Gluonium content of the η'

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When the light is not enough to paint....

There is the possibility that a pseudoscalar glue ball mixs with a $q\bar{q}$ pair in the η' meson

The glue ball weight

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

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

$$|q\bar{q}\rangle = \frac{|u\bar{u}\rangle + |d\bar{d}\rangle}{\sqrt{2}}$$

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

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

$$Z_{\eta'} = \sin\phi_G$$

If SU(3) were not broken $\phi_P = 45°$

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Pseudoscalar glue balls are predicted by QCD driven models and Lattice

First 3σ hint of η' gluonium content by KLOE

Phys. Lett. B648 (2007) 267

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Good impact on the physics community

11 genuine citations in few months

One not fair Escribano (JHEP 0705:006,2007)

Very recently, the KLOE Collaboration has reported a new measurement of the ratio $R_\phi \equiv B(\phi \to \eta'\gamma)/B(\phi \to \eta\gamma)$ [1]. Combining the value of R_ϕ with other constraints, they have estimated the gluonium content of the η' meson as $Z^2_{\eta'} = 0.14 \pm 0.04$, which points to a significant gluonium fraction in the η' wave function incompatible with zero by more than 3σ. This new result contrasts with the former value $Z^2_{\eta'} = 0.06^{+0.09}_{-0.06}$, which was compatible with zero within 1σ and consistent with a gluonium fraction below 15% [2].

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Fully compatible within errors!!!

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small amount of gluonium in the η' wave function, in fact compatible with zero within 1σ. Using Eq. (A.6) to calculate $Z_{\eta'}$ from $\phi_{\eta' G}$ gives $|Z_{\eta'}| = 0.2 \pm 0.2$. This is one of the main results of our analysis. Accepting the absence of gluonium for the η meson, the gluonic content of the η' wave function amounts to $|\phi_{\eta' G}| = (12 \pm 13)^\circ$ or $Z^2_{\eta'} = 0.04 \pm 0.09$.

In other words, our values for ϕ_P and $\phi_{\eta' G}$ (or $Z_{\eta'}$) contrast with those reported by KLOE recently, $\phi_P = (39.7 \pm 0.7)^\circ$ and $|\phi_{\eta' G}| = (22 \pm 3)^\circ$ —or $Z^2_{\eta'} = 0.14 \pm 0.04$— [1]. As

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Again problems with comparison within errors

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To understand the objection we need more details.

In order to fit the gluonium we use our measurement of

$$R_\phi = \frac{Br(\phi \to \eta' \gamma)}{Br(\phi \to \eta \gamma)} = \cot^2 \phi_P \cdot \cos^2 \phi_G \left(1 - \frac{m_s}{\bar{m}} \frac{C_{NS}}{C_S} \cdot \tan \frac{\phi_V}{\sin 2\phi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

Together with

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

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

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

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

These parameters multiply the gluonium component

We took them from a fit to the same quantities + further constraints without assuming gluonium content

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Redo the fit using different tools and different fitter (myself) in order to check for material errors.

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Redo the fit using different tools and different fitter (myself) in order to check for material errors.

Redo the Escribano fit in order to check it (Camilla).

The MINUIT fit

(The original fit was made with excel)

The MINUIT fit

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Fit result

```
FCN=   1.420049     FROM MIGRAD    STATUS=CONVERGED     30 CALLS       31 TOTAL
                    EDM=  0.46E-08    STRATEGY= 1      ERROR MATRIX ACCURATE

 EXT PARAMETER                                   STEP        FIRST
 NO.   NAME        VALUE          ERROR          SIZE      DERIVATIVE
  1     z2        0.14239      0.33030E-01   0.22096E-04   0.32092E-02
  2     PHIP       39.685       0.72252      0.48340E-03   0.10265E-03

 EXTERNAL ERROR MATRIX.    NDIM=  50    NPAR=  2    ERR DEF=  1.00
  0.109E-02-0.113E-01
 -0.113E-01 0.522E+00

 PARAMETER  CORRELATION COEFFICIENTS
       NO.  GLOBAL      1      2
        1  0.47489  1.000-0.475
        2  0.47489 -0.475 1.000
```

