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

Workshop on production and decay of η and η' mesons
Krakow 16 -17 Septemeber 2005

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for the KLOE collaboration

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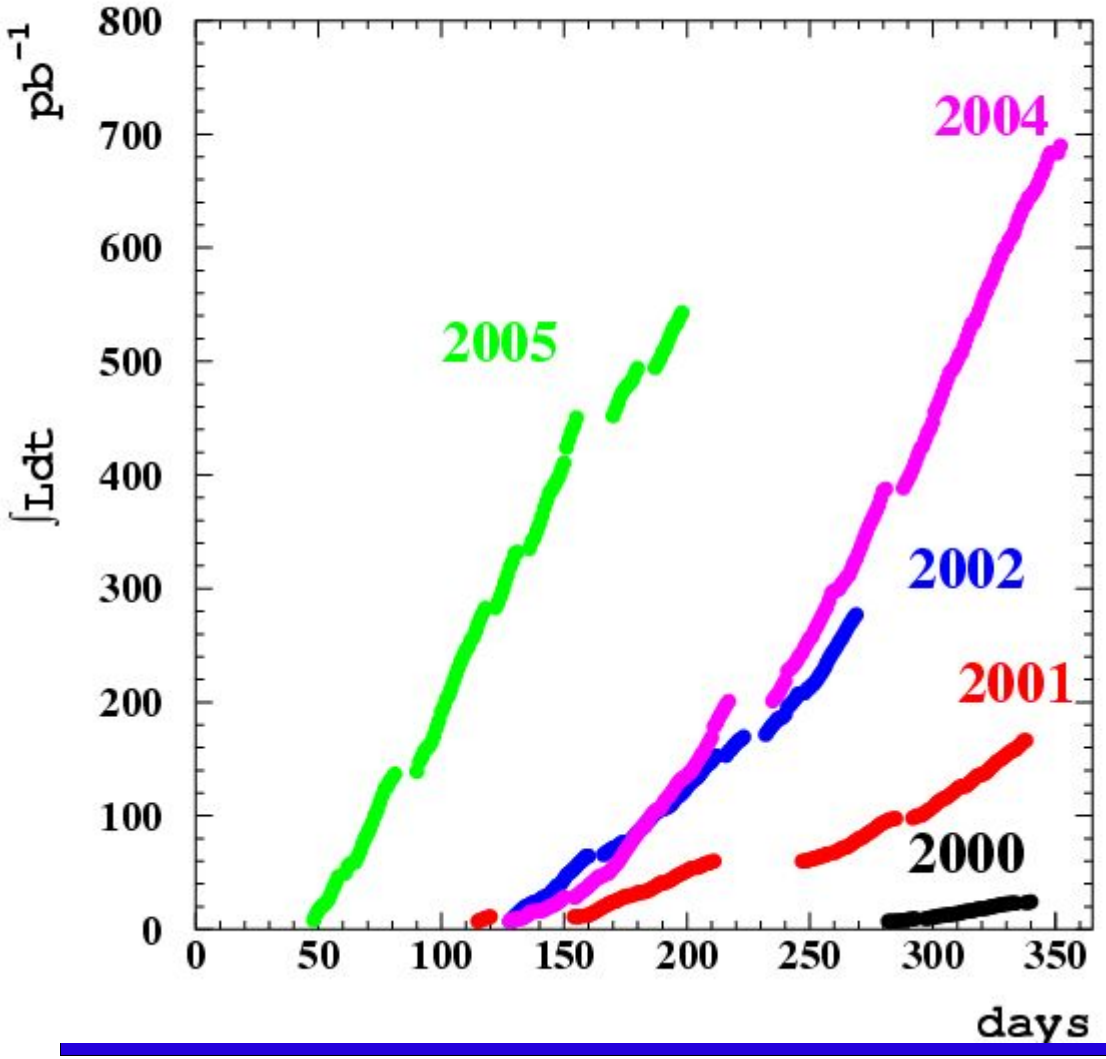
Integrated luminosity

$\sqrt{s} = M_\Phi = 1.02$ GeV $\sigma(\Phi) \approx 3$ μb

e^+e^- in two separate rings with crossing angle ~25mrad at IP (small Φ momentum p_Φ~13MeV)

Int. Lum.	pb^{-1}
2001+2002	450
2004+2005	1300
end data taking December 2005	2500



Decay	BR(%)
$\phi \to K^+ K^-$	49.1
$\phi \to K_S K_L$	33.8
$\phi \to \pi^+\pi^-\pi^0$	15.6
$\phi \to \eta \gamma$	1.26

on tape

5.6×10^9 φ $1.9\times10^9 K_S K_L$

2.8×10^9 $K^\pm$ 70×10^6 η

The KLOE detector

Electromagnetic Calorimeter (EMC)

Fine sampling Pb (0.5 mm thick) / Scifi (1 mm ø)

Hermetical coverage

High efficiency for low energy photons

$\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$

$\sigma_t = 54ps/\sqrt{E(GeV)}$

Central drift chamber (DCH)

Large detection volume

Uniform tracking and vertexing in all volume

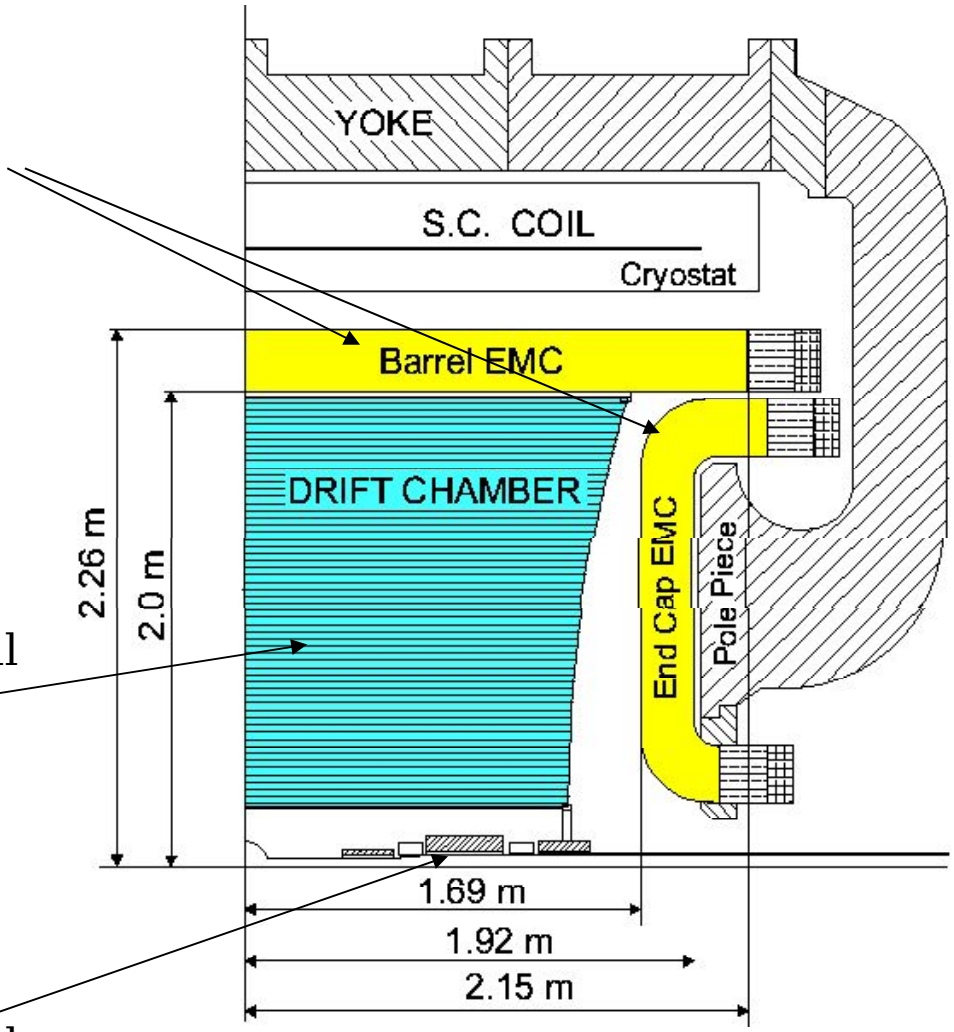
Helium based gas mixture

$\sigma_v = 1$ mm $\quad \sigma_{pt}/p_t = 0.5\%$

$\sigma_{r,\phi} = 200$ μm $\quad \sigma_z = 2$ mm

Quadrupoles' calorimeter (QCAL)

Pb/Sci tile calorimeter covering quads inside KLOE



Outline

- $Br(\phi \to \eta'\gamma)/Br(\phi \to \eta\gamma)$ with $\pi^+ \pi^- 7\gamma$ final state;
- $Br(\eta \to \pi^0 \gamma\gamma)$ measurement;
- η mass measurement.

