eta, eta′ Physics in KLOE

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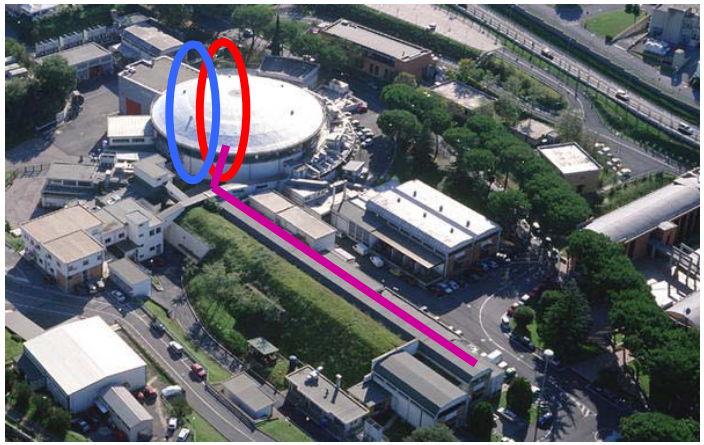
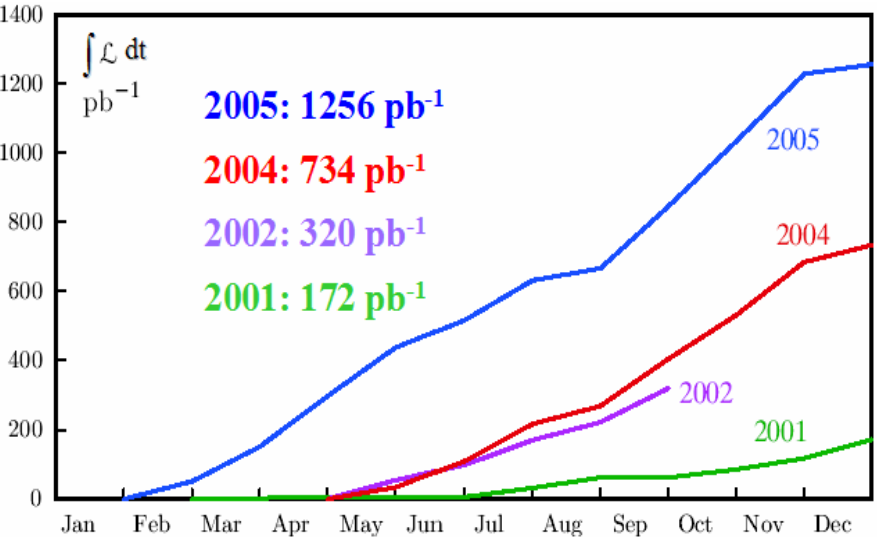
DAΦNE



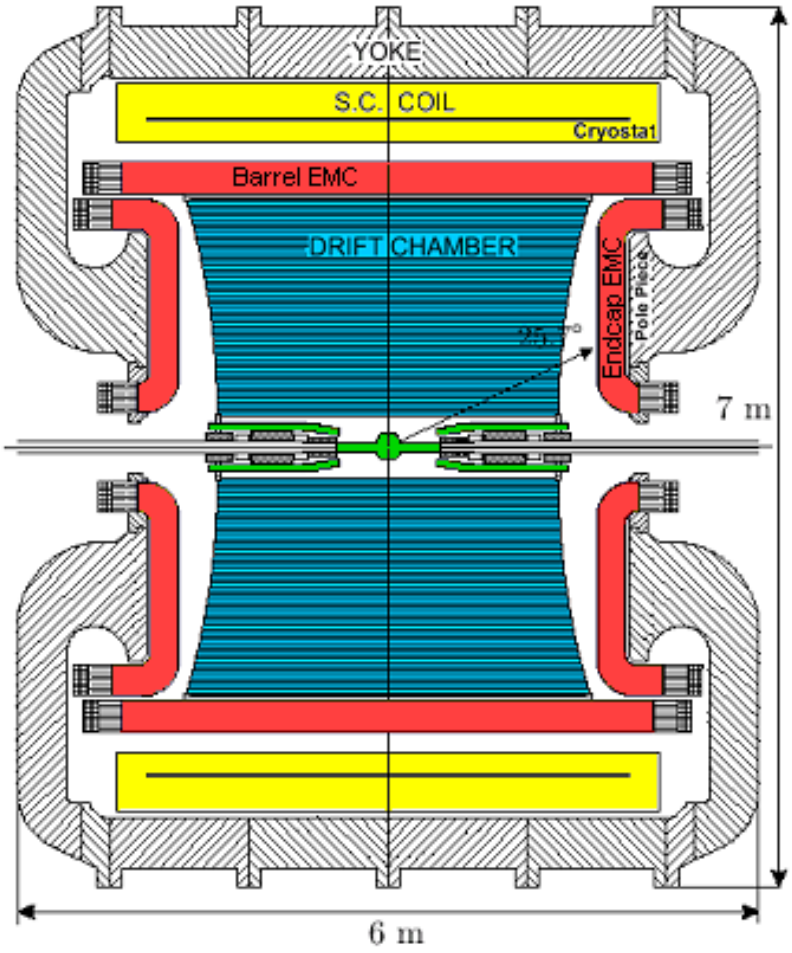
- $\sigma(e^+e^- \rightarrow \phi) \sim 3\ \mu b$ @ $\sqrt{s} = M(\phi) = 1019.4$ MeV
- Separate e^+e^- rings to reduce beam–beam interactions
- crossing angle: 25 mrad, $P_x(\phi) \sim 12{,}6$ MeV/c
- Bunch crossing every 2.7 ns
- injection during acquisition



Data taking ended on March 2006

- **2.5 fb⁻¹ on tape @ $\sqrt{s} = M_\phi$**
  ($8\times10^9\ \phi$) ⇒ ~ $10^8\ \eta$ ⇒ ~ $5\times10^5\ \eta'$
- **~10 pb⁻¹ @ 1010, 1018, 1023, 1030 MeV**
- **250 pb⁻¹ @ 1000 MeV**

KLOE



- Beryllium beam pipe (spherical, 10 cm ∅, 0.5 mm thick) + tile calorimeter surrounding magnet quadrupoles

- Drift chamber (4 m ∅ X 3.75 m)
  - Gas mixture: 90% He + 10% iso-C_4H_{10}
  - 12582 stereo sense wires
  - almost squared cells

  $\delta p_t / p_t < 0.4\%$ ($\theta > 45°$)

  $\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm

- Calorimeter
  - **lead/scintillating fibers** (1 mm ∅), 15 X_0
  - readout by 4880 PMT's
  - 98% solid angle coverage

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

  $\sigma_t = 57$ ps $/ \sqrt{(E(GeV))} \oplus 100$ ps

- Superconducting coil (B = 0.52 T)

η/η′ mixing and gluonium

KLOE PLB 648(2007) 267

$$R_\phi = \frac{BR(\phi\to\eta'\gamma)}{BR(\phi\to\eta\gamma)} = (4.77 \pm 0.09_{stat.} \pm 0.19_{syst.}) \times 10^{-3}$$

η and η′ decomposed in the quark mixing base

J.L.Rosner, PRD 27 (1983)1101

ϕ_P = η–η' mixing angle

$|\eta'\rangle = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_G|G\rangle$

