Analysis of the gluonium content in η'

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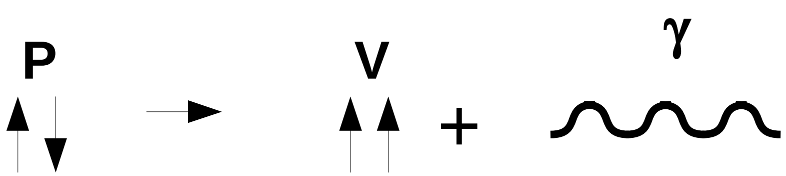
η, η': mixing and gluonium

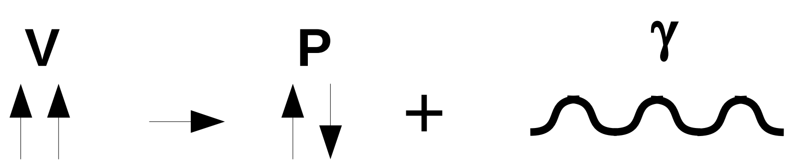
The η,η' mesons wave function can be decomposed in the quark mixing base as in the folowing (J. L. Rosner, Phys. Rev. D 27 (1983) 1101.).

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

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

The $\phi \to \eta,\eta'\gamma$ 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 ($Y_{\eta'} \sim \cos\varphi_G$)

On the meaning of gluonium

$Z_{\eta'}$ can be interpreted as a mixing with a glue ball. The mass of this glue ball has been determined
[Hai-Yang Cheng, Phys. Rev. D79 (2009) 014024]

θ_i = 54.7° **$\phi \to \psi_P$** **$\phi_G \to \psi_G$**

$$\frac{c\theta(s\phi - c\theta s\theta_i \Delta_G) m^2_{\eta'} - s\theta(c\phi + s\theta s\theta_i \Delta_G)^2 m^2_\eta - s\theta_i c\phi_G m^2_G}{c\theta(c\phi - c\theta c\theta_i \Delta_G) m^2_{\eta'} + s\theta(s\phi - s\theta c\theta_i \Delta_G)^2 m^2_\eta - c\theta_i c\phi_G m^2_G} = \frac{\sqrt{2} f_s}{f_q},$$

m_G = (1.41 ± 0.1) GeV

The glue-ball is identified as η(1405) copiously produced in $J/\psi \to \eta(1405)\gamma$

Prediction Br(η(1405) $\to \gamma\gamma$) = $6 \pm 1 \times 10^{-5}$
Decay never observed

V P γ and Pγγ transitions

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

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

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

together with the measured branching ratio: $\phi\to\eta'\gamma$

$\eta'\to\pi^+\pi^-\eta$, $\eta\to 3\pi^0$

$R_\phi = (4.77 \pm 0.09 \pm 0.19)\times 10^{-3}$ ~ 4000

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

~ 1.7×10^6 $\phi\to\eta\gamma$, $\eta\to 3\pi^0$

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

and the ratio:

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

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

V P γ and Pγγ transitions

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

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

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

Were taken from a global fit without gluonium:

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

together with the measured branching ratio: $\phi\to\eta'\gamma$

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

~ 4000 $\eta' \to \pi^+\pi^-\eta$, $\eta\to 3\pi^0$; $\eta' \to \pi^0\pi^0\eta$, $\eta \to \pi^+\pi^-\pi^0$

~ 1.7×10^6 $\phi\to\eta\gamma$, $\eta \to 3\pi^0$

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

and the ratio:

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

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

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

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

T. Feldmann, Int. J. Mod. Phys. A 15 (2000) 159

together with the measured branching ratio: $\phi\to\eta'\gamma$

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

~ 4000 $\eta'\to\pi^+\pi^-\eta$, $\eta\to 3\pi^0$; $\eta'\to\pi^0\pi^0\eta$, $\eta\to\pi^+\pi^-\pi^0$

~ 1.7× 10^6 $\phi\to\eta\gamma$, $\eta\to 3\pi^0$

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

and the ratio:

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

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

New fit trying to handle all the free parameters

1) Leave the z's parameter free;
2) Add more constraints (needed to perform the fit with larger number of parameters);
3) Check the contribution from $\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$

$$\frac{\Gamma(\omega\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)}=\frac{1}{9}\left[z_q\cos(\psi_p)-2\frac{m_s}{\bar{m}}z_s\tan(\psi_V)\sin(\psi_p)\right]^2(1-z_G^2)\left(\frac{m_\omega^2-m_\eta^2}{m_\omega^2-m_{\pi^0}^2}\right)^3$$

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

$$\frac{\Gamma(\phi\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)}=\frac{1}{9}\left[z_q\tan(\psi_V)\cos(\psi_P)+2\frac{\bar{m}}{m_s}z_s\sin(\psi_P)\right]^2\left(\frac{m_\phi^2-m_\eta^2}{m_\omega^2-m_\pi^2}\frac{m_\omega}{m_\phi}\right)^3$$

$$\frac{\Gamma(\phi\to\pi^0\gamma)}{\Gamma(\omega\to\pi^0\gamma)}=\tan^2\psi_V\cdot\left(\frac{m_\phi^2-m_{\pi^0}^2}{m_\omega^2-m_{\pi^0}^2}\cdot\frac{m_\omega}{m_\phi}\right)^3,\ \frac{\Gamma(K^{+*}\to K^+\gamma)}{\Gamma(K^{*0}\to K^0\gamma)}=\left(\frac{2\frac{m_s}{\bar{m}}-1}{1+\frac{m_s}{\bar{m}}}\right)^2\cdot\left(\frac{m_{K^{*+}}^2-m_{K^{+0}}^2}{m_{K^{*0}}^2-m_{K^0}^2}\cdot\frac{m_{K^{*0}}}{m_{K^{*+}}}\right)^3$$

Fit procedure.