Br($\phi \to \eta' \gamma$)/Br($\phi \to \eta\gamma$) event selection

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

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

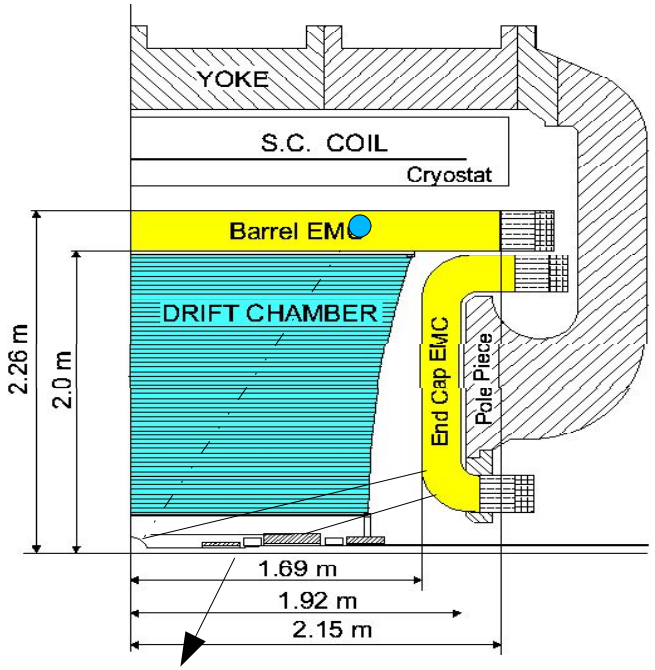
$\phi \to \eta\gamma$, $\eta \to 3\pi^0$, $\pi^0 \to \gamma\gamma$

Signal selection

select particle coming from the I.P

- charged vertex in a cylinder with a 4 cm radius and a 16 cm height around the interaction point;
- 7 prompt photons $|t - r/c| < 5\sigma_t$;
- $21° < \theta_\gamma < 159°$
- anti $K_S K_L$ tag.

identification of photons coming from the I.P (powerful thanks to the optimum calorimeter time resolution)



Background source together beam background.

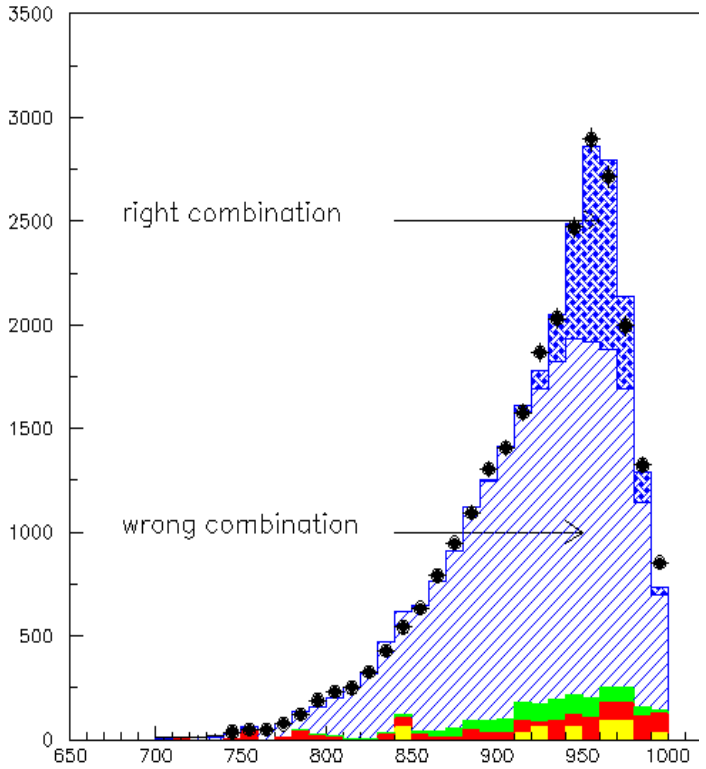
Signal extraction

$\phi \rightarrow \eta' \gamma,\ \eta' \rightarrow \pi^+ \pi^- 6\gamma$

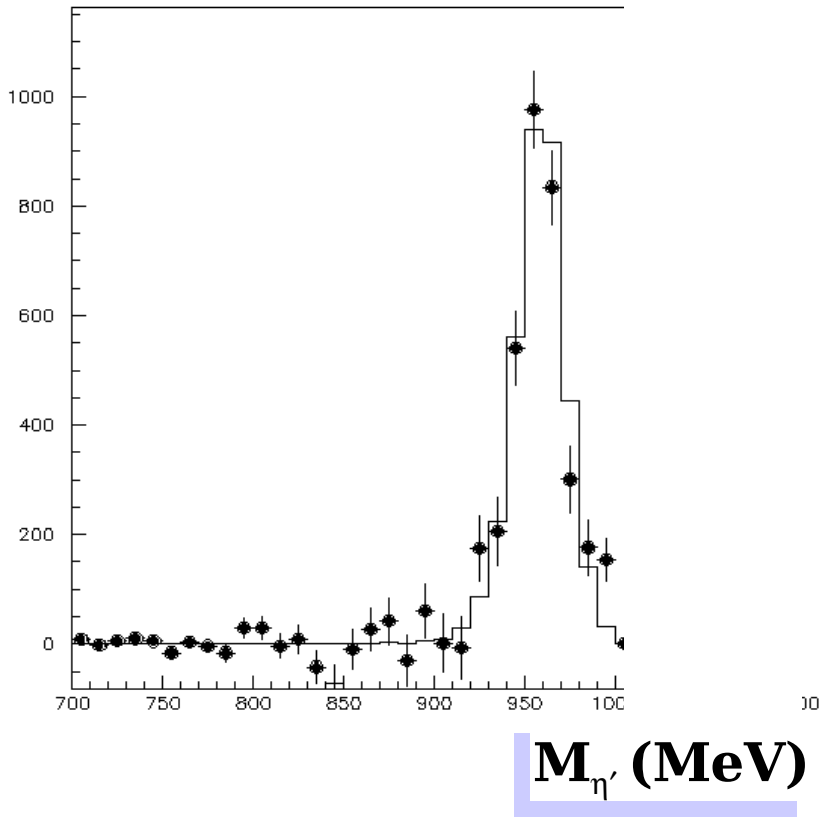
wrong combination

n. obs. events	3750
n. estim. bkg	345
n. signal (N_{obs} - N_{bkg})	$3405 \pm 65_{stat} \pm 28_{syst}$

- **Ks**$\rightarrow \pi^+ \pi^-$ **Kl**$\rightarrow \pi^0 \pi^0 \pi^0$
- **Ks**$\rightarrow \pi^0 \pi^0$ **Kl**$\rightarrow \pi^+ \pi^- \pi^0$
- **Ks**$\rightarrow \pi^+ \pi^- \gamma$ **Kl**$\rightarrow \pi^0 \pi^0 \pi^0$
- Signal



η' mass distribution after subtraction



Preliminary result

$$\mathcal{R} = \frac{\mathcal{BR}(\phi \to \eta'\gamma)}{\mathcal{BR}(\phi \to \eta\gamma)} = \frac{\mathcal{N}^{\eta'\gamma}}{\mathcal{N}^{\eta\gamma}} \left[\frac{\varepsilon^{\eta\gamma}_{MC}\, \mathcal{BR}(\eta \to 3\pi^0)}{\mathcal{BR}_{erg}\, \varepsilon_{crgMC} + \mathcal{BR}_{ntr}\, \varepsilon_{ntrMC}} \right] \cdot \frac{\varepsilon^{\eta\gamma}_{\mathcal{F}/\mathcal{E}\mathcal{R}\mathcal{D}}}{\varepsilon^{\eta'\gamma}_{\mathcal{F}/\mathcal{E}\mathcal{R}\mathcal{D}}} \cdot \mathcal{K}_\rho$$

n. $\eta \to 3\pi^0$ 1665000±1300

where
$$\begin{cases} \mathcal{BR}_{erg} = \mathcal{BR}(\eta' \to \pi^+\pi^-\eta) \cdot \mathcal{BR}(\eta \to \pi^0\pi^0\pi^0) \\ \mathcal{BR}_{nrt} = \mathcal{BR}(\eta' \to \pi^0\pi^0\eta) \cdot \mathcal{BR}(\eta \to \pi^+\pi^-\pi^0) \end{cases}$$

Previous KLOE result

$$\mathcal{R} = (4.76 \pm 0.08 \pm 0.20) \cdot 10^{-3}$$

$Br(\phi\to\eta'\gamma)/Br(\phi\to\eta\gamma) = 4.70 \pm 0.47 \pm 0.31$
Phys. Lett. B541 (2002) 45-51

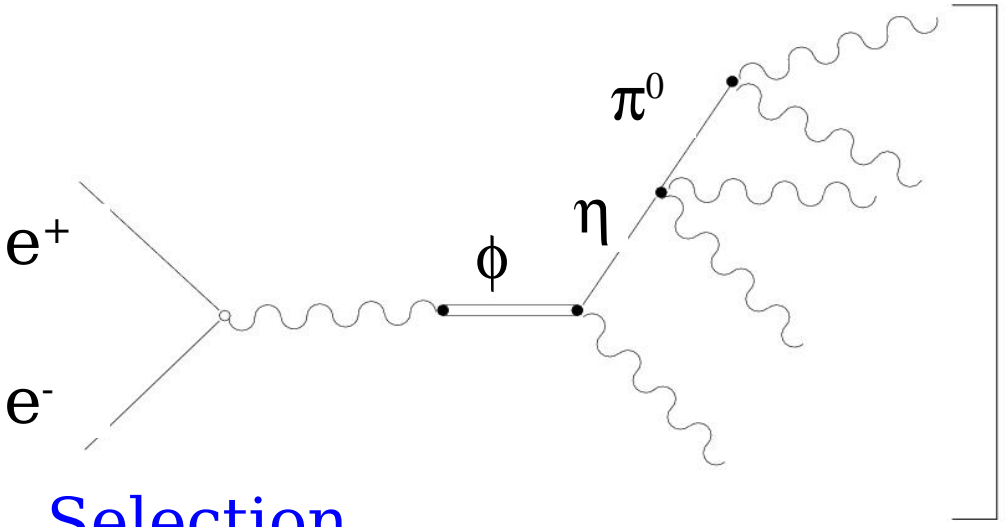
$1\% \oplus 1.3\% \oplus 1.4 \oplus 0.08\% \oplus 0.4\% \oplus 1.5\% \oplus 3\%$

