Baryon Resonances from the interaction of vector mesons and baryons

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Hidden gauge formalism for vector mesons, pseudoscalars and photons

Derivation of chiral Lagrangians

Vector baryon molecules:

from octet of vectors and octet of baryons

from octet of vectors and decuplet of baryons

Hidden gauge formalism for vector mesons, pseudoscalars and photons

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

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

with

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

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

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

$$D_\mu U = \partial_\mu U - ieQA_\mu U + ieUQA_\mu, \quad (4)$$

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

$$U = e^{i\sqrt{2}\phi/f} \quad (5)$$

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

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

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

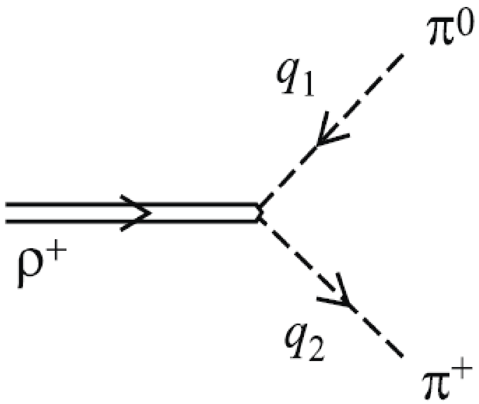
with $u^2 = U$. The hidden gauge coupling constant g is related to f and the vector meson mass (M_V) through

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

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

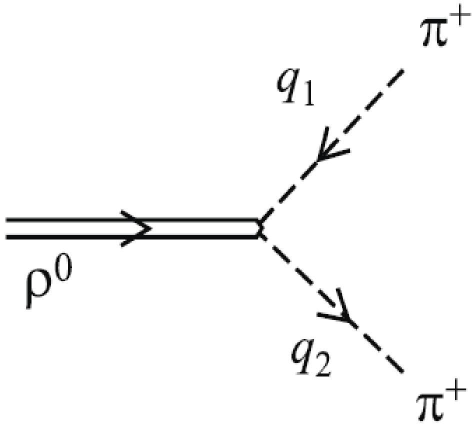
$$\mathcal{L}_{III}^{(c)} = \frac{g^2}{2} \langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu \rangle \ , \qquad \mathcal{L}_{III}^{(3V)} = ig\langle (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu \rangle \ ,$$

1)


π^0
q_1
ρ^+
q_2
π^+

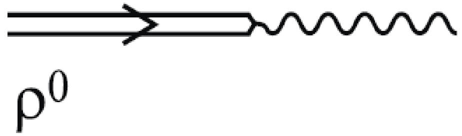
(a)

2)


π^+
q_1
ρ^0
q_2
π^+

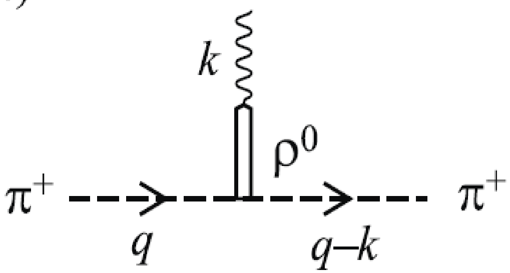
(b)

3)

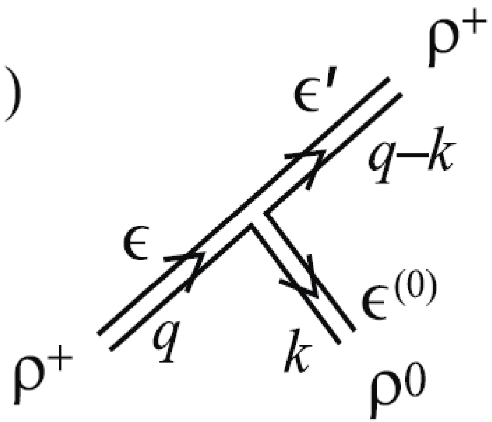

ρ^0

(c)

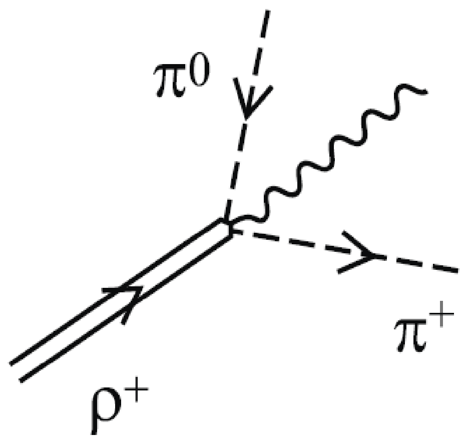
4)

