Meson and Baryon Resonances

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Hidden gauge formalism for vector mesons, pseudoscalars and photons

Derivation of chiral Lagrangians

Vector-pseudoscalar interactions. The case for two K_1 axial vector states

Vector-vector interaction. New meson resonances, f_0, f_2, ….

Meson baryon molecules. New challenges for the two $\Lambda(1405)$ resonances

Progress unraveling the nature of resonances

Vector baryon molecules

Systems of two mesons and a baryon. New insight into $\frac{1}{2}^+$ baryon resonances

PANIC2008

Hidden gauge formalism for vector mesons, pseudoscalars and photons

Bando et al. PRL, 112 (85); Phys. Rep. 164, 217 (88)

$$\mathcal{L} = \mathcal{L}^{(2)} + \mathcal{L}_{III} \tag{1}$$

with

$$\mathcal{L}^{(2)} = \frac{1}{4} f^2 \langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + \chi^\dagger U \rangle \tag{2}$$

$$\mathcal{L}_{III} = -\frac{1}{4} \langle V_{\mu\nu} V^{\mu\nu} \rangle + \frac{1}{2} M_V^2 \langle [V_\mu - \frac{i}{g} \Gamma_\mu]^2 \rangle, \tag{3}$$

where $\langle ... \rangle$ represents a trace over $SU(3)$ matrices. The covariant derivative is defined by

$$D_\mu U = \partial_\mu U - ieQA_\mu U + ieUQA_\mu, \tag{4}$$

with $Q = diag(2, -1, -1)/3$, $e = -|e|$ the electron charge, and A_μ the photon field. The chiral matrix U is given by

$$U = e^{i\sqrt{2}\phi/f} \tag{5}$$

$$\phi \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{pmatrix}, \quad V_\mu \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & \rho^+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu . \tag{6}$$

In $\mathcal{L}_{III}$, $V_{\mu\nu}$ is defined as

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu] \tag{9}$$

and

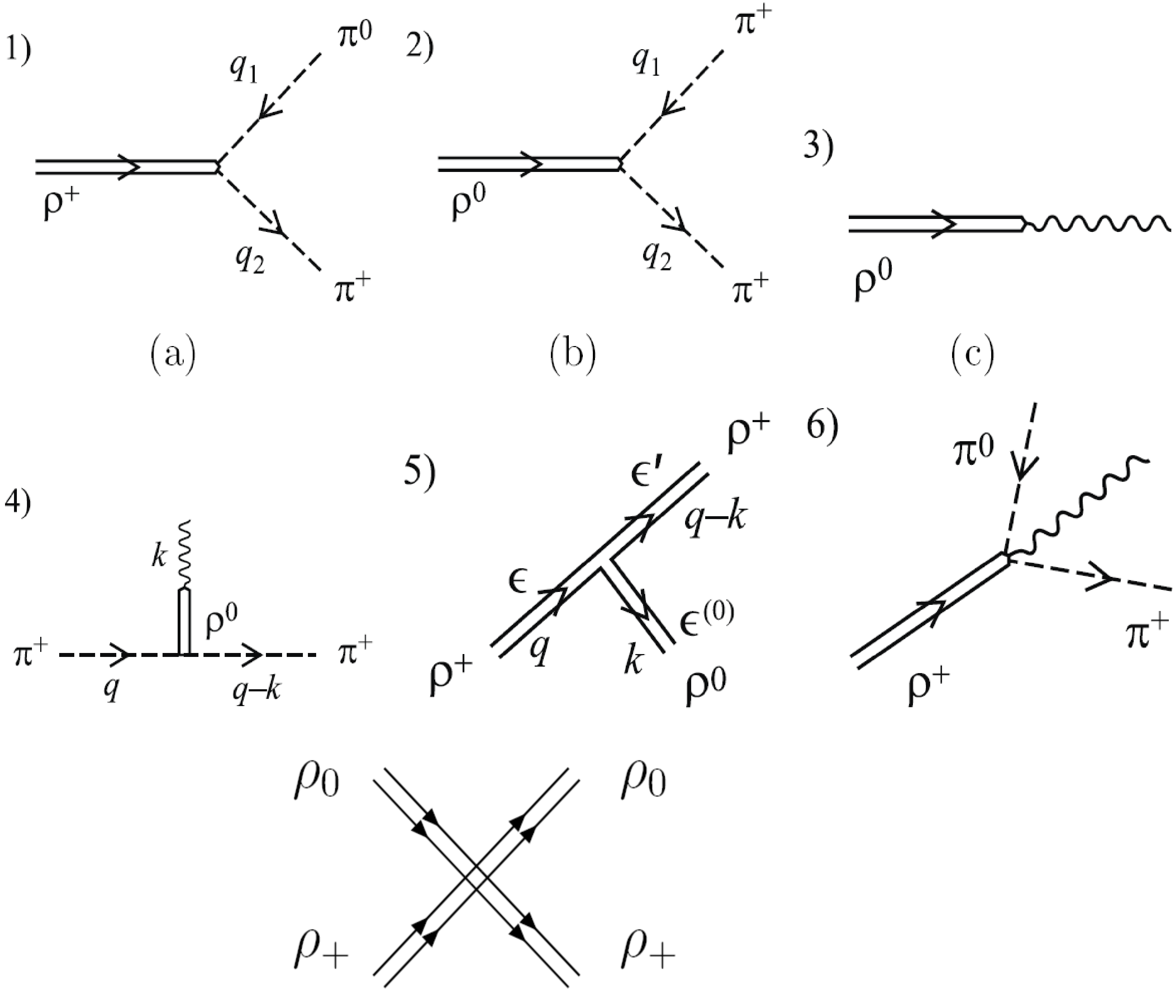
$$\Gamma_\mu = \frac{1}{2}[u^\dagger(\partial_\mu - ieQA_\mu)u + u(\partial_\mu - ieQA_\mu)u^\dagger] \tag{10}$$

with $u^2 = U$. The hidden gauge coupling constant g is related to f and the vector meson mass (M_V) through

$$g = \frac{M_V}{2f}, \tag{11}$$

$$\mathcal{L}_{V\gamma} = -M_V^2 \frac{e}{g} A_\mu \langle V^\mu Q \rangle$$
$$\mathcal{L}_{V\gamma PP} = e\frac{M_V^2}{4gf^2} A_\mu \langle V^\mu (Q\phi^2 + \phi^2 Q - 2\phi Q \phi) \rangle$$
$$\mathcal{L}_{VPP} = -i\frac{M_V^2}{4gf^2} \langle V^\mu [\phi, \partial_\mu \phi] \rangle$$

$$\mathcal{L}_{III}^{(c)} = \frac{g^2}{2} \langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu \rangle \ , \qquad \mathcal{L}_{III}^{(3V)} = ig\langle (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu \rangle \ ,$$


