

S-Wave Meson scattering and spectroscopy

M. Albaladej

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S-wave meson scattering up to 2 GeV and its spectroscopy

[M. Albaladejo, J.A. Oller arXiv:hep-ph/0801.4929]

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Introduction

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Objective and tools:

- Problem: Scalar mesons identification. How many? Where? Nature?
- Very broad resonances, strongly coupled channels open up in the nearby of resonances, which have very different natures: dynamically generated, $q\bar{q}$, glueballs...
- Our objective: study of strongly interacting channels with quantum numbers $I=0, I=1/2 J^{PC}=0^{++}$ for $\sqrt{s} < 2$ GeV.
- We use Chiral Lagrangians, implementing Unitarity (UCHPT) in a standard way (N/D-type equations).
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 - σσ states. Rescattering
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Lagrangians

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Our lagrangian is:

$$\mathcal{L} = \mathcal{L}_2 + \mathcal{L}_{S_8} + \mathcal{L}_{S_1}$$

- In SU(3) UCHPT, we have eight Goldstone bosons: π, K, η .
- Large N_c limit implies η' becomes the ninth Goldstone boson: $SU(3) \to U(3)$. [Herrera-Siklody et al, NP, B497, 345 (1997)], [Herrera-Siklody et al, PL, B419, 326 (1998)]

$$\mathcal{L}_{2} = rac{f^{2}}{4}\langle D_{\mu}U^{\dagger}D^{\mu}U
angle + rac{f^{2}}{4}\langle \chi^{\dagger}U + \chi U^{\dagger}
angle - rac{1}{2}M_{1}^{2}\eta_{1}^{2}$$

$$U(\phi) = \exp\left(i\sqrt{2}\Phi/f\right) \quad \Phi = \sum_{i=0}^{8} \frac{\lambda_i}{\sqrt{2}}\phi_i \quad \lambda_0 = \sqrt{\frac{2}{3}}\mathbf{I}_3$$

$$D_{\mu}U = \partial_{\mu}U - ir_{\mu}U + iUl_{\mu} = \partial_{\mu}U - ig\left[v_{\mu}, U\right]$$

- In our case, $r_{\mu}=l_{\mu}=gv_{\mu}$: vectorial resonances nonet (Massive Yang-Mills fields)
- Mixing: $\eta_1, \eta_8 \to \eta, \eta'$. Mixing angle is $\theta \approx -20^{\circ}$.
- $\chi = 2B_0 \mathcal{M}$, with \mathcal{M} quark mass matrix

Lagrangians (II)

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Lagrangians

Vector field v_u is given by:

$$v_{\mu} = \begin{pmatrix} \frac{\rho^{0}}{\sqrt{2}} + \frac{1}{\sqrt{6}}\omega_{8} + \frac{1}{\sqrt{3}}\omega_{1} & \rho^{+} & K^{*+} \\ \rho^{-} & -\frac{\rho^{0}}{\sqrt{2}} + \frac{1}{\sqrt{6}}\omega_{8} + \frac{1}{\sqrt{3}}\omega_{1} & K^{*0} \\ K^{*-} & \overline{K}^{*0} & -\frac{2}{\sqrt{6}}\omega_{8} + \frac{1}{\sqrt{3}}\omega_{1} \end{pmatrix}$$

Assuming ideal mixing between ω₈, ω₁:

$$\frac{1}{\sqrt{2}}\omega = \frac{1}{\sqrt{6}}\omega_8 + \frac{1}{\sqrt{3}}\omega_1 \qquad \phi = -\frac{2}{\sqrt{6}}\omega_8 + \frac{1}{\sqrt{3}}\omega_1$$

Derivative piece of \mathcal{L}_2 has interactions of: $\Phi\Phi$, $V\Phi\Phi$ y $VV\Phi\Phi$:

•
$$\mathcal{L}_{2}^{\Phi\Phi} = \frac{f^{2}}{4} \langle \partial_{\mu} U \partial_{\mu} U^{\dagger} \rangle$$

$$\mathcal{L}_{2}^{VV\Phi\Phi} = g^{2} \langle \Phi^{2} v^{\mu} v_{\mu} - v_{\mu} \Phi v^{\mu} \Phi \rangle$$

$$\bullet \ \mathcal{L}_{2}^{V\Phi\Phi} = -\frac{igf^{2}}{4} \langle \partial_{\mu}U[v^{\mu}, U^{\dagger}] + [v^{\mu}, U]\partial_{\mu}U^{\dagger} \rangle$$

• g is determined through decay width $\rho \to \pi\pi$, from $\mathcal{L}_2^{V\Phi\Phi}$, being g=4.23

Lagrangians (III)

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We introduce explicit resonances from RChPT [Ecker et al., NP, B321, 311 (1999)].