The χ^2 is defined as follows:

$$\chi^2 = \Sigma_{i,j=1,3} \left(y_i - y_i^{th}\right) \times V_{ij}^{-1} \left(y_j - y_j^{th}\right)$$

$$V_{ij} = [B_{ij} + (A_{ik} \times C_{kl} \times A_{lj}^T)]$$

Experimental covariance matrix

Theoretical parameters covariance matrix

B_{ij} = **Full covariance matrix (correlation comes from the constrained fit to η' Br)**

$$A_{ik} = \begin{pmatrix} \frac{\partial y_1^{th}}{\partial f_q} & \frac{\partial y_1^{th}}{\partial f_s} \\ \frac{\partial y_2^{th}}{\partial f_q} & \frac{\partial y_2^{th}}{\partial f_s} \\ \dots & \dots \end{pmatrix}$$

Re-evaluated at each minimization step

$$C_{kl} = \begin{pmatrix} \sigma_{f_q}^2 & 0 \\ 0 & \sigma_{f_s}^2 \end{pmatrix}$$

The experimental covariance matrix B contains correlation among common used quantities in the fitted relations:

$$\frac{\Gamma(\omega\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)},\frac{\Gamma(\rho\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)},\frac{\Gamma(\phi\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)} \longrightarrow$$

Introduces a correlation in the fitted quantities

$$\frac{\Gamma(\eta'\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)}=\frac{Br(\eta'\to\gamma\gamma)\Gamma_{\eta'}}{\Gamma(\pi^0\to\gamma\gamma)} \qquad \frac{\Gamma(\eta'\to\rho\gamma)}{\Gamma(\omega\to\pi^0\gamma)}=\frac{Br(\eta'\to\rho\gamma)\Gamma_{\eta'}}{\Gamma(\omega\to\pi^0\gamma)}$$

x_2	−34					
x_3	−78	−29				
x_4	−35	−24	32			
x_5	−26	−12	26	8		
x_6	−28	−11	35	11	9	
Γ	32	−2	−24	−5	−88	−8
	x_1	x_2	x_3	x_4	x_5	x_6

PDG-2006

$x_i = \Gamma_i/\Gamma$

	Mode	Rate (MeV)	Scale factor
Γ_1	$\pi^+\pi^-\eta$	0.090 ±0.008	1.2
Γ_2	$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	0.060 ±0.005	1.2
Γ_3	$\pi^0\pi^0\eta$	0.042 ±0.004	1.6
Γ_4	$\omega\gamma$	0.0062 ±0.0008	1.2
Γ_5	$\gamma\gamma$	0.00430±0.00015	1.1
Γ_6	$3\pi^0$	(3.2 ±0.6) $\times 10^{-4}$	1.1

Br and Γ strongly correlated (above all Γ(η'→γγ))

the Γ is measured using:

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

New preliminary measurement of the η' total width: update in this presentation.

KLOE new fit

JHEP 0907:105, 2009

USING PDG06 DATA

Parameter	KLOE published	KLOE New fit	K. New fit (no $P\gamma\gamma$)	R.Escribano, J. Nadal 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 only with $\eta' \to \gamma\gamma$

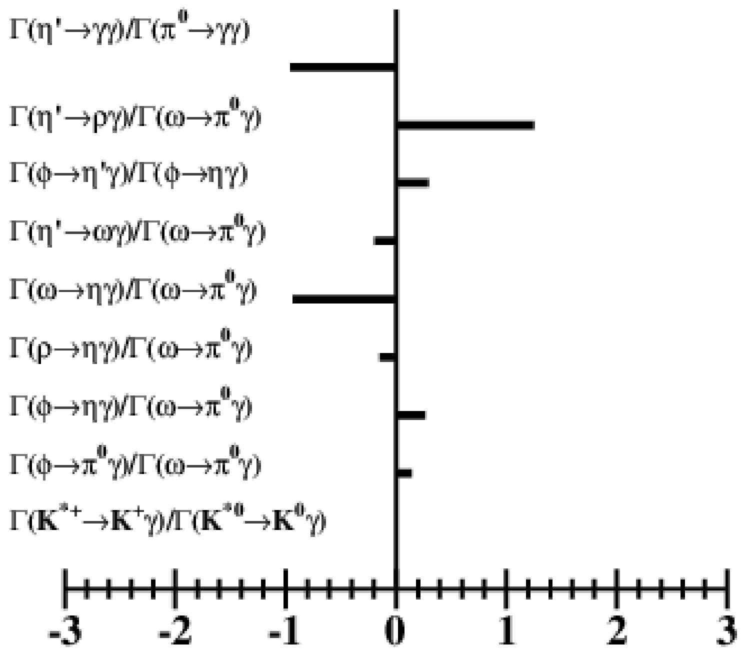
Gluonium content @ ~3σ level confirmed ($Z_{\eta'} = 0$: $\psi_P = (41.6 \pm 0.5)°$, $P(\chi^2) = 1\%$)

$\eta' \to \gamma\gamma$ is the only measurement sensitive to the gluonium

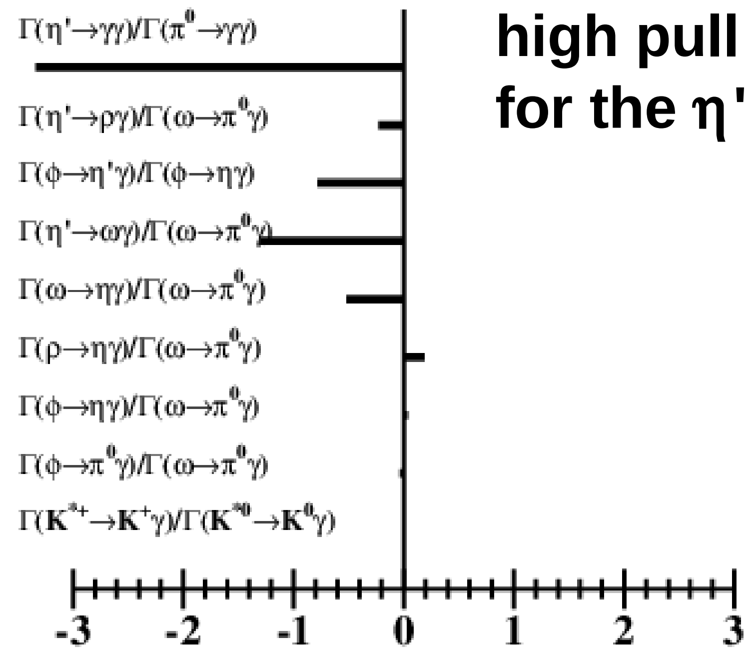
The $\eta' \rightarrow \gamma\gamma$ role.