Filfo-EVCL TRK VTX Bg εη/εη' χ2 BR"

$\varphi_P = (41.3^{+2.0}_{-0.6})^\circ$

syst. dominated by the uncertainties on $Br(\eta'\to\eta\pi^+\pi^-)$ and $Br(\eta'\to\eta\pi^0\pi^0)$
We will measure them with 2 fb^{-1}

$Br(\eta \to \pi^0 \gamma\gamma)$ background and selection



5γ final state

Selection

- 5 prompt photons
- Total energy > 800 MeV
- $21^o < \theta_\gamma < 159^o$
- kinematic fit with energy momentum conservation

Prompt photon

$|t - r/c| < \min(5\sigma_t, 2\,ns)$

not associated to a charged track

Main background

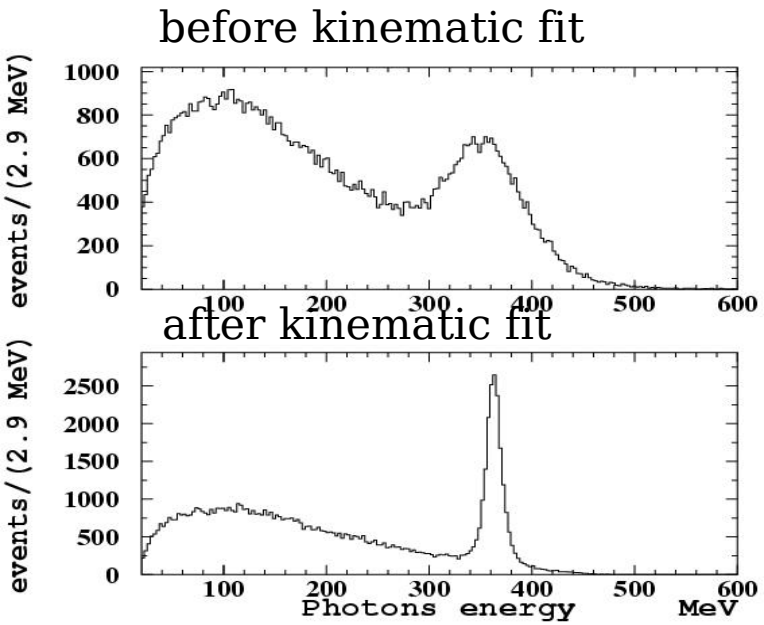
$$\phi \to f_0(\to\pi^0\pi^0)\gamma,\ \phi \to a_0(\to\eta\pi^0)\,\gamma$$

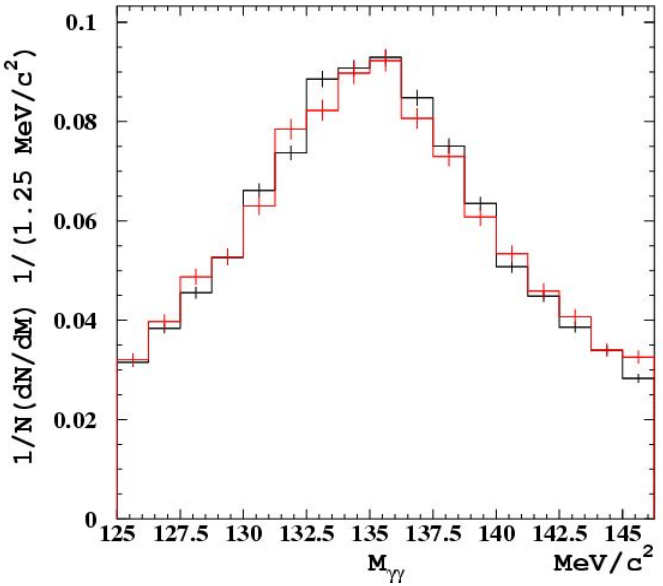
$$e^+\ e^- \to \omega(\to\pi^0\gamma)\pi^0$$

$$\phi \to \eta(\to 3\pi^0)\gamma$$

with lost and merging of photons

Kinematic fit effect





The most energetic photon is in the main part of cases that coming from the $\phi \rightarrow \eta\gamma$ decay (363 MeV)

We build the invariant mass $m_{4\gamma}$ of the 4 least energetic photon.

DATA – MC comparison

DATA

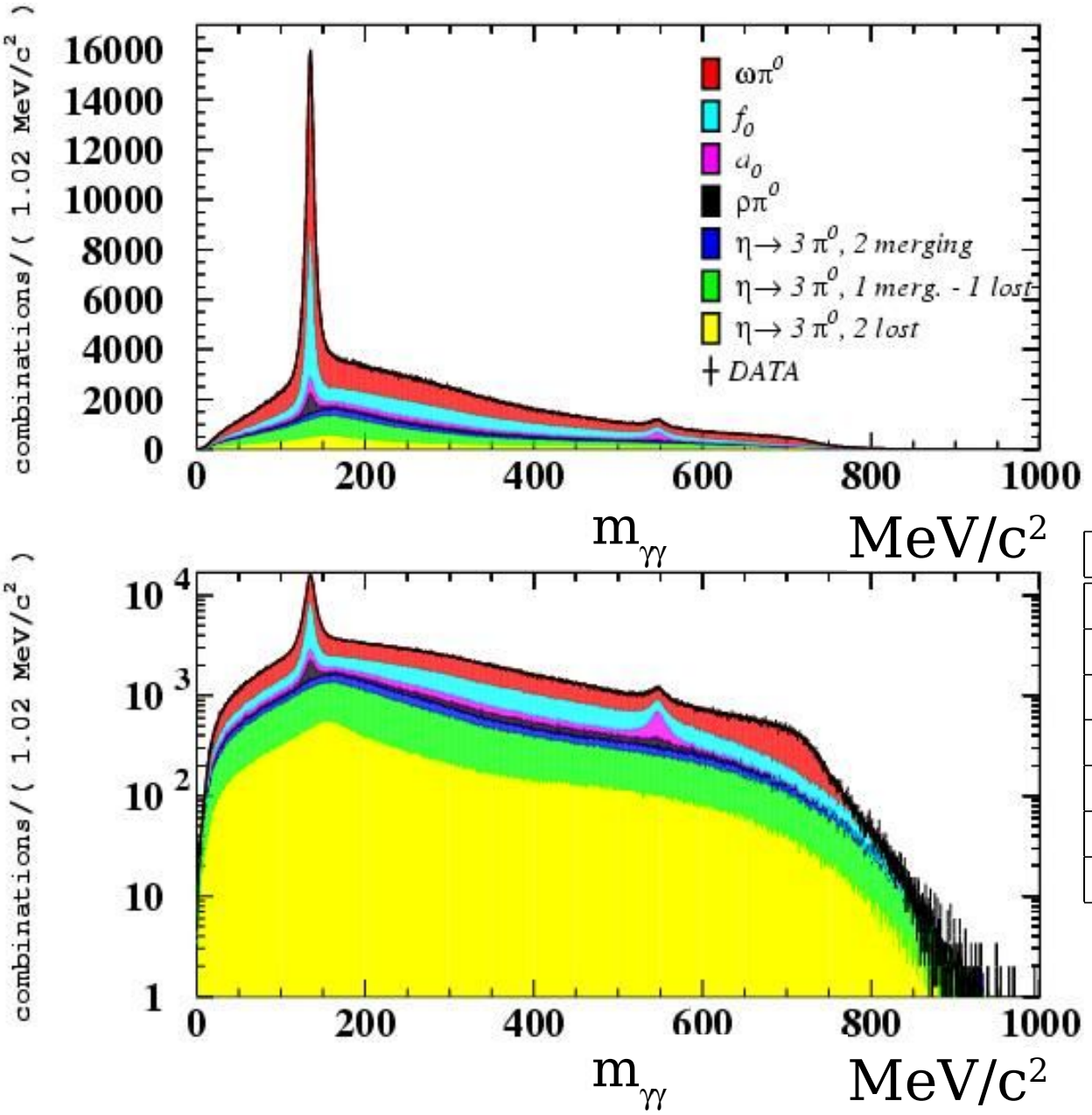
MC

the π^0 peak is well reproduced

$m_\pi(\mathrm{MC}) = 134.93 \pm 0.04\ \mathrm{MeV/c^2}$

$m_\pi(\mathrm{DATA}) = 135.08 \pm 0.07\ \mathrm{MeV/c^2}$

Background composition



Background composition obtained by fitting $m_{\gamma\gamma}$ distribution

Correction factors

Channel	Correction factor
$\omega\pi^0$	0.704 ±0.008
f_0	1.07 ± 0.04
a_0	0.68 ± 0.04
$\rho\pi^0$	0.4 ± 0.1
η 2 merged	2.9 ± 0.3
η 1 lost 1 merged	1.50 ± 0.09
η 2 lost	0.76 ±0.06