• Scalar resonances $J^{PC} = 0^{++}$:

$$\begin{array}{rcl} \mathcal{L}_{S_8} & = & c_d \left\langle S_8 u_\mu u^\mu \right\rangle + c_m \left\langle S_8 \chi_+ \right\rangle \\ \mathcal{L}_{S_1} & = & \tilde{c}_d S_1 \left\langle u_\mu u^\mu \right\rangle + \tilde{c}_m S_1 \left\langle \chi_+ \right\rangle \\ \chi_+ & = & u^\dagger \chi u^\dagger + u \chi^\dagger u, \\ U(x) = u(x)^2 & u_\mu = i u^\dagger D_\mu U u^\dagger = u^\dagger_\mu \end{array}$$

• $S_1^{(i)}$ singlet and $S_8^{(i)}$ octet scalar resonance, with M, c_d and c_m fitted to data.

$$S_8 = \left(egin{array}{ccc} rac{a_0}{\sqrt{2}} + rac{f_8}{\sqrt{6}} & a_0^+ & K_0^{*+} \ a_0^- & -rac{a_0}{\sqrt{2}} + rac{f_8}{\sqrt{6}} & K_0^{*0} \ K_0^{*-} & \overline{K}_0^{*0} & -rac{2}{\sqrt{6}}f_8 \ \end{array}
ight).$$

- Channels to be considered:
 - I = 0: $\pi\pi$, $K\overline{K}$, $\eta\eta$, $\sigma\sigma$, $\eta\eta'$, $\rho\rho$, $\omega\omega$, $\eta\eta'$, $\omega\phi$, $\phi\phi$, $K^*\overline{K}^*$, $a_1(1260)\pi$, $\pi^*\pi$
 - I = 1/2, I = 3/2: $K\pi$, $K\eta$ and $K\eta'$ [Jamin, Oller, Pich, NP, B622, 279 (2002)], [Jamin, Oller, Pich, NP, B587, 331 (2000)]



σσ channel amplitudes. Pion rescattering

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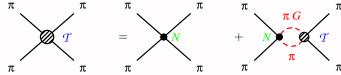
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We want to obtain $\sigma\sigma$ amplitudes starting from our lagrangian. σ is S-wave $\pi\pi$ interaction, $|\sigma\rangle=|\pi\pi\rangle_0$, [Oller, Oset, NP, B620, 438 (1997)]

- Pion rescattering, given by factor $D^{-1}(s) = (1 + t_2 G(s))^{-1}$, with:
 - $t_2 = \frac{s m_\pi^2/2}{f_\pi^2}$ basic $\pi\pi \to \pi\pi$ amplitude.
 - $(4\pi)^2 G(s) = \alpha + \log \frac{m_\pi^2}{\mu^2} \sigma(s) \log \frac{\sigma(s) 1}{\sigma(s) + 1}$, two pion loop.
- To isolate transition amplitude $N_{i o \sigma \sigma}$:

$$\lim_{s_i \to s_{\sigma}} \frac{T_{i \to (\pi\pi)_0(\pi\pi)_0}}{D_{II}(s_1)D_{II}(s_2)} = \frac{N_{i \to \sigma\sigma}g_{\sigma\pi\pi}^2}{(s_1 - s_{\sigma})(s_2 - s_{\sigma})}$$



σσ channel amplitudes. Pion rescattering

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• To isolate transition amplitude $N_{i\to\sigma\sigma}$:

$$\lim_{s_i \to s_\sigma} \frac{T_{i \to (\pi\pi)_0(\pi\pi)_0}}{D_H(s_1)D_H(s_2)} = \frac{N_{i \to \sigma\sigma}g_{\sigma\pi\pi}^2}{(s_1 - s_\sigma)(s_2 - s_\sigma)}$$

• Now as (σ pole) $D_{II}(s)^{-1}=(1+t_2G(s))^{-1}pprox rac{lpha_0}{s-s_\sigma}+\cdots$, then:

$$N_{a
ightarrow(\sigma\sigma)_0} = T_{a
ightarrow(\pi\pi)_0(\pi\pi)_0} \left(rac{lpha_0}{g_{\sigma\pi\pi}}
ight)^{2}$$

