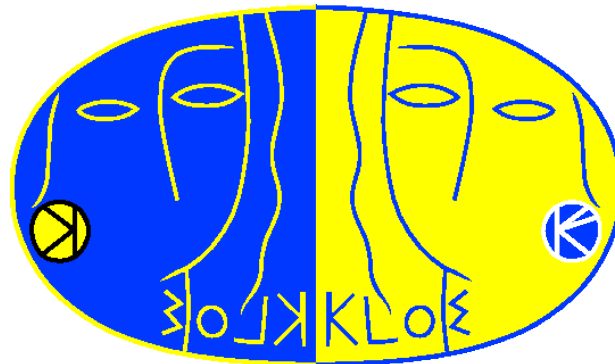


η/η' decays with KLOE

Marek Jacewicz, LNF-INFN Frascati

on behalf of the KLOE Collaboration



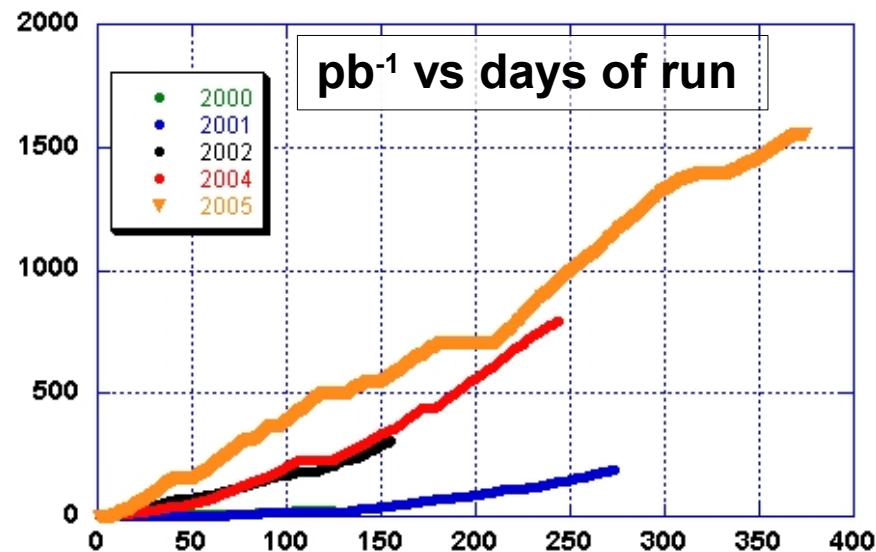
DAFNE collider in Frascati

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

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

This translates to $\sim 8 \times 10^9$ ϕ 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%

$a_0(980)\gamma$

$f_0(980)\gamma$

$\sim 1 \times 10^8$ η mesons

$\sim 5 \times 10^5$ η' mesons



KLOE experiment

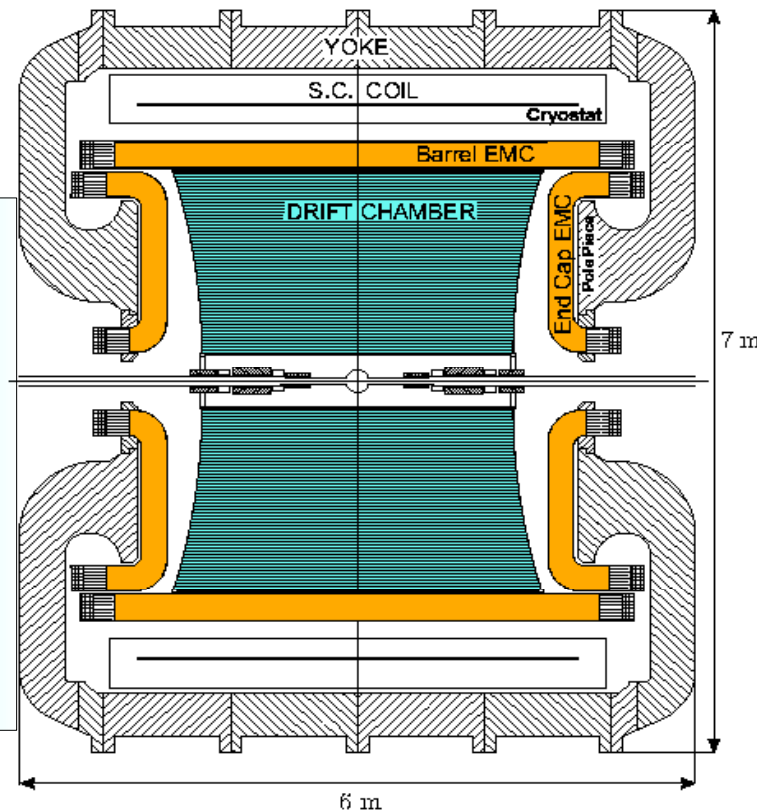
Detector design optimized for K_L measurement:

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

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

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

η - η' mixing and η' gluonic content

KLOE old result

η' considered a good candidate to host **gluonium** content
 In the constituent quark model one can extract gluonium content together with the η - η' mixing angle

Rosner PRD 27 (1983) 1101

$\phi_P = \eta$ - η' mixing angle

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

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

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

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

$$Z_G = \sin \phi_G \text{ gluonium content}$$

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 3σ

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

Escribano-Nadal JHEP 0705:006, 2007

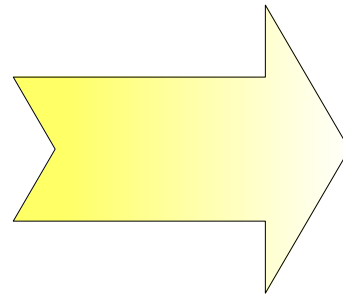
$$(Z_G)^2 = 0.04 \pm 0.09$$

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

KLOE new fit

5 more relations added

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



Parameters

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

are left free

The new result includes the recent KLOE BR measurement

$$\text{BR}(\omega \rightarrow \pi^0\gamma) = (8.09 \pm 0.14) \% \quad [\text{PLB } 669 \text{ (2008) } 223]$$

