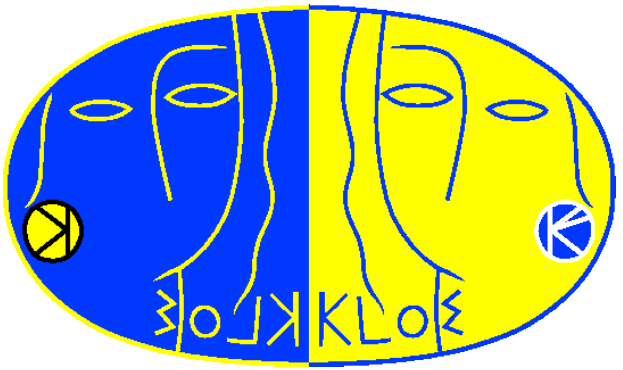
Low energy QCD and ChPT studies with KLOE

Marek Jacewicz, Uppsala University

on behalf of the KLOE Collaboration



Les Rencontres de Physique de la Vallée d'Aoste 28/02 – 06/03 2010

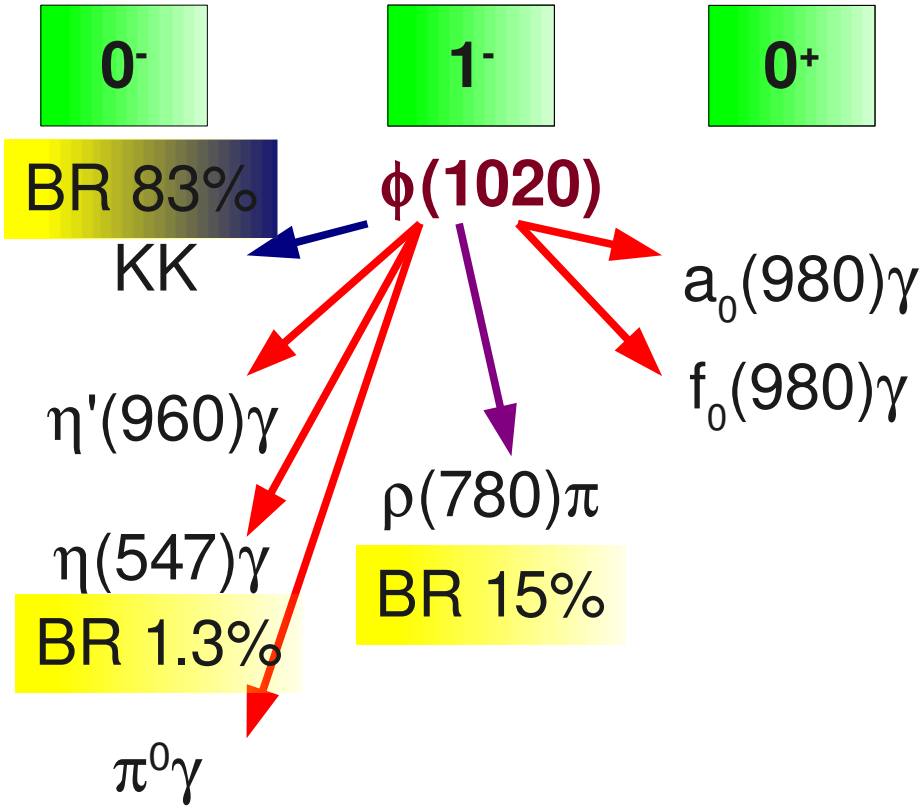
DAFNE collider in Frascati

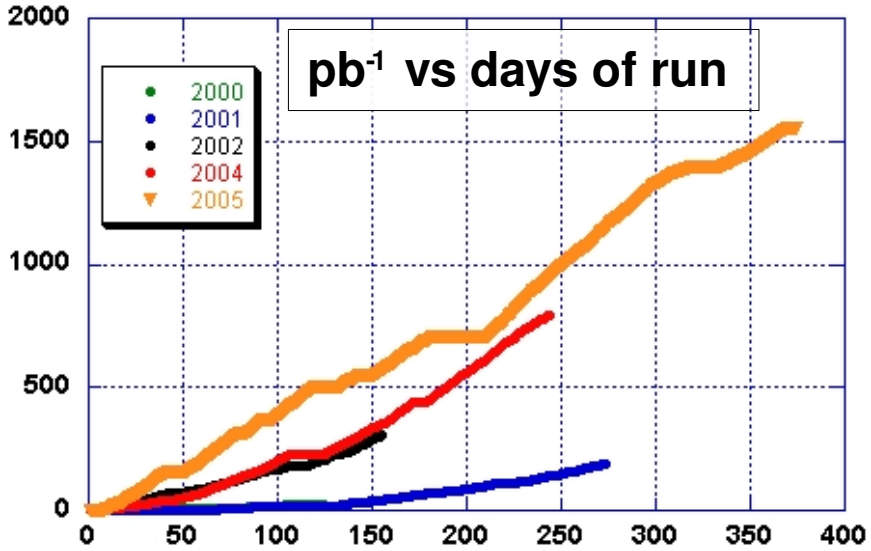
e^+e^- collider @ $\sqrt{s} = m_\phi = 1.019$ GeV

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

This translates to ~8×10^9 ϕ mesons

Also collected 240 pb^{-1} @ 1 GeV "off-peak"





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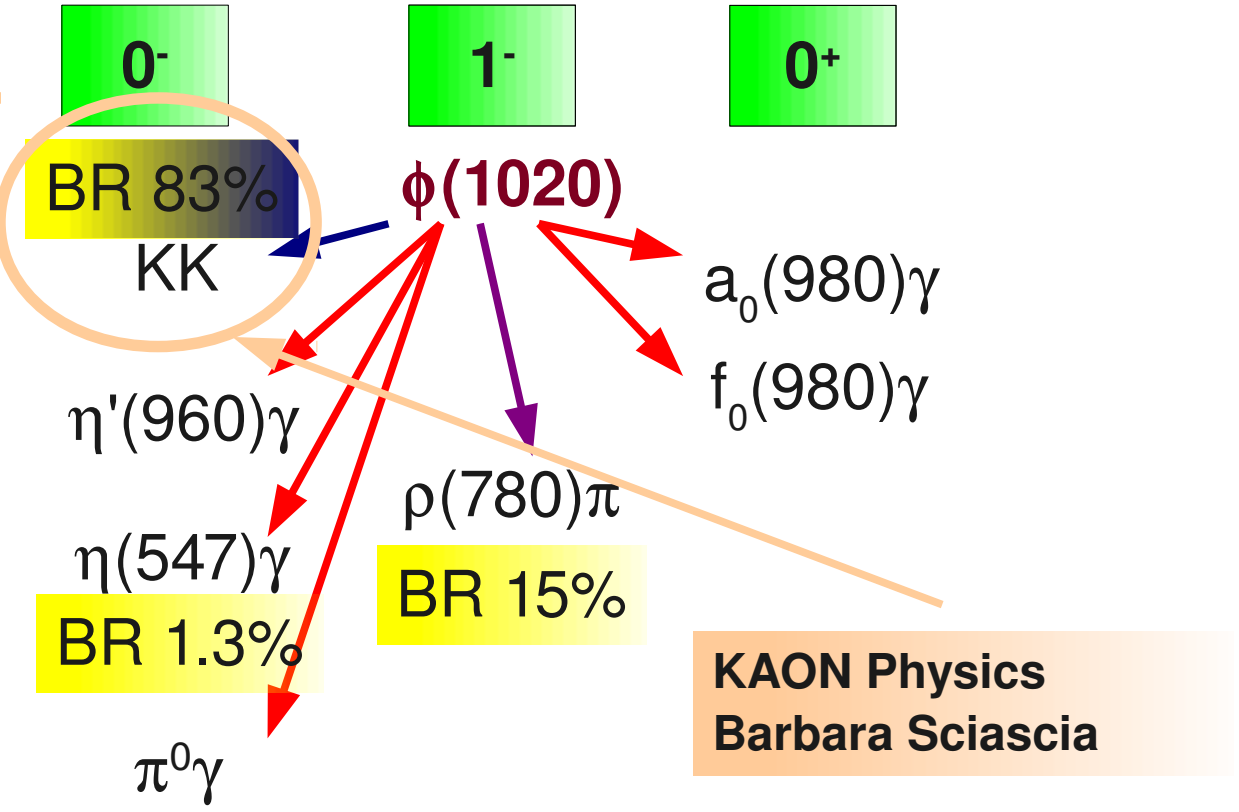
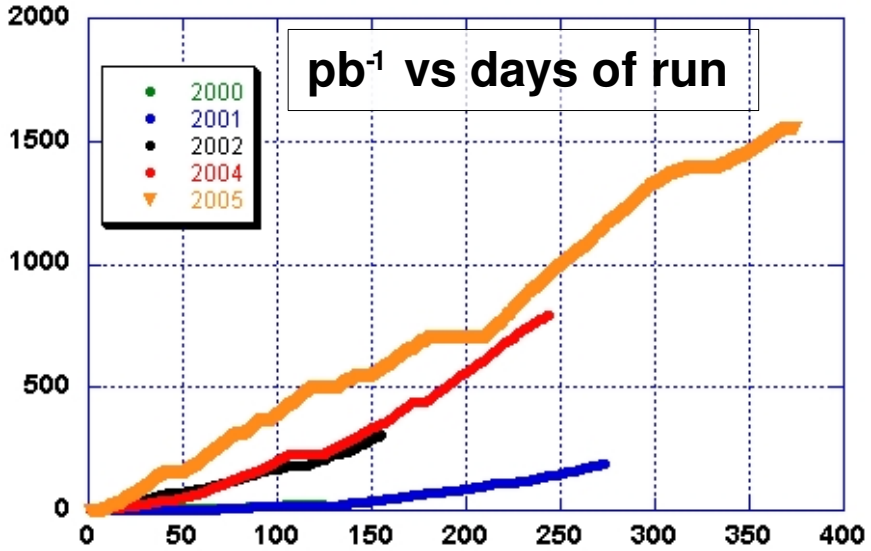




KAON Physics
Barbara Sciascia

KLOE experiment

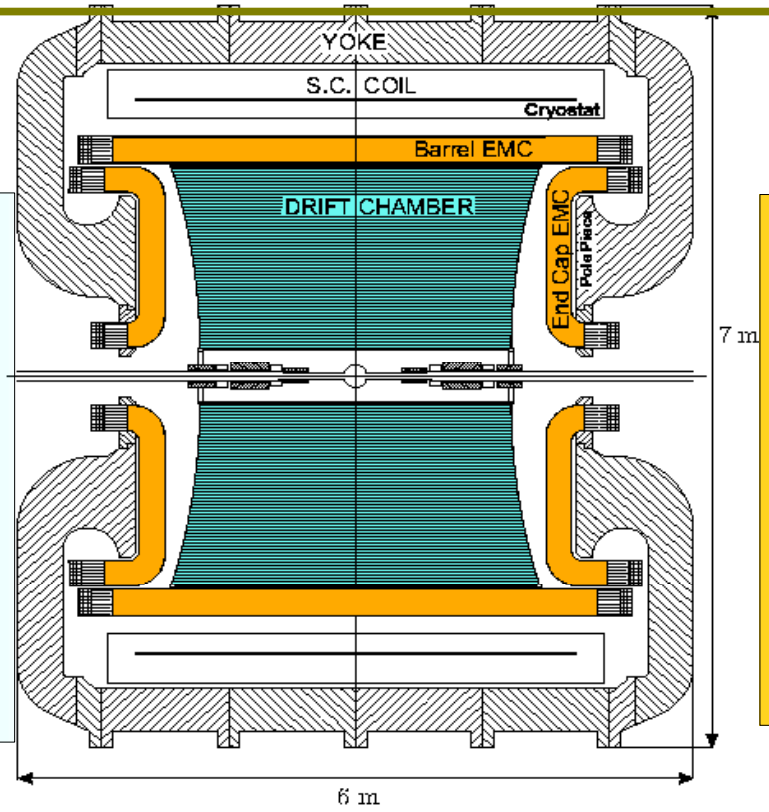
Detector design optimized for K_L measurement:

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 μm

σ_z = 2 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 ϕ decays

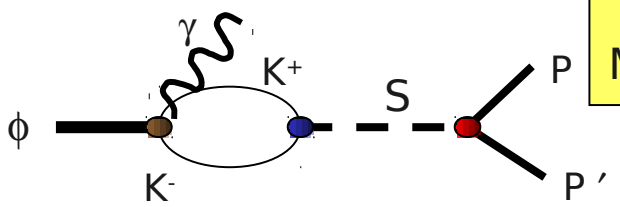
The problem of the internal structure of the scalar mesons with mass < 1GeV is still open.
Are they $q\bar{q}$ mesons, $q\bar{q}q\bar{q}$ states, bound states of $K\bar{K}$ pair or a mixing ?
KLOE has studied radiative $\phi(1020)$ decays $\phi \to P_1P_2\ \gamma$ dominated by exchange of scalar meson S in the intermediate state $\phi \to S\ \gamma \to P_1P_2\ \gamma$

