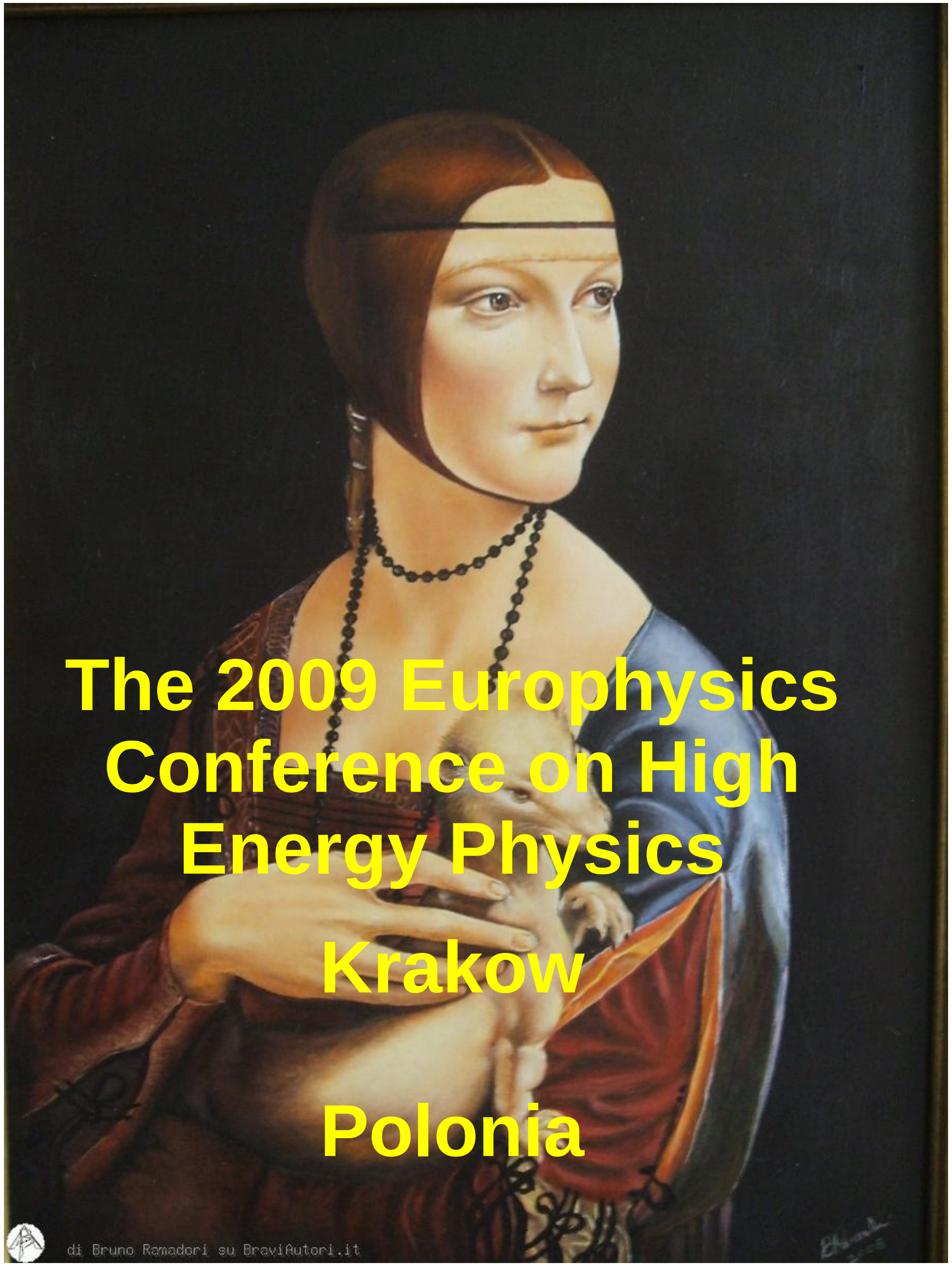
KLOE results on light meson properties

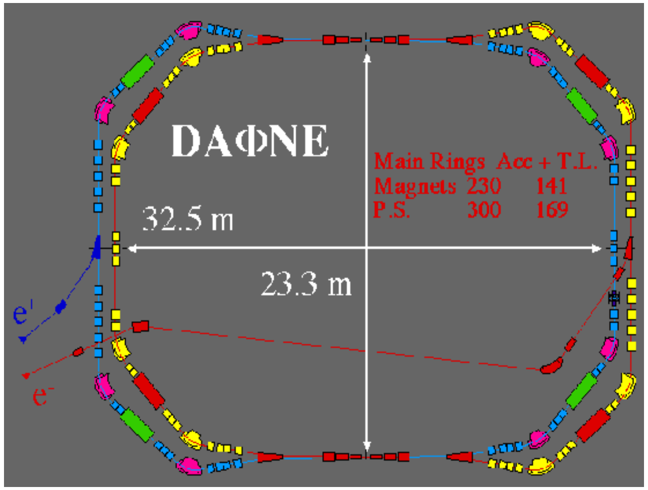
Biagio Di Micco
Istituto Nazionale di Fisica Nucleare sez. Roma Tre