$|\eta\rangle = \cos\phi_P|q\bar{q}\rangle - \sin\phi_P|s\bar{s}\rangle$

$X_{\eta'} = \sin\phi_P \cos\phi_G$

$Y_{\eta'} = \cos\phi_P \cos\phi_G$

$Z_G = \sin\phi_G$ gluonium content

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

$Z^2 = (0.14 \pm 0.04)$

$P(\chi^2) = 49\ \%$

Imposing $Z_G = 0 \longrightarrow P(\chi^2) = 0.01$

Parameters from
Bramon et al. PLB 503 (2001) 271
where $Z_G = 0$ is assumed

Gluonium at 3 σ

η/η′ mixing and gluonium

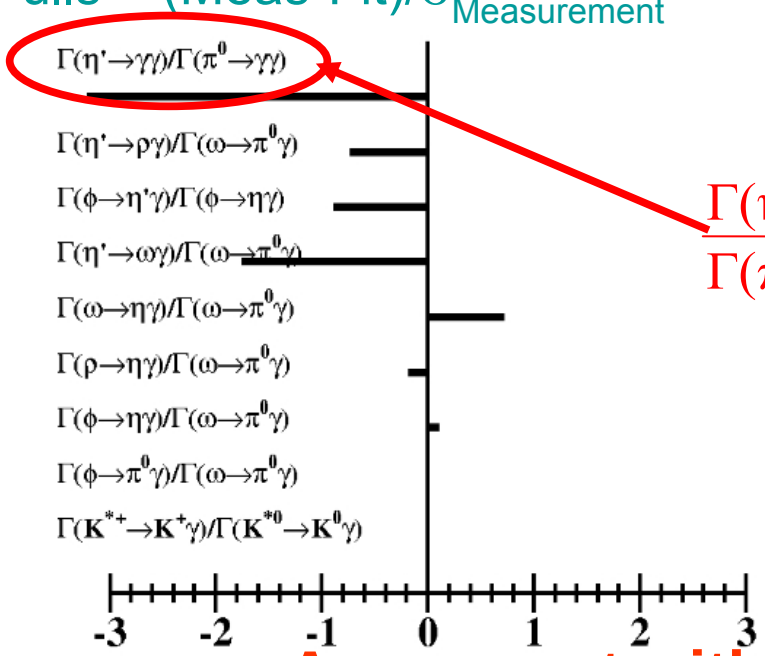
JHEP 108P 0609

NEW FIT USING: PDG 2008 + KLOE results on ω + 5 constraints more

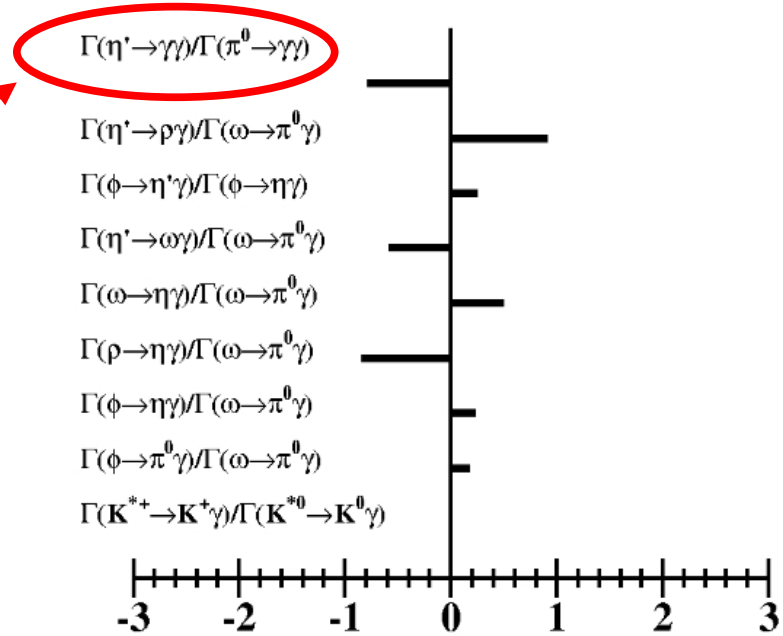
WITHOUT GLUE			
$(Z_G)^2$	fixed 0	χ^2 /dof	14.7/4
ϕ_P	(41.4±0.5)°	P(χ^2)	0.005

WITH GLUE			
$(Z_G)^2$	0.115±0.036	χ^2 /dof	4.6/8
ϕ_P	(40.4±0.6)°	P(χ^2)	0.20

Pulls = (Meas-Fit)/$\sigma_{Measurement}$



$$\frac{\Gamma(\eta'\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)}$$



Agreement with old results: Gluonium at 3 σ

η/η′ mixing and gluonium

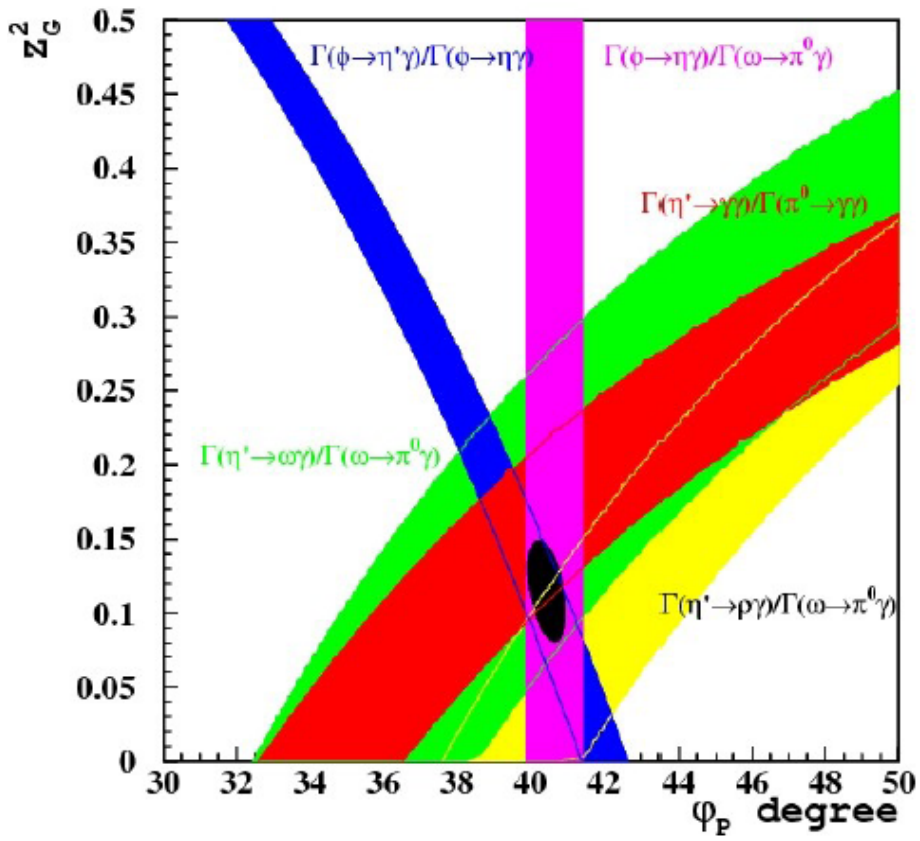
JHEP 108P 0609

NEW FIT USING: PDG 2008 + KLOE results on ω + 5 constraints more

$(Z_G)^2$	0.115 ± 0.036
ϕ_P	(40.4 ± 0.6)°
Z_q	0.94 ± 0.03
Z_s	0.83 ± 0.05
ϕ_V	(3.32 ± 0.09)°
m_s/m	1.24 ± 0.07

χ^2/dof = 4.6/3

P(χ^2) = 0.20



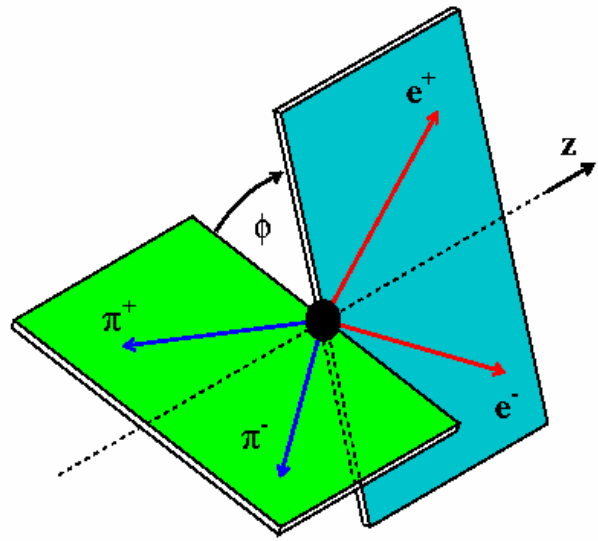
Agreement with old results: Gluonium at 3 σ

$\eta \to \pi^+\pi^-e^+e^-$ decay

- ✓ Poorly measured (4 events CMD-2, 16 events CELSIUS-WASA)
- ✓ BR predicted by ChPT and VMD models ($2.6 \div 3.6 \times 10^{-4}$)
- ✓ η structure, using virtual photon
- ✓ Angular asymmetry between e^+e^- and $\pi^+\pi^-$ planes:

$$A_\phi = \frac{N_{\sin\varphi\cos\varphi>0} - N_{\sin\varphi\cos\varphi<0}}{N_{\sin\varphi\cos\varphi>0} + N_{\sin\varphi\cos\varphi<0}}$$

test of non-CKM CP violation [D.Gao, Mod.Phys.Lett



Within SM constrained by BR($\eta \to \pi^+\pi^-$):

- using experimental upper bound: $A_\phi < 10^{-4}$
- using theoretical predictions: $A_\phi \sim 10^{-15}$

The unconventional CPV term increases A_ϕ up to 10^{-2}

$\eta \to \pi^+\pi^-e^+e^-$: event counting

KLOE PLB 675(2009)283

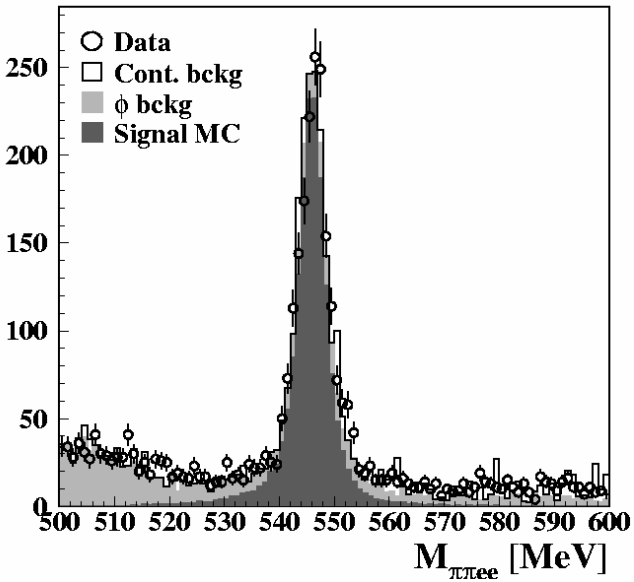
Data sample: 1.73 fb^{-1}

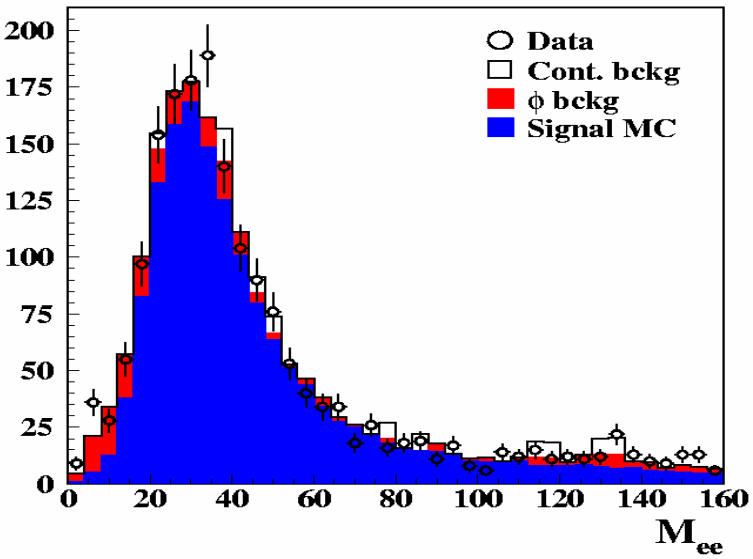
- ✓ PID con ToF EMC info
- ✓ Fit on $M_{\pi\pi ee}$ side bands for background
- ✓ Photon conversion on Beam Pipe rejected