	This fit	**Paper**
z^2	0.14 ± 0.03	0.14 ± 0.04
ϕ_p	$(39.7 \pm 0.7)^\circ$	$(39.7 \pm 0.7)^\circ$

The MINUIT fit

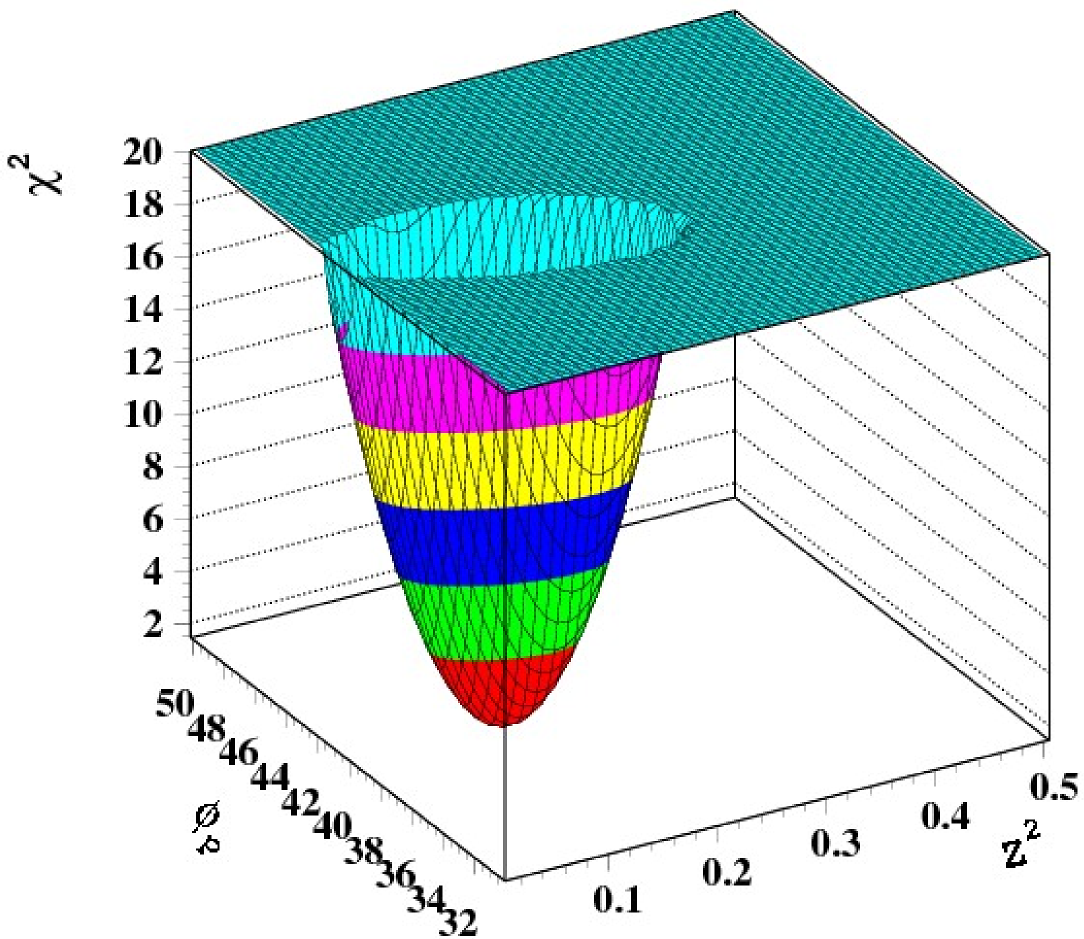
(The original fit was made with excel)

