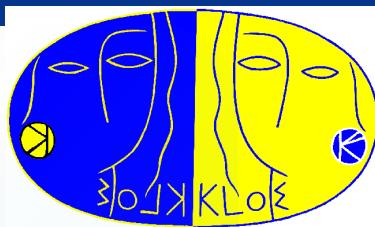


Determination of the BR ratio $R_\phi = \text{Br}(\phi \rightarrow \eta' \gamma) / \text{Br}(\phi \rightarrow \eta \gamma)$
and measurement of the η mass at KLOE.

Biagio Di Micco

for the KLOE collaboration



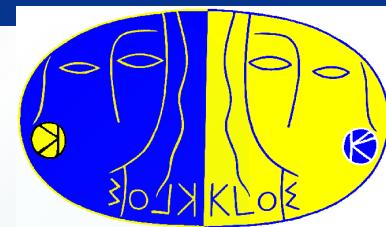
Outline

η mass

- Experimental situation on the measurement of the η mass;
- The KLOE method;
- Analysis selection;
- ISR correction;
- Detector alignment and energy calibration systematics;
- Absolute calibration of the \sqrt{s} with the ϕ line shape;
- results

$R_\phi = \text{Br}(\phi \rightarrow \eta' \gamma) / \text{Br}(\phi \rightarrow \eta \gamma)$ measurement and η' gluonium content

- Measurement of R_ϕ ;
- Extraction of the pseudo-scalar mixing angle ϕ_p and of the η' gluonium content;
- Updates...



η mass – present situation

ABDEL-BARY (GEM) 2005: Phys. Lett. B533, 196
missing mass in $p\bar{d} \rightarrow X(\eta) \ ^3\text{He}^+$

LAI (NA48) 2002: Phys. Lett. B533, 196
measurement using the $\eta \rightarrow 3\pi^0$ decay;

KRUSCHE (MAMI) 1995: Zeit. Phys. A351, 237
Determination of the threshold of the reaction
 $\gamma p \rightarrow \eta p$

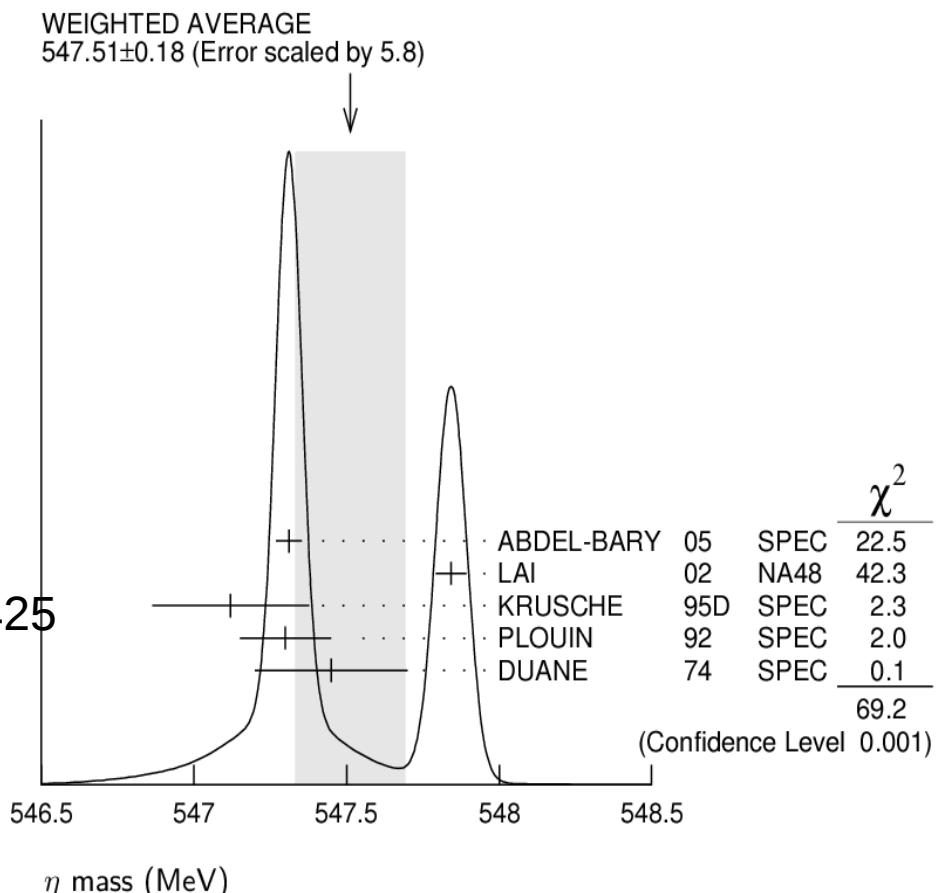
PLOUIN (SATURNE) 1992: Phys. Lett. B276, 526
same of GEM

DUANE (Ruther. Lab) 1974: Phys. Rev. Lett. 32, 425
Missing mass measurement in the
reaction $\pi^- p \rightarrow \eta \eta$

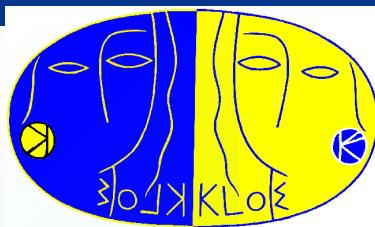
More recent measurements:

KLOE (2006) Acta Phys. Slov. 56, 403 (Eta05)
MAMI (2007) presented at Eta07 (Valencia)

From PDG 2007



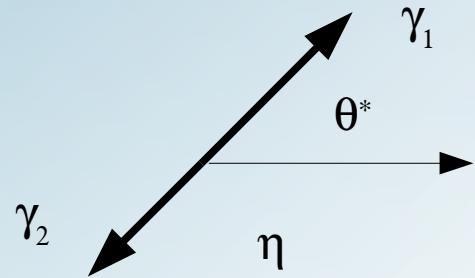
CLEO (2007) PRL99,12002



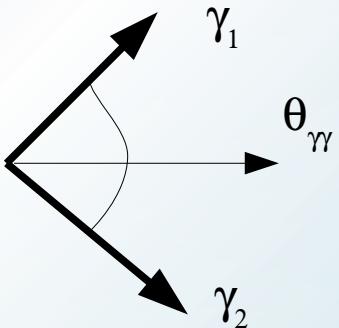
If the world were simple...

Selected sample: $\phi \rightarrow \eta\gamma, \eta \rightarrow \gamma\gamma$

η reference frame



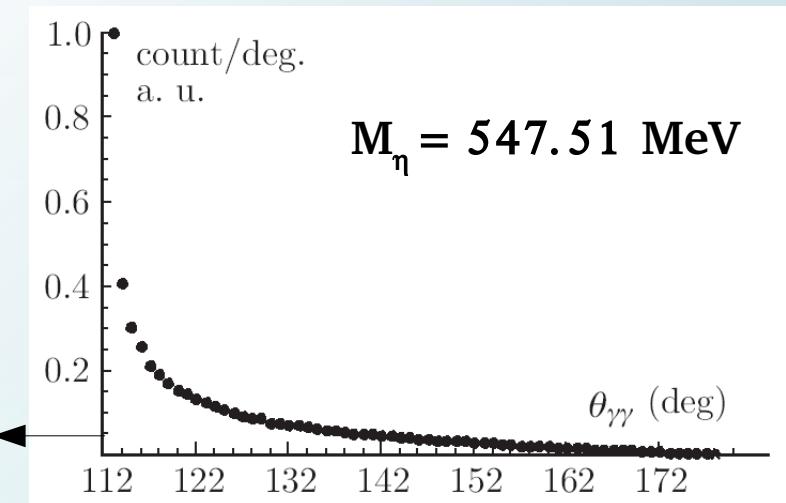
ϕ reference frame

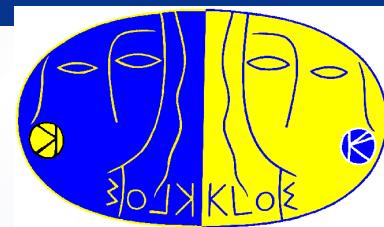


$$\cos\left(\frac{\theta_{\gamma\gamma min}}{2}\right) = \frac{m_\phi^2 - m_\eta^2}{m_\phi^2 + m_\eta^2}$$

The η mass could be evaluated just using the cluster positions.