1)
2)
3)
4)
5)
6)
π^0
π^+
q_1
q_2
ρ^+
ρ^0
(a)
(b)
(c)
k
q
$q-k$
ϵ'
ϵ
$\epsilon^{(0)}$
ρ_0
ρ_+

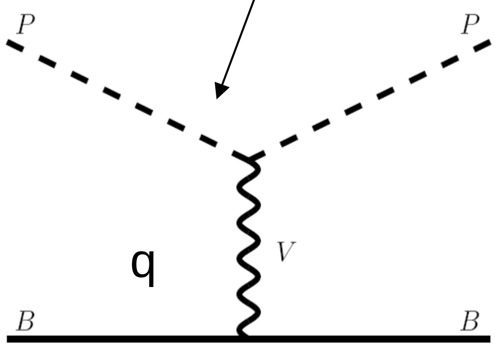
Extension to the baryon sector

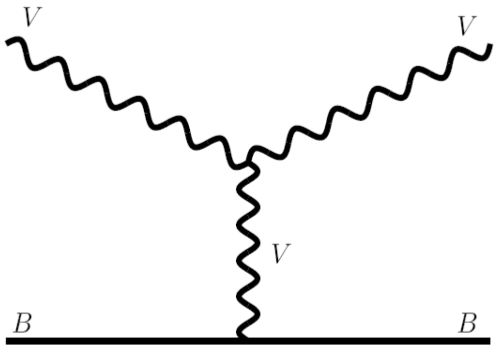
$$\mathcal{L}_{BBV} = -\frac{g}{2\sqrt{2}}\left(tr(\bar{B}\gamma_\mu[V^\mu, B] + tr(\bar{B}\gamma_\mu B)tr(V^\mu)\right)$$

Vector propagator $1/(q^2-M_V^2)$

In the approximation $q^2/M_V^2 = 0$ one recovers the chiral Lagrangians Weinberg-Tomozawa term.

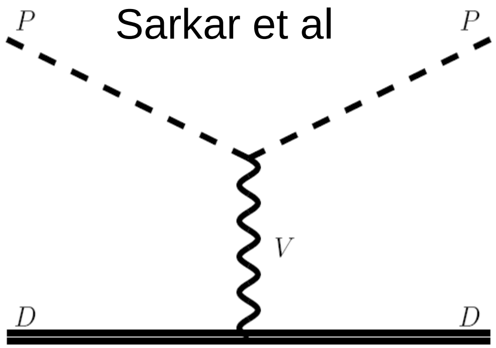
> 200 works

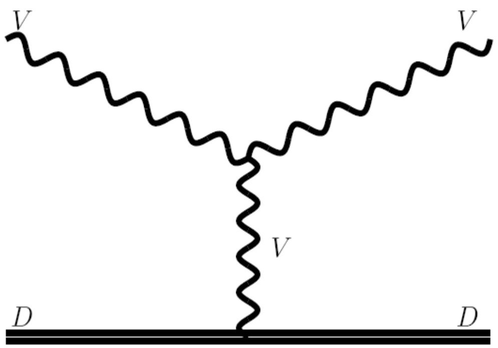




New: A. Ramos, E. O.

Kolomeitsev et al
Sarkar et al





New: J. Vijande, P. Gonzalez. E.O
Sarkar, Vicente Vacas, B.X.Sun, E.O

Vector-pseudoscalar interaction: in the approximation $q/M_V=0$ one obtains the Chiral Lagrangians used by Lutz and kolomeitsev (04)
Roca, Oset, Singh (05)

V from Lagrangian
G: pseudoscalar-vector propagator

$$T = \frac{V}{1 - VG}$$

Low lying axial vector meson, a_1, b_1, … are generatated

Novelty of Roca, Oset, Singh : Two $K_1(1270)$ states are generated

Table 1: Effective couplings of the two poles of the $K_1(1270)$ to the five nels: ϕK, ωK, ρK, $K^*\eta$ and $K^*\pi$. All the units are in MeV.

$\sqrt{s_p}$	$1195 - i123$		$1284 - i73$	
	g_i	$\|g_i\|$	g_i	$\|g_i\|$
ϕK	$2096 - i1208$	2420	$1166 - i774$	1399
ωK	$-2046 + i821$	2205	$-1051 + i620$	1220
ρK	$-1671 + i1599$	2313	$4804 + i395$	4821
$K^*\eta$	$72 + i197$	210	$3486 - i536$	3526
$K^*\pi$	$4747 - i2874$	5550	$769 - i1171$	1401

Experimental support for the two K1 states

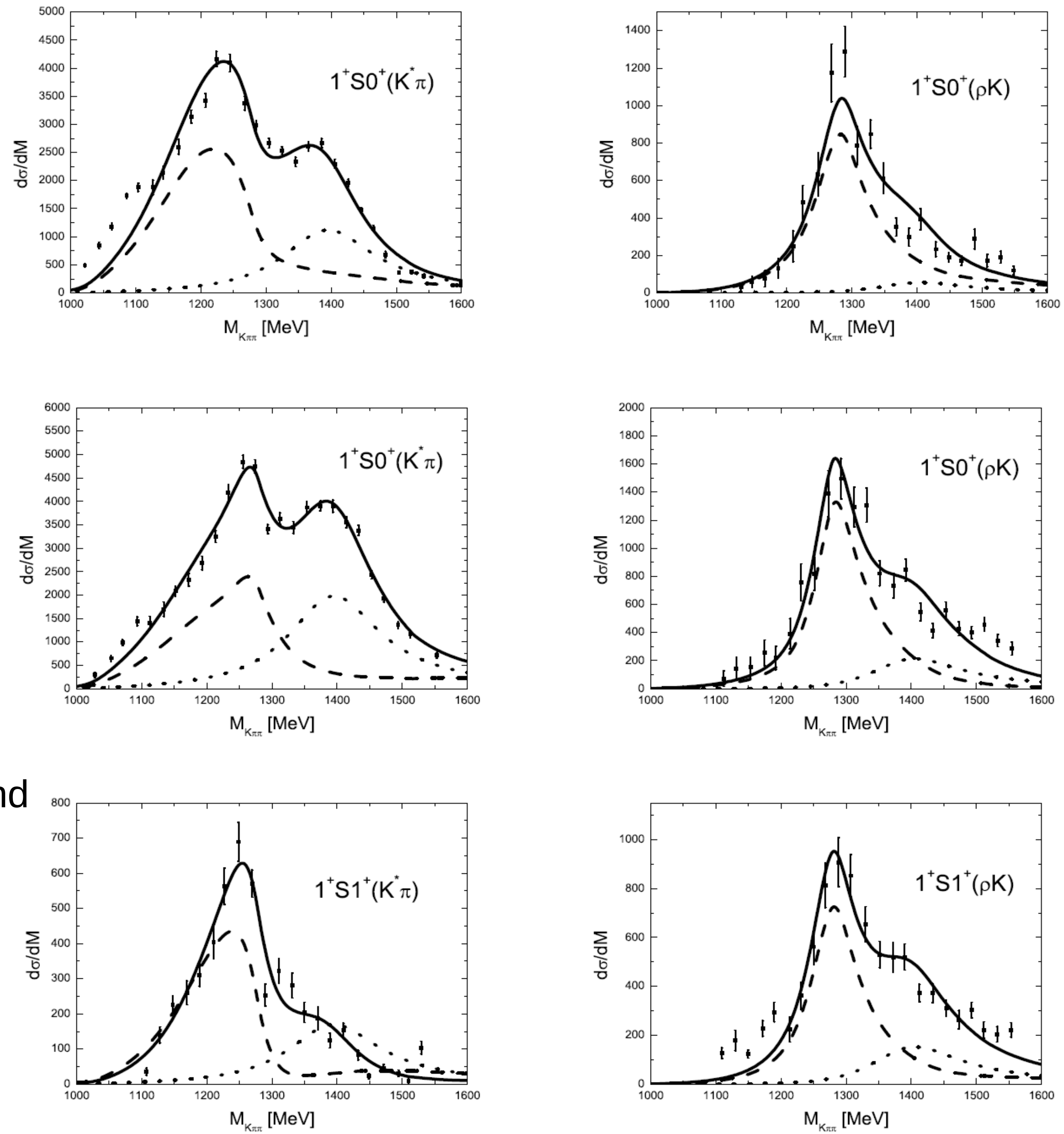
Exp. Daum, NPB (81)