~ 900 bins

$\chi^2 = 1.2$

5γ rejection

$\phi \to f_0(\to\pi^0\pi^0)\gamma$

$\phi \to a_0(\to\eta\pi^0)\,\gamma$

$e^+\ e^- \to \omega(\to\pi^0\gamma)\pi^0$

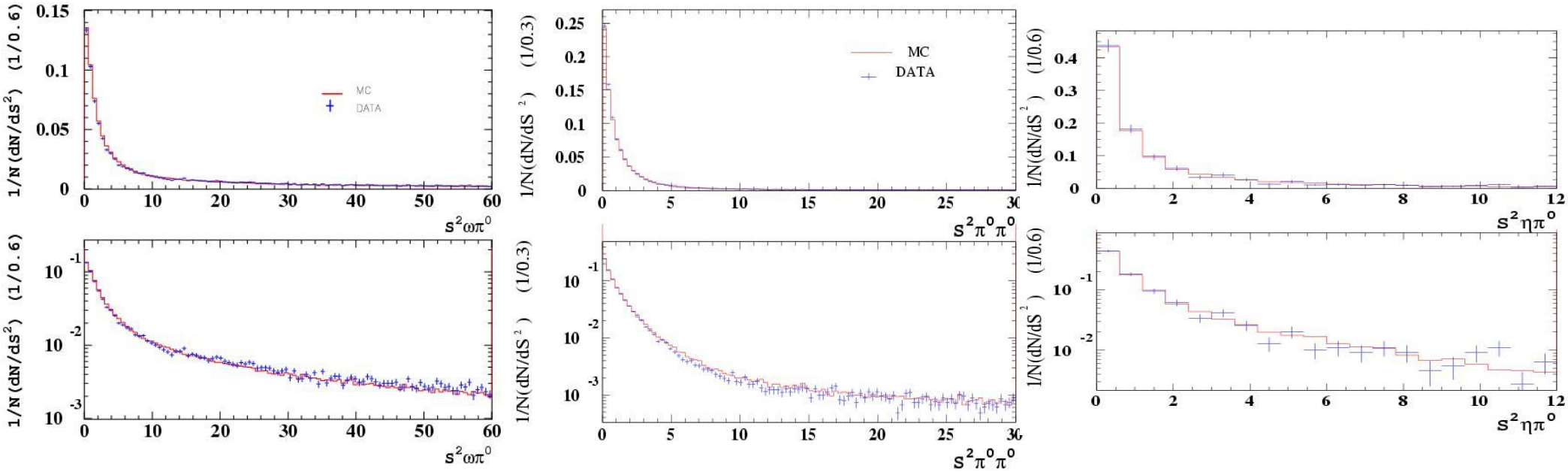
$\phi \to \rho^0(\to\eta\,\gamma)\pi^0, \rho^0(\to\pi^0\gamma)\pi^0$

$$S^2(2\pi^0) = \frac{(m(\gamma_1\gamma_2) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_3\gamma_4) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}}$$

$$S^2(\eta\pi^0) = \frac{(m(\gamma_1\gamma_2) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_3\gamma_4) - m(\eta))^2}{\sigma^2_{m(\eta)}}$$

$$S^2(\omega\pi^0) = \frac{(m(\gamma_1\gamma_2) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_4\gamma_5) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_1\gamma_2\gamma_3) - m(\omega))^2}{\sigma^2_{m(\omega)}}$$

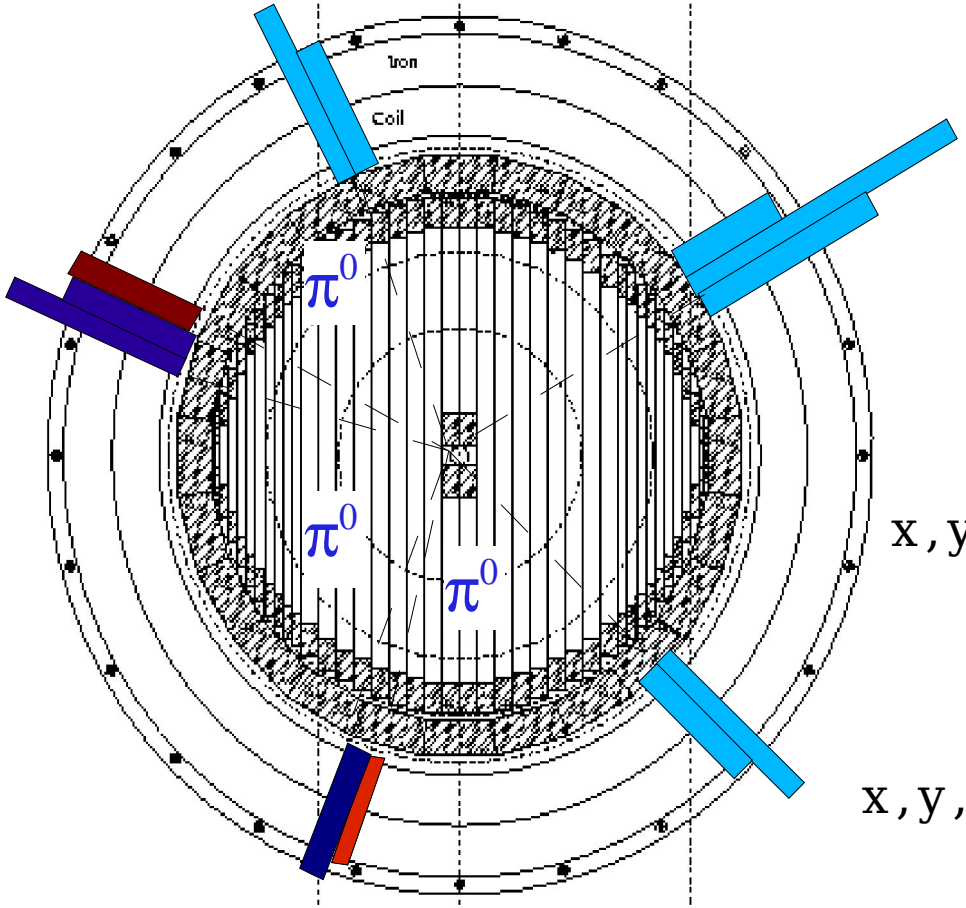
2

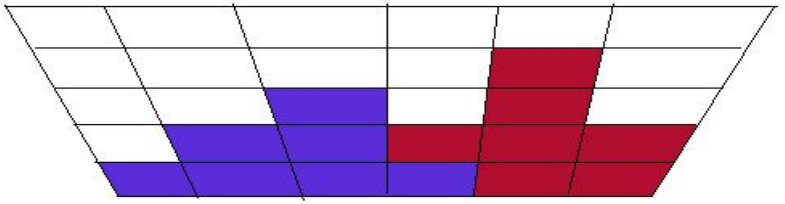


Merged clusters identification

$\phi \rightarrow \eta\gamma_\phi$

$\eta \rightarrow \pi^0\pi^0\pi^0 \quad 7\gamma$





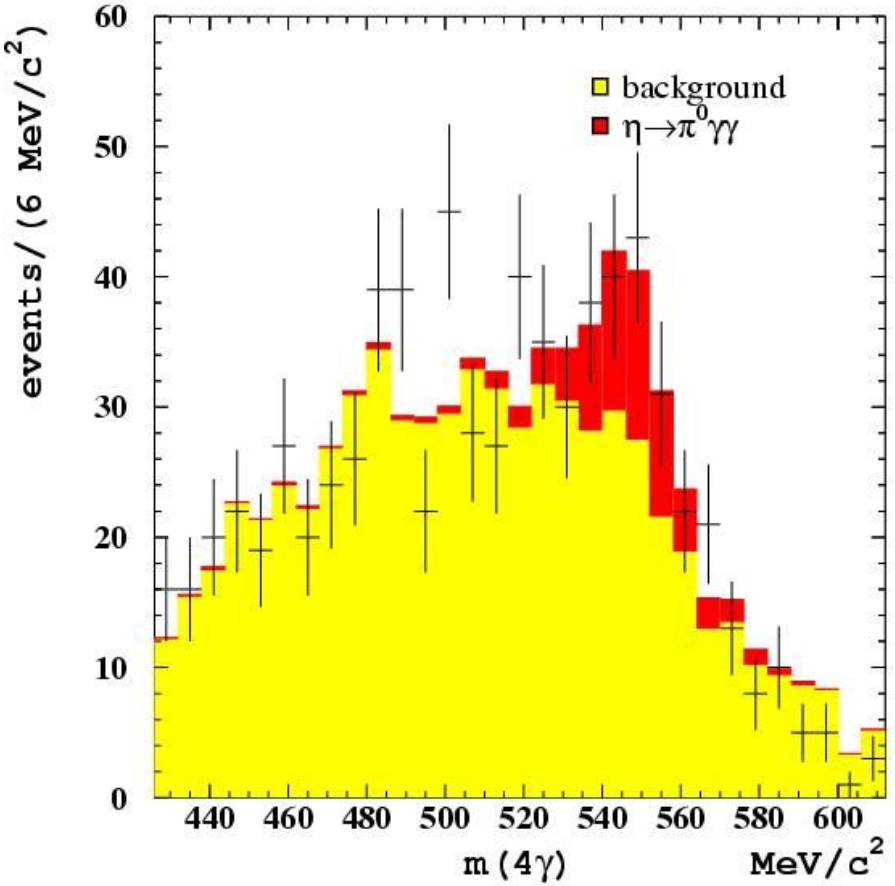
γ_1 γ_2

$$x,y,z,t_{rms} = \frac{\sum_i^{n.cells} E_i \cdot (x_i - x_{mean})^2}{\sum_i^{n.cells} E_i}$$

$$x,y,z,t_{skew} = \frac{\sum_i^{n.cells} (x_i - x_{mean})^3}{\sum_i^{n.cells} E_i}$$

$$r = \log\left(\frac{L^{good}}{L^{merged}}\right)$$

Preliminary results



The shape of background + signal after fit well reproduce the DATA.