θ_γ min

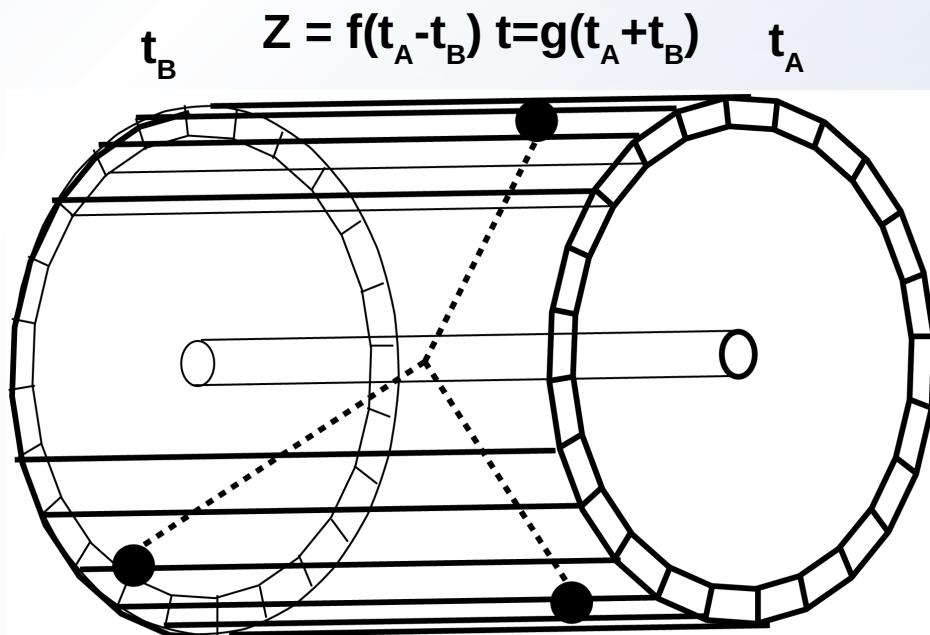
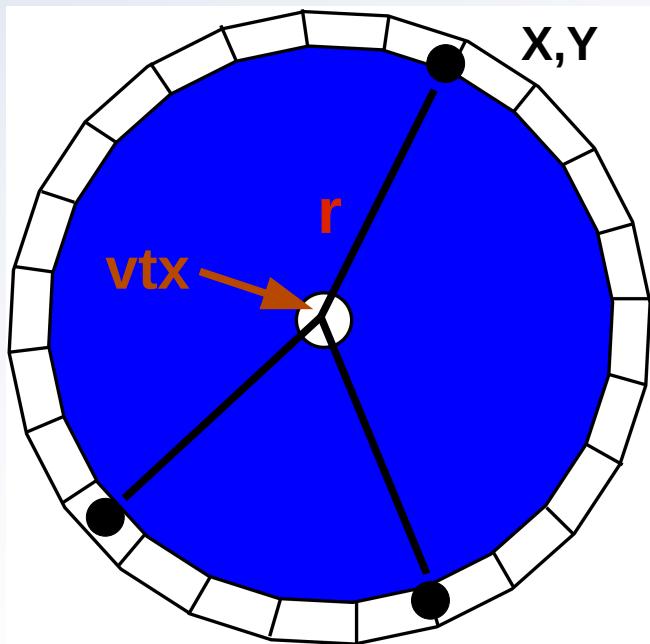


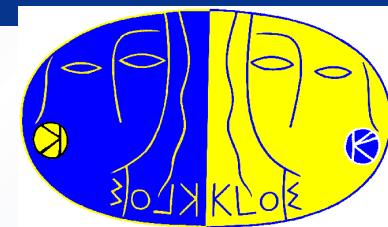


Our technique

- a) Measure the energy, position and times of the photons in the calorimeter;
- b) Measure the mean energy, momentum and vertex position of e^+e^- beam;
- c) Perform a kinematic fit imposing the following constraints:

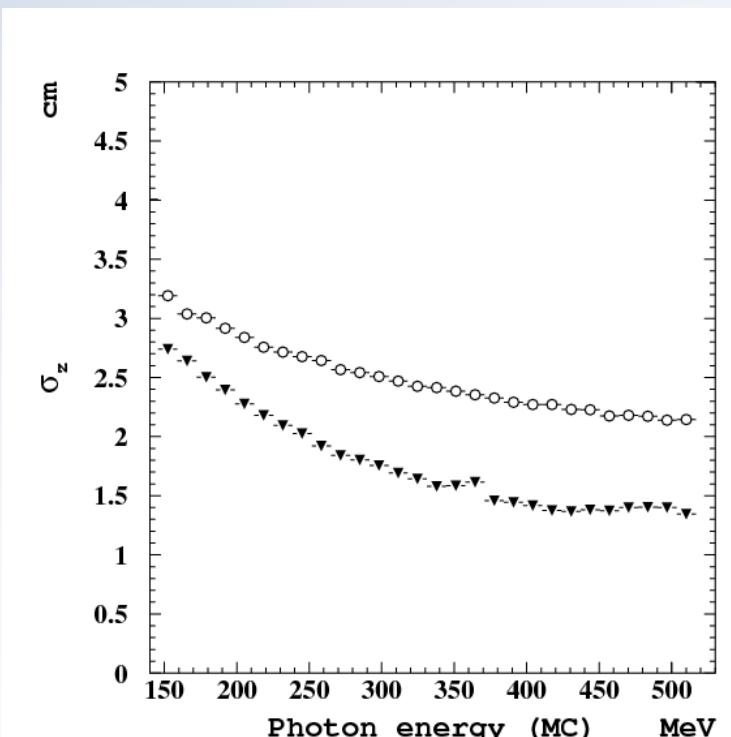
$$1. \beta_\gamma(1,2,3) = 1 \quad (t_{1,2,3} - r_{1,2,3}/c = 0) \quad 2. E_{3\gamma} = E_\phi, \vec{p}_{3\gamma} = \vec{p}_\phi$$



