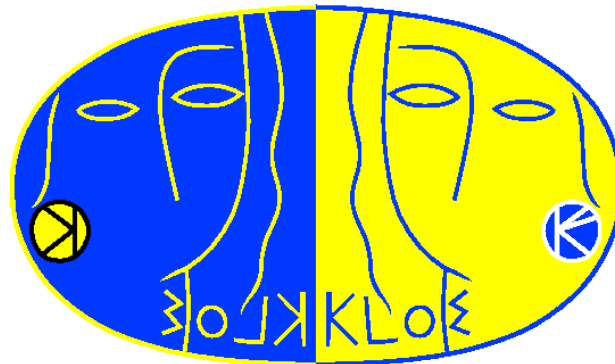


# Low energy QCD and ChPT studies with KLOE

Marek Jacewicz, Uppsala University  
on behalf of the KLOE Collaboration



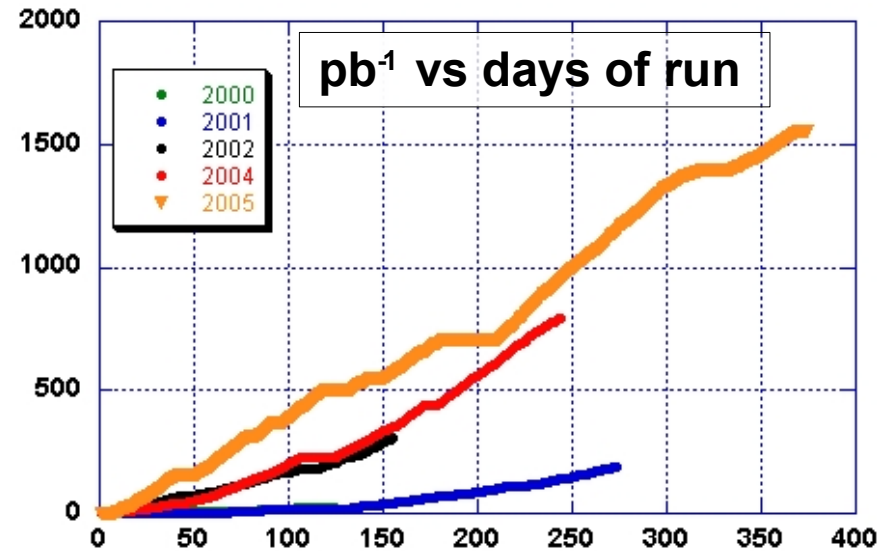
# DAFNE collider in Frascati

$e^+e^-$  collider @  $\sqrt{s} = m_\phi = 1.019$  GeV

in KLOE runs  $\sim 2.5$  fb $^{-1}$  collected

This translates to  $\sim 8 \times 10^9$   $\phi$  mesons

Also collected 240 pb $^{-1}$  @ 1 GeV “off-peak”



0 $^-$

1 $^-$

0 $^+$

BR 83%

$\phi(1020)$

KK

$\eta'(960)\gamma$

$\eta(547)\gamma$

BR 1.3%

$\pi^0\gamma$

$\rho(780)\pi$

BR 15%

$a_0(980)\gamma$

$f_0(980)\gamma$



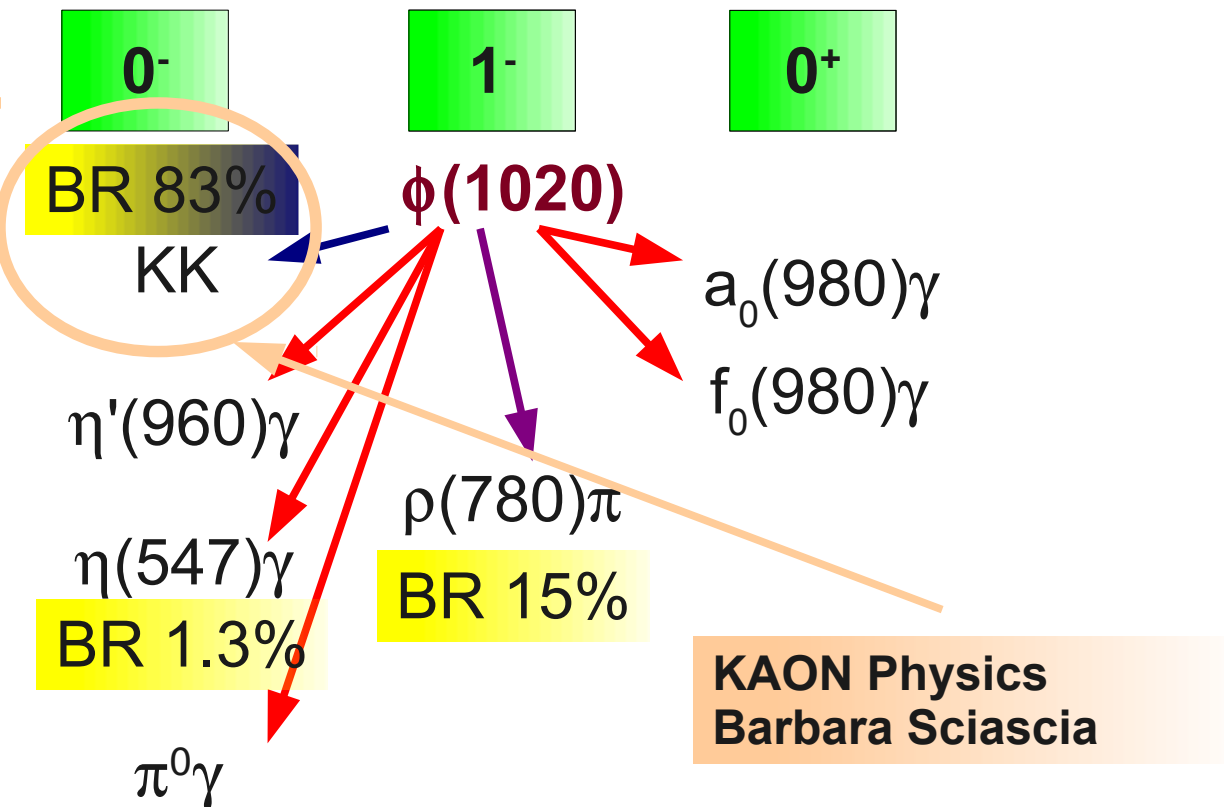
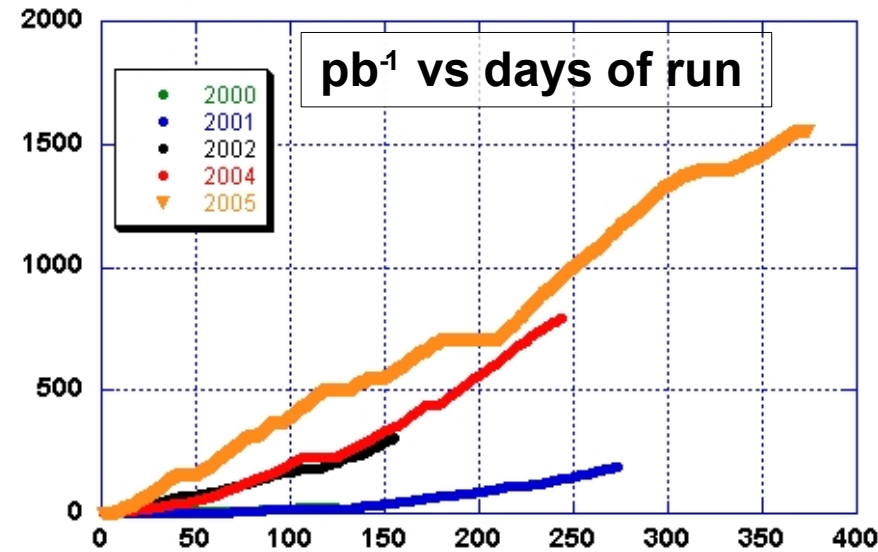
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# KLOE experiment

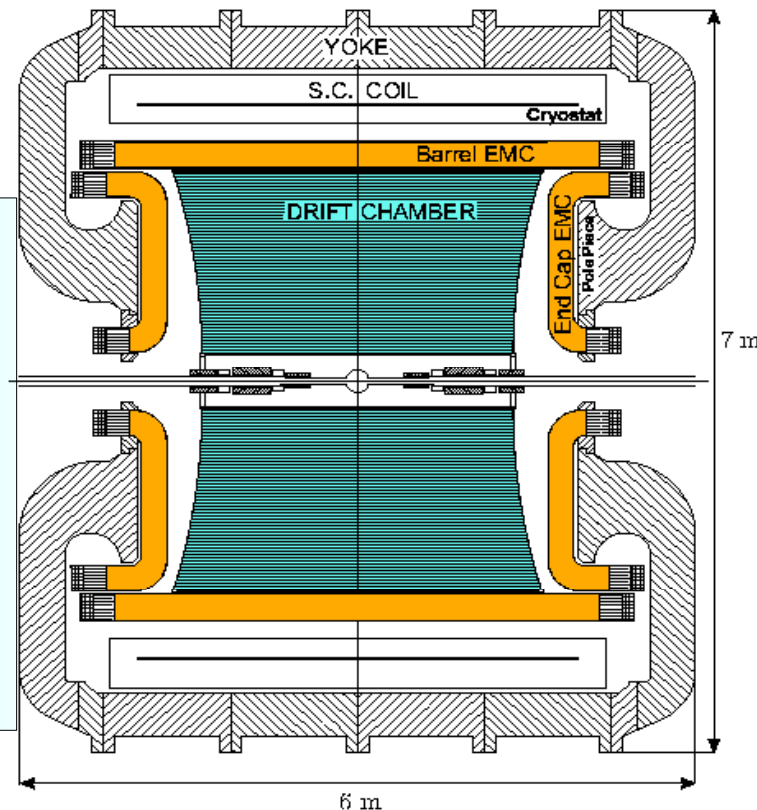
Detector design optimized for  $K_L$  measurement:

big volume with good ability for kaon decay vertex reconstruction

high track reconstruction efficiency

very good momentum resolution

very good time resolution



## Drift Chamber

58 layers, 52140 wires

90% He 10%  $C_4H_{10}$

$\sigma_{r\phi} = 150 \mu\text{m}$

$\sigma_z = 2 \text{ mm}$

$\sigma_p/p \sim 4 \times 10^{-3}$

## Electromagnetic Calorimeter

### Barrel + End caps

Lead-scintillating fibers

98% solid angle coverage

$\sigma_t = 57 \text{ ps} / \sqrt{E[\text{GeV}]} \oplus 100 \text{ ps}$

$\sigma_E/E = 0.057 / \sqrt{E[\text{GeV}]}$

# Scalar studies in $\phi$ decays

The problem of the internal structure of the scalar mesons with mass  $< 1\text{GeV}$  is still open.