σσ channel amplitudes. Pion rescattering

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• Now as $(\sigma \text{ pole})$ $D_{II}(s)^{-1}=(1+t_2G(s))^{-1}\approx \frac{\alpha_0}{s-s_\sigma}+\cdots$, then:

$$N_{a
ightarrow(\sigma\sigma)_0} = T_{a
ightarrow(\pi\pi)_0(\pi\pi)_0} \left(rac{lpha_0}{g_{\sigma\pi\pi}}
ight)^2$$

• To calculate $(\alpha_0/g_{\sigma\pi\pi})^2$, consider $\pi\pi$ elastic scattering,

$$V = \frac{t_2(s)}{1 + t_2(s)G(s)} \approx -\frac{g_{\sigma\pi\pi}^2}{s - s_{\sigma}} + \cdots$$

So we can write, using that (σ pole) $g_{II}(s_{\sigma}) = -1/t_2(s_{\sigma})$:

$$\left(\frac{\alpha_0}{g_{\sigma\pi\pi}}\right)^2 = \frac{f^2}{1 - G'_{II}(s_{\sigma})f^2t_2(s_{\sigma})^2} \approx 1.1f^2$$

$\sigma\sigma$ channel amplitudes. Pion rescattering

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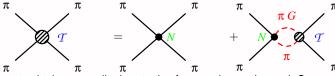
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$$\left(\frac{\alpha_0}{g_{\sigma\pi\pi}}\right)^2 = \frac{f^2}{1 - G'_{IJ}(s_{\sigma})f^2t_2(s_{\sigma})^2} \approx 1.1f^2$$

 In conclusion, we follow a novel method to calculate amplitudes involving σσ, through:

$$N_{a o (\sigma\sigma)_0} = T_{a o (\pi\pi)_0(\pi\pi)_0} \left(rac{lpha_0}{g_{\sigma\pi\pi}}
ight)$$



Coupled channels Unitarization

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Coupled channel partial wave

$$T = (I + N(s)g(s))^{-1}N(s)$$

- ullet N(s): N_{ij} amplitudes matrix, obtained from Lagrangian, $i,j=1,\dots 13$
- \bullet g(s): Unitarization loops (diagonal) matrix (including all intermediate states).

$$g_i(s) = g_i(s_0) - \frac{s - s_0}{8\pi^2} \int_{s_{\text{th},i}}^{\infty} ds' \frac{p_i(s')/\sqrt{s'}}{(s' - s_0)(s' - s + i\varepsilon)}$$

We fold this g(i) for the case of $\rho\rho$ and $\sigma\sigma$, following a mass distribution, due to large ρ and σ widths: $\Gamma_{\rho} \simeq 150$ MeV, $\Gamma_{\sigma} \simeq 500$ MeV

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	M (MeV)	c _d (MeV)	c _m (MeV)
$S_8^{(1)}$	1290 ± 5	25.8 ± 0.5	25.8 ± 1.1
S ₈ ⁽²⁾	1905 ± 13	20.3 ± 1.4	-13.9 ± 2.0
$S_1^{(1)}$	894 ± 13	14.4 ± 0.3	46.6 ± 1.1

- First octet $(M_8^{(1)}, c_d^{(1)}, c_m^{(1)})$ is fixed to the work in [Jamin, Oller, Pich, NP, B**622**, 279 (2002)], [Jamin, Oller, Pich, NP, B**587**, 331 (2000)]
- Second octet has only fixed its mass, $M_8^{(2)}$, but not its couplings.
- Singlet mass $M_1^{(2)} \lesssim 1$ GeV, but for lower values, we can obtain the same physics with higher couplings.
- Since SU(3) breaking is milder in the vector sector, we take just one substraction constant for the whole set of vector channels.

$$a_{\mathsf{PP}} = a_{\mathsf{W}\mathsf{W}} = a_{\mathsf{K}^{\star}\bar{\mathsf{K}}^{\star}} = a_{\mathsf{W}\mathsf{\Phi}} = a_{\mathsf{\Phi}\mathsf{\Phi}}$$

• Together, we have $a_{\pi\pi}$, $a_{K\bar{K}}$, $a_{\eta\eta}$, $a_{\eta\eta'}$, $a_{\eta'\eta'}$, $a_{\sigma\sigma}$ and $a_{\rho\rho}$

Total: just 12 free parameters, for 370 data points.

