Di-photon coupling of $f_0(600)$, $f_0(980)$, $f_2(1270)$ resonances and $g^2_{\sigma\pi\pi}$

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[1]Representing L. C. Jin, Y. Mao, X. G. Wang, Ou Zhang, Z. Y. Zhou

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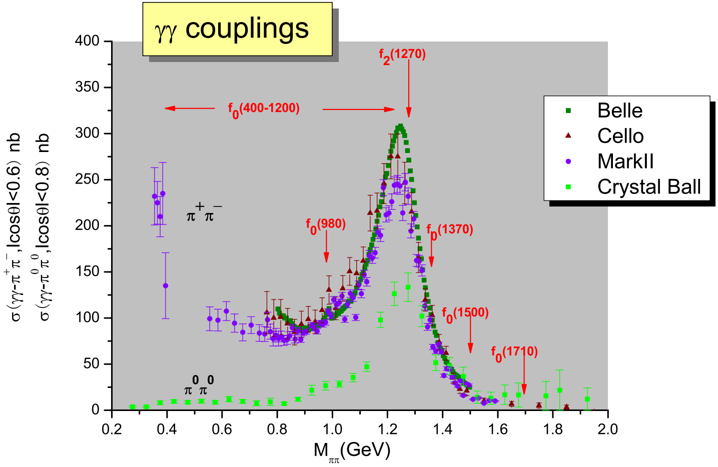
$\gamma\gamma \to \pi\pi$ data

T. Mori *et al.* (Belle Collaboration) 07;



M. R. Pennington, Mod. Phys. Lett. A22(2007)1439.

composition	prediction	author(s)
$(\overline{u}u + \overline{d}d)/\sqrt{2}$	4.0	Babcock and Rosner 76
$\overline{s}s$	0.2	Barnes 85
gg	$0.2 \sim 0.6$	Narison 06
$\overline{[ns]}[ns]$	0.27	Achasov *et al* 82
	0.6	Barnes 92
$\overline{K}K$	0.22	Hanhart 07

Table: Summary of two photon decay width of scalars calculated in different models.

D. Morgan, M. R. Pennington, Z. Phys. **C48**(1990)623.
G. Mennessier, Z. Phys. **C16**(1983)241.
A. V. Anisovich, V. V. Anisovich, Phys. Lett. **B467**(1999)289.
L. V. Fil'kov, V. L. Kashevarov, Phys. Rev. **C72**(2005)035211.
N. N. Achasov, G. N. Shestakov, arXive:0712.0885 [hep-ph].
J. A. Oller, L. Roca, C. Schat, Phys. Lett. **B659**(2008)201.
J. Bernabeu, J. Prades, Phys. Rev. Lett. **100**(2008)241804.
G. Mennessier, S. Narison, W. Ochs, Phys. Lett. **B665**(2008)205.
. . . . . .

A couple channel calculation in IJ=00 channel

Y. Mao et al., arXive::0904.1445 v2, to appear in PRD (Babelon et al. 76; Donoghue, Holstein 93; Morgan, Pennington 91):

$$F(s) = F_B + D(s)[Ps - \frac{s^2}{\pi}\int_{4m_\pi^2}^{\infty} \frac{\mathrm{Im}D^{-1}(s')F_B(s')}{s'^2(s'-s-i\epsilon)}ds'] \ . \qquad (1)$$

2 by 2 matrix D only contains $r.h.c.$ and satisfies couple channel unitarity; iteration method.

$$\begin{aligned} \mathrm{Im}D_{11} &= D_{11}\rho_1 T_{11}^*\theta_1 + D_{21}\rho_2 T_{12}^*\theta_2 \ , \\ \mathrm{Im}D_{21} &= D_{11}\rho_1 T_{21}^*\theta_1 + D_{21}\rho_2 T_{22}^*\theta_2 \ ; \end{aligned} \qquad (2)$$

F_B Born term amplitudes: π + V + A + exponential form-factor. Single channel approx. for other channels⇒ D=Omnés function.

Couple channel T matrix

K_3 fit of Au, Morgan, Pennington 88;
Refit by adding Pislak et al. 03:

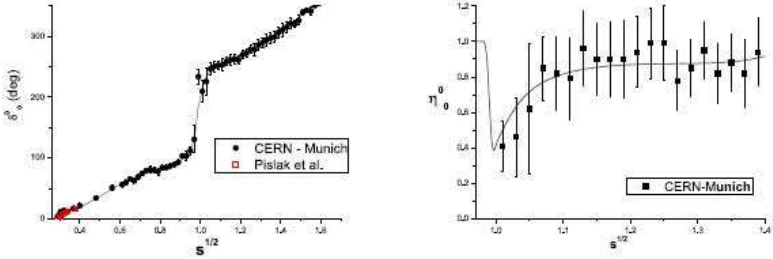


Figure 2: The fit curve of $\pi\pi$ $I = 0$ S-wave phase shift and inelasticity with CERN-Munich data [20] and data from Pislak et al. [21].