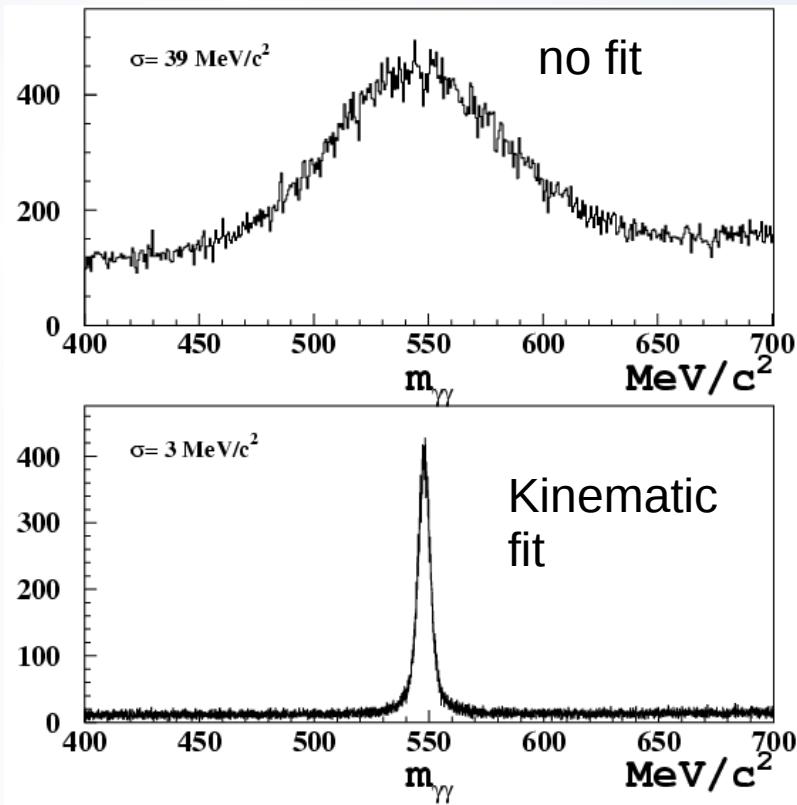


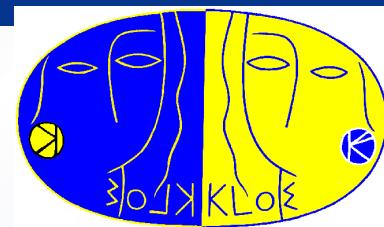
Kinematic fit effect

Photon time of flight constraint improves resolution on z



4-momentum constraint improves the $m_{\gamma\gamma}$ resolution





Event selection

3 γ final state

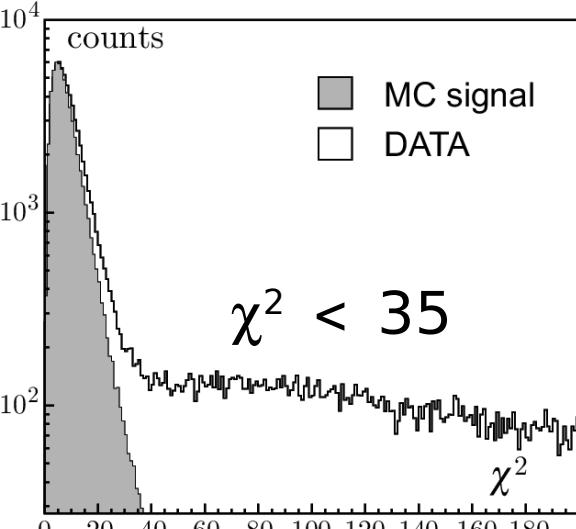
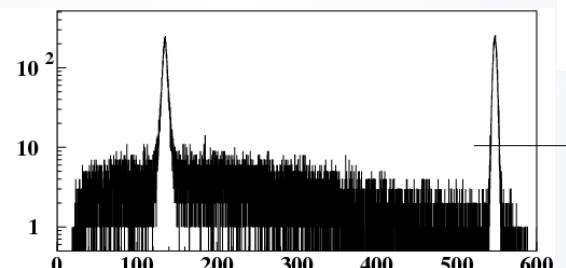
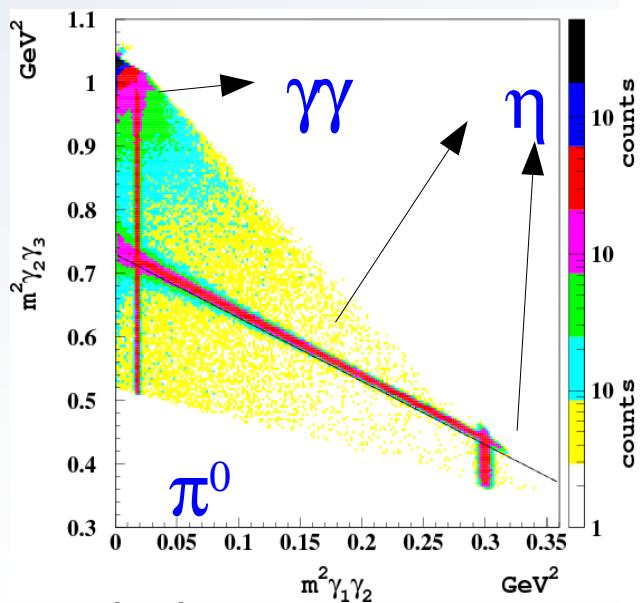
$\phi \rightarrow \eta\gamma$ ($\eta \rightarrow \gamma\gamma$) η mass

$\phi \rightarrow \pi^0\gamma$ ($\pi^0 \rightarrow \gamma\gamma$) π^0 mass

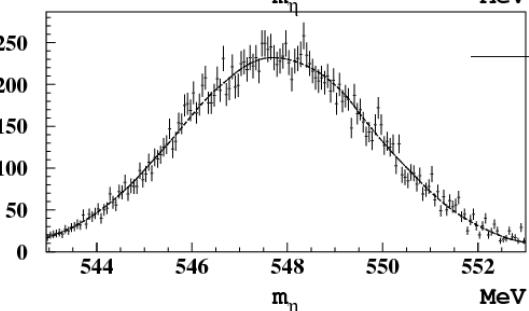
Selection

At least 3 photons with the requirements:

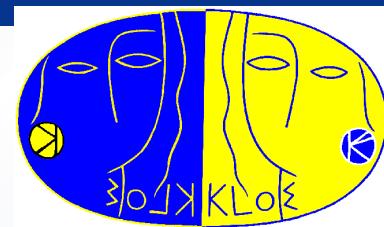
- $|t - r/c| < \min(5\sigma_t, 2\text{ns})$
- $50^\circ < \theta_\gamma < 130^\circ$ (barrel)
- the kinematic fit is performed on all combinations and the smallest χ^2 combination is retained.



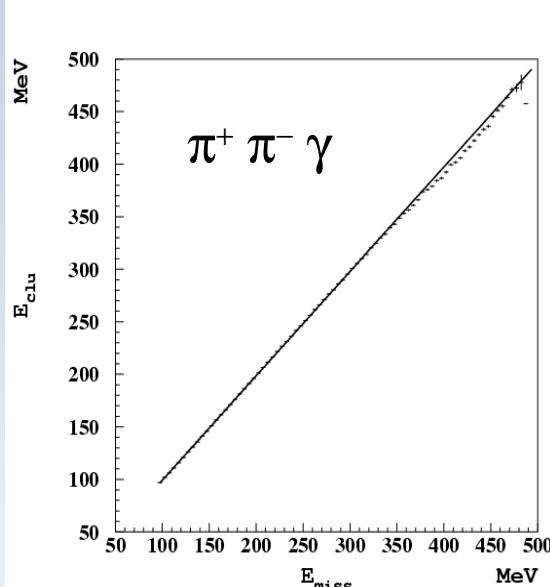
$m_{\gamma\gamma}$ after Dalitz cut



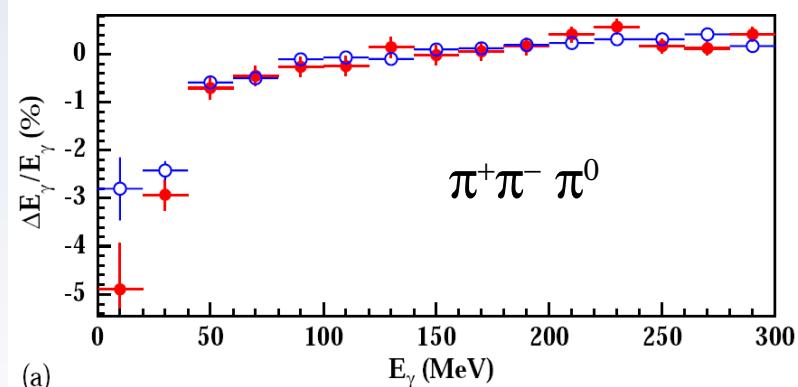
Fit to the mass.



Energy and \sqrt{s}

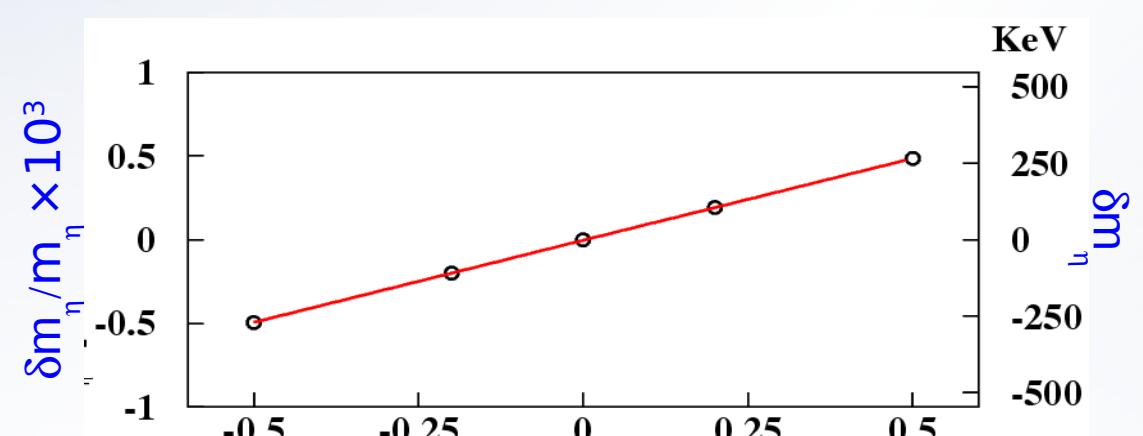


Energy absolute scale and linearity checked with 2 samples

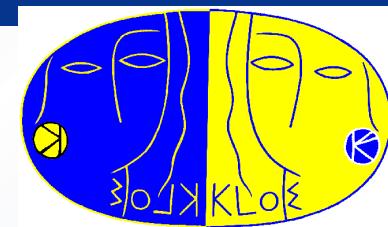


linearity better than 2%
scale better than 1%

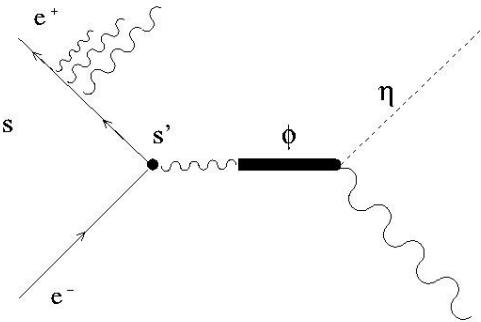
η mass $\delta m/m$ (δm)
scale 8×10^{-6} (4 keV)
linearity 7×10^{-6} (4 keV)



The \sqrt{s} sets the mass scale.
Careful evaluation of the absolute
scale and ISR corrections.



