Hadronic Resonances Generated from the Dynamics of the Light Scalar Ones

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In collaboration with

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1. Introduction
2. Formalism and Applications
3. Conclusions

1. Introducion

Chiral Symmetry of the QCD Lagrangian is spontaneoulsy broken

The lightest pseudoscalars π, K, η are the associated Goldstone bosons

These pseudoscalars interact among them and give rise to the Lightest Scalar Resonances

$f_0(980)$, $a_0(980)$, σ or $f_0(600)$, κ Oller, Oset 1997–

These scalar themselves interact with the pseudoscalars and give rise to New Excited Pseudoscalars

$\eta(1295)$,$\eta(1405)$,$\eta(1475)$,$\eta(1760)$,$X(1835)$,$K(1460)$,$K(1830)$,$\pi(1300)$, $\pi(1800)$ Albaladejo,Roca,Oller forthcoming

TOWER OF RESONANCES ...

The scalars could also interact with the vectors:

$f_0(980)\phi(1020) \to Y(2175)$ or $\phi(2170)$ Álvarez-Ruso,Alarcón,Oller PRD80(2010)054011

$a_0(980)\phi(1020)$ Álvarez-Ruso,Alarcón,Oller forthcoming

We arrive to the 2 GeV Region (QCD asymptotic?) Albaladejo,Oller PRL(2008)

The Y(2175) was recently observed by BABAR(2006), BES(2008), BELLE(2009)

Interest was triggered

$\eta(1405)$ It does not fit in quark model ($\eta(1295)$, $\eta(1475)$). PDG, Close, Farrar, Z. Li PRD(1997)

It couples mainly to $a_0(980)\pi$

Its mass is too low for glueball/hybrid. Lattice QCD Morningstar,Peardon (1999), Michael,MacNeil (2006), QCD Sum Rules Narison PLB(2009).

There were proposals of corresponding to a gluino-gluino bound state Farrar PRL(1996)

$\eta(1475)$ more standard. It couples strongly to $s\bar{s}$, seen in $\gamma\gamma$

$X(1835)$ Recently observed by BES PRL(2003, 2005) in $\pi\eta\eta'$ ($a_0(980)\eta'$). Omitted ST

Produces enhancement at threshold for $p\bar{p}$. The most likely assignment is $J^{PC} = 0^{-+}$

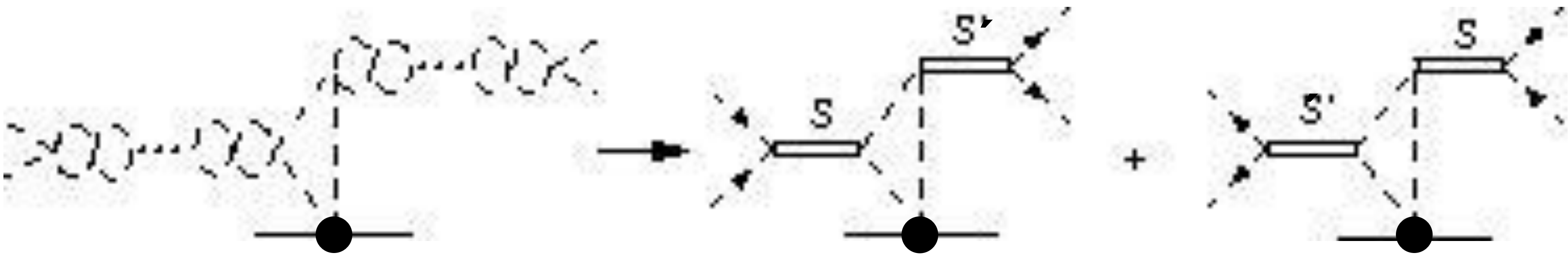
Broad resonances in $I = 1$ $\pi(1300)$, $\pi(1800)$ with $\Gamma = 0.2 - 0.3$ GeV

$K(1460)$ I=1/2, wide (omitted ST)

2. Scalar Pseudoscalar Scattering

Basic mechanism for the Interaction Kernel $PS(k) \to QS'(k')$

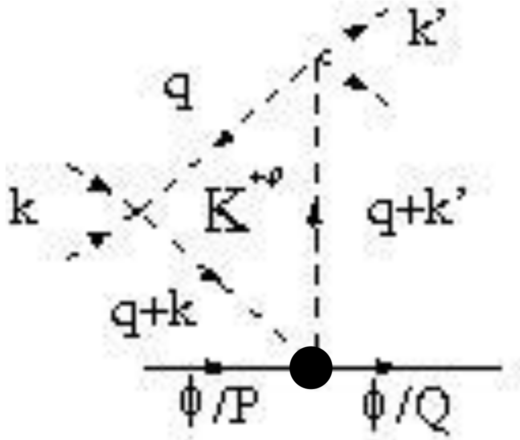
S, $S' = f_0(980)$ or $a_0(980)$

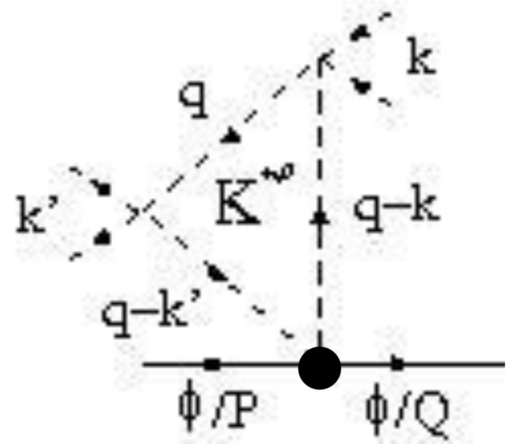


$f_0(980)$, $a_0(980)$ are dynamically generated resonances from the interactions of S-wave states with two pseudoscalar