Fit pulls

gluonium allowed



gluonium at zero



high pull only for the $\eta' \rightarrow \gamma\gamma$.

Updates...

Fit redone using:

1) **new PDG-2008 measurements;**

2) $\Gamma(\omega \to \pi^0\gamma)$ **from KLOE;**

3) **Lattice evaluation of f_K and f_π;**

4) **New preliminary measurement of the η' total width.**

Fit redone using PDG-2008.

$x_i = \Gamma_i/\Gamma$

x_2	−35					
x_3	−77	−28				
x_4	−35	−24	33			
x_5	−23	−10	23	7		
x_6	−28	−11	35	11	8	
Γ	29	−5	−21	−4	−85	−7
	x_1	x_2	x_3	x_4	x_5	x_6

	Mode	Rate (MeV)	Scale factor
Γ_1	$\pi^+\pi^-\eta$	0.091 ± 0.008	1.1
Γ_2	$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	0.060 ± 0.005	1.2
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Γ_4	$\omega\gamma$	0.0062 ± 0.0008	1.2
Γ_5	$\gamma\gamma$	0.00430 ± 0.00015	1.1
Γ_6	$3\pi^0$	$(3.2 \pm 0.6) \times 10^{-4}$	1.1

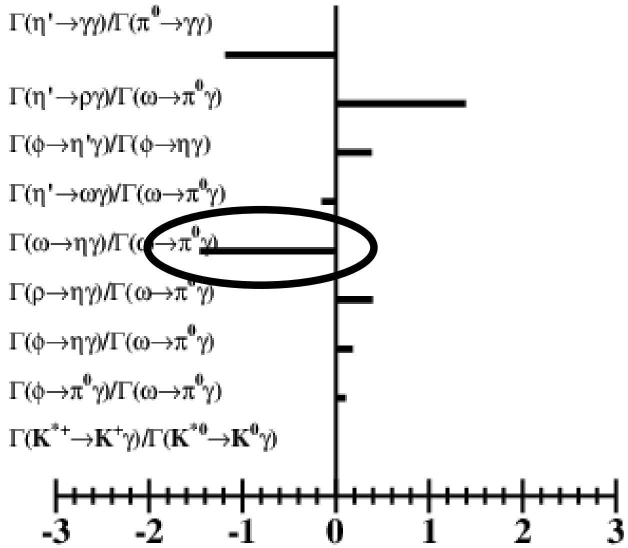
	Gluonium allowed	Gluonium at zero
$\chi^2/n.d.f(Prob)$	$7.9/3$ (5 %)	$15/4$ (5×10^{-3})
Z_G^2	0.097 ± 0.037	0 fixed
ψ_P	$(41.0 \pm 0.7)^\circ$	$(41.7 \pm 0.5)^\circ$
Z_q	0.86 ± 0.02	0.858 ± 0.021
Z_s	0.79 ± 0.05	0.78 ± 0.05
ψ_V	$(3.17 \pm 0.09)^\circ$	$(3.19 \pm 0.09)^\circ$
$m_s/\bar{m}$	1.24 ± 0.07	1.24 ± 0.07

Table 5: Fit results using the PDG-2008 values.

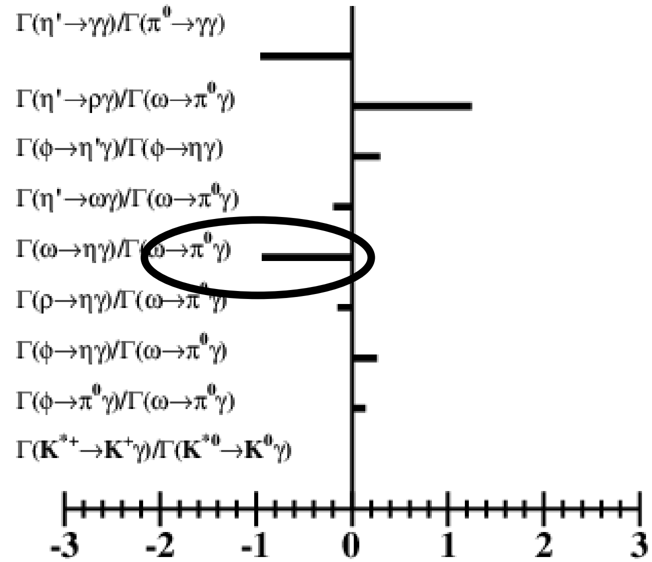
PDG08

The same gluonium content but unsatisfying fit quality.

PDG08



PDG06



$\omega \to \eta\gamma$ pull has increased

The $\omega \to \eta\gamma$ branching ratio changed from

$(4.9 \pm 0.5)\times 10^{-4}$
to
$(4.6 \pm 0.4)\times 10^{-4}$

This value is determined by the global PDG fit, and it is mainly determined by:

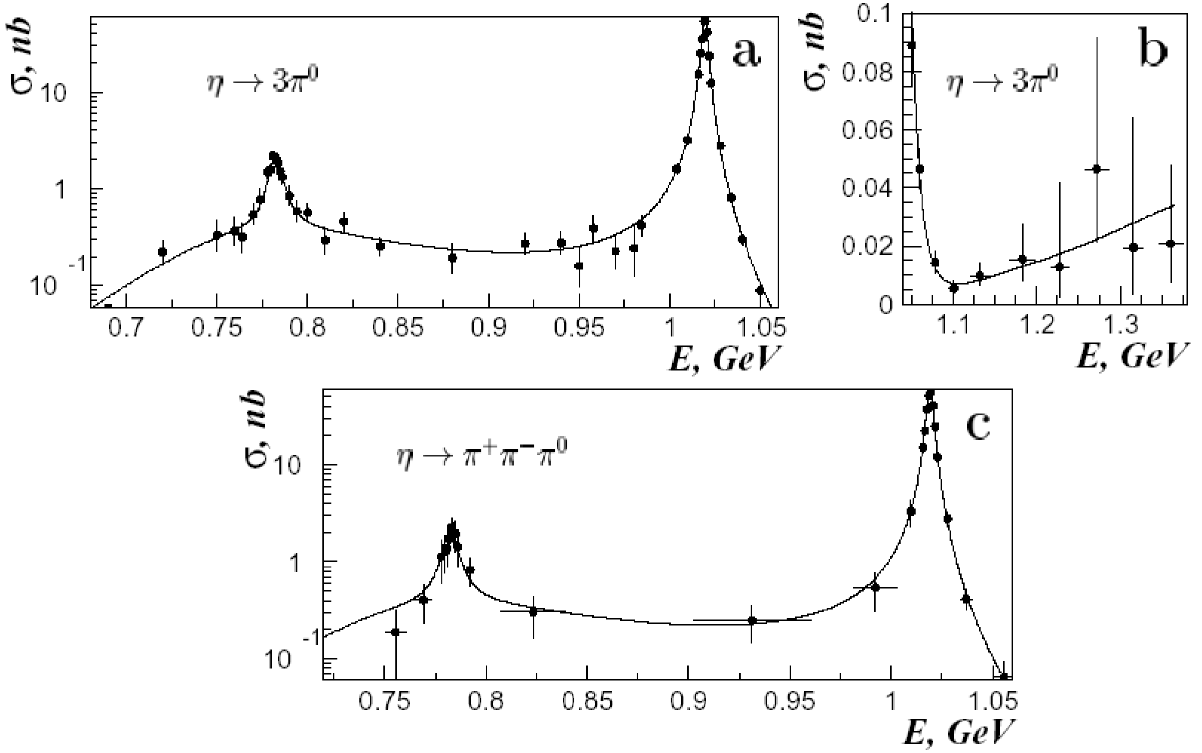
$\Gamma(e^+e^-) \times \Gamma(\eta\gamma)/\Gamma^2_{total}$ $\qquad \Gamma_9\Gamma_5/\Gamma^2$

VALUE (units 10^{-8})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
3.31±0.28 OUR FIT	Error includes scale factor of 1.1.				
3.18±0.28 OUR AVERAGE					
$3.10\pm0.31\pm0.11$	33k	[24] ACHASOV	07B	SND	$0.6–1.38\ e^+e^- \to \eta\gamma$
$3.17^{+1.85}_{-1.31}\pm0.21$	17.4k	[25] AKHMETSHIN	05	CMD2	$0.60–1.38\ e^+e^- \to \eta\gamma$
$3.41\pm0.52\pm0.21$	23k	[26,27] AKHMETSHIN	01B	CMD2	$e^+e^- \to \eta\gamma$

Phys. Rev. D76 (2007) 077101

$\omega \to \eta\gamma$ branching ratio measurement from SND

The branching ratio is extracted with a global fit to the $e^+e^- \to \eta\gamma$ with a VMD model with $\rho, \omega, \phi, \rho'$ included (ρ' parameters varied to compute systematics and constrained from $e^+e^- \to \eta\rho$).



ω contribution overwhelmed by the $\rho \to \eta\gamma$ contribution
no correlation matrix is given in the paper

Direct $\omega \to \eta\gamma$ branching ratio measurement

The fit is dominated by the SND measurement

$\Gamma(\eta\gamma)/\Gamma_{total}$

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
4.6 ±0.4	**OUR FIT**	Error includes scale factor of 1.1.			
6.3 ±1.3	**OUR AVERAGE**	Error includes scale factor of 1.2.			
6.6 ±1.7		[53] ABELE	97E	CBAR	0.0 $\bar{p}p \to 5\gamma$
8.3 ±2.1		ALDE	93	GAM2	38 $\pi^- p \to \omega n$
3.0 $^{+2.5}_{-1.8}$		[54] ANDREWS	77	CNTR	6.7–10 γCu

In Crystal Barrel the channel $p\bar{p} \to \eta\,\omega$ is used that is 6 times larger than $p\bar{p} \to \eta\,\rho$, the $\omega \to \eta\gamma$ Br was normalized to the $\omega \to \pi^0\gamma$ Br

using $\omega \to \eta\gamma$ from PDG average

	Gluonium allowed	Gluonium at zero
$\chi^2/n.d.f(Prob)$	3.9/3 (27.5 %)	13/4 (1.1 %)
Z_G^2	0.111 ± 0.036	0 fixed
ψ_P	$(40.6 \pm 0.7)^\circ$	$(41.5 \pm 0.5)^\circ$
Z_q	0.890 ± 0.025	0.882 ± 0.023
Z_s	0.79 ± 0.05	0.78 ± 0.05
ψ_V	$(3.15 \pm 0.10)^\circ$	$(3.18 \pm 0.09)^\circ$
$m_s/\bar{m}$	1.24 ± 0.07	1.24 ± 0.07

Direct $\omega \to \eta\gamma$ branching ratio measurement

The fit is dominated by the SND measurement

$\Gamma(\eta\gamma)/\Gamma_{total}$

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
4.6 ±0.4 OUR FIT Error includes scale factor of 1.1.				
6.3 ±1.3 OUR AVERAGE Error includes scale factor of 1.2.				
6.6 ±1.7		[53] ABELE 97E	CBAR	0.0 $\bar{p}p \to 5\gamma$
8.3 ±2.1		ALDE 93	GAM2	38 $\pi^- p \to \omega n$
3.0 $^{+2.5}_{-1.8}$		[54] ANDREWS 77	CNTR	6.7–10 γ Cu

In Crystal Barrel the channel $p\bar{p} \to \eta\,\omega$ is used that is 6 times larger than $p\bar{p} \to$ … γ Br

Important discrepancy in the experimental determination. A new measurement is welcome!!!