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

KLOE new fit

$\chi^2/\text{dof} = 14.7/4$

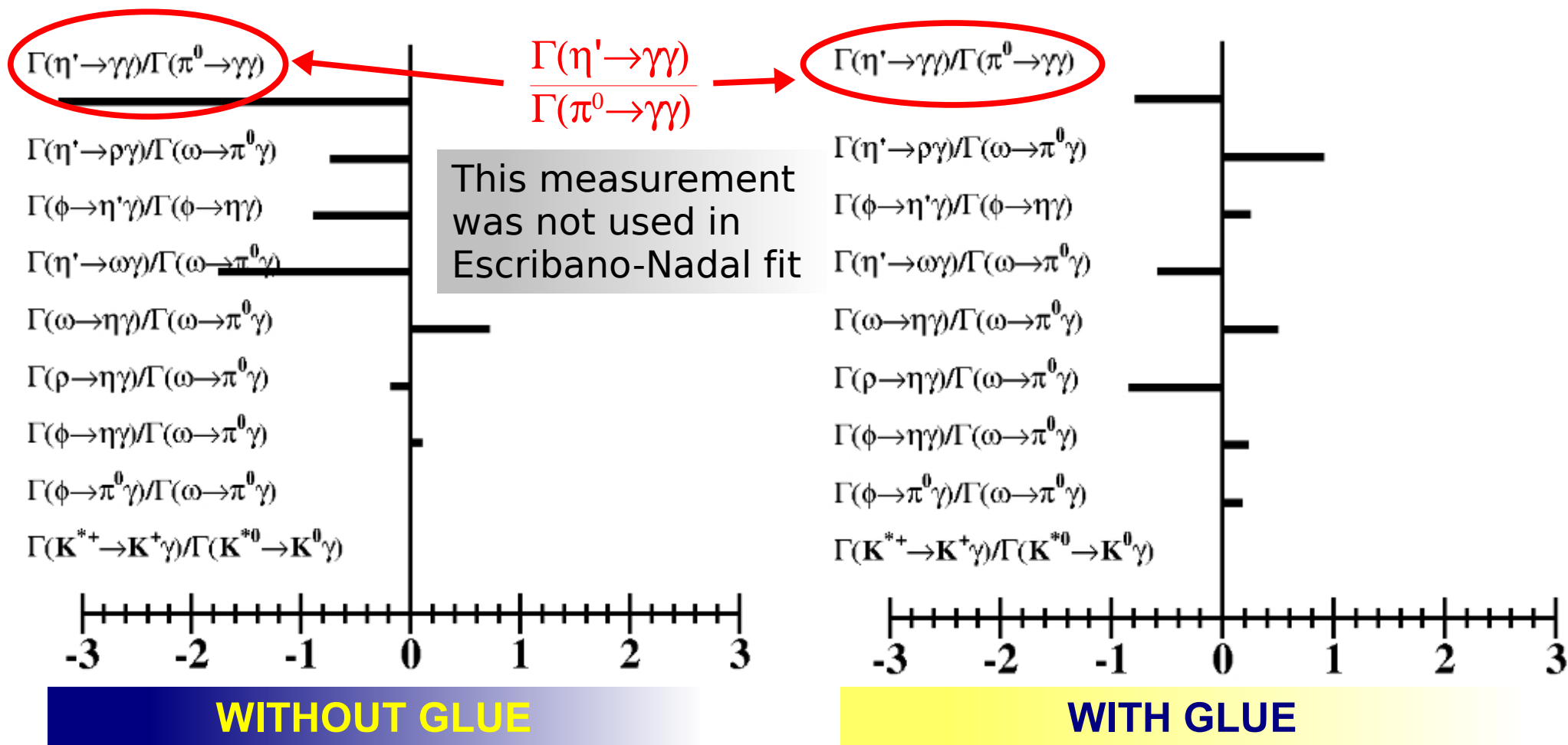
$P(\chi^2) = 0.005$

$(Z_G)^2$	fixed 0	0.115 ± 0.036
ϕ_P	$(41.4 \pm 0.5)^\circ$	$(40.4 \pm 0.6)^\circ$

$\chi^2/\text{dof} = 4.6/3$

$P(\chi^2) = 0.20$

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



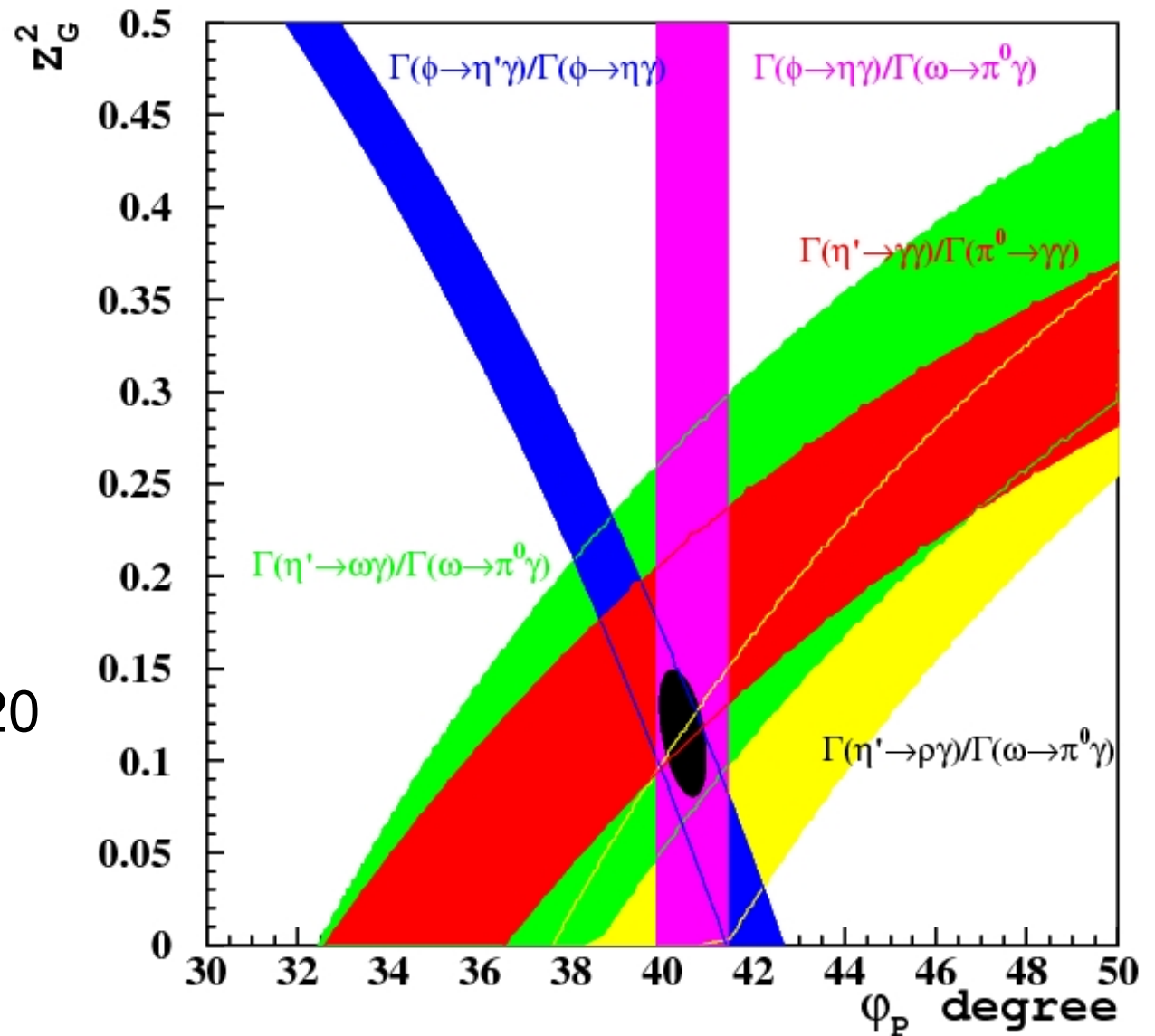
KLOE new fit results

with glue

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

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

Using PDG 2008
KLOE results on ω
5 constraints more
gluonium at 3σ confirmed



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

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

Motivations

Existing data: 4 events CMD-2, 16 events CELSIUS-WASA

η structure studying virtual photon via M_{ee}

Test of CP violation by measurement of angular asymmetry between e^+e^- and $\pi^+\pi^-$ planes