● Full S-wave meson-meson interaction

Weinstein, Isgur PRL(1982), PRD(1990). Quark Model
Jansen et al. PRD(1995). Meson-Exchange Jülich Model
Oller, Oset NPA(1997), PRD(1999). Unitary ChPT





$\{k^2 = m_S^2,\, k'^2 = m_S^2\} \simeq 4m_K^2$

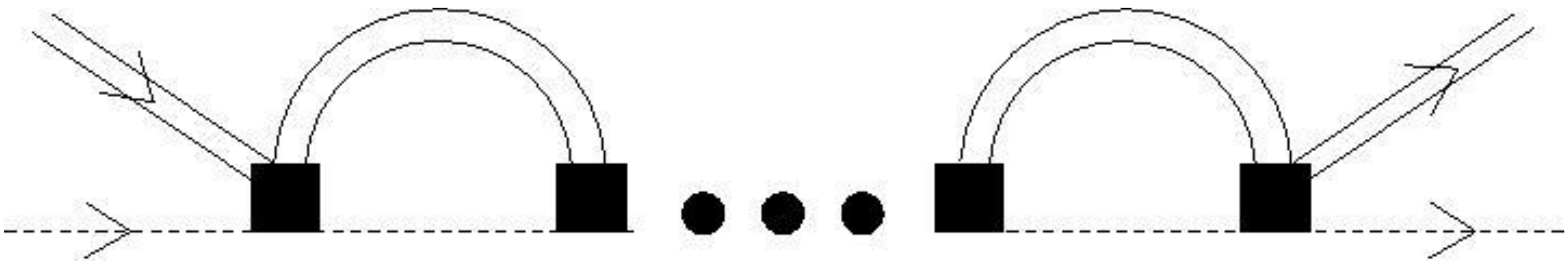
Near threshold scattering

$k \simeq k'$. One of the two kaon-propagators on the bottom is almost on-shell

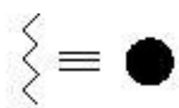
$\sim \frac{1}{\sqrt{m_S^2/4 - m_K^2}}$

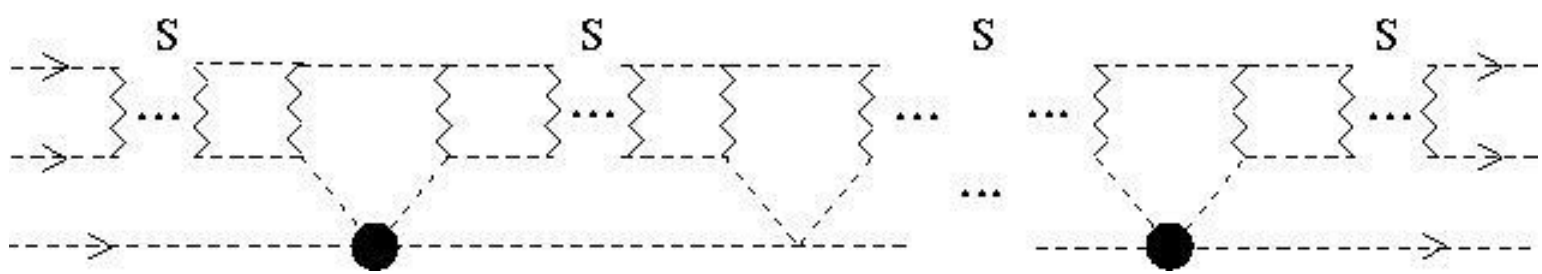
It is then very large

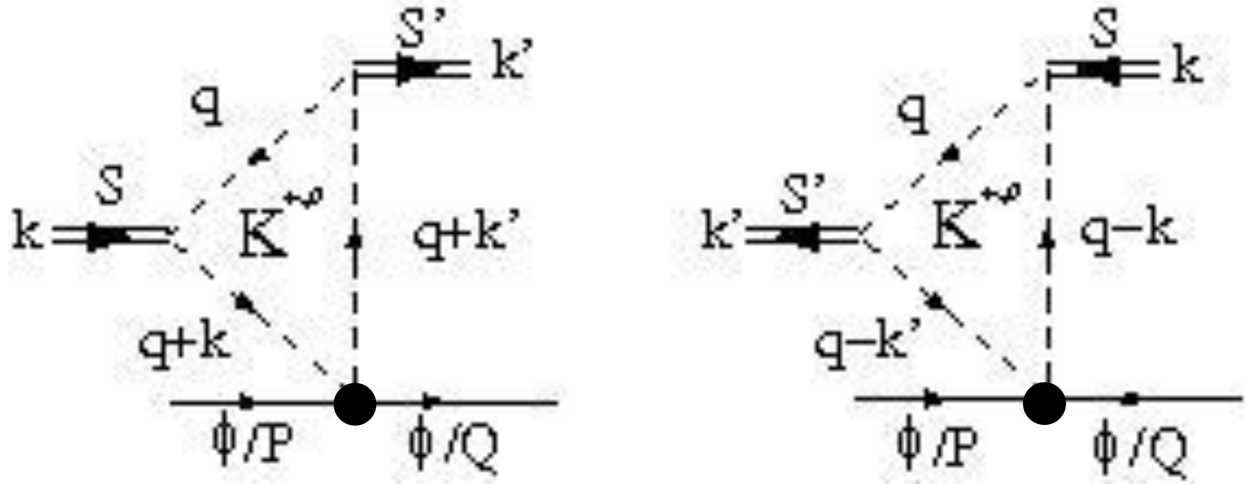
Iteration of the Interaction Kernel: Scalar-Pseudoscalar Intermediate States



Three-Body Scattering Like Diagrams







Note: The Full Dot is a NON-PERTURBATIVE Amplitude.