Decays' BRs and P_1P_2 invariant mass shapes depend on scalar structure

P_1P_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_SK_S	$f_0(980)/a_0(980)$	[PLB 679 (2009) 10]

Phenomenological models used by KLOE to describe $\phi \to S\gamma \to P_1P_2\ \gamma$:

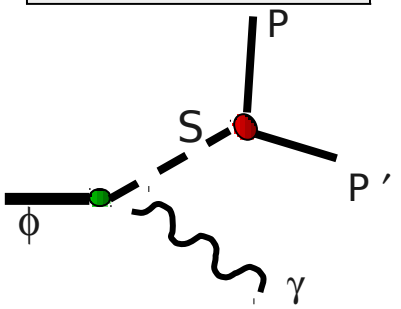
Kaon Loop



Fit params:
M_S, g_{SPP} , g_{SKK}

[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]

No Structure



Fit params:
M_S, $g_{\phi S\gamma}$, g_{SPP} , g_{SKK} ,
continuum (polynomial)

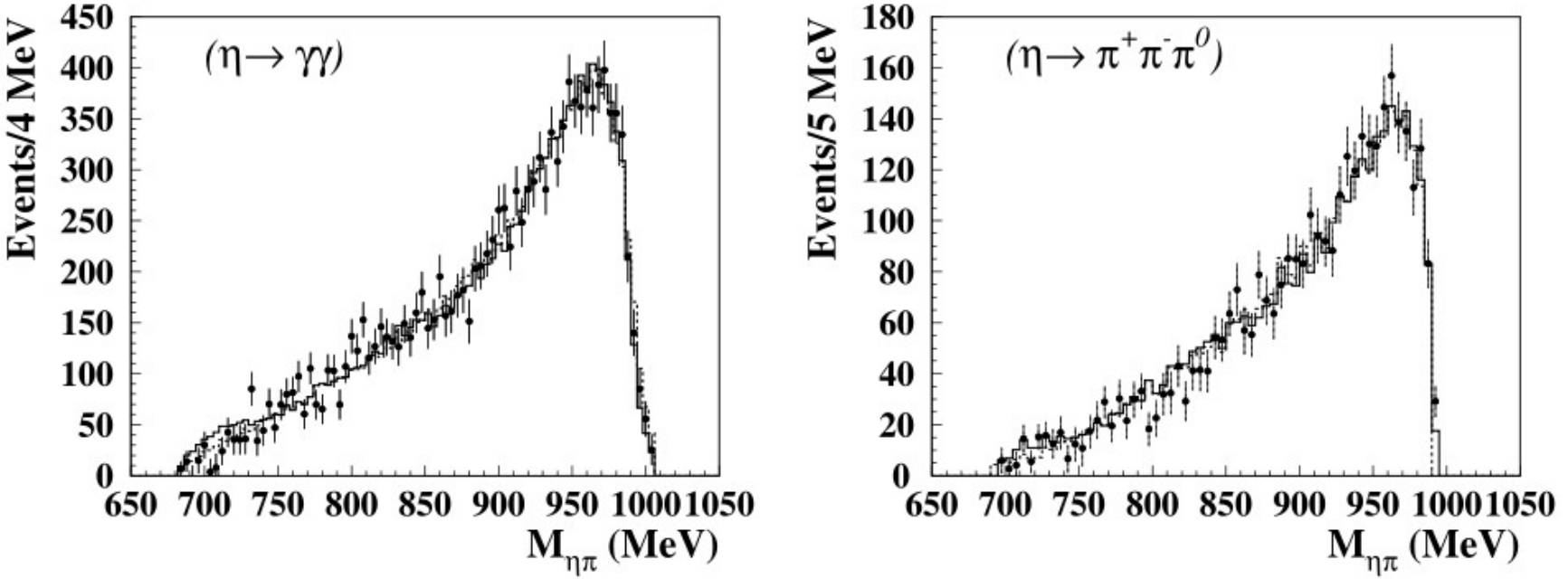
G.Isidori et al, JHEP05 (2006)049

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

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

$$BR(\phi \to \eta\pi^0\gamma) = (7.01 \pm 0.10_{stat} \pm 0.20_{syst}) \cdot 10^{-5} \ (\eta \to \gamma\gamma)$$
$$BR(\phi \to \eta\pi^0\gamma) = (7.12 \pm 0.13_{stat} \pm 0.22_{syst}) \cdot 10^{-5} \ (\eta \to \pi^+\pi^-\pi^0)$$

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

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

	KL	NS	
M_{a_0} (MeV)	982.5±1.6±1.1	982.5 (fixed)	984.7±1.2 from PDG08
$g_{aK^+K^-}$ (GeV)	2.15±0.06±0.06	2.01±0.07±0.28	
$g_{a\eta\pi}$ (GeV)	2.82±0.03±0.04	2.46±0.08±0.11	
$g_{\phi a\gamma}$ (GeV^{-1})	1.58±0.10±0.16	1.83±0.03±0.08	
BR(VDM)x10^6	0.92±0.40±0.15	~0	
R_η	1.70±0.04±0.03	1.70±0.03±0.01	1.729±0.028 from PDG08
$(g_{aK^+K^-}/g_{a\eta\pi})^2$	0.58±0.03±0.03	0.67±0.06±0.13	
P(χ2)	10.4%	30.9%	
Γ_{a_0} (MeV)	105	80	

the vector contribution is very small, $Br(\phi \to V\,P \to \eta\pi^0\gamma) < 10^{-6}$; V = ρ, ω

a_0 (980) mass agrees at one standard deviation level with the PDG value

Search for $\phi \to K^0\overline{K}^0\gamma$

Never been observed

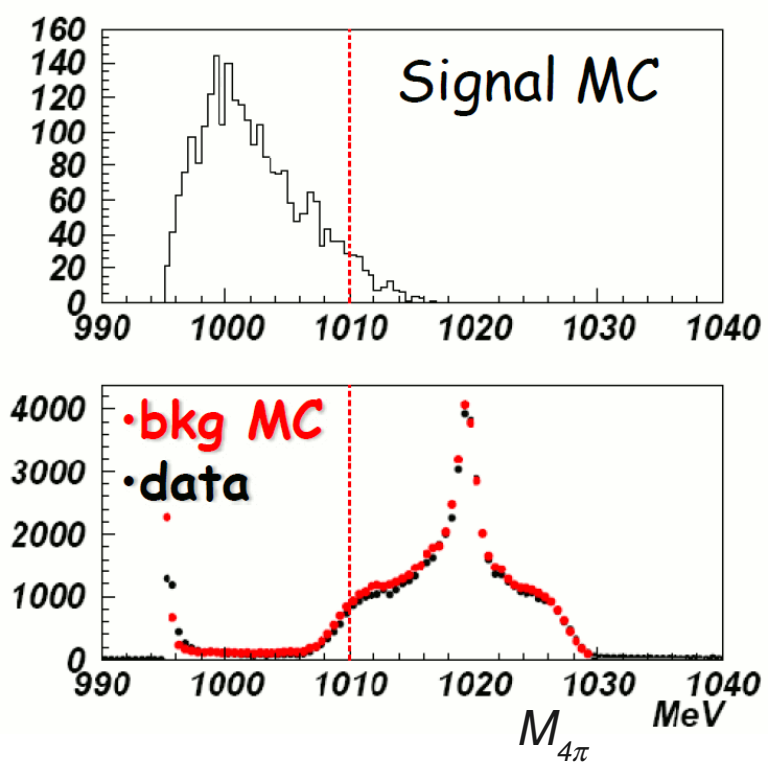
Selected channel :

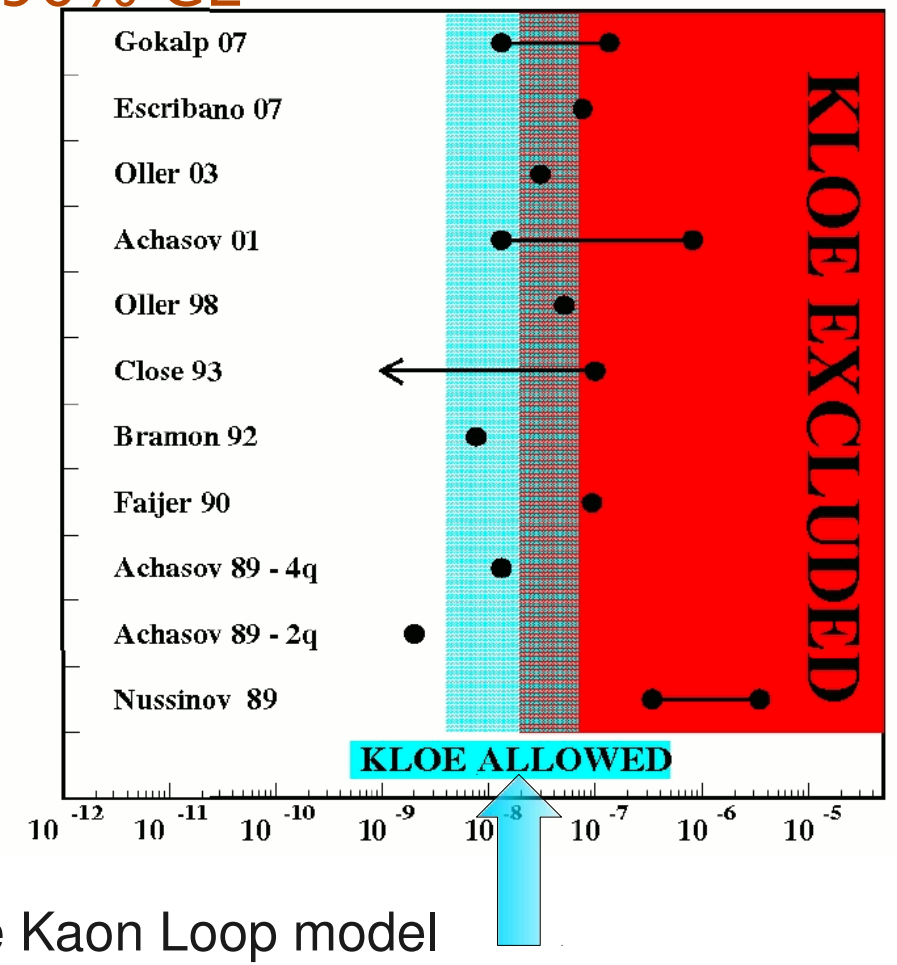
$$\phi \to (f_0 + a_0)\,\gamma \to K^0\overline{K}^0\gamma \to K_S K_S\,\gamma \to \pi^+\pi^-\pi^+\pi^-\gamma$$

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

5 events in data ⇨ 3.2 ± 0.7 background events

BR($\phi \to K^0\overline{K}^0\gamma$) < 1.9 × 10^{-8} at 90% CL





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

η–η' mixing and η' gluonic content

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

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

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

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

$$Z_G = \sin\phi_G$$ gluonium content

ϕ_P = η–η' mixing angle

KLOE PLB 648 (2007) 267

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

$\phi_P = (39.7 \pm 0.7)°$

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

$P(\chi^2) = 0.49$

Gluonium at 3σ

Imposing Z_G =0 → $P(\chi^2)$ = 0.01

Escribano-Nadal *JHEP* 0705:006, 2007

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

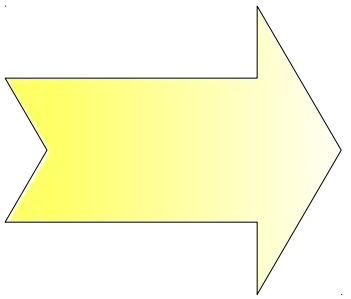
Difference attributed to the use in the fit of theoretical parameters $\mathbf{Z_s}$, $\mathbf{Z_q}$, $\boldsymbol{\phi_V}$, $\mathbf{m_s/m}$ from Bramon *et al.* PLB 503 (2001) 271 where Z_G =0 is assumed