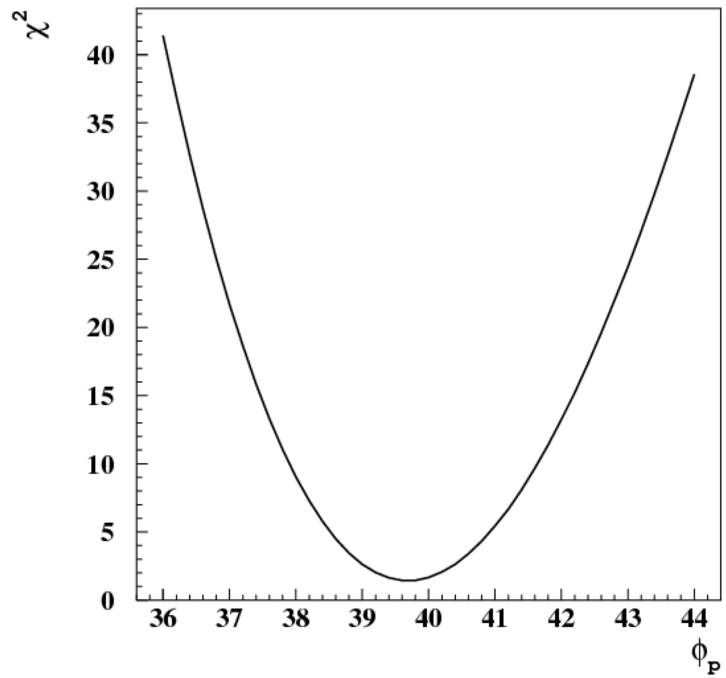
Fit result

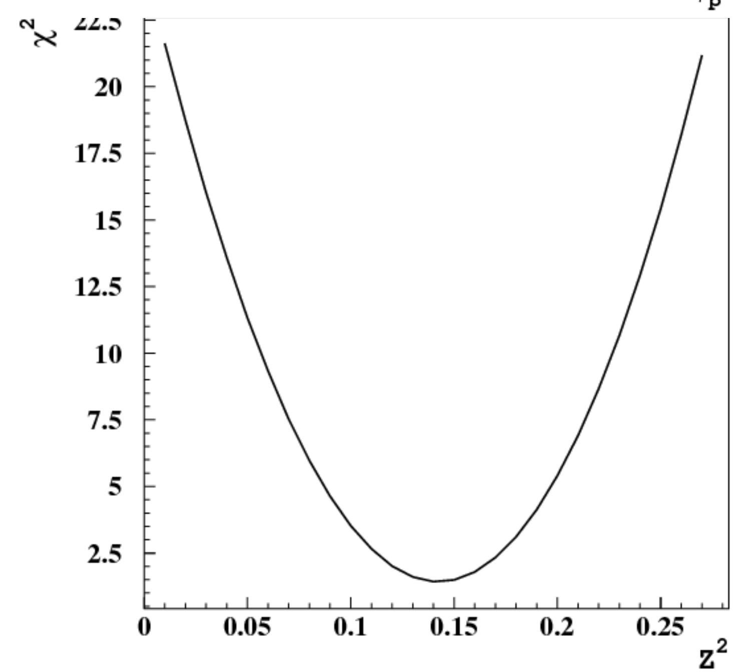
Central value in perfect agreement
Error even smaller
Gluonium at 4.7 σ

	This fit	Paper
z^2	0.14 ± 0.03	0.14 ± 0.04
ϕ_p	$(39.7 \pm 0.7)^\circ$	$(39.7 \pm 0.7)^\circ$

Check of the χ^2 behaviour







Only one minimum in the
whole parameters' domain.