$P_{bkg} = 0.907 \pm 0.049$

$P_{sig} = 0.093 \pm 0.031$

$N_{DATA} = 735$

$N_{bkg} = 667 \pm 36$ $\quad N_{sig} = 68 \pm 23$

$\varepsilon(\eta \to \pi^0\gamma\gamma) = 4.63 \pm 0.09$ (only stat)

$N(\eta \to 3\pi^0) = 2288882$

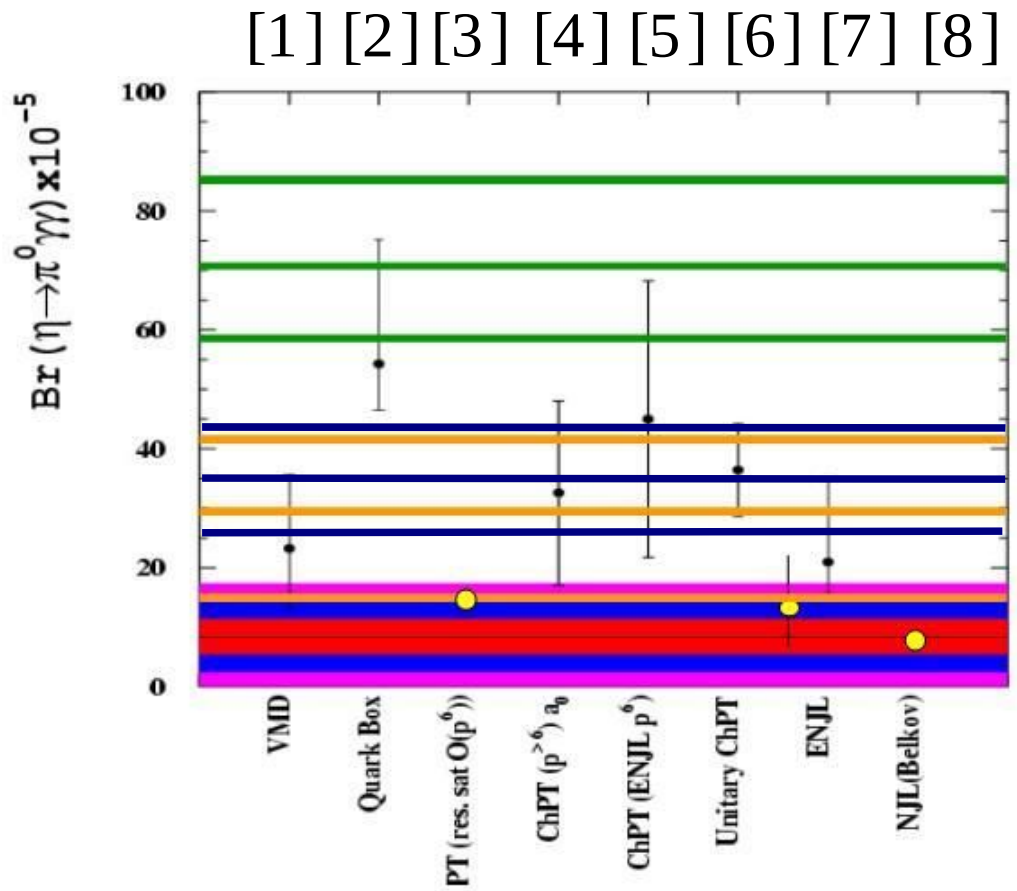
$\varepsilon(\eta \to \pi^0\pi^0\pi^0) = 0.378 \pm 0.08_{syst} \pm 0.01_{stat}$

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

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

Preliminary

Comparison with theory (preliminary)



GAMS (1984)

Crystal Ball (2004 2005)

KLOE

KLOE 1σ
KLOE 2σ
KLOE 3σ
$O(p^6)$ calculations

- **Factor ~ 10 less than GAMS**
- **Marginally compatible with Crystal Ball**
- **Good agreement with $O(p^6)$ calculations**

[1] J.N. Ng and D. J. Peters, Phys. Rev. D46 (1992) 5034

[2] J.N. Ng and D. J. Peters, Phys. Rev. D47 (1993) 4939

[3-4] L. Ametller, J. Bijnens, A. Bramon, F. Cornet, Phys. Lett. B276 (1992)

[5] S. Bellucci and C. Bruno, Nucl. Phys. B452 (1995) 626

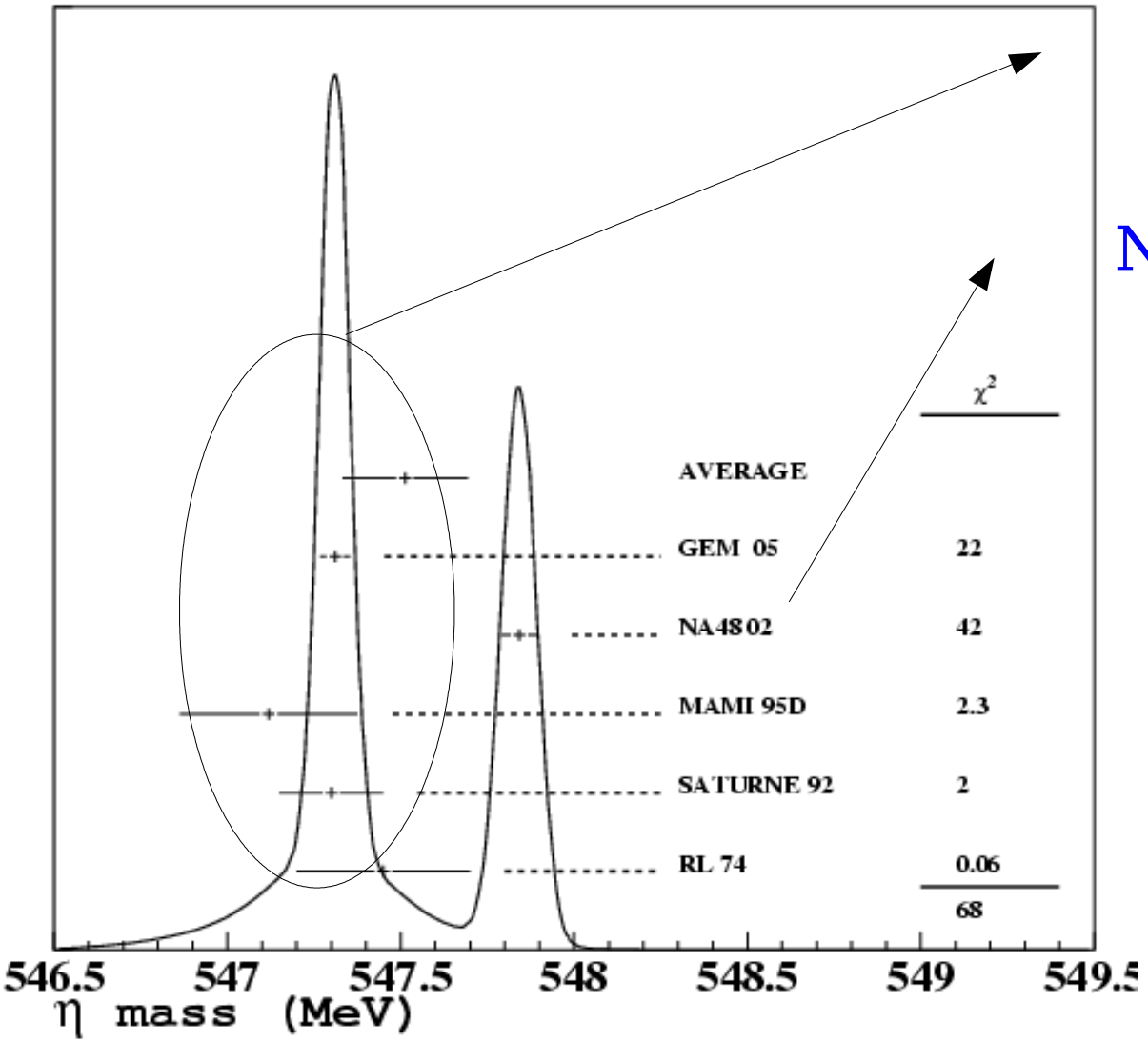
[6] E. Oset, J. R. Pelaź and L. Roca, Phys. Rev. D67 (2003) 073013

[7] J. Bijnens, A. Fayyazuddin and J. Prades, Phys. Lett. B379 (1996) 209

[8] A. A. Belkov, A. V. Lanyov, S. Scherer, J. Phys. G 22 (1996) 1383

η mass actual situation

Very good agreement



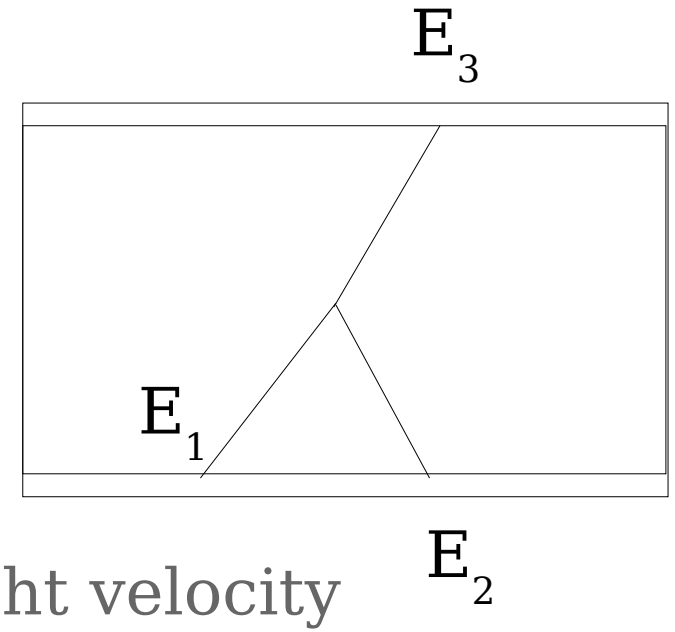
NA48 wrong?