η–η' mixing and η' gluonic content

5 more relations added

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

KLOE new fit



Parameters

Z_s , Z_q , ϕ_V , m_s/m

are left free

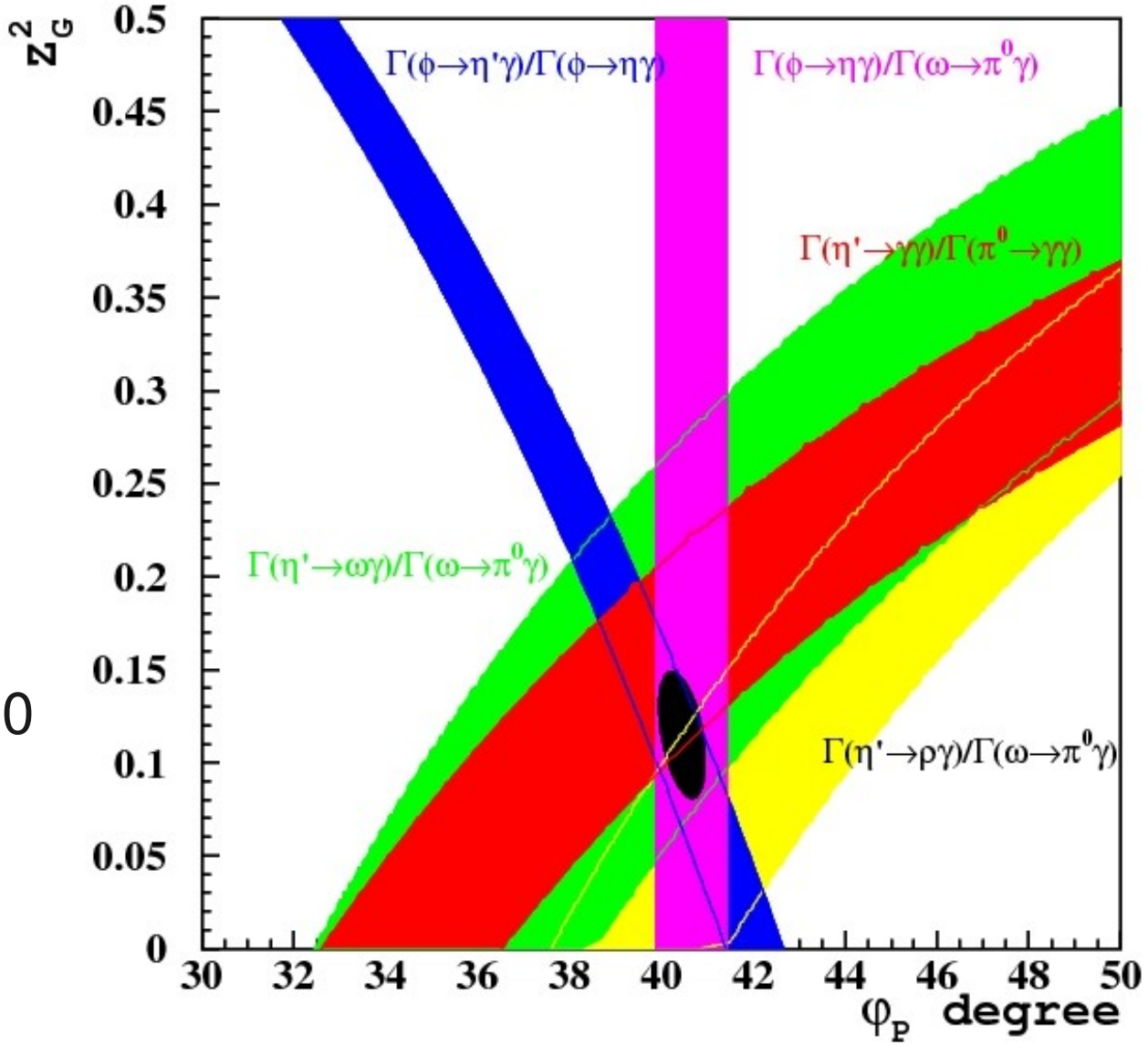
η–η' mixing and η' gluonic content

Published in JHEP07(2009)105

	with glue
$(Z_G)^2$	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

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^2_G - ϕ_P plane

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

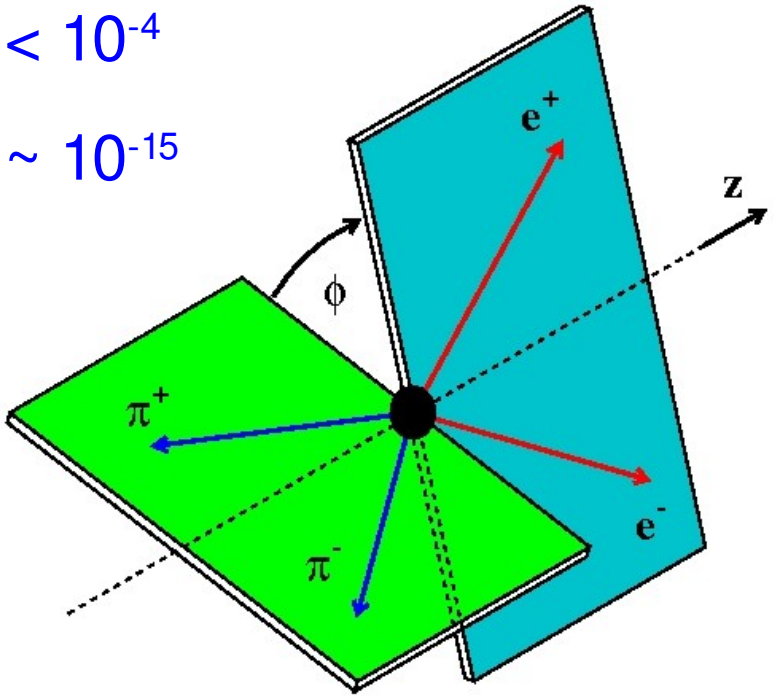
Gao, Mod. Phys. Lett. A17(2002) 1583

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

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}



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

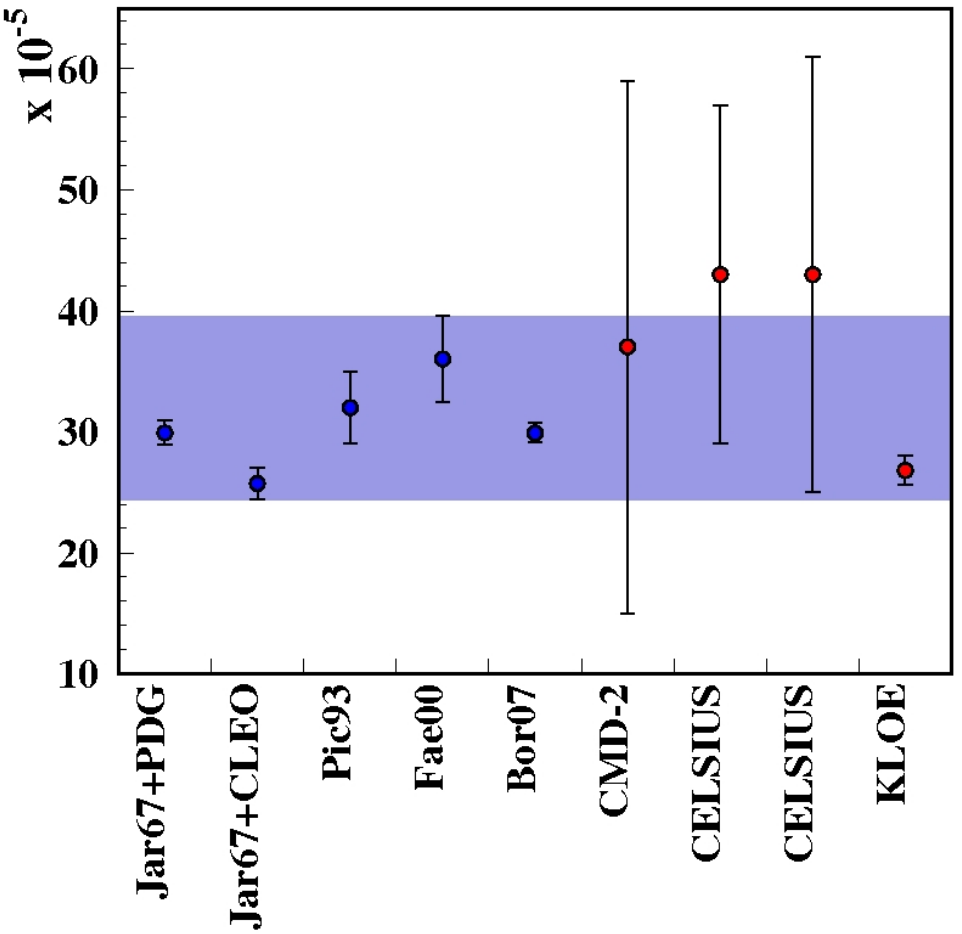
$\eta \to \pi^+\pi^-e^+e^-$ decay: BR and asymmetry

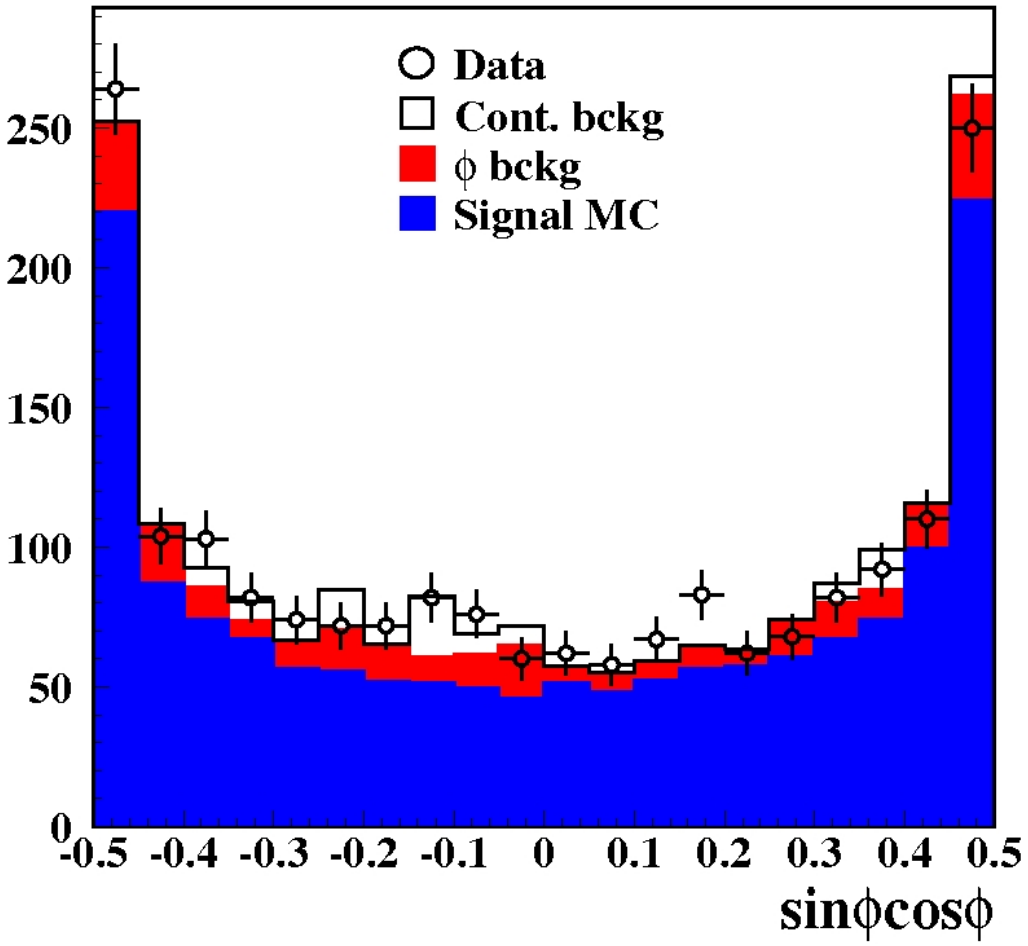
$$BR(\eta \to \pi^+\pi^- e^+ e^-) = (26.8 \pm 0.9_{Stat.} \pm 0.7_{Syst.}) \cdot 10^{-5}$$

PLB 675(2009) 283

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

First measurement!