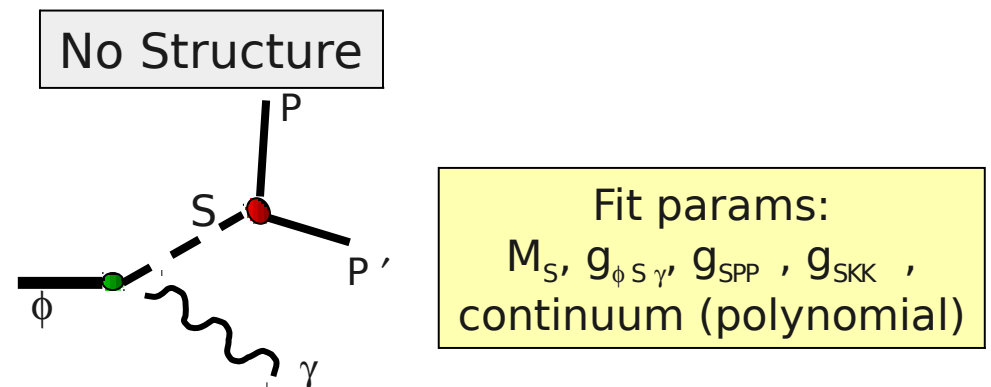
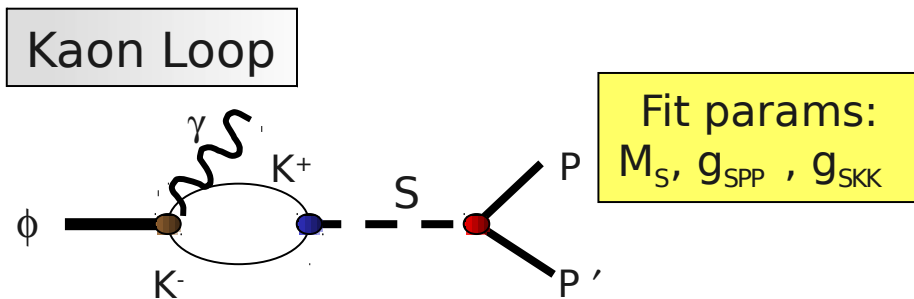
Are they  $q\bar{q}$  mesons,  $q\bar{q}q\bar{q}$  states, bound states of  $K\bar{K}$  pair or a mixing ?

KLOE has studied radiative  $\phi(1020)$  decays  $\phi \rightarrow P_1 P_2 \gamma$  dominated by exchange of scalar meson  $S$  in the intermediate state  $\phi \rightarrow S \gamma \rightarrow P_1 P_2 \gamma$

Decays' BRs and  $P_1 P_2$  invariant mass shapes depend on scalar structure

| $P_1 P_2$     | $S$                    | Publications                            |
|---------------|------------------------|---|
| $\pi^0 \pi^0$ | $f_0(980)/\sigma(600)$ | [EPJ C49 (2007) 473, PLB 537 (2002) 21] |
| $\pi^+ \pi^-$ | $f_0(980)/\sigma(600)$ | [PLB 634 (2006) 148]                    |
| $\eta \pi^0$  | $a_0(980)$             | [PLB 681 (2009) 5, PLB 536 (2002) 209]  |
| $K_S K_S$     | $f_0(980)/a_0(980)$    | [PLB 679 (2009) 10]                     |

Phenomenological models used by KLOE to describe  $\phi \rightarrow S \gamma \rightarrow P_1 P_2 \gamma$  :



[N.N.Achasov, V.N.Ivanchenko, NPB315 (1989) 465]

[N.N.Achasov, V.V.Gubin, PRD 56 (1997) 4084]

[N.N.Achasov, A.V.Kiselev, PRD 68 (2003) 014006]

G.Isidori et al, JHEP05 (2006)049

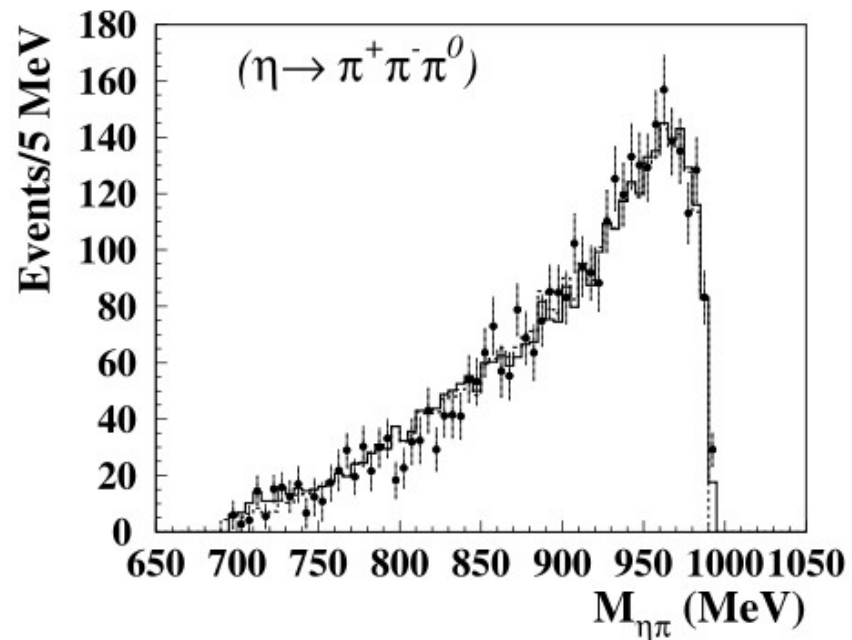
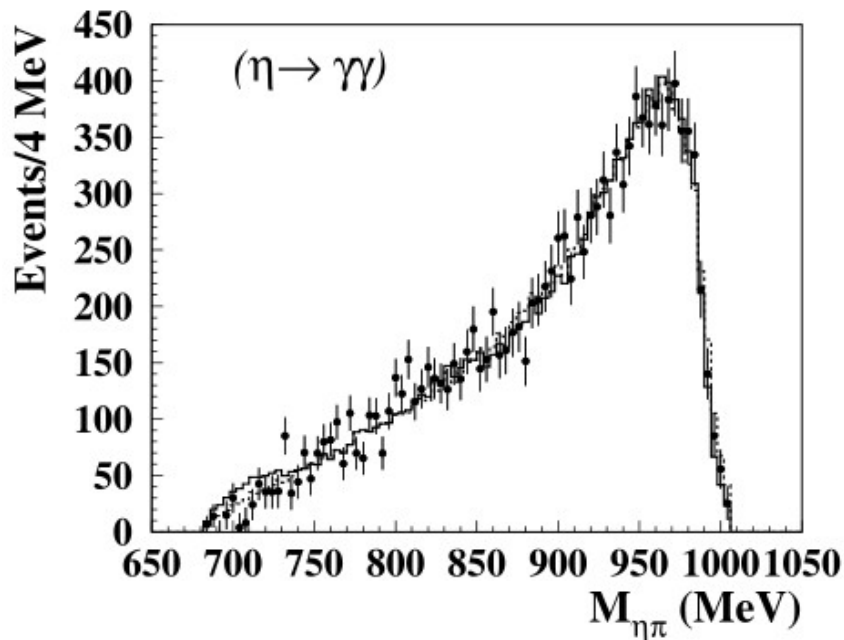
# Study of $a_0$ (980) meson with $\phi \rightarrow \eta\pi^0\gamma$

BR( $\phi \rightarrow \eta\pi^0\gamma$ ) has been measured twice using two different  $\eta$  decays ( $\eta \rightarrow \gamma\gamma$  and  $\eta \rightarrow \pi^+\pi^-\pi^0$ )

$$\text{BR}(\phi \rightarrow \eta\pi^0\gamma) = (7.01 \pm 0.10_{\text{stat}} \pm 0.20_{\text{syst}}) \cdot 10^{-5} (\eta \rightarrow \gamma\gamma)$$

$$\text{BR}(\phi \rightarrow \eta\pi^0\gamma) = (7.12 \pm 0.13_{\text{stat}} \pm 0.22_{\text{syst}}) \cdot 10^{-5} (\eta \rightarrow \pi^+\pi^-\pi^0)$$

In order to extract relevant  $a_0$  parameters a simultaneous fit of the two invariant mass distributions has been performed.



Both models (KL model [solid line] and NS model [dashed line]), are able to reproduce the experimental  $M_{\eta\pi^0}$  mass distribution.

# Study of $a_0(980)$ meson with $\phi \rightarrow \eta\pi^0\gamma$

Extra free parameter, relative normalization :  $R_\eta = \text{Br}(\eta \rightarrow \gamma\gamma) / \text{Br}(\eta \rightarrow \pi^+\pi^-\pi^0)$

|  | KL                       | NS                       |
|--|--------------------------|--------------------------|
| $M_{a_0}(\text{MeV})$                      | $982.5 \pm 1.6 \pm 1.1$  | $982.5$ (fixed)          |
| $g_{a_0 K\bar{K}}$ (GeV)                   | $2.15 \pm 0.06 \pm 0.06$ | $2.01 \pm 0.07 \pm 0.28$ |
| $g_{a_0 \eta\pi}$ (GeV)                    | $2.82 \pm 0.03 \pm 0.04$ | $2.46 \pm 0.08 \pm 0.11$ |
| $g_{\phi a_0 \gamma}$ (GeV <sup>-1</sup> ) | $1.58 \pm 0.10 \pm 0.16$ | $1.83 \pm 0.03 \pm 0.08$ |
| $\text{BR}(\text{VDM}) \times 10^6$        | $0.92 \pm 0.40 \pm 0.15$ | $\sim 0$                 |
| $R_\eta$                                   | $1.70 \pm 0.04 \pm 0.03$ | $1.70 \pm 0.03 \pm 0.01$ |
| $(g_{a_0 K\bar{K}} / g_{a_0 \eta\pi})^2$   | $0.58 \pm 0.03 \pm 0.03$ | $0.67 \pm 0.06 \pm 0.13$ |
| $P(\chi^2)$                                | 10.4%                    | 30.9%                    |
| $\Gamma_{a_0}$ (MeV)                       | 105                      | 80                       |

$984.7 \pm 1.2$  from PDG08

$1.729 \pm 0.028$  from PDG08

the vector contribution is very small,  $\text{Br}(\phi \rightarrow V P \rightarrow \eta\pi^0\gamma) < 10^{-6}$  ;  $V = \rho, \omega$   
 $a_0(980)$  mass agrees at one standard deviation level with the PDG value