Check of the Escribano hypothesis

Fit redone using Escribano fit parameters:

C_{NS} = 0.86 ± 0.03 C_S=0.78± 0.05

	Fit	Paper
z^2	0.12±0.03	0.14±0.04
ϕ_p	$(40.0 \pm 0.7)^\circ$	$(39.7 \pm 0.7)^\circ$

The fit is very stable respect to the overlapping parameters

Differences between Escribano and our fit

Our fit | **Escribano**

Differences between Escribano and our fit

Our fit

Only ϕ_p and Z^2 are left free

Escribano

All theoretical parameters are left free

Differences between Escribano and our fit

Our fit

Only ϕ_p and Z^2 are left free

The ratios of Γ's are used in the fit.

Escribano

All theoretical parameters are left free

The Γ's are used in the fit.

Differences between Escribano and our fit

Our fit	**Escribano**
Only ϕ_p and Z^2 are left free	All theoretical parameters are left free
The ratios of Γ's are used in the fit.	The Γ's are used in the fit.
4 measured quantities are used in the fit	11 measured quantities are used in the fit

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Our fit	Escribano
Only ϕ_p and Z^2 are left free	All theoretical parameters are left free
The ratios of Γ's are used in the fit.	The Γ's are used in the fit.
4 measured quantities are used in the fit	11 measured quantities are used in the fit
DATA from PDG '06 + KLOE R_ϕ '07	DATA from PDG '06

Escribano amplitudes

$$g_{\omega\eta\gamma} = \frac{1}{3} g \left(z_q \, X_\eta \cos\phi_V + 2 \frac{\bar{m}}{m_s} z_s \, Y_\eta \sin\phi_V \right) \; ,$$

$$g_{\omega\eta'\gamma} = \frac{1}{3} g \left(z_q \, X_{\eta'} \cos\phi_V + 2 \frac{\bar{m}}{m_s} z_s \, Y_{\eta'} \sin\phi_V \right) \; ,$$

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$Z_q = C_{NS}$

$Z_s = C_s$

Constrain

ϕ_p, Z_G

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$Z_q = C_{NS}$
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Constrain ϕ_p, Z_G

$$g_{\rho^0\pi^0\gamma} = g_{\rho^+\pi^+\gamma} = \frac{1}{3} g \ , \quad g_{\omega\pi\gamma} = g \cos\phi_V \ , \quad g_{\phi\pi\gamma} = g \sin\phi_V \ ,$$

$$g_{K^{*0}K^0\gamma} = -\frac{1}{3} g \, z_K \left(1 + \frac{\bar{m}}{m_s} \right) \ , \quad g_{K^{*+}K^+\gamma} = \frac{1}{3} g \, z_K \left(2 - \frac{\bar{m}}{m_s} \right) \ ,$$

Fix the parameters $m_s/\bar{m}, \phi_V, g$

Escribano amplitudes

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$z_q = C_{NS}$

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Constrain ϕ_p, Z_G

$\tan\phi_V << 1$ ($\phi_V = 3.2°$)

$$R_\phi = \frac{Br(\phi \to \eta' \gamma)}{Br(\phi \to \eta \gamma)} = \cot^2\phi_P \cdot \cos^2\phi_G \left(1 - \frac{m_s}{\overline{m}} \frac{C_{NS}}{C_S} \cdot \tan\frac{\phi_V}{\sin 2\phi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

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Contains terms up to $\tan^2\phi_V$, but it is not $o(\tan^2\phi_V)$

Escribano amplitudes

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$z_q = C_{NS}$
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$$+ \left(\frac{C_{NS}}{C_S}\frac{m_S}{\bar{m}} \tan\phi_V\right)^2 \left(1 + 2\cos^2\phi_P\right) \left(\frac{p_{\eta'}}{p_\eta}\right)^3 + o\left(\tan^2\phi_V\right)$$

KLOE fit with full formula

$$R_\phi = \frac{Br(\phi\to\eta'\gamma)}{Br(\phi\to\eta\gamma)} = \cot^2\phi_P\cdot\cos^2\phi_G\left(1-\frac{m_s}{\bar{m}}\frac{C_{NS}}{C_S}\cdot\tan\frac{\phi_V}{\sin 2\phi_P}\right)^2\cdot\left(\frac{p_{\eta'}}{p_\eta}\right)^3$$
$$+\left(\frac{C_{NS}}{C_S}\frac{m_S}{\bar{m}}\tan\phi_V\right)^2\left(1+2\cos^2\phi_P\right)$$