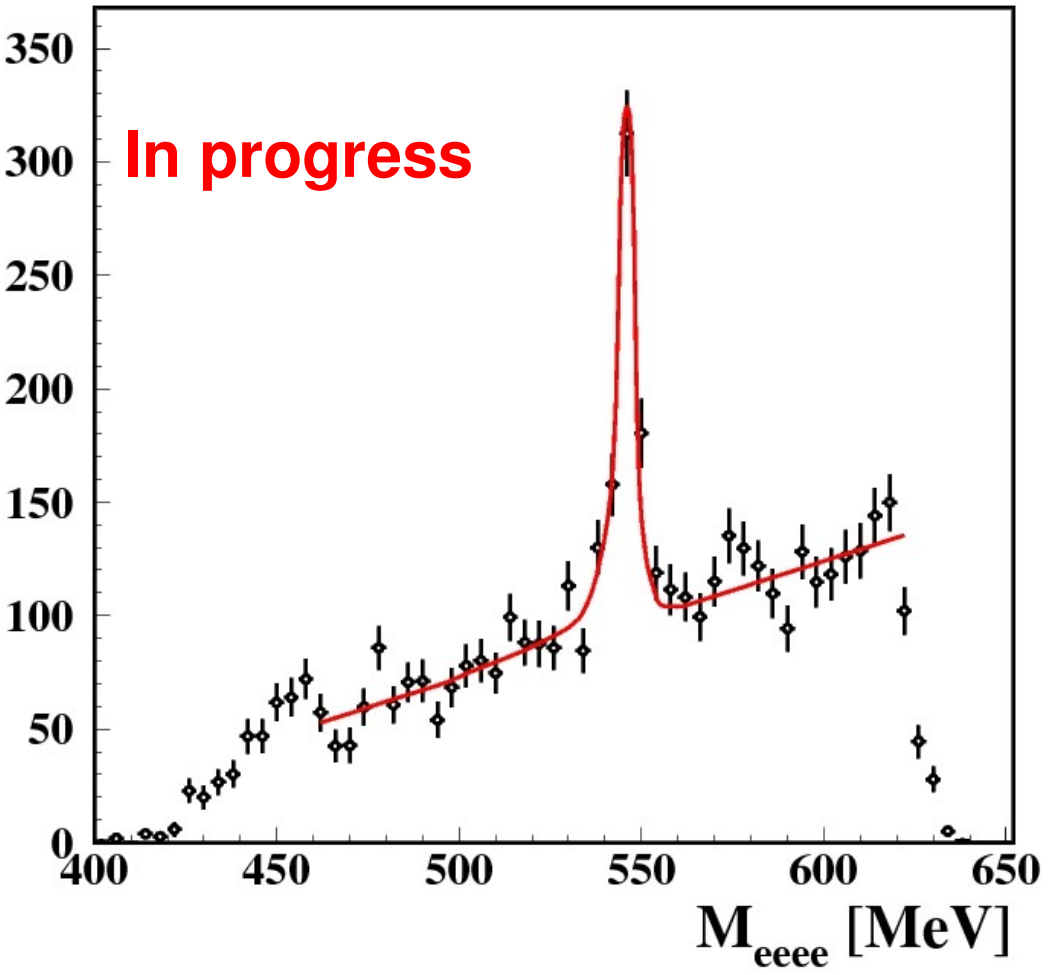
$\eta \to e^+e^-e^+e^-$ analysis

- 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 ± 31

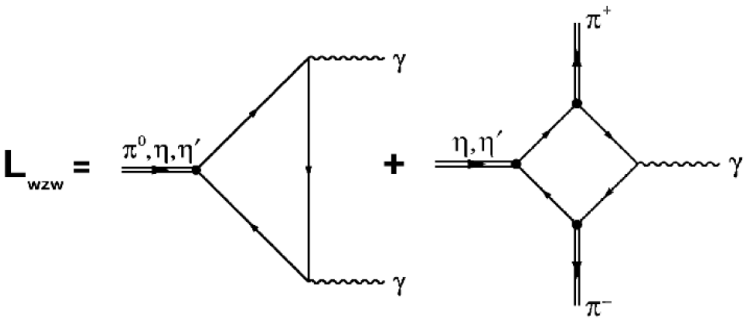
First observation!



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

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.

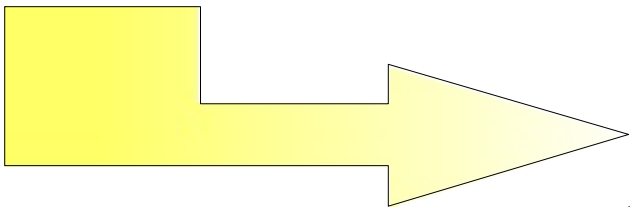
Holstein, Phys. Scripta, T99 55 (2002)
Benayoun, Eur. Phys. J., C31 525 (2003)
Borasoy, Nissler, Nucl. Phys., A740 362 (2004)

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)

Latest results from CLEO on the ratio of charged decays BRs differ > 3σ from old results



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

VALUE	EVTS	DOCUMENT ID		TECN
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

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

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

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

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 %

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

Similar cuts ((E_γ–P_γ) instead of missing mass, angle selection)

Simultaneous fit to two distribution

Eff = 29 %

Data sample: 1.2 fb^{-1}

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

PRELIMINARY RESULT

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

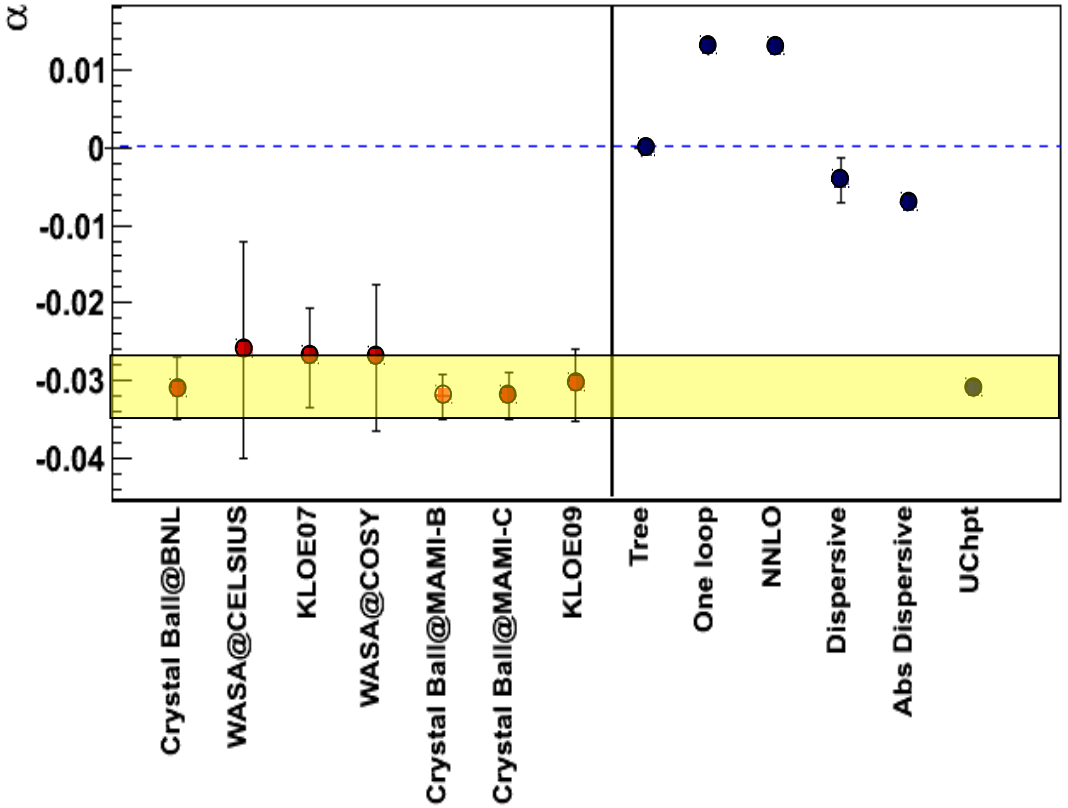
$\eta \to \pi^0\pi^0\pi^0$

Preliminary results:
arXiv 0707.4137

At the lowest order $\eta \to \pi^0\pi^0\pi^0$ decay amplitude can be parametrize by

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

The slope α 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 ÷ 0.7]:

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

paper in writing ...

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

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 3σ

The error on a_μ is dominated by the hadronic contribution

($e^+e^- \to \pi^+\pi^-$ @ < 1 GeV contributes 70% to a_μ !)

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

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

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(s)*** →

EVA + PHOKHARA MC NLO [PLB459(1999)279, EPJC27(2003)563]

radiative corrections also included (Vacuum Polarization and FSR)

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

·Two selections were used:

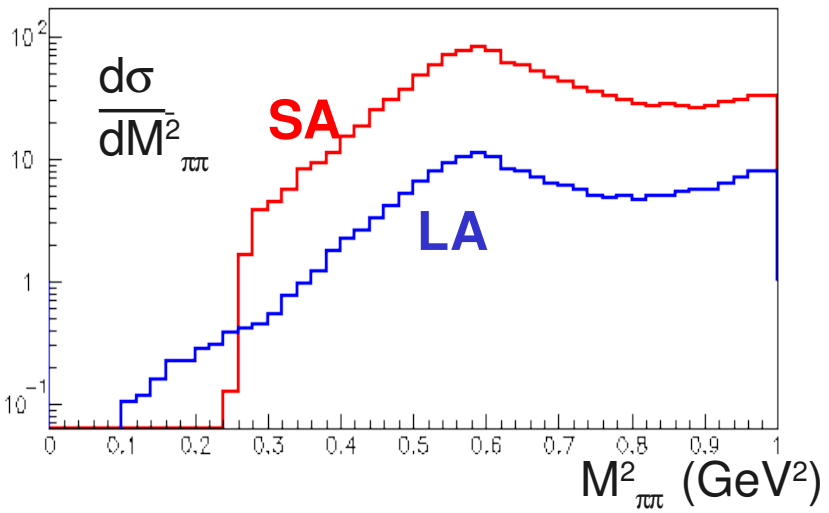
·1) **Small Angle: $\theta_\gamma < 15°$ or $\theta_\gamma > 165°$**

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

PLB670(2009)285

·2) **Large Angle: $50° < \theta_\gamma < 130°$**

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



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

Comparison between two samples: (0.35 – 0.85 GeV²)

$$\Delta a_\mu^{\pi\pi} = \frac{1}{4\pi^3}\int_{0.35}^{0.85} \sigma^{\pi\pi}(s)K(s)ds$$

KLOE08 (Small Angle)

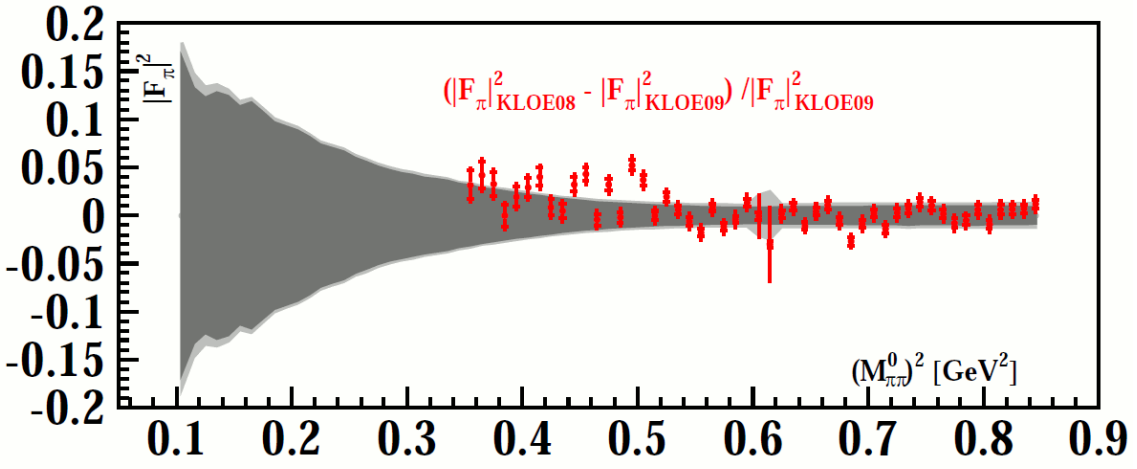
$a_\mu^{\pi\pi} = (379.6 \pm 0.4_{stat} \pm 2.4_{sys} \pm 2.2_{theo}) \cdot 10^{-10}$

KLOE09 (Large Angle)

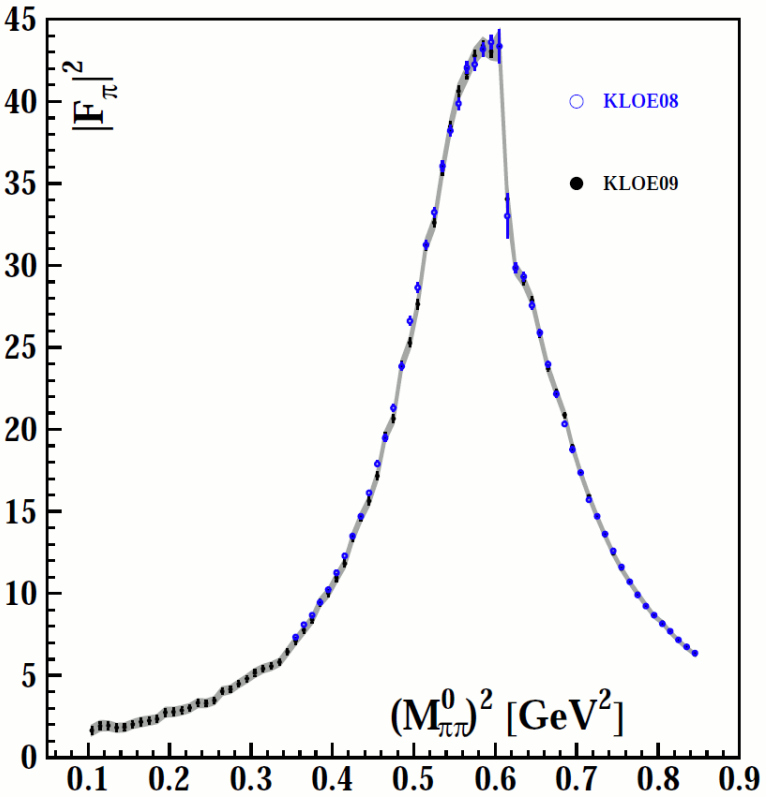
$a_\mu^{\pi\pi} = (376.6 \pm 0.9_{stat} \pm 2.4_{sys} \pm 2.1_{theo}) \cdot 10^{-10}$