Measurement method

Using the decays:

$\phi \to \eta\gamma$ $\quad\hookrightarrow \gamma\gamma$ $\qquad$ $\phi \to \pi^0\gamma$ $\quad\hookrightarrow \gamma\gamma$

cross checking pourpose



A kinematic fit is performed imposing:

Px,Py,Pz,Etot conservation

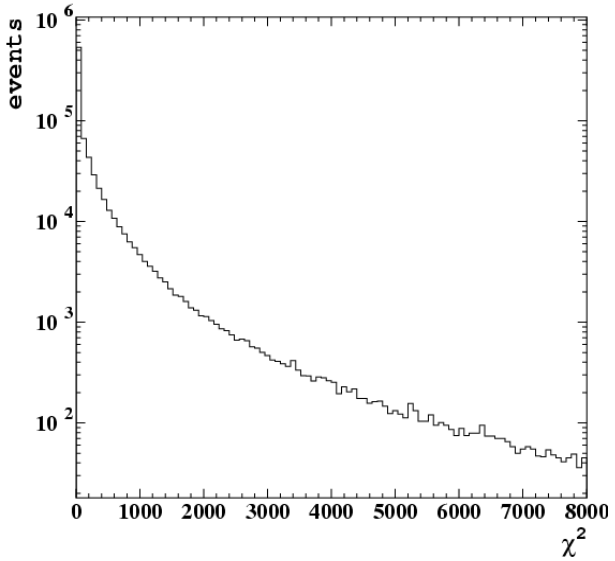
t-r/c of clusters compatible with light velocity

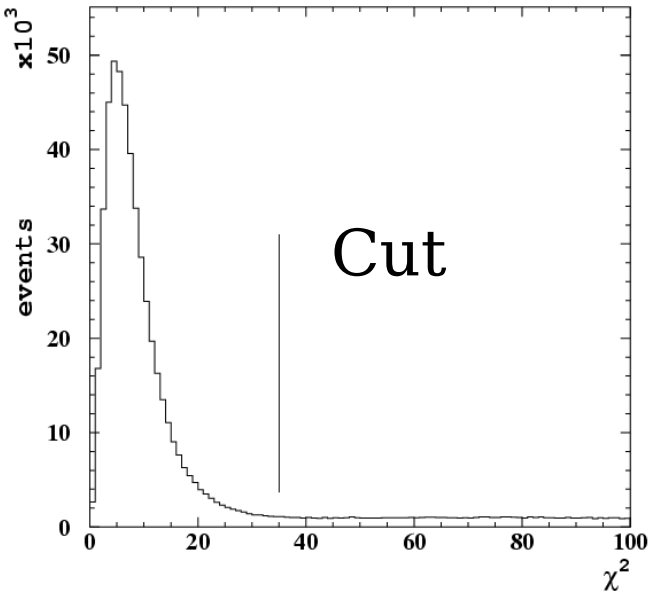
As a consequnce of the kinematic fit the mass measurement is almost independent from the energy of the cluster, it is given by the cluster positions.

The ϕ momentum and the vertex position are very well determined run by run from the study of the Bhabha scattering at large angle $e^+e^- \to e^+e^-$ (90000 events for each run).