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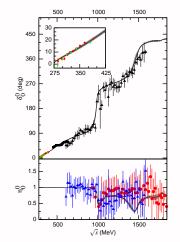
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- ππ → ππ: Although reaching energies of 2 GeV, description of low energy data is still very good
- ππ → KK̄: Near threshold, Cohen data are favored
- ππ → ηη,ηη': In good agreement for a low weight on χ². In addition, the data are unnormalized.
- $I = 1/2 K^- \pi^+ \to K^- \pi^+$ amplitude and phase from LASS.



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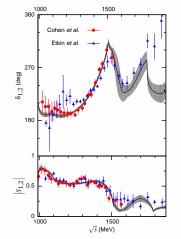
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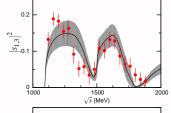
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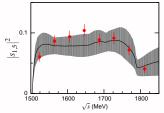
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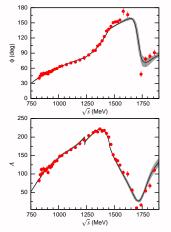
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No parametrization

We determine interaction kernels from Chiral Lagrangians, avoiding ad hoc parametrizations

Less free parameters

We have less free parameters, because of our chiral approach and our treatment of $\sigma\sigma$ amplitude

Higher energies

We have included enough channels to get at 2 GeV.

Compare with: [Lindenbaum, Longacre, PL, B274, 492 (1992)], [Kloet, Loiseau, ZP A353, 227 (1995)], [Bugg, NP B471, 59 (1996)]



Spectroscopy. Pole content: Summary

S-Wave Meson scattering and

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We move to the complex plane, exploring those Riemann sheets wich are continuosly connected to the physical s-real axis.

Resonance	I=0 Poles (MeV)	M (PDG)	Γ (PDG)
$\sigma \equiv f_0(600)$	$456 \pm 6 - i \ 241 \pm 7$		
$f_0(980)$	$983 \pm 4 - i \ 25 \pm 4$	980 ± 10	40 - 100
$f_0(1370)$	$1466 \pm 15 - i \ 158 \pm 12$	1200 - 1500	200 - 500
$f_0(1500)$	$1602 \pm 15 - i \ 44 \pm 15$	1505 ± 6	109 ± 7
$f_0(1710)$	$1690 \pm 20 - i \ 110 \pm 20$	1724 ± 7	137 ± 8
$f_0(1790)$ (BESII)	$1810 \pm 15 - i \ 190 \pm 20$	1790^{+40}_{-30}	270^{+30}_{-60}
Pesonance	I = 1/2 Poles (MeV)	M (PDG) I	(PDC)

Resonance	I = 1/2 Poles (MeV)	M (PDG)	I (PDG)
$\kappa \equiv K_0^*(800)$	$708 \pm 6 - i \ 313 \pm 10$	_	_
$K_0^*(1430)$	$1435 \pm 6 - i \ 142 \pm 8$	1414 ± 6	290 ± 21
$K_0^*(1950)$	$1750 \pm 20 - i \ 150 \pm 20$	_	_



Spectroscopy. Pole content: $f_0(1370)$

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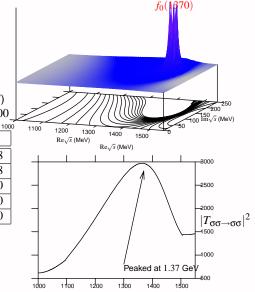
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$f_0(1370)$

 $\begin{array}{ccc} (1466\pm15-i\ 158\pm12)\ {\rm MeV} \\ {\rm PDG} & M\ ({\rm MeV}) & \Gamma\ ({\rm MeV}) \\ & 1200-1500 & 200-500 \end{array}$

Coupling	bare	final
$g_{\pi^+\pi^-}$	3.9	3.59 ± 0.18
$g_{K^0ar{K}^0}$	2.3	2.23 ± 0.18
$g_{\eta\eta}$	1.4	1.70 ± 0.30
$g_{\eta\eta'}$	3.7	4.00 ± 0.30
<i>g</i> η′η′	3.8	3.70 ± 0.40

- Shift in mass peak
- Strong couplings to σσ, ππ.