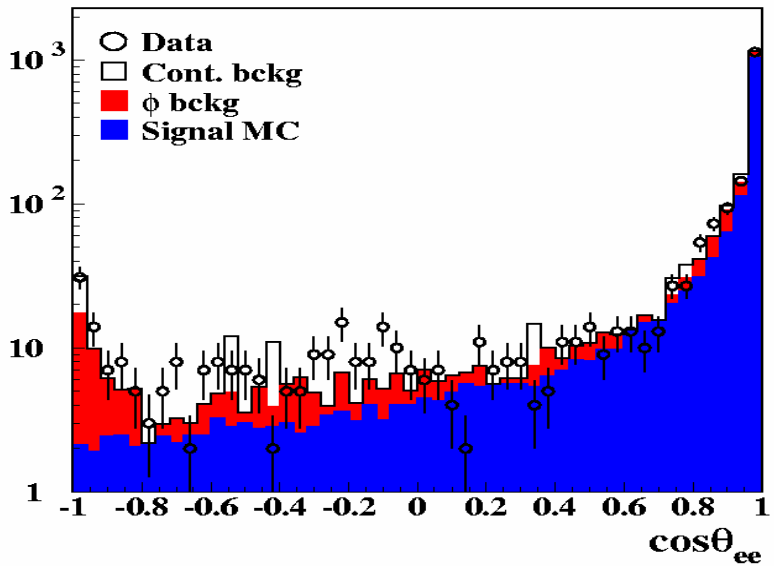
Counting on $M_{\pi\pi ee}$ in the signal region:

$N_{\pi\pi ee} = 1555 \pm 52$ (368 bckg evts)

Analysis efficiency: 8%







$\eta \to \pi^+\pi^-e^+e^-$: results

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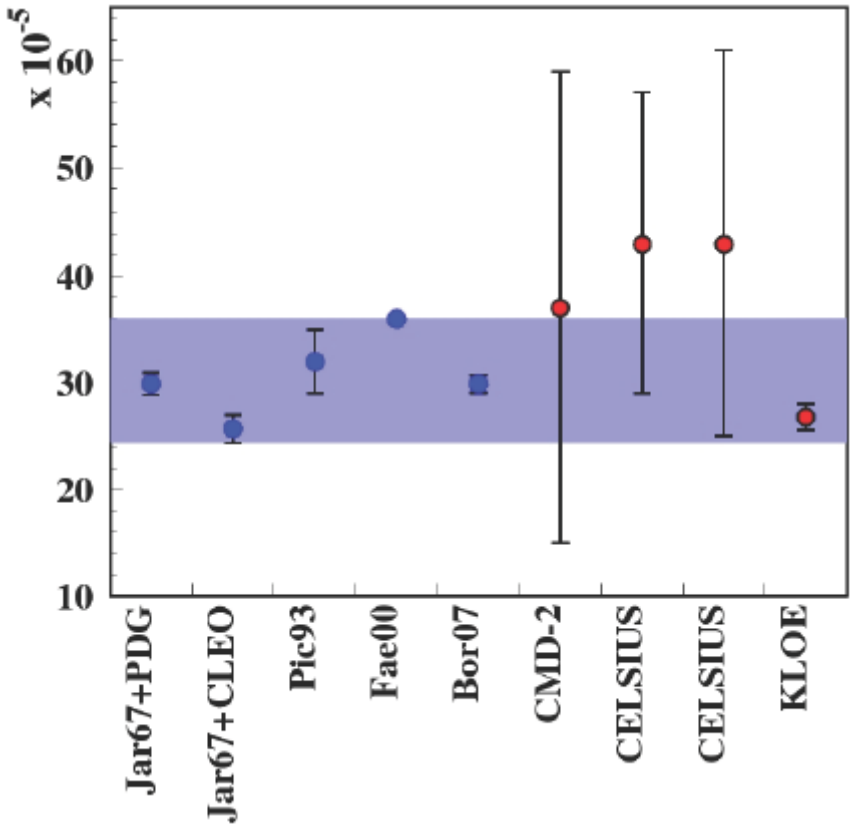
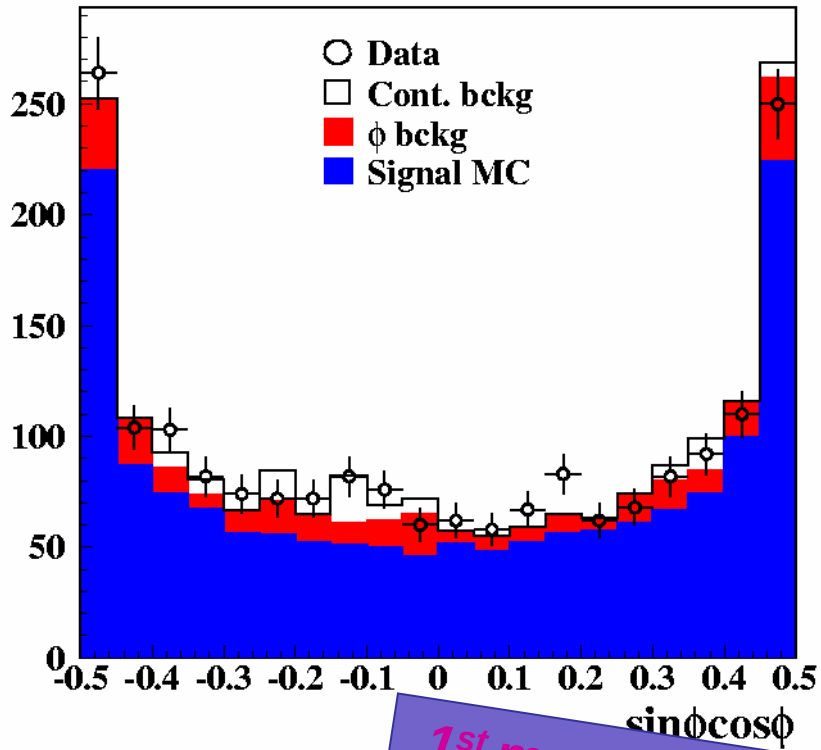
$$BR(\eta \to \pi^+\pi^-e^+e^- (\gamma)) = (26.8 \pm 0.9_{stat} \pm 0.7_{syst}) \cdot 10^{-5}$$





1st measurement!

$$A_\phi = \frac{N_{\sin\varphi\cos\varphi>0} - N_{\sin\varphi\cos\varphi<0}}{N_{\sin\varphi\cos\varphi>0} + N_{\sin\varphi\cos\varphi<0}}$$