on the behalf of the KLOE collaboration



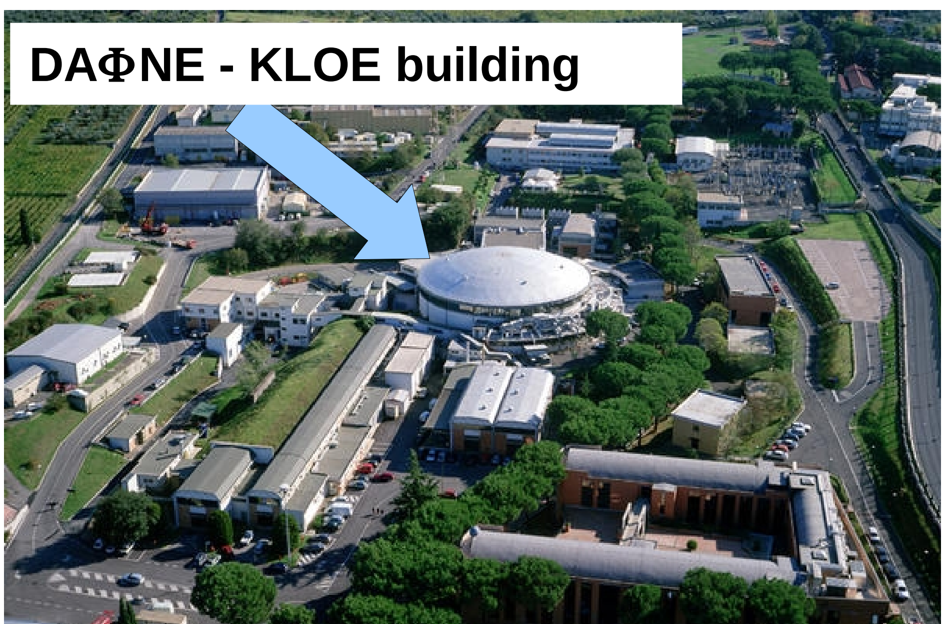
DAΦNE and KLOE

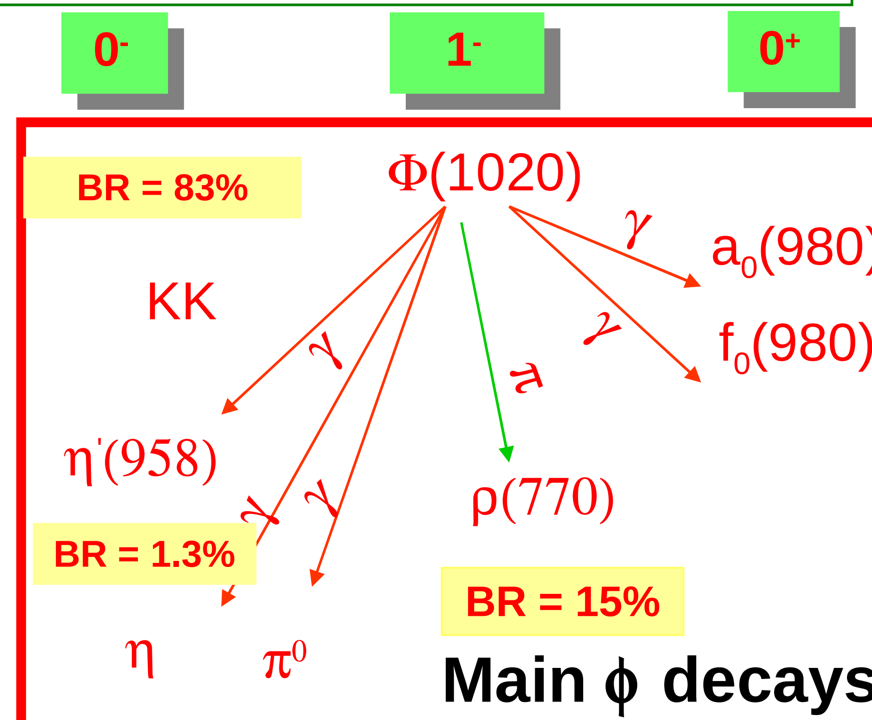
Collected luminosity (2.5 fb^{-1})



High luminosity e^+e^- collider

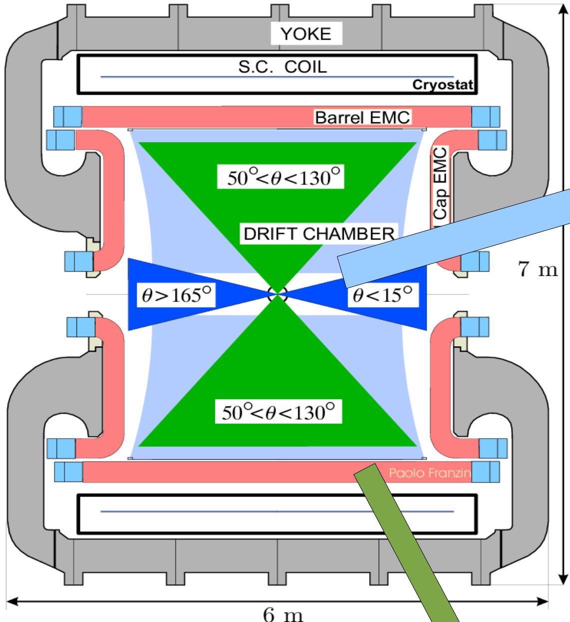
- $\sigma(e^+e^- \to \phi) \sim 3\ \mu\beta$ $\sqrt{s} = m(\phi) = 1\,019.4\,MeV$
- Independent e^+e^- rings to reduce beam-beam interactions
- crossing angle: 25 mrad, $p_x(\phi)$ ~12.6 MeV/c
- Bunch crossing every 2.7 ns
- injection during acquisition

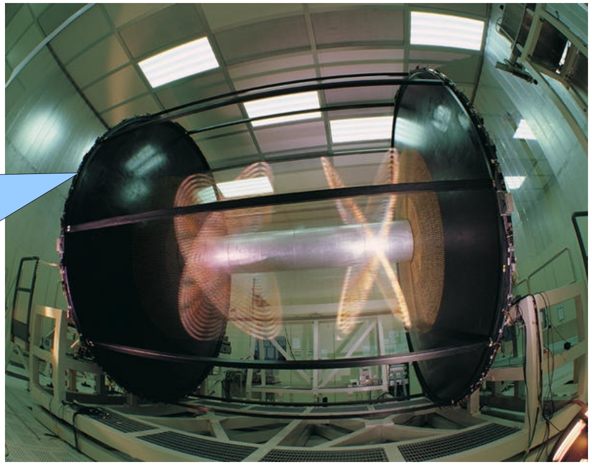




The KLOE Detector

Detector scheme





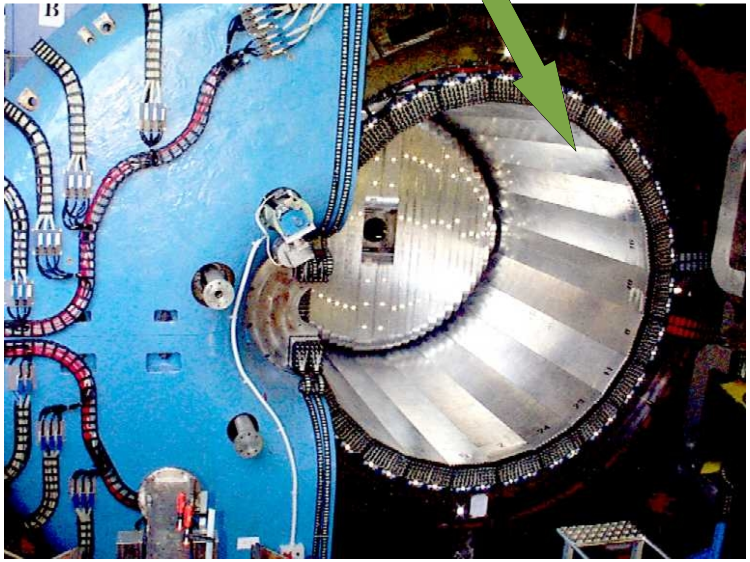
Cylindrical Drift Chamber

Stereo wires structure to reconstruct longitudinal position

52140 wires – 12582 drift cell
90% He 10% iC_4H_{10}
0.5 T Magnetic field

$\sigma_v = 1$ mm $\quad \sigma_{pt}/p_t = 0.5\%$

$\sigma_{r,\phi} = 200\ \mu$m $\quad \sigma_z = 2$ mm



Electromagnetic calorimeter

- 1 barrel + 2 end-caps
- 98% solid angle coverage
- Fine sampling Pb / Scintillating Fibers
- Hermetical coverage
- High efficiency for low energy photons
- two side PM read out, longitudinal position from arrival time

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

$$\sigma_t = 54\text{ps}/\sqrt{E(\text{GeV})} \oplus 140\text{ ps}$$

Outline

- ϕ decays to scalars, the a_0 parameters, the scalar structure and the instanton model;
- Search for $\phi \to (f_0 + a_0)\gamma \to \overline{K}^0 K^0 \gamma \to K_S K_S \gamma$
- Measurement of the $e^+e^- \to \omega\pi^0$ cross section and determination of the $Br(\omega \to \pi^0\gamma)$
- The determination of the η' gluonium content;
- Measurement of the $Br(\eta \to \pi^+\pi^- e^+ e^- (\gamma))$ and looking for unconventional CP violation in the decay.