Geng, E.O., Roca, Oller PRD(07)   (theory)

The higher mass one Couples strongly to ρK

The lower mass one Couples strongly to K* π

The peaks of the ρK and K* π are separated by about 100 MeV



Charm See talk of Karliner

In the charm sector one generates scalars and axial vector mesons
Lutz et al
Chiang et al
D. Gamermann et al

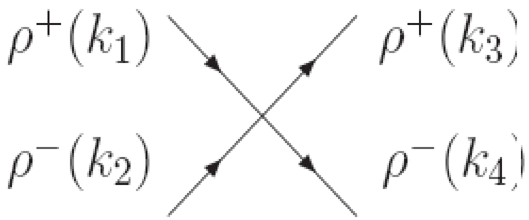
In Gamermann there is a novelty: Hidden charm states

X(3872) comes with two C-parities
X(3700) scalar meson is predicted (poster Gamermann)

Work on baryons, Lutz, Ramos, Tolos, Mizutani ….

Rho-rho interaction in the hidden gauge approach R.Molina, D. Nicmorus, E. O. (08)

V=



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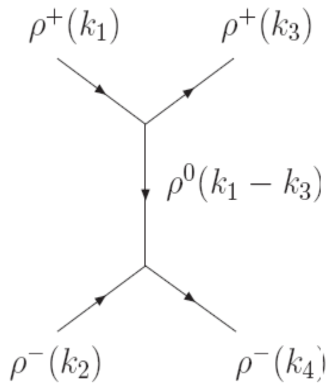

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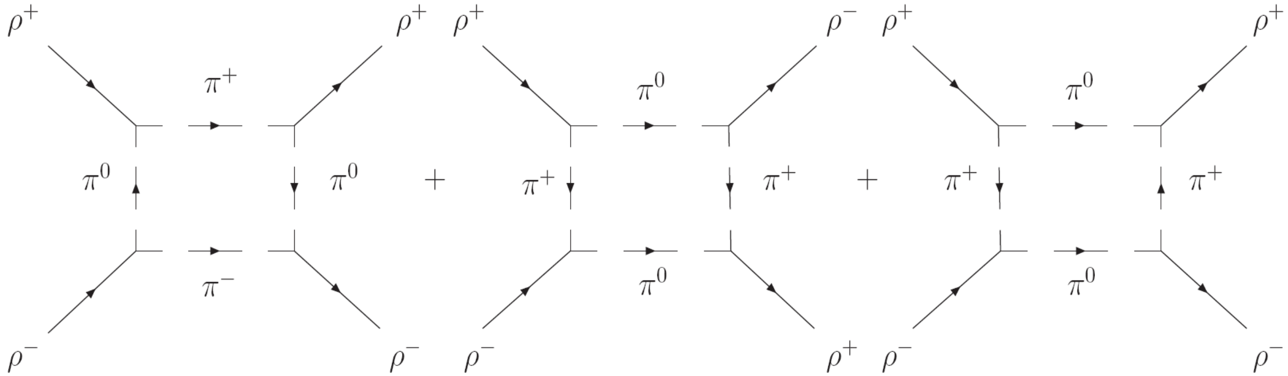


Spin projectors neglecting q/M_V, in L=0

$$\mathcal{P}^{(0)} = \frac{1}{3}\epsilon_\mu\epsilon^\mu\epsilon_\nu\epsilon^\nu$$

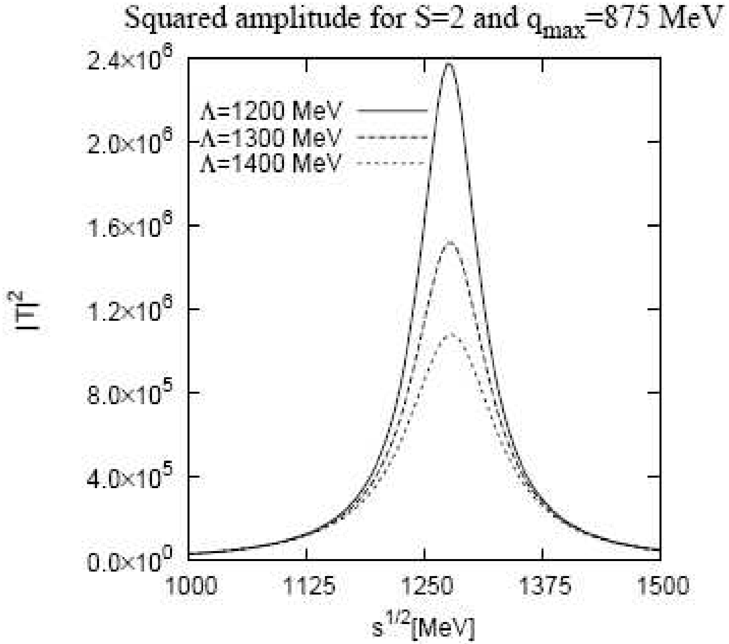
$$\mathcal{P}^{(1)} = \frac{1}{2}(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu - \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu)$$