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

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

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

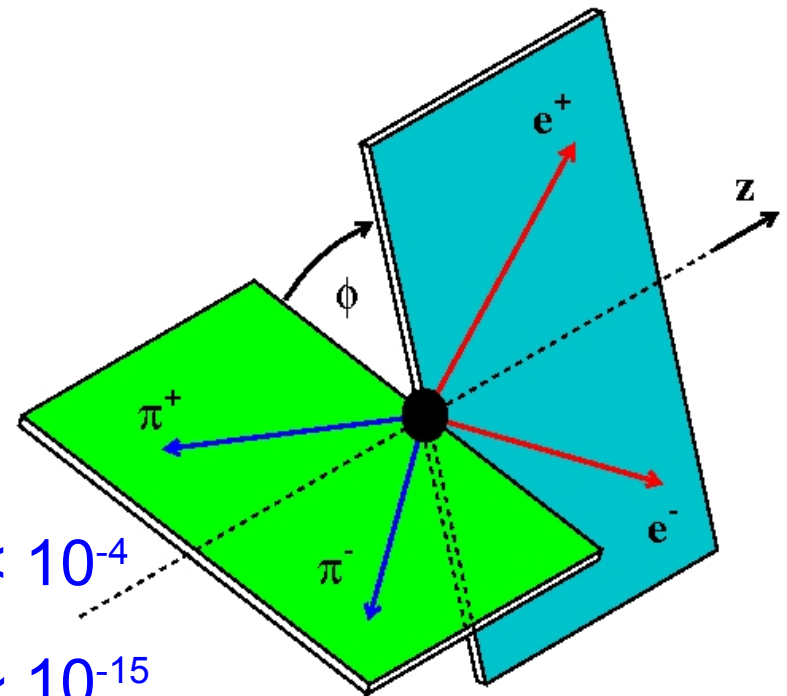
using experimental upper limit:

$$A_\phi < 10^{-4}$$

using theoretical prediction:

$$A_\phi \sim 10^{-15}$$

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



Analysis scheme

Data sample: 1.7 fb^{-1}

PID using TOF from EM calorimeter

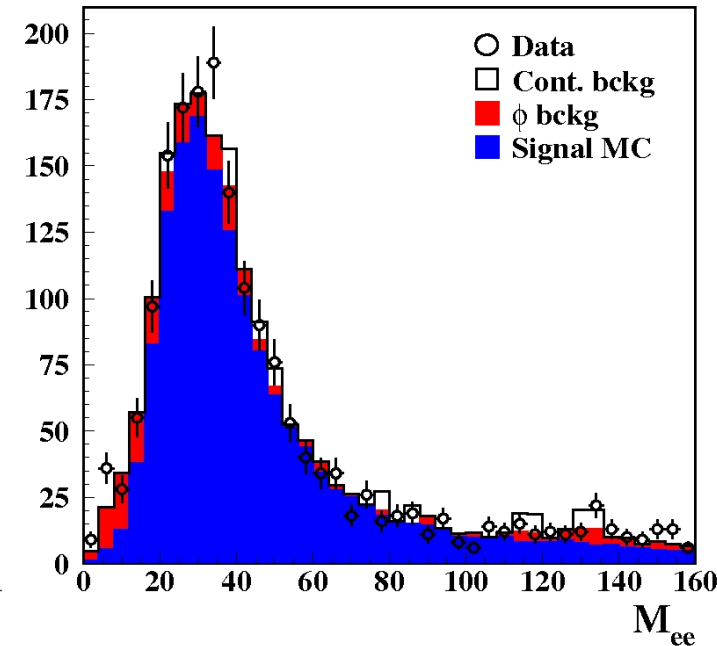
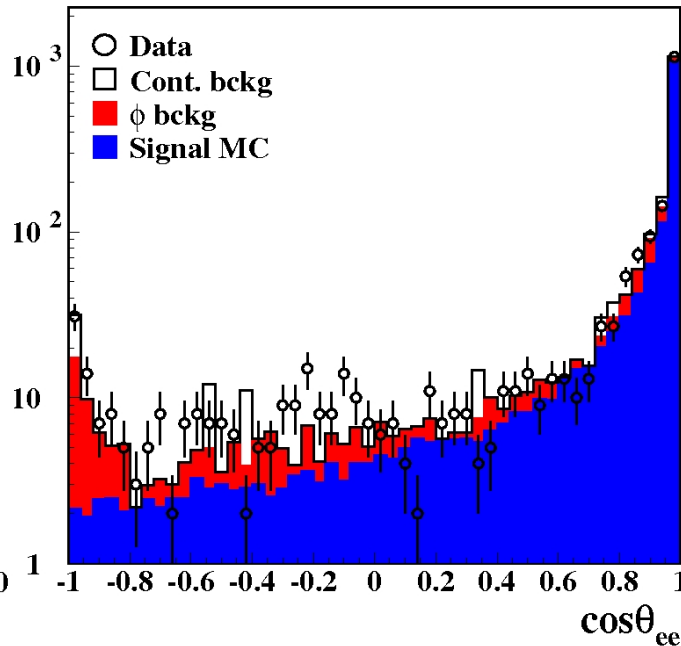
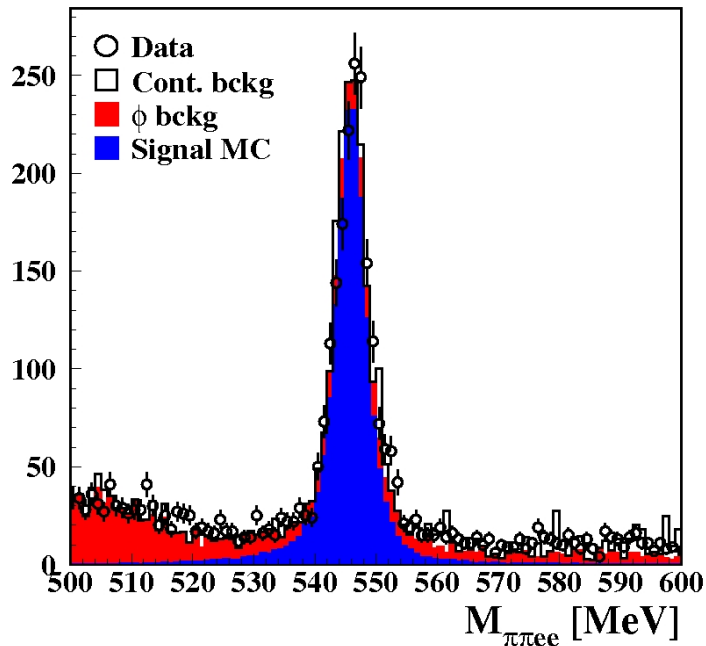
Fit to $M_{\pi\pi ee}$ sidebands for background scale factors