Spectroscopy. Pole content: $f_0(1370)$

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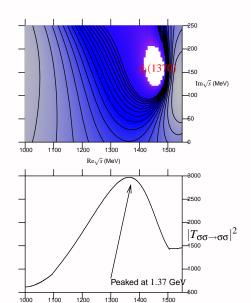
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$f_0(1370)$

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Spectroscopy. Pole content: $f_0(1370)$

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$f_0(1370) \ (I=0)$			$K_0^*(1430) \ (I=1/2)$		
Coupling	bare	final	Coupling	bare	final
$g_{\pi^+\pi^-}$	3.9	3.59 ± 0.18	<i>8K</i> π	5.0	4.8
$g_{K^0ar{K}^0}$	2.3	2.23 ± 0.18	gKη	0.7	0.9
gηη	1.4	1.70 ± 0.30	$g_{K\eta'}$	3.4	3.8
$g_{\eta\eta'}$	3.7	4.00 ± 0.30			
$g_{\eta'\eta'}$	3.8	3.70 ± 0.40			

- Bare coupling are very similar to the physical ones.
- Octet is $S_8^{(1)}$, with $M_8^{(1)}=1290$, $c_d^{(1)}=c_m^{(1)}=25.8$ MeV.
- The first scalar octet is a pure one, not mixed with the nearby $f_0(1500)$ and $f_0(1710)$

For instance, we have, for $\pi^+\pi^-$:

$$g_{\pi^+\pi^-} = \sqrt{\frac{2}{3}} \frac{c_d M_8^2 + 2(c_m - c_d) m_\pi^2}{f_\pi^2}$$



Spectroscopy. Pole content: $f_0(1500)$

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 $f_0(1500)$

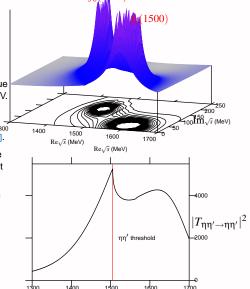
 $(1602 \pm 15 - i \ 44 \pm 15) \ \text{MeV}$

• The peak position is at 1.5 GeV due to the $\eta\eta'$ threshold, $\sqrt{s} \approx 1.5$ GeV.

 $\begin{tabular}{ll} \bullet & This is similar to the $a_0(980)$ because the $K\bar{K}$ threshold [Oller, Oset, PR, D $\bf 60$, 0740023 (1999)]. \\ \end{tabular}$

- $\Gamma=1.2\times 88\simeq 105$ MeV, because the BW at (1.6-i0.04) GeV is cut by the $\eta\eta'$ threshold.
- Complicated energy region. There are three interfering effects:
 - Pole at (1.6 i 0.04) GeV
 - $f_0(1370)$ pole (1.47 i0.16) GeV
 - Nearby ηη', ωω thresolds

 $M \ (\text{MeV}) \qquad \Gamma \ (\text{MeV})$ PDG $1505 \pm 6 \qquad 109 \pm 7$





Spectroscopy. Pole content: $f_0(1500)$

S-Wave Meson scattering and spectroscopy

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Amplitudes

Results

Spectroscopy

Summar

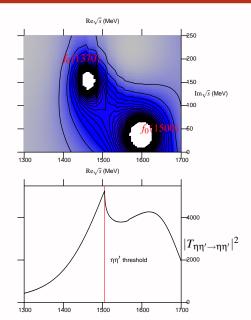
Spectrosc

 $f_0(1500)$

 $(1602 \pm 15 - i \ 44 \pm 15) \ \text{MeV}$

- The peak position is at 1.5 GeV due to the $\eta\eta'$ threshold, $\sqrt{s}\approx 1.5$ GeV.
- ullet This is similar to the $a_0(980)$ because the $K\bar{K}$ threshold [Oller, Oset, PR, D **60**, 0740023 (1999)].
- $\Gamma=1.2\times 88\simeq 105$ MeV, because the BW at (1.6-i0.04) GeV is cut by the $\eta\eta'$ threshold.
- Complicated energy region. There are three interfering effects:
 - Pole at (1.6 − i 0.04) GeV
 - $f_0(1370)$ pole (1.47 i0.16) GeV
 - Nearby ηη', ωω thresolds

 $\begin{array}{cc} & M \text{ (MeV)} & \Gamma \text{ (MeV)} \\ \text{PDG} & 1505 \pm 6 & 109 \pm 7 \end{array}$





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Two sigms

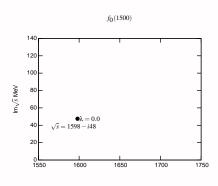
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- They are the same underlying pole, but reflected on different Riemann sheets
- They are not generated from preexisting resonances



Re√s MeV



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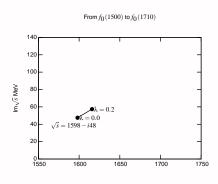
Amplitude:

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Re√s MeV



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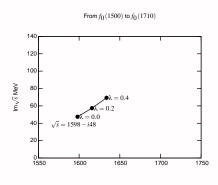
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Re√s MeV