S-wave Meson-Meson Partial Wave for I=0, 1/2, 1, 3/2, 2

$I = 0 : \pi\pi,\ K\bar{K},\ \eta\eta,\ \eta\eta',\ \eta'\eta'$
$I = 1 : \pi\eta,\ K\bar{K},\ \pi\eta'$
$I = 1/2 : K\pi,\ K\eta,\ K\eta'$

It Contains the poles of $f_0(980)$, $a_0(980)$, σ and κ

Oller,Oset NPA(1997),PRD(1998); Jamin, Oller, Pich NPB(2002), see Zhi-Hui Guo's talk Unitarized U(3)×U(3) CHPT.

These amplitudes are obtained from Unitary CHPT

. Oller, Meissner PLB(2001)

Applied also to meson-baryon, baryon-baryon interactions, Final State Interactions Corrections, QCD Sum Rules, nuclear matter, etc

Meson-meson partial waves fulfill a once-subtracted dispersion relation:

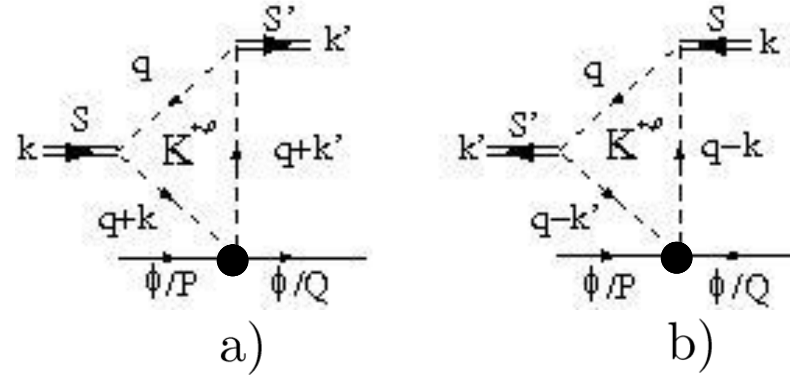
$$T(s) = T(s_1) + \sum \frac{s - s_1}{s - s_P} \frac{Res[T(s_P)]}{s_P - s_1} + \frac{s - s_1}{\pi} \int_{s_{th}}^{\infty} ds' \frac{\text{Im}[T(s')]}{(s' - s)(s' - s_1)}$$

Deep far away poles (Do not give imaginary part along the real s-axis)

. Right Hand Cut

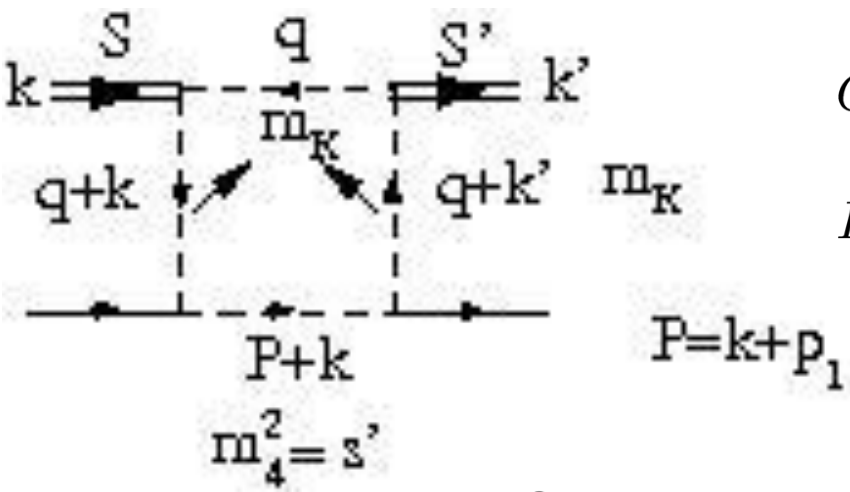
s_1 is the subtraction point. $T(s_1)$ is the subtraction constant

When inserted in the triangle diagram:



$$i \int \frac{d^4q}{(2\pi)^4} \frac{T[(\mathcal{P}+q)^2]}{(\ell^2 - m^2 + i\epsilon)((k+q)^2 - m^2 + i\epsilon)((k'+q)^2 - m^2 + i\epsilon)}$$

The Disperssive Integral and Poles give rise to the Box Diagram: $s \to (\mathcal{P}+q)^2$