	Fit	Paper
Z^2	0.14 ± 0.03	0.14 ± 0.04
ϕ_p	$(39.9\pm0.7)^\circ$	$(39.7\pm0.7)^\circ$

Freeing the overlapping parameters

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

$$\frac{\Gamma(\eta'\rightarrow\rho\gamma)}{\Gamma(\omega\rightarrow\pi^0\gamma)}=\frac{C_{NS}}{\cos\phi_V}\cdot3\left(\frac{m_{\eta'}^2-m_\rho^2\,m_\omega}{m_\omega^2-m_\pi^2\,m_{\eta'}}\right)^3X_{\eta'}^2$$

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Not enough constraints to leave free C_{NS} and C_S

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Not enough constraint to leave free C_{NS} and C_S

We add to the fit:

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

Fit result

FCN= 1.406759 FROM MINOS STATUS=SUCCESSFUL 187 CALLS 277 TOTAL
EDM= 0.34E-06 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT	PARAMETER		PARABOLIC	MINOS ERRORS	
NO.	NAME	VALUE	ERROR	NEGATIVE	POSITIVE
1	z2	0.11720	0.41464E-01	-0.41484E-01	0.41463E-01
2	PHIP	40.056	0.97108	-0.94271	1.0031
3	CNSP	0.86965	0.31043E-01	-0.31096E-01	0.31044E-01
4	CSPA	0.79071	0.47577E-01	-0.44712E-01	0.50965E-01

	Fit with free C_{NS} C_S	Paper	Escribano
z^2	0.12 ± 0.04	0.14 ± 0.04	$(0.04 \pm 0.09)^{\circ}$
ϕ_p	$(40.1 \pm 1.0)^{\circ}$	$(39.7 \pm 0.7)^{\circ}$	$(41.4 \pm 1.3)^{\circ}$
C_{NS}	0.87 ± 0.03		0.86 ± 0.03
C_S	0.79 ± 0.05		0.78 ± 0.05

Fit result

FCN= 1.406759 FROM MINOS STATUS=SUCCESSFUL 187 CALLS 277 TOTAL
EDM= 0.34E-06 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT NO.	PARAMETER NAME	VALUE	PARABOLIC ERROR	MINOS ERRORS NEGATIVE	MINOS ERRORS POSITIVE
1	z2	0.11720	0.41464E-01	-0.41484E-01	0.41463E-01
2	PHIP	40.056	0.97108	-0.94271	1.0031
3	CNSP	0.86965	0.31043E-01	-0.31096E-01	0.31044E-01
4	CSPA	0.79071	0.47577E-01	-0.44712E-01	0.50965E-01

	Fit with free C_{NS} C_S	Paper	Escribano
z^2	0.12 ± 0.04	0.14 ± 0.04	$(0.04 \pm 0.09)^\circ$
ϕ_p	$(40.1 \pm 1.0)^\circ$	$(39.7 \pm 0.7)^\circ$	$(41.4 \pm 1.3)^\circ$
C_{NS}	0.87 ± 0.03		0.86 ± 0.03
C_S	0.79 ± 0.05		0.78 ± 0.05

Perfect agreement

Fit results

Gluonium still at 3σ

Fit with free C_{NS} C_S		Paper	Escribano
Z^2	0.12 ± 0.04	0.14 ± 0.04	$(0.04 \pm 0.09)^\circ$
ϕ_p	$(40.1 \pm 1.0)^\circ$	$(39.7 \pm 0.7)^\circ$	$(41.4 \pm 1.3)^\circ$
C_{NS}	0.87 ± 0.03		0.86 ± 0.03
C_S	0.79 ± 0.05		0.78 ± 0.05