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

In overlap region very good agreement with previous result



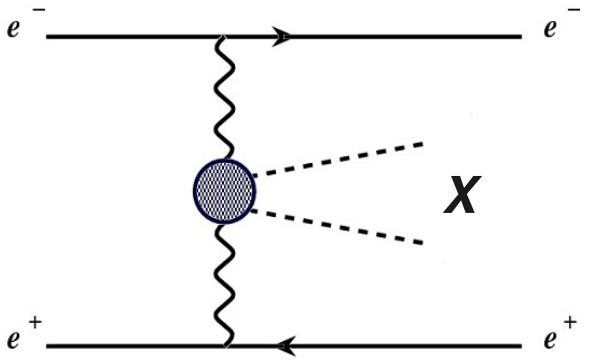
Fractional difference: (band → KLOE09 error)

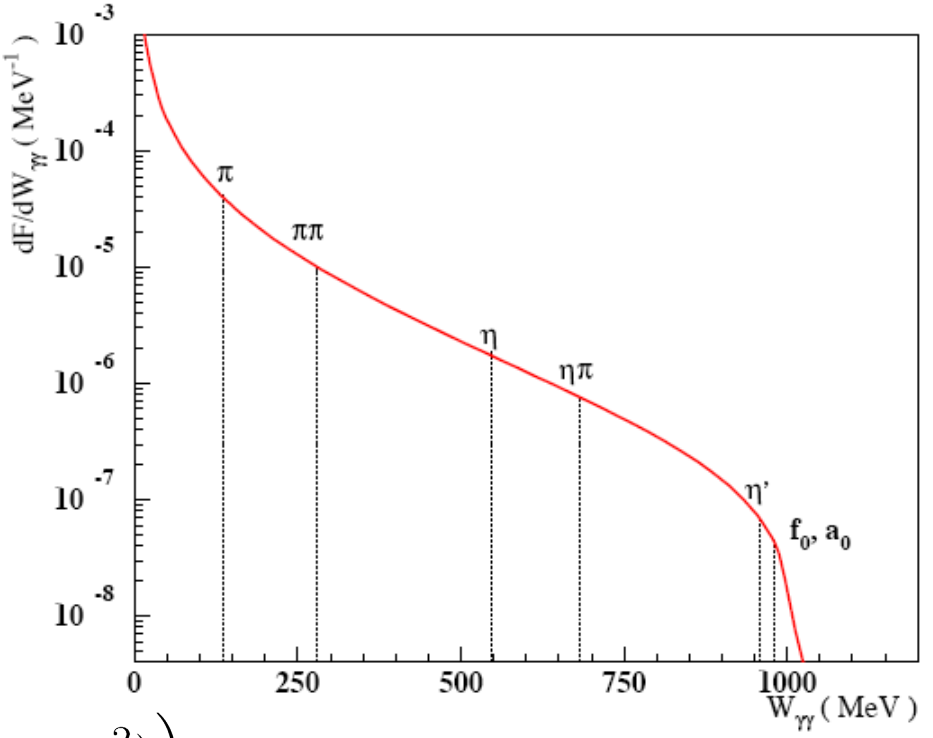


"Large Angle" paper ready for publication

γγ physics at KLOE

Production of scalar and pseudoscalar mesons via γγ interactions





$$\sigma_{e^+e^- \to e^+e^- X} = \frac{16\alpha^2 \Gamma_{X\gamma\gamma}}{m_X^3} \left(ln\frac{E_b}{m_e}\right)^2 \left((y^2+2)^2\, ln\frac{1}{y} - (1-y^2)(3+y^2)\right)$$

where $y = m_X/(2E_b)$

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

Search for η production
with $\eta \to \pi^+\pi^-\pi^0$ decay (BR=22.73%)
η candidates selected with kin. fit
10 variables (for 2 γ) and 4 constraints:
major background: $e^+e^- \to \eta\gamma$

Search for "σ" production
with $\sigma \to \pi^0\pi^0$ decay
4 clusters, DC veto
$\sum E^{min}_{2\gamma} > 60$ MeV
$\sum E^{i}_{\gamma} / E_{CALO} > 0.8$
Background from events with undetected energy: $K_S K_L$ (K_L undetected)

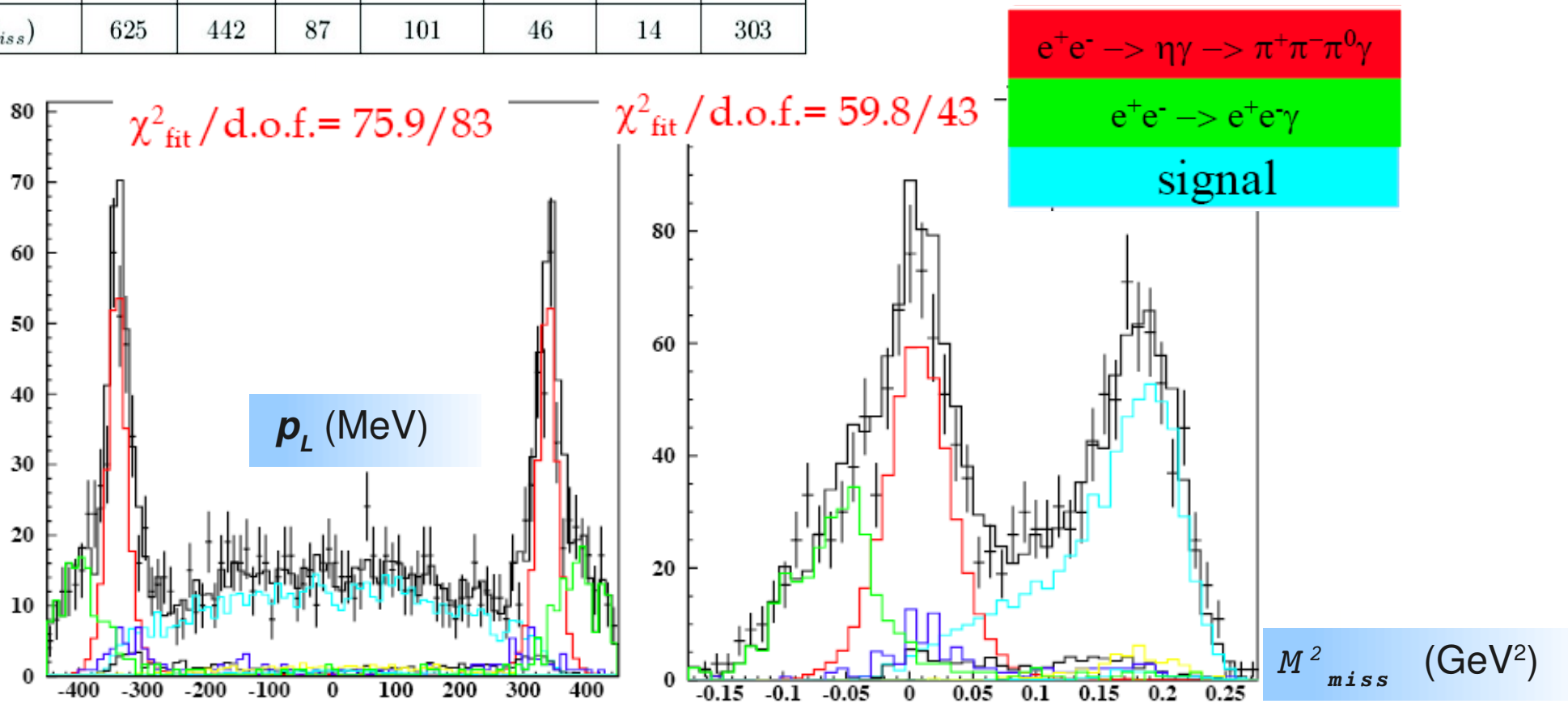
$\gamma\gamma$ physics at KLOE

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

Number of events comes from a fit to η 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_SK_L	$e^+e^-\gamma$
range variation	free	±15%	±1%	±7%	±25%	±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

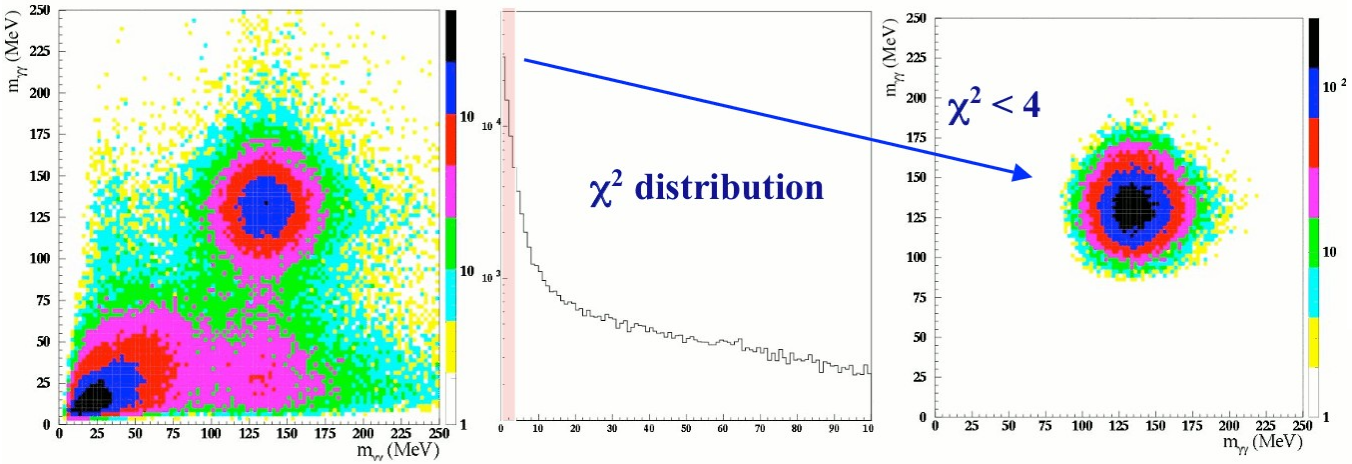


Extraction of $\sigma(e^+e^- \to e^+e^- \eta)$ and $\Gamma_{\gamma\gamma}$ is in progress)