C_3: S-wave projected 3-point loop

$D_4(m_4^2)$: S-wave projected 4-point loop

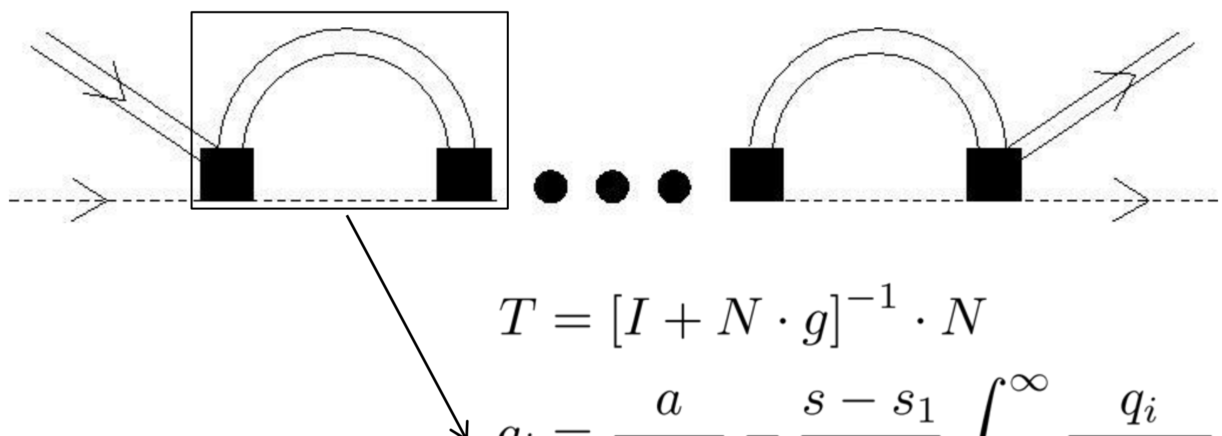
Note: m_4^2 can be positive or negative (and even complex)

$$C_3\Big[T(s_1)+\sum\frac{Res[T(s_P)]}{s_P-s_1}\Big]+\sum Res[T(s_P)]D_4(s_P)$$
$$+\frac{1}{\pi}\int_{s_{th}}^{\infty}ds'\mathrm{Im}T(s')\Big[\frac{C_3}{s_1-s'}-D_4(s')\Big]$$

Multiply by $g_{SK\bar{K}}\,g_{S'K\bar{K}}$

Sum over all isospin: e.g. $f_0K^+\to f_0K^+$ one has $\frac{3}{2}T_{I=1}+\frac{1}{2}T_{I=0}$

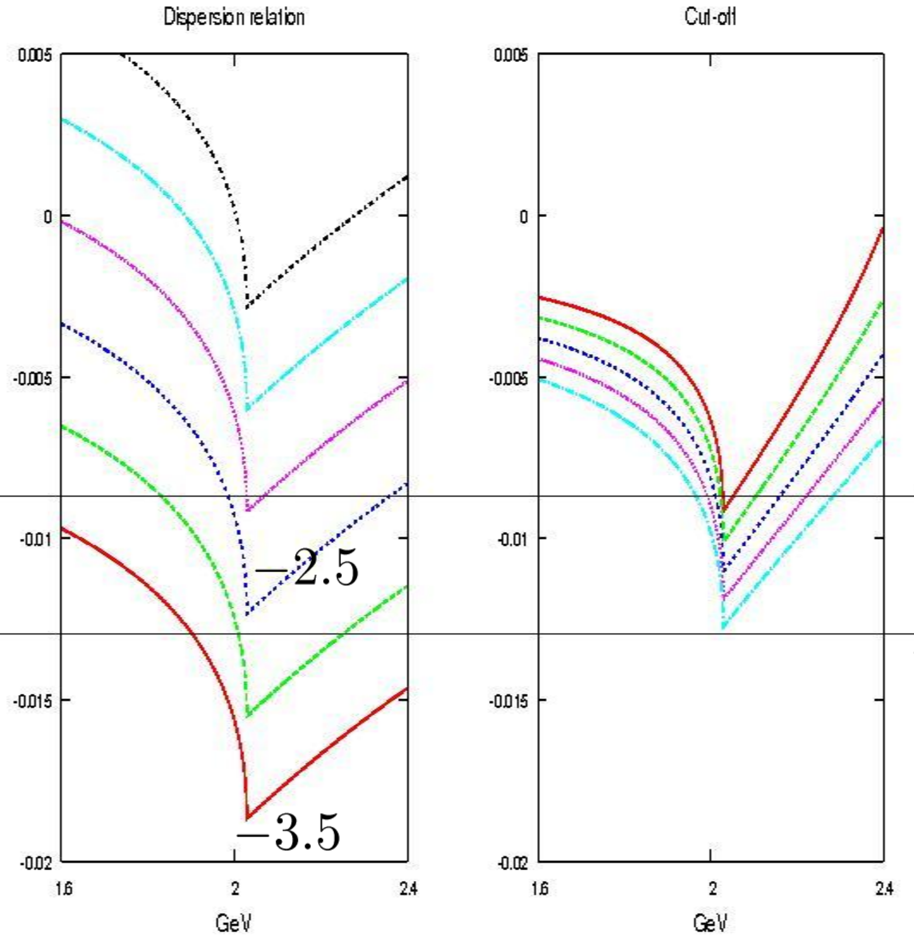
For diagram b) $k^2\leftrightarrow {k'}^2$



Done following Unitary ChPT

$$T=[I+N\cdot g]^{-1}\cdot N$$
$$g_i=\frac{a}{16\pi^2}-\frac{s-s_1}{\pi}\int_{s_{th}}^{\infty}\frac{q_i}{8\pi\sqrt{s'}}\frac{1}{(s'-s-i\epsilon)(s'-s_1)}$$
$$g=diag(g_1,g_2,\ldots,g_n)$$