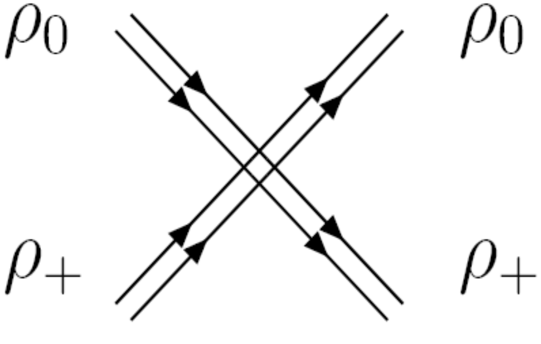

k
ρ^0
π^+
π^+
q
$q-k$

5)


ρ^+
ϵ'
$q-k$
ϵ
$\epsilon^{(0)}$
ρ^+
q
k
ρ^0

6)


π^0
π^+
ρ^+


ρ_0
ρ_0
ρ_+
ρ_+

Philosophy behind the idea of dynamically generated baryons:

The first excited N* states: N*(1440)(1/2^+) , N*(1535) (1/2^-).
In quark models this tells us the quark excitation requires 500-600 MeV.

It is cheaper to produce one pion, or two (140-280 MeV), if they can be bound. Many resonances are generated in this way, like the $1/2^-$ states from meson baryon (N* (1535), two Λ(1405)…) or the $1/2^+$ states from two mesons and a baryon (N*(1710) …..see talk of A. Martinez)

But now we will bind vector mesons

There is another approach for vector-baryon by J. Nieves et al. based on SU(6) symmetry of flavor and spin.

The two approaches are not equivalent.

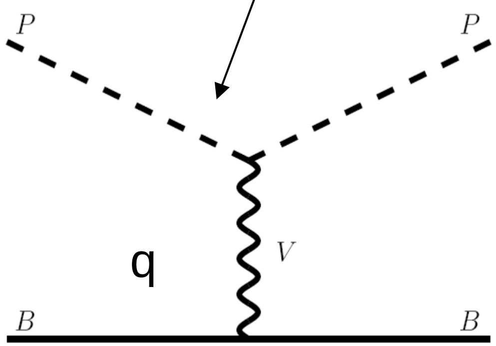
Extension to the baryon sector

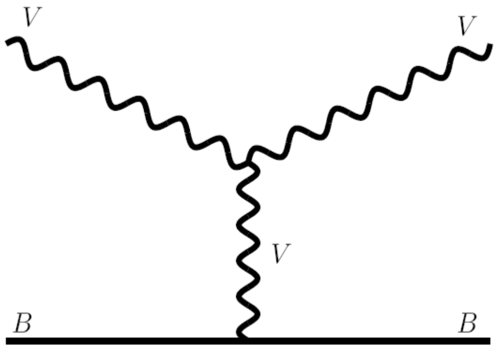
$$\mathcal{L}_{BBV} = -\frac{g}{2\sqrt{2}} (tr(\bar{B}\gamma_\mu[V^\mu, B] + tr(\bar{B}\gamma_\mu B)tr(V^\mu))$$

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. For consistency, for vectors we take $\vec{q}/M_V=0$

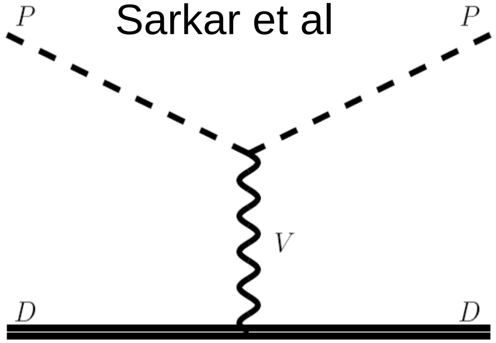
> 200 works

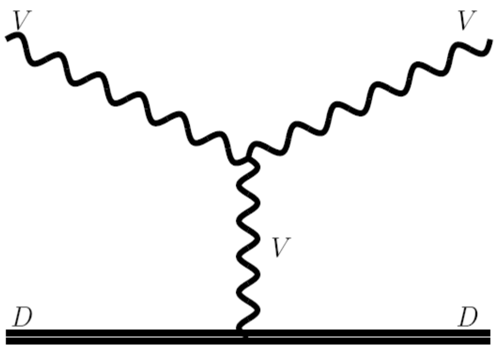




New: A. Ramos, E. O.