Still open questions on the nature of the light scalars:

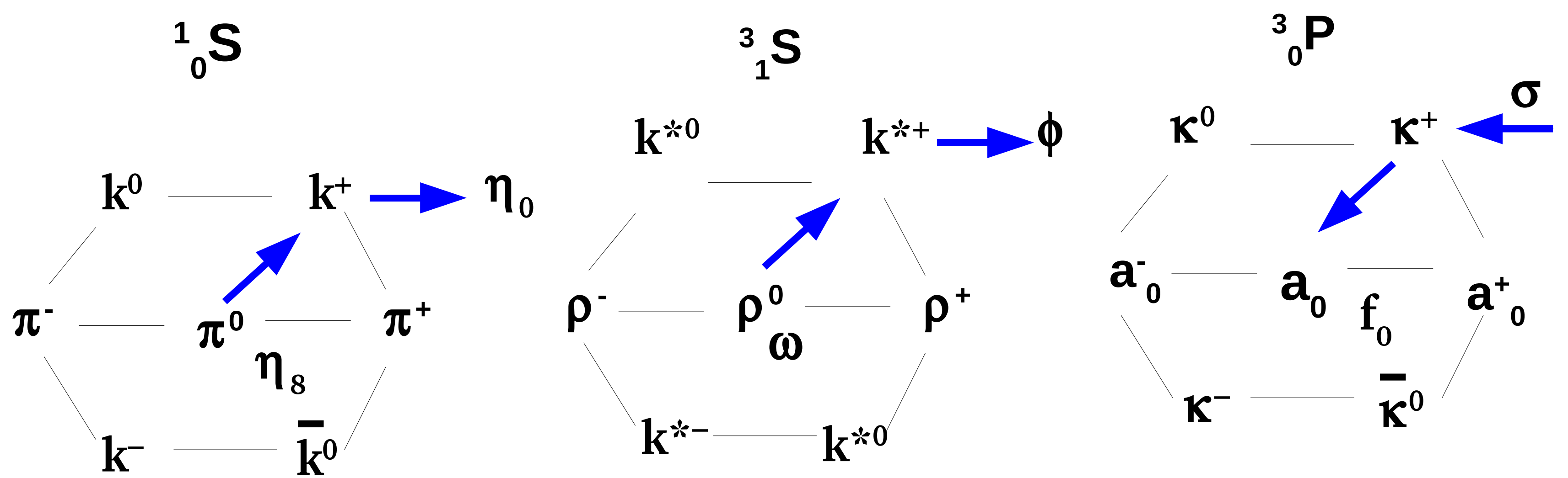
a_0 f_0 σ κ

The natural answer (2 quarks states in ^3_0P configuration) cannot explain the inverted hierarchy.

Increasing mass arrow

$q\bar{q}$

nonets



Why scalars show an inverted mass spectrum respect to the pseudoscalar and vector partners?

Natural explanation in the 4q hypothesys Jaffe

f_0 a_0 ssdd ssuu σ uudd

Scalar study in ϕ decays

Scalars nature can be studied with the ϕ decays

$e^+e^- \to \phi \to (f_0 + \sigma)\gamma \to \pi^0\pi^0\gamma,\ \pi^+\pi^-\gamma$

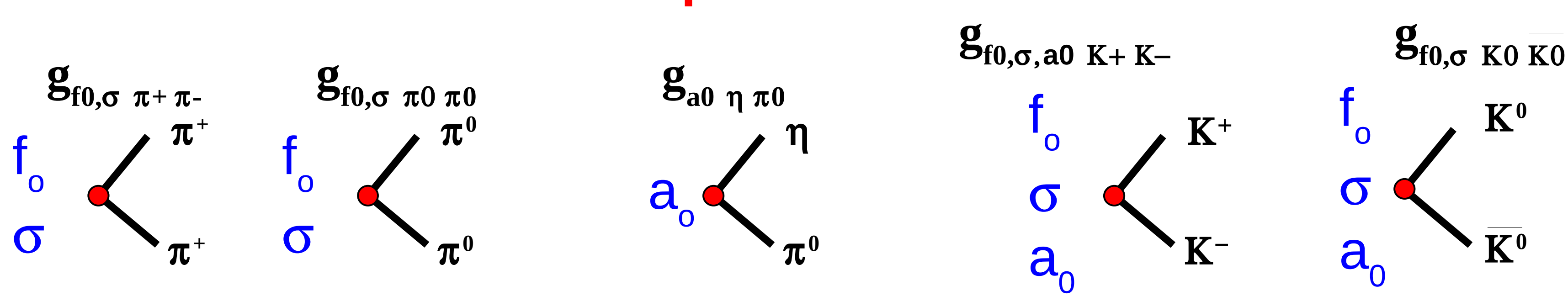
Eur. Phys. J. C49 (2007) 473
Phys. Lett. B 634 (2006) 148

$e^+e^- \to \phi \to a_0\gamma \to \eta\pi^0\gamma$

Sensitive to the scalar structure

$e^+e^- \to \phi \to (a_0 + f_0)\gamma \to K^0\bar{K}^0\gamma \to K_sK_s\gamma$ Sensitive to the a_0-f_0 interference.

The couplings to the pseudoscalar mesons ($\pi\pi$, K^+K^-, $\eta\pi$) are sensitive to the quark structure.