using $\omega \to \eta\gamma$ from PDG average

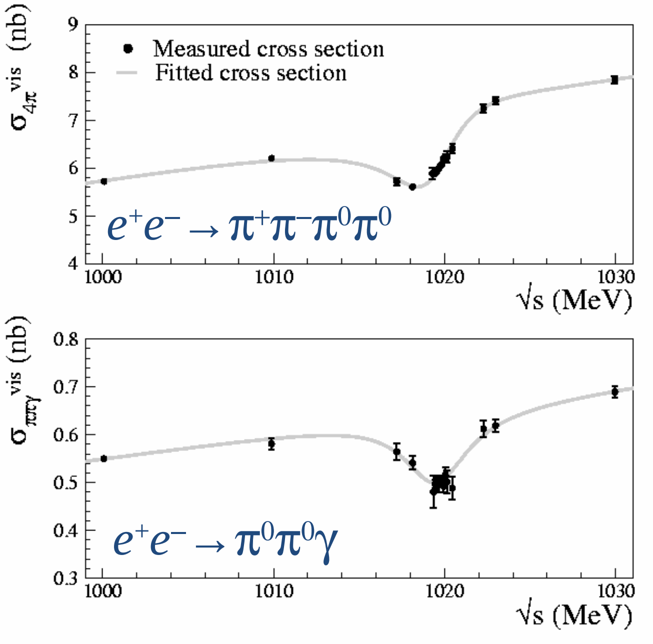
		… zero
		…%)
…	…	…5)°
Z_q	0.890 ± 0.025	0.882 ± 0.023
$Z_{\tilde{s}}$	0.79 ± 0.05	0.78 ± 0.05
ψ_V	$(3.15 \pm 0.10)^\circ$	$(3.18 \pm 0.09)^\circ$
$m_s/\bar{m}$	1.24 ± 0.07	1.24 ± 0.07

KLOE measurement of $\omega \to \pi^0\gamma$ KLOE PLB 669 (2008) 223

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

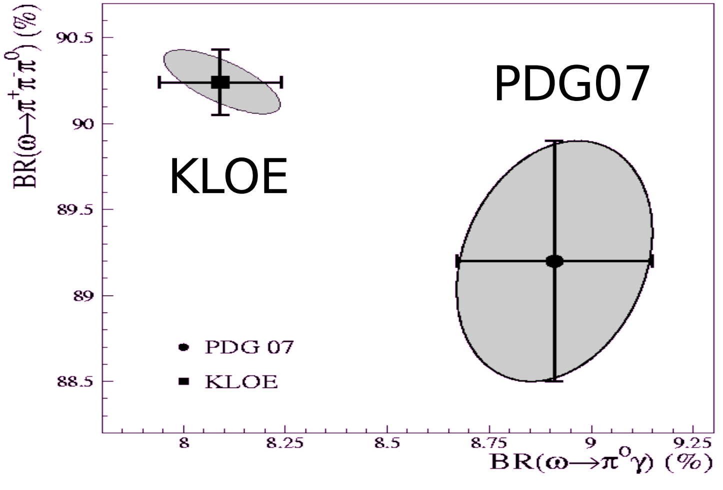


$\Gamma(\omega \to \pi^0\gamma)/\Gamma(\omega \to \pi^+\pi^-\pi^0)$ & assuming

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

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

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



3σ discrepancy

Estimate of f_q and f_s – old KLOE

Estimates used in our previous paper

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

T. Feldmann, Int. J. Mod. Phys. A 15 (2000) 159

source	f_q/f_π	f_s/f_π	ϕ_q	ϕ_s
Mass matrix and radiative decays[16,17]	[1.0]	[1.4]	44°	
$U(1)_A$ anomaly & meson masses[18]	1.0	1.4	[42°]	
Phenomenology[2,19,20,21]	[1.1 – 1.2]	[1.1 – 1.3]	[28°-34°]	[35°-41°]
NJL quark model & phenom.[22]	[1.07]	[1.36]	[44.1°]	[40.6°]
Current mixing model & phenom.[43]	[0.98]	[0.66]	[35.9°]	[26.2°]
Phenomenology[23]	[1.00]	[1.45]	39.2°	
GMO mass formula[42]	[1.13]	[1.16]	[31.2°]	[35.4°]
χPT & $1/N_C$ expansion & phenom.[24]	[1.08]	[1.43]	[44.8°]	[40.5°]
FKS scheme & theory[26]	1.00	1.41	42.4°	
FKS scheme & phenom.[26]	1.07	1.34	39.3°	
Vector meson dominance & phenom.[44]	[1.09]	[1.55]	[47.5°]	[42.1°]
Energy dependent scheme & phenom.[45]	[1.10]	[1.46]	[38.9°]	[41.0°]

Value used up to now, 1% error assumed.
Reasonable if compared to $U(1)_A$ anomaly and meson masses.

Alternative approach

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

In the Isospin symmetry limit:

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

$$f_q/f_\pi = 1$$ **with no error**

$$\frac{f_s}{f_\pi} = \sqrt{2\frac{f_K^2}{f_\pi^2} - 1}$$

$f_K/f_\pi = 1.189(7)$

Lattice-UKQCD:

Follana et al., Phys. Rev. Lett. 100 (2008) 062002

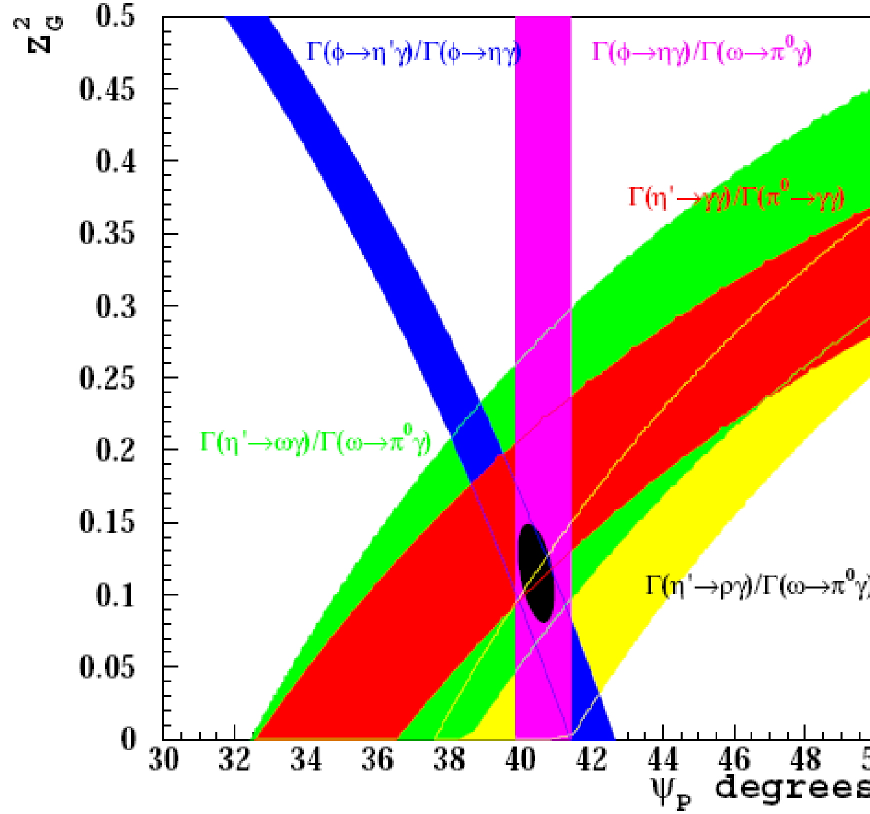
$$\frac{f_s}{f_\pi} = 1.352 \pm 0.007$$

0.5% error but 4% difference with our previous value.