Kolomeitsev et al
Sarkar et al





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

Vector octet – baryon octet interaction

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

$$\mathcal{L}_{VPP} = -ig \ tr\left([P, \partial_\mu P] V^\mu\right)$$

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}$$

V^ν cannot correspond to an external vector.
Indeed, external vectors have only spatial components in the approximation of neglecting three momenta, ε^0= k/M for longitudinal vectors, ε^0=0 for transverse vectors. Then ∂_ν becomes three momentum which is neglected. →
V^ν corresponds to the exchanged vector. → complete analogy to VPP
Extra $\varepsilon_\mu \varepsilon^\mu = -\varepsilon_i \varepsilon_i$ but the interaction is formally identical to the case of PB→PB
In the same approximation only γ^0 is kept for the baryons → the spin dependence is only $\varepsilon_i \varepsilon_i$ and the states are degenerate in spin 1/2 and 3/2

$$V_{ij} = -C_{ij} \frac{1}{4f^2} \left(k^0 + k'^0\right) \vec{\epsilon}\vec{\epsilon}'$$

K^0 energy of vector mesons

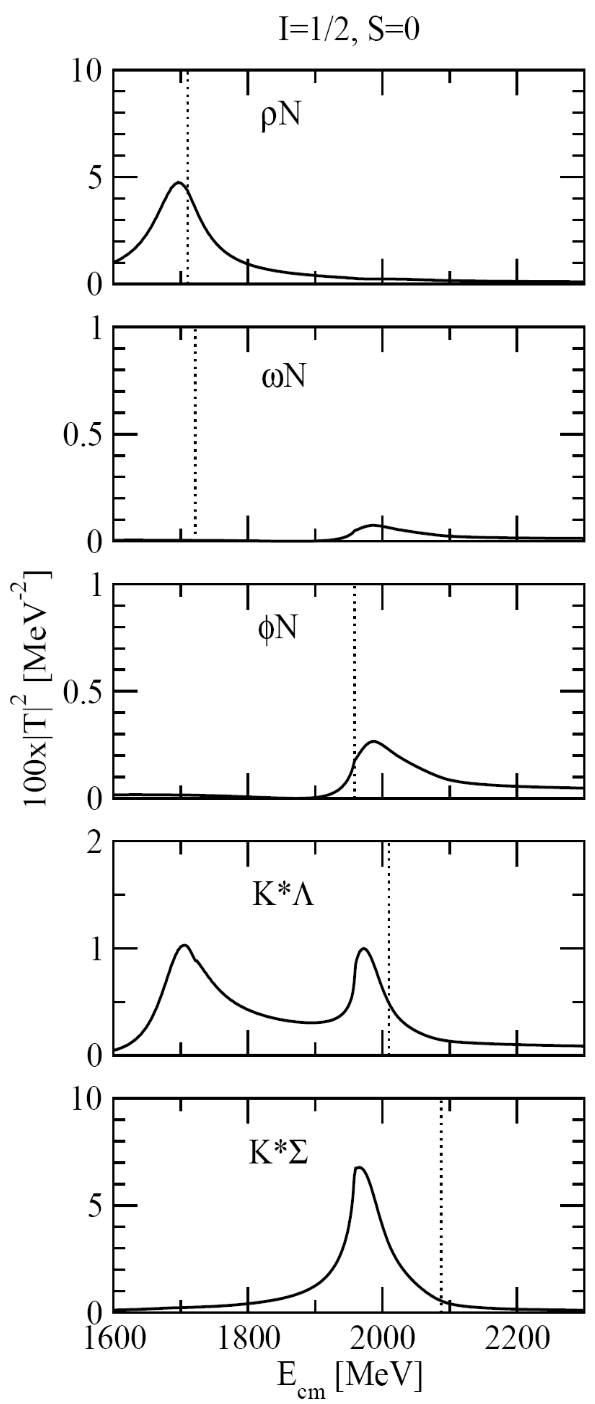
We solve the Bethe Salpeter equation in coupled channels Vector-Baryon octet.