Event selection

χ^2 fit distribution

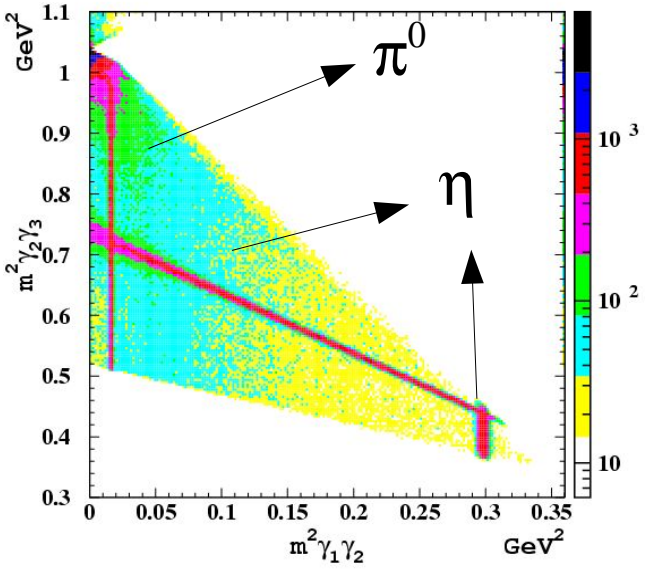


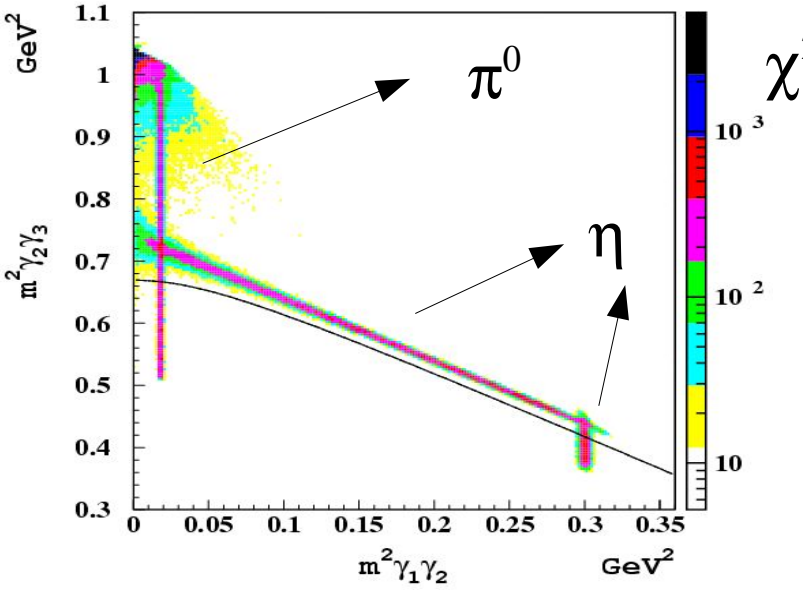


no χ^2 cut

Dalitz plot

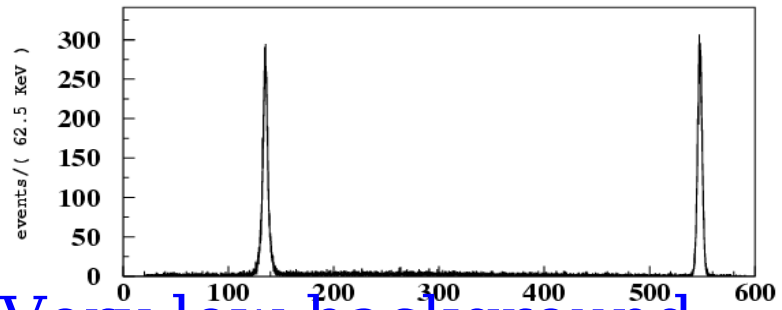
$E_1 < E_2 < E_3$



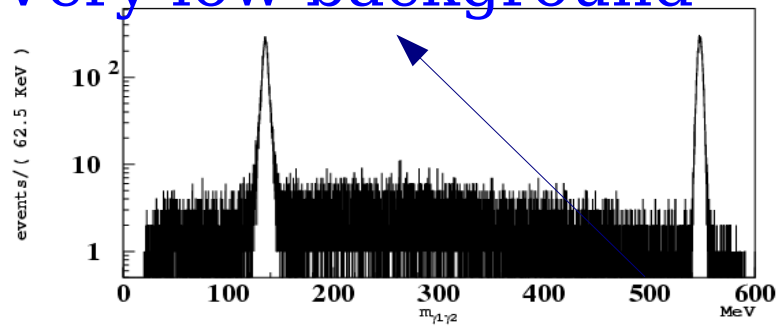


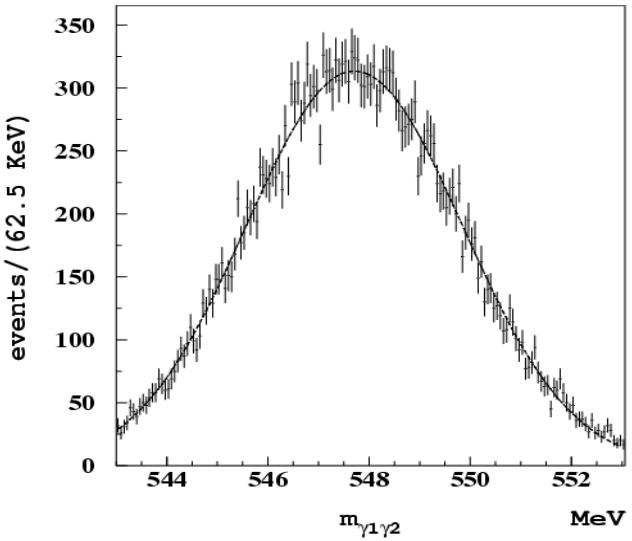
$\chi^2 < 35$

Mass extraction

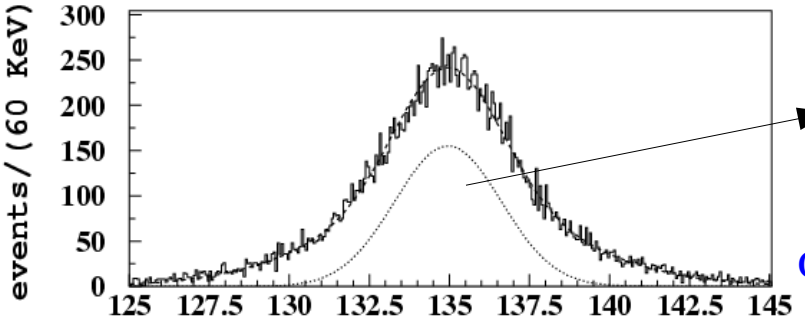


Very low background

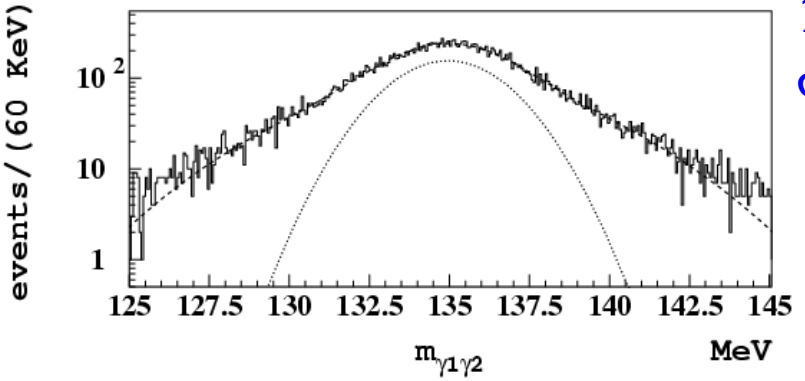




Single gaussian fit



Double gaussian fit



core gaussian mean

134.956 ± 0.018 MeV

$\sigma_{core} = 1.66 \pm 0.05$ MeV

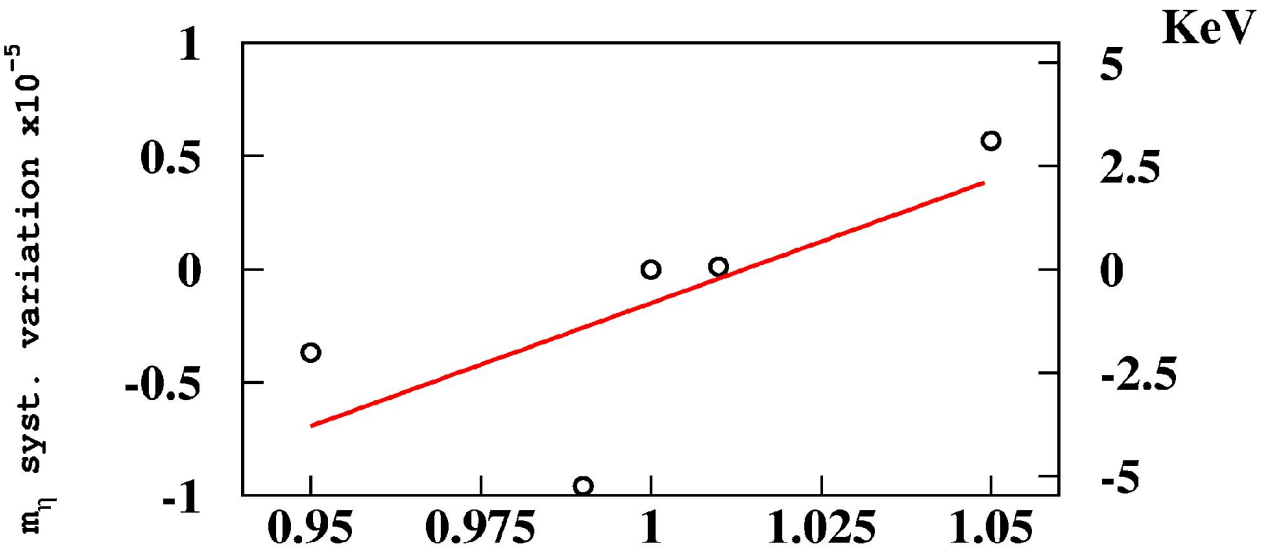
χ^2/n.d.f = 304/257

Mean 547.708 $\pm$ 0.014 MeV

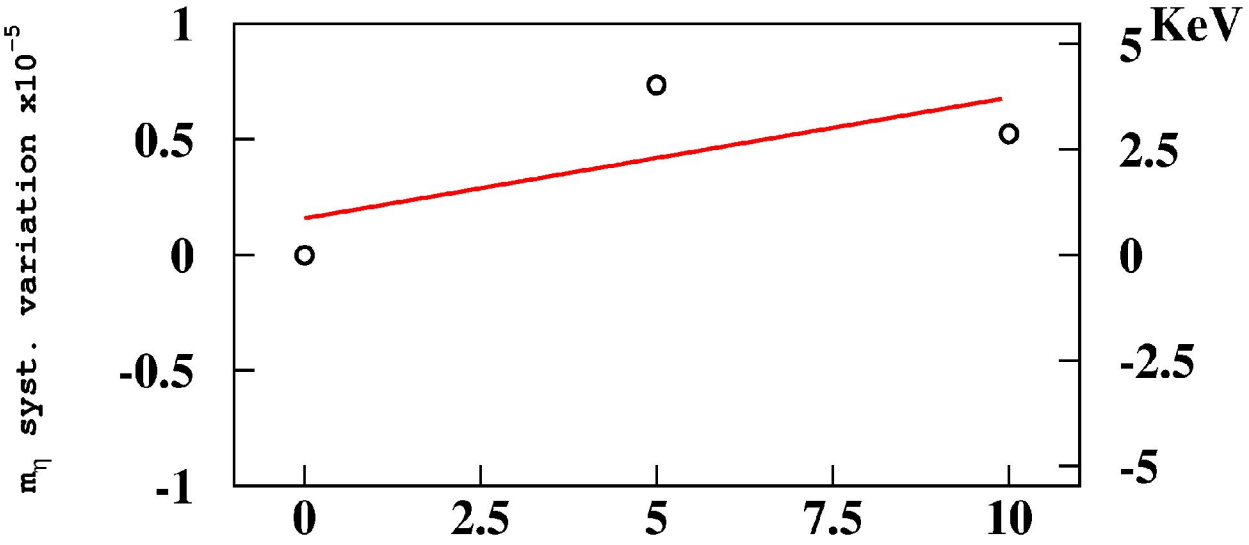
Sigma 2.143 $\pm$ 0.012 MeV

χ^2/n.d.f = 146/161

Energy calibration independence



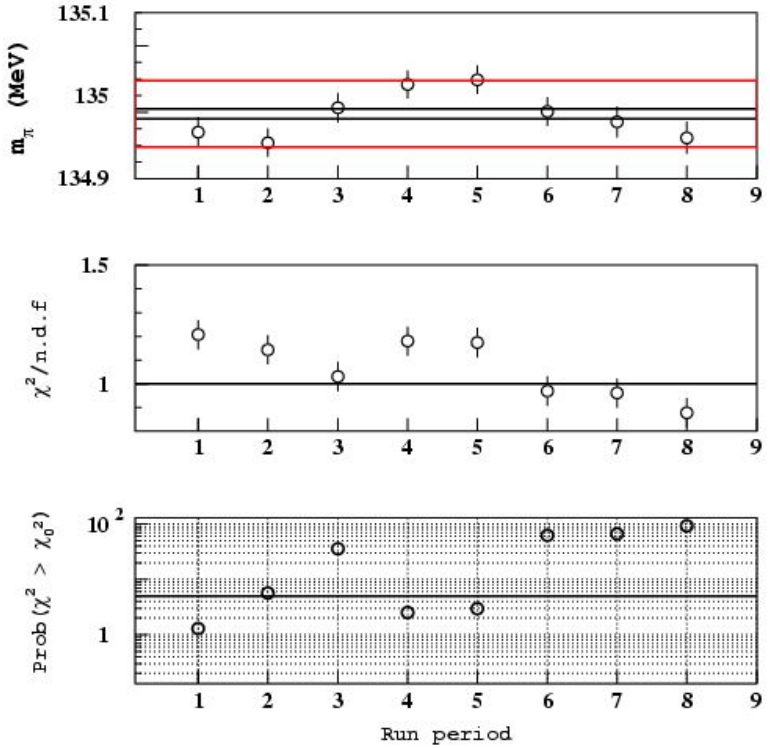
Variation of 5% in the calibration constant produces a tiny effect (10^{-6}) on the measured mass