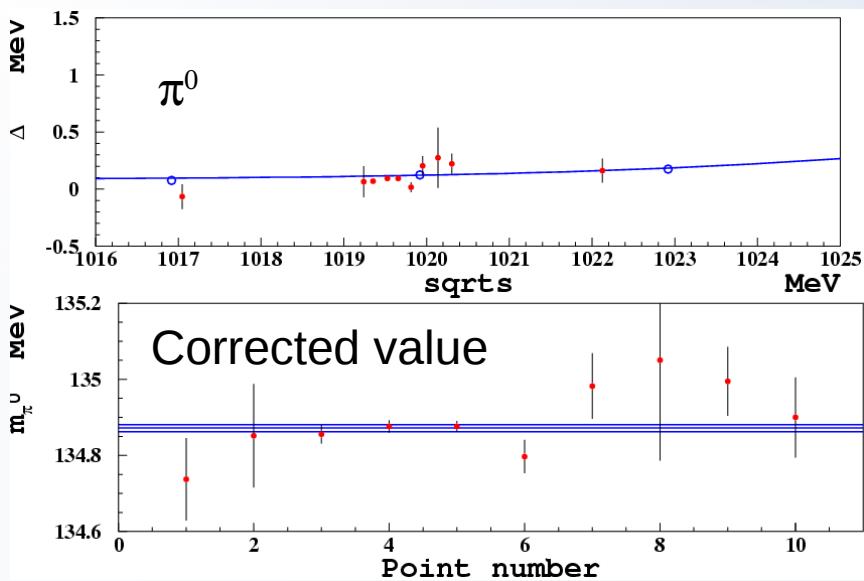
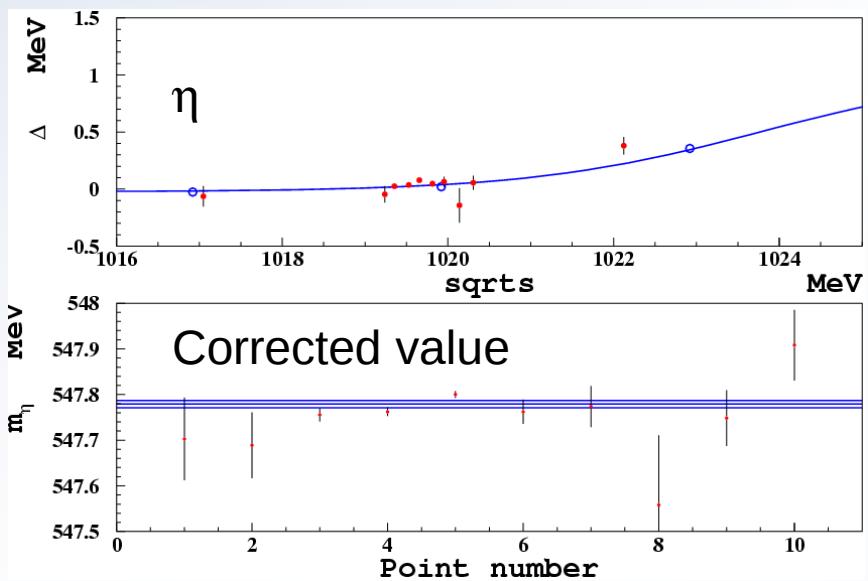
ISR correction

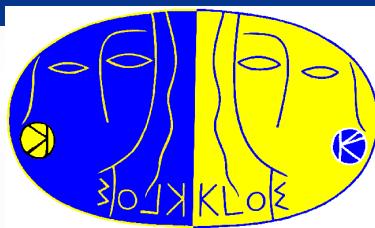


The energy available for the ϕ decay is lower than the e^+e^- beam energy.

It produces an important correction Δ to the measured η mass.

The correction has been evaluated on MC and checked with DATA as a function of \sqrt{s}

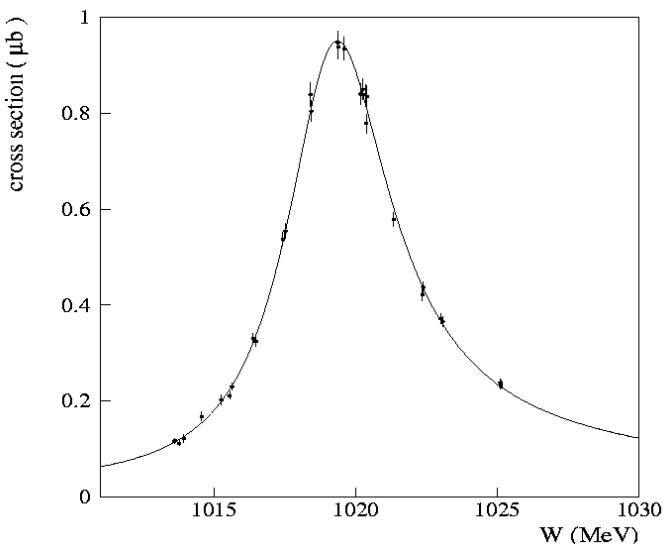




\sqrt{s} absolute calibration

The \sqrt{s} is measured run by run using $e^+e^- \rightarrow e^+e^-$ @ $\tau_\gamma > 50^\circ$ ($\sim 40,000$ each 2h of data taking)

The absolute scale is determined fitting the $e^+e^- \rightarrow K_s K_L$ cross section (ϕ line shape).



The fit takes into account the ISR effect and the phase space factor of the KK couple.
The fitting function is the same used by CMD-2 at VEPP-2M.

We obtain: $m_\phi = 1019.329 \pm 0.011 \text{ MeV}$

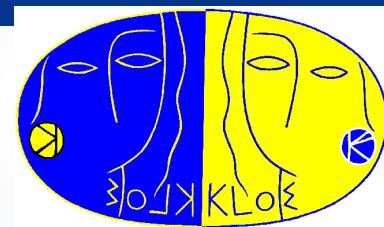
To compare with:

m_ϕ (CMD-2) = $1019.483 \pm 0.011 \pm 0.025 \text{ MeV}$

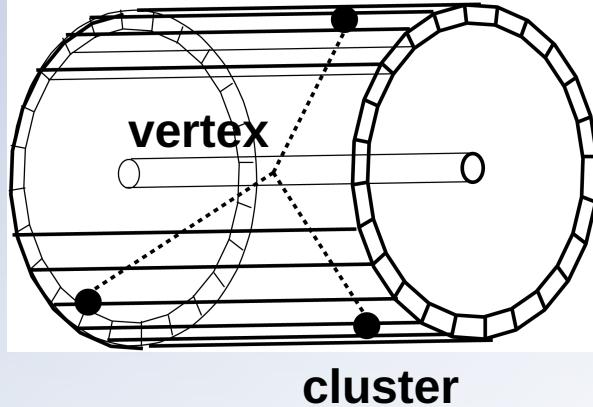
Phys. Lett. B508, 217

VEPP-2M very good knowledge of beam energies through resonant depolarization technique.

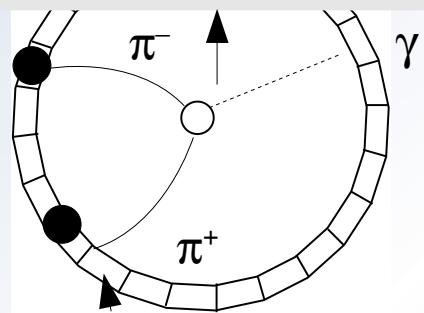
The ratio m_ϕ (CMD-2)/ m_ϕ (KLOE) is used to set the absolute \sqrt{s} scale.



Cluster and vertex position determination



$V_{\pi\pi}$ mean position checks the I.P.

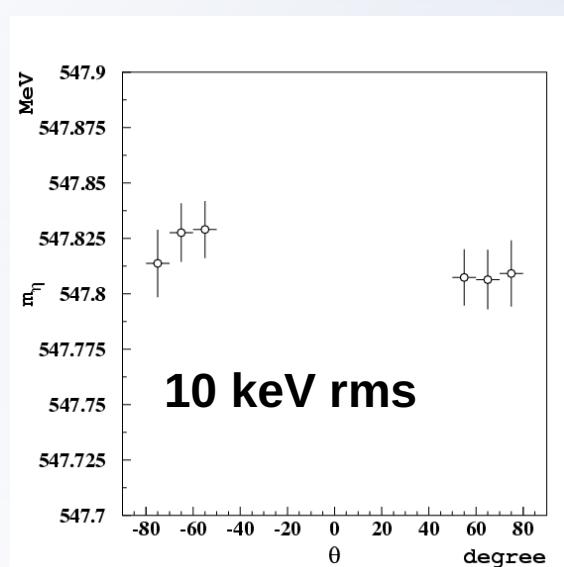
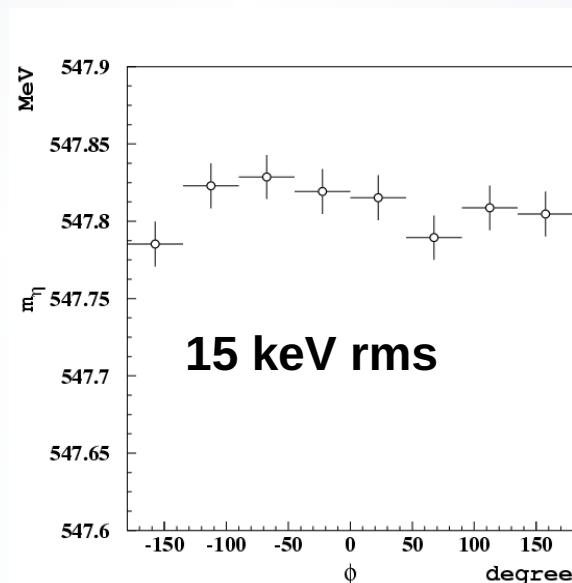
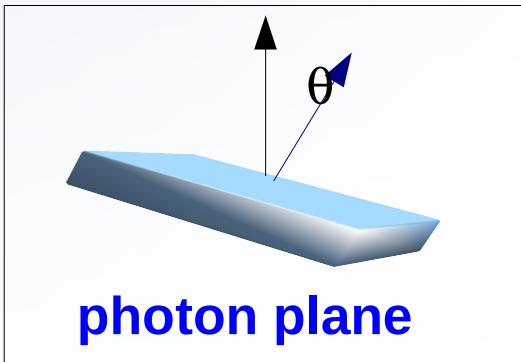