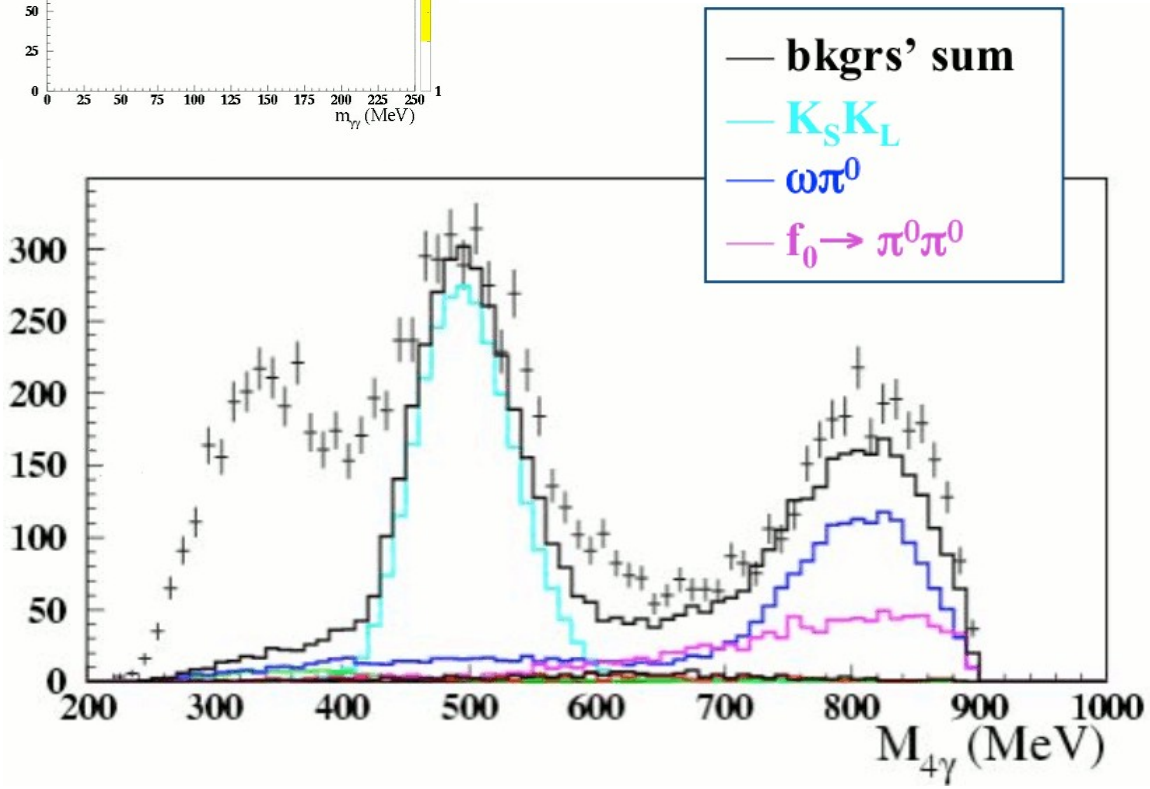
$\gamma\gamma$ physics at KLOE

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

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



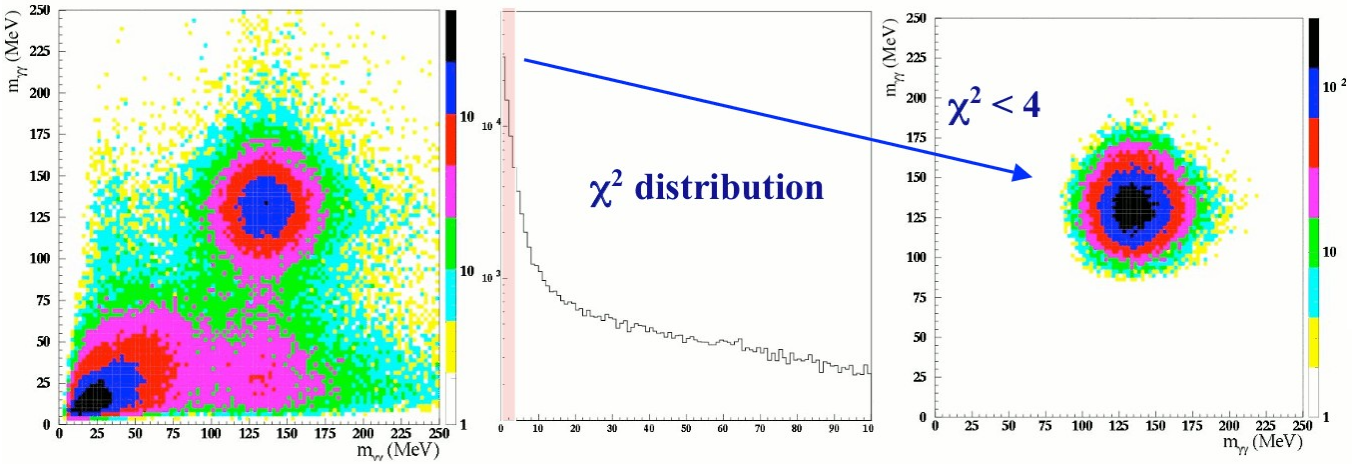
	ϵ	σ (nb)	$n = \epsilon L \sigma$
$K_S K_L$	5.60×10^{-3}	2.0	2 682
$\eta \to 3\pi^0$	1.79×10^{-3}	0.33	142
$\omega\pi^0$	1.55×10^{-2}	0.55	2 045
$f_0 \to 2\pi^0$	2.58×10^{-2}	0.17	1 052
$a_0 \to \eta\pi^0$	4.55×10^{-3}	0.11	120
$e^+e^- \to \gamma\gamma$	1.92×10^{-5}	360	166
$\eta \to \gamma\gamma$	1.57×10^{-4}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



$\gamma\gamma$ physics at KLOE

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

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



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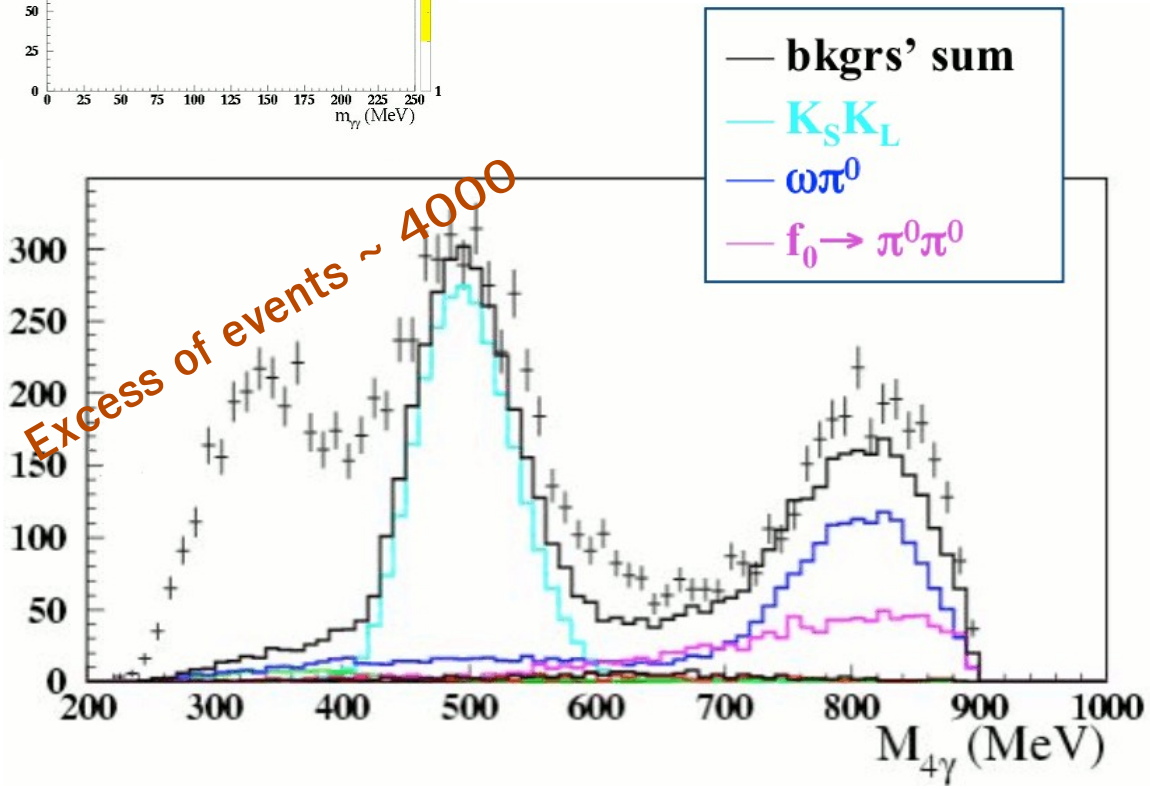


Subtraction of backgrounds and study of differential cross section are in progress

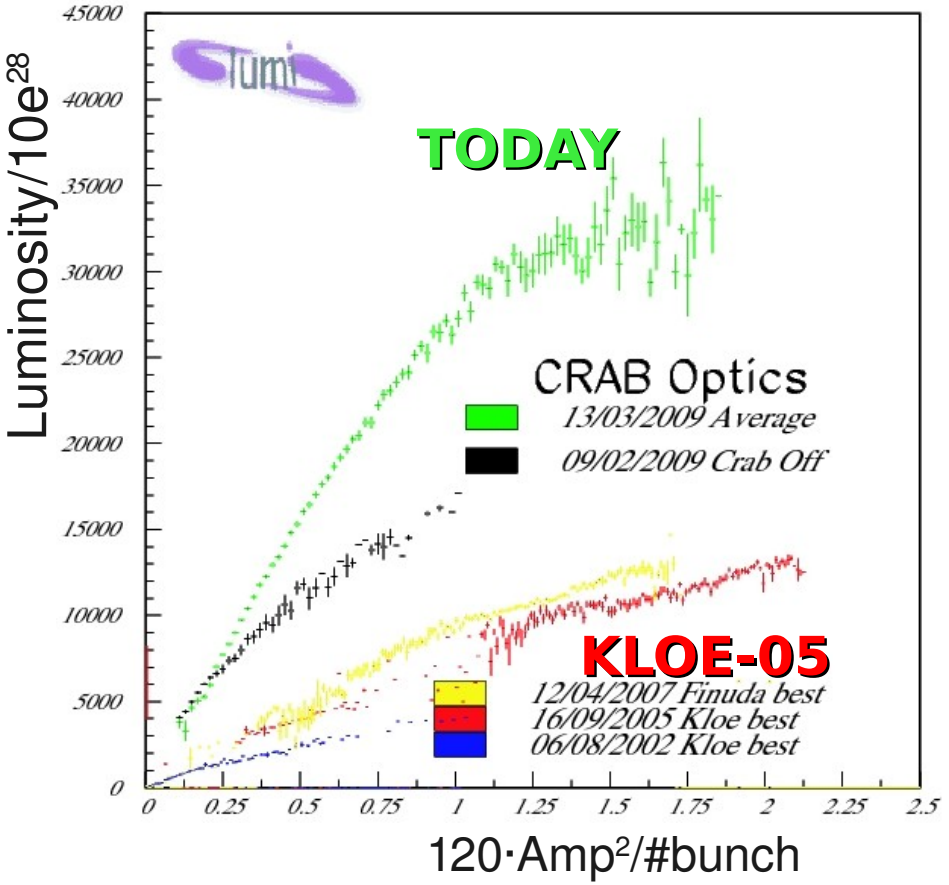
DAΦNE and KLOE upgrades

New machine magnetic scheme:

crab waist

$L_{peak} = 5 \times 10^{32}\ cm^{-2}\ s^{-1}$

$\int L = 15\ pb^{-1}/day$



STEP-0 [2010]: **5fb^{-1}**

$\gamma\gamma$ tagger

STEP-1 [2011]: **>20fb^{-1}**

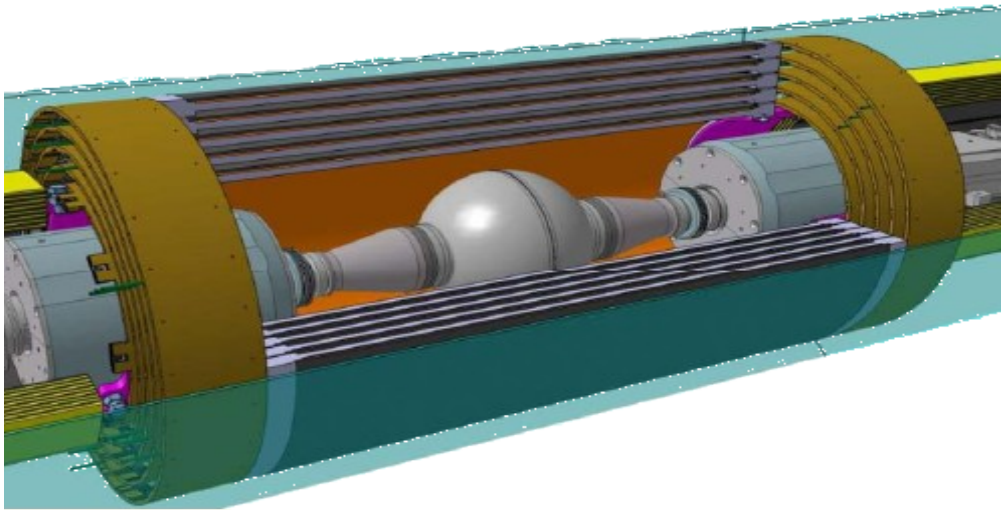
Low Angle Calorimeter

Quadrupole Calorimeter

Inner Tracker

New interaction region:

larger crossing angle



SUMMARY

- SCALARS
  - Measurement of 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
  - 3σ evidence for gluonium in η′ (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 ~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 measurment of $\sigma_{\pi\pi}$ is in agreement with the KLOE published one and confirms the 3σ discrepancy btw SM and BNL
- γγ physics
  - $e^+e^- \rightarrow e^+e^-\pi^+\pi^-\pi^0$: $\eta \rightarrow \pi^+\pi^-\pi^0$ (~ 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 η decay measurements

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

Hadronic cross section: higher statistics and reduced systematics

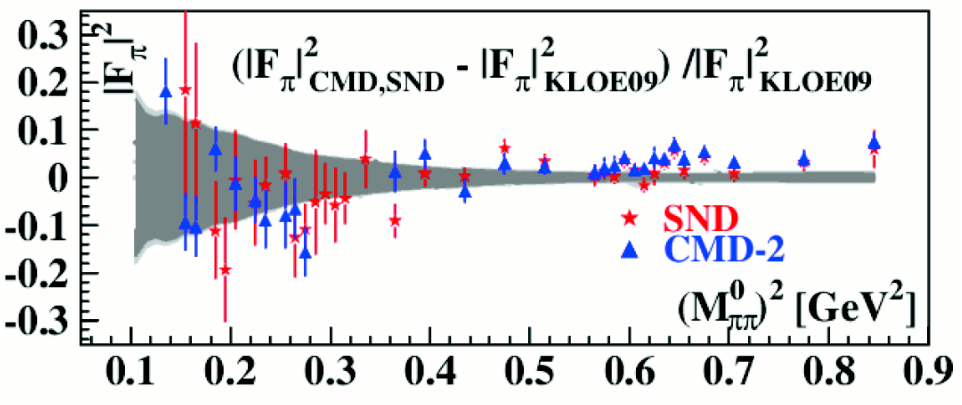
In step-0 detector upgrade for $\gamma\gamma$ physics