# Search for $\phi \rightarrow K^0 \bar{K}^0 \gamma$

## Never been observed

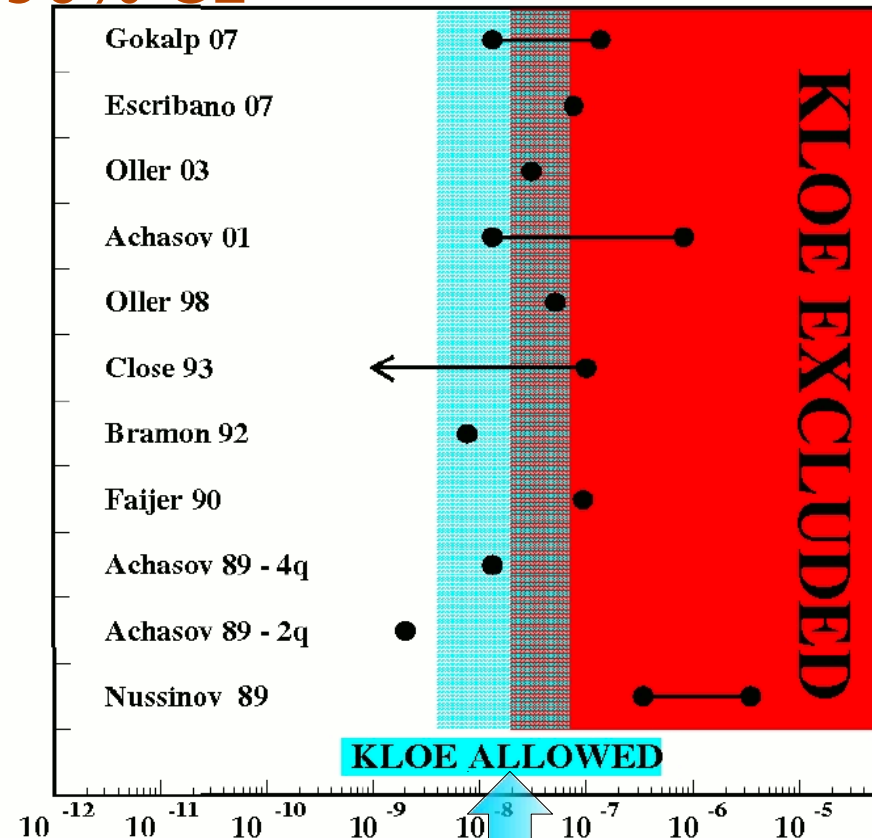
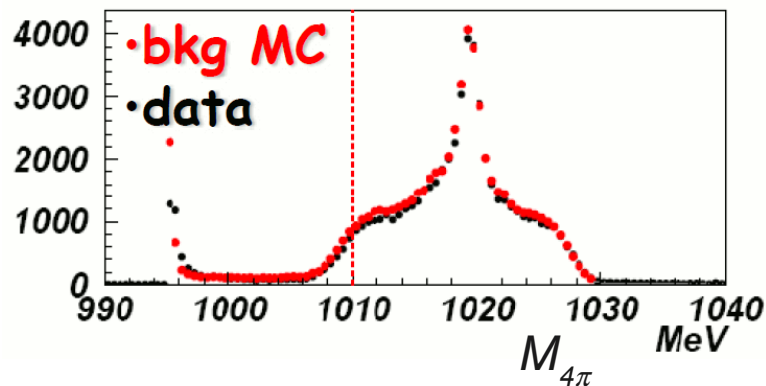
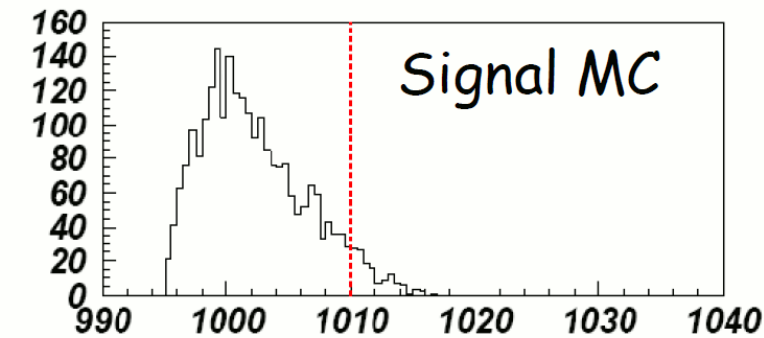
Selected channel :

$$\phi \rightarrow (f_0 + a_0) \gamma \rightarrow K^0 \bar{K}^0 \gamma \rightarrow K_S K_S \gamma \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma$$

Using  $2.18 \text{ fb}^{-1}$  data with 24% signal efficiency:

5 events in data  $\Rightarrow 3.2 \pm 0.7$  background events

$BR(\phi \rightarrow K^0 \bar{K}^0 \gamma) < 1.9 \times 10^{-8}$  at 90% CL



Consistency check using couplings from KLOE fit of  $\phi$  decays to  $\pi\pi\gamma$  and  $\eta\pi\gamma$  in the Kaon Loop model



# $\eta$ - $\eta'$ mixing and $\eta'$ gluonic content

$\eta'$  considered a good candidate to host **gluonium** content

In the constituent quark model one can extract gluonium content together with the  $\eta$ - $\eta'$  mixing angle

Rosner PRD 27 (1983) 1101

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

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

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

$\phi_P = \eta$ - $\eta'$  mixing angle

$Z_G = \sin \phi_G$  gluonium content

**KLOE** PLB 648 (2007) 267

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

$$\phi_P = (39.7 \pm 0.7)^\circ$$

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

$$P(\chi^2) = 0.49$$

**Gluonium at  $3\sigma$**

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

**Escribano-Nadal** *JHEP* 0705:006, 2007

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

Difference attributed to the use in the fit of theoretical parameters  $Z_s, Z_q, \phi_v, m_s/m$

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

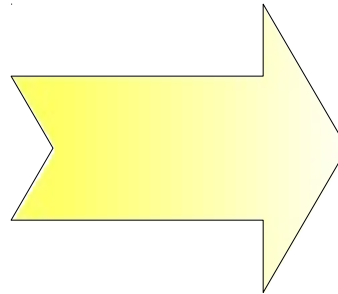
where  $Z_G = 0$  is assumed

# $\eta$ - $\eta'$ mixing and $\eta'$ gluonic content

5 more relations added

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

**KLOE new fit**



Parameters

$Z_s, Z_q, \phi_V, m_s/m$

are left free

# $\eta$ - $\eta'$ mixing and $\eta'$ gluonic content

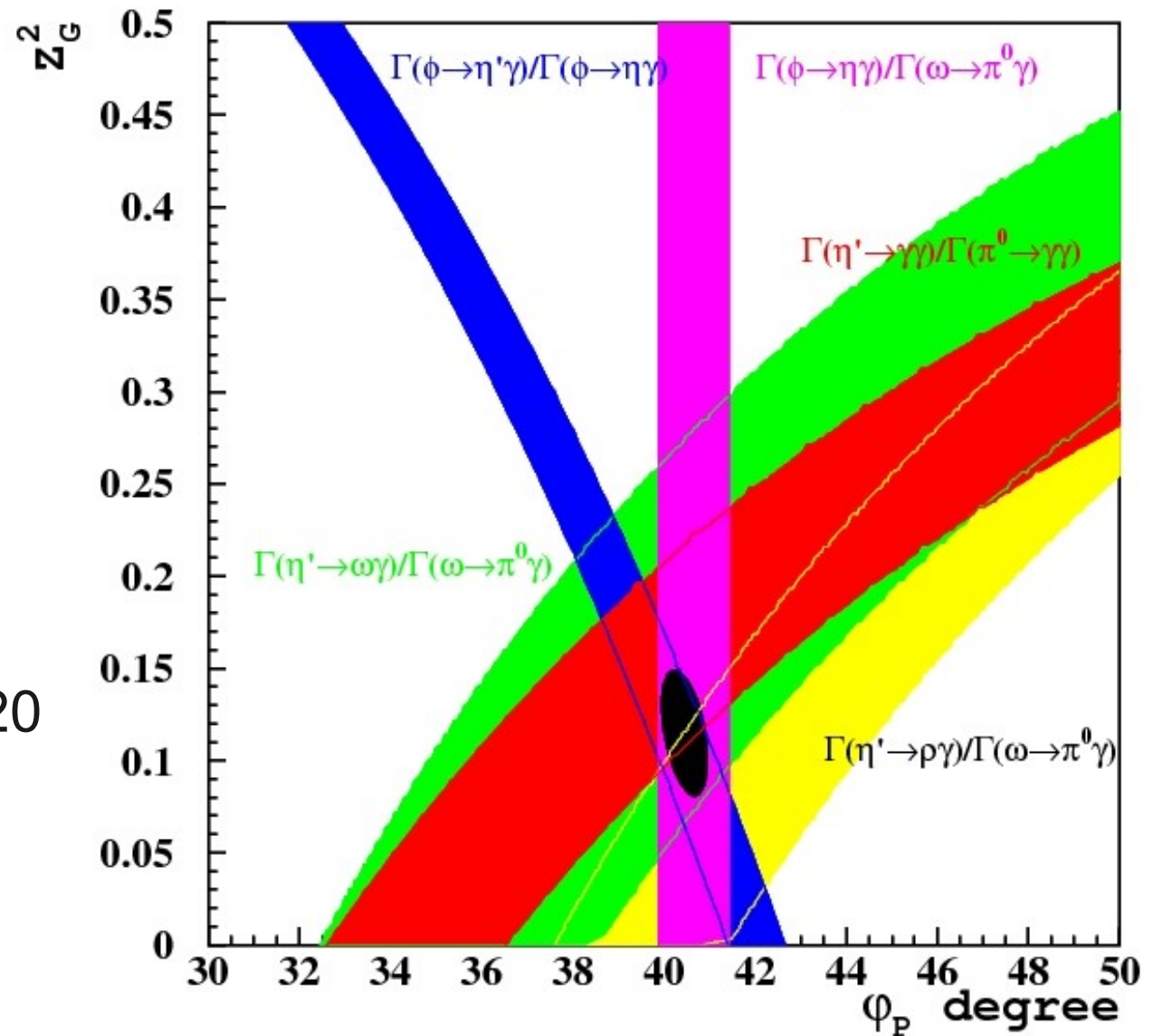
Published in JHEP07(2009)105

with glue

|           |                         |
|-----------|-------------------------|
| $(Z_G)^2$ | $0.115 \pm 0.036$       |
| $\phi_P$  | $(40.4 \pm 0.6)^\circ$  |
| $Z_q$     | $0.94 \pm 0.03$         |
| $Z_s$     | $0.83 \pm 0.05$         |
| $\phi_V$  | $(3.32 \pm 0.09)^\circ$ |
| $m_s/m$   | $1.24 \pm 0.07$         |

$\chi^2/\text{dof} = 4.6/3$   $P(\chi^2) = 0.20$

Using PDG 2008  
KLOE results on  $\omega$   
5 constraints more  
gluonium at  $3\sigma$  confirmed



68% CL contour of the  $\eta'$  related measurements in the  $Z_G^2 - \phi_P$  plane

# $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ decay

Existing data: 4 events CMD-2, 16 events CELSIUS-WASA  
Test of CP violation by measurement of angular asymmetry  
between  $e^+e^-$  and  $\pi^+\pi^-$  planes