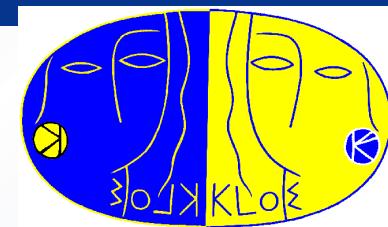
Closest approach point
to the cluster

The mass is very sensitive to the position of the clusters and of the I.P.

$\pi\pi\gamma$ used to cross check both calorimeter global alignment and vertex position (measured run by run using Bhabha events)

Systematic effects due to single module displacement are evaluated studying the spatial dependence of the measured value.



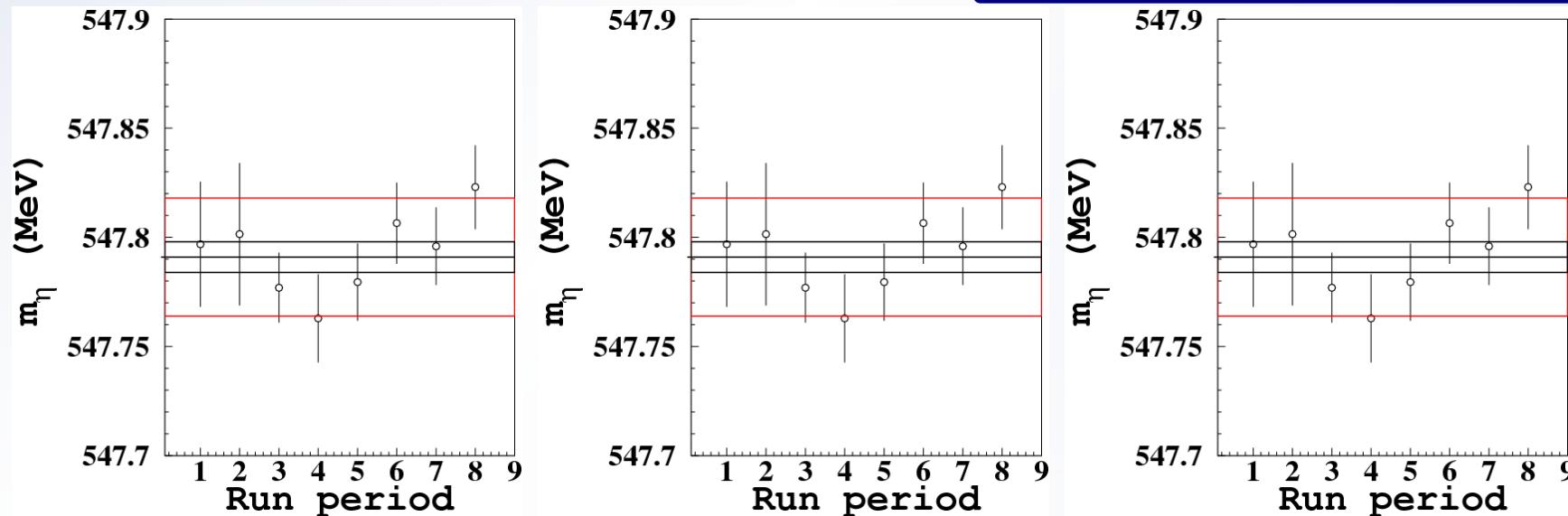


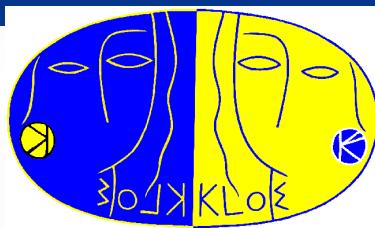
Systematics and time dependence

The systematic error has been evaluated for m_η , m_{π^0} and m_η/m_{π^0} . The main effect coming from the module by module alignment.

The parameters of the machine and the detector calibration is performed run by run with high precision, the value obtained in different run periods are in perfect agreement.

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
Line cut in the Dalitz plot	17	4	18
ISR emission	8	9	28
Total	27	49	136





Results

Fit results				
	Value	Error	$\chi^2/n.d.f$	C.L
m_η	547791 keV	7 keV	6.9/7	45%
m_{π^0}	134886 keV	12 keV	7.7/7	34%
m_η/m_π	4.0610	0.0004	8.9/7	26%

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

$$m_{\pi^0} (\text{PDG}) = 134976.6 \pm 0.6 \text{ keV}$$

$$m_\eta = 548140 \pm 50_{\text{stat.}} \pm 190_{\text{syst.}} \text{ keV}$$

To correct for the \sqrt{s} scale we compute:

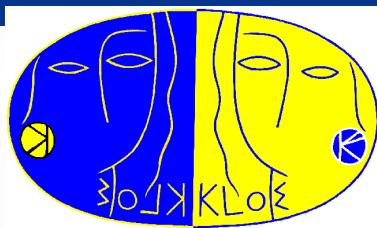
$$\frac{m_\eta}{m_\phi} = 0.537403 \pm 0.000007(\text{stat.}) \pm 0.000026(\text{syst.}) \pm 0.000006(m_\phi \text{ stat.})$$

$$\frac{m_{\pi^0}}{m_\phi} = 0.132328 \pm 0.000012(\text{stat.}) \pm 0.000048(\text{syst.}) \pm 0.000001(m_\phi \text{ stat.})$$

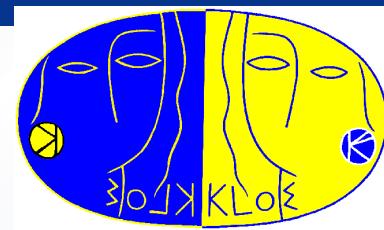
Using: m_ϕ (CMD-2) = $1019.483 \pm 0.011 \pm 0.025$ MeV

$$m_{\pi^0} = 134.906 \pm 0.012(\text{stat.}) \pm 0.048(\text{syst.}) \text{ MeV} \quad 1.4 \sigma \text{ from PDG}$$

$$m_\eta = 547.873 \pm 0.007(\text{stat.}) \pm 0.031(\text{syst.}) \text{ MeV}$$



Updates on the η/η' mixing angle and η' gluonium content



η, η' : mixing and gluonium

The η, η' mesons wave function can be decomposed in the quark mixing base as in the following.

$$|\eta'\rangle = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|G\rangle \quad |\eta\rangle = \cos\phi_P|q\bar{q}\rangle - \sin\phi_P|s\bar{s}\rangle \quad |q\bar{q}\rangle = \frac{|u\bar{u}\rangle + |d\bar{d}\rangle}{\sqrt{2}}$$

$$\begin{aligned} X_{\eta'} &= \sin\phi_P \cos\phi_G \\ Y_{\eta'} &= \cos\phi_P \cos\phi_G \\ Z_{\eta'} &= \sin\phi_G \end{aligned}$$

$$R_\phi = \frac{Br(\phi \rightarrow \eta' \gamma)}{Br(\phi \rightarrow \eta \gamma)} \cot^2\phi_P \cdot \cos^2\phi_G \left(1 - \frac{m_s}{\bar{m}} \cdot \tan \frac{\phi_V}{\sin 2\phi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

$\phi_V \omega - \phi$ mixing angle

Comparing with other decay rates using SU(3) relations and neglecting the gluonium coupling to the final state:

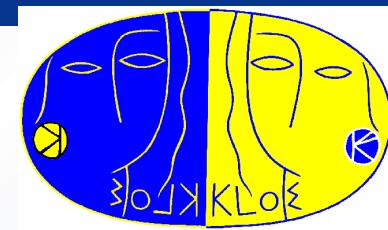
$$\frac{\Gamma(\eta' \rightarrow \gamma\gamma)}{\Gamma(\pi^0 \rightarrow \gamma\gamma)} = \frac{1}{9} \left(\frac{m_{\eta'}}{m_\pi} \right)^3 \left(5X_{\eta'} + \sqrt{2} \frac{f_q}{f_s} Y_{\eta'} \right)^2$$

$$\frac{\Gamma(\eta' \rightarrow \rho\gamma)}{\Gamma(\omega \rightarrow \pi^0\gamma)} = \frac{C_{NS}}{\cos\phi_V} \cdot 3 \left(\frac{m_{\eta'}^2 - m_\rho^2 m_\omega}{m_\omega^2 - m_\pi^2 m_{\eta'}} \right)^3 X_{\eta'}^2$$

$$\frac{\Gamma(\eta' \rightarrow \omega\gamma)}{\Gamma(\omega \rightarrow \pi^0\gamma)} = \frac{1}{3} \left(\frac{m_{\eta'}^2 - m_\omega^2 m_\omega}{m_\omega^2 - m_\pi^2 m_{\eta'}} \right)^3 \left[C_{NS} X_{\eta'} + 2 \frac{m_s}{\bar{m}} C_s \cdot \tan\phi_V \cdot Y_{\eta'} \right]^2$$

Parameter	f_q	f_s	C_{NS}	C_s	$\frac{m_s}{\bar{m}}$
Value	1 ± 0.01	1.4 ± 0.014	0.91 ± 0.05	0.89 ± 0.07	1.24 ± 0.07

$$C_{NS} = \langle q\bar{q}|u\bar{u}\rangle \quad C_s = \langle s\bar{s}|s\bar{s}\rangle$$



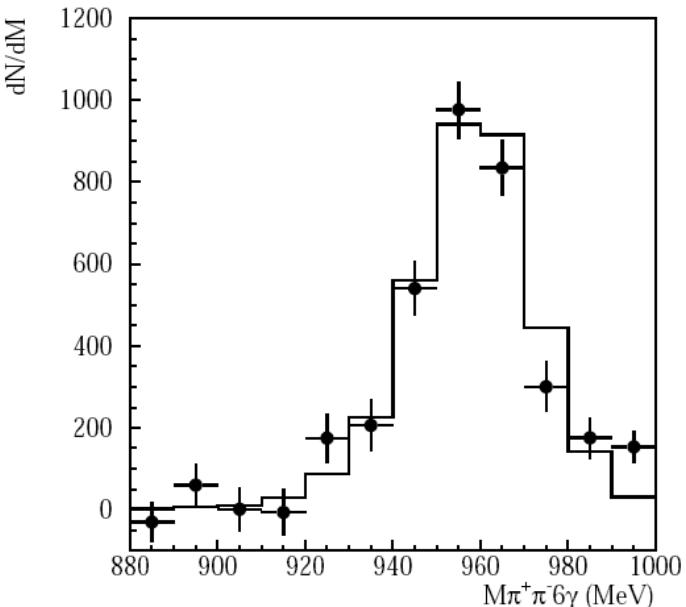
427 pb⁻¹ ('01-'02 data)

$N(\eta\gamma) = 1.665 \times 10^6$ (no bck)

$N(\pi^+\pi^- 7\gamma's) = 3750 \pm 60$ ($N_{\text{bckg}} = 345$)

$N(\eta' \gamma) = 3405 \pm 61_{\text{stat}} \pm 43_{\text{syst}}$

Using PDG BR($\phi \rightarrow \eta\gamma$) $\text{Br}(\phi \rightarrow \eta' \gamma) = (6.20 \pm 0.09_{\text{stat.}} \pm 0.25_{\text{syst.}}) \times 10^{-5}$



Decay channel topology

$$\eta' \rightarrow \pi^+ \pi^- \eta, \eta \rightarrow 3\pi^0$$

$$\eta' \rightarrow \pi^0 \pi^0 \eta, \eta \rightarrow \pi^+ \pi^- \pi^0$$

$$R_\phi = (4.77 \pm 0.09_{\text{stat.}} \pm 0.19_{\text{syst.}}) \times 10^{-3}$$

Dominated by the η' Br uncertainty

In perfect agreement with previous KLOE result Phys. Lett. B541 (2002)

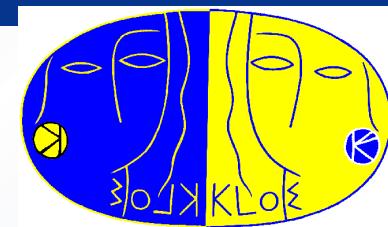
$$\eta' \rightarrow \pi^+ \pi^- \eta, \eta \rightarrow \gamma\gamma (\sim 20 \text{ pb}^{-1})$$

$$R = (4.70 \pm 0.47_{\text{stat}} \pm 0.31_{\text{sys}}) \cdot 10^{-3}$$

$$BR(\phi \rightarrow \eta' \gamma) = (6.10 \pm 0.61 \pm 0.43) \cdot 10^{-5}$$

η' gluonium content

PLB 648 (2007) 267



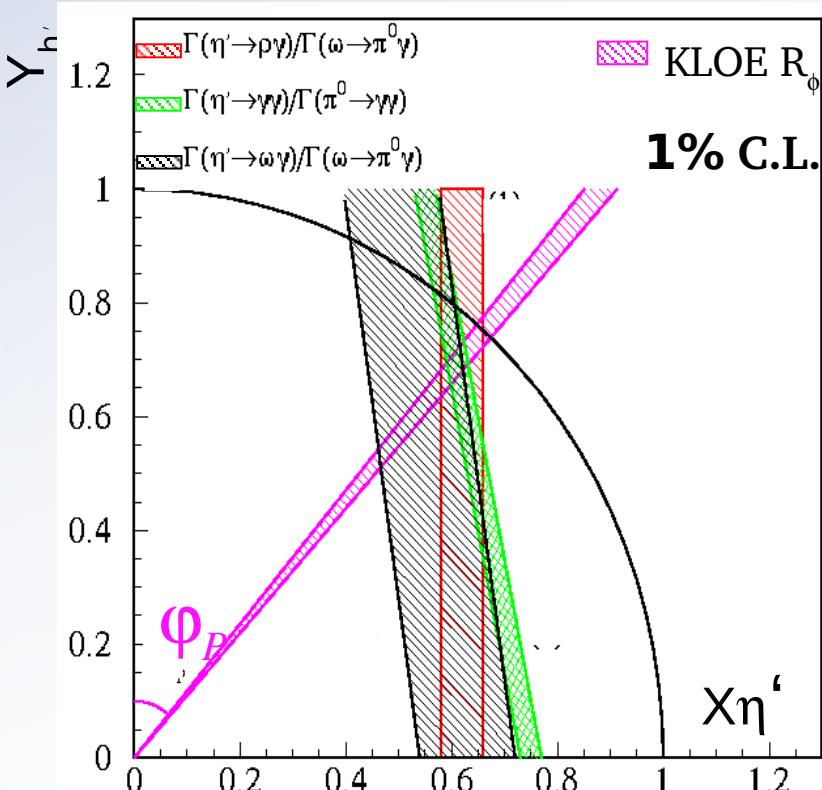
Fit results:

$$\phi_P = (39.7 \pm 0.7_{\text{tot}})^\circ$$

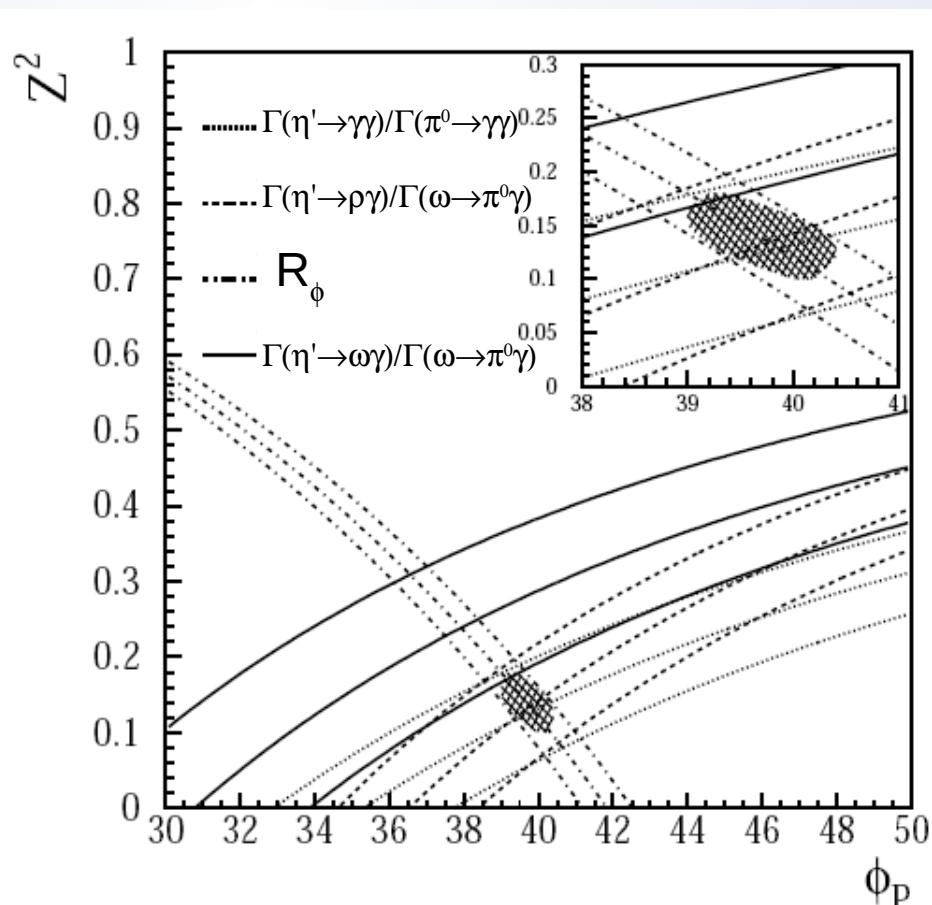
$$|\phi_G| = (22 \pm 3)^\circ$$

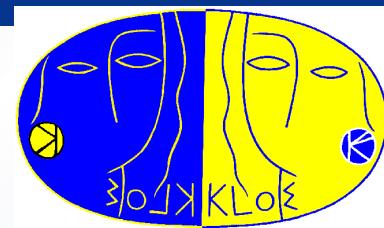
$$\sin^2 \phi_G = Z^2 = 0.14 \pm 0.04$$

Assuming no gluonium ($Z=0$)



49% C.L.





η' gluonium content (updates...)

Using $\text{Br}(\omega \rightarrow \pi^0 \gamma)_{\text{KLOE}} = 8.40 \pm 0.19 \%$ (hep-ex:arXiv:0707.4130)

$$\phi_P = (40.0 \pm 0.7_{\text{tot}})^\circ$$

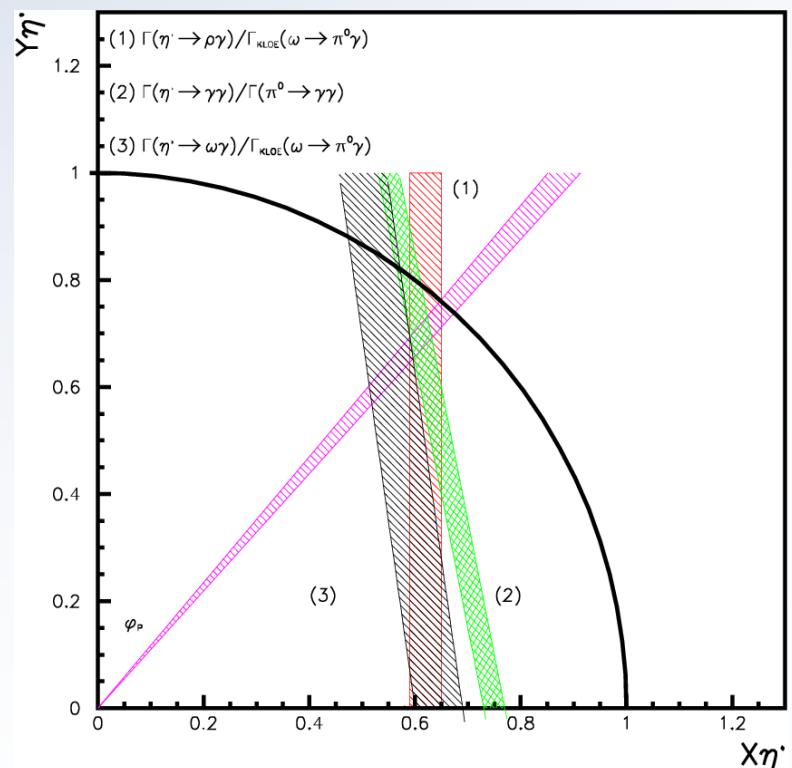
$$|\phi_G| = (21 \pm 3)^\circ$$

$$\sin^2 \phi_G = Z^2 = 0.13 \pm 0.04$$

$$C_s/C_{NS} = 1.0 \pm 0.1$$

Other approaches

C.L 55%



Thomas:
arXiv:0705.1500

$$C_s/C_{NS} = 0.90 \pm 0.02$$

$$Z^2 = 0.04 \pm 0.06$$

$$Z^2 = 0.19 \pm 0.11$$

Using only VP γ transitions
(1.2 σ from KLOE)

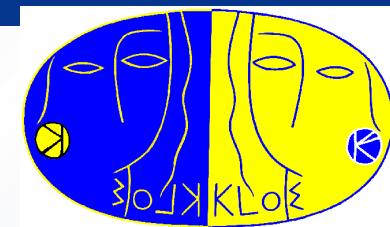
Escribano:
JHEP0705:006,2007

$$C_s/C_{NS} = 0.92 \pm 0.07$$

$$Z^2 = 0.04 \pm 0.09$$

Using only VP γ transitions
(1 σ from KLOE)

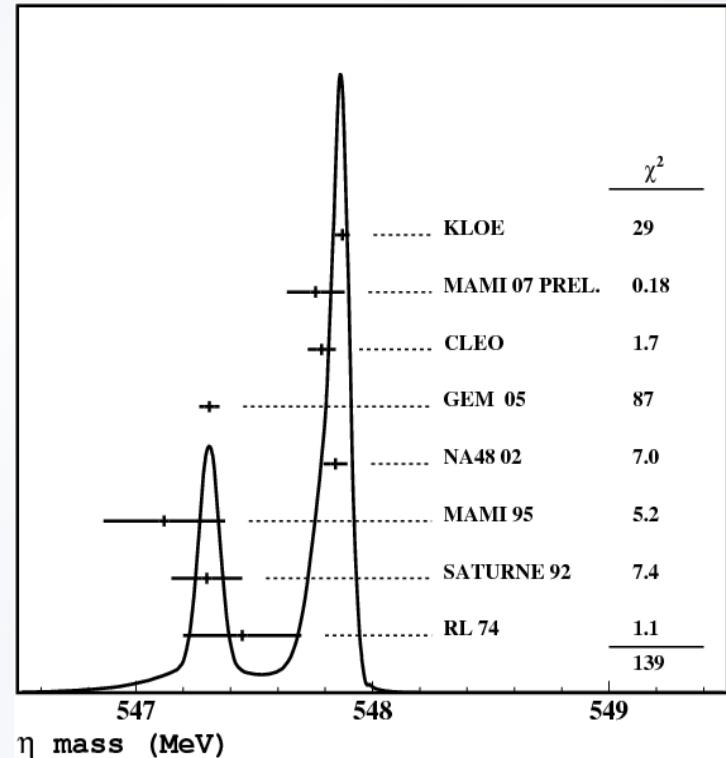
Stability versus $C_s, C_{NS}, C_s/C_{NS}$ checked.
Results always stable (gluonium content at 10%) if P $\gamma\gamma$ coupling included in the fit.



Conclusions

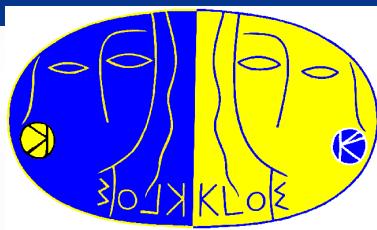
η mass

- We performed the best measurement of the η mass;
 - If the MAMI 07 result is confirmed only ${}^3\text{He}$ based experiment are at low mass value;
 - Possible explanations:
 - common systematics not correctly evaluated?
 - anything interesting in ${}^3\text{He}$ physics ?
-

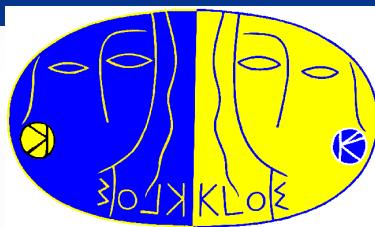


η/η' mixing angle and η' gluonium content

- In our phenomenological approach a gluonium content at 3σ level is observed;
- The result is stable against wave functions overlapping parameters;
- The $\eta' \rightarrow \gamma\gamma$ partial width is the key point of our approach
 - Stabilize the result respect to the overlapping wave functions parameters;
 - strongly constraints the gluonium component.