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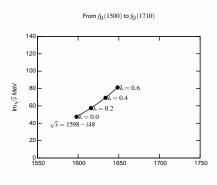
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Re√s MeV



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Amplitude

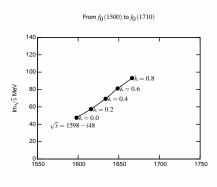
Results

Spectroscopy

Summai

<u>______</u>

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Re√s MeV



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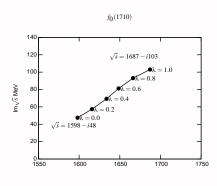
Amplitude unitarization

Results

Spectroscopy

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Re√s MeV

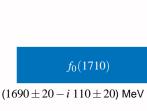


Spectroscopy. Pole content: $f_0(1710)$

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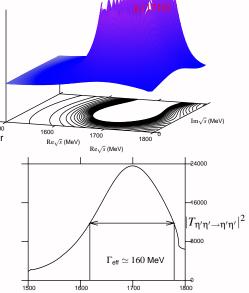
Spectroscopy

 $M ext{ (MeV)}$



- The peak is shifted to slightly higher energy, at 1700 MeV.
- The effective width can depend on the processes.
- $\Gamma_{\text{eff}} \simeq 160 \text{ MeV}$

 Γ (MeV) PDG 1724 + 7 137 ± 8





Spectroscopy. Pole content: $f_0(1710)$

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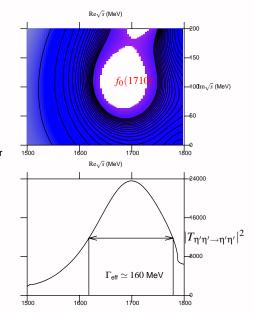
Spectroscopy

$f_0(1710)$

$$(1690 \pm 20 - i\ 110 \pm 20)\ \text{MeV}$$

- The peak is shifted to slightly higher energy, at 1700 MeV.
- The effective width can depend on the processes.
- $\Gamma_{\text{eff}} \simeq 160 \text{ MeV}$

$$\begin{array}{cc} & \textit{M} \; (\text{MeV}) & \Gamma \; (\text{MeV}) \\ \text{PDG} & 1724 \pm 7 & 137 \pm 8 \end{array}$$



Spectroscopy. Pole content: $f_0(1790)$

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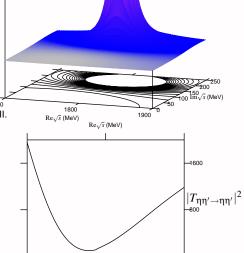
Spectrosco

$f_0(1790)$

 $(1810 \pm 15 - i\ 190 \pm 20)\ {
m MeV}$

- Weak signal on the real axis
 - It couples weakly to $K\bar{K}$, a major difference with respect to the $f_0(1710)$, as also observed by BESII.
- It is the partner of the pole at 1.75 i0.15 GeV in I = 1/2.
- These poles originate from the higher bare octet, $S_8^{(2)}$ with $M_8^{(2)} = 1905$, $c_d^{(2)} = 20.3$, $c_d^{(2)} = -13.9$ MeV.

$$\begin{array}{ccc} & M \text{ (MeV)} & \Gamma \text{ (MeV)} \\ \text{BESII} & 1790^{+40}_{-30} & 270^{+30}_{-60} \end{array}$$



1800

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1700

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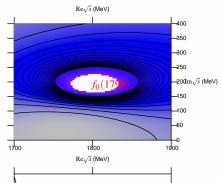
Spectrosco

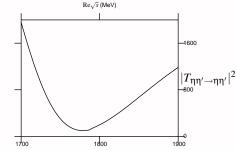
$f_0(1790)$

 $(1810 \pm 15 - i\ 190 \pm 20)\ {
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- Weak signal on the real axis
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$$M \text{ (MeV)} \qquad \Gamma \text{ (MeV)}$$
 BESII $1790^{+40}_{-30} \qquad 270^{+30}_{-60}$





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Coupling (GeV)	f0(1500)	$f_0(1710)$
$g_{\pi^+\pi^-}$	1.31 ± 0.22	1.24 ± 0.16
$g_{K^0\bar{K}^0}$	2.06 ± 0.17	2.00 ± 0.30
<i>g</i> ηη	3.78 ± 0.26	3.30 ± 0.80
$g_{\eta\eta'}$	4.99 ± 0.24	5.10 ± 0.80
$g_{\eta'\eta'}$	8.30 ± 0.60	11.7 ± 1.60