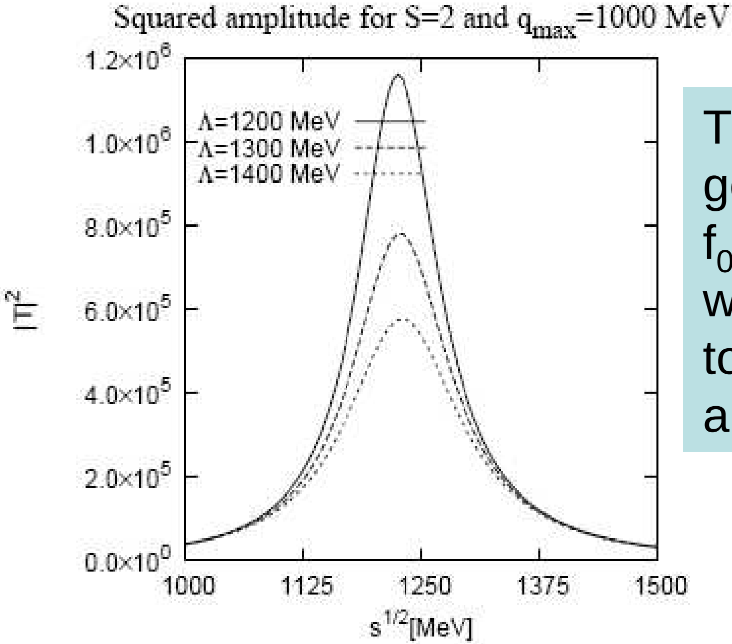
$$\mathcal{P}^{(2)} = \{\frac{1}{2}(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu + \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu) - \frac{1}{3}\epsilon_\alpha\epsilon^\alpha\epsilon_\beta\epsilon^\beta\}$$

Bethe Salpeter eqn.

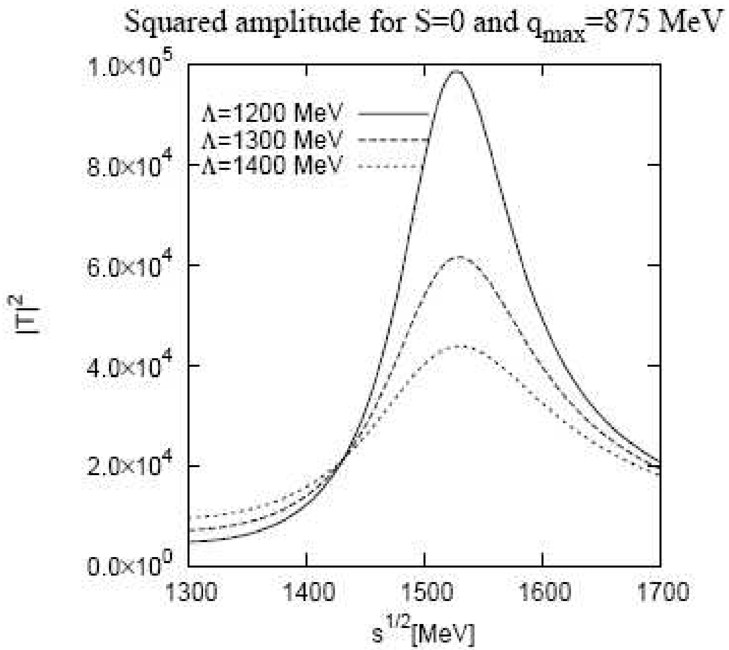
$$T = \frac{V}{1-VG}$$

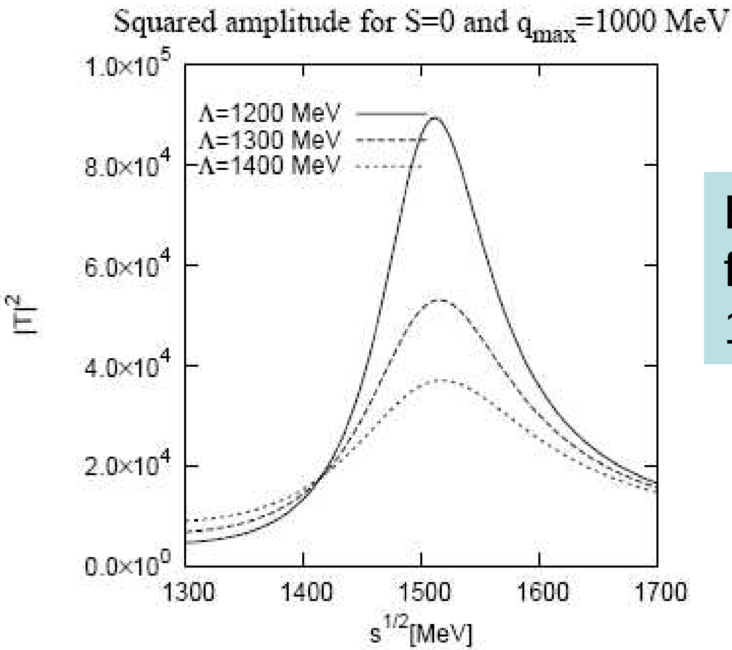
G is the ρρ propagator





Two I=0 states generated f_0, f_2 that we associate to $f_0(1370)$ and $f_2(1270)$



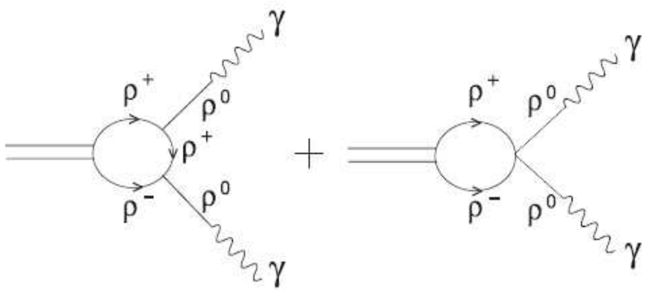


Belle finds the f0(1370) around 1470 MeV

Can one make more predictions concerning these states?