Final KLOE result

JHEP 0907:105, 2009

	Z_G free	$Z_G = 0$ fixed
χ^2/ndf (CL)	4.6/3 (20%)	14.7/4 (0.5%)
Z_G^2	0.115 ± 0.036	0
ψ_P	$(40.4 \pm 0.6)^\circ$	$(41.4 \pm 0.5)^\circ$
Z_q	0.936 ± 0.025	0.927 ± 0.023
Z_s	0.83 ± 0.05	0.82 ± 0.05
ψ_V	$(3.32 \pm 0.09)^\circ$	$(3.34 \pm 0.09)^\circ$
$m_s/\bar{m}$	1.24 ± 0.07	1.24 ± 0.07



ψ_P	-0.507				
Z_q	0.063	-0.018			
Z_s	0.092	-0.189	0.013		
ψ_V	-0.059	-0.012	0.045	0.028	
$m_s/\bar{m}$	-0.002	0.003	0.001	0.949	0.000
	Z_G^2	ψ_P	Z_q	Z_s	ψ_V

Update with the preliminary η' width measurement from COSY-11

The width is dominated by $G(\eta' \to \gamma\gamma)$ and $Br(\eta' \to \gamma\gamma)$

$\eta'(958)$ WIDTH — **PDG 08**

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
0.205±0.015 OUR FIT	Error includes scale factor of 1.2.					
0.30 ±0.09 OUR AVERAGE						
0.40 ±0.22	4800	WURZINGER	96	SPEC		$1.68\ pd \to {}^3\mathrm{He}\eta'$
0.28 ±0.10	1000	BINNIE	79	MMS	0	$\pi^- p \to n\mathrm{MM}$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.20 ±0.04		BAI	04J	BES2		$J/\psi \to \gamma\gamma\pi^+\pi^-$

New measurement from COSY-11 E. Czerwiński PDG thesis arXiv:0909.2781

$$\Gamma_{\eta'} = (0.226 \pm 0.017 \pm 0.014)\ \mathrm{MeV}$$

Error just two times larger than PDG fit.

Let's try to include this measurement in the fit.

Global fit to branching ratio and decay widths

Lagrange multiplier method: free minimization of χ^2 and constraint equation times a Lagrange multiplier parameter.

number of measurements

number of experimental determinations

constraint equation

$$F=\sum_{l=1}^{r}\sum_{k=1}^{n_l}\frac{\left(R_{lk}-R_l(x_j,\Gamma)\right)^2}{\delta_{lk}^2}+\lambda\left(\sum x_j-1\right)$$

errors, square sum of statistic and systematic error

$R_l(x_j,\Gamma)$ **Measurements as a function of the fitting parameters**

x_j 6 main η' branching ratios

Γ η' total width

Fit done with: 7 parameters, 20 measurements, 51 experimental determinations

Fit results.

PDG 08

η′(958) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor Confidence leve
Γ_1	$\pi^+\pi^-\eta$	(44.6 ±1.4) %	S=1.
Γ_2	$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	(29.4 ±0.9) %	S=1.
Γ_3	$\pi^0\pi^0\eta$	(20.7 ±1.2) %	S=1.
Γ_4	$\omega\gamma$	(3.02±0.31) %	
Γ_5	$\gamma\gamma$	(2.10±0.12) %	S=1.
Γ_6	$3\pi^0$	(1.54±0.26) $\times 10^{-3}$	

$\Gamma = 0.205 \pm 0.015$ keV (S= 1.2)

	x_1	x_2	x_3	x_4	x_5	x_6
x_2	−35					
x_3	−77	−28				
x_4	−35	−24	33			
x_5	−23	−10	23	7		
x_6	−28	−11	35	11	8	
Γ	29	−5	−21	−4	−85	−7

$\chi^2 = 36.9/44$ (77 %)

This Fit (no scale factors)

η′(958) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\pi^+\pi^-\eta$	(44.8 ± 1.2)%
Γ_2	$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	(29.4 ± 0.8) %
Γ_3	$\pi^0\pi^0\eta$	(20.5 ± 1.0) %
Γ_4	$\omega\gamma$	(3.01 ± 0.29) %
Γ_5	$\gamma\gamma$	(2.06 ± 0.09) %
Γ_6	$3\pi^0$	(1.53 ± 0.25) $\times 10^{-3}$

$\Gamma = 0.210 \pm 0.011$ keV

	x_1	x_2	x_3	x_4	x_5	x_6
x_2	- 40					
x_3	- 74	- 28				
x_4	- 33	- 21	27			
x_5	- 42	- 21	55	15		
x_6	- 23	- 9	29	7	16	
Γ	45	-3	-42	-9	-78	-12

$\chi^2 = 37.6/45$ (77 %)

Gluonium fit results.

	PDG 08	new $\Gamma_{\eta'}$
$\chi^2/\mathrm{ndf}\ (\mathrm{CL})$	$4.6/3\ (20\%)$	5.7/3 (13%)
Z_G^2	0.115 ± 0.036	0.101 ± 0.031
ψ_P	$(40.4 \pm 0.6)^\circ$	(40.7 ± 0.6)°
Z_q	0.936 ± 0.025	0.943 ± 0.023
Z_s	0.83 ± 0.05	0.83 ± 0.05
ψ_V	$(3.32 \pm 0.09)^\circ$	(3.32 ± 0.09)°
$m_s/\bar{m}$	1.24 ± 0.07	1.24 ± 0.07