This pattern suggests an enhancement in $s\bar{s}$ production. With a pseudoscalar mixing angle $\sin\beta = -1/3$ for η and η' :

The $G_0 o qar q imes m_q$ chiral suppresion [Chanowitz, PRL95, 172001 (2005)] implies $|g_{ss}| \gg |g_{nn}|$. This together with the OZI rule requires $|g_{ss}| \gg |g_{ns}|$



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Coupling (GeV)	f0(1500)	$f_0(1710)$
gss	11.5 ± 0.5	13.0 ± 1.0
g _{ns}	-0.2	2.1
gnn	-1.4	1.2
$g_{ss}/6$	1.9 ± 0.1	2.1 ± 0.2

f0(1500)	$f_0(1710)$
1.31 ± 0.22	1.24 ± 0.16
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This pattern suggests an enhancement in $s\bar{s}$ production. With a pseudoscalar mixing angle $\sin \beta = -1/3$ for η and η' :

$$g_{\eta'\eta'} = \frac{2}{3}g_{ss} + \frac{1}{3}g_{nn} + \frac{2\sqrt{2}}{3}g_{ns} \qquad \qquad \eta = -\frac{1}{\sqrt{3}}\eta_s + \sqrt{\frac{2}{3}}\eta_u$$

$$g_{\eta\eta'} = -\frac{\sqrt{2}}{3}g_{ss} + \frac{\sqrt{2}}{3}g_{nn} + \frac{1}{3}g_{ns} \qquad \qquad \eta' = -\sqrt{\frac{2}{3}}\eta_s + \frac{1}{\sqrt{3}}\eta_u$$

$$g_{\eta\eta} = \frac{1}{3}g_{ss} + \frac{2}{3}g_{nn} - \frac{2\sqrt{2}}{3}g_{ns} \qquad \qquad \eta_s = s\bar{s} \qquad \eta_u = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}}$$

The $G_0 o qar q ext{ } \sim m_q$ chiral suppresion [Chanowitz, PRL95, 172001 (2005)] implies $|g_{ss}| \gg |g_{nn}|$. This together with the OZI rule requires $|g_{ss}| \gg |g_{ns}|$

This is precisely what we obtain from the previous couplings and equations



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Now let us consider the $K\bar{K}$ coupling

- Valence quarks: K^0 corresponds to $\sum_{i=1}^3 \bar{s}_i u^i/\sqrt{3}$, and analogously \bar{K}^0
- The production of a colour singlet $s\bar{s}$ requires the combination of the colour indices of K^0 , \bar{K}^0
- Decompose $\bar{s}_i s^j = \delta^j_i \bar{s} s/3 + (\bar{s}_i s^j \delta^j_i \bar{s} s/3)$ and similarly $\bar{u}_i u^j$
- Only $s\bar{s}\,u\bar{u}$ contributes (factor 1/3) and $s\bar{s}\,s\bar{s}$ has an extra factor 2 compared to $s\bar{s}\,u\bar{u}$, so one expects $g_{K^0\bar{K}^0}=g_{s\bar{s}}/6$



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Wich is the origin of this $\bar{s}s$ enhanced production: chiral suppression mechanism for a glueball or the OZI rule for a $\bar{s}s$?

Arguments favouring the first interpretation for the $f_0(1500)$ - $f_0(1710)$:

- $f_0(1370)$ does not mix, is pure I=0 octet state
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- ② If $f_0(1370)$ were an $n\bar{n}$, then OZI rule would suggest $f_0(1500)$ – $f_0(1710)$ to be an $s\bar{s}$. However, $f_0(1370)$ remains as pure octet.
- Unquenched lattice calculations give the mass and the couplings [Sexton, Vaccarino, Weingarten, PRL 75, 4563 (1995)] of the lightest 0⁺⁺ glueball.
 - Mass [Chen et al, PRD, 73, 014516 (2006)

$$M_{0^{++}}^{90} = 1.66 \pm 0.05 \text{ GeV}$$
 $M_{f_0} = 1.69 \pm 0.02 \text{ GeV}$

 Couplings are calculated in the SU(3) limit and are linear in the pseudoscalar mass squared in agreement with chiral suppresion mechanism [Chanowitz, PRL95, 172001 (2005)]