↔ **Perfect agreement**

Fit results

C[illegible] ll at 3σ

TO BE CONTINUED

	Fit wi[illegible] S	Paper	Escribano
z^2	[illegible].12±0.04	0.14±0.04	$(0.04 \pm 0.09)^\circ$
ϕ_p	$(40.1 \pm 1.0)^\circ$	$(39.7 \pm 0.7)^\circ$	$(41.4 \pm 1.3)^\circ$
C_{NS}	0.87±0.03		0.86±0.03
C_S	0.79 ± 0.05		0.78±0.05

Perfect agreement

The $\eta' \to \gamma\gamma/\pi^0 \to \gamma\gamma$ constraint

Removing this constraint we obtain:

Fit with free C_{NS} C_S no $P \to \gamma\gamma$ constraint		Fit with free C_{NS} C_S		Escribano
z^2	0.09 ± 0.06	z^2	0.12 ± 0.04	$(0.04 \pm 0.09)^\circ$
ϕ_p	$(40.2 \pm 1.0)^\circ$	ϕ_p	$(40.1 \pm 1.0)^\circ$	$(41.4 \pm 1.3)^\circ$
C_{NS}	0.86 ± 0.03	C_{NS}	0.87 ± 0.03	0.86 ± 0.03
C_S	0.79 ± 0.05	C_S	0.79 ± 0.05	0.78 ± 0.05

The $\eta' \to \gamma\gamma / \pi^0 \to \gamma\gamma$ constraint

Removing this constraint we obtain:

Fit with free C_{NS} C_S no $P \to \gamma\gamma$ constraint		Fit with free C_{NS} C_S		Escribano
z^2	0.09 ± 0.06	z^2	0.12 ± 0.04	$(0.04 \pm 0.09)^\circ$
ϕ_p	$(40.2 \pm 1.0)^\circ$	ϕ_p	$(40.1 \pm 1.0)^\circ$	$(41.4 \pm 1.3)^\circ$
C_{NS}	0.86 ± 0.03	C_{NS}	0.87 ± 0.03	0.86 ± 0.03
C_S	0.79 ± 0.05	C_S	0.79 ± 0.05	0.78 ± 0.05

The $P \to \gamma\gamma$ constraint is important!! It moves the central value and reduce the error (Here someone is cheating..)

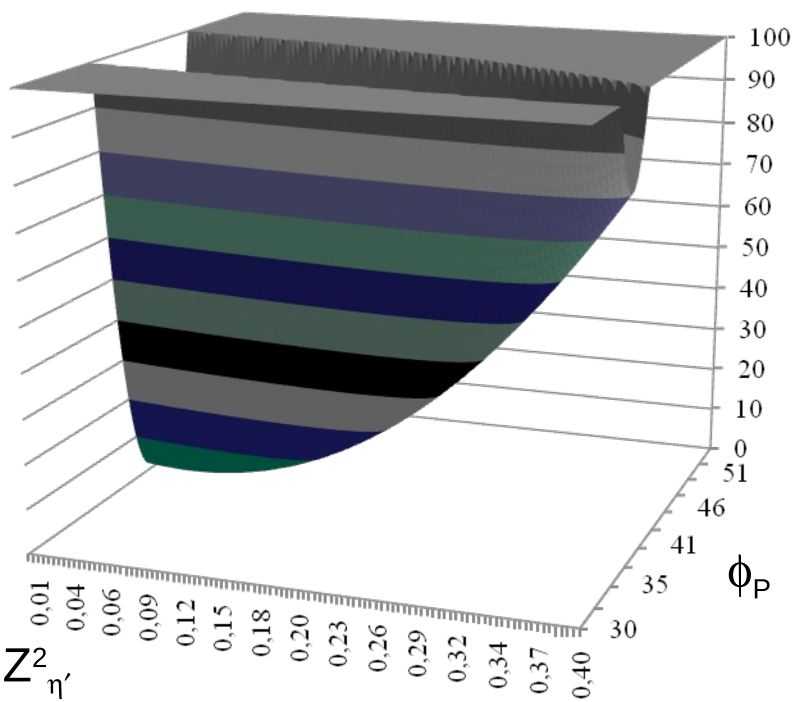
Fitting the Width
(using KLOE and last SND results)