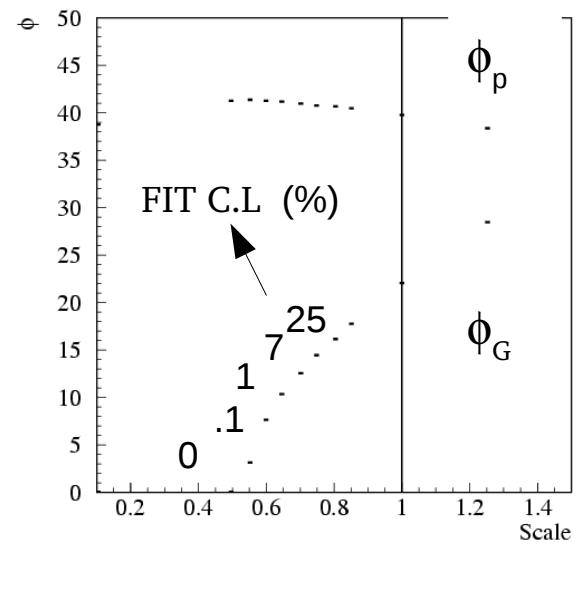
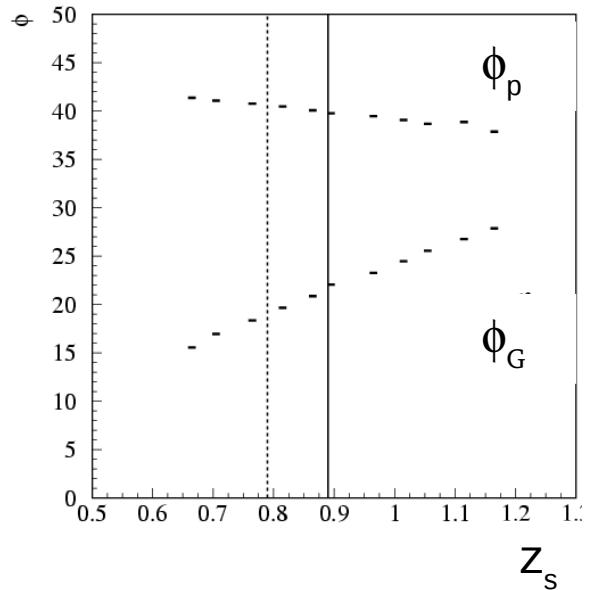
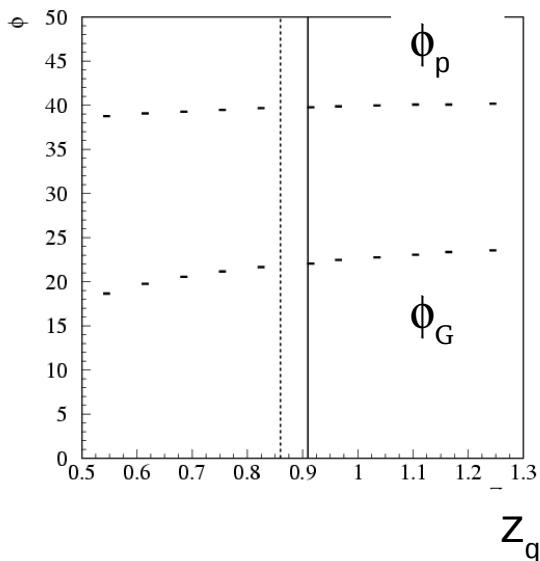
Backup slides



Stability versus overlapping parameters

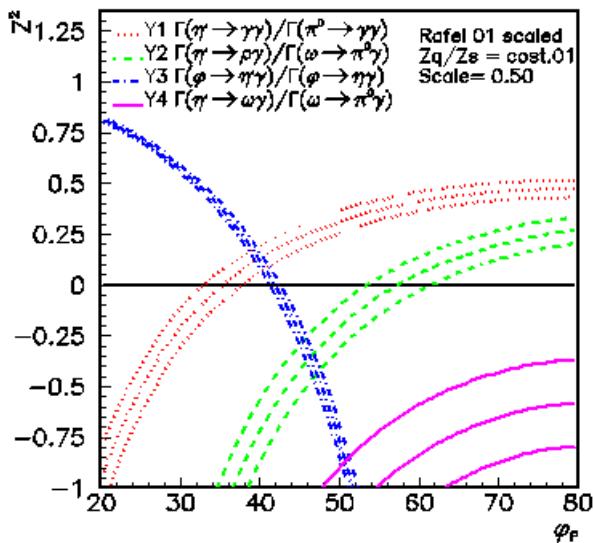
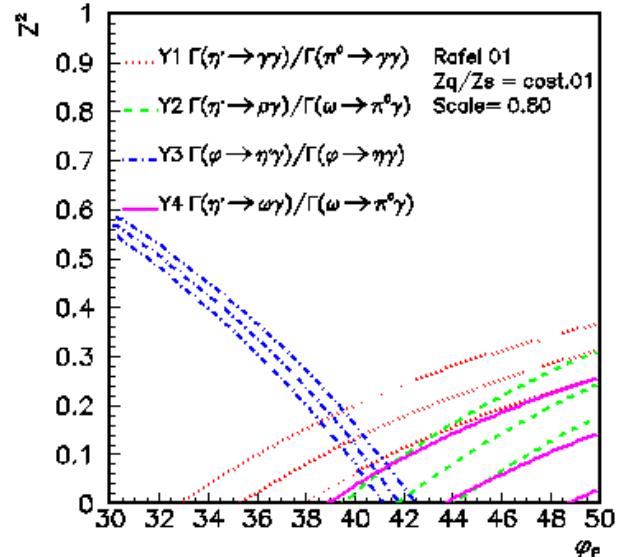
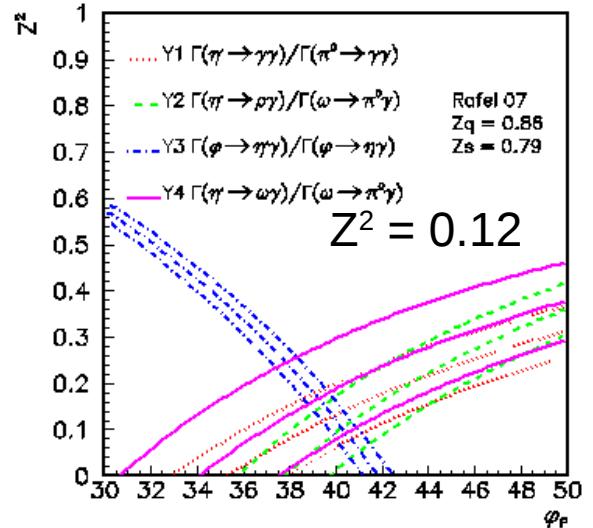
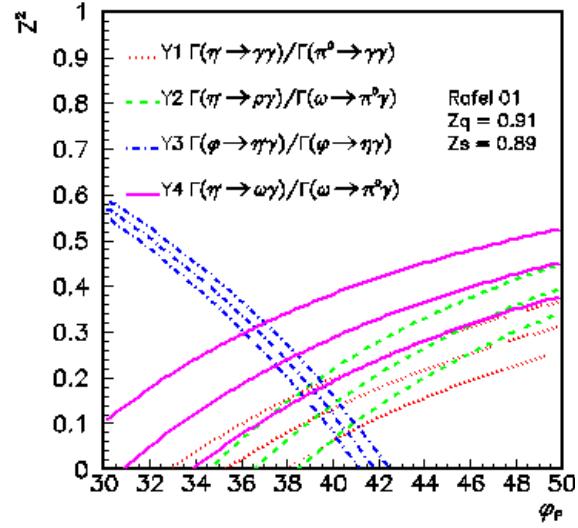
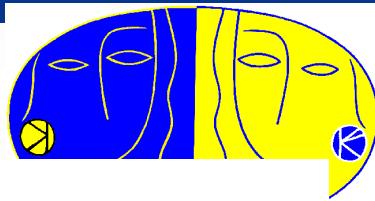
z_q and z_s are taken from a fit of existing data without assumption of gluonium
We investigated the dependence of the fit result from the z_q and z_s parameter.

$$\begin{array}{ll} \text{KLOE} & z_q = 0.91 \pm 0.05 \quad z_s = 0.89 \pm 0.07 \\ \text{Escribano} & z_q = 0.83 \pm 0.03 \quad z_s = 0.79 \pm 0.05 \end{array} \quad \frac{z_q(\text{Escribano})}{z_q(\text{KLOE})} \sim \frac{z_s(\text{Escribano})}{z_s(\text{KLOE})} \sim 0.9$$



The gluonium is sensitive to a scale factor variation of both overlapping parameters.
But to reach the null value we obtain meaningless χ^2 values

Constraints variation with the scale factor.



Not including $\Gamma(\eta' \rightarrow \gamma\gamma)$ makes the fit much more sensitive to the overlapping parameters.
 The $\eta' \rightarrow \gamma\gamma$ constraint makes the fit more stable.