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

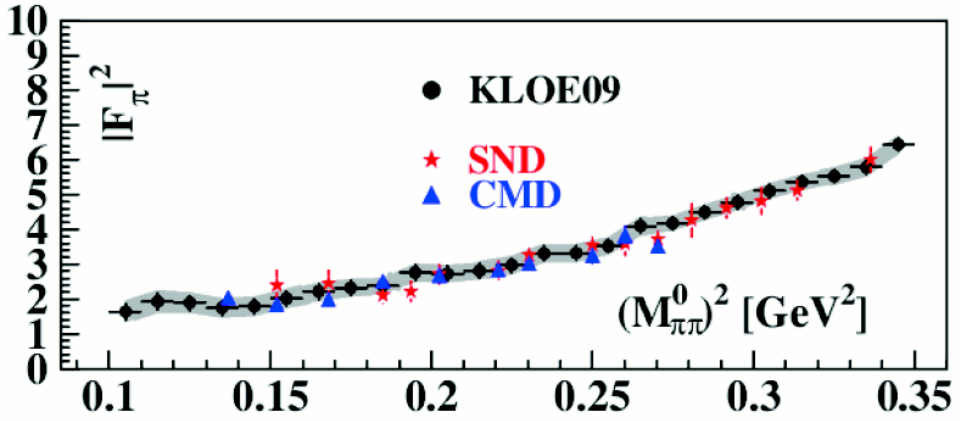
Open a window on η' physics

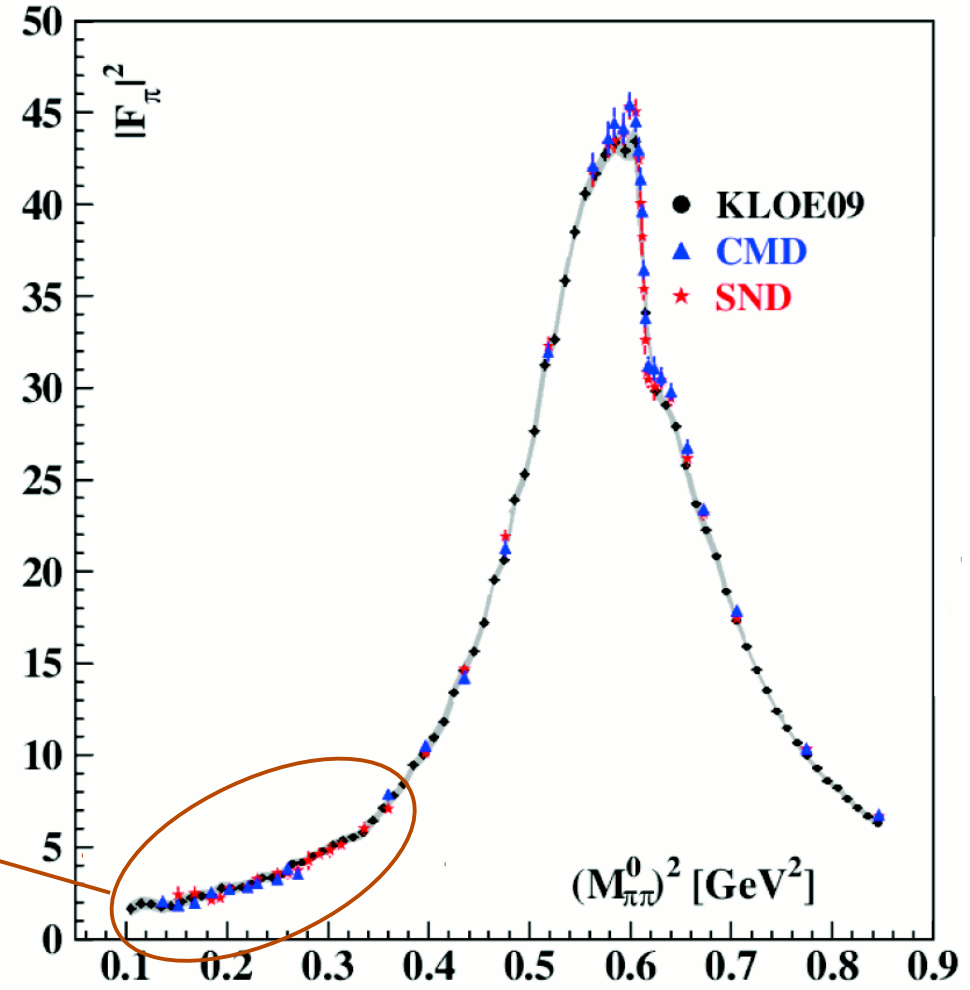
Measurement of all the main η' BR's together with η' decay width $\sigma(e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^- \eta')$ at 1% precision would be necessary to solve the gluonium puzzle

Hadronic cross section $\sigma(e^+e^- \to \pi^+\pi^-)$
CMD and SND results compared to KLOE09



Fractional difference: (band → KLOE09 error)

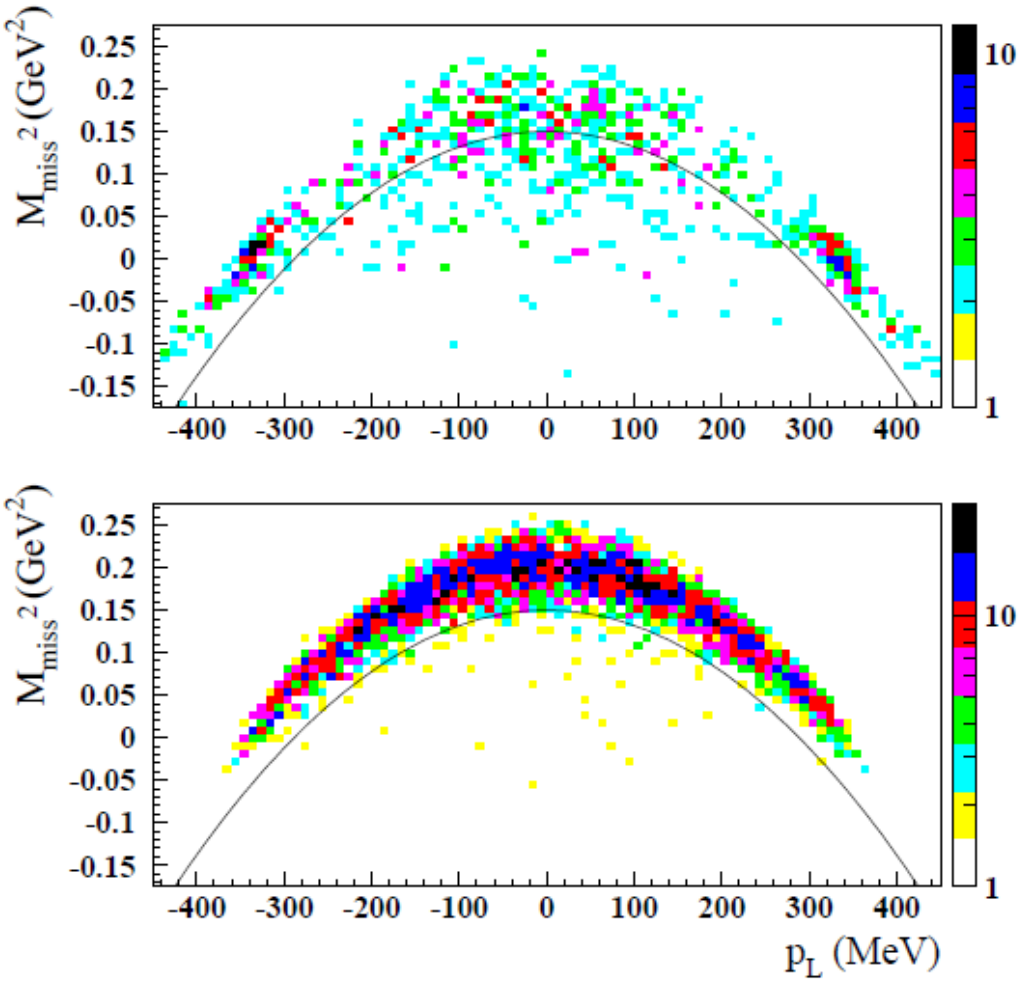




Good agreement in with results from CMD-2 and SND
(especially at low $M_{\pi\pi}^2$ range)

$$\sigma_{e^+e^-\to\ e^+e^-X} = \frac{16\alpha^2\Gamma_{X\gamma\gamma}}{m_X^3}\left(ln\frac{E_b}{m_e}\right)^2\left((y^2+2)^2\ ln\frac{1}{y} - (1-y^2)(3+y^2)\right)$$

$$M_{miss}^2 \approx s + M_\eta^2 - 2E_T\sqrt{s} - \frac{p_L^2}{E_T}\sqrt{s}$$



KLOE-2 Step 0

Luminosity goal: 5 fb^{-1} @ $\sqrt{s} \approx M_\phi$ Approved ⇒ start May 2010

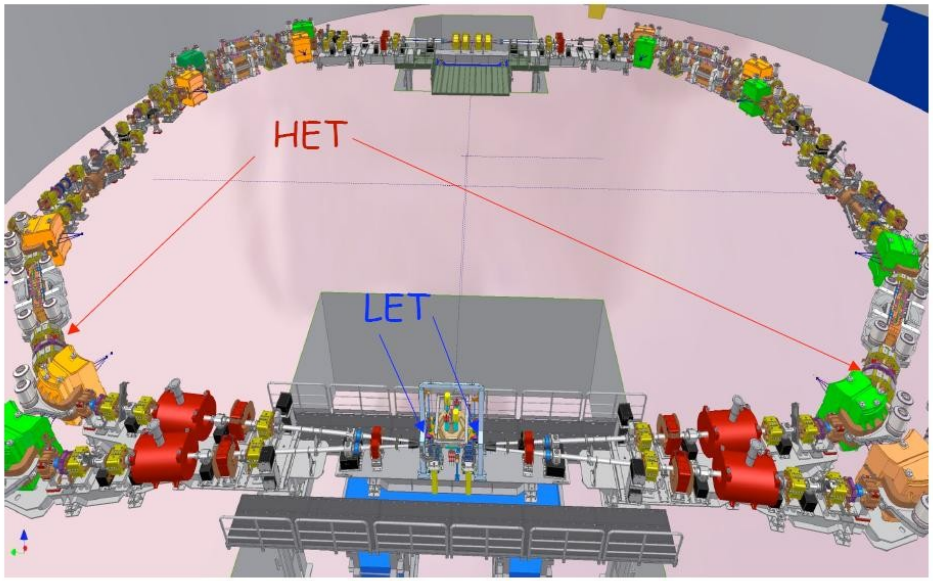
Minimal detector upgrade

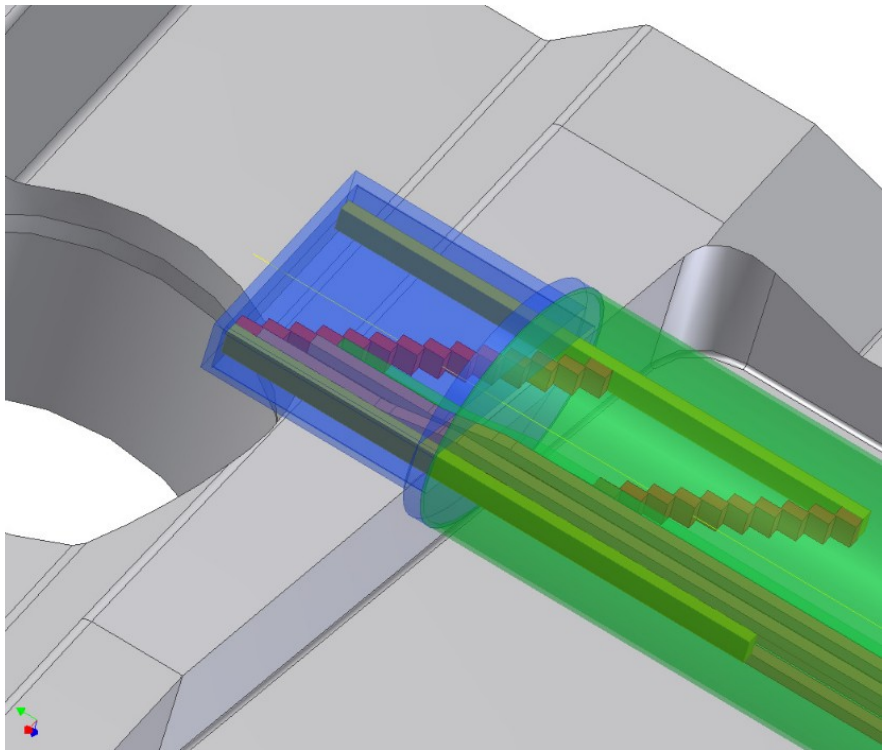
- Tagger for $\gamma\gamma$ physics: to detect off-momentum $e^\pm$ from

$$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$$

  - Low Energy Tagger (130-230 MeV) calorimeters, LYSO + SiPM
  - High Energy Tagger (E > 400 MeV) position sensitive detectors