Natural values:
$-2.5 \lesssim a \lesssim -2.0$



$q_{max} \in [0.8, 1.2]$ GeV

Typical Hadronic Scale,
$1/\Lambda_\chi \simeq 0.2 fm^{-1}$

Unitarity Scale: $\Lambda_U = \frac{4\pi f_\pi}{\sqrt{|a|}}$

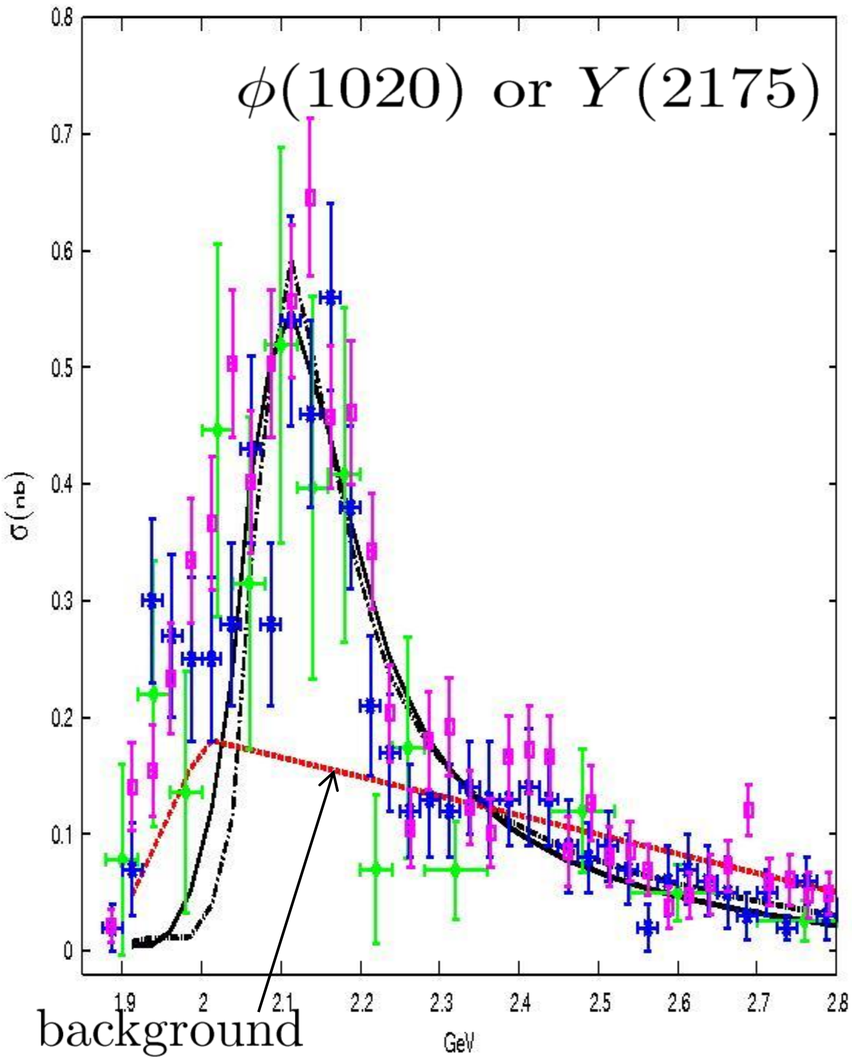
a	-3	-2.5	-2.0	-1.5
Λ_U (GeV)	0.67	0.73	0.82	0.95

The resonances generated qualify as “Dynamically Generated Ones”

Álvarez-Ruso, Alarcón, Oller
PRD80(2009)054011

g^2 characteristic of
$\phi K \to \phi K$ scattering

$e^+e^- \to \phi(1020) f_0(980)$



GeV	a	$\sqrt{-g^2}$
$M_{f_0} = 0.980$	-2.41 ± 0.14	7.33 ± 0.30
$M_{f_0} = 0.988$	-2.61 ± 0.14	5.21 ± 0.12

Maximum of $|T_{\phi f_0}|^2$:
$M_\phi = 2090$ MeV and $\Gamma = 150$ MeV

BELLE (2009):
$M_\phi = 2079 \pm 13^{+79}_{-28}$ MeV
$\Gamma_\phi = 192 \pm 23^{+25}_{-61}$ MeV