$\gamma\gamma$ decay: Yamagata, Nagahiro,E.O. , Hirenzaki (08)

The approach allows one to get the coupling of the Resonance to the ρρ channel from the residues at the pole of the scattering matrix



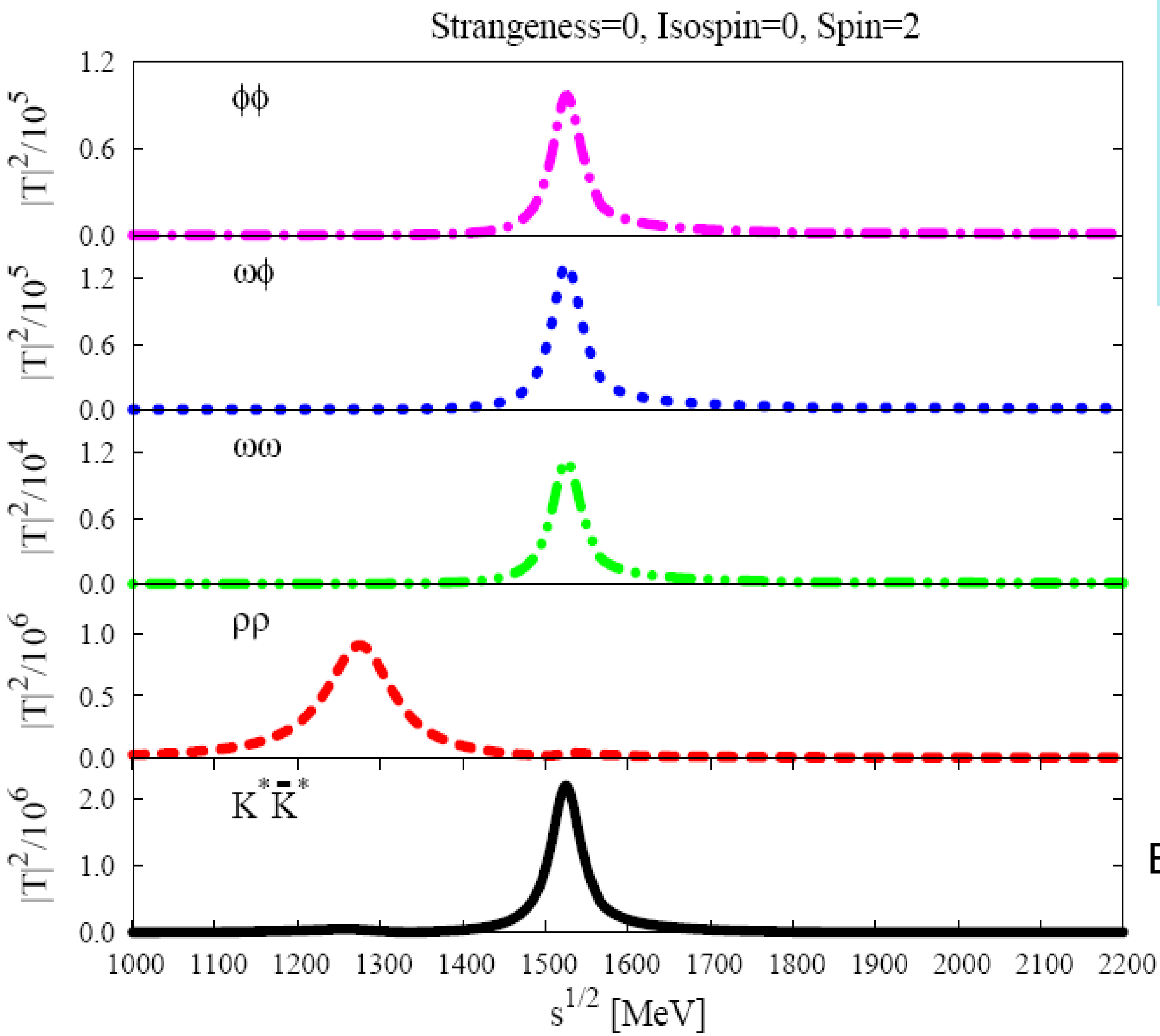
$$\Gamma(f_0(1370) \to \gamma\gamma) = 0.54 \ \ \mathrm{keV}$$
$$\Gamma(f_2(1270) \to \gamma\gamma) = 2.6 \ \ \mathrm{keV}$$

Uehara al Belle peliminary results in agreement for the f0(1370)

Exp (PDG): $\Gamma(f_2(1270)) = 2.6 \pm 0.24$ KeV

Generalization to coupled channels: L. S. Geng , E.O (08)

Attraction found in many channels



The $f_2(1270)$ is not changed by the addition of new channels, but a new resonance appears can be associated to $f'_2(1525)$

Exp :$\Gamma(f_2(1270))$= 185 MeV

Exp: $\Gamma(f'_2(1525))$ = 76 MeV

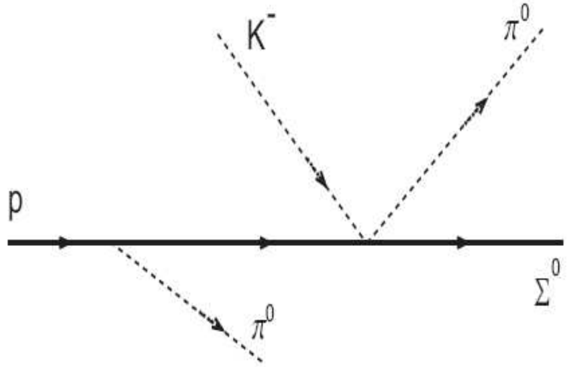
Baryons: The case for two Λ(1045) states

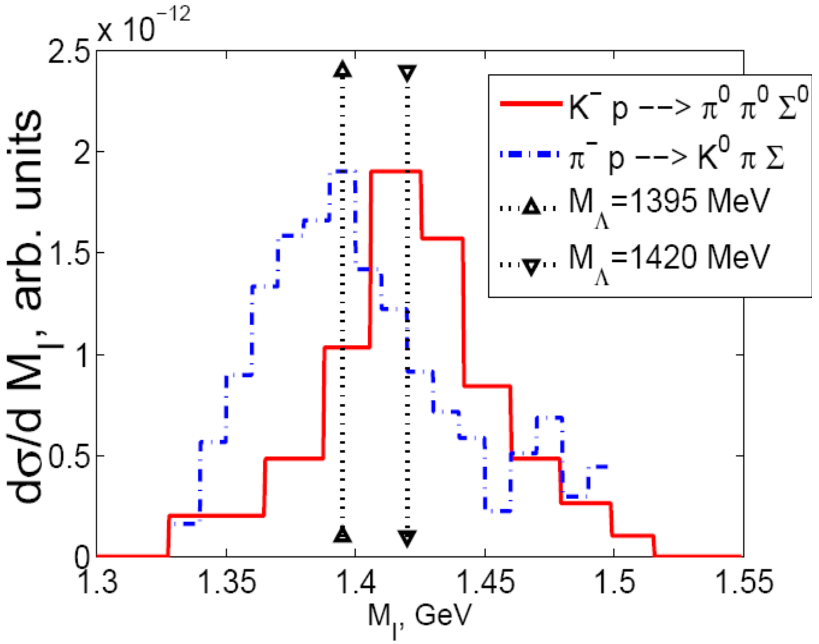
Oller, Meissner (2001)