    (strong energy-position correlation ⇒ use the DAΦNE magnets as $e^\pm$ spectrometer)





η–η' mixing and η' gluonic content

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

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

KLOE PLB 648 (2007) 267

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

$\phi_P = (39.7 \pm 0.7)°$

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

$P(\chi^2) = 0.49$

Gluonium at 3σ

Imposing Z_G=0 → $P(\chi^2)$ = 0.01

Escribano-Nadal *JHEP* 0705:006, 2007

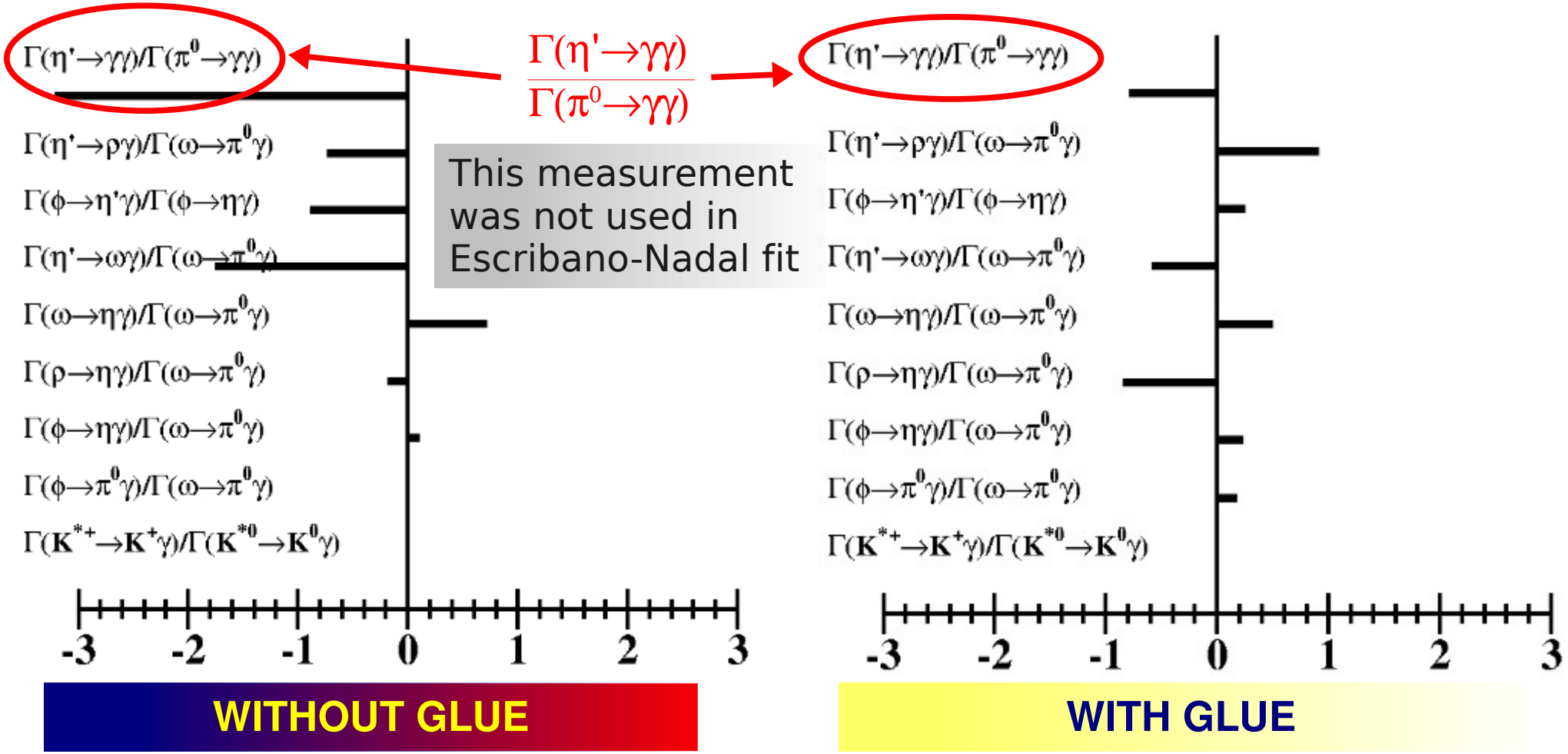
$(Z_G)^2 = 0.04 \pm 0.09$

Difference attributed to the use in the fit of theoretical parameters $\mathbf{Z_s}$, $\mathbf{Z_q}$, $\boldsymbol{\phi_V}$, $\mathbf{m_s/m}$ from Bramon *et al.* PLB 503 (2001) 271 where Z_G=0 is assumed

KLOE new fit

χ^2/dof = 14.7/4	$(Z_G)^2$	fixed 0	0.115 ± 0.036	χ^2/dof = 4.6/3
P(χ^2) = 0.005	ϕ_P	(41.4 ± 0.5)°	(40.4 ± 0.6)°	P(χ^2) = 0.20

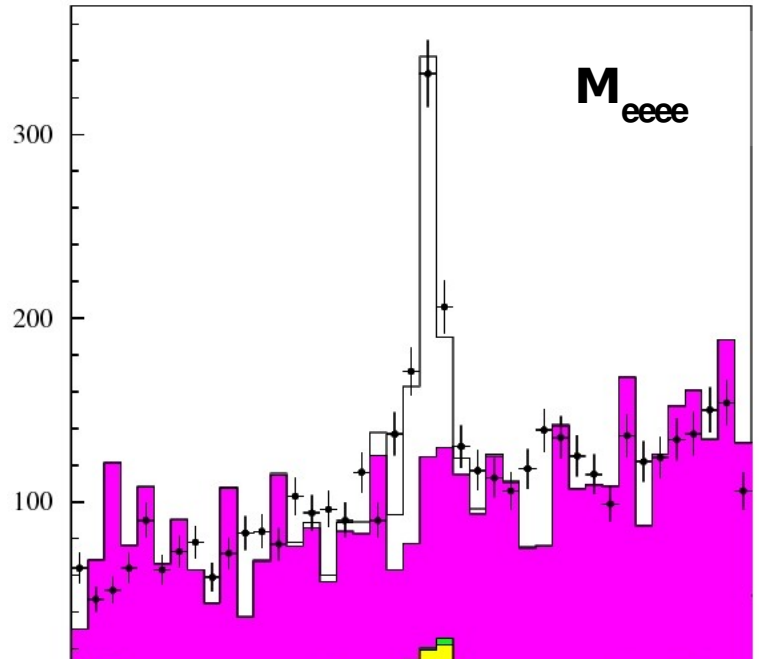
Pulls = (Meas-Fit)/$\sigma_{Measurement}$

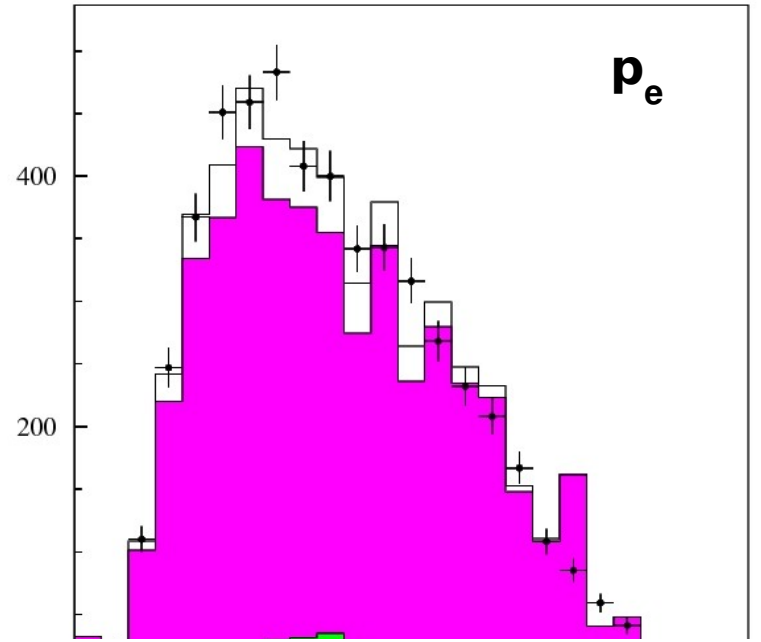


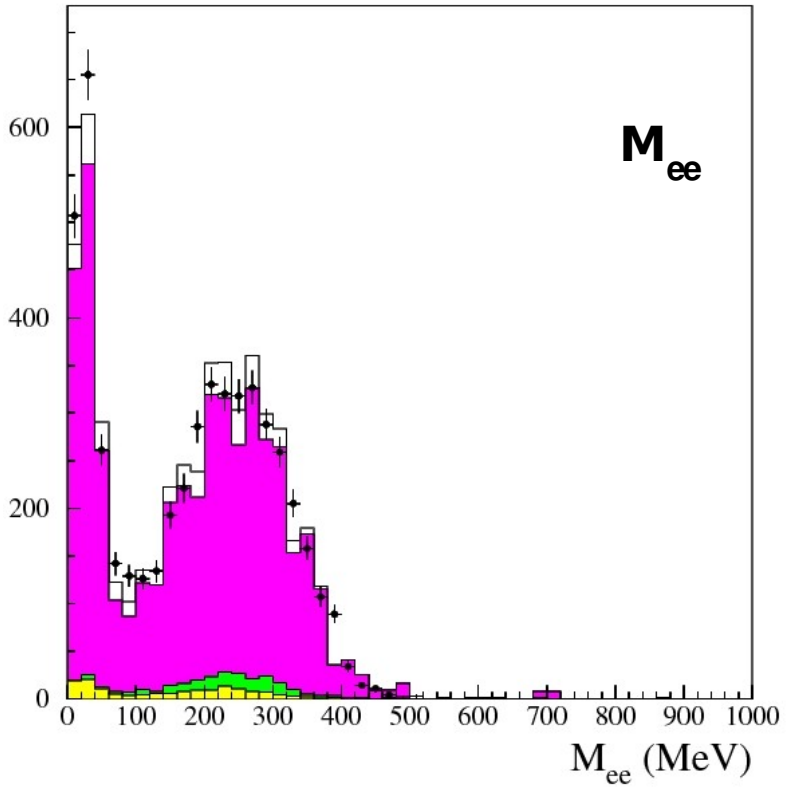
$$\frac{\Gamma(\eta'\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)}$$

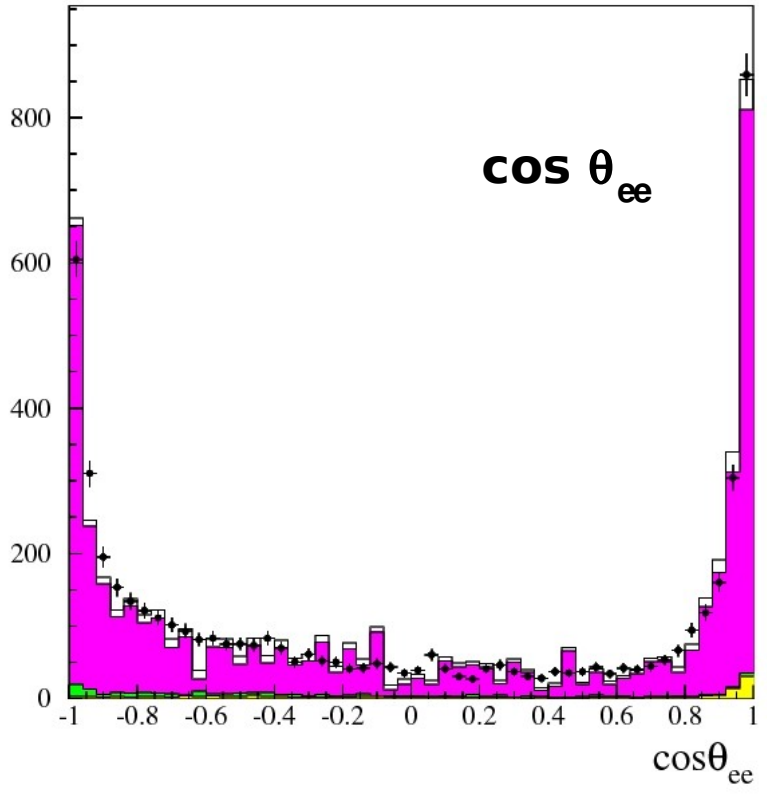
This measurement was not used in Escribano-Nadal fit

Experiment - MC comparison









Data
MC signal
Cont. bkg
ϕ bkg