PERSPECTIVES

η,η ': mixing and gluonium at KLOE-2

1 fb^{-1}

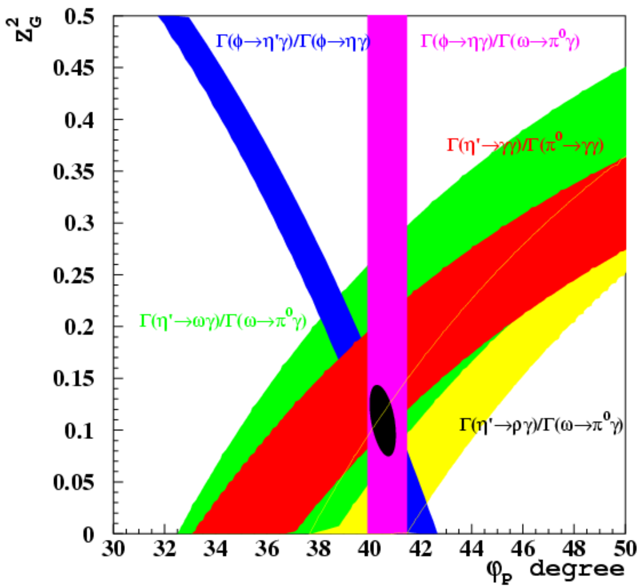
KLOE-2 expected integrated luminosity 8 fb^{-1}

η'(958) DECAY MODES	Fraction (Γ_i/Γ)	events	main bkg
$\pi^+\pi^-\eta$	(44.6 ±1.4) %	730k	—
$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	(29.4 ±0.9) %	480k	$\phi\to\pi^+\pi^-\pi^0$
$\pi^0\pi^0\eta$	(20.7 ±1.2) %	340k	ηγ or KsKl
$\omega\gamma$	(3.02±0.31) %	50k	$e^+e^-\to\omega\pi^0$
$\gamma\gamma$	(2.10±0.12) %	34k	$e^+e^-\to\gamma\gamma(\gamma)$

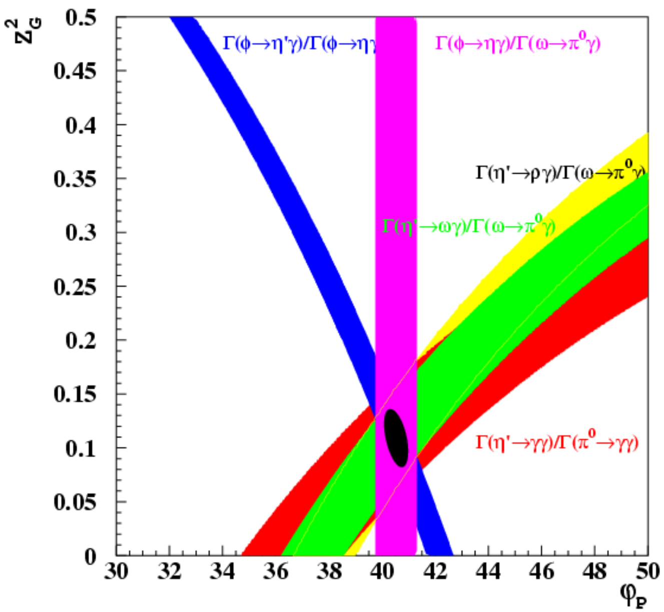
If all Br can be measured at ~1%

Sensitivity to the gluonium also without the η'→γγ

NOW

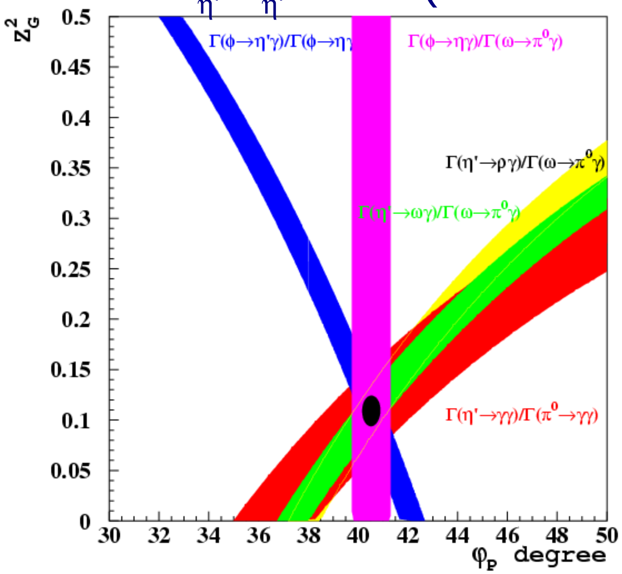


KLOE-2

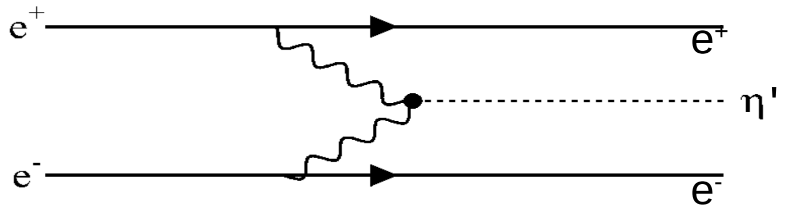


Measurement of the η' width

$\delta\Gamma_{\eta'}/\Gamma_{\eta'} \sim 1\%$ (5.5% now)



$$\Gamma_{\eta'} = \frac{\Gamma_{\eta'\to\gamma\gamma}}{Br(\eta'\to\gamma\gamma)}$$



$$\sigma_{e^+e^-\to e^+e^-\eta'}(s) = \frac{8\alpha^2\Gamma_{\eta'\to\gamma\gamma}}{m^3_{\eta'}} \times \left[f\left(\frac{m^2_{\eta'}}{s}\right)\left(ln\frac{m^2_V s}{m^2_e m^2_{\eta'}} - 1\right)^2 - \frac{1}{3}\left(ln\frac{s}{m^2_{\eta'}}\right)^3 \right]$$

background

	$e^+e^- \to \eta' e^+e^-$		$e^+e^- \to \phi(\gamma) \to \eta'\gamma(\gamma)$		
$\sqrt{s}GeV$	σ (pb)	events at 1 fb^{-1}	σ (pb)	events at 1 fb^{-1}	$S/\sqrt{B}$
0.987 $(2m_{K^+})$	2.3	2300	0.23	230	152
0.995 $(2m_{K^0})$	2.9	2900	0.67	670	112
1.020 (m_ϕ)	5.1	5100	190	190000	12
1.2	20	20000	1.2	1200	578
1.4	39	39000	5.8	5800	512

→ Very long run at low energy would be required.