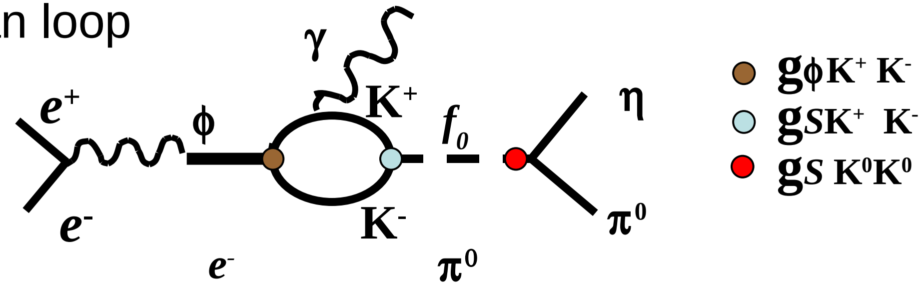


Isospin symmetry: $g_{f0,\sigma\ \pi+\pi-} = 2\, g_{f0,\sigma\ \pi0\ \pi0}$

$M_{\eta\pi 0}$ fit to $\eta\pi^0\gamma$ events at KLOE

Submitted to PLB
arXiv:0904.2539

Koan loop



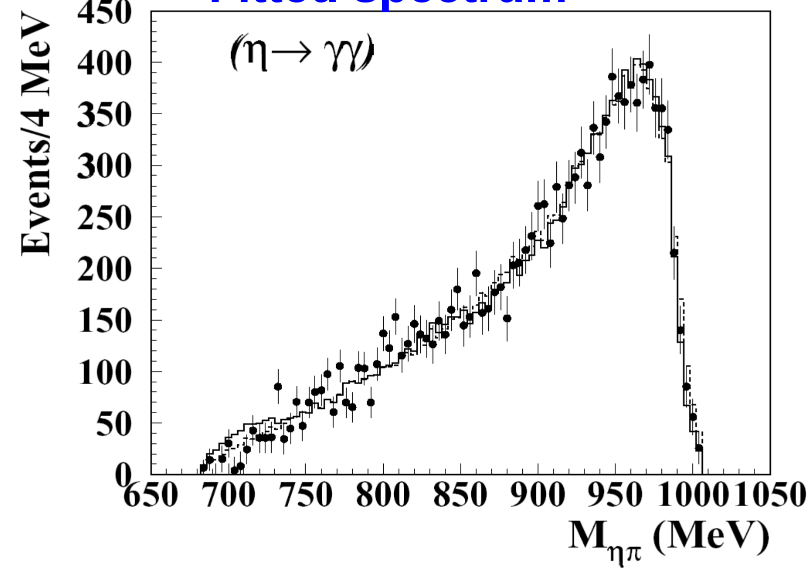
e^- π^0

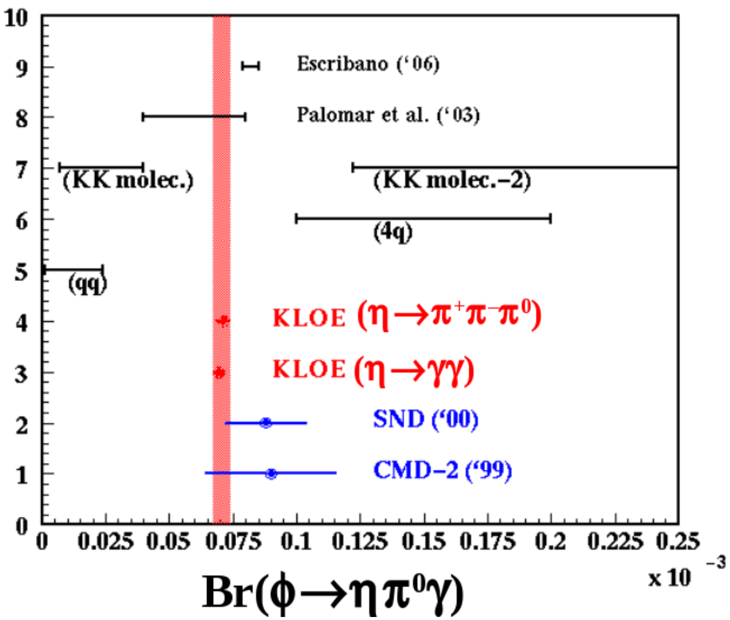
extraction of Br($\phi \to \eta\pi^0\gamma$)
from event counting (model independent).

$\eta\to\gamma\gamma$ – $Br(\phi\to\eta\pi^0\gamma) = (7.01 \pm 0.10_{stat} \pm 0.20_{syst}) \times 10^{-5}$

$\eta\to\pi^+\pi^-\pi^0$ – $Br(\phi\to\eta\pi^0\gamma) = (7.12 \pm 0.13_{stat} \pm 0.22_{syst}) \times 10^{-5}$

Fitted spectrum





M_{a0}	$982.5 \pm 1.6 \pm 1.1$ MeV	$g_{a0\eta\pi}$	$2.82 \pm 0.03 \pm 0.04$ GeV
$Br(\phi\to\rho\pi\to\eta\gamma\pi)$	$(0.92 \pm 0.40 \pm 0.15)\times 10^{-6}$		
$\delta(\phi\to\rho\pi\to\eta\gamma\pi)$	$(222 \pm 13 \pm 3)^\circ$	g_{a0K+K-}	$2.15 \pm 0.06 \pm 0.06$ GeV

qq: Achasov-Ivanchenko NPB315(1989)
Close et al., NPB389(1993)
4q: Achasov-Ivanchenko NPB315(1989)
KK molec.: Close et al., NPB389(1993)
Achasov et al., PRD56(1997)
KK molec.-2: Kalashnikova et al., EPJA24(2005)
Palomar et al., NPA729(2003): UχPT
Escribano, PRD74(2006): Linear σ model

Scalar couplings to pseudoscalars 2q versus 4q

Couplings compatible with a 2 quarks hypothesys with $f_0 = s\bar{s}$

4q cannot fit the small value of g_{a0KK}.

	KLOE	SU(3)		
		4q	$q\bar{q}$	
$(g_{aK^+K^-}/g_{a\eta\pi})^2$	0.6 – 0.7	1.2 – 1.7	0.4 q (u,d)	
$(g_{f0K^+K^-}/g_{f0\pi^+\pi^-})^2$	4.6 – 4.8	>>1	>>1 ($f_0=s\bar{s}$)	1/4 ($f_0=q\bar{q}$)
$(g_{f0K^+K^-}/g_{aK^+K^-})^2$	4 - 5	1	2 ($f_0=s\bar{s}$)	1 ($f_0=q\bar{q}$)

Scalar couplings to pseudoscalars 2q versus 4q

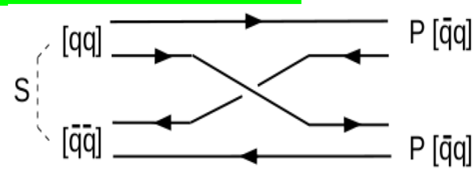
Couplings compatible with a 2 quarks hypothesys with $f_0 = s\bar{s}$

4q cannot fit the small value of g_{a0KK}.