Jido, Oller, E.O. Ramos, Meissner (2003)

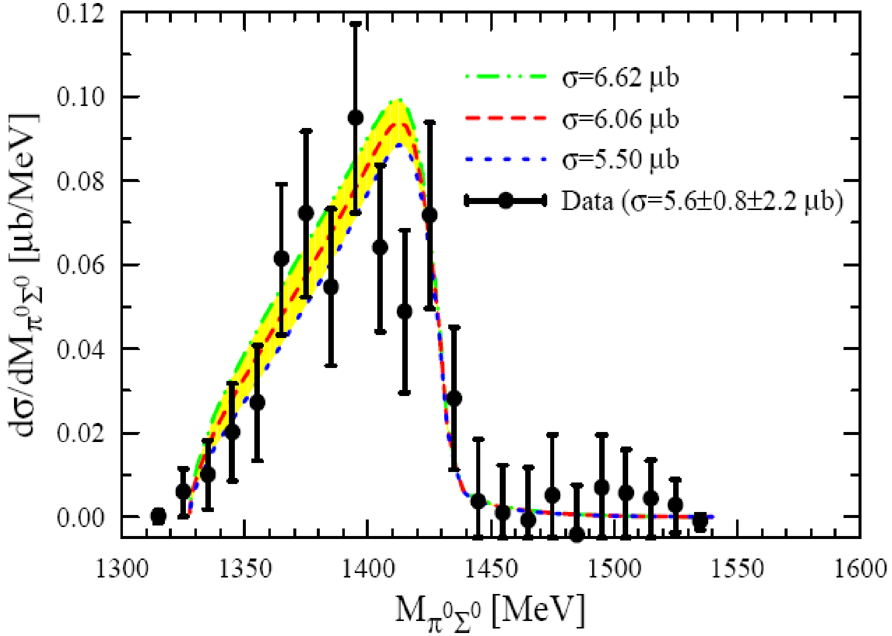
Two states appear: Λ_1 around 1420 MeV and narrow, couples strongly to KN
Λ_2 around 1390 and wide, couples strongly to πΣ

$K^- p \to \pi^0\pi^0\Sigma^0$ reaction, Prakhov et al, PRC (2004)
Theoretical analysis, Magas, E. O., Ramos PRL(2005)

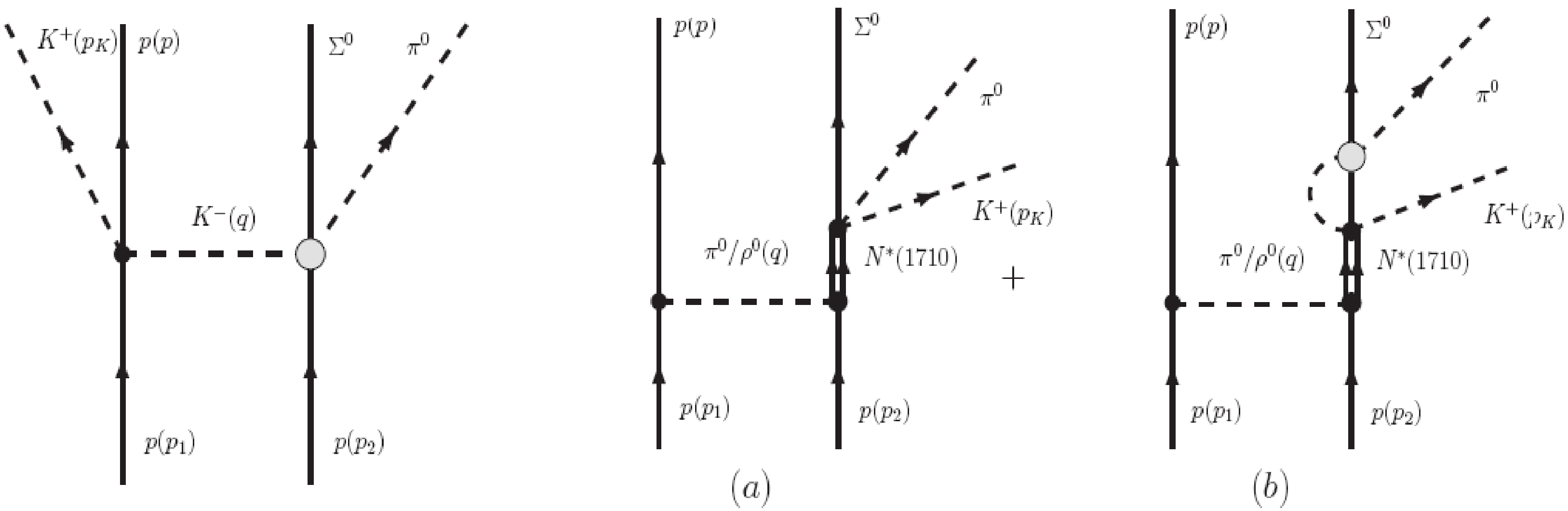




New Challenge to the theory from COSY exp. Zychor et al ., PLB(2008)

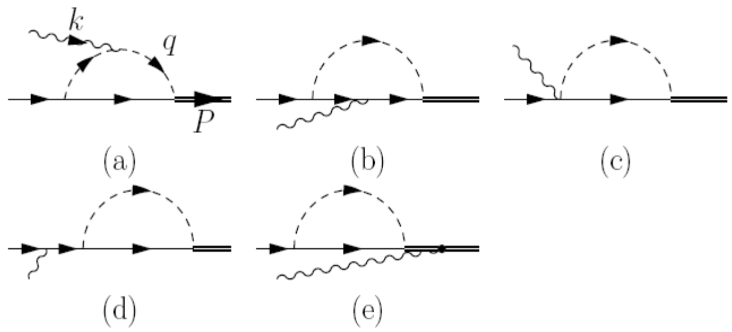


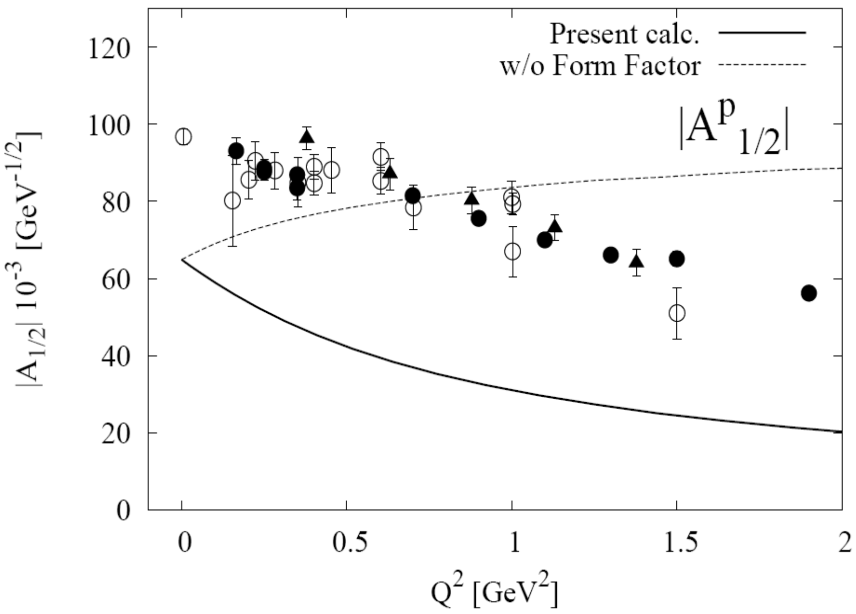
Theoretical calculation
Geng, E. O, EPJA(2007)