Photon conversion on Beam Pipe rejected

Counting on $M_{\pi\pi ee}$ in the signal region: $N_{\pi\pi ee} = 1555 \pm 52$

Analysis efficiency $\sim 8\%$

368 bkg events



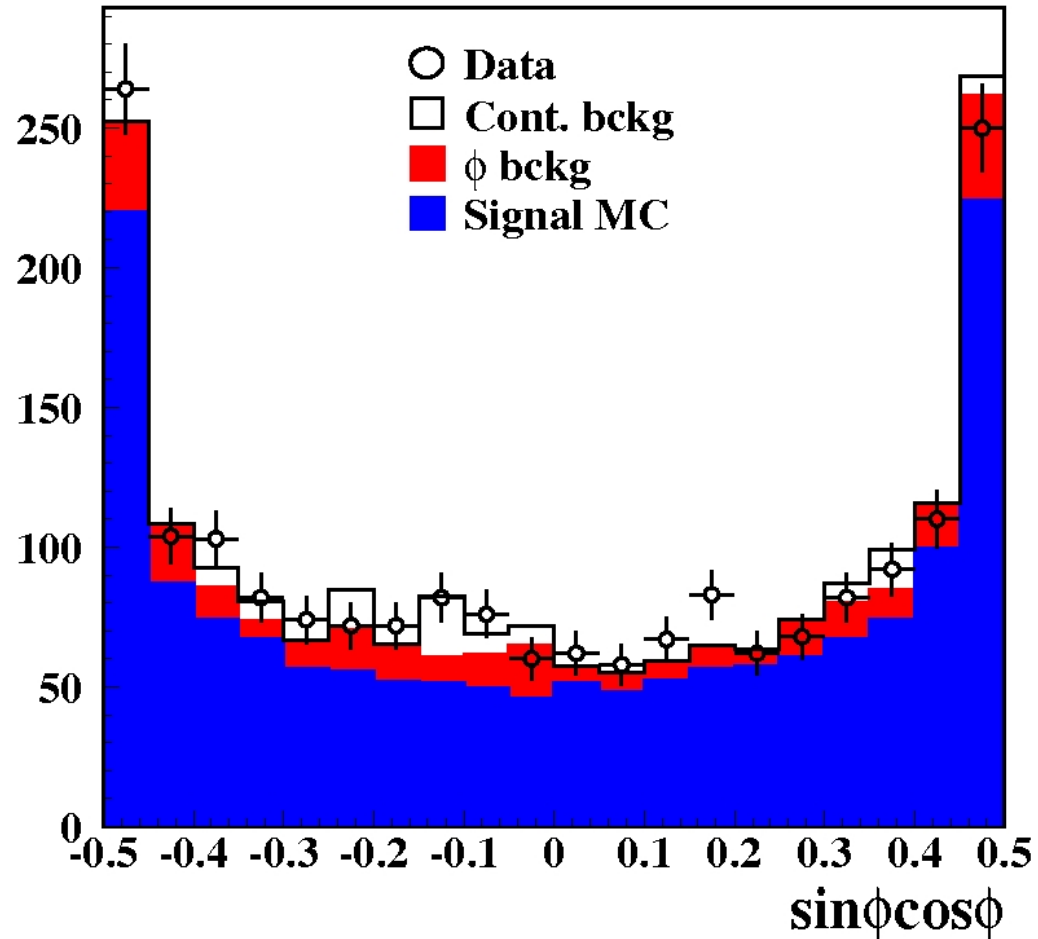
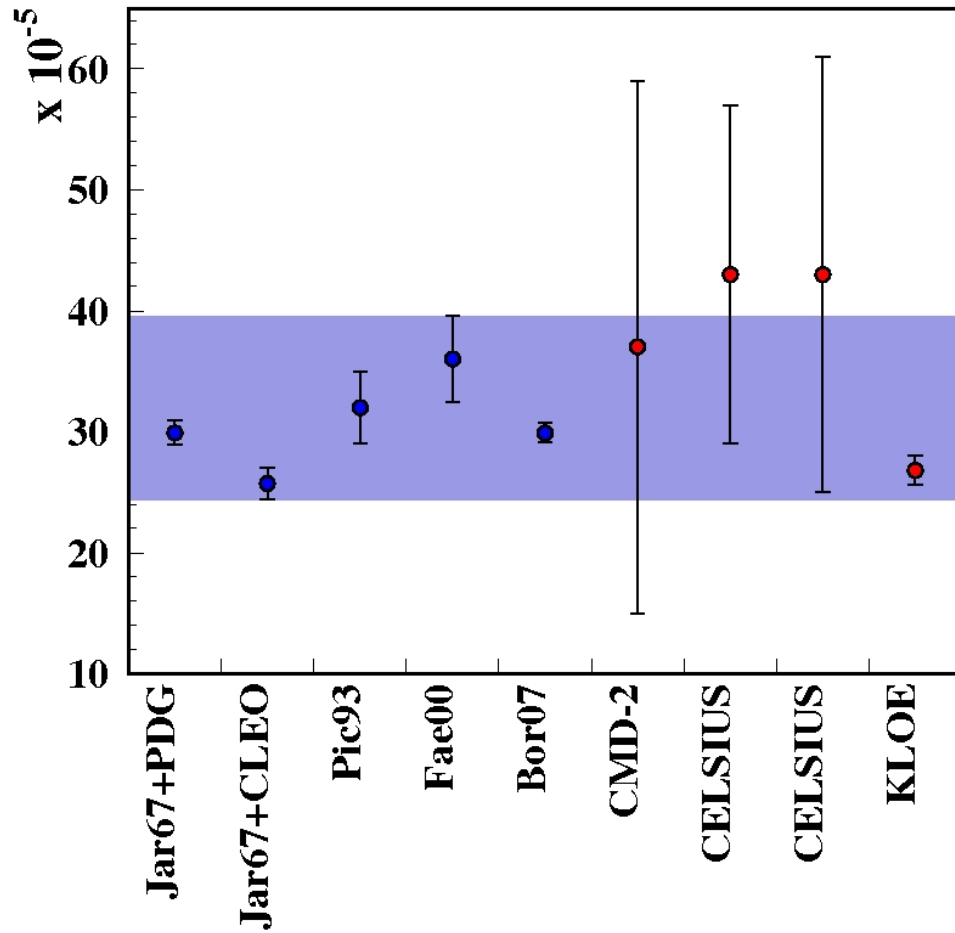
Results: BR and Asymmetry

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

PLB 675(2009) 283

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

First measurement!