	KLOE	SU(3)		
		4q	$q\bar{q}$	
$(g_{aK^+K^-}/g_{a\eta\pi})^2$	0.6 – 0.7	1.2 – 1.7	0.4 q (u,d)	
$(g_{f0K^+K^-}/g_{f0\pi^+\pi^-})^2$	4.6 – 4.8	>>1	>>1 ($f_0=s\bar{s}$)	1/4 ($f_0=q\bar{q}$)
$(g_{f0K^+K^-}/g_{aK^+K^-})^2$	4 - 5	1	2 ($f_0=s\bar{s}$)	1 ($f_0=q\bar{q}$)

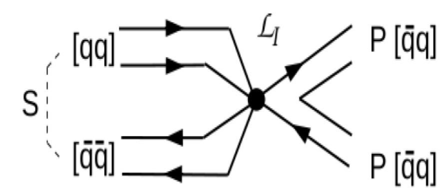
New model from T'Hooft, Isidori, Maiani, Polosa and Riquer (Phys. Lett. B662 (2008) 424

Standard interaction (quark exchange)



Interference allows small a0KK coupling

Instanton interaction



allows $f_0 \to \pi\pi$

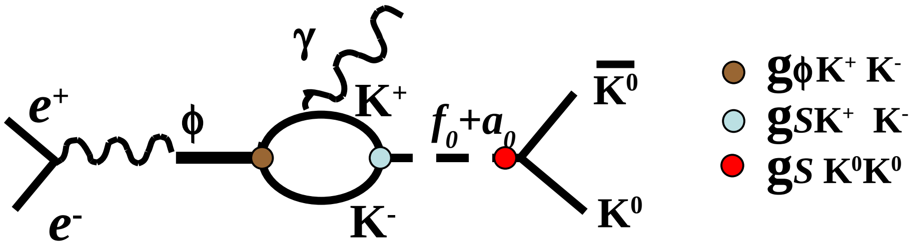
inputs: g_{f0KK}, $g_{f0\pi\pi}$, m_{f0}, m_{a0}, ψ_P

outputs: g_{a0KK}, $g_{a0\eta\pi}$

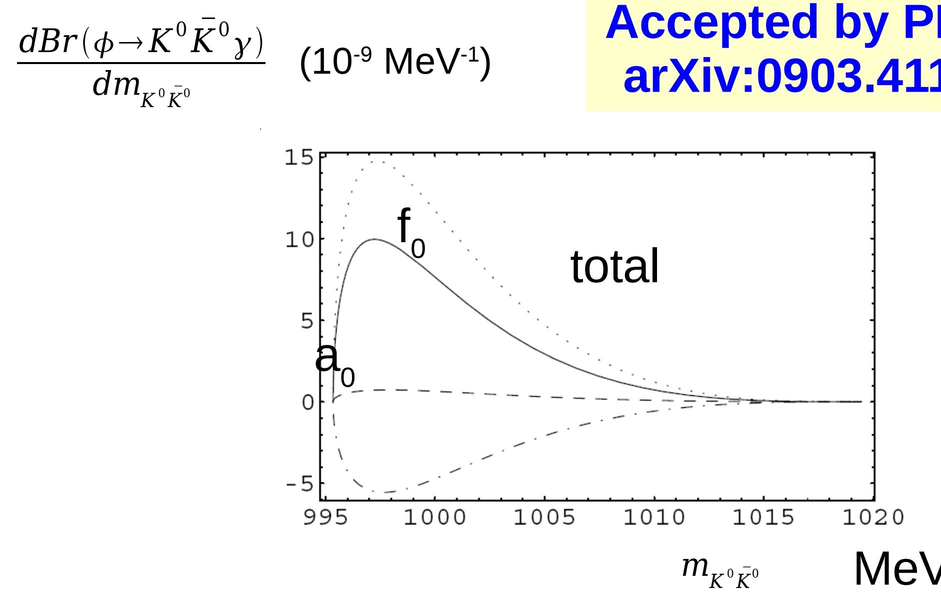
	KLOE (KL)		$[qq][\bar{q}\bar{q}]$	$q\bar{q}$
$g_{f0K^+K^-}$ (GeV)	3.97 — 4.74	}	c_I = - 2.8 — - 3.4 GeV $^{-1}$	c_I = - 3.9 — - 4.8 GeV $^{-1}$
$g_{f0\pi^+\pi^-}$ (GeV)	-1.82 — -2.23		c_f = 20.5 — 24.5 GeV $^{-1}$	c_f = 16.5 — 19.7 GeV $^{-1}$
			⇓	⇓
$g_{a0K^+K^-}$ (GeV)	2.01 — 2.15		2.1 — 2.5	2.4 — 2.9
$g_{a0\eta\pi}$ (GeV)	2.46 — 2.82		3.3 — 3.9	6.6 — 7.9

very good agreement in the 4 quarks hypothesis

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



Accepted by PLB
arXiv:0903.4115



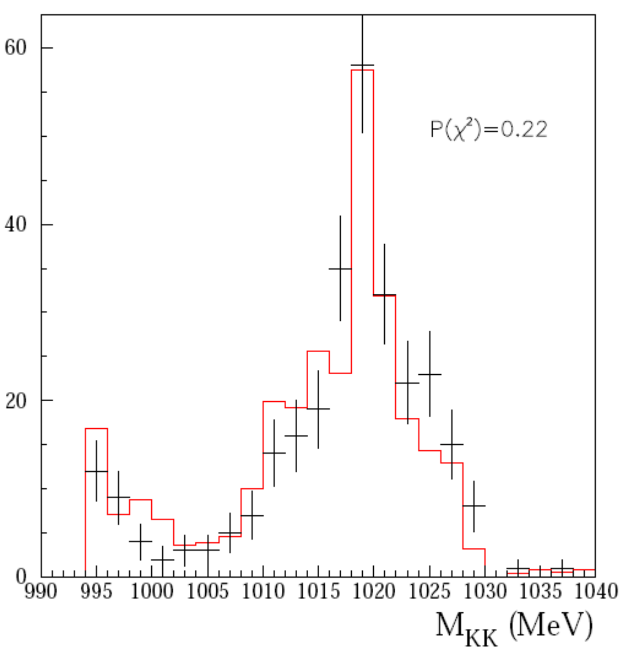
Isospin symmetry relates the couplings

$g\, f_0\pi^+\pi^- = 2\, g\, f_0\pi^0\pi^0$

$g\, f_0 K^0 K^0 = g\, f_0 K^+ K^-$

$g\, a_0 K^0 K^0 = -g\, a_0 K^+ K^-$

strong destructive interference between a_0 and f_0 is expected in the KK channel



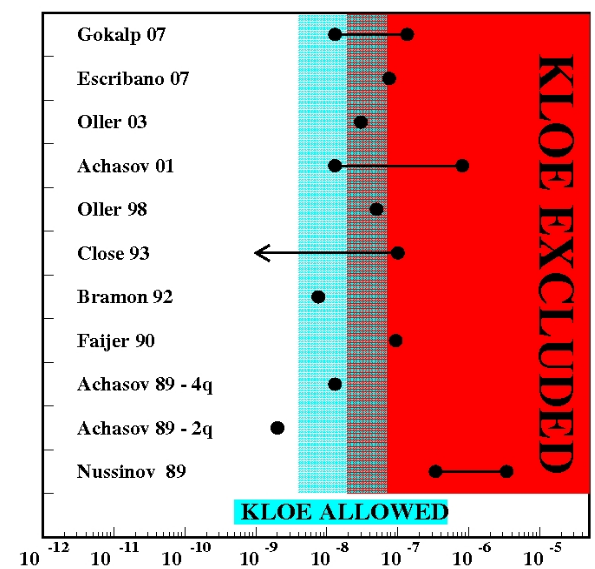
Dataset: 2.2 fb^{-1}

5 events in data (ε = 24%)

3.2 ± 0.7 exp. background

First experimental result

BR($\phi \to \bar{K}^0 K^0 \gamma$) < 1.9 × 10^{-8} 90% C.L.



