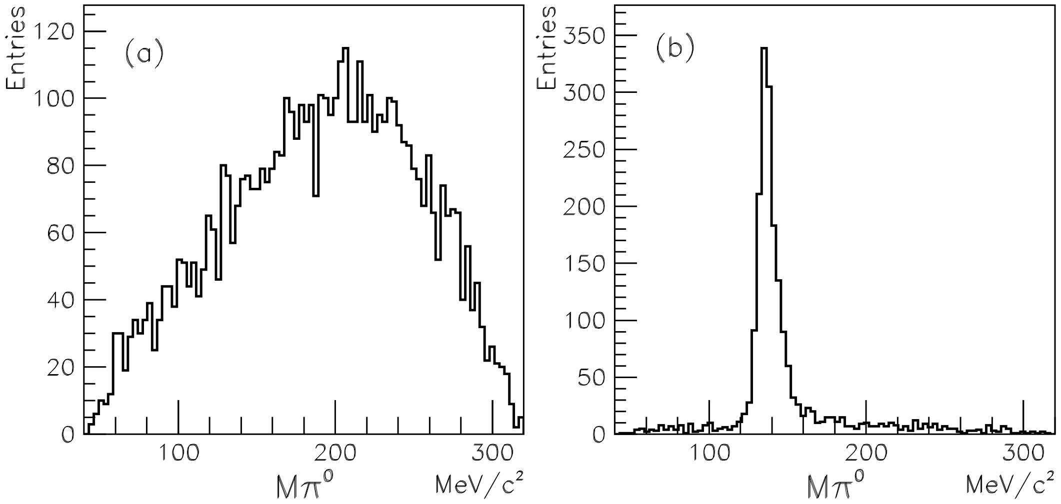


Figure 1: $\pi^0$ candidates mass spectrum a): MC ; b): DATA

ments since spatial resulotion could be well omitted relative to energy resolution for the calorimeter and it also makes the constraints be linear functions.The number of the constraints ($F_j$) is 3: Total energy, total x-direction momentum,total y-direction momentum conservations while z-direction momenta are free,which is very important to reconstruct $\pi^0$ from 5 photon final states: such as $\phi \rightarrow \rho^0\pi^0 \rightarrow \pi^0\pi^0\gamma$,since the lost photon escapes from z-direction where is blind regions for the calorimeter,but such events with 4 detectable photons basically keep total momentum balance at x and y directions.If applying a 4C-fit (i.e. adding total z-direction momentum conservation),$\pi^0$ mass resolution will turn worse.Using 3C-fitted 4 photons' energies to minimize $\chi^2_\eta$= (Erad-363)$^2/9^2$ + ($M_{3\gamma}$-547.3)$^2/13^2$ for all possible combinations to find out the radiative photon and $\eta$ candidate which decays into other three photons to reconstruct possible signal events.Independently to $\eta$ finding,using fitted 2 photons' energies to minimize $\Delta_{\pi^0}$=$|M_{\gamma\gamma}-135|$ for all possible combinations to find out $\pi^0$ candidate for the backgrounds with $\pi^0$ decays. 7) Eclu>130MeV.it well rejects $\eta \rightarrow \gamma\gamma$,$\phi \rightarrow \pi^0\gamma$ and QED process $e^+e^- \rightarrow \gamma\gamma(\gamma)$ backgrounds,while $\eta \rightarrow 3\pi^0$,$\eta \rightarrow \pi^0\gamma\gamma$ and 5 photon backgrounds could be suppressed greatly. 8) $|M_{\pi^0}-140|$>20MeV.All survival MC studied backgrounds have been well reconstructed with $\pi^0$ signals,which are consistent with DATA distribution while no $\pi^0$ signal in MC signal sample,see Figure 1. 9)$|M_\eta - 550|$<45MeV. This cut is just to determine $M_\eta$ spectrum fit range.DATA $M_\eta$ spectrum is well approximated as a linear shape.MC studies indicate that:$\phi \rightarrow \rho^0\pi^0$,$\phi \rightarrow \eta\pi^0\gamma$, $\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ and $e^+e^- \rightarrow \omega\pi^0$ 5 photon final state backgrounds are dominant,their $M_\eta$ spectrum are linear while $\eta \rightarrow 3\pi^0$ spectrum is approximately linear(about 5% of the total background) and $\eta \rightarrow \pi^0\gamma\gamma$(about 6% of the total backround) has a peak around 545MeV upon its wide distribution.