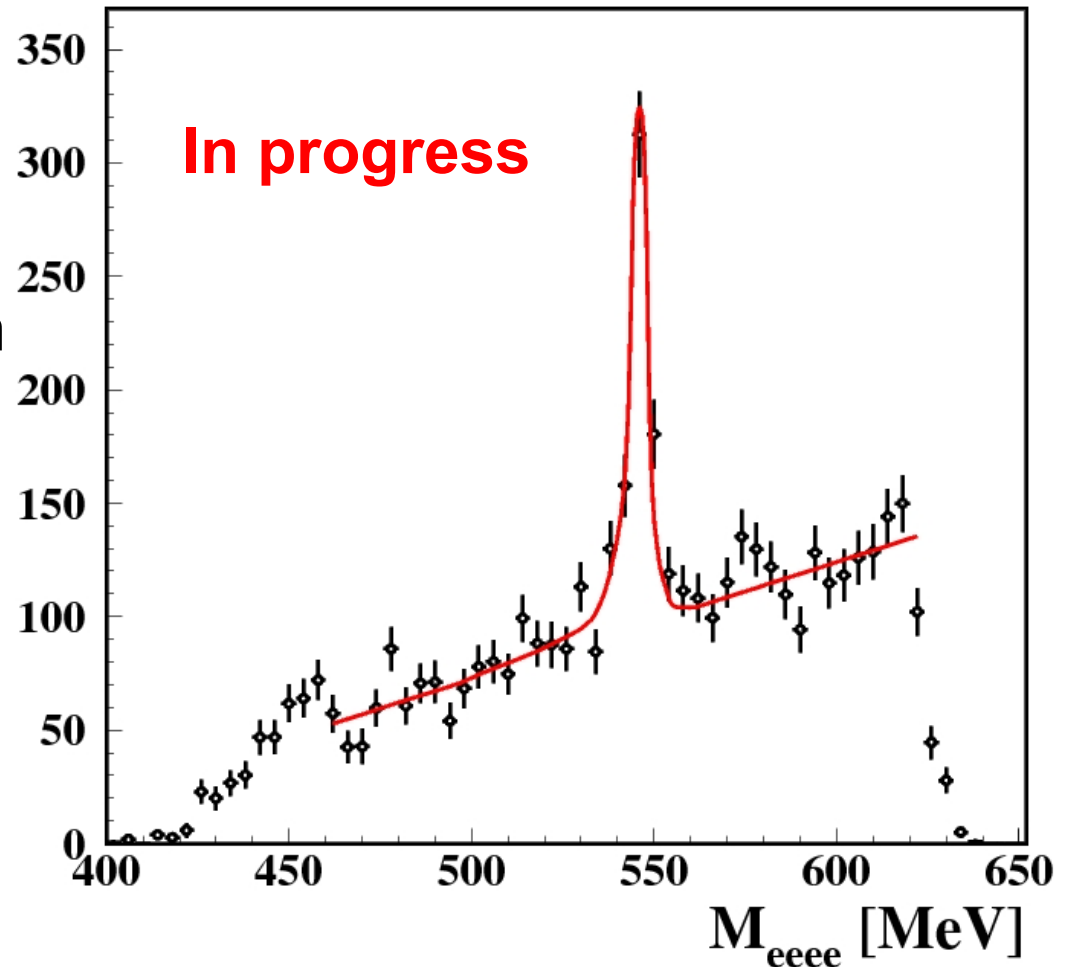
$$\eta \rightarrow e^+ e^- e^+ e^-$$

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

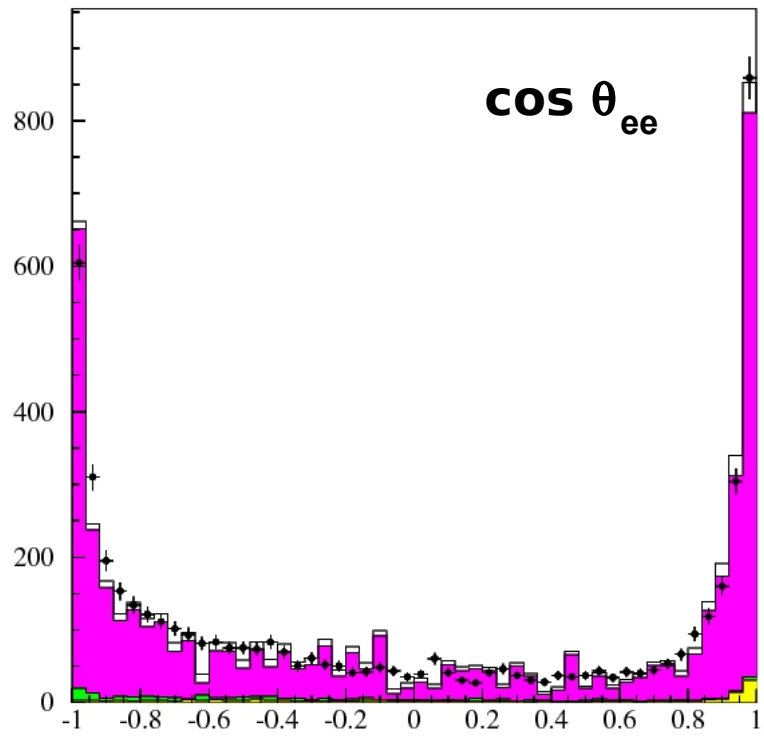
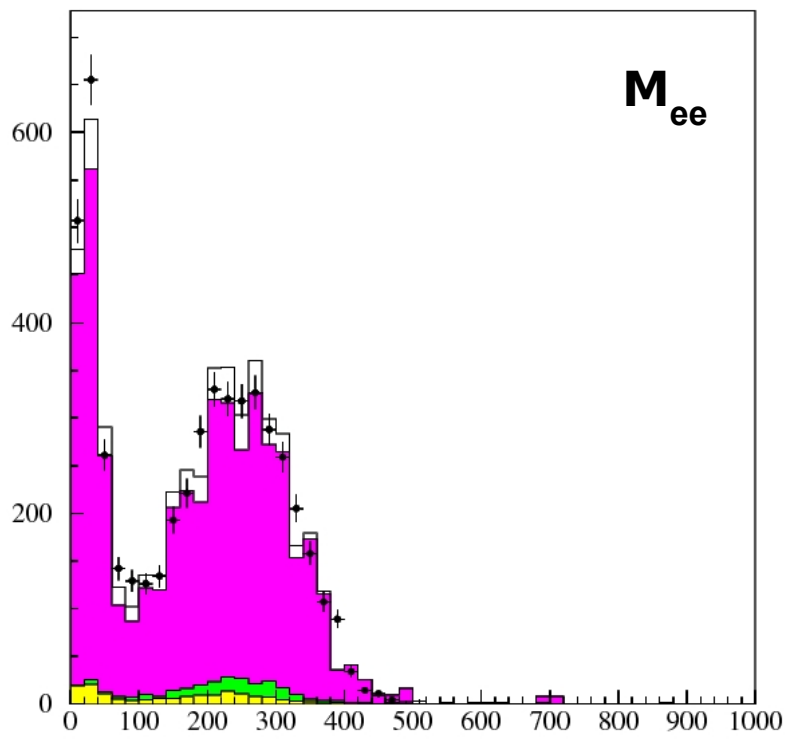
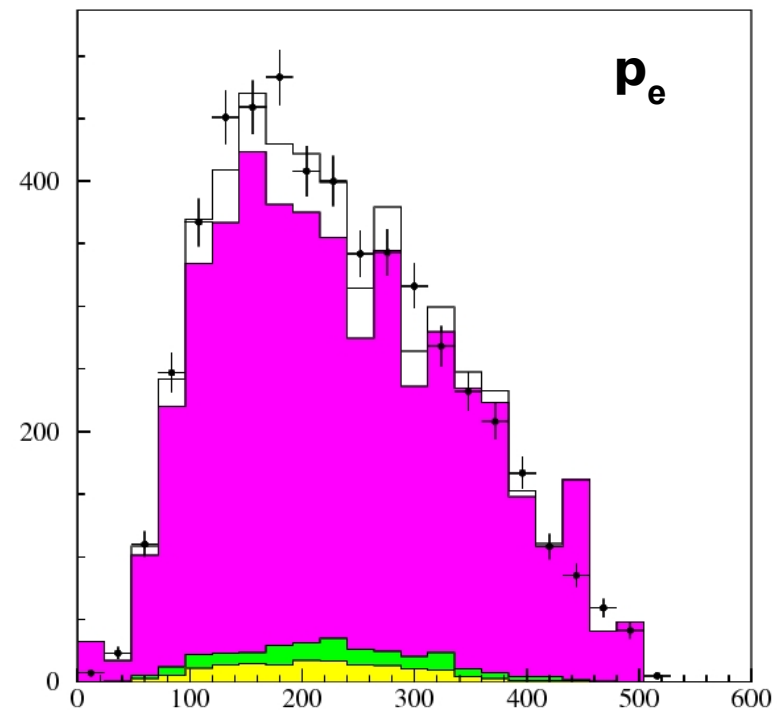
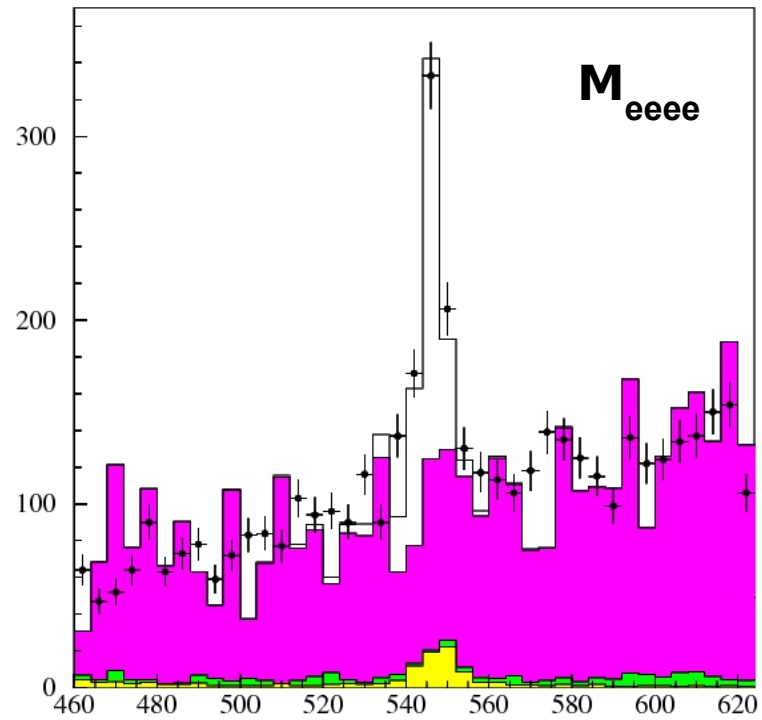
- Data sample: 1.7 fb^{-1}
- e^+e^- pairs from photon conversion on Beam Pipe and Drift Chamber wall rejected
- Remaining background from ϕ decay is subtracted