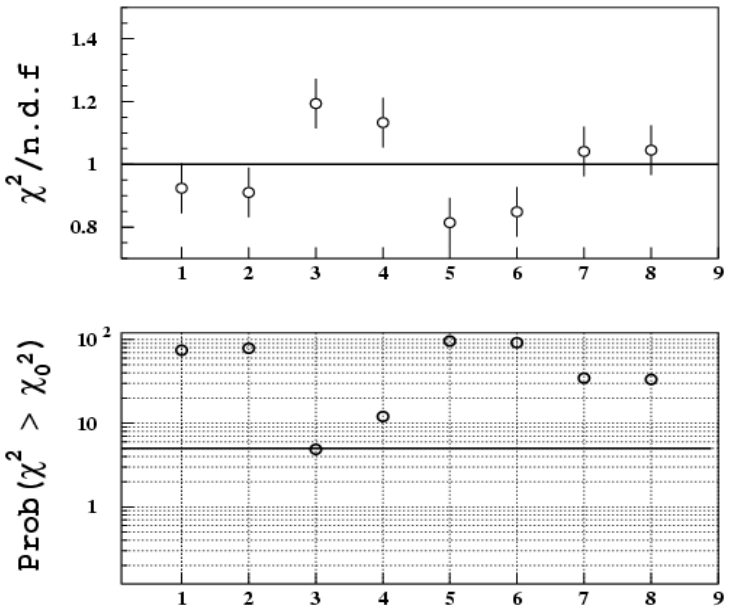


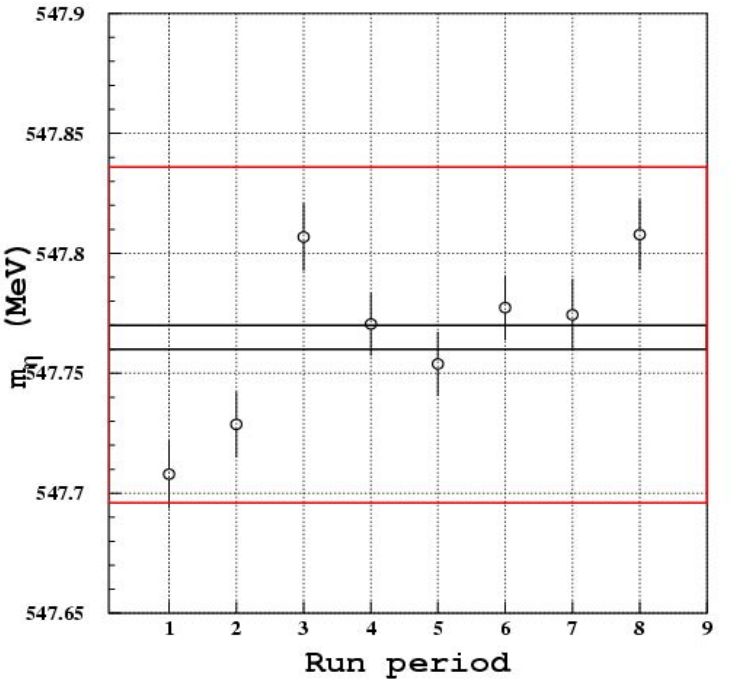
A shift of 10 MeV on the photon energy produces an effect of 4 KeV on the η mass (10^{-6})

Preliminary mass measurement

Data-set divided in 8 periods







$m(\pi^0) = 134990 \pm 6_{stat} \pm 30_{syst}$ KeV

$m(\pi^0)_{PDG} = 134976.6 \pm 0.6$ KeV

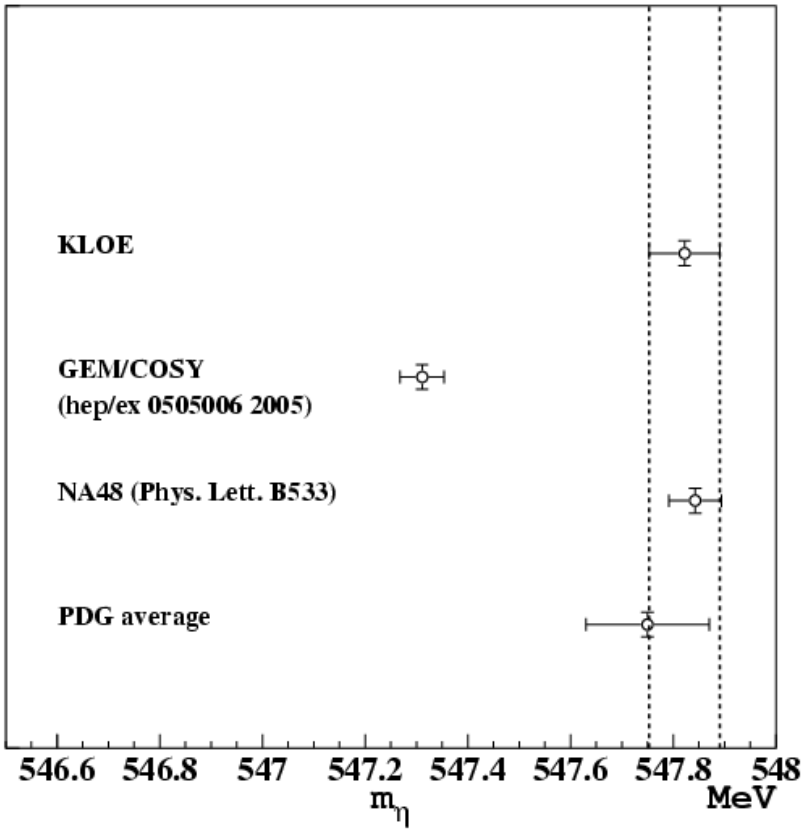
$m(\eta) = 547822 \pm 5_{stat} \pm 69_{syst}$ KeV

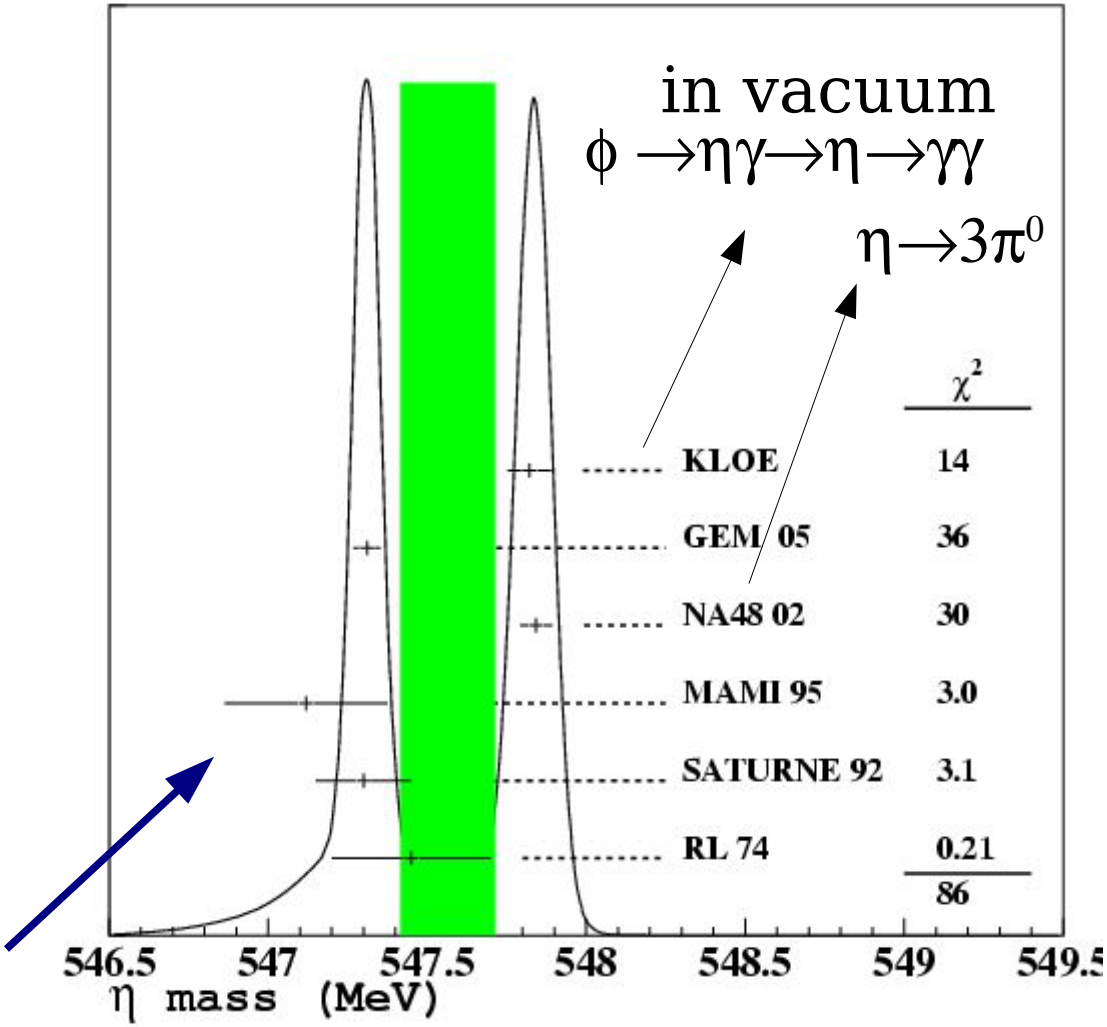
Syst from sqrt(s), vertex position

New situation with KLOE

KLOE PRELIMINARY

NA48 compatibility
0.24 σ





Produced at threshold on nuclear target.

?

Conclusions

- **η decays:**
  - **Preliminary KLOE Br($\eta\to\pi^0\gamma\gamma$) smaller than the previous measurements, final result for the end of this year with 2001+2002 data, to redo with 2fb^{-1} (C. Bloise talk)**
  - **η forbidden decays (not included in this talk)**

  Br($\eta\to\pi^+\pi^-$) < 1.3×10^{-5} @ 90% C.L. [Phys.Lett.B606 (2005) 276]

  Br($\eta\to\gamma\gamma\gamma$) < 1.6 ×10^{-5} @ 90% C.L. [Phys.Lett.B591 (2004) 49]

- **$\phi\to\eta'\gamma$ in $\pi^+\pi^-$ + 7 γ final state, in agreement with the KLOE previous result in $\pi^+\pi^-$ + 3 γ final state;**

- **η mass measurement: KLOE preliminary result is in agreement with NA48 measurement.**