Update of η-η' mixing from $J/\psi \to VP$ decays

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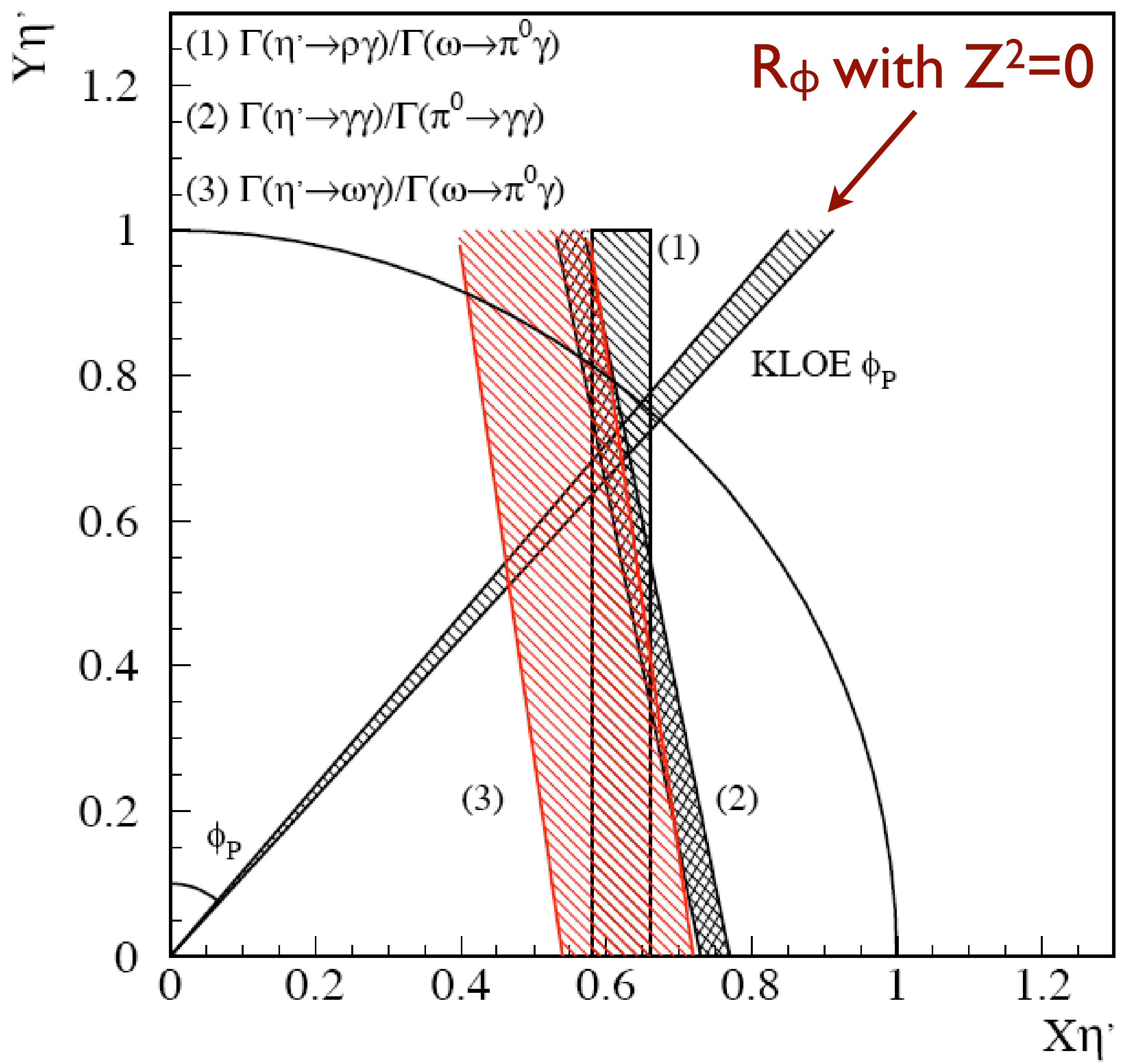
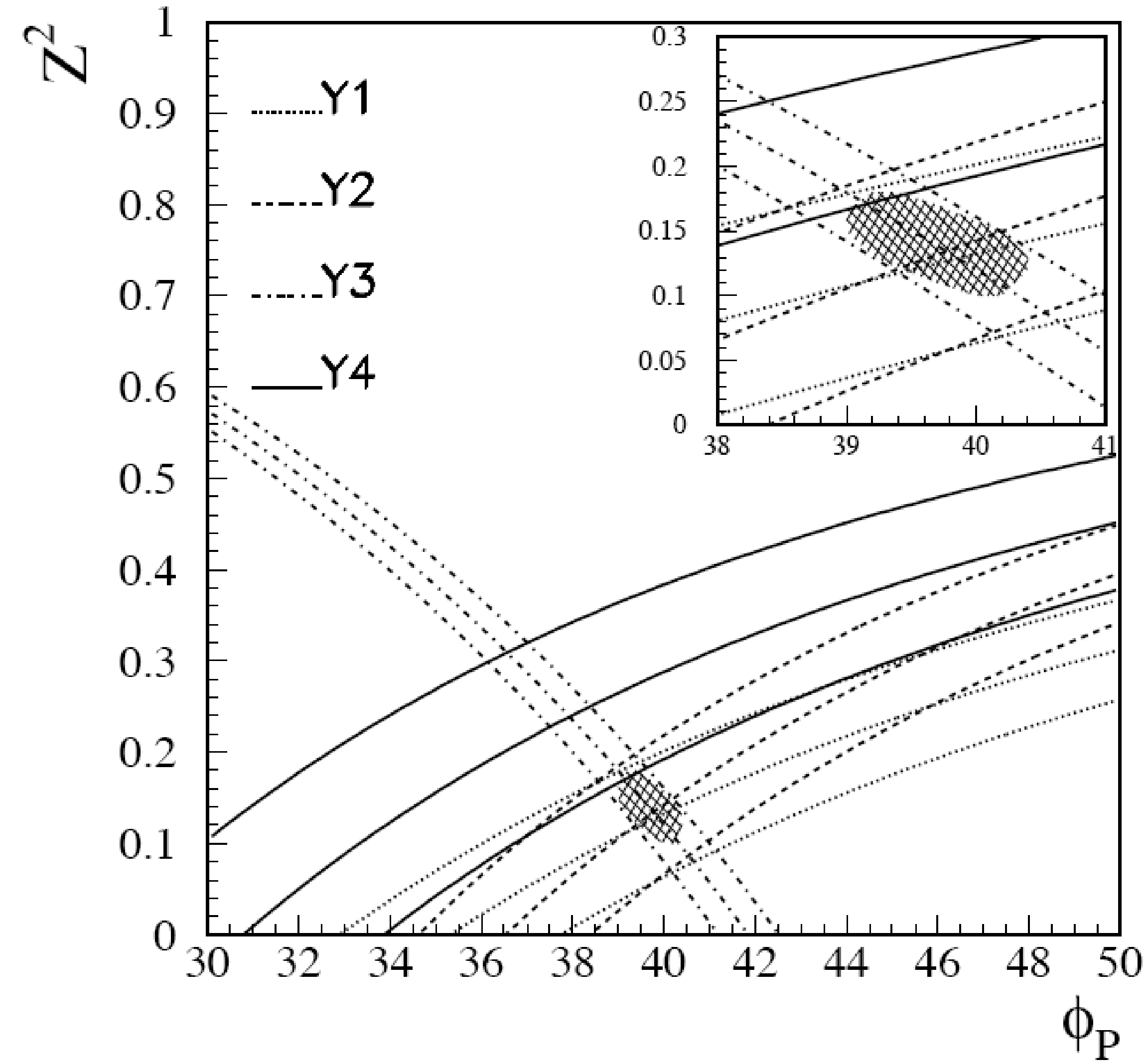
• *Motivation*