$\sigma(e^+e^- \to \omega\pi^0)$

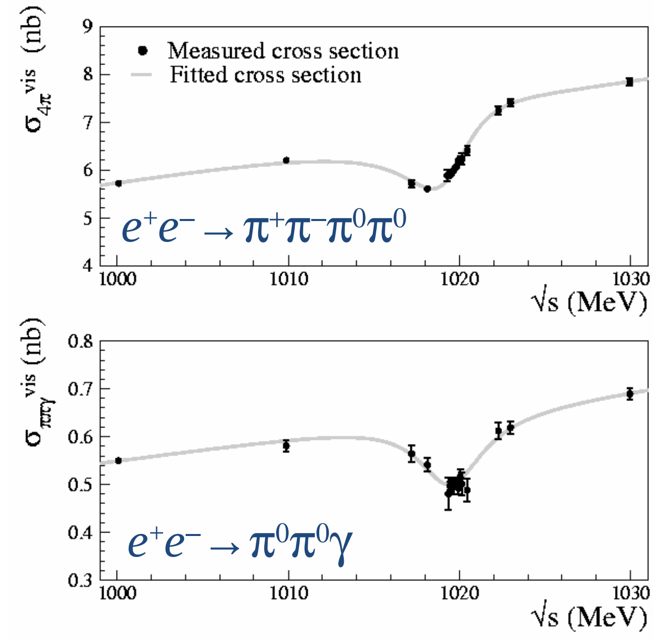
Interference pattern between non-resonant $e^+e^- \to \omega\pi^0$ and ϕ decays:

$$\sigma(\sqrt{s}) = \sigma_0(\sqrt{s}) \cdot \left| 1 - Z \frac{M_\phi \Gamma_\phi}{D_\phi} \right|^2$$

model independent $\Rightarrow$ $\sigma_0(\sqrt{s}) = \sigma_0 + \sigma'(\sqrt{s} - M_\phi)$

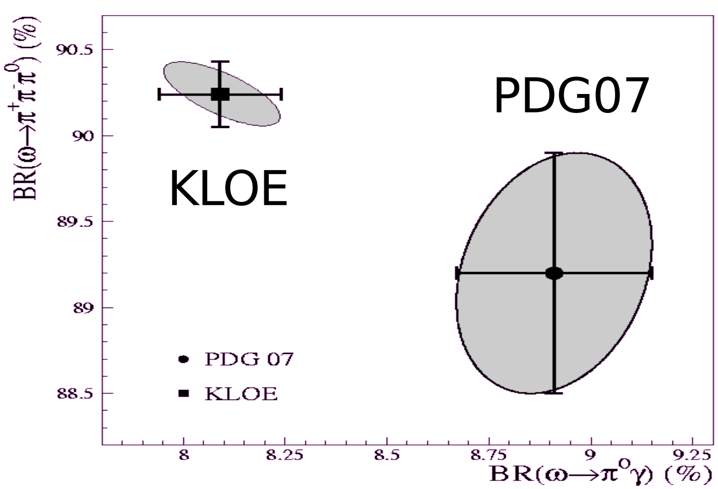
$\Gamma(\omega \to \pi^0\gamma)/\Gamma(\omega \to \pi^+\pi^-\pi^0)$ & assuming

$\Sigma_i \, Br_i = 1$ $Br(\omega \to \pi^+\pi^-)$ from PDG average



$BR(\omega \to \pi^+\pi^-\pi^0) = (90.24 \pm 0.19)\%$

$BR(\omega \to \pi^0\gamma) = (8.09 \pm 0.14)\%$



OZI + G-parity violating

$$BR(\phi \to \omega\pi^0) = \frac{\sigma_0^{\omega\pi} |Z_{4\pi}|^2}{\sigma_\phi} = (5.63 \pm 0.70) \times 10^{-5}$$

$$\text{SND(2000)}: BR(\phi \to \omega\pi^0) = (5.2^{+1.3}_{-1.1}) \times 10^{-5}$$

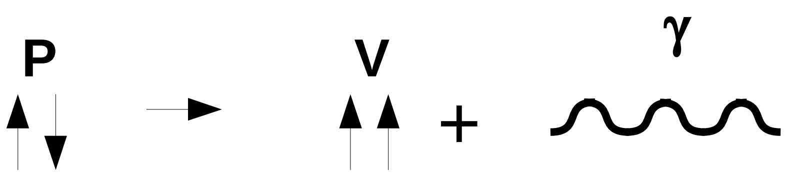
η, η': mixing and gluonium

The η,η ' mesons wave function can be decomposed in the quark mixing base as in the folowing (J. L. Rosner, Phys. Rev. D 27 (1983) 1101.).

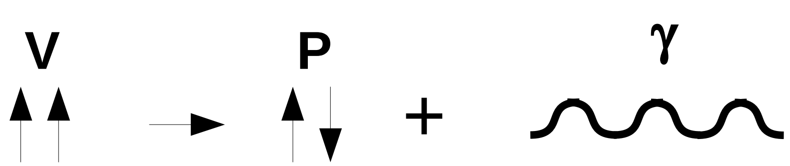
$$|\eta'\rangle = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|G\rangle \qquad |\eta\rangle = \cos\psi_P|q\bar{q}\rangle - \sin\psi_P|s\bar{s}\rangle \qquad |q\bar{q}\rangle = \frac{|u\bar{u}\rangle + |d\bar{d}\rangle}{\sqrt{2}}$$

$$X_{\eta'} = \sin\psi_P \cos\psi_G$$
$$Y_{\eta'} = \cos\psi_P \cos\psi_G$$
$$Z_{\eta'} = \sin\psi_G$$

The ϕ → η,η' γ transition is modelled according a spin flip transition



$$\Gamma(P \to V\gamma) = \frac{g^2}{4\pi}|p_\gamma|^3$$



$$\Gamma(V \to P\gamma) = \frac{1}{3}\frac{g^2}{4\pi}|p_\gamma|^3$$

Only quarks participate to the electromagnetic transition, gluonium is spectator.
It appears in the η' decay amplitudes only through the normalisation to 1 ($Y_{\eta'} \sim \cos\psi_G$)

KLOE past fit

KLOE [Phys. Lett. B648 (2007) 267] has fitted:

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

$$\frac{\Gamma(\eta'\to\omega\gamma)}{\Gamma(\omega\to\pi^0\gamma)}=\frac{1}{3}\left(\frac{m_{\eta'}^2-m_\omega^2}{m_\omega^2-m_\pi^2}\frac{m_\omega}{m_{\eta'}}\right)^3\left[z_q X_{\eta'}+2\frac{m_s}{\bar{m}}z_s\cdot\tan\psi_V\cdot Y_{\eta'}\right]^2$$

taken from a global fit without gluonium

A. Bramon, R. Escribano, M.D. Scadron
Phys. Lett. B503 (2001) 271

Using KLOE measured branching ratio:

$$R_\phi=\frac{Br(\phi\to\eta'\gamma)}{Br(\phi\to\eta\gamma)}=\cot^2\psi_P\cdot\cos^2\psi_G\left(1-\frac{m_s}{\bar{m}}\frac{z_q}{z_S}\cdot\frac{\tan\psi_V}{\sin 2\psi_P}\right)^2\cdot\left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