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

$N_{eeee} = 413 \pm 31$
First observation!



Experiment - MC comparison



- Data
- MC signal
- Cont. bkg
- ϕ bkg

$$\eta \longrightarrow \pi^+ \pi^- \gamma \quad \text{and} \quad \eta \longrightarrow \pi^+ \pi^- \pi^0$$

Motivations

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.

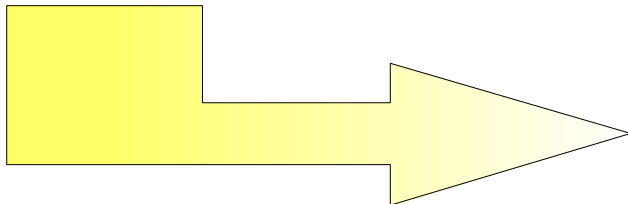
Holstein, Phys. Scripta, T99 55 (2002)
 Benayoun, Eur. Phys. J., C31 525 (2003)
 Borasoy, Nissler, Nucl. Phys., A740 362 (2004)

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>	
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.			
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

Selection: $\underline{\eta \rightarrow \pi^+ \pi^- \pi^0}$ and $\eta \rightarrow \pi^+ \pi^- \gamma$

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

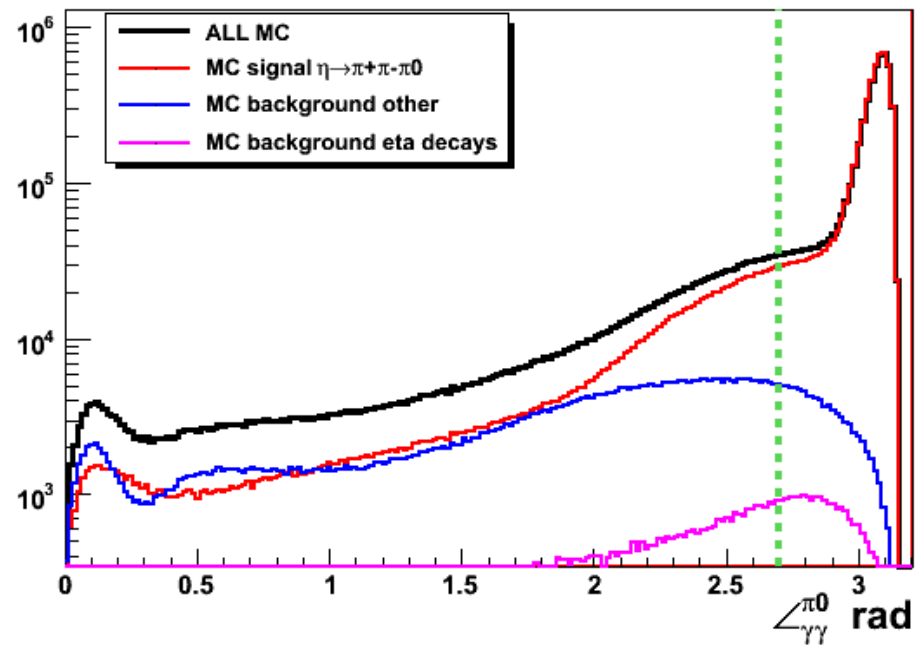
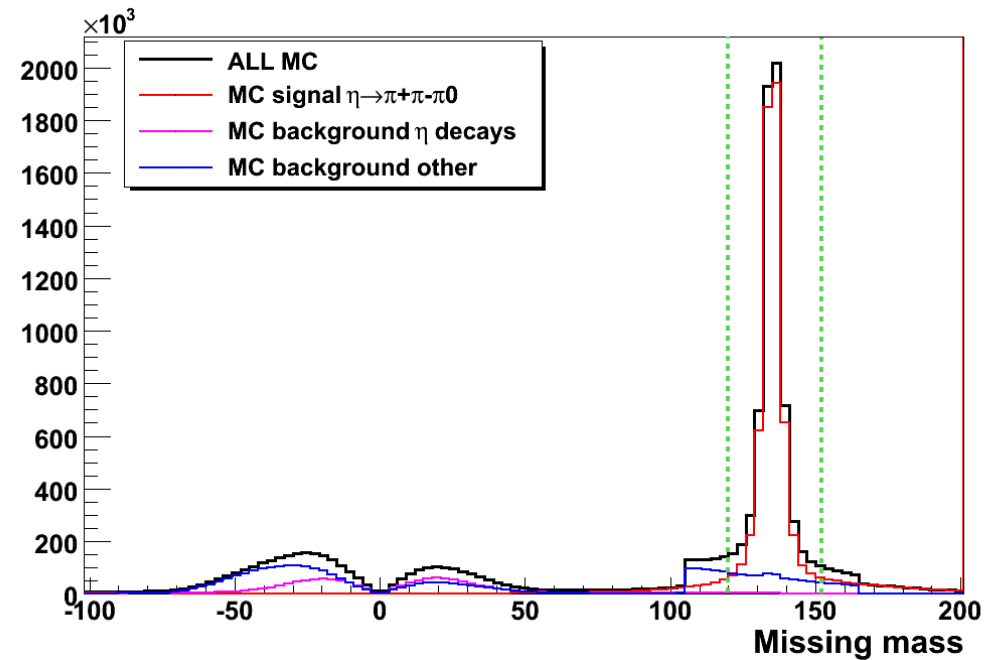
$$\phi \rightarrow \eta \gamma, \quad \eta \rightarrow \pi^+ \pi^- \pi^0, \quad \pi^0 \rightarrow \gamma \gamma$$