KLOE Collaboration, Phys. Lett. B648 (2007) 267





$$\phi_P = (39.7 \pm 0.7)^\circ$$

$$Z^2_{\eta'} = 0.14 \pm 0.04$$

Y1=$\eta'\to\gamma\gamma/\pi^0\to\gamma\gamma$
Y2=$\eta'\to\rho\gamma/\omega\to\pi^0\gamma$
Y3=$\phi\to\eta'\gamma/\phi\to\eta\gamma$
Y4=$\eta'\to\omega\gamma/\omega\to\pi^0\gamma$

• *Motivation*

R. E. and J. Nadal, JHEP 05 (2007) 6

Purpose: to perform a phenomenological analysis of radiative $V \to P\gamma$ and $P \to V\gamma$ decays, with $V=\rho, K^*, \omega, \phi$ and $P=\pi, K, \eta, \eta'$, aimed at determining the gluonic content of the η and η' wave functions

Conclusions:

i) assuming $Z_\eta = Z_{\eta'} = 0$ from the beginning, we got $\phi_P = (41.1 \pm 1.1)^\circ$ with $\chi^2/\text{d.o.f.} = 4.4/5$

ii) 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 $(Z_{\eta'})^2 = 0.04 \pm 0.09$ and the η-η' mixing angle is found to be $\phi_P = (41.4 \pm 1.3)^\circ$ $\chi^2/\text{d.o.f.} = 4.2/4$

iii) accepting the absence of gluonium for the η' meson, the gluonic content of the η wave function amounts to $|\phi_{\eta G}| \simeq 0^\circ$ or $(Z_\eta)^2 = 0.00 \pm 0.12$ and the η-η' mixing angle is found to be $\phi_P = (41.5 \pm 1.3)^\circ$ $\chi^2/\text{d.o.f.} = 4.4/4$

→ The current experimental data on $VP\gamma$ transitions indicated within our model a negligible gluonic content for the η and η' mesons

Purpose: to perform a phenomenological analysis of $J/\psi \to VP$ decays, with $V=\rho, K^*, \omega, \phi$ and $P=\pi, K, \eta, \eta'$, aimed at determining the gluonic content of the η and η' wave functions

Why? to confirm or not the gluonic content of the η' wave function

Feasible? yes, because we have at our disposal all the needed experimental information

Outline:

- *Notation*
- *Experimental input*
- *A model for $J/\psi \to VP$ transitions*
- *Preliminary results*
- *Summary and conclusions*

• *Notation*

J. L. Rosner, Phys. Rev. D27 (1983) 1101

We work in a basis consisting of the states

$$|\eta_q\rangle \equiv \frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}\rangle \qquad |\eta_s\rangle = |s\bar{s}\rangle \qquad |G\rangle \equiv |\mathrm{gluonium}\rangle$$

The physical states η and η' are assumed to be the linear combinations

$$\begin{aligned} |\eta\rangle &= X_\eta|\eta_q\rangle + Y_\eta|\eta_s\rangle + Z_\eta|G\rangle \ , \\ |\eta'\rangle &= X_{\eta'}|\eta_q\rangle + Y_{\eta'}|\eta_s\rangle + Z_{\eta'}|G\rangle \ , \end{aligned}$$

with $X^2_{\eta(\eta')} + Y^2_{\eta(\eta')} + Z^2_{\eta(\eta')} = 1$ and thus $X^2_{\eta(\eta')} + Y^2_{\eta(\eta')} \leq 1$

A significant gluonic admixture in a state is possible only if

$$Z^2_{\eta(\eta')} = 1 - X^2_{\eta(\eta')} - Y^2_{\eta(\eta')} > 0$$

Assumptions:

- no mixing with π^0 (isospin symmetry)
- no mixing with η_c states
- no mixing with radial excitations

- *Notation*

In absence of gluonium (standard picture)

$$Z_{\eta(\eta')} \equiv 0 \quad \Rightarrow \quad \begin{aligned} |\eta\rangle &= \cos\phi_P|\eta_q\rangle - \sin\phi_P|\eta_s\rangle \\ |\eta'\rangle &= \sin\phi_P|\eta_q\rangle + \cos\phi_P|\eta_s\rangle \end{aligned}$$

with $X_\eta = Y_{\eta'} \equiv \cos\phi_P$ and $X^2_{\eta(\eta')} + Y^2_{\eta(\eta')} = 1$