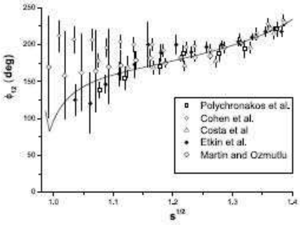


Figure 3: The phase shift $\phi_{12} = \delta_\pi + \delta_K$ of $\pi\pi \to K\bar{K}$ $I = 0$ S-wave scattering with data sets from Res. [22, 23, 24, 25, 26]. Notice that Ref. [22] is not used in the fit.

Poles from K_3 matrix fit

pole	sheet–II	sheet–III
σ	0.507 - 0.229i	0.638 - 0.165 i
$f_0(980)$	0.994 - 0.019 i	0.984 - 0.033 i

Table: The poles's location on the $\sqrt{s}$–plane, in units of GeV.

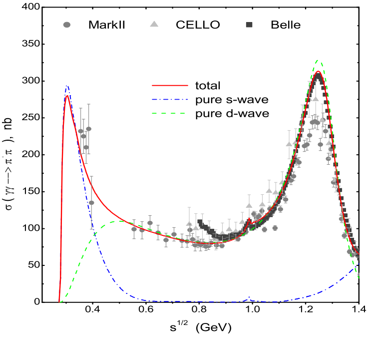
Breit–Wigner description of $f_0(980)$?

"Ambiversion of X(3872)", Ou Zhang et al., arXiv:0901.1553

	Pole-positions(GeV)	$\Gamma(f_J \to \gamma\gamma)$(keV)
$f_0^{II}(980)$	$0.999 - 0.021i$	0.12
$f_0^{III}(980)$	$0.977 - 0.060i$	0.35
$f_0(600)$	$0.549 - 0.230i$	0.76
$f_2(1270)(\lambda = 0)$	$1.272 - 0.087i$	0.66
$f_2(1270)(\lambda = 2)$		3.70

Table: Di-photon decay width of poles

$\lambda = 2$ dominates; $\Gamma_{f_2(1270)\to 2\gamma}(4.36keV) >$ $\Gamma(Pennington08)(3.82 \pm 0.30) > \Gamma(PDG)(3.03 \pm 0.35)$; $f_0^{II}(980)$ width agrees with M. R. Pennington, T. Mori, S. Uehara, Y. Watanabe, Eur. Phys. J.C56(2008)1; $\Gamma(f_0(600) \to 2\gamma)$ very small.



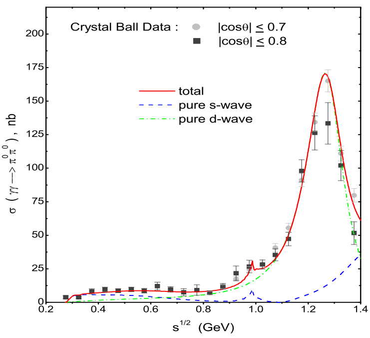
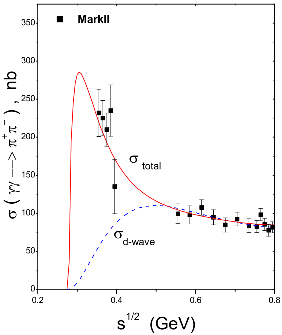


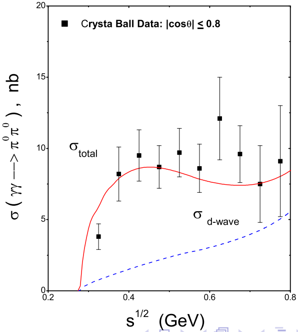
Figure: The coupled channel fit to the $\gamma\gamma \to \pi^+\pi^-$, $\pi^0\pi^0$ data.

A refined fit using single channel amplitude

T matrix from Zhou et al. 05

upto 800MeV; one parameter fit; others fixed by couple channel fit and treated as background.





χ^2	pole location	$\Gamma(\sigma \to \gamma\gamma)$ (keV)
0.8	$0.456 - 0.276i$	2.08

Table: One parameter fit up to 0.8GeV of data.

- Non $\bar{q}q$ meson.
- Chiral partner of Nambu-Goldstone bosons in a linearly realized chiral symmetry.