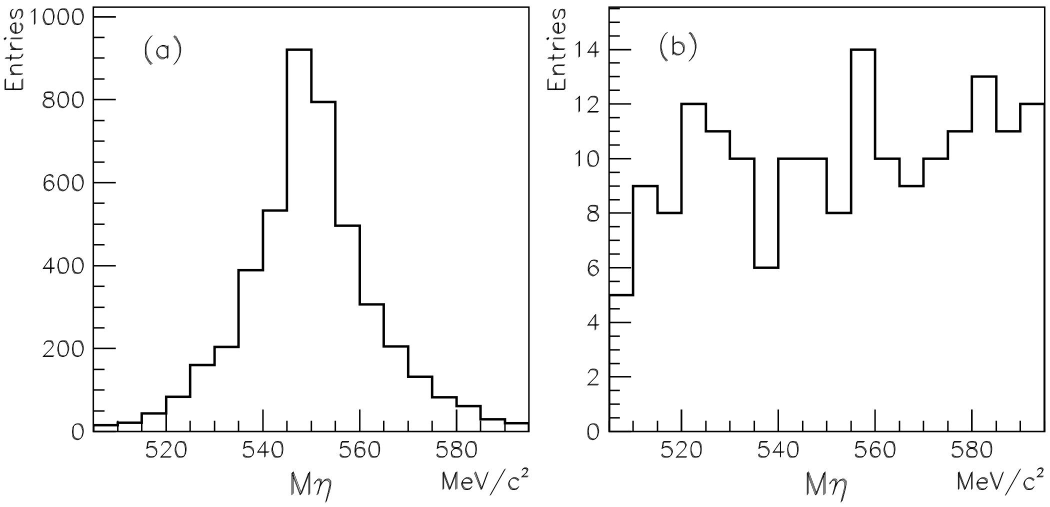


Figure 2: $\eta$ candidates mass spectrum a): MC ; b): DATA

# 3 Result

Finally, 179 events are survival in the data sample,MC total efficiency is 15%.The data and MC $M_\eta$ spectrums are shown in Figure 2.Using MINUIT to minimize the following $l(a_0, a_1, f_s)$,the double negative logarithm of the unbinned likelihood function of data $M_\eta$ spectrum to abstract the signal events number:

$$l(a_0, a_1, f_s) = -2\sum_i logL_i, i = 179 \tag{2}$$

$$L_i(a_0, a_1, f_s, M_i) = (1 - f_s) \times BCK_i + f_s \times SN_i \tag{3}$$

$$BCK_i(a_0, a_1, M_i) = (a_0 + a_1 \times M_i)/con_1 \tag{4}$$

$$con_1 = a_0(M_h - M_l) + a_1(M_h^2 - M_l^2)/2, M_h, M_l = 595, 505MeV \tag{5}$$

$$SN_i(f_s, M_i) = con_2 \times e^{-(Mi-M_\eta)^2/2\sigma_\eta^2}, con_2 = 1/\sqrt{2\pi}\sigma_\eta \tag{6}$$

Taking the signal Gaussian shape as $M_\eta$=549.45MeV,$\sigma_\eta$=12.868MeV of MC signal $M_\eta$ Gaussian fit result,MINUIT fitting results are in Table 1 and 2.

Table. 1 Correlation Coefficients

| | Global | $a_0$ | $a_1$ | $f_s$ |
|---|---|---|---|---|
| $a_0$ | 0.90727 | 1.000 | -0.907 | -0.013 |
| $a_1$ | 0.90727 | -0.907 | 1.000 | -0.011 |
| $f_s$ | 0.05513 | -0.013 | -0.011 | 1.000 |

Table. 2 MINUIT Fitting Result

| | $a_0$ | $a_1$ | $f_s$ |
|---|---|---|---|
| Value | -0.26163974516801 | 7.8270350319644D-04 | -6.4771471145967D-03 |
| Error | 0.24814243036885 | 7.4202724823991D-04 | 7.5795728940287D-02 |