$X_{\eta'} = -Y_\eta \equiv \sin\phi_P$

where ϕ_P is the η-η' mixing angle in the quark-flavour basis related to its octet-singlet analog through

$$\theta_P = \phi_P - \arctan\sqrt{2} \simeq \phi_P - 54.7^\circ$$

Similarly, for the vector states ω and ϕ the mixing is given by

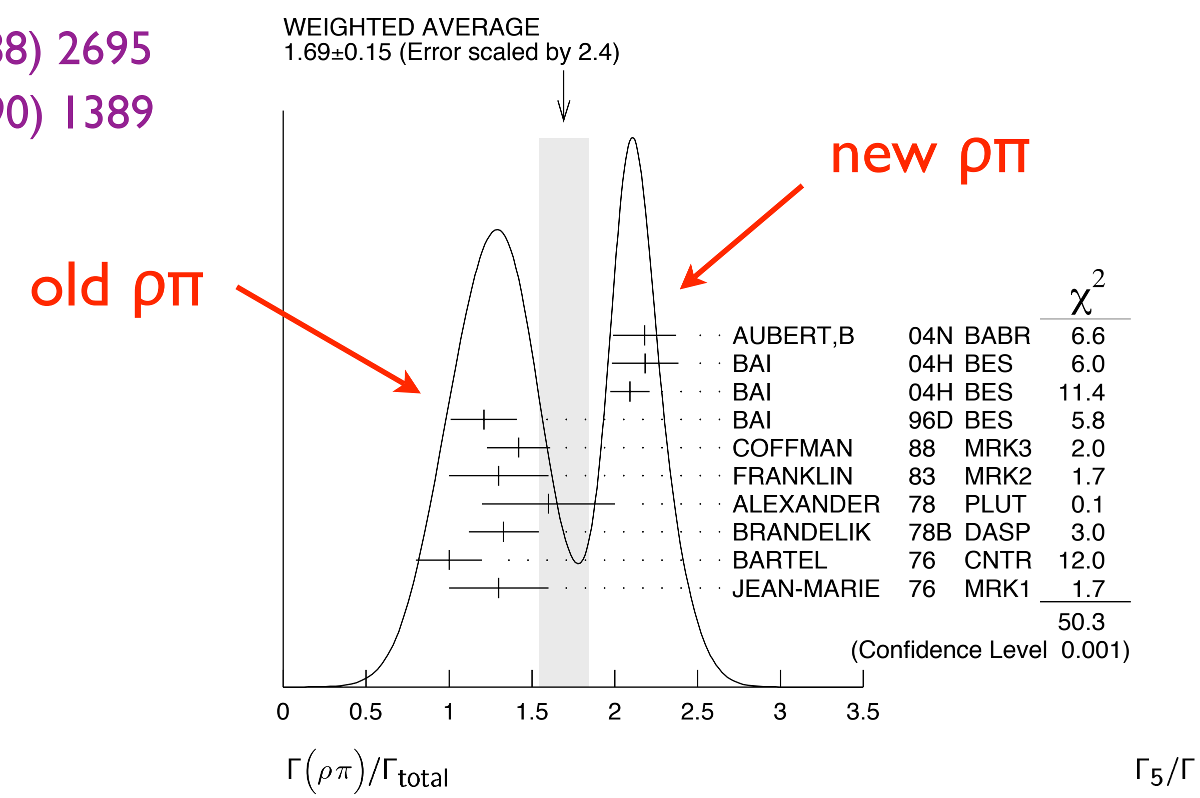
$$\begin{aligned} |\omega\rangle &= \cos\phi_V|\omega_q\rangle - \sin\phi_V|\phi_s\rangle \\ |\phi\rangle &= \sin\phi_V|\omega_q\rangle + \cos\phi_V|\phi_s\rangle \end{aligned}$$

where ω_q and ϕ_s are the analog non-strange and strange states of η_q and η_s, respectively.