$R_\phi = (4.77 \pm 0.09 \pm 0.19)\times 10^{-3}$

$\phi\to\eta'\gamma$

$\eta'\to\pi^+\pi^-\eta$, $\eta\to3\pi^0$

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

$\phi\to\eta\gamma$, $\eta\to3\pi^0$

and the ratio:

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

E. Kou, Phys. Rev. D 63 (2001) 54027

KLOE new fit

Accepted by JHEP
arXiv:0906.3819

New global fit with more free parameters: Z_N, Z_{NS}, ψ_V, m_s/m

Other input are needed $\frac{\Gamma(\omega\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)}, \frac{\Gamma(\rho\to\pi^0\gamma)}{\Gamma(\omega\to\pi^0\gamma)}, \frac{\Gamma(\phi\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)}, \frac{\Gamma(\phi\to\pi^0\gamma)}{\Gamma(\omega\to\pi^0\gamma)}, \frac{\Gamma(K^{*+}\to K^+\gamma)}{\Gamma(K^{*0}\to K^0\gamma)}$

From PDG06

				R.Escribano, J. Nadal
Parameter	**KLOE published**	**KLOE New fit**	**K. New fit (no Pγγ)**	**JHEP 05 (2007) 6**
$Z^2_{\eta'}$	0.14 ± 0.04	0.105 ± 0.037	**0.03 ± 0.06**	**0.04 ± 0.09**
ψ_P	(39.7 ± 0.7)°	(40.7 ± 0.7)°	**(41.6 ± 0.8)°**	**(41.4 ± 1.3)°**
Z_{NS}	0.91 ± 0.05	0.866 ± 0.025	**0.85 ± 0.03**	**0.86 ± 0.03**
Z_S	0.89 ± 0.07	0.79 ± 0.05	**0.78 ± 0.05**	**0.79 ± 0.05**
ψ_V	3.2°	(3.15 ± 0.10)°	**(3.16 ± 0.10)°**	**(3.2 ± 0.1)°**
m_s/m	1.24 ± 0.07	1.24 ± 0.07	**1.24 ± 0.07**	**1.24 ± 0.07**
$P(\chi^2)$	49%	17%	**41%**	**38%**

Gluonium content @ ~3σ level confirmed ($Z_{\eta'}$ = 0: ψ_P = (41.6±0.5)°, $P(\chi^2)$=1%)

η'→γγ is the only measurement sensitive to the gluonium

USING PDG-08 and KLOE $\omega\to\pi^0\gamma$

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

exact isospin symmetry limit

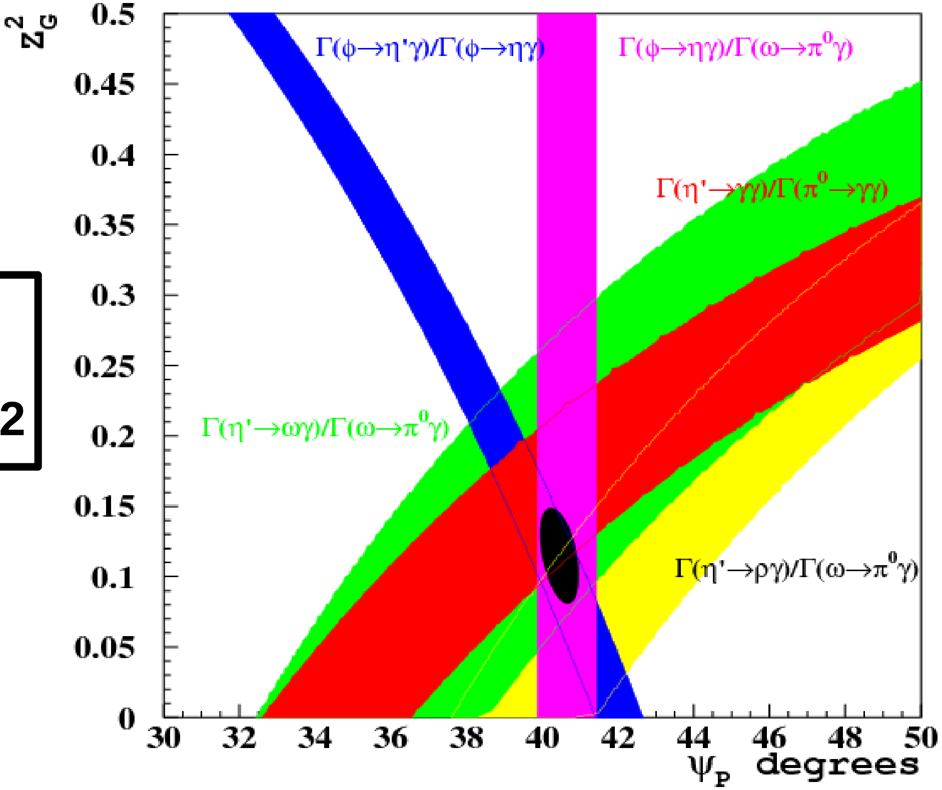
$$f_q/f_\pi=1 \qquad f_s/f_\pi=\sqrt{2f_K^2/f_\pi^2-1}$$

f_K/f_π	from lattice (UKQCD) **E.Follana *et a l.*** **Phys. Rev. Lett. 100 (2008) 062002**

χ^2/ndof = 4.6/3

P(χ^2) = 20%

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



Z_G can be interpreted as a mixing with a glue ball. The mass of this glue ball has been determined using KLOE fit [Hai-Yang Cheng, Phys. Rev. D79 (2009) 014024]

m_G = (1.41 ± 0.1) GeV

The glue-ball is identified as η(1405)

$\eta \to \pi^+\pi^- e^+ e^- (\gamma)$

- Poorly measured (4 events CMD-2, 16 events CELSIUS-WASA)
- Br predicted by ChPT and VMD models $(26 \div 36) \cdot 10^{-5}$
- η structure using virtual photon

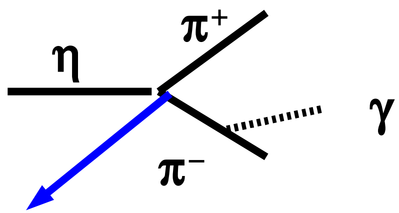
D. N. Gao, Mod. Phys. Lett. A17(2002) 1583

CP violation source not constrained by CKM measurements and neutron elecrìtrc dipole moment

$$\mathcal{O} = \frac{1}{m_\eta^3} G\bar{s}i\sigma_{\mu\nu}\gamma_5(p-q)^\nu s\bar{\psi}\gamma^\mu\psi$$