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

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

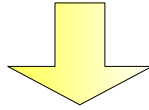
Eff = 40 % with BKG/SIG = 0.5 %



Selection: $\eta \rightarrow \pi^+ \pi^- \pi^0$ and $\underline{\eta \rightarrow \pi^+ \pi^- \gamma}$

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

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

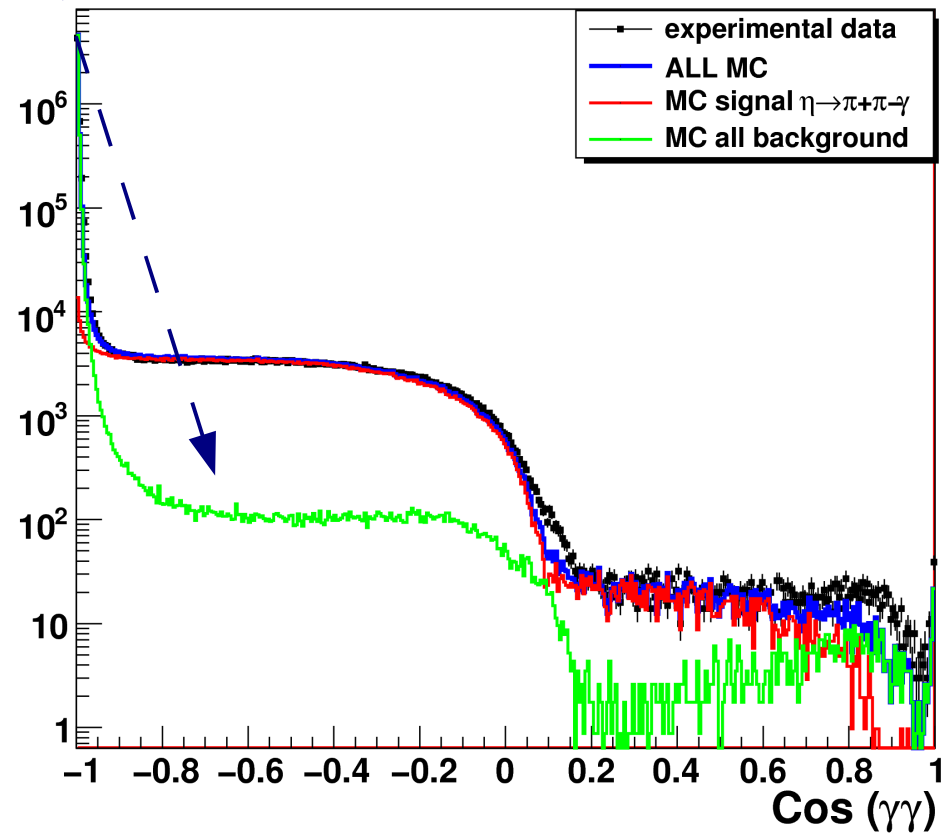
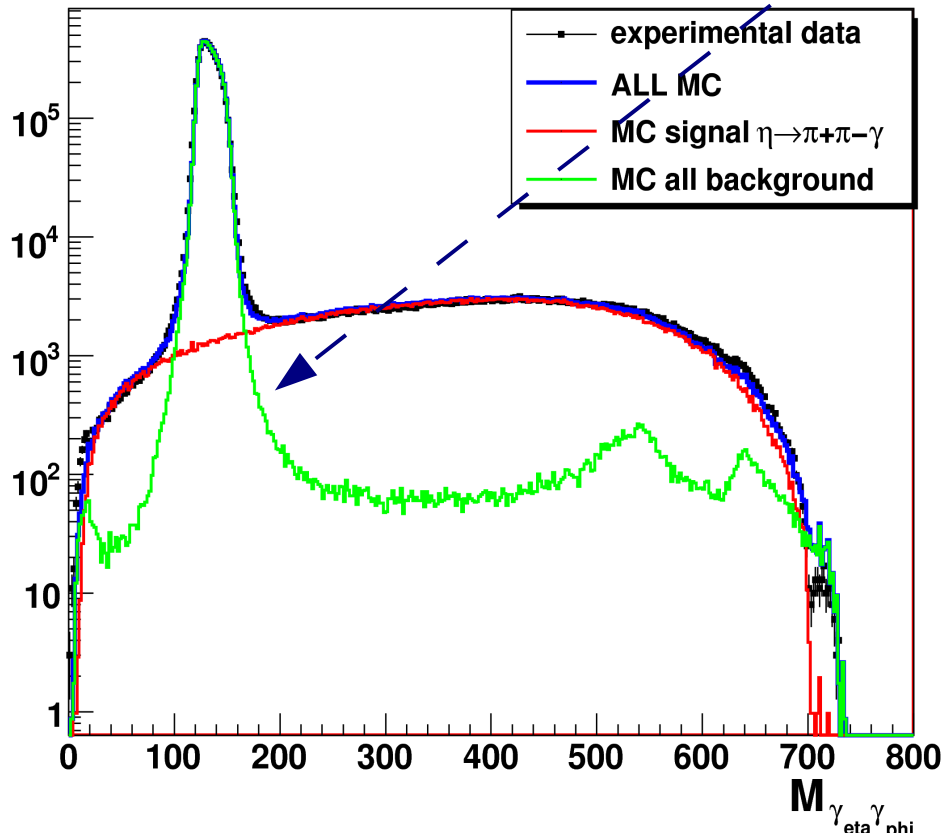


Eff = 29 % , BKG/SIG = 10:1

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

different topology in $\gamma\gamma$ distributions

simultaneous fit to both spectra



PRELIMINARY RESULTS:

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

(based on 1.2 fb⁻¹ data set)

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

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.