- *Experimental input*

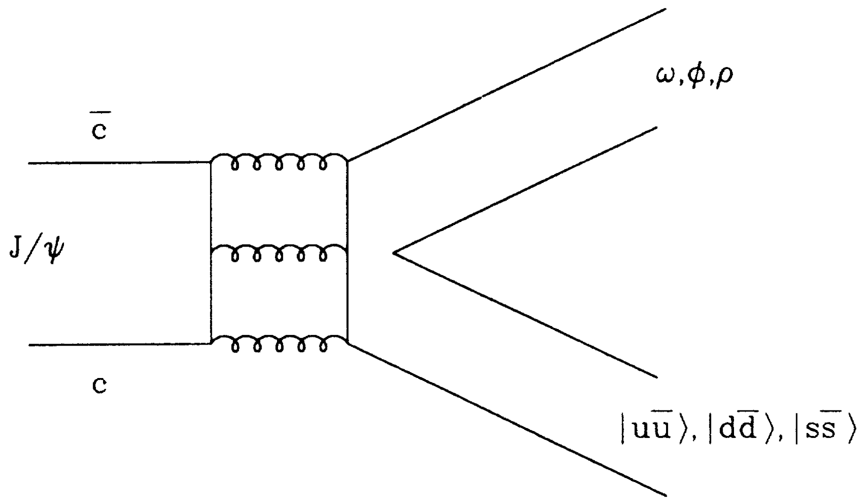
$BR \times 10^{-3}$	PDG'97*	PDG'07	
$\rho\pi$	12.8 ± 1.0	16.9±1.5	BABAR Coll., Phys. Rev. D70 (04) 072004 BES Coll., Phys. Rev. D70 (04) 012005
$K^{*+}K^{-}$ + c.c.	5.0 ± 0.4	=	
$K^{*0}\bar{K}^{0}$ + c.c.	4.2 ± 0.4	=	
$\omega\eta$	1.58 ± 0.16	1.74±0.20	BABAR Coll., Phys. Rev. D73 (06) 052003
$\omega\eta'$	0.167 ± 0.025	0.182±0.021	BES Coll., Phys. Rev. D73 (06) 052007
$\phi\eta$	0.65 ± 0.07	0.74±0.08	BES Coll., Phys. Rev. D71 (05) 032003
$\phi\eta'$	0.33 ± 0.04	0.40±0.07	
$\rho\eta$	0.193 ± 0.023	=	
$\rho\eta'$	0.105 ± 0.018	=	
$\omega\pi^0$	0.42 ± 0.06	0.45±0.05	BES Coll., Phys. Rev. D73 (06) 052007
$\phi\pi^0$	< 0.0068	<0.0064 C.L. 90%	BES Coll., Phys. Rev. D71 (05) 032003