Helicity form factors of the N*(1535)

Jido, Doring, E. O. PRC(2008)

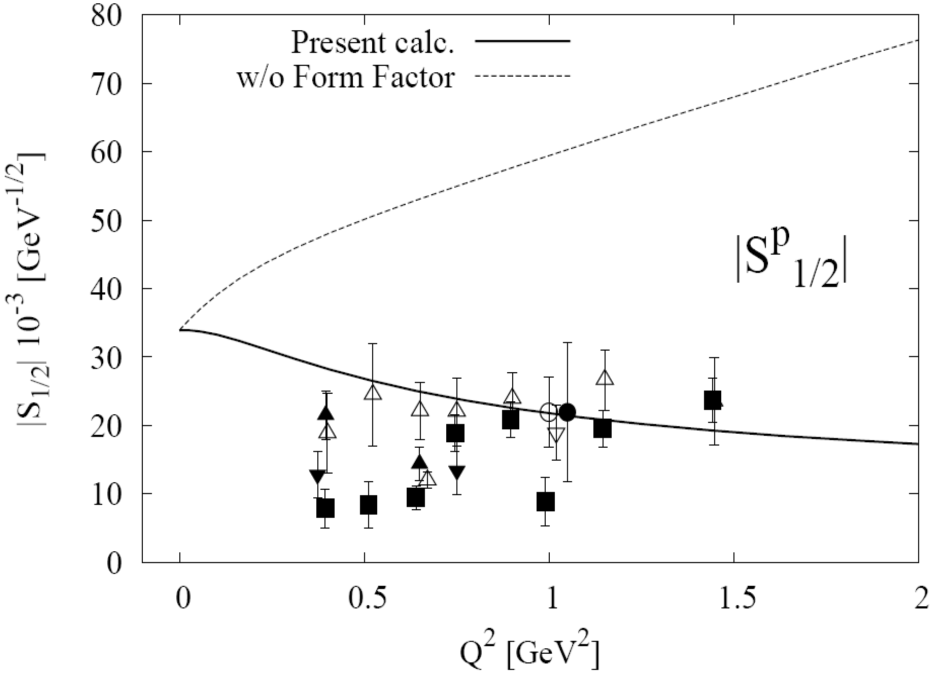


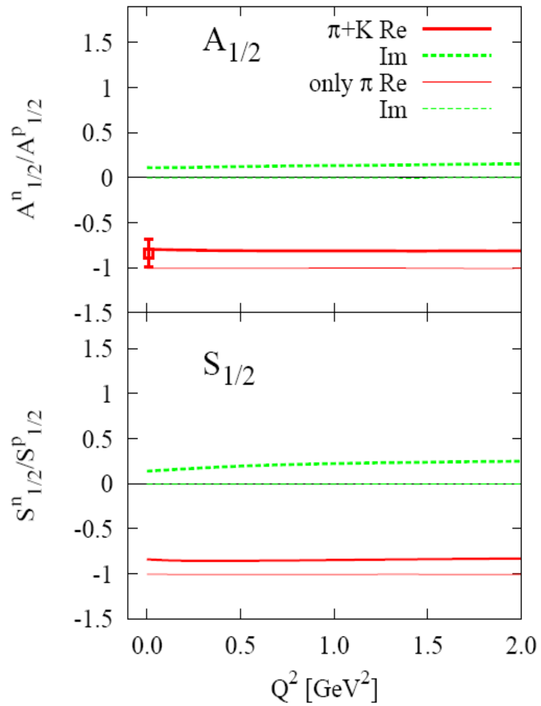


MAID 2007 gives 66 units at Q^2=0

But the theoretical fall off is too fast

--> room for more components (3q?)





Charge distribution of the dynamically generated resonances,

Sekihara, Hyodo, Jido PLB(2008)

The EM form factor of the the two Λ(1405)
Is evaluated

$$\langle r^2 \rangle_E \equiv -6 \left. \frac{dG_E}{dQ^2} \right|_{Q^2=0}$$

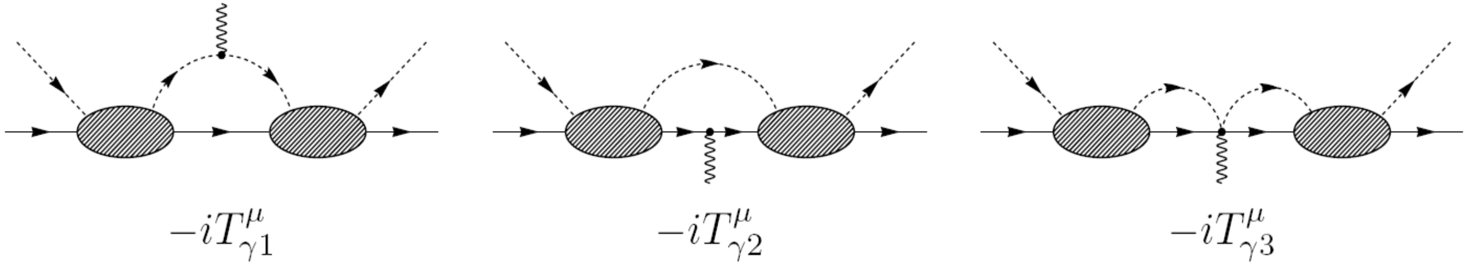


Table 1. Electric mean squared radii $\langle r^2 \rangle_E$ of Λ(1405). Physical Λ(1405) is accompanied by the poles z_1 and z_2. "Λ(1405)" is described as a $\bar{K}N$ bound state.