SUMMARY

- Gluonium content confirmed at 3σ level in η' using the Rosner model (paper submitted to JHEP (ArXiv 0906.3819))
- BR and the first measurement of asymmetry in $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ decay:

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

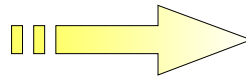
$$A_{\phi} = (-0.6 \pm 2.5_{\text{Stat.}} \pm 1.8_{\text{Syst.}}) \cdot 10^{-2}$$

- First observation of the $\eta \rightarrow e^+ e^- e^+ e^-$ decay ~ 400 events
- New analysis has been started on $\eta \rightarrow \pi^+ \pi^- \gamma$. Preliminary results on the ratio of BRs: $\frac{\Gamma(\eta \rightarrow \pi^+ \pi^- \gamma)}{\Gamma(\eta \rightarrow \pi^+ \pi^- \pi^0)} = 0.2014 \pm 0.0004 (stat)$
- Other analysis in progress:

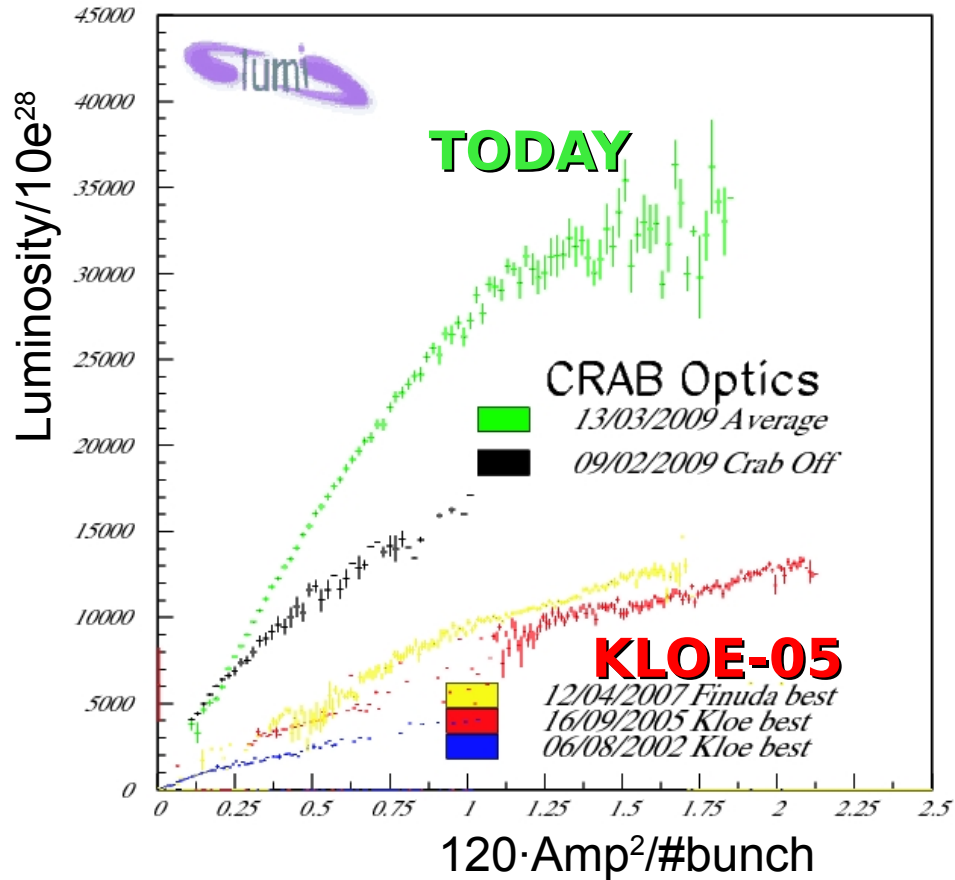
$$\eta \rightarrow \pi^0 \gamma \gamma, \quad \eta \rightarrow \mu^+ \mu^-, \quad \eta' \rightarrow \pi^+ \pi^- \eta, \quad \eta' \rightarrow \pi^+ \pi^- \gamma.$$

DAΦNE and KLOE upgrades

New machine magnetic scheme:
crab waist



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

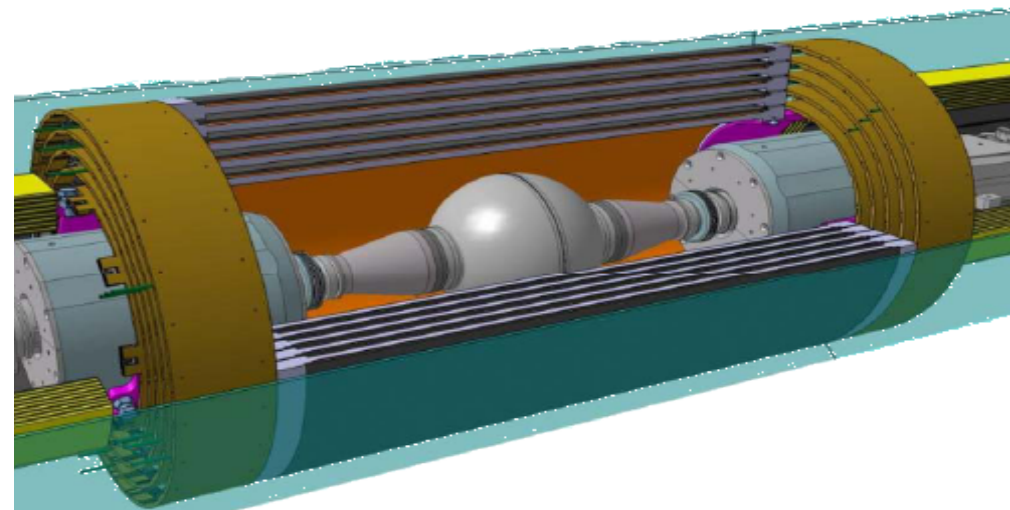


New interaction region:
larger crossing angle



STEP-0 [2009]: **5fb⁻¹**
γγ tagger

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



KLOE-2 perspectives on eta/eta' physics examples:

Refinement of rare η decay measurements

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

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

Test of theoretical calculation

High statistics study of the process $\eta \rightarrow \pi^0 \gamma\gamma$ 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 $\sigma(e^+e^- \rightarrow e^+e^- \gamma^* \gamma^* \rightarrow e^+e^- \eta')$ at 1% precision would be necessary to solve the gluonium puzzle