Gao, Mod. Phys. Lett. A17(2002) 1583

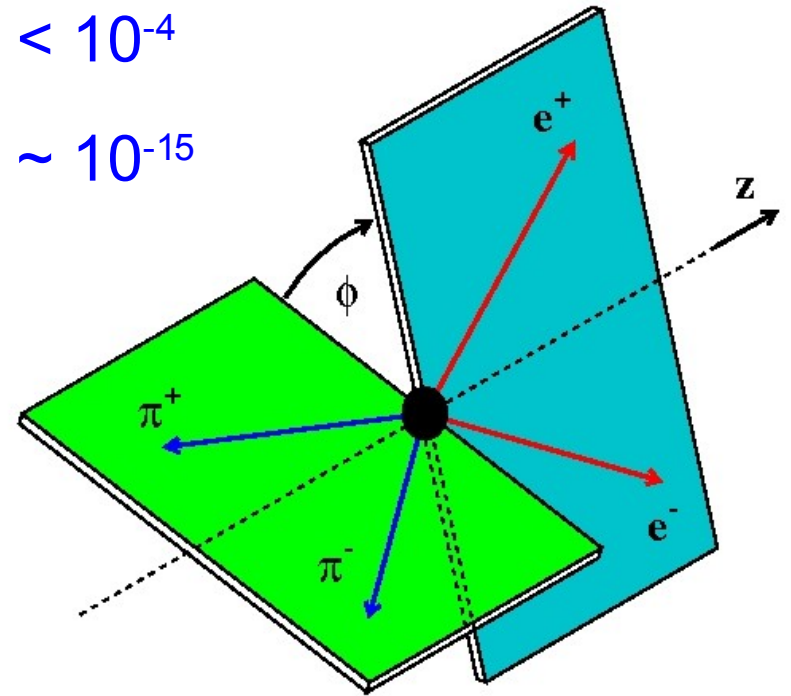
Within SM constrained by  $BR(\eta \rightarrow \pi\pi)$ :

using experimental upper limit:  $A_\phi < 10^{-4}$

using theoretical prediction:  $A_\phi \sim 10^{-15}$

**The unconventional CPV term can  
increase  $A_\phi$  up to  $10^{-2}$**

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

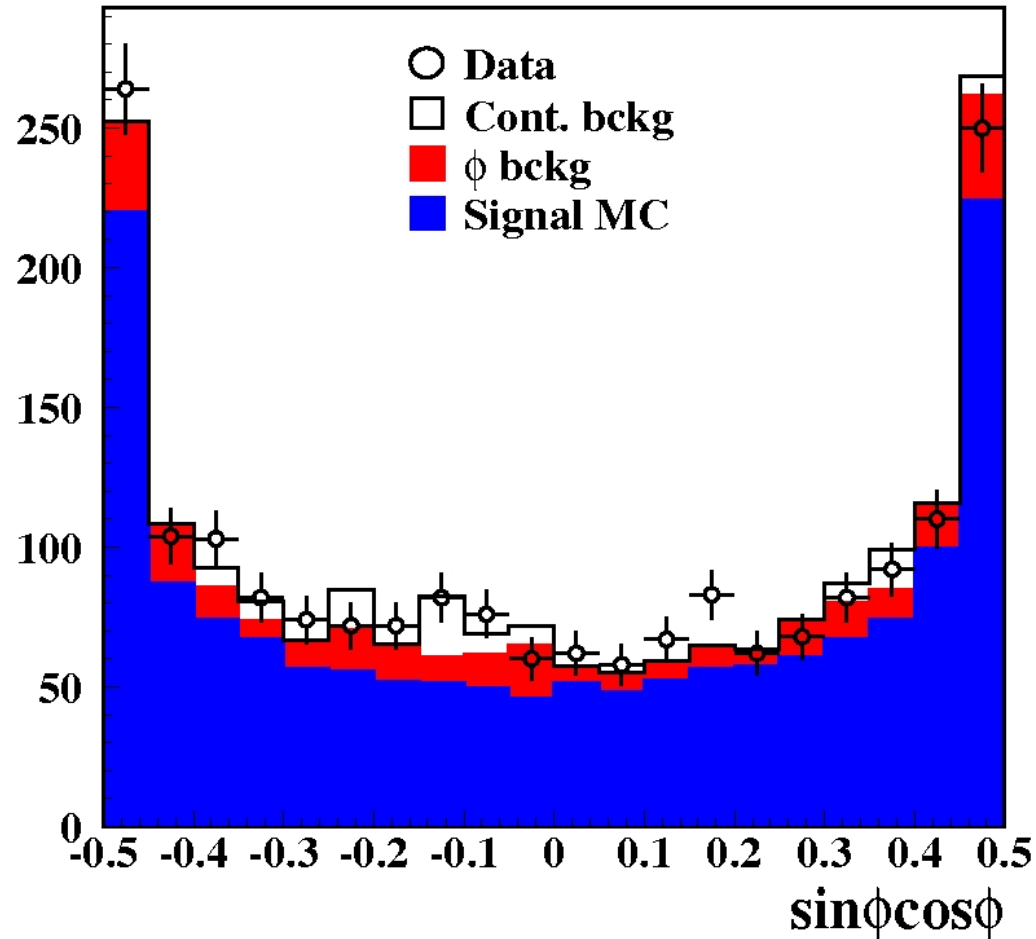
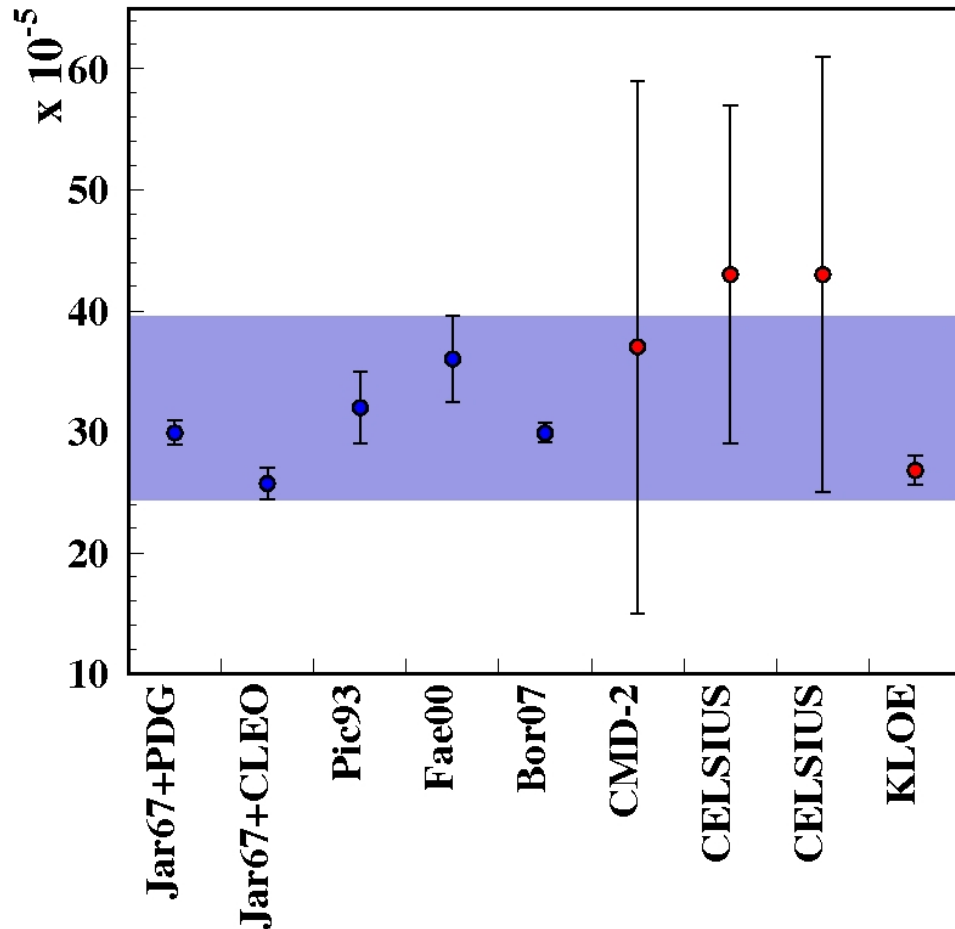


# $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ decay: BR and asymmetry

$$\text{BR}(\eta \rightarrow \pi^+ \pi^- e^+ e^-) = (26.8 \pm 0.9_{\text{Stat.}} \pm 0.7_{\text{Syst.}}) \cdot 10^{-5}$$

PLB 675(2009) 283

$$A_\phi = (-0.6 \pm 2.5_{\text{Stat.}} \pm 1.8_{\text{Syst.}}) \cdot 10^{-2} \quad \text{First measurement!}$$



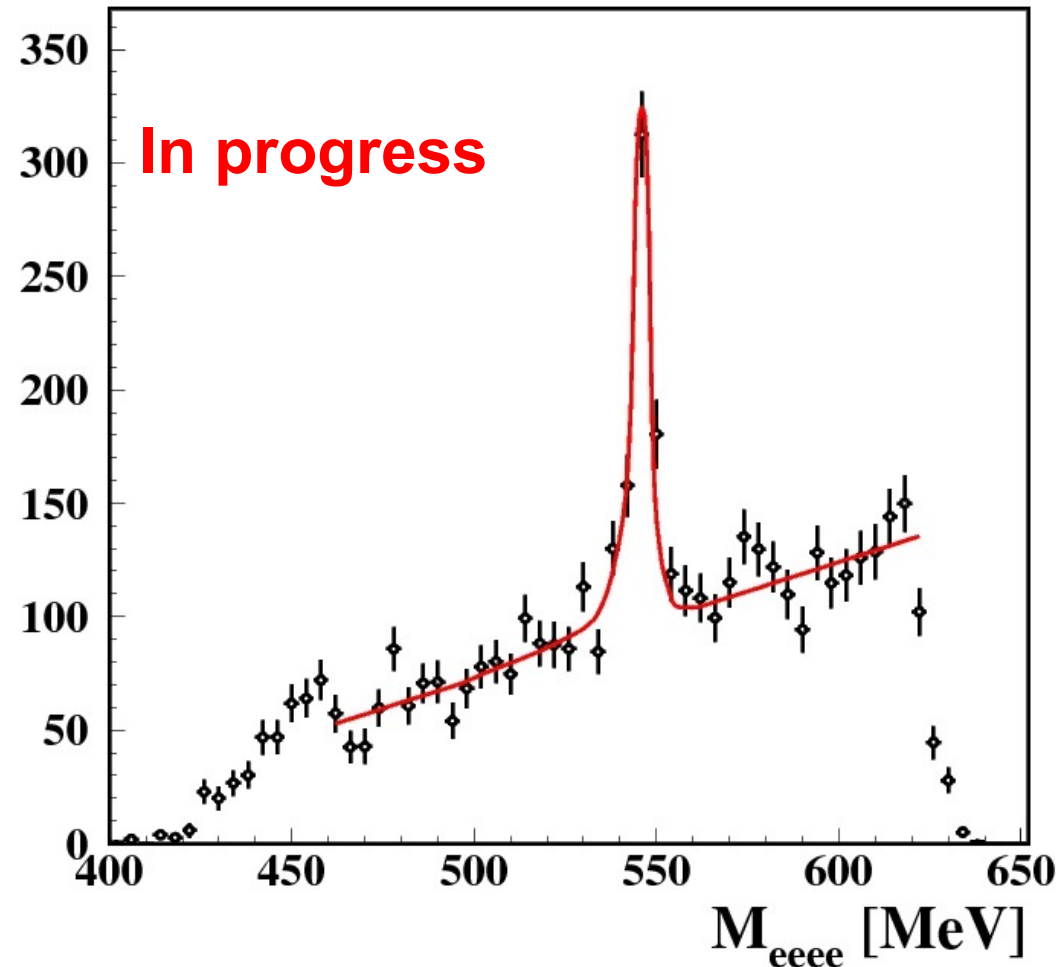
# $\eta \rightarrow e^+ e^- e^+ e^-$ analysis