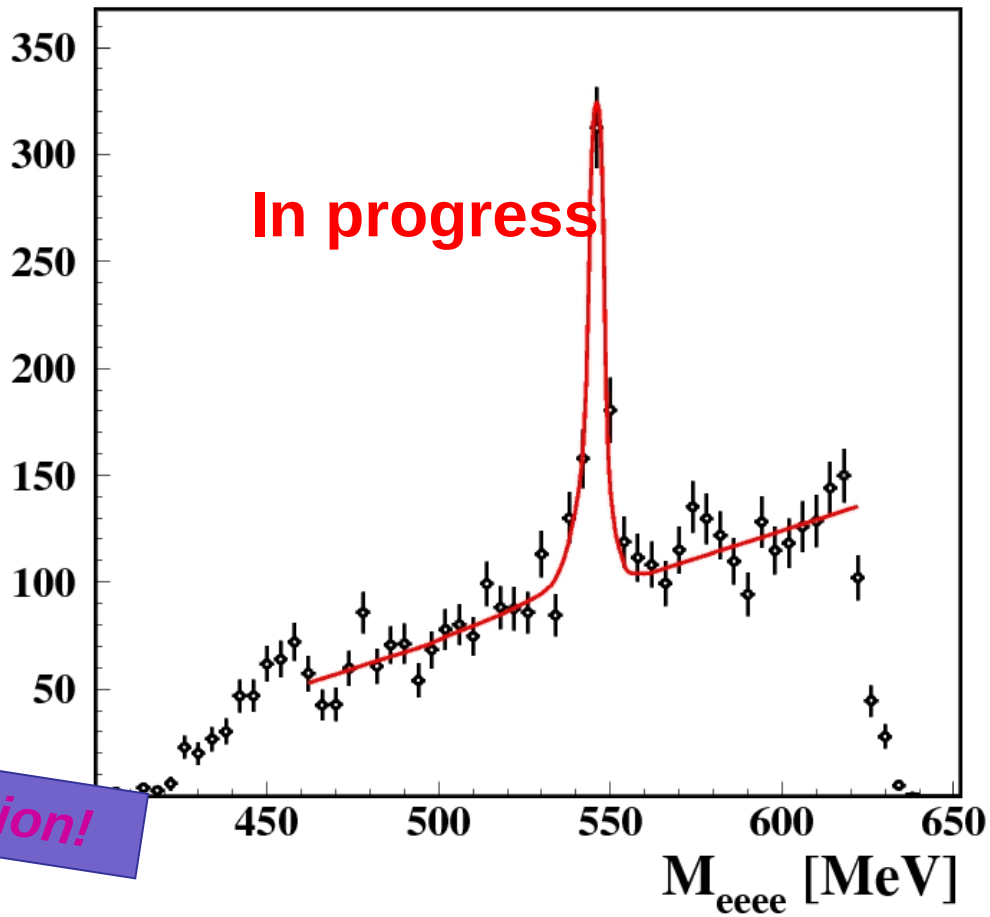
$$A_\phi = (-0.6 \pm 2.5_{stat} \pm 1.8_{syst}) \cdot 10^{-2}$$

$\eta \to e^+e^-e^+e^-$ decay

KLOE preliminary

- Data sample: 1.7 fb^{-1}
- Photon conversion on Beam Pipe and Drift Chamber wall rejected
- Remaining background from ϕ decay is subtracted

Preliminary fit to M_{eeee} distribution with MC signal + continuum background shapes yields:

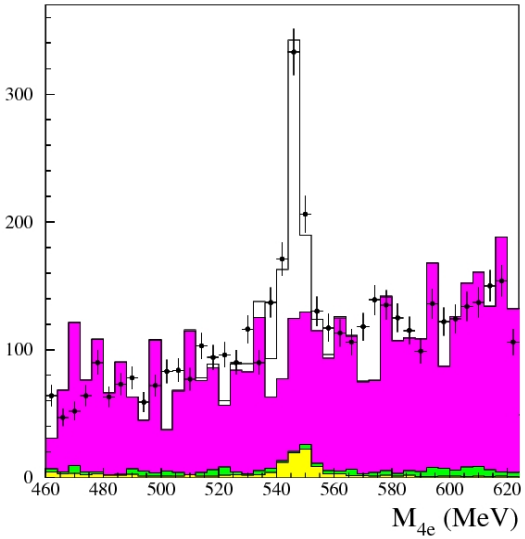


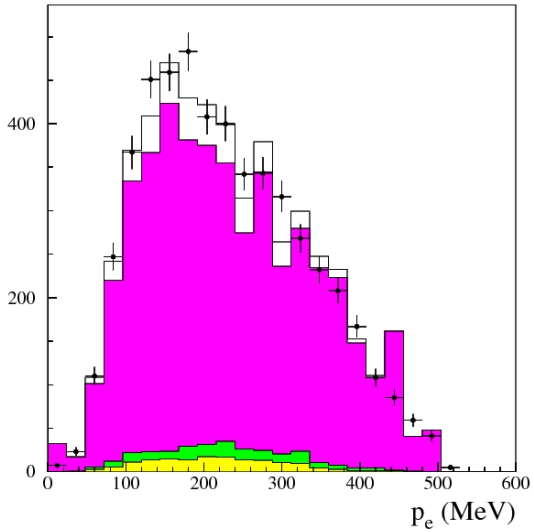
1st observation!

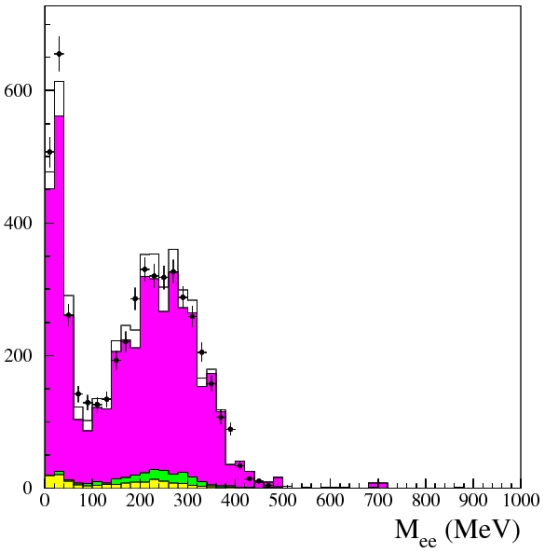
$N_{eeee} = 413 \pm 31$

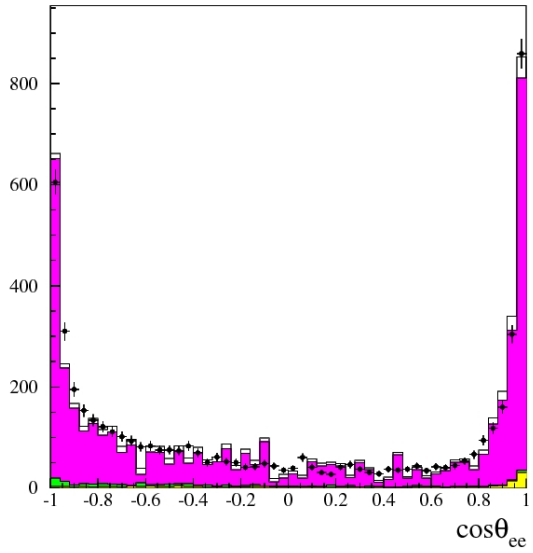
$\eta \to e^+e^-e^+e^-$ decay

KLOE preliminary









Data
MC signal
Cont. bkg
ϕ bkg

$\eta \to \pi^+\pi^-\gamma$

The Box Anomaly

In the $\eta\to\pi^+\pi^-\gamma$ decay a significant contribution from the chiral anomaly responsible for $\eta\to\gamma\gamma$ decay is expected

Studies of the two pion system allow for tests of ChPT and its unitarized extensions, e.g. VMD or the chiral unitary approach.

Holstein, Phys. Scripta, T99 55 (2002)
Benayoun, Eur. Phys. J., C31 525 (2003)
Borasoy, Nissler, Nucl. Phys., A740 362 (2004)

Existing data

Low in statistic and not acceptance corrected.

Not sufficient for unambiguous theoretical interpretation

Gormley, Phys.Rev. D2 501 (1970)
Layter, Phys.Rev. D7 2565 (1973)

$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ Γ_{10}/Γ_9

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.202±0.007 OUR FIT	Error includes scale factor of 2.4.				
0.203±0.008 OUR AVERAGE	Error includes scale factor of 2.4. See the ideogram below.				
0.175±0.007±0.006	859	LOPEZ	07	CLEO	$\psi(2S) \to J/\psi\eta$
0.209±0.004	18k	THALER	73	ASPK	
0.201±0.006	7250	GORMLEY	70	ASPK	

$\eta \to \pi^+\pi^-\gamma$

KLOE preliminary

No kinematical fit, signal selection with help of kinematical constraints from consecutive decays i.e.

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

  Missing mass to $(\phi - \pi^+ - \pi^- - \gamma_\phi)$ system

  Opening angle ($\gamma_\eta{}^1 \quad \gamma_\eta{}^2$) in the π^0 rest frame

  Eff = 40 % with BKG/SIG = 0.5 %

- $\phi \to \eta\gamma, \quad \eta \to \pi^+\pi^-\gamma$

  Similar cuts ($(E_\gamma - P_\gamma)$ instead of missing mass, angle selection)

  Eff = 29 % , BKG/SIG = 10:1

Data sample: 1.2 fb^{-1}

$$\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.2014 \pm 0.0004_{stat}$$

$\eta \to \pi^0\pi^0\pi^0$

The decay $\eta \to 3\pi$ violates iso-spin invariance and it is induced dominantly by the strong interaction via the u−d quark mass difference. In the chiral expansion:

$$A(s,t,u) = \frac{1}{Q^2}\frac{m_K^2}{m_\pi^2}(m_\pi^2 - m_K^2)\frac{M(s,t,u)}{3\sqrt{3}F_\pi^2} \qquad \text{with} \qquad Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$

The Dalitz plot density corresponding to the intrinsic $\eta\to\pi^0\pi^0\pi^0$ decay amplitude is approximately described by

$$|A|^2 \propto 1 + 2\alpha z$$

with:

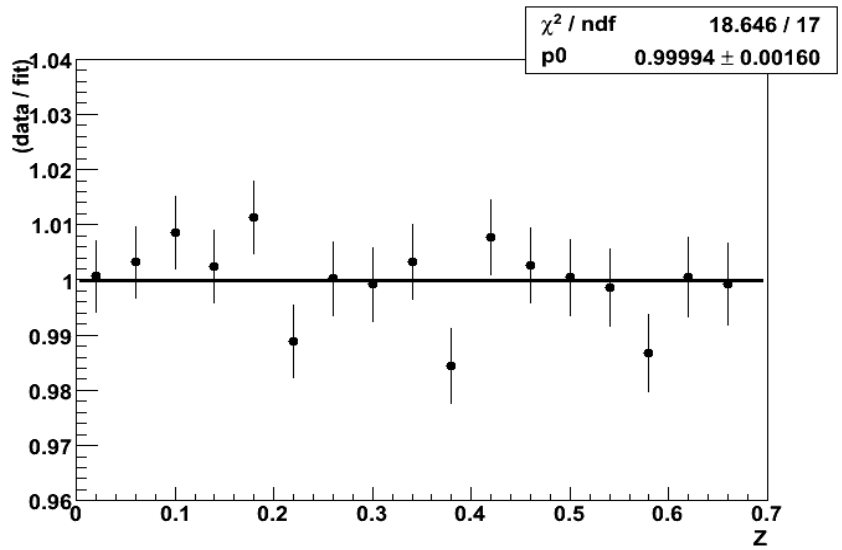
$$z = \frac{2}{3}\sum_{i=1}^{3}\left(\frac{3E_i - m_\eta}{m_\eta - 3m_{\pi^0}}\right)^2 = \frac{\rho^2}{\rho^2_{\max}}$$

Precise measurements of $\Gamma(\eta\to3\pi^0)$ and α are important tests of χPT calculations

$\eta \to \pi^0\pi^0\pi^0$

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

- Selection:
  - 7 γ candidates
  - Global kinematic fit
  - π^0 pairing
  - Kinematic fit with π^0 and η mass constraint ($M_\eta = M(\eta)_{KLOE}$)
- MC sample generated according to $\alpha = -0.027$ KLOE preliminary arXiv 0707.4137
- Corrected for the Data-MC discrepancy in the photon energies resolution in the π^0 rest frame.



3 different purity samples

LOW Purity = 90.4%, ε = 21%

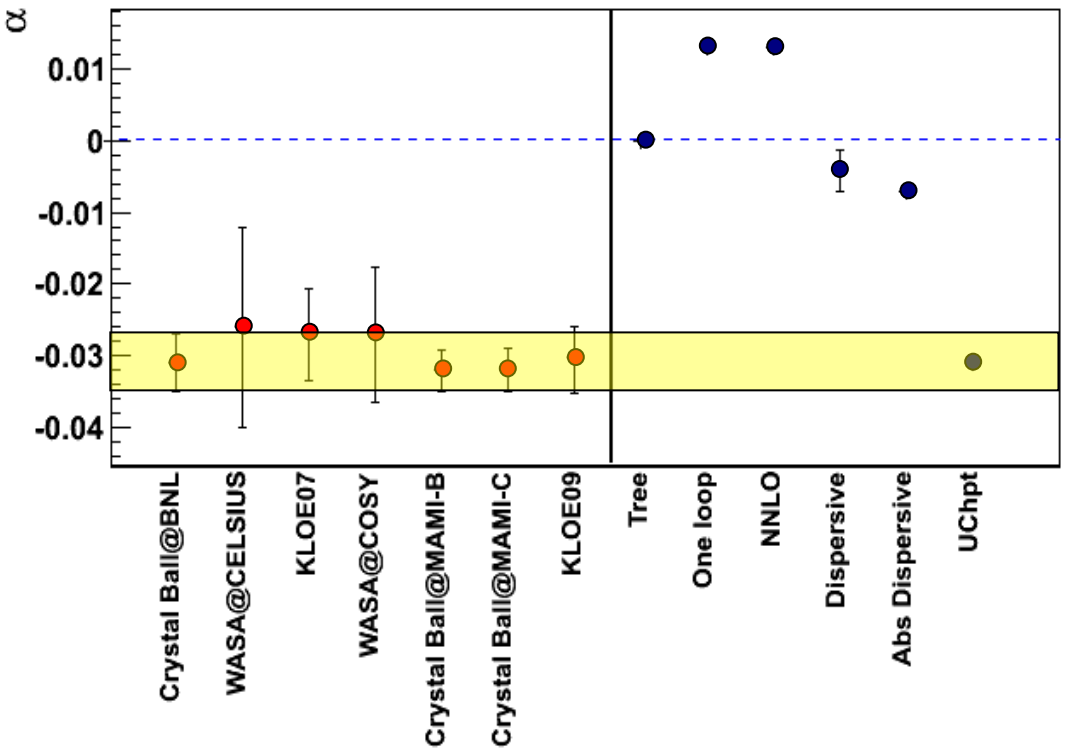
MEDIUM Purity = 95.0 %, ε = 14%

HIGH Purity = 97.3%, ε = 7%

$\eta \to \pi^0\pi^0\pi^0$

Using 615000 evts and fitting the Z distribution in the range [0 ÷ 0.7]:

$$\alpha = -0.0301 \pm 0.0035_{stat} - 0.0036_{syst} + 0.0022_{syst}$$



- Experiment: α = −0.031 ± 0.004
- KLOE, CBall and WASA consistent
- ChPT LO: α = 0
- ChPT one and two loop: α > 0
- Quark masses from $\eta \to \pi^0\pi^0\pi^0$

[DeAndrea, Nehme, Talavera PRD78(2008)034032]

Conclusions

- Gluonium content confirmed at 3σ level in η′ using the Rosner model.
- BR and the first measurement of asymmetry in $\eta \to \pi^+\pi^-e^+e^-$ decay:

$$BR = (26.8 \pm 0.9_{Stat} \pm 0.7_{Syst}) \cdot 10^{-5}$$
$$A\phi = (-0.6 \pm 2.5_{Stat} \pm 1.8_{Syst}) \cdot 10^{-2}$$

- First observation of the $\eta \to e^+e^-e^+e^-$ decay ~400 events
- New measurement of the slope parameter α

$$\alpha = -0.0301 \pm 0.0035\text{stat} - 0.0036\ \text{syst} + 0.0022\ \text{syst}$$

- New analysis has been started on $\eta\to\pi^+\pi^-\gamma$. Preliminary results on the ratio of BRs $\frac{\Gamma(\eta\to\pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.2014 \pm 0.0004_{stat}$

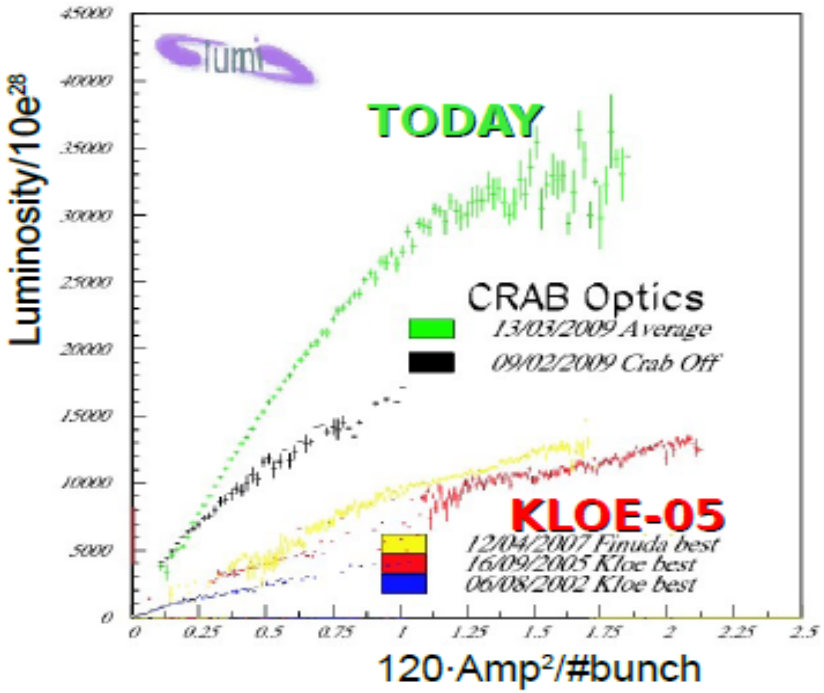
Other analysis in progress:

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

DAΦNE and KLOE upgrades

New machine magnetic scheme:
crab waist

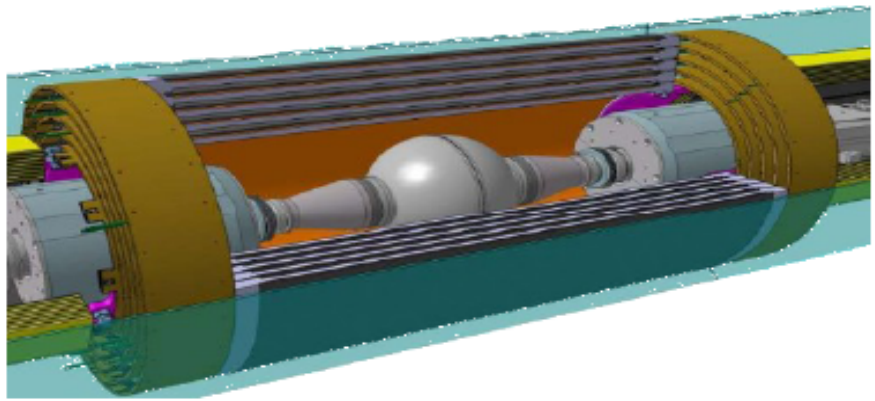
$L_{peak} = 5\times10^{32}\,cm^{-2}s^{-1}$
$\int L = 15\ pb^{-1}/day$