$g^2_{\sigma\pi\pi}$ couplings

T matrix from Zhou et al., JHEP 0502(2005)043$\Rightarrow$

$$M_\sigma = 457 MeV \ , \ \Gamma_\sigma = 551 MeV \ ,$$

and the residue:

$$g^2_{\sigma\pi\pi} = (-0.20 - 0.13i)\mathrm{GeV}^2 \ .$$

G. Mennessier, S. Narison, W. Ochs, Phys. Lett. B665(2008)205:

$$g^2_{\sigma\pi\pi} = (-0.25 - 0.06i)\mathrm{GeV}^2 \ .$$

$\mathrm{Re}[g^2] < 0$!

The PKU representation

$$S^{phy.} = S^{f_0(600)} \times \prod_i S^{R_i} \cdot S^{cut} .$$

$$S^R(s) = \frac{M^2(z_0) - s + i\rho(s)sG[z_0]}{M^2(z_0) - s - i\rho(s)sG[z_0]} ,$$

$$M^2(z_0) = \mathrm{Re}[z_0] + \frac{\mathrm{Im}[z_0]\,\mathrm{Im}[z_0\,\rho(z_0)]}{\mathrm{Re}[z_0\,\rho(z_0)]} ,\ G[z_0] = \frac{\mathrm{Im}[z_0]}{\mathrm{Re}[z_0\,\rho(z_0)]} .$$

Mainly a kinematical effect?: Neglecting everything rather than $f_0(600)$,

$$g^2_{\sigma\pi\pi} = (-0.18 - 0.20i)\mathrm{GeV}^2 .$$

More than a pure kinematical effect!

The O(N) model, v1

$$T^{00}(s) = \frac{1}{32\pi}\frac{s - m_\pi^2}{f_\pi^2 - (s - m_\pi^2)\left(\frac{1}{\lambda_0} + \widetilde{B}_0(s)\right)}$$

$$\widetilde{B}_0(p^2) = \frac{-i}{2}\int \frac{\mathrm{d}^4 q}{(2\pi)^4}\frac{1}{q^2 - m_\pi^2}\frac{1}{(p+q)^2 - m_\pi^2}$$

Renormalization:

$$\frac{1}{\lambda(M)} = \frac{1}{\lambda_0} - \frac{i}{2}\int \frac{d^4 q}{(2\pi)^4}\frac{1}{(q^2 + i\epsilon)(q^2 - M^2 + i\epsilon)}\,, \qquad (3)$$

$$\frac{1}{\lambda(M)} + \tilde{B}(p^2; M) = \frac{1}{\lambda_0} + \tilde{B}_0(p^2)\ .$$

$$\tilde{B}(s; M) = \frac{1}{32\pi^2}\left[1 + \rho(s)\log\frac{\rho(s) - 1}{\rho(s) + 1} - \log\frac{m_\pi^2}{M^2}\right]$$

Chivukula, Golden 92

$$\mu^2 \frac{d\lambda}{d\mu^2} = \frac{\lambda^2(\mu^2)}{32\pi^2} \ . \tag{4}$$

To define the theory:

$$\frac{1}{\lambda(M)} = 0 \ .$$

M denotes the scale where perturbation expansion fails –
The theory is still fine!
However, Tachyon occurs at m_t^2. Theory only works when $|s| << |m_t^2|$.

The O(N) model, v2

Sharp momentum cutoff at Λ:
No tachyon. Spurious cut and spurious pole nearby, instead.
Cutoff version of effective theory.
Set for example

$$\frac{1}{\lambda(\Lambda)} = 0 \ ,$$

defines (another) theory.

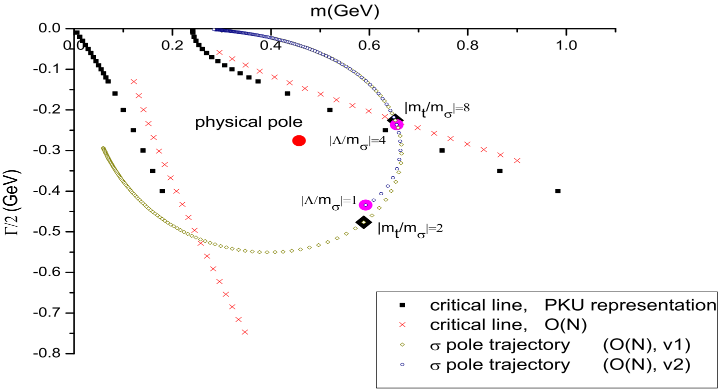


Figure: Region on the $\sqrt{s}$-plane with $\mathrm{Re}[g^2_{\sigma\pi\pi}] < 0$.

Furthermore, to get the 'real' sigma pole position, $\lambda(M)$ blows up at very low value:

$$\lambda(M \sim .55\mathrm{GeV}) = \infty \ .$$

Conclusion: The "σ" pole manifests the extreme 'nonperturbativity' that QCD could offer.

Thanks for patience!