* MARK III Coll., Phys. Rev. D38 (88) 2695
DM2 Coll., Phys. Rev. D41 (90) 1389

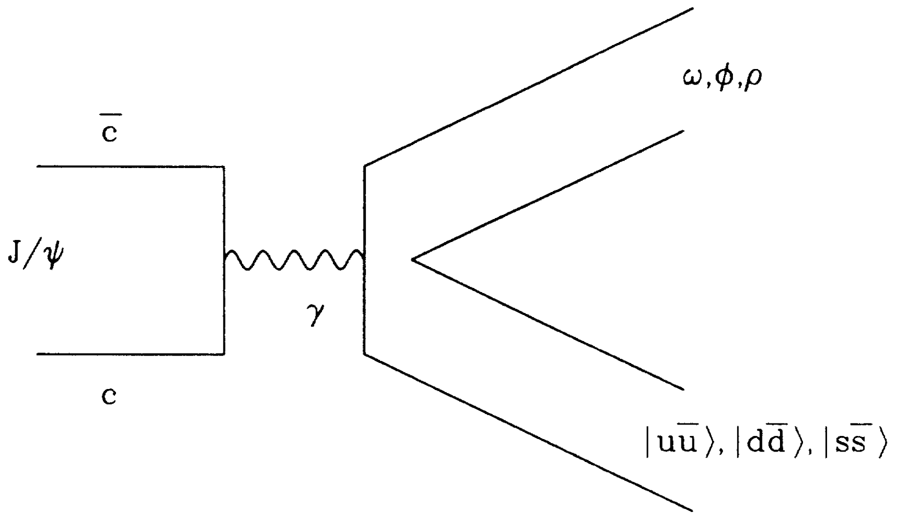


- *A model for J/ψ→VP transitions*

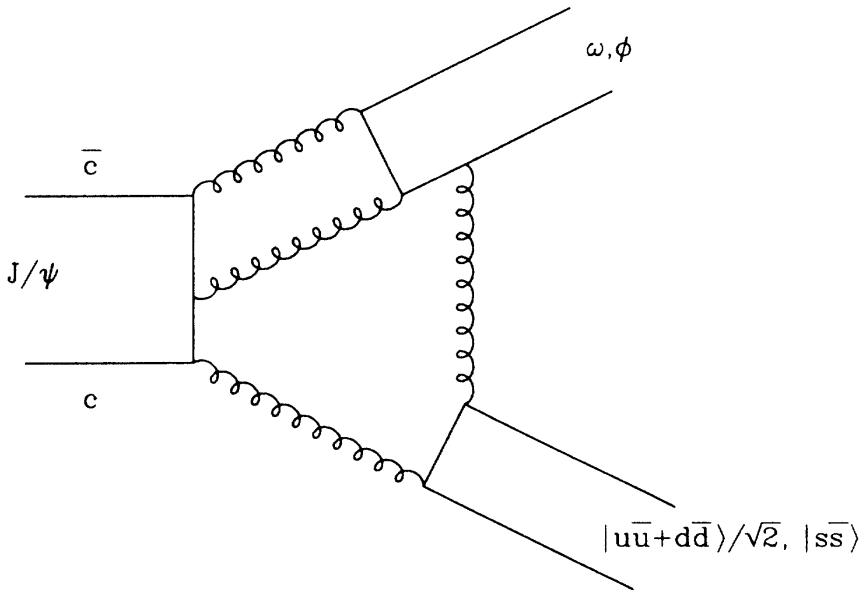
Amplitudes:



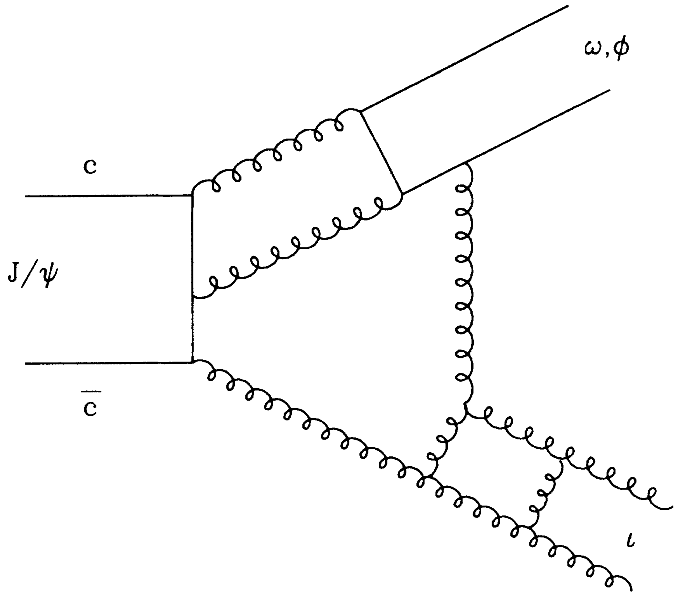
strong singly disconnected (SOZI) ≡ g



electromagnetic singly disconnected (eSOZI) ≡ e



strong doubly disconnected (DOZI) ≡ rg



DOZI for J/ψ→V+Glueball ≡ r'g

• A model for $J/\psi \to VP$ transitions

Amplitudes:

TABLE VIII. General parametrization of amplitudes for $J/\psi \to P + V$.