→ 34 @8fb^{-1}

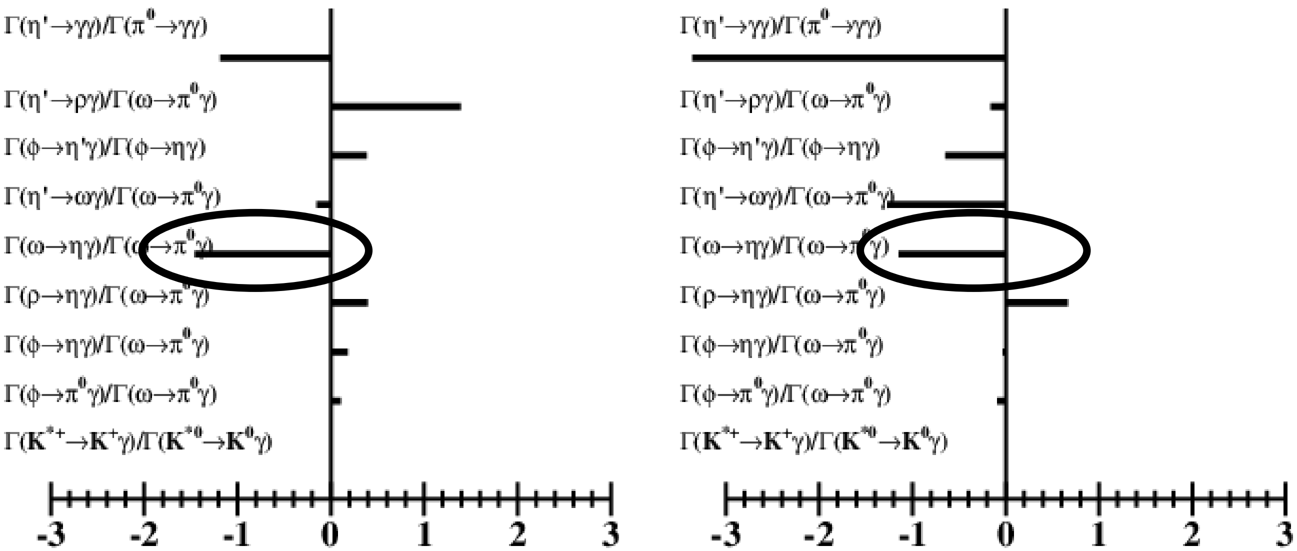
Feasible with 1 fb^{-1} at the φ peak with γγ tagger.

Possible at higher energies if the luminosity is at least 1/8 of the φ peak luminosity.

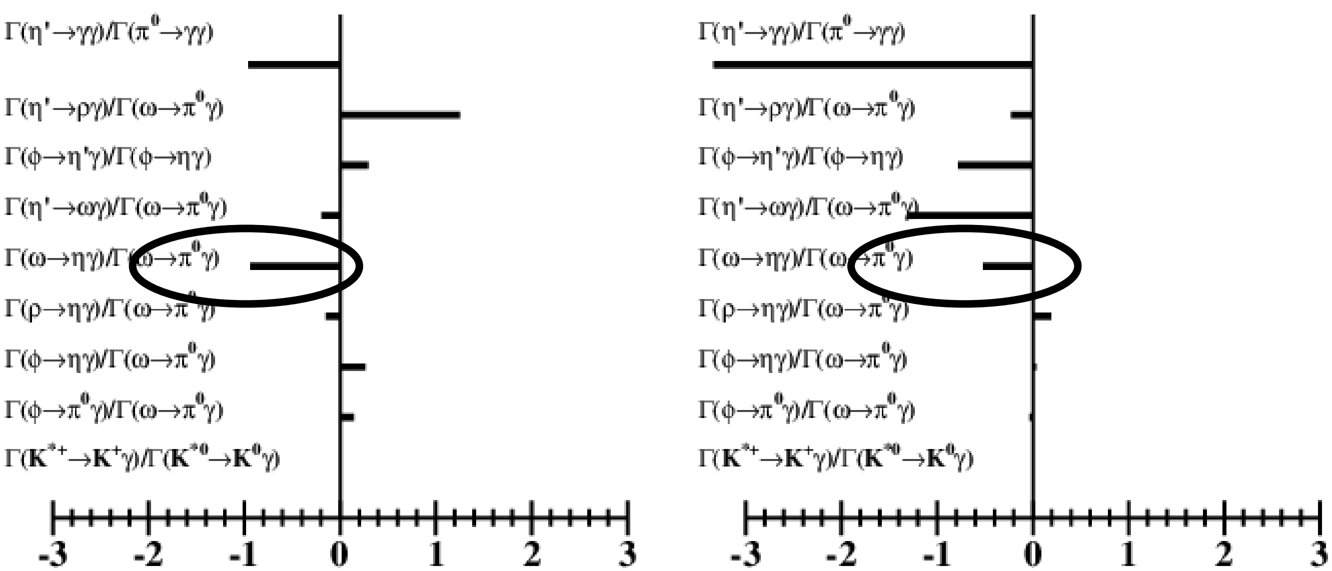
Conclusion

- Gluonium at 3σ also with recent measurements;
- Measurement of $\omega \rightarrow \eta\gamma$ Br is welcome to clarify experimental situation (but small effect on gluonium);
- Still only one measurement is sensitive to the gluonium ($\eta' \rightarrow \gamma\gamma$);
- KLOE-2 with the copious number of η' will allow to give further independent determination of the gluonium content;
- The mixed glue-ball candidate is the $\eta(1405)$

Pulls of the fit



PDG08



PDG06

$\omega\to\eta\gamma$ pull has increased in both gluonium hypothesis

Check if the $\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$ introduces any distorstion

$$\frac{\Gamma(\omega\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)}=\frac{1}{9}\left[Z_q\cos(\psi_P)-2\frac{\bar{m}}{m_s}Z_s\tan(\psi_V)\sin(\psi_P)\right]^2\left(\frac{m_\omega^2-m_\eta^2}{m_\omega^2-m_{\pi^0}^2}\right)^3$$

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

with $\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$ — **without $\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$**