- Data sample:  $1.7 \text{ fb}^{-1}$
- $e^+e^-$  pairs from photon conversion on Beam Pipe and Drift Chamber wall rejected
- Remaining background from  $\phi$  decay is subtracted

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

$$N_{eeee} = 413 \pm 31$$

**First observation!**

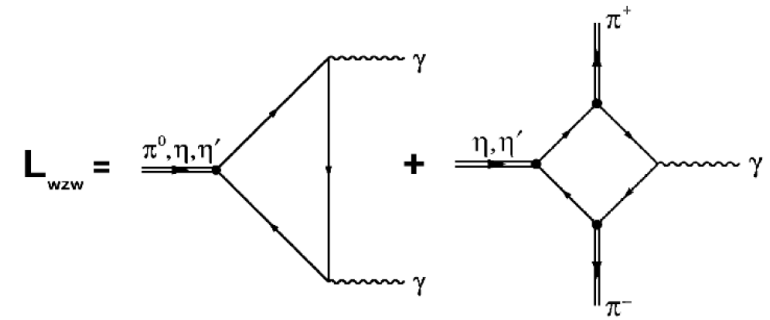


# $\eta \rightarrow \pi^+ \pi^- \gamma$ decay

## The Box Anomaly

In the  $\eta \rightarrow \pi^+ \pi^- \gamma$  decay a significant contribution from the chiral anomaly responsible for  $\eta \rightarrow \gamma\gamma$  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.



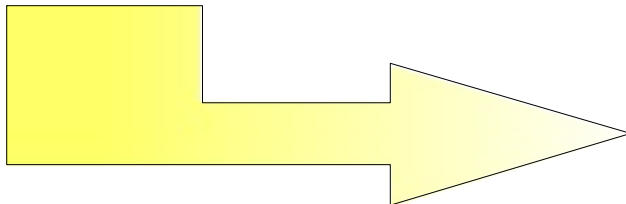
Holstein, Phys. Scripta, T99 55 (2002)  
 Benayoun, Eur. Phys. J., C31 525 (2003)  
 Borasoy, Nissler, Nucl. Phys., A740 362 (2004)

## 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)

Latest results from CLEO on the ratio of charged decays BRs differ  $> 3\sigma$  from old results



| $\Gamma(\pi^+ \pi^- \gamma) / \Gamma(\pi^+ \pi^- \pi^0)$ |                                     |                    |             |      |
|--|-------------------------------------|--------------------|-------------|------|
| <u>VALUE</u>   | <u>EVTS</u>                         | <u>DOCUMENT ID</u> | <u>TECN</u> |      |
| <b>0.202 ± 0.007 OUR FIT</b>                             | Error includes scale factor of 2.4. |                    |             |      |
| <b>0.203 ± 0.008 OUR AVERAGE</b>                         | Error includes scale factor of 2.4. |                    |             |      |
| 0.175 ± 0.007 ± 0.006                                    | 859                                 | LOPEZ              | 07          | CLEO |
| 0.209 ± 0.004  | 18k                                 | THALER             | 73          | ASPK |
| 0.201 ± 0.006  | 7250                                | GORMLEY            | 70          | ASPK |

# Ratio: $\Gamma(\eta \rightarrow \pi^+ \pi^- \gamma) / \Gamma(\eta \rightarrow \pi^+ \pi^- \pi^0)$

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

$\phi \rightarrow \eta \gamma, \eta \rightarrow \pi^+ \pi^- \pi^0, \pi^0 \rightarrow \gamma \gamma$   
Missing mass to  $(\phi - \pi^+ - \pi^- - \gamma_\phi)$   
system  
Opening angle  $(\gamma_\eta^1 \gamma_\eta^2)$  in the  $\pi^0$  rest  
frame  
**Eff = 40 %**

$\phi \rightarrow \eta \gamma, \eta \rightarrow \pi^+ \pi^- \gamma$   
Similar cuts  $(E_\gamma - P_\gamma)$  instead of  
missing mass, angle selection)  
Simultaneous fit to two distribution  
**Eff = 29 %**

**Data sample: 1.2 fb<sup>-1</sup>**

$$\frac{\Gamma(\eta \rightarrow \pi^+ \pi^- \gamma)}{\Gamma(\eta \rightarrow \pi^+ \pi^- \pi^0)} = 0.201 \pm 0.006_{stat \oplus syst}$$

**PRELIMINARY RESULT**

Extraction of  $M_{\pi\pi}$  spectrum and  $BR_{\eta \rightarrow \pi\pi\gamma}$  is close to completion



# $\eta \rightarrow \pi^0 \pi^0 \pi^0$

Preliminary results:  
arXiv 0707.4137

At the lowest order  $\eta \rightarrow \pi^0 \pi^0 \pi^0$  decay amplitude can be parametrized by

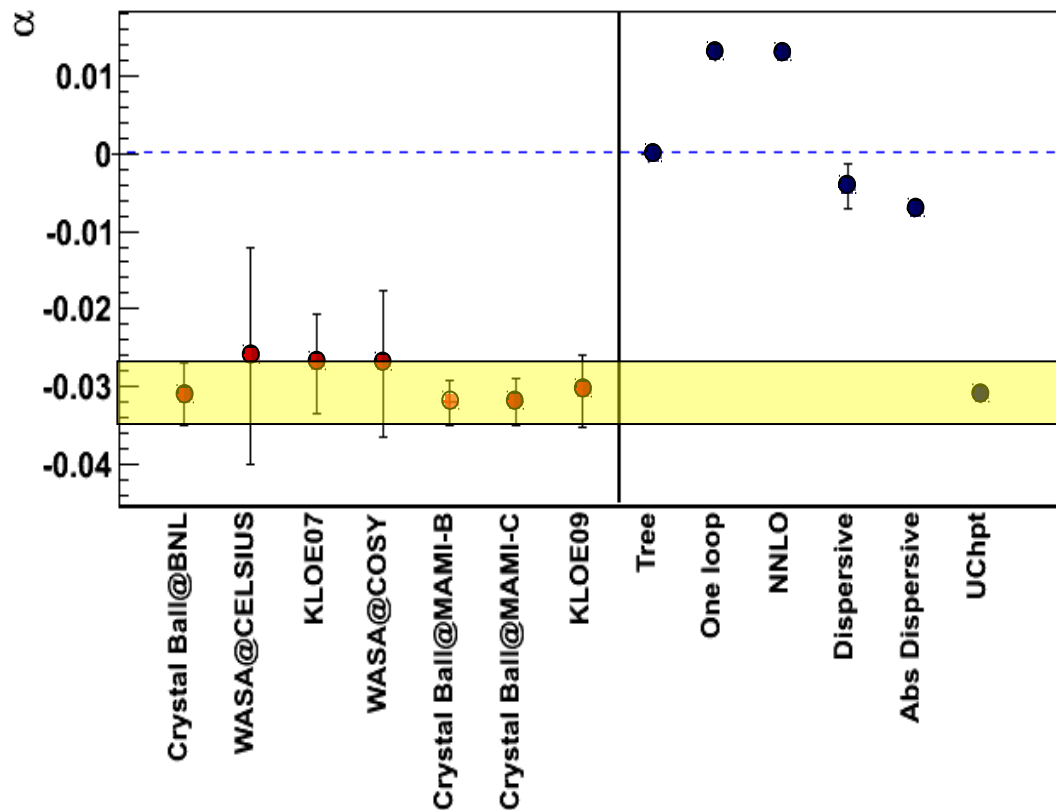
$$|A|^2 \propto 1 + 2 \alpha z \quad \text{where} \quad z = \frac{2}{3} \sum_{i=1}^3 \frac{(3E_i - M_\eta)^2}{(M_\eta - 3M_\pi)^2}$$

The slope  $\alpha$  was measured to be negative and small in disagreement with CA ( $\alpha = 0$ )

The explanation of this effect poses a challenge for **ChPT**

LO calculations in ChPT coincide with CA

NLO calculations significantly improve the agreement for the partial decay width but predict a small positive value ( $\alpha > 0$ ).



KLOE final:  
615000 events  
Fit  $Z$  in the range  $[0 \div 0.7]$ :

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

paper in writing ...

# Hadronic cross section $\sigma(e^+e^- \rightarrow \pi^+ \pi^-)$

The comparison between experiment and theory for the muon anomaly  $a_\mu = (g_\mu - 2)/2$  is a precise test of SM and differs at the moment by  $3\sigma$

The error on  $a_\mu$  is dominated by the **hadronic** contribution

$(e^+e^- \rightarrow \pi^+\pi^- @ < 1 \text{ GeV}$  contributes **70%** to  $a_\mu$  !)