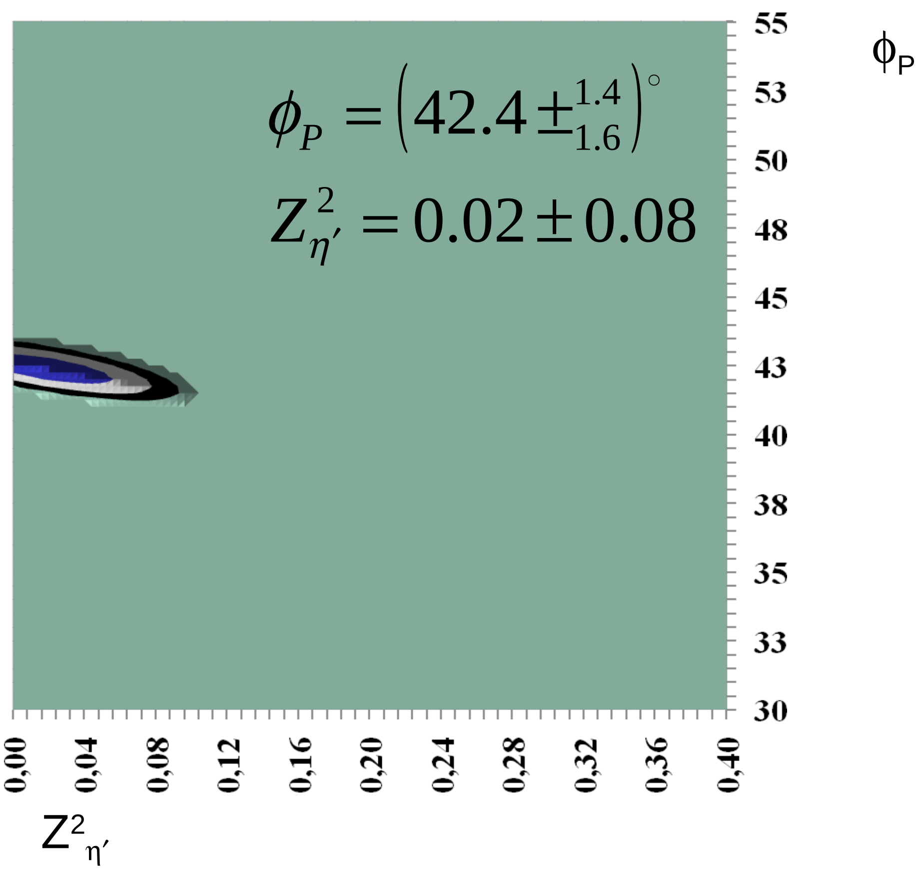
Slide from Camilla

We fit as Escribano - constraints from partial width
with our method - only $\cos\phi_P$, $\cos\phi_G$ left free
We find the following results to compare with Rafel's ones

Escribano fit

$$\left(\phi_P, Z^2_{\eta'}\right) = \left(42.6^\circ, 0.01\right)$$





Conclusions and outlook

- All the objections to our paper have been rejected by the check performed;
- To complete the study we have to implement 4 further constraints and fit with all free parameters;

- From the preliminary study we can say:
  - The gluonium is at 3σ whatever we use for the overlapping parameters or include them in the fit;
  - The $P \rightarrow \gamma\gamma$ is proved to be an important constraint: increases the gluonium component and reduces the error by 33%
  - The fit to the Γ's looks promising
- We would like to write a short answer to Escribano and Thomas at the end of the work.