New interaction region:
larger crossing angle

STEP-0 [2009]: **5fb⁻¹**
γγ tagger

STEP-1 [2011]: **>20fb⁻¹**
Low Angle Calorimeter
Quadrupole Calorimeter
Inner Tracker



KLOE-2 perspectives on eta - eta′ physics

Refinement of rare η decay measurements

Improve result on $\eta \to \pi^+\pi^- e^+ e^-$ BR and CPV asymmetry

Form factor studies

Decays $\eta \to ee\gamma$, $\eta \to \mu\mu\gamma$, $\eta \to eeee$

Comparison between $\eta \to \pi\pi ee$, $\eta \to eeee$, $\eta \to \mu\mu ee$ channels

Test of theoretical calculation

High statistics study of the process $\eta \to \pi^0\gamma\gamma$ would allow to strongly test ChPT $O(p^6)$ calculations

Open a window on η' physics

Measurement of the all main η' BR's together with η' decay width $\sigma(e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^- \eta')$ at 1% precision would be necessary to solve the gluonium puzzle

Spare

Spare

5 more relations added

- $\Gamma(\eta'\to\gamma\gamma)/\Gamma(\pi^0\to\gamma\gamma)$
- $\Gamma(\eta'\to\rho\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\eta'\to\omega\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\omega\to\eta\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\rho\to\eta\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\phi\to\eta\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\phi\to\pi^0\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(K^{*+}\to K^+\gamma)/\Gamma(K^{*0}\to K^0\gamma)$

Parameters

Z_s , Z_q , ϕ_V , m_s/m

are left free

The new result includes the recent KLOE BR measurement

$BR(\omega \to \pi^0\gamma) = (8.09 \pm 0.14)\%$ **[PLB 669 (2008) 223]**

and the lattice results for decay constants ratios assuming exact isospin symmetry.

In addition the fit has been updated with all recent measurements from PDG'08

Spare

$$R_\phi = \frac{BR(\phi\to\eta'\gamma)}{BR(\phi\to\eta\gamma)} = (4.77 \pm 0.09_{stat.} \pm 0.19_{syst.}) \times 10^{-3}$$

PLB 648 (2007) 267

Experimental inputs:

- R_ϕ
- $\Gamma(\eta'\to\gamma\gamma)/\Gamma(\pi^0\to\gamma\gamma)$
- $\Gamma(\eta'\to\rho\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\eta'\to\omega\gamma)/\Gamma(\omega\to\pi^0\gamma)$

$\phi_P = (39.7 \pm 0.7)°$

$(Z_G)^2 = 0.14 \pm 0.04$

$P(\chi^2) = 0.49$

Theoretical parameters

Z_s, Z_q, ϕ_V, m_s/m

taken from

Bramon *et al.* PLB 503(2001) 271

where $Z_G = 0$ is assumed

$Z_q = \langle\eta_q|\omega_q\rangle/\langle\pi|\omega_q\rangle = \langle\eta_q|\rho\rangle/\langle\pi|\rho\rangle$

$Z_s = \langle\eta_s|\phi_s\rangle/\langle\pi|\rho\rangle$

ϕ_V is ϕ-ω mixing angle

Spare

KLOE *Phys. Lett.* B648 (2007) 267

$\phi_P = (39.7 \pm 0.7)°$

$|\phi_G| = (22 \pm 3)°$

$\sin^2\phi_G = (Z_G)^2 = 0.14 \pm 0.04$

Only ϕ_P and Z_G are free

Γ's used in the fit

4 measured quantities <u>including</u>

$\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$

Data from

PDG'06 and KLOE R_ϕ '07

Escribano-Nadal *JHEP* 0705:006, 2007

$\phi_P = (41.4 \pm 1.3)°$

$|\phi_G| = (12 \pm 13)°$

$\sin^2\phi_G = (Z_G)^2 = 0.04 \pm 0.09$

All theoretical parameters are free

Couplings used in the fit

12 measured quantities <u>without</u>

$\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$

Data from

PDG'06

Spare

$$\Gamma(\eta' \to \rho\gamma)/\Gamma(\omega \to \pi^0\gamma) = 3\frac{Z_{NS}^2}{\cos^2\varphi_V}\cdot\left(\frac{m_{\eta'}^2 - m_\rho^2}{m_\omega^2 - m_\pi^2}\cdot\frac{m_\omega}{m_{\eta'}}\right)^3 X_{\eta'}^2$$

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

$$\Gamma(\eta' \to \omega\gamma)/\Gamma(\omega \to \pi^0\gamma) = \frac{1}{3}\cdot\left(\frac{m_{\eta'}^2 - m_\omega^2}{m_\omega^2 - m_\pi^2}\cdot\frac{m_\omega}{m_{\eta'}}\right)^3\cdot\left(Z_{NS}X_{\eta'} + 2\frac{m_s}{\overline{m}}Z_S\cdot\tan\varphi_V Y_{\eta'}\right)^2$$

$\eta \to \pi^+\pi^-e^+e^-$

Event Selection

- ≥ 4 tracks from the Interaction Point
- 1 high energy neutral cluster ($E_{cl} \geq 250$ MeV)
- 0 medium energy neutral cluster ($50 \leq E_{cl} \leq 250$ MeV)

Track Selection

- Tracks are required to came from a cylinder around the IP:
  $R \leq 4$ cm $h/2 = 10$ cm
- Check on broken tracks is applied: $\Delta P_T < 4.5$ MeV $\Delta P_Z < 3$ MeV

≥ 2 positive and ≥ 2 negative tracks are requested

- Tracks are ordered by momentum:
  higher momentum → pions lower momentum → electrons

Spare

No kinematical fit, signal selection with help of kinematical constraints from consecutive decays i.e.

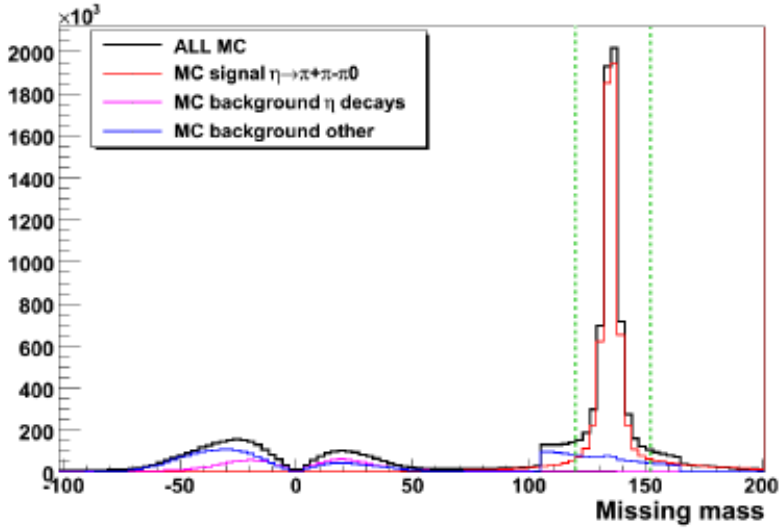
$\phi \rightarrow \eta\gamma, \quad \eta \rightarrow \pi^+\pi^- \pi^0, \quad \pi^0 \rightarrow \gamma\gamma$

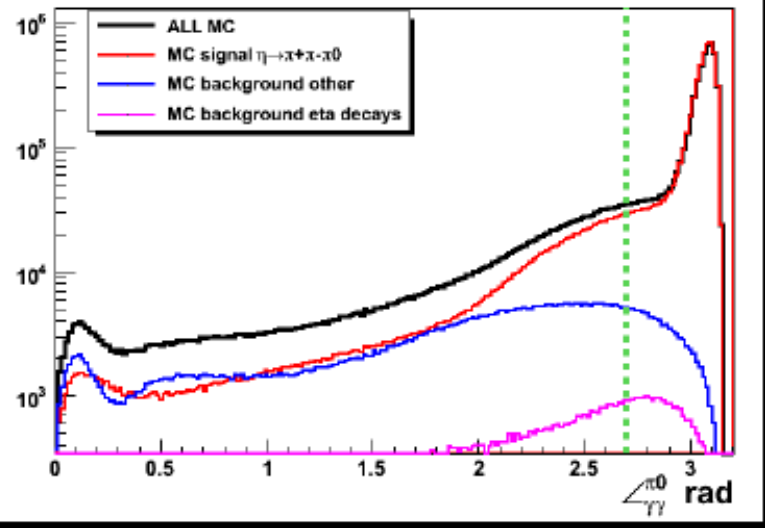
$\phi \rightarrow \eta\gamma, \quad \eta \rightarrow \pi^+\pi^-\gamma$

For $\eta \rightarrow \pi^+\pi^- \pi^0$:

- Missing mass to ($\phi - \pi^+ - \pi^- - \gamma_\phi$) system
- Opening angle ($\gamma_\eta{}^1\ \gamma_\eta{}^2$) in the π^0 rest frame

Eff = 40 % with BKG/SIG = 0.5 %





Spare

For $\eta \rightarrow \pi^+\pi^-\gamma$:

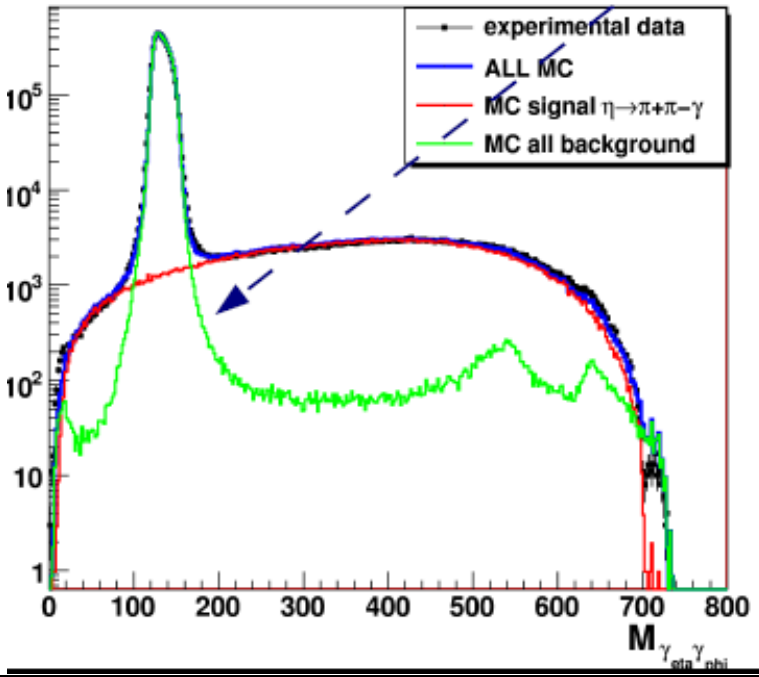
- Similar cuts ($(E_\gamma - P_\gamma)$ instead of missing mass, angle selection)

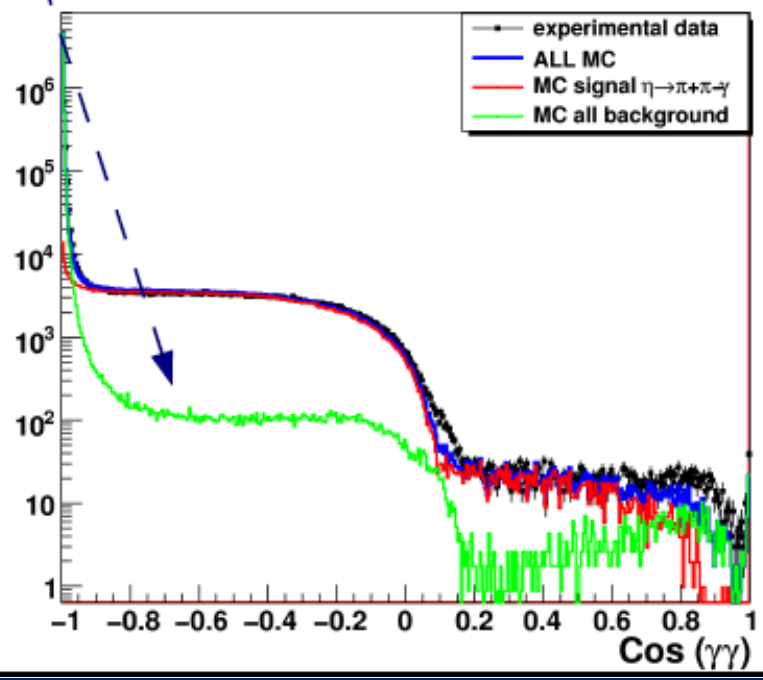
Eff = 29 % , BKG/SIG = 10:1

surviving background $\phi \rightarrow \pi^+\pi^-\pi^0$

different topology in $\gamma\gamma$ distributions

simultaneous fit to both spectra





Spare

$\Gamma(\eta\to\pi^+\pi^-\gamma) / \Gamma(\eta\to\pi^+\pi^-\pi^0)$

(based on 1.2 fb^{-1} data set)

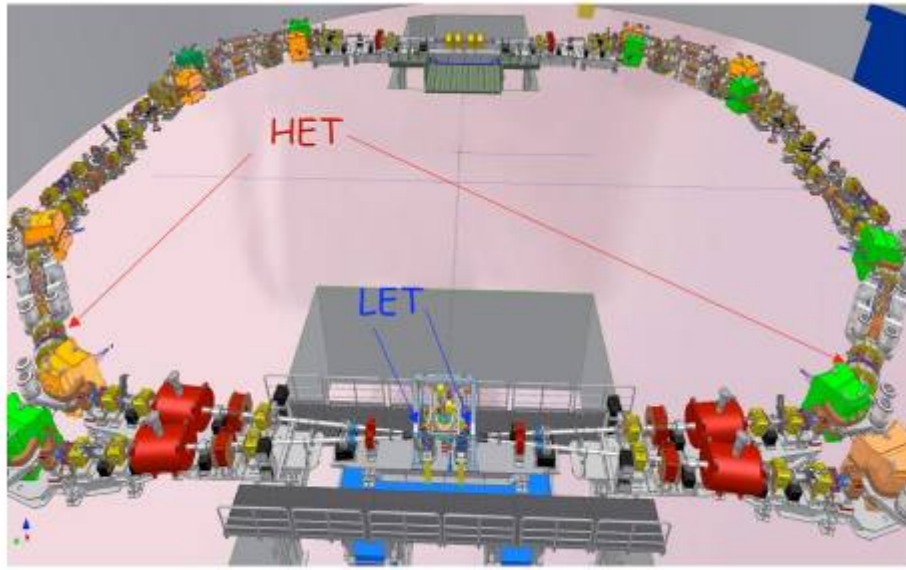
$$\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.2014 \pm 0.0004_{\text{stat}}$$

OUTLOOK

- Our preliminary results agrees with PDG values, confirming old results from '70s.
- We are evaluating systematics, aiming at value < 1%
- Cuts on $M_{\gamma\gamma}$ and $\cos(\gamma_\phi \gamma_\eta)$ in the π^0 rest frame will allow for significant background reduction
- Plan to use full KLOE data set (*statistical precision ~0.15%*) and investigate in detail the $\pi^+\pi^-$ invariant mass distribution and photon energy spectrum in order to disentangle non-resonant contributions and settle the inconsistencies of previous measurements.

Tagger for $\gamma\gamma$ physics

- $e^{\pm}$ tagger needed to reject background from $\phi \rightarrow K_S K_L$ (K_L lost, $K_S \rightarrow \pi\pi$ S/B ~ 10^{-3}-10^{-4}) and to improve resolution on $W_{\gamma\gamma}$
- 2 detectors:
  - LET (Low Energy Tagger)
    Crystals + SiPM
    σ_E/E= 5 – 10% , σ_t ~ 2 ns
    @ $E_e \approx 200$ MeV
  - HET (High Energy Tagger)
    uses dipoles as $e^{\pm}$ spectrometer
    position detector needed (σ < 1mm)
    @ 11 m from IP



	E_e' (MeV)	E_γ (MeV)
LET	(165 - 235)	(275 - 345)
HET	(330 - 390)	(120, 180)

- Coincidence will cover the interesting $W_{\gamma\gamma}$ range

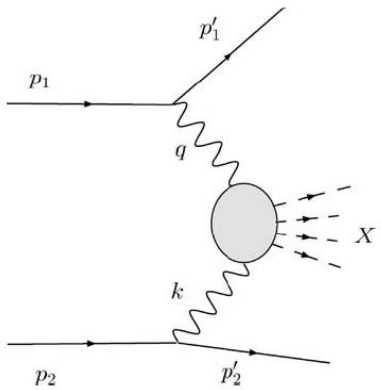
Search for $\gamma\gamma \to \sigma(600) \to \pi^0\pi^0$

KLOE preliminary

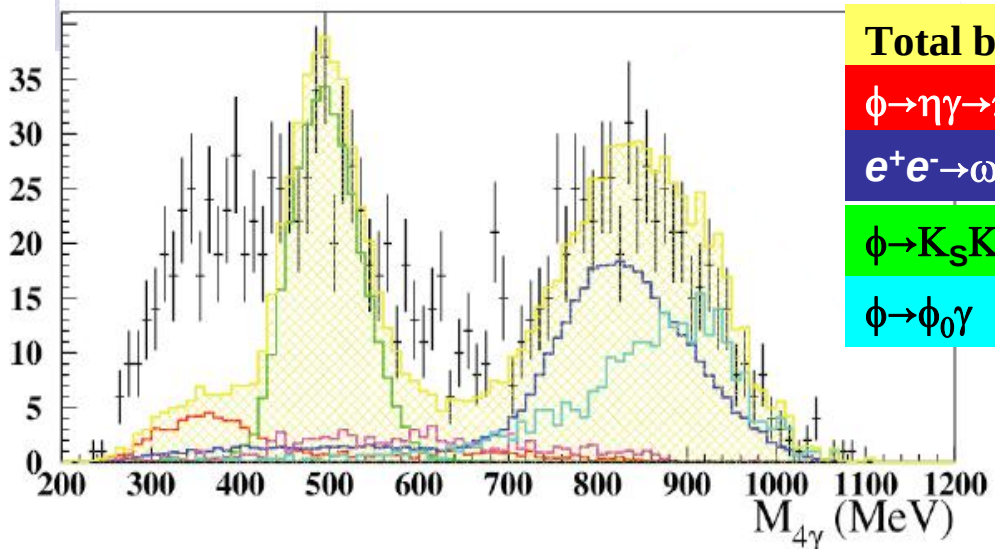
- Long debate about the experimental evidence of the $\sigma(600)$ meson
- Evidence for a $\pi^+\pi^-$ bound state from E791, CLEO, BES
- Values of mass and width with large uncertainties
- **Indirect evidence in the $e^+e^- \to \pi^0\pi^0\gamma$ Dalitz plot analysis @ KLOE**