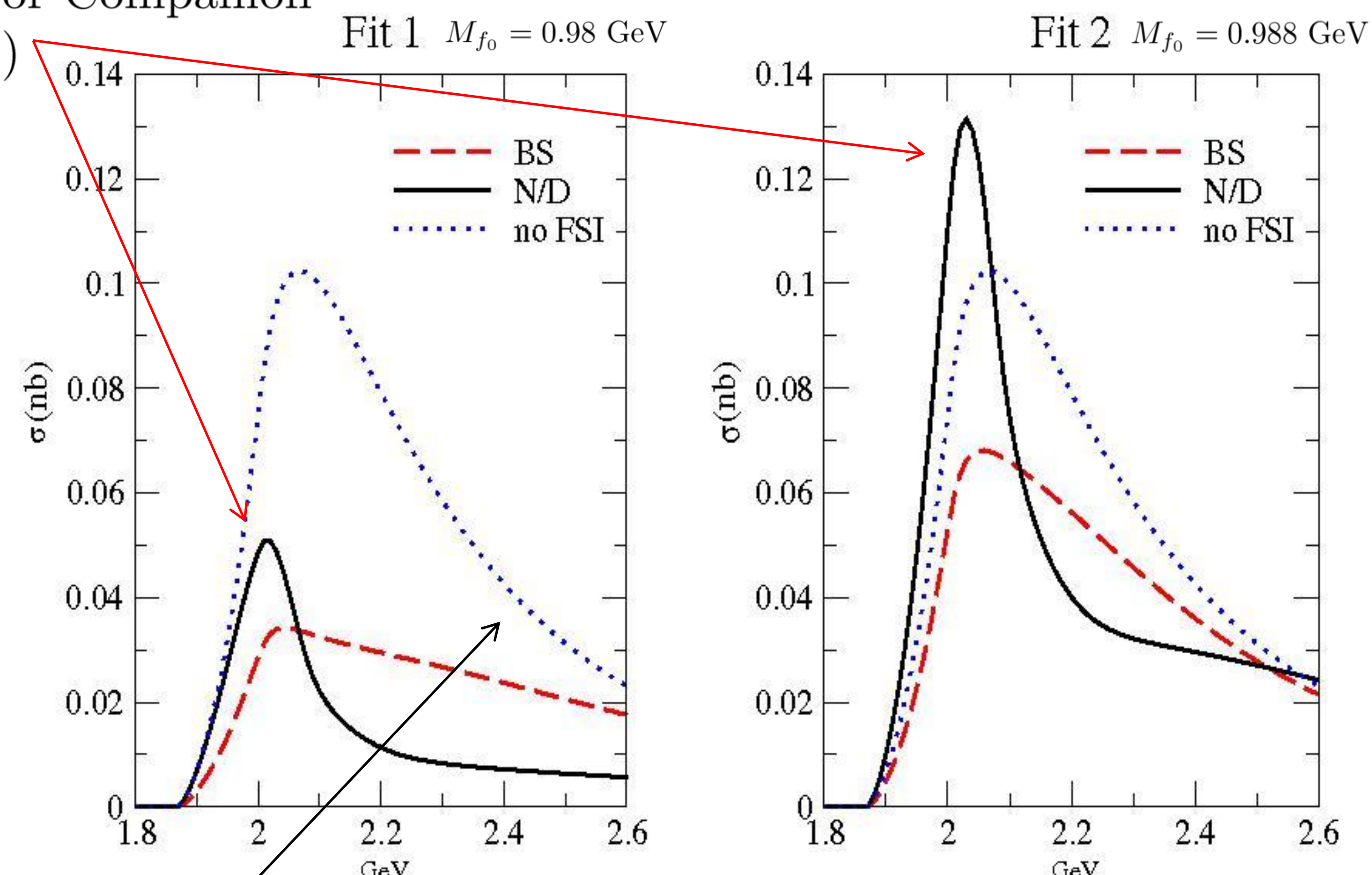
BABAR (2006):
$M_\phi = 2175 \pm 18$ MeV
$\Gamma_\phi = 58 \pm 16 \pm 20$ MeV

$e^+e^- \to \phi(1020)a_0(980)$ Álvarez-Ruso, Alarcón, Oller forthcoming

N/D: Oller,Oset PRD60(1999)
$a_0(980)$ Pole: (1.055,0.025) GeV

BS: Oller,Oset NPA620(1997)
$a_0(980)$ Pole: (1.009,0.056) GeV

Isovector Companion
$\phi(2170)$



background: Vaquera-Araujo,Napsuciale PLB681(2009)434

$e^+e^- \to \phi(1020)\pi^0\eta$

N/D is preferred $\rightarrow$ Existence of threshold resonane in $\phi(1020)a_0(980)$

$\phi(1020) \rightarrow \gamma K^0 \bar{K}^0$

Oller, NPA714(2003)161

$BR(\phi \rightarrow \gamma K^0 \bar{K}^0) = 3.17 \times 10^{-8}$ with BS

$BR(\phi \rightarrow \gamma K^0 \bar{K}^0) = 6.43 \times 10^{-9}$
with a_0 pole as in N/D

KLOE Collaboration PLB679(2009)10:

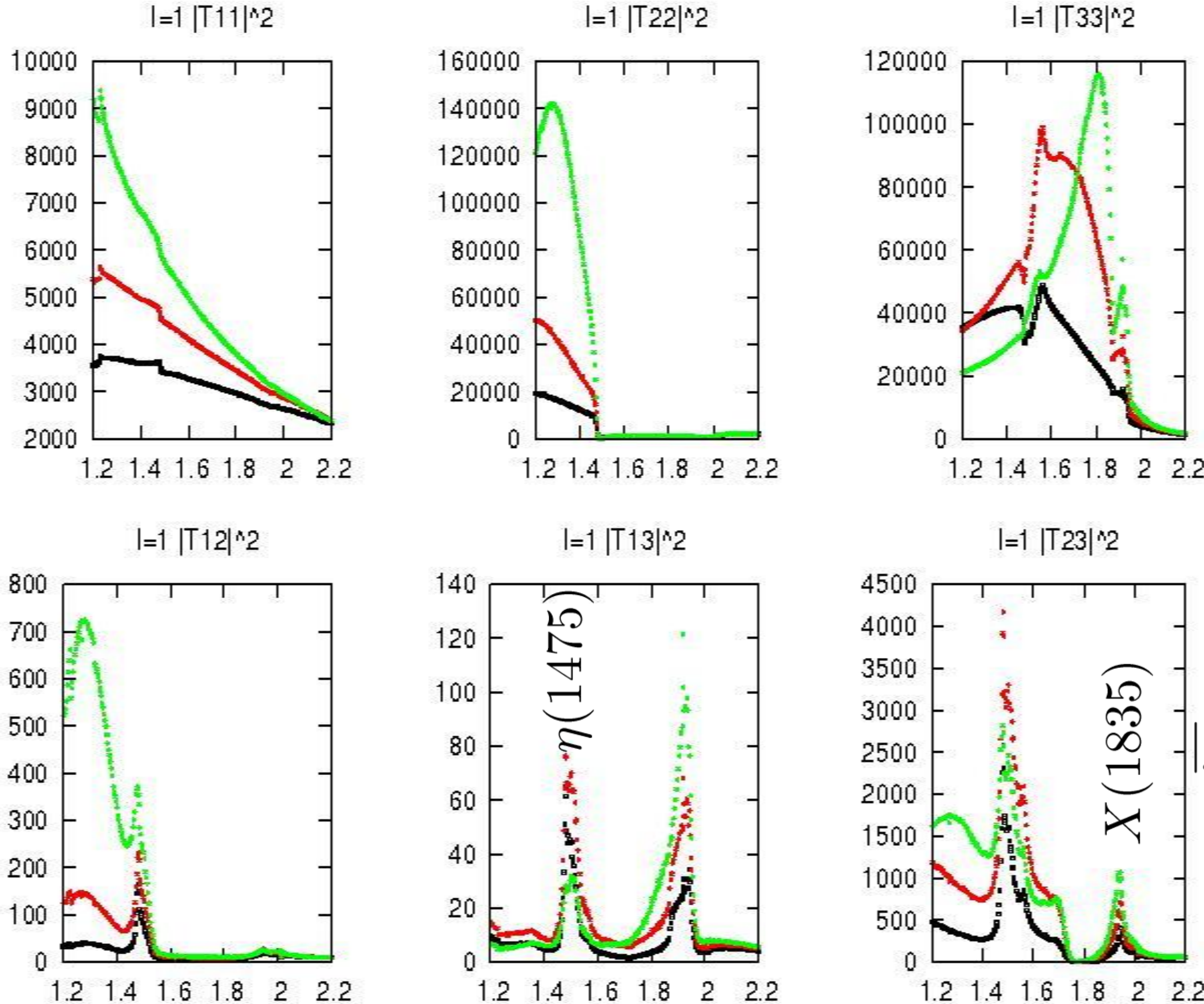
$BR(\phi \rightarrow \gamma K^0 \bar{K}^0) < 1.9 \times 10^{-8}$