KLOE has shown, for the first time [PLB606(2005)12], that it is possible to measure  $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma)$  at fixed  $\mathbf{s}$  and **extract** with high accuracy  $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$  in range from  $2m_\pi$  to  $\sqrt{\mathbf{s}}$  using **ISR**

$$\sigma_{\pi\pi} = s \frac{d\sigma_{\pi\pi\gamma}}{dM_{\pi\pi}^2} \cdot \frac{1}{H(s)}$$

Inserting  $\sigma_{\pi\pi}$  into a dispersion integral allows to evaluate the dipion contribution to the muon anomaly,  $\Delta a_\mu^{\pi\pi}$

$$\Delta a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{x1}^{x2} \sigma^{\pi\pi}(s) K(s) ds$$

Requires precise calculations of the radiator function  **$H(\mathbf{s})$**   $\rightarrow$

**EVA + PHOKHARA MC NLO**

[PLB459(1999)279, EPJC27(2003)563]

radiative corrections also included (Vacuum Polarization and FSR)

# Hadronic cross section $\sigma(e^+e^- \rightarrow \pi^+ \pi^-)$

• Two selections were used:

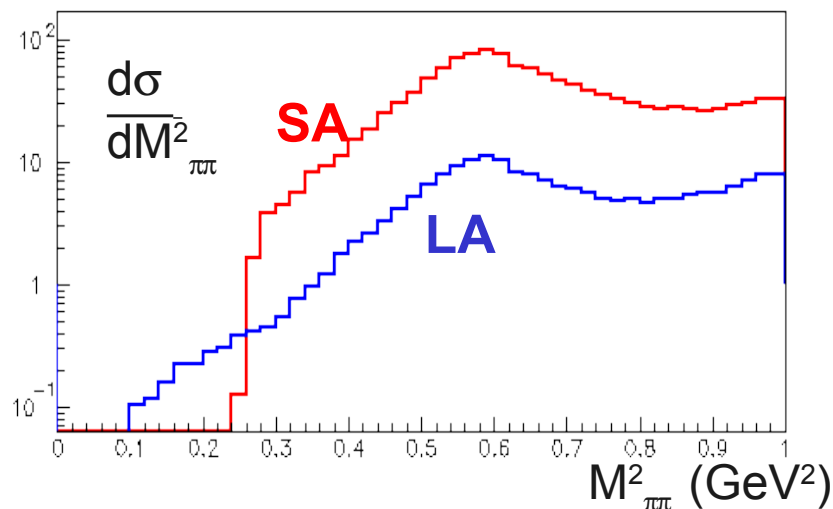
• 1) **Small Angle:**  $\theta_\gamma < 15^\circ$  or  $\theta_\gamma > 165^\circ$

- higher x-section (21 nb)
- less background
- low relative FSR contribution

• 2) **Large Angle:**  $50^\circ < \theta_\gamma < 130^\circ$

- independent complementary analysis
- region close to  $2m_\pi$  threshold is probed
- $\gamma_{\text{ISR}}$  detected
- lower x-section (3 nb)
- larger contribution from FSR and background

PLB670(2009)285



# Hadronic cross section $\sigma(e^+e^- \rightarrow \pi^+ \pi^-)$

Comparison between two samples: (0.35 – 0.85 GeV<sup>2</sup>)  $\Delta a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{0.35}^{0.85} \sigma^{\pi\pi}(s) K(s) ds$   
 KLOE08 (Small Angle)

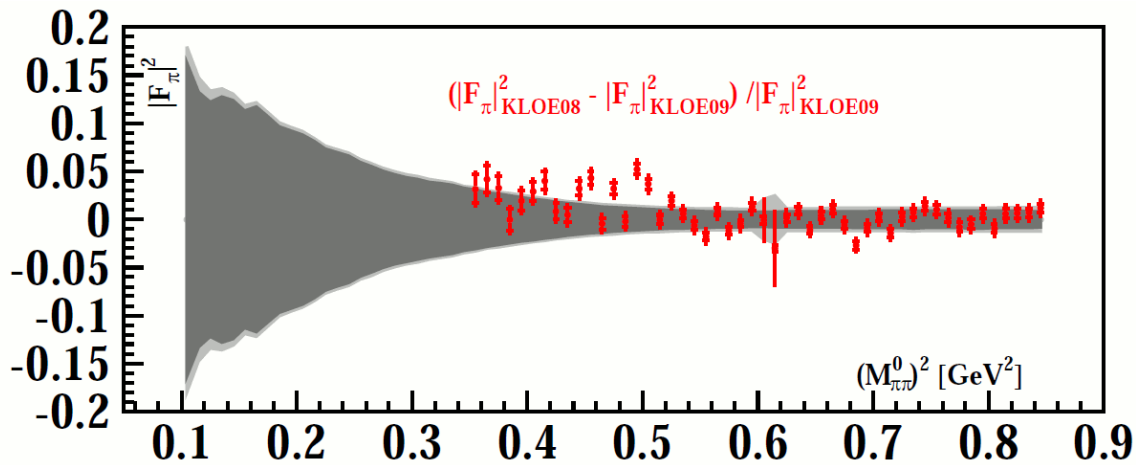
$$a_\mu^{\pi\pi} = (379.6 \pm 0.4_{\text{stat}} \pm 2.4_{\text{sys}} \pm 2.2_{\text{theo}}) \cdot 10^{-10}$$

KLOE09 (Large Angle)

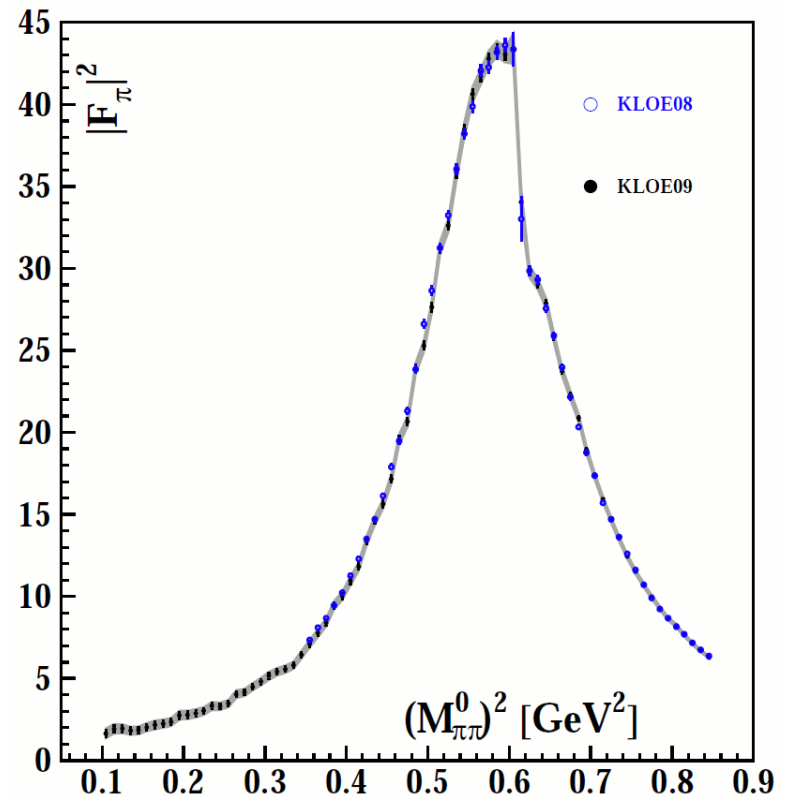
$$a_\mu^{\pi\pi} = (376.6 \pm 0.9_{\text{stat}} \pm 2.4_{\text{sys}} \pm 2.1_{\text{theo}}) \cdot 10^{-10}$$

$$\sigma^{\pi\pi}(s) = \frac{\pi\alpha^2\beta_\pi^3}{3 \cdot s} |F_\pi|^2$$

In overlap region very good agreement with previous result



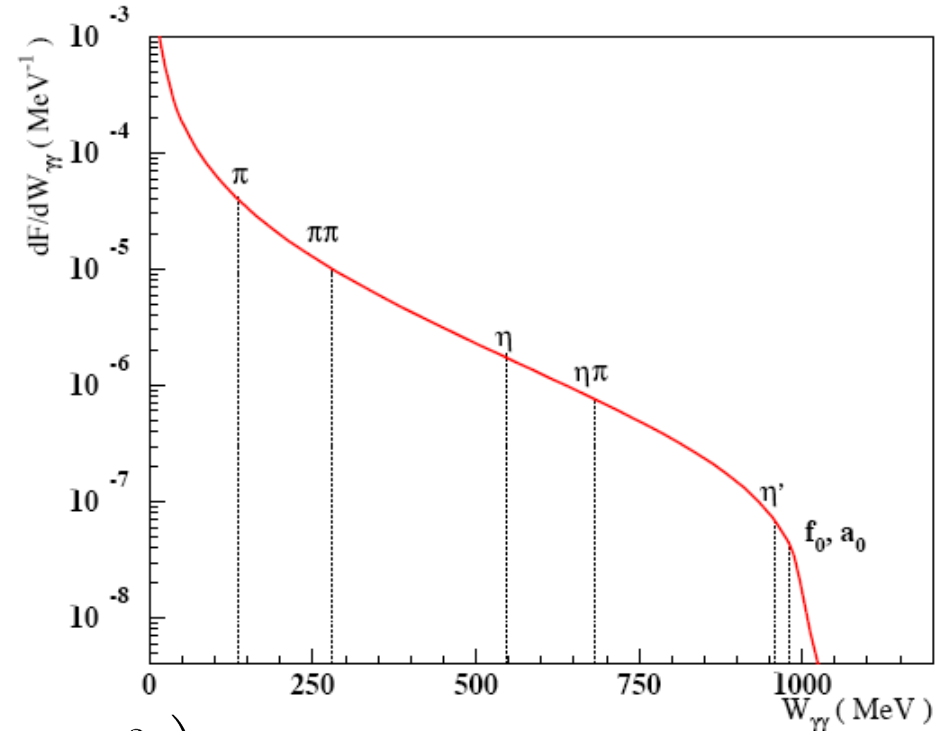
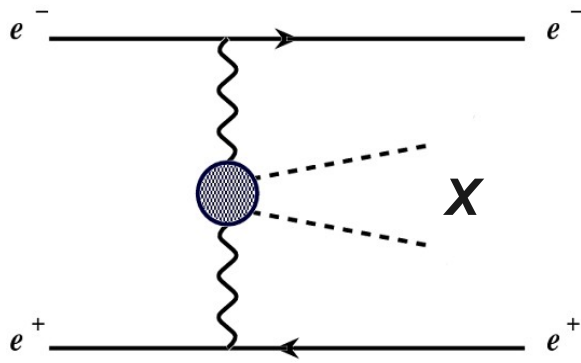
Fractional difference: (band → KLOE09 error)



**"Large Angle" paper ready for publication**

# $\gamma\gamma$ physics at KLOE

Production of scalar and pseudoscalar mesons via  $\gamma\gamma$  interactions



$$\sigma_{e^+e^- \rightarrow e^+e^-X} =$$

$$= \frac{16\alpha^2 \Gamma_{X\gamma\gamma}}{m_X^3} \left( \ln \frac{E_b}{m_e} \right)^2 \left( (y^2 + 2)^2 \ln \frac{1}{y} - (1 - y^2)(3 + y^2) \right) \quad \text{where } y = m_X / (2E_b)$$

Data at  $\sqrt{s} = 1$  GeV (off  $\phi$ -meson peak suppressing  $\phi$  bkg);  $\int L \sim 250 \text{ pb}^{-1}$

## Search for $\eta$ production

with  $\eta \rightarrow \pi^+\pi^-\pi^0$  decay (BR=22.73%)

$\eta$  candidates selected with kin. fit

10 variables (for 2  $\gamma$ ) and 4 constraints:

major background:  $e^+e^- \rightarrow \eta\gamma$

## Search for “ $\sigma$ ” production

with  $\sigma \rightarrow \pi^0\pi^0$  decay

4 clusters, DC veto

$$\sum E_{2\gamma}^{\min} > 60 \text{ MeV}$$

$$\sum E_{\gamma}^i / E_{\text{CALO}} > 0.8$$

Background from events with undetected energy:  $K_s K_L$  ( $K_L$  undetected)