Process	Amplitude
$\rho^+\pi^-, \rho^0\pi^0, \rho^-\pi^+$	$g+e$
$K^{*+}K^-, K^{*-}K^+$	$g(1-s)+e(1+s_e)$
$K^{*0}\bar{K}^0, \bar{K}^{*0}K^0$	$g(1-s)-e(2-s_e)$
$\omega\eta$	$(g+e)X_\eta+\sqrt{2}rg[\sqrt{2}X_\eta+(1-s_p)Y_\eta]+\sqrt{2}r'gZ_\eta$
$\omega\eta'$	$(g+e)X_{\eta'}+\sqrt{2}rg[\sqrt{2}X_{\eta'}+(1-s_p)Y_{\eta'}]+\sqrt{2}r'gZ_{\eta'}$
$\phi\eta$	$[g(1-2s)-2e(1-s_e)]Y_\eta+rg(1-s_v)[\sqrt{2}X_\eta+(1-s_p)Y_\eta]+r'g(1-s_v)Z_\eta$
$\phi\eta'$	$[g(1-2s)-2e(1-s_e)]Y_{\eta'}+rg(1-s_v)[\sqrt{2}X_{\eta'}+(1-s_p)Y_{\eta'}]+r'g(1-s_v)Z_{\eta'}$
$\rho^0\eta$	$3eX_\eta$
$\rho^0\eta'$	$3eX_{\eta'}$
$\omega\pi^0$	$3e$
$\phi\pi^0$	0

A. Seiden *et al.*, Phys. Rev. D38 (1988) 824

s, s_e, s_p and s_v are SU(3)-breaking parameters

Simplifications of our analysis:

i) second order SU(3)-breaking contributions s_p and s_v are neglected

ii) $x \equiv 1-s_e = m/m_s$ with $m_s/m = 1.24 \pm 0.07$ and $\phi_V = (3.2 \pm 0.1)^\circ$

iii) $Z_\eta = 0$ from $V \to P\gamma$ and $P \to V\gamma$ decays
R. E. and J. Nadal, JHEP 05 (2007) 6

- *Preliminary results* R. E., work in preparation

a) gluonium not allowed for η' → $Z_{\eta'}=0$

i) $x=1$ and $\phi_V=0°$ → $\chi^2/\text{d.o.f.}=3.4/4$ with $\phi_P=(40.2\pm2.4)°$

ii) $x=0.81\pm0.05$ and $\phi_V=(3.2\pm0.1)°$ → $\chi^2/\text{d.o.f.}=4.2/4$ with $\phi_P=(40.5\pm2.4)°$

with $s=(29\pm3)\%$ and $|r|=(37\pm1)\%$ in i)

b) gluonium allowed for η' → $Z_{\eta'}\neq0$

i) $x=1$ and $\phi_V=0°$ → $\chi^2/\text{d.o.f.}=1.9/2$ with $\phi_P=(45.0\pm4.3)°$ and $(Z_{\eta'})^2=0.30\pm0.20$

ii) as before → $\chi^2/\text{d.o.f.}=3.0/2$ with $\phi_P=(44.5\pm4.4)°$ and $(Z_{\eta'})^2=0.28\pm0.23$

with $s=(27\pm3)\%$, $|r|=(36\pm8)\%$ and $|r'|=(12\pm23)\%$ in i)

Remarks:

- the effect of second order SU(3)-breaking contributions s_p and s_v is negligible
- the same fits with the pion modes removed are slightly better
- the same fits with the old data are worse, $\chi^2/\text{d.o.f.}=7.3/4$ vs. $\chi^2/\text{d.o.f.}=3.4/4$ for instance

• *Summary and preliminary conclusions*

We have performed an updated phenomenological analysis of an accurate and exhaustive set of $J/\psi \to VP$ decays with the purpose of determining the quark and gluon content of the η and η' mesons

1) The current experimental data on $J/\psi \to VP$ decays are described in terms of one mixing angle in a consistent way

2) Accepting the absence of gluonium for the η' meson, the η-η' mixing angle is found to be $\phi_P=(40.2\pm2.4)^\circ$ or $\theta_P=(-14.5\pm2.4)^\circ$, in agreement with recent phenomenological estimates

3) The values found for $(Z_{\eta'})^2=0.30\pm0.20$ or $\phi_{\eta'G}=(33\pm15)^\circ$ suggest within the model some small gluonic component of the η'

3) The inclusion of the vector mixing angle (not included in previous analyses) is irrelevant