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> M. Albalad

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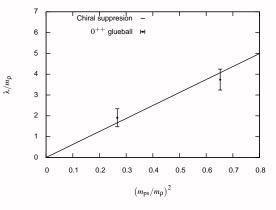
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- We have performed the first coupled channel study of the meson-meson S-waves for I=0 and I=1/2 up to 2 GeV with 13 coupled channels
 - ullet We determine our interaction kernels from Chiral Lagrangians, implemented in N/D-type coupled channel equations
- We have many less free parameters, compared with previous work in the literature, for a vast quantity of data
- We generate all scalar resonances below 2 GeV: σ , $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ and $f_0(1790)$ for I=0 and κ , $K_0^*(1430)$ and $K_0^*(1950)$ for I=1/2
- The structure of the couplings to pairs of pseudoscalars implies that:
 - $f_0(1370)$, $K_0^*(1430)$ (and $a_0(1450)$) remain as pure octet
 - \bullet $f_0(1500)$ and $f_0(1710)$, which are the same pole reflected on different sheets
 - Their decays show an enhanced s\$\bar{s}\$ production, in agreement with the chiral supression mechanism of [Chanowitz, PRL95, 172001 (2005)], so
 - They should be considered as the lightest 0⁺⁺ glueball



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Thank you for your attention!



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With s_{σ} complex, $N_{i \to \sigma \sigma}$ would be complex, thus violating unitarity. So we take s_i real, but varying according to a mass distribution.

Lehman propagator representation (dispersion relation):

$$P(s) = -rac{1}{\pi} \int_{\sqrt{s_{ ext{th}}}}^{\infty} \mathrm{d}s' rac{ ext{Im} P(s')}{s - s' + i \epsilon},$$

In a first approach:

$$\begin{array}{rcl} {\rm Im} P(s') & \propto & {\rm Im} \left(\frac{1}{s' - m_{\sigma}^2 + i \; m_{\sigma} \Gamma_{\sigma}(s')} \right) \\ \\ \Gamma_{\sigma}(s') & = & \Gamma_{\sigma} \sqrt{\frac{1 - 4 m_{\pi}^2/s'}{1 - 4 m_{\pi}^2/m_{\sigma}^2}} \\ \int_{\sqrt{s}_{\rm th}}^{\infty} {\rm d}s' {\rm Im} P(s') & = & 1 \end{array}$$

• g(s) (unitarity loop) for σ channel can be written as:

$$\int_{\sqrt{s_{\rm th}}}^{\infty} \mathrm{d}s_1 \int_{\sqrt{s_{\rm th}}}^{\infty} \mathrm{d}s_2 \mathrm{Im} P(s_1) \mathrm{Im} P(s_2) \; g_4(s;s_1,s_2) \; ,$$



Spectroscopy, poles and Riemann sheets

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- When parameters are fitted to data, we extrapolate our amplitudes to the s-complex plane, finding poles, and we identify them with resonances through $\sqrt{s_0} \approx M i\Gamma/2$.
- Analytical extrapolations are needed in the T_{ij} to the different Riemann sheets, which appear because of the cuts in G(s) at opening thresholds:

$$p(s) = \frac{\sqrt{s - (m_a + m_b)^2} \sqrt{s - (m_a - m_b)^2}}{2\sqrt{s}}$$

• Using continuity, for \sqrt{s} real, $> m_a + m_b$, we have:

$$G^{II}(s+i\varepsilon) = G(s-i\varepsilon) = G(s+i\varepsilon) - 2i \operatorname{Im}G(s+i\varepsilon) = G(s+i\varepsilon) + \frac{i}{4\pi} \frac{p(s)}{\sqrt{s}}$$

Other amplitudes

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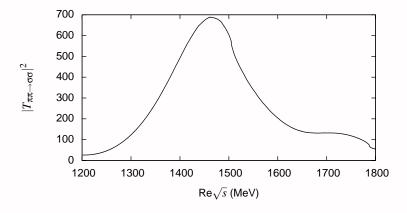
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Amplitude

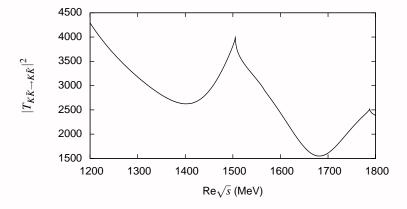
Results confront experimer

Spectrosco

Summar

Width effect







Argand diagram

S-Wave Meson scattering and spectroscopy

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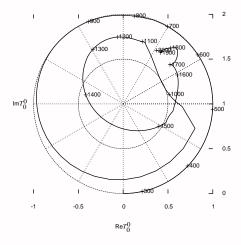
confront experimen

Op000:0000|

Summar

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Spectroscopy





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