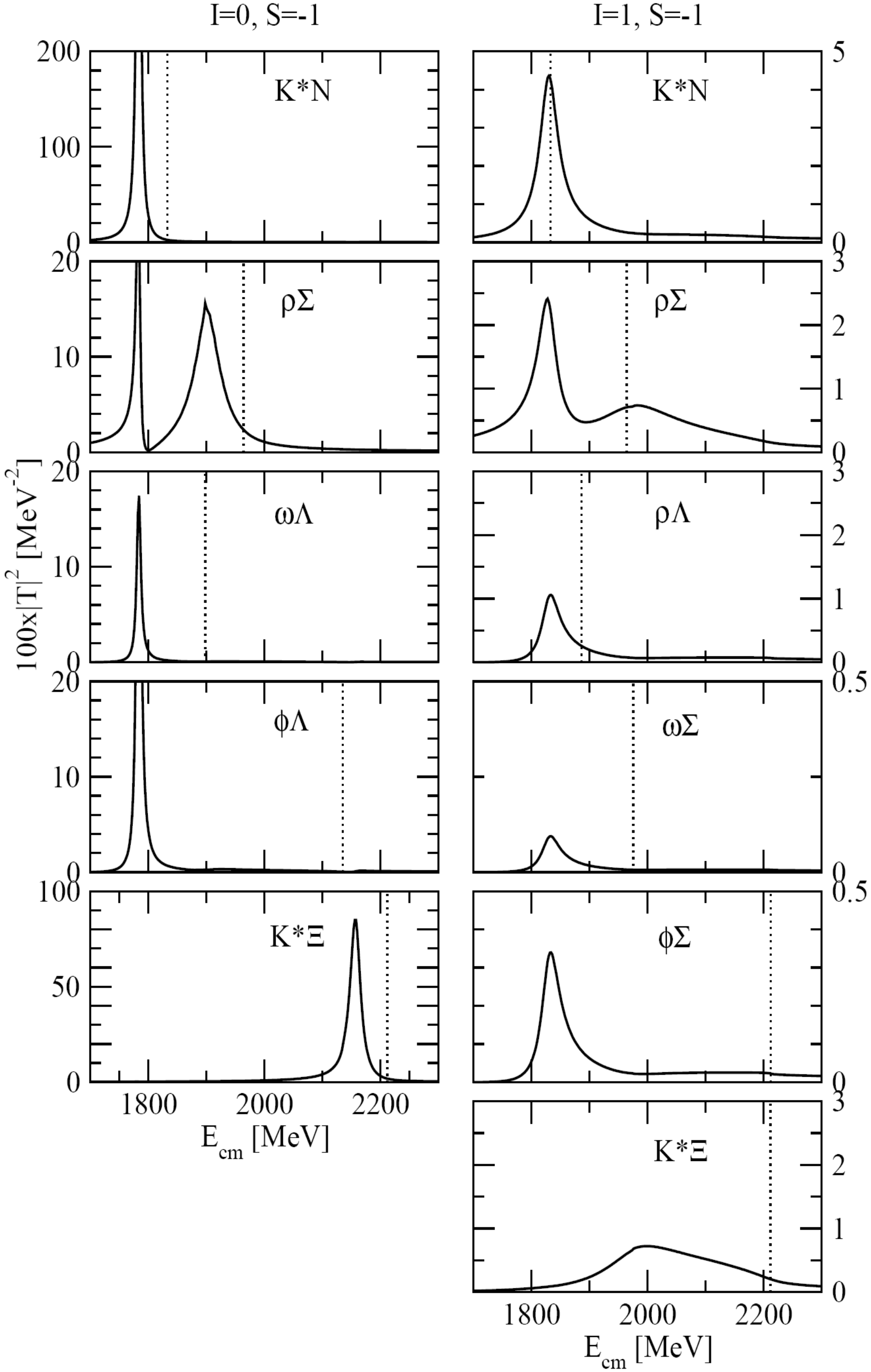
$T = (1-GV)^{-1} V$

with G the loop function of vector-baryon

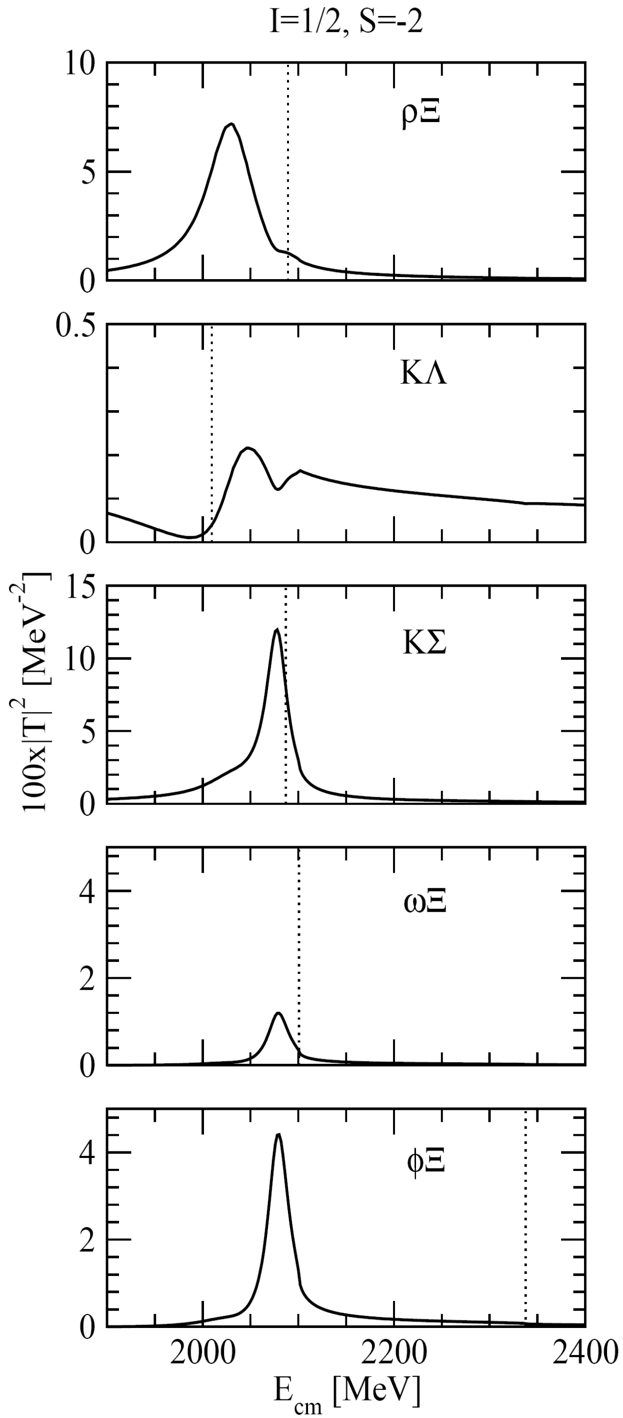
Apart from the peaks, poles are searched In the second Riemann sheet and pole positions and residues are determined.

The G function takes into account the mass distribution of the vectors (width). Decay into pseudoscalar-baryon not yet considered.





I=0, S=-1
I=1, S=-1
K*N
ρΣ
ωΛ
φΛ
K*Ξ
ρΛ
ωΣ
φΣ
100x|T|^2 [MeV^-2]
E_cm [MeV]
1800
2000
2200