State	Pole position [MeV]	Strongly couple to	$\langle r^2 \rangle_E$ [fm^2]
z_1	$1390 - 66\ i$	$\pi\Sigma$	$(1.8 - 0.2i) \times 10^{-2}$
z_2	$1426 - 17\ i$	$\bar{K}N$	$-0.131 + 0.303i$
"Λ(1405)"	1429	K^-p, $\bar{K}^0 n$	-2.193

$$\sqrt{|\langle r^2 \rangle_E|} \simeq 1.48\ \text{fm}$$

Size larger than the proton

Negative sign comes form the K$^-$ cloud in K$^-$ p

The structure of the N*(1535) and chiral symmetry

Hyodo, Jido, Hosaka (2008)

How much of the nature can be associated to a meson-baryon component?

$$T(\sqrt{s}) = \frac{1}{V_{\rm WT}^{-1}(\sqrt{s}) - G(\sqrt{s}; a_{\rm pheno})},$$

WT for Weinberg Tomozawa

$$T(\sqrt{s}) = \frac{1}{V_{\rm natural}^{-1}(\sqrt{s}) - G(\sqrt{s}; a_{\rm natural})}$$

In G, loop function of intermediate PB component, the a_i are different for N*(1535) but nearly equal for the Λ(1405)

$a_{i,natural}$ are around -2 (cut off of about 700 MeV/c)

$$\begin{aligned} &V_{\rm natural}^{-1}(\sqrt{s}) - G(\sqrt{s}; a_{\rm natural}) \\ &\quad = V_{\rm WT}^{-1}(\sqrt{s}) - G(\sqrt{s}; a_{\rm pheno}) \end{aligned}$$

$$\begin{aligned} V_{\rm natural}(\sqrt{s}) &= -\frac{C}{2f^2}(\sqrt{s} - M_T) + \frac{C}{2f^2}\frac{(\sqrt{s} - M_T)^2}{\sqrt{s} - M_{\rm eff}} \\ &\equiv V_{\rm WT}(\sqrt{s}) + \Delta V(\sqrt{s}; \Delta a). \end{aligned} \tag{23}$$

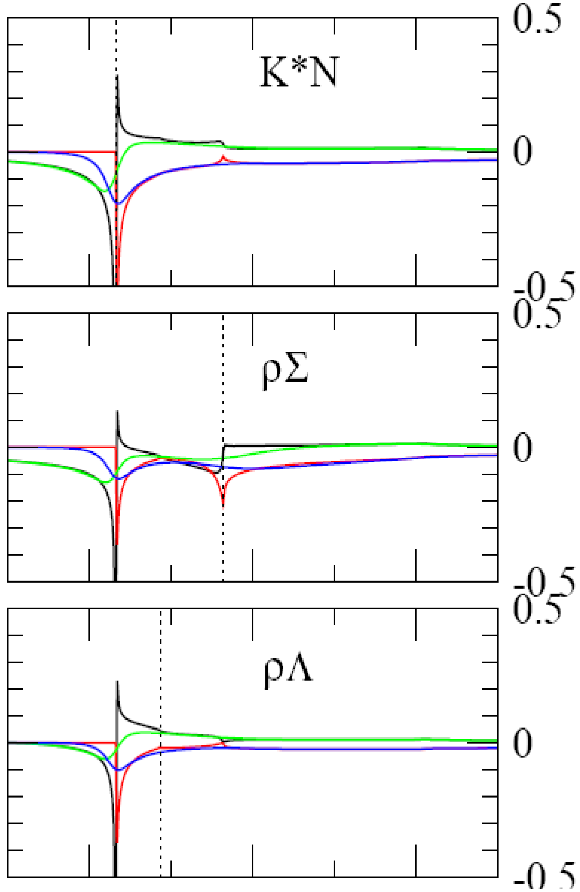
The extra potential, consequence of the need for unnatural subtraction constants, is accounted for by an extra potential, which has the structure of a CDD pole → genuine state component

Octet of vectors-Octet of baryons interaction A. Ramos, E. O. (2008)

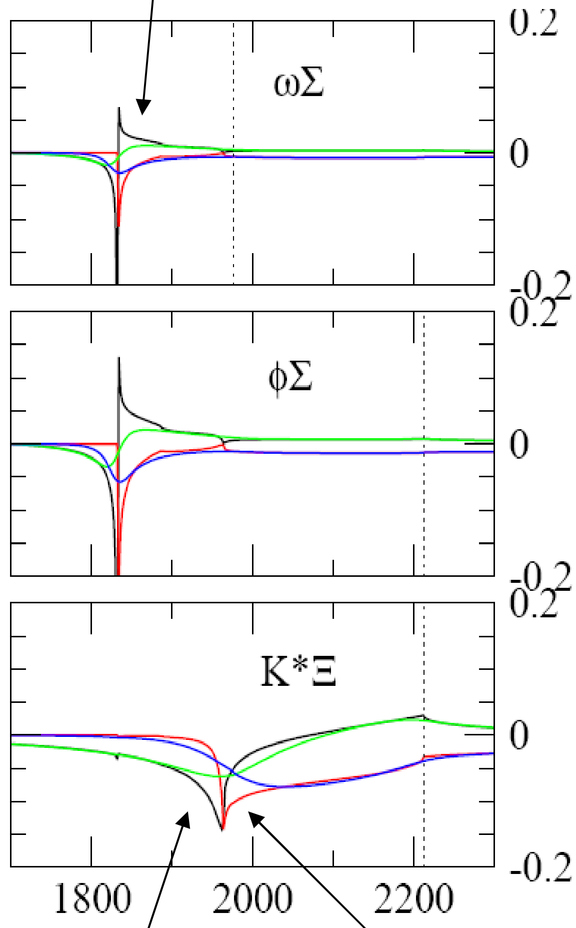
Attraction found in I=1/2,S=0 ; I=0,S=-1; I=1,S=-1; I=1/2,S=-2

Degenerate states $1/2^-$ and $3/2^-$ found

I=1, S=-1



Σ(1750) ($1/2^-$) ?



Σ(1940) ($3/2^-$) ; Σ(2000) ($1/2^-$) ?

Three body systems

Recent developments with three body systems: two mesons and one baryon or three mesons.

Low lying states of $J^P = ½^+$ reproduced with Faddeev equations in coupled channels and chiral dynamics,

A. Martinez, K. Khemchandani. E. O. PRC(08), EPJA(08)

System of K K N or K K N investigated in Jido, En'yo PRC(08), using a variational approach and get bound states.

Conclusions

Chiral dynamics plays an important role in hadron physics.

Its combination with nonperturbative unitary techniques allows to study the interaction of hadrons. Poles in amplitudes correspond to dynamically generated resonances. Many of the known meson and baryon resonances can be described in this way.

The introduction of vector mesons as building blocks brings a new perspective into the nature of higher mass mesons and baryons.

Progress done making new predictions of resonance properties: helicity form factors, charge form factors …

Interesting new developments in three body systems, some known mesons and baryons can be interpreted in this way.

Experimental challenges to test the nature of these resonances looking for new decay channels or production modes.