4) The recent values of $BR(J/\psi \to \rho\pi)$ by BABAR and BES Coll. are crucial in order to get a consistent description of data

- *Euler angles*

In presence of gluonium,

glueball-like state η(1440)? →

$$
\begin{aligned}
|\eta\rangle &= X_\eta|\eta_q\rangle + Y_\eta|\eta_s\rangle + Z_\eta|G\rangle \\
|\eta'\rangle &= X_{\eta'}|\eta_q\rangle + Y_{\eta'}|\eta_s\rangle + Z_{\eta'}|G\rangle \\
|\iota\rangle &= X_\iota|\eta_q\rangle + Y_\iota|\eta_s\rangle + Z_\iota|G\rangle
\end{aligned}
$$

Normalization:

$$
\begin{aligned}
X_\eta^2 + Y_\eta^2 + Z_\eta^2 &= 1 \\
X_{\eta'}^2 + Y_{\eta'}^2 + Z_{\eta'}^2 &= 1 \\
X_\iota^2 + Y_\iota^2 + Z_\iota^2 &= 1
\end{aligned}
$$

Orthogonality:

$$
\begin{aligned}
X_\eta X_{\eta'} + Y_\eta Y_{\eta'} + Z_\eta Z_{\eta'} &= 0 \\
X_\eta X_\iota + Y_\eta Y_\iota + Z_\eta Z_\iota &= 0 \\
X_{\eta'} X_\iota + Y_{\eta'} Y_\iota + Z_{\eta'} Z_\iota &= 0
\end{aligned}
$$

⇒ 3 independent parameters: ϕ_P, $\phi_{\eta G}$ and $\phi_{\eta' G}$

$$
\begin{pmatrix} \eta \\ \eta' \\ \iota \end{pmatrix} = \begin{pmatrix} c\phi_{\eta\eta'}c\phi_{\eta G} & -s\phi_{\eta\eta'}c\phi_{\eta G} & -s\phi_{\eta G} \\ s\phi_{\eta\eta'}c\phi_{\eta' G} - c\phi_{\eta\eta'}s\phi_{\eta' G}s\phi_{\eta G} & c\phi_{\eta\eta'}c\phi_{\eta' G} + s\phi_{\eta\eta'}s\phi_{\eta' G}s\phi_{\eta G} & -s\phi_{\eta' G}c\phi_{\eta G} \\ s\phi_{\eta\eta'}s\phi_{\eta' G} + c\phi_{\eta\eta'}c\phi_{\eta' G}s\phi_{\eta G} & c\phi_{\eta\eta'}s\phi_{\eta' G} - s\phi_{\eta\eta'}c\phi_{\eta' G}s\phi_{\eta G} & c\phi_{\eta' G}c\phi_{\eta G} \end{pmatrix} \begin{pmatrix} \eta_q \\ \eta_s \\ G \end{pmatrix}
$$

- *Euler angles*

$$X_\eta = \cos\phi_P \cos\phi_{\eta G}\ , \quad X_{\eta'} = \sin\phi_P \cos\phi_{\eta' G} - \cos\phi_P \sin\phi_{\eta G} \sin\phi_{\eta' G}\ ,$$
$$Y_\eta = -\sin\phi_P \cos\phi_{\eta G}\ , \quad Y_{\eta'} = \cos\phi_P \cos\phi_{\eta' G} + \sin\phi_P \sin\phi_{\eta G} \sin\phi_{\eta' G}\ ,$$
$$Z_\eta = -\sin\phi_{\eta G}\ , \quad Z_{\eta'} = -\sin\phi_{\eta' G} \cos\phi_{\eta G}\ .$$

In the limit $\phi_{\eta G}=0$:

$$X_\eta = \cos\phi_P\ , \quad Y_\eta = -\sin\phi_P\ , \quad Z_\eta = 0\ ,$$
$$X_{\eta'} = \sin\phi_P \cos\phi_{\eta' G}\ , \quad Y_{\eta'} = \cos\phi_P \cos\phi_{\eta' G}\ , \quad Z_{\eta'} = -\sin\phi_{\eta' G}\ .$$