Practically,only $f_s$ has an important physical significance since it relates with the signal events number,while $a_0, a_1$ just relate with the background shape description.In order to test stability of the value and its standard deviation of fitted $f_s$ in table 2,let only $f_s$ parameter could be fitted by MINUIT while $a_0$,$a_1$ parameters are fixed as their fitted values in table 2, the result indicates that both $f_s$ and its standard deviation are consistent with the values in table 2 within a difference less than 0.2%.Futher to check $f_s$ stability related with $a_0$ and $a_1$,just make MINUIT to fit $f_s$ under fixing $a_0$,$a_1$ values as $a_0 + s_{a_0}\sigma_{a_0}$ and $a_1 + s_{a_1}\sigma_{a_1}$($a_0$,$\sigma_{a_0}$,$a_1$,$\sigma_{a_1}$ values are taken from table 2) respectively,the results is in Table 3 :

Table. 3 $f_s$ stability relative to $(a_0, a_1)$

| $(s_{a_0}, s_{a_1})$ | $f_s$ | $\sigma_{f_s}$ |
|---|---|---|
| (+2,+2) | -9.2707507868245D-03 | 7.5666677774613D-02 |
| (+2,-2) | -6.4658893722043D-03 | 7.5680953757397D-02 |
| (-2,+2) | -6.4720658987988D-03 | 7.5680311499078D-02 |
| (-2,-2) | -9.4611713678839D-03 | 7.5668953975753D-02 |

Over all the $f_s$ value and its standard deviation in Table 2 are reliable,then $\eta \to 3\gamma$ signal events number:N$_s$ = $(N_{obs} \times f_s)^{+}_{-}(N_{obs} \times \sigma_{f_s}) = -1.1594^{+}_{-}13.567$,N$_{obs}$= 179 events.$f_s$ and $\sigma_{f_s}$ take the values in table 2.The contribution of $\sigma_{N_{obs}} \times f_s$ to $\sigma_{N_s}$ is well omitted.The formula of $\eta \to \gamma\gamma\gamma$ upper limit calculation is as follows:

$$Br(\eta \to \gamma\gamma\gamma) < N_U/(N_\eta \times \epsilon) \tag{7}$$

$N_\eta$=2.567 $\times$ $10^6$ events($\sigma_\phi$=3300nb; Br($\phi \to \eta\gamma$)= 1.298%, PDG2001), Total analysis efficiency:$\epsilon$=15%. The upper limit of the signal number:$N_U$= -1.1594+ 1.64$\times$13.567 =21.09 events(95% CL); $N_U$=-1.1594+1.28$\times$13.567= 16.21 events (90% CL),so the upper limit of $\eta \to \gamma\gamma\gamma$ decay is:

Br($\eta \to \gamma\gamma\gamma$)<5.5$\times 10^{-5}$ (95% CL)

Br($\eta \to \gamma\gamma\gamma$)<4.2$\times 10^{-5}$ (90% CL)

# 4 CONCLUSION

In this analysis,no convincing event of $\eta \to \gamma\gamma\gamma$ decay is observed in the KLOE data sample of 2.57 $\times$ $10^6$ $\eta$ events,The upper limits under 95% CL and 90% CL have to be determined for $\eta \to \gamma\gamma\gamma$ decay,they are consistent with the theoretical predictions.So no C-violating phenomenon is observed in this study.

# References


[1] P. Herczeg, in Production and Decay of Light Mesons ,P. Fleury,World Scientific, 1988, P16.

[2] S. Kullander et al.,ACTA Phys. Polonica B 29 (1998) P97-111.

[3] A. Calcacatera et al., Nucl. Instr. and Meth. A 367 (1995) P104-107.
J. Lee-Franzini et al., Nucl. Instr. and Meth. A 360 (1995) P201-205.
M. Adinolfi et al., Nucl. Instr. and Meth. A 482 (2002) P363-385.

[4] D. Alde et al.,Z. Phys. C-Particle and Field 25 (1984) P225-229.

[5] B.M.K. NEFKENS and A.B. Strarostin,ACTA Phys. Polonica B 31 (2000) P2669-2681. Presented at the Meson 2000,Sixth International Workshop on Production,Properties and Interaction of Meson,Cracow,Poland,May 19-23,2000.