} asymmetry in the particle decay angle

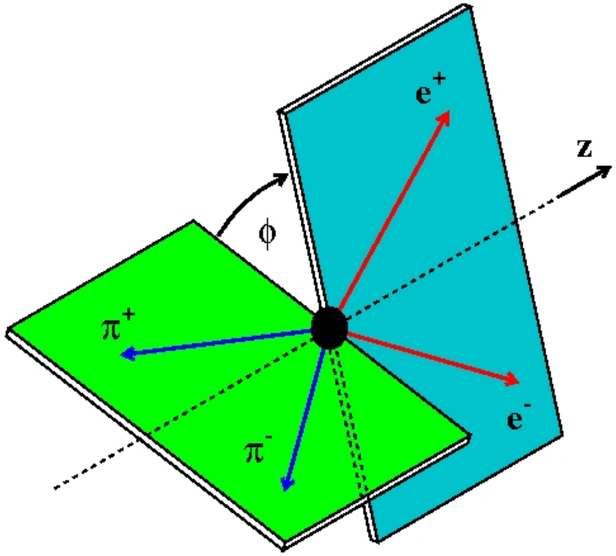
Within the SM:



$Br(\eta \to \pi^+\pi^-) < 1.3\times10^{-5}$
KLOE, Phys. Lett. B606 (2005) 276

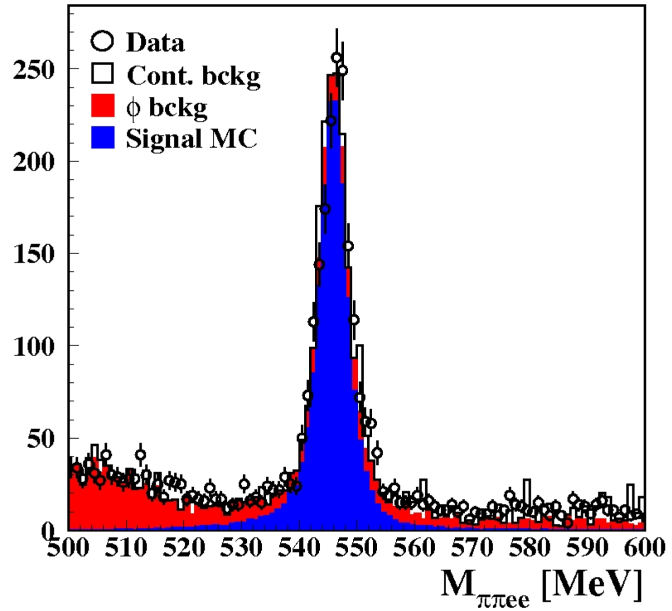
$A_\phi < 10^{-4}$ **SM** $A_\phi \sim 10^{-15}$

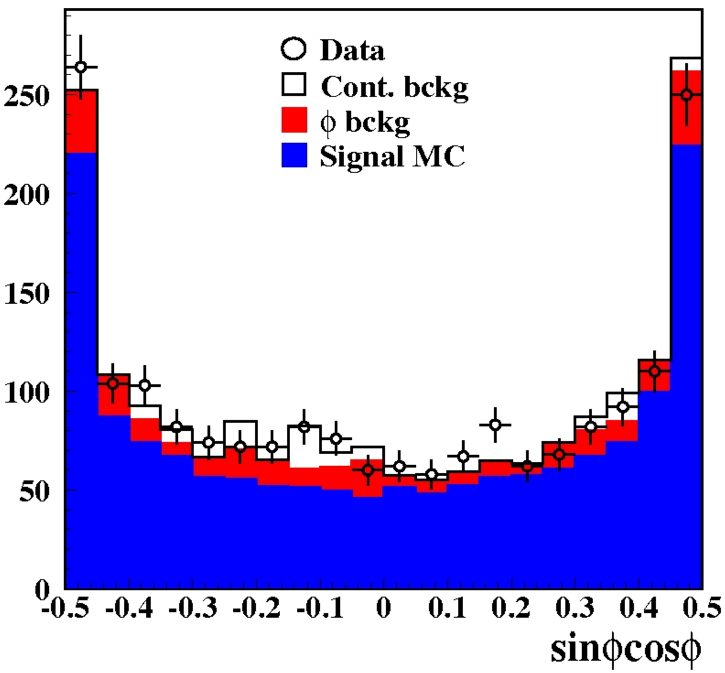
The unconventional CPV term can increase A_ϕ up to 10^{-2}



Results: BR and A_ϕ

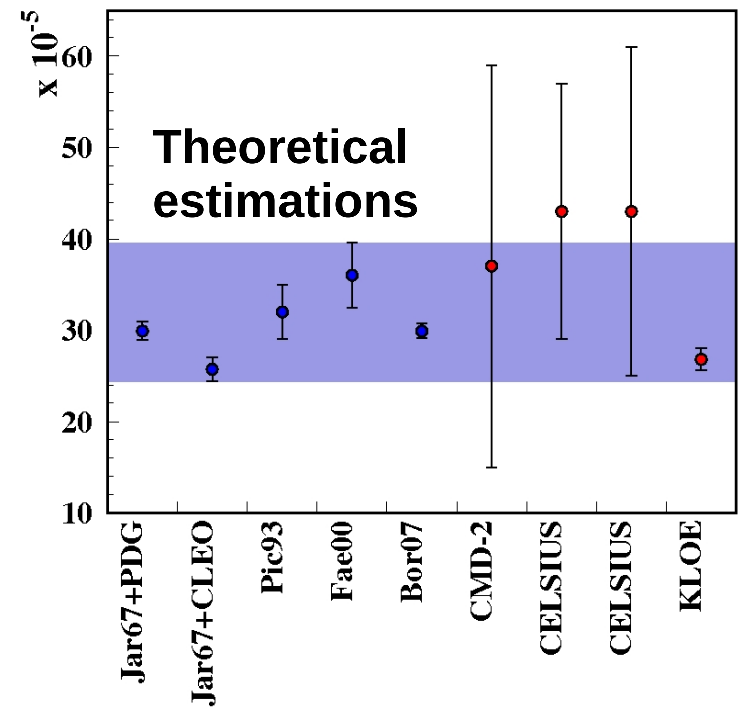
PLB 675(2009) 283





$BR(\eta \rightarrow \pi^+\pi^- e^+ e^- (\gamma))$

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



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

$|G| < 1.8$

First measurment of the CP asymmetry and attempt to constraint |G|.

Conclusion & Outlook

- New KLOE data on a_0 together with the old f_0 results nicely agree with the 4 quark hypothesis in the instanton model;

- First upper limit on $\phi \to (f_0 + a_0)\gamma \to K^0 K^0 \gamma \to K_S K_S \gamma$, sensitivity near the obsevation threshold;

- Refit of the η' gluonium content confirms the 3σ KLOE claim, the main sensitive measurement has been identified with the $\eta' \to \gamma\gamma$;

- Precise measurement of the $\eta \to \pi^+ \pi^- e^+ e^- (\gamma)$ branching ratio and first measurement of the CP violating asymmetry.

OUTLOOK: see next talk of P. Gauzzi