N/D is a later more complete approach than BS

(1) $a_0(980)\pi$
(2) $f_0(980)\eta$
(3) $f_0(980)\eta'$

$J^{PC} = 0^{-+}$ $\eta-$channel

$a = -2.5$ ●
$a = -2.0$ ●
$a = -1.5$ ●



Wide Bumps
at the $\eta(1295)$ position

No $\eta(1405)$

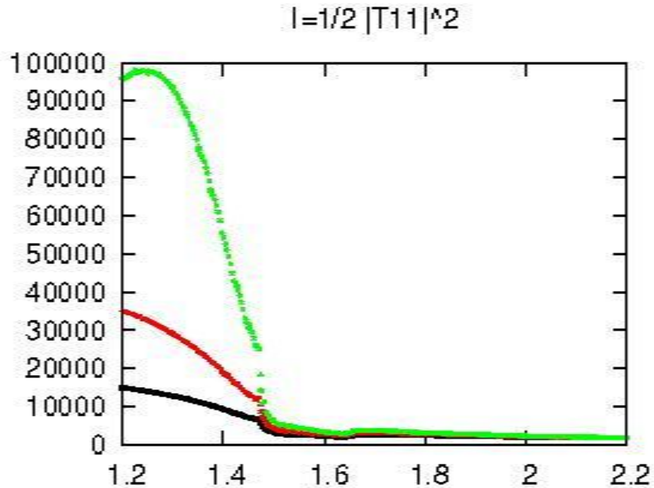
$|g_3|^2 \simeq 1.3|g_2|^2 \simeq 9|g_1|^2$

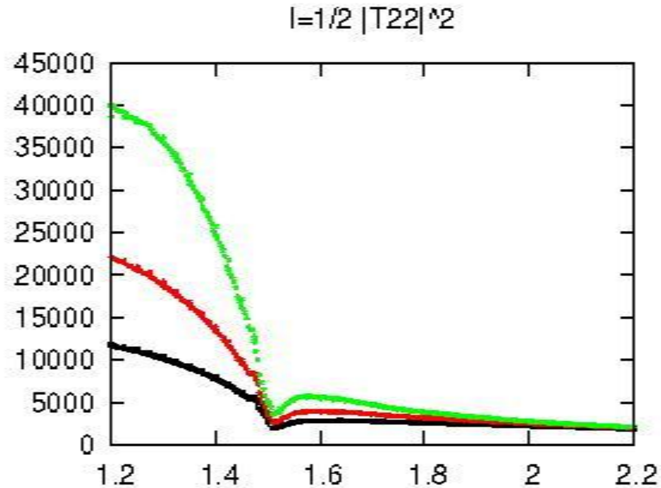
$|g_2|^2 \simeq 5|g_3|^2 \simeq 7|g_1|^2$