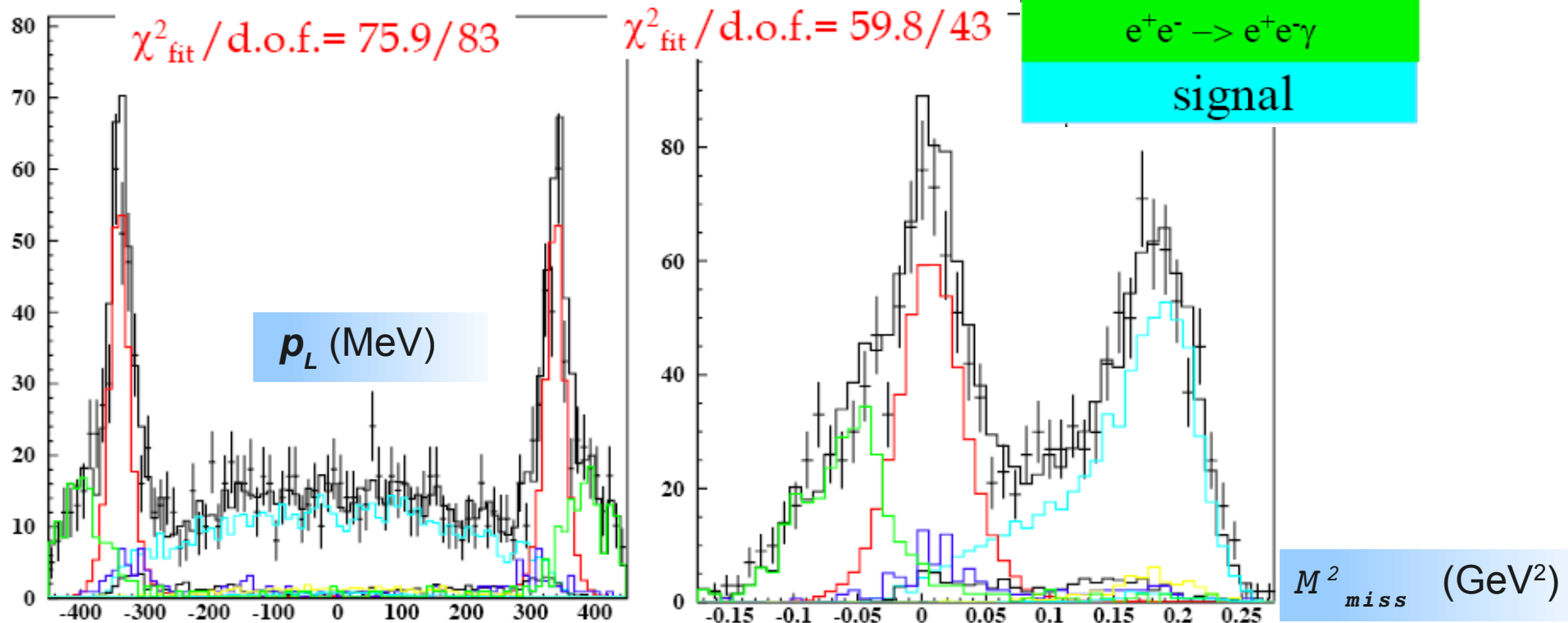
# $\gamma\gamma$ physics at KLOE

## $e^+e^- \rightarrow e^+ e^- \pi^+ \pi^- \pi^0$ preliminary result

Number of events comes from a fit to  $\eta$  longitudinal momentum  $p_L$  and  $M^2_{miss}$  distributions

(where  $M^2_{miss} = s + m_\eta^2 - 2\sqrt{s}E_T\sqrt{1 + p_L^2/E_T^2}$ )

|                       | signal | $\eta\gamma$ | $\omega\pi^0$ | $\pi^+\pi^-\pi^0$ | $K^+K^-$   | $K_S K_L$ | $e^+e^-\gamma$ |
|-----------------------|--------|--------------|---------------|-------------------|------------|-----------|----------------|
| range variation       | free   | $\pm 15\%$   | $\pm 1\%$     | $\pm 7\%$         | $\pm 25\%$ | $\pm 15$  | free           |
| $N_{fit}(p_L)$        | 646    | 442          | 87            | 101               | 46         | 14        | 286            |
| $N_{fit}(M^2_{miss})$ | 625    | 442          | 87            | 101               | 46         | 14        | 303            |

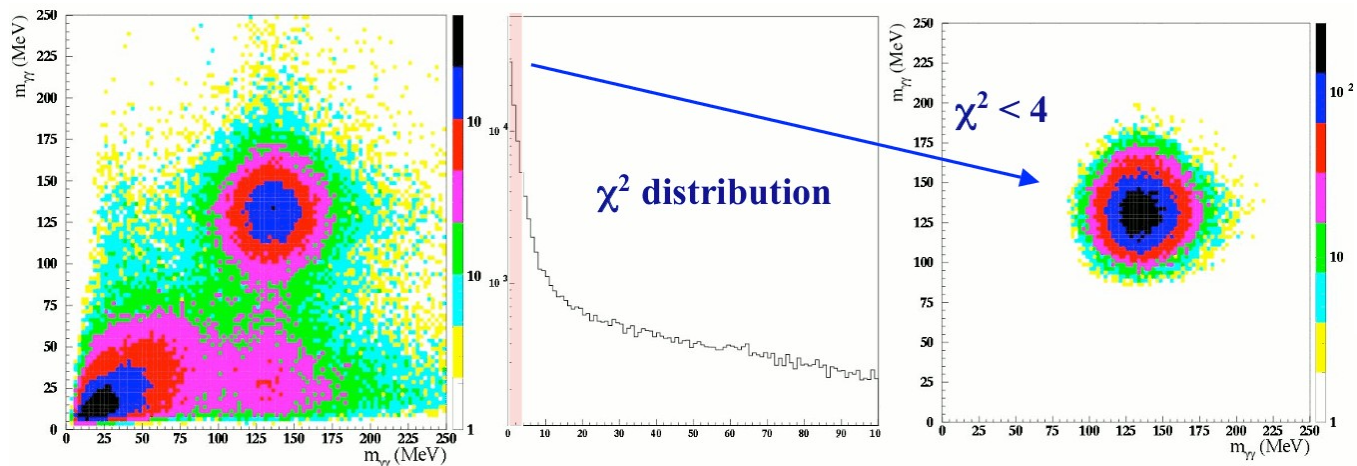


Extraction of  $\sigma(e^+e^- \rightarrow e^+e^-\eta)$  and  $\Gamma_\gamma$  is in progress)

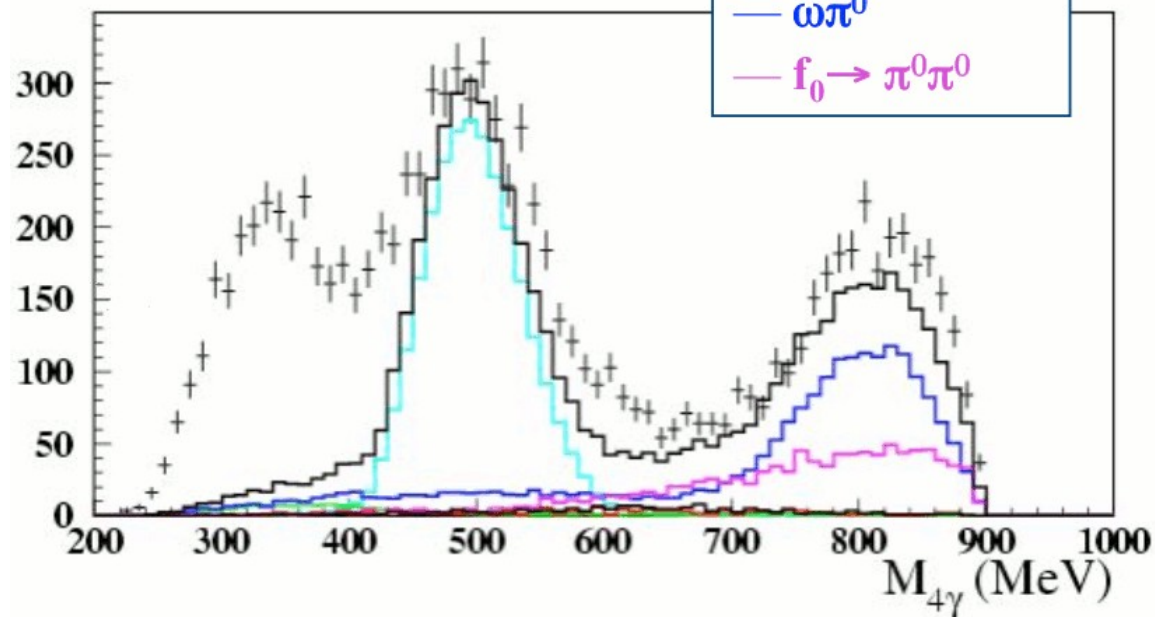
# $\gamma\gamma$ physics at KLOE

$e^+e^- \rightarrow e^+ e^- \pi^0 \pi^0$  preliminary result

Identification of 4  $\gamma$  events coming from  $2\pi^0$



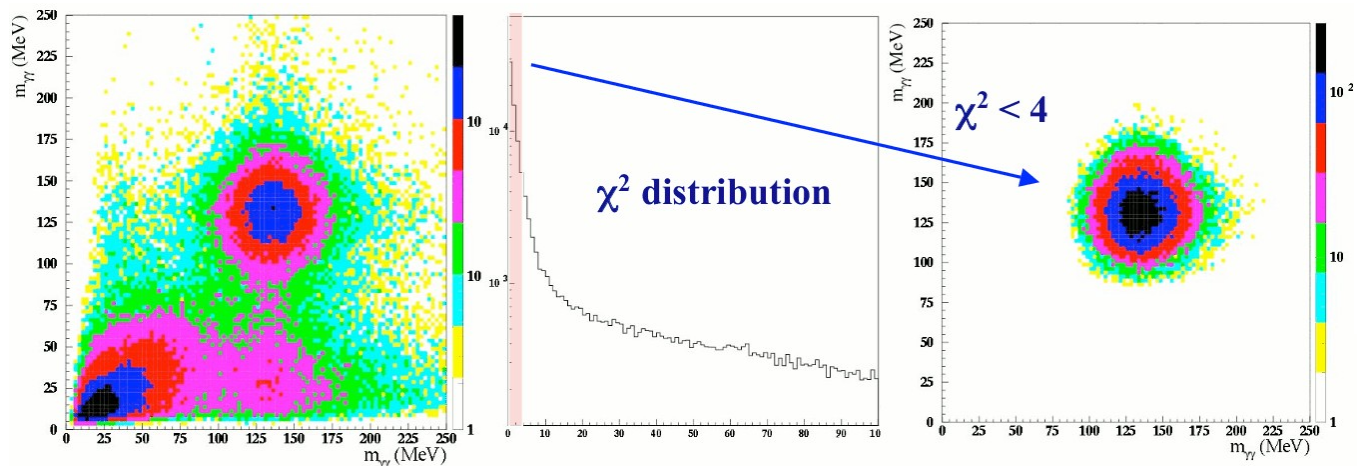
|                                   | $\epsilon$            | $\sigma$ (nb) | $n = \epsilon L \sigma$ |
|-----------------------------------|-----------------------|---------------|-------------------------|
| $K_S K_L$                         | $5.60 \times 10^{-3}$ | 2.0           | 2 682                   |
| $\eta \rightarrow 3\pi^0$         | $1.79 \times 10^{-3}$ | 0.33          | 142                     |
| $\omega\pi^0$                     | $1.55 \times 10^{-2}$ | 0.55          | 2 045                   |
| $f_0 \rightarrow 2\pi^0$          | $2.58 \times 10^{-2}$ | 0.17          | 1 052                   |
| $a_0 \rightarrow \eta\pi^0$       | $4.55 \times 10^{-3}$ | 0.11          | 120                     |
| $e^+e^- \rightarrow \gamma\gamma$ | $1.92 \times 10^{-5}$ | 360           | 166                     |
| $\eta \rightarrow \gamma\gamma$   | $1.57 \times 10^{-4}$ | 0.39          | 15                      |