KLOE preliminary: 11 pb^{-1} @ $\sqrt{s}$ = 1 GeV (1/20 of the off-peak data sample)

$e^+e^- \to e^+e^-\pi^0\pi^0$



Fit with bckg components only: χ^2/N_{dof}=441/94

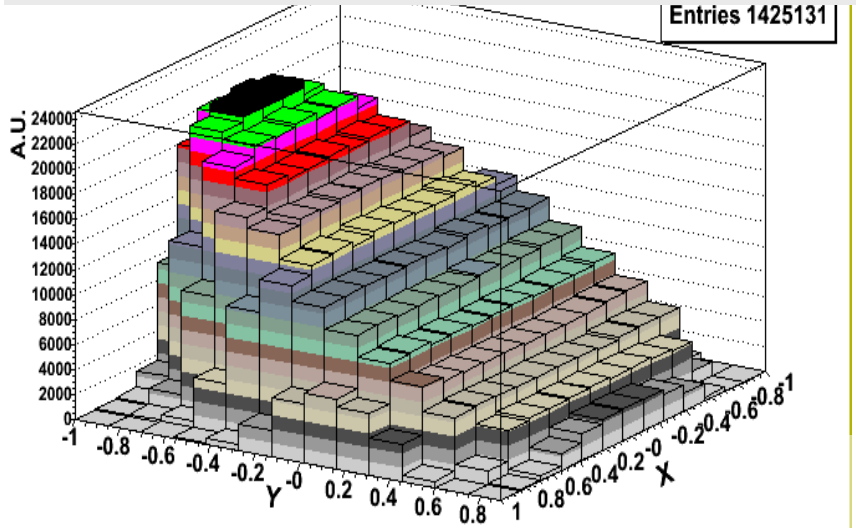


Excess of events w.r.t. the known background in the $\gamma\gamma \to \sigma(600) \to \pi\pi$ region

Dalitz plot analysis

19×10^6 η from φ→ηγ. Tagging: recoil monochromatic photon (363 MeV)

$$|M^2| = 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3$$



$a = -1.090 \pm 0.005\,(\text{stat})\ ^{+0.008}_{-0.019}\ (\text{syst})$

$b = 0.124 \pm 0.006\,(\text{stat}) \pm 0.010\,(\text{syst})$

$d = 0.057 \pm 0.006\,(\text{stat})\ ^{+0.007}_{-0.016}\ (\text{syst})$

$f = 0.14 \pm 0.01\,(\text{stat}) \pm 0.02\,(\text{syst})$

$c = 0.002 \pm 0.003\,(\text{stat}) \pm 0.001\,(\text{syst})$

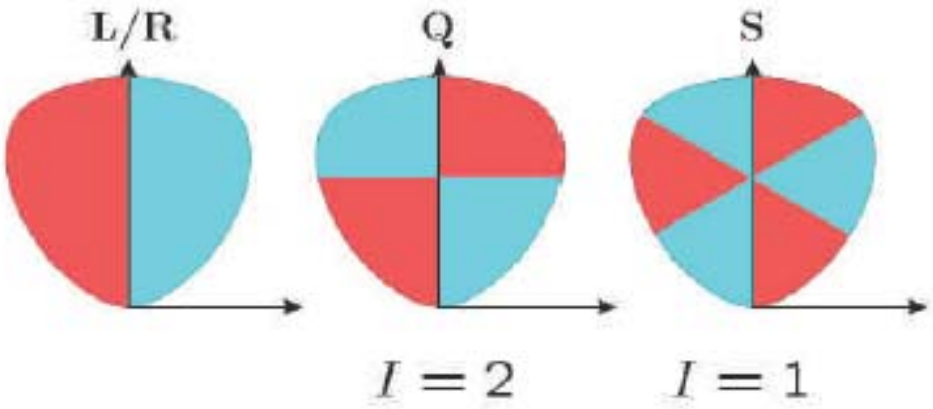
$e = -0.006 \pm 0.007\,(\text{stat})\ ^{+0.005}_{-0.003}\ (\text{syst})$

Bckg. contamination ~ 0.3%

	a	b	d	f
Tree	-1.039	0.270	0.00	0.000
One-loop	-1.371	0.452	0.053	0.027
NNLO	-1.271	0.394	0.055	0.025
Dispersive	-1.33	0.26	0.10	---
Tree dispersive	-1.10	0.33	0.001	---
Abs dispersive	-1.21	0.33	0.04	---

Asymmetries

C-parity conservation tested also with the charge asymmetries:



Left-Right C-invariance
Quadrant C-invariance in ΔI=2 amplit.
Sextant C-invariance in ΔI=1 amplit.
(see *J.G.Layter et al.,Phys.Rev.Lett.29 (1972) 316*)

$$A_{LR} = \frac{N_1 - N_2}{N_1 + N_2} \qquad A_Q = \frac{N_1 + N_3 - N_2 + N_4}{N_1 + N_3 + N_2 + N_4} \qquad A_S = \frac{N_1 + N_3 + N_5 - N_2 + N_4 + N_6}{N_1 + N_3 + N_5 + N_2 + N_4 + N_6}$$

$$A_{LR} = (\ 0.09 \pm 0.10\,(\text{stat})\ ^{+0.09}_{-0.14}\ (\text{syst})\ ) \times 10^{-2}$$

$$A_Q = (-0.05 \pm 0.10\,(\text{stat})\ ^{+0.03}_{-0.05}\ (\text{syst})\ ) \times 10^{-2}$$

$$A_S = (\ 0.08 \pm 0.10\,(\text{stat})\ ^{+0.08}_{-0.13}\ (\text{syst})\ ) \times 10^{-2}$$

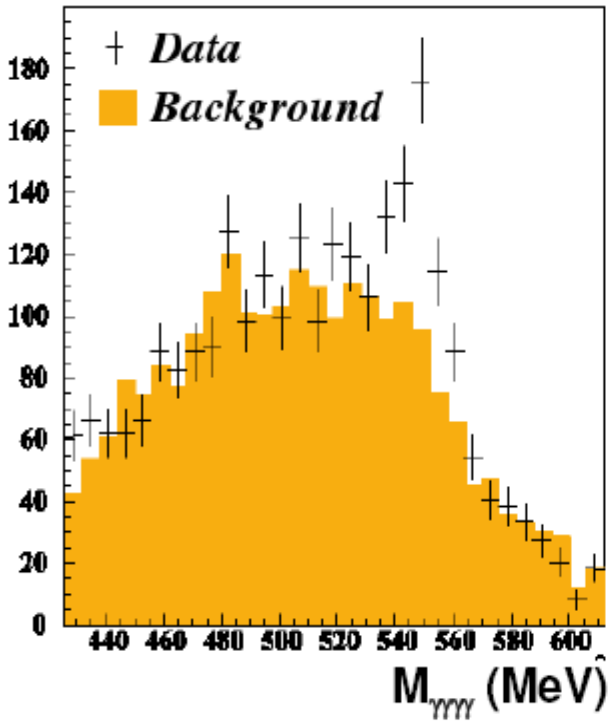
All asymmetries consistent with zero at 10^{-3} level

$\eta \to \pi^0 \gamma \gamma$

ChPT "golden mode": **p^2 null, p^4 suppressed, p^6 dominates**

KLOE has presented a 3σ signal (only 1/5 of full statistics)

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



CB@MAMI-B: BR = (22.5 ± 4.6 ± 1.7) × 10^{-5}

CB@AGS: BR = (22.1 ± 2.4 ± 3.8) × 10^{-5}

Analysis repeated with 1.5 fb^{-1} (2005 data):

- **the signal is confirmed**
- **BR updated result with the full sample will have ~15% error**

Spare

$$\Gamma(\eta' \to \rho\gamma)/\Gamma(\omega \to \pi^0\gamma) = 3\frac{Z_{NS}^2}{\cos^2\varphi_V} \cdot \left(\frac{m_{\eta'}^2 - m_\rho^2}{m_\omega^2 - m_\pi^2} \cdot \frac{m_\omega}{m_{\eta'}}\right)^3 X_{\eta'}^2$$

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

$$\Gamma(\eta' \to \omega\gamma)/\Gamma(\omega \to \pi^0\gamma) = \frac{1}{3} \cdot \left(\frac{m_{\eta'}^2 - m_\omega^2}{m_\omega^2 - m_\pi^2} \cdot \frac{m_\omega}{m_{\eta'}}\right)^3 \cdot \left(Z_{NS}X_{\eta'} + 2\frac{m_s}{\overline{m}}Z_S \cdot \tan\varphi_V Y_{\eta'}\right)^2$$