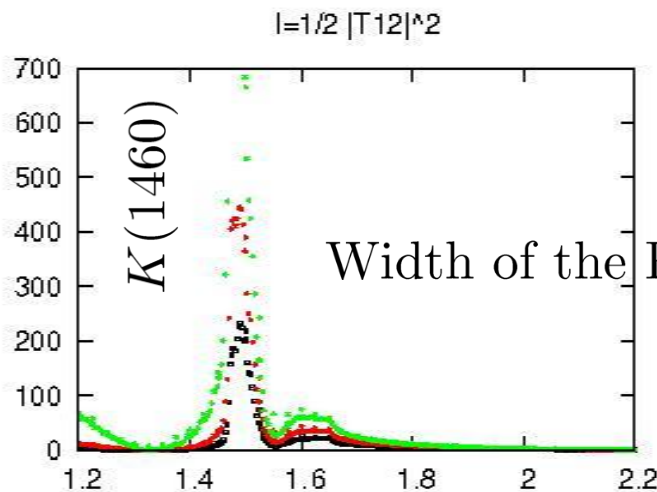
(1) $f_0(980)K$
(2) $a_0(980)K$

$J^P = 1/2^-$ $K-$channel

$a = -2.5$ ●
$a = -2.0$ ●
$a = -1.5$ ●







Width of the Peak around 100 MeV

(1) $f_0(980)\pi$
(2) $a_0(980)\eta$
(3) $a_0(980)\eta'$

$J^{PC} = 0^{-+}$ $\pi-$channel

$a = -2.5$ ●
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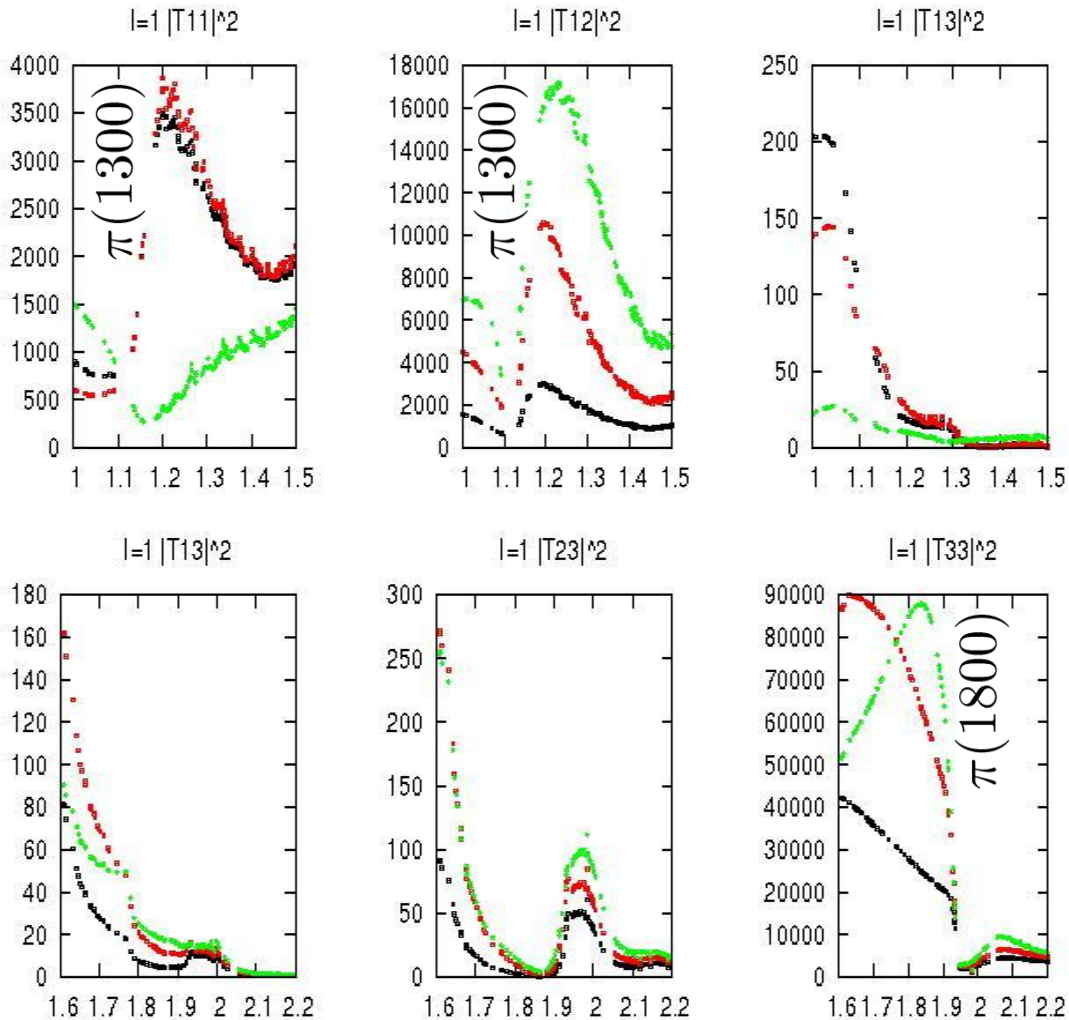

Green Lines:
Clear $\pi(1800)$ signal
$|g_3|^2 >> |g_1|^2,\ |g_2|^2$

$\pi(1300)$

Black lines	$\lvert g_2\rvert^2 \simeq \lvert g_1\rvert^2 \gg \lvert g_3\rvert^2$
Red lines	$\lvert g_2\rvert^2 \simeq 3\lvert g_1\rvert^2 \gg \lvert g_3\rvert^2$
Green lines	$\lvert g_2\rvert^2 \gg \lvert g_1\rvert^2,\ \lvert g_3\rvert^2$

3. Conclusions

• Calculation of Interaction Kernels between Scalar and Vector Resonances and between Scalar and Pseudoscalar ones

• No free parameters for the Scalar-Pseudoscalar case and one, g^2, for Scalar-Vector interactions.
Concatenation Light Pseudoscalars→Scalars (1 GeV)→Excited Pseudoscalars

• Dynamical Generation of $\phi(2170)$ and Prediction for the Existence of its Isovector Companion

• Dynamical Generation of Excited Pseudoscalar Resonances
Peaks with Mass and Width and Properties in Correspondence with $\eta(1475)$, $X(1835)$, $K(1460)$, $\pi(1300)$ and $\pi(1800)$

• Future: Vector-Pseudoscalar will be Included and Coupled with the Scalar-Pseudoscalar ones