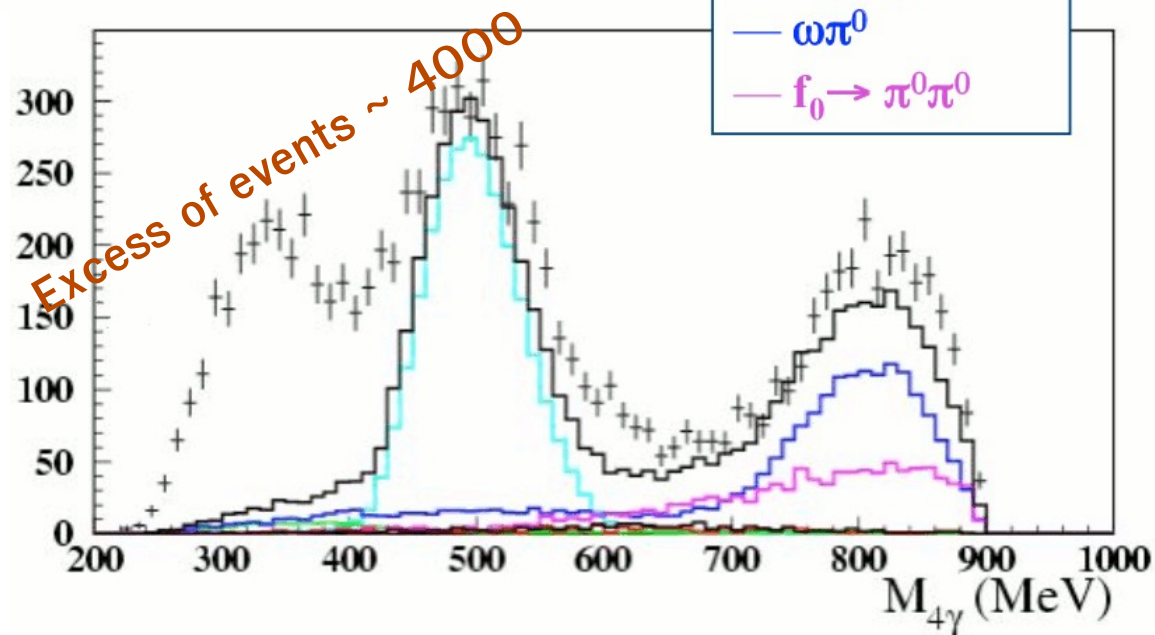
# $\gamma\gamma$ physics at KLOE

$e^+e^- \rightarrow e^+ e^- \pi^0 \pi^0$  preliminary result

Identification of 4  $\gamma$  events coming from  $2\pi^0$



|                                   | $\epsilon$            | $\sigma$ (nb) | $n = \epsilon L \sigma$ |
|-----------------------------------|-----------------------|---------------|-------------------------|
| $K_S K_L$                         | $5.60 \times 10^{-3}$ | 2.0           | 2 682                   |
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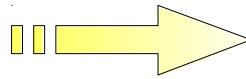


subtraction of backgrounds and study of differential cross section are in progress

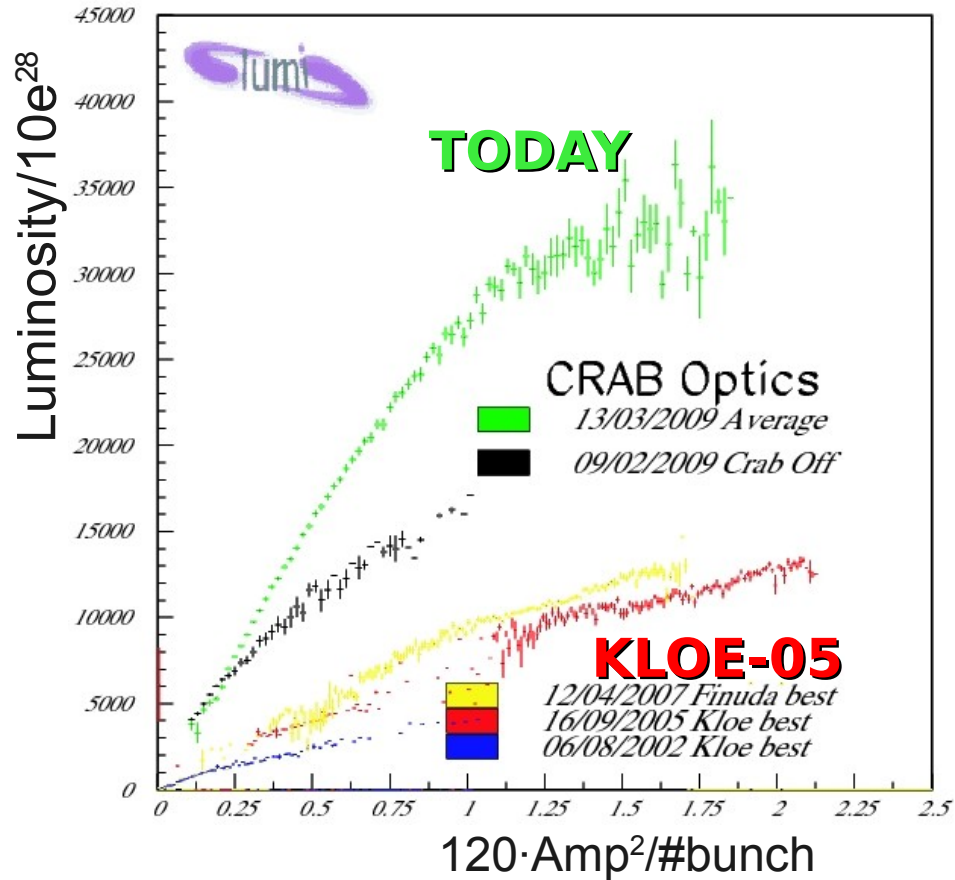


# DAΦNE and KLOE upgrades

New machine magnetic scheme:  
**crab waist**



$$L_{\text{peak}} = 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$$
$$\int L = 15 \text{ pb}^{-1} / \text{day}$$

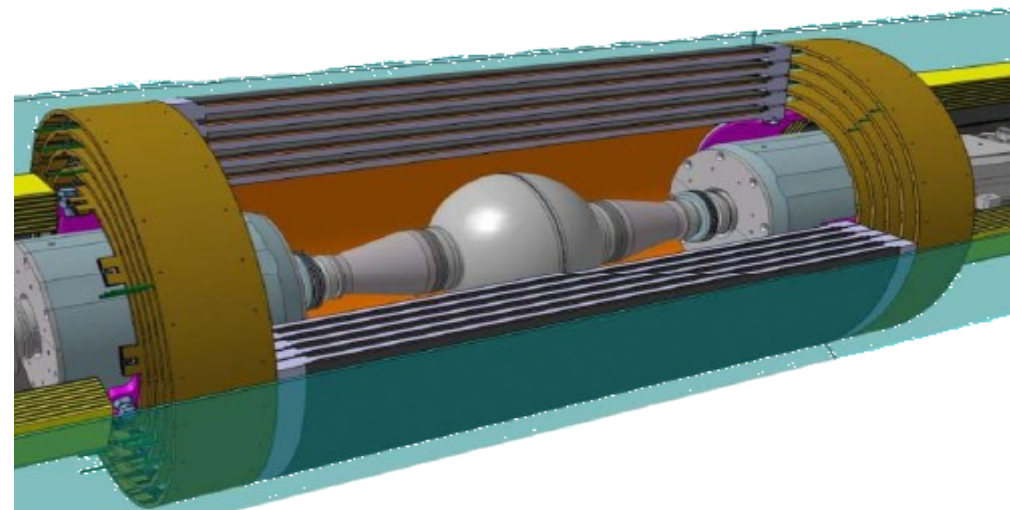


New interaction region:  
**larger crossing angle**



**STEP-0** [2010]: **5fb<sup>-1</sup>**  
γγ tagger

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



# SUMMARY

- SCALARS

- Measurement of  $\text{BR}(\phi \rightarrow \eta \pi^0 \gamma)$ ,  $a_0$  parameters extracted from fit to  $M_{\eta\pi}$
- Upper limit for  $\phi \rightarrow (f_0 + a_0) \gamma \rightarrow K_0 \bar{K}_0 \gamma$

- PSEUDOSCALARS

- $3\sigma$  evidence for gluonium in  $\eta'$  (using the Rosner parametrization)
- BR and the first measurement of asymmetry in  $\eta \rightarrow \pi^+ \pi^- e^+ e^-$  decay
- First observation of the  $\eta \rightarrow e^+ e^- e^+ e^-$  decay  $\sim 400$  events
- Analysis in progress on  $\eta \rightarrow \pi^+ \pi^- \gamma$
- Dalitz plot analysis  $\eta \rightarrow \pi^0 \pi^0 \pi^0$
- Hadronic cross section  $\sigma(e^+ e^- \rightarrow \pi^+ \pi^-)$ 
  - A new independent measurement of  $\sigma_{\pi\pi}$  is in agreement with the KLOE published one and confirms the  $3\sigma$  discrepancy btw SM and BNL
- $\gamma\gamma$  physics
  - $e^+ e^- \rightarrow e^+ e^- \pi^+ \pi^- \pi^0 : \eta \rightarrow \pi^+ \pi^- \pi^0$  ( $\sim 600$  evts observed)
  - $e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0 : \sigma(600) \rightarrow \pi^0 \pi^0$  (evidence for low mass enhancement)

# KLOE-2 perspectives

**Refinement of rare  $\eta$  decay measurements**

**Form factor studies**

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

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

**Hadronic cross section:** higher statistics and reduced systematics

**In step-0 detector upgrade for  $\gamma\gamma$  physics**

tagging  $\gamma\gamma$  events by measuring  $e^+e^-$  will significantly reduce bkg

**Open a window on  $\eta'$  physics**

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