I=1/2, S=-2
ρΞ
KΛ
KΣ
ωΞ
φΞ
100x|T|^2 [MeV^{-2}]
E$_{cm}$ [MeV]
2000
2200
2400

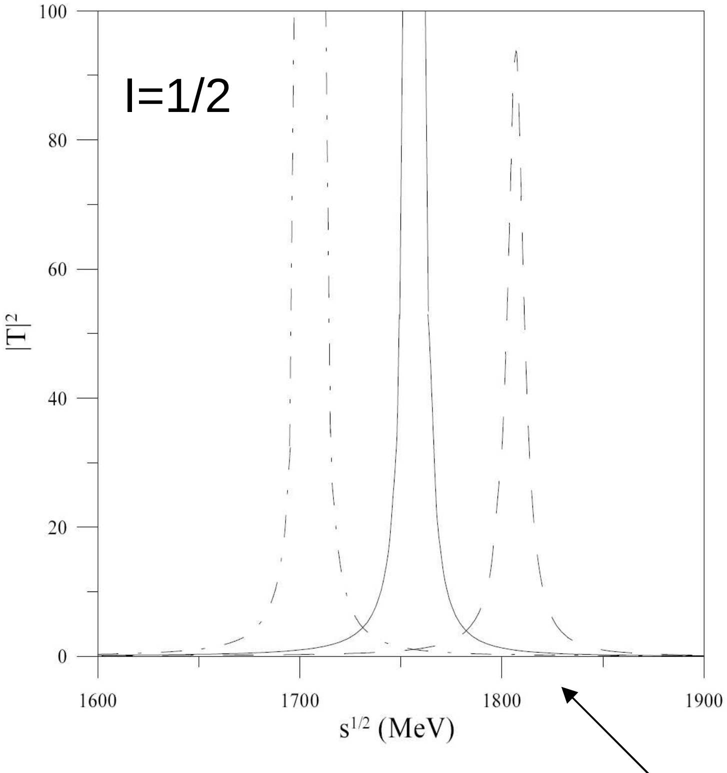
$S,\ I$	Theory (real axis)		PDG data				
	mass	width	name	J^P	status	mass	width
$0, 1/2$	1699	84	$N(1650)$	$1/2^-$	$\star\star\star\star$	1645-1670	145-185
			$N(1700)$	$3/2^-$	$\star\star\star$	1650-1750	50-150
	1967	82	$N(2080)$	$3/2^-$	$\star\star$	≈ 2080	180-450
			$N(2090)$	$1/2^-$	$\star$	≈ 2090	100-400
$-1, 0$	1783	8	$\Lambda(1690)$	$3/2^-$	$\star\star\star\star$	1685-1695	50-70
			$\Lambda(1800)$	$3/2^-$	$\star\star\star$	1720-1850	200-400
	1900	54	$\Lambda(2000)$	$?^?$	$\star$	≈ 2000	73-240
	2158	20					
$-1, 1$	1830	44	$\Sigma(1750)$	$1/2^-$	$\star\star\star$	1730-1800	60-160
	1985	244	$\Sigma(1940)$	$3/2^-$	$\star\star\star$	1900-1950	150-300
			$\Sigma(2000)$	$1/2^-$	$\star$	≈ 2000	100-450
$-2, 1/2$	2030	52	$\Xi(2030)$	$?^?$	$\star\star\star$	2025 ± 5	21 ± 6
	2080	24	$\Xi(2120)$	$?^?$	$\star$	≈ 2120	25

Table 1: The properties of the 9 dynamically generated resonances and their possible PDG counterparts.

ρΔ interaction

P. Gonzalez, E. O, J. Vijande 2008, PRC

Complete analogy to the case of pseudoscalar-baryon decuplet studied in Kolomeitsev et al 04, Sarkar et al 05



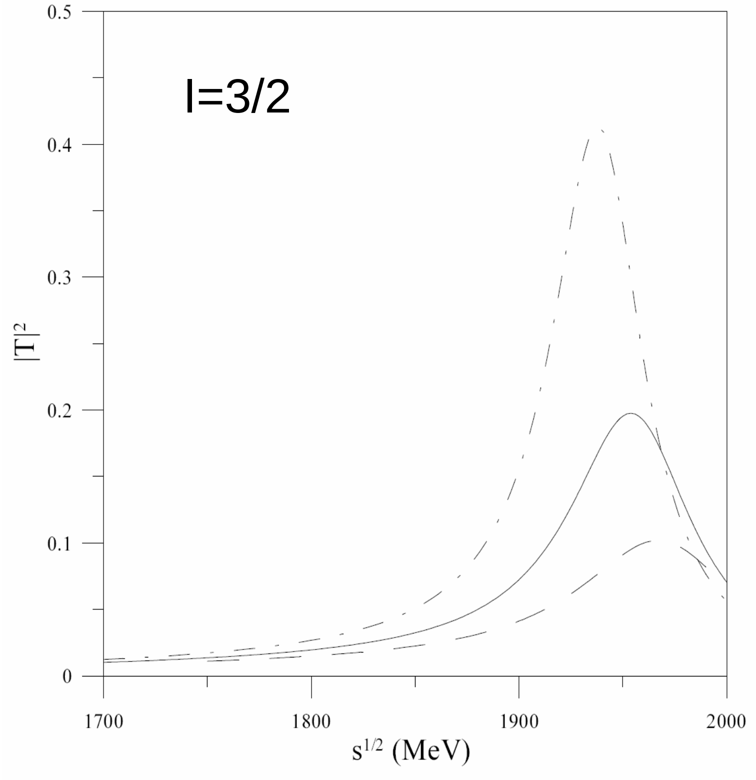


FIG. 5: $|T|^2$ for $\rho\Delta \to \rho\Delta$ in the $I = 1/2$ channel for several values of the cutoff q_{max} including ρ and Δ mass distributions: solid line $q_{max} = 770$ MeV, dashed line $q_{max} = 700$ MeV, dashed-dotted

The Vector Baryon decuplet coupling is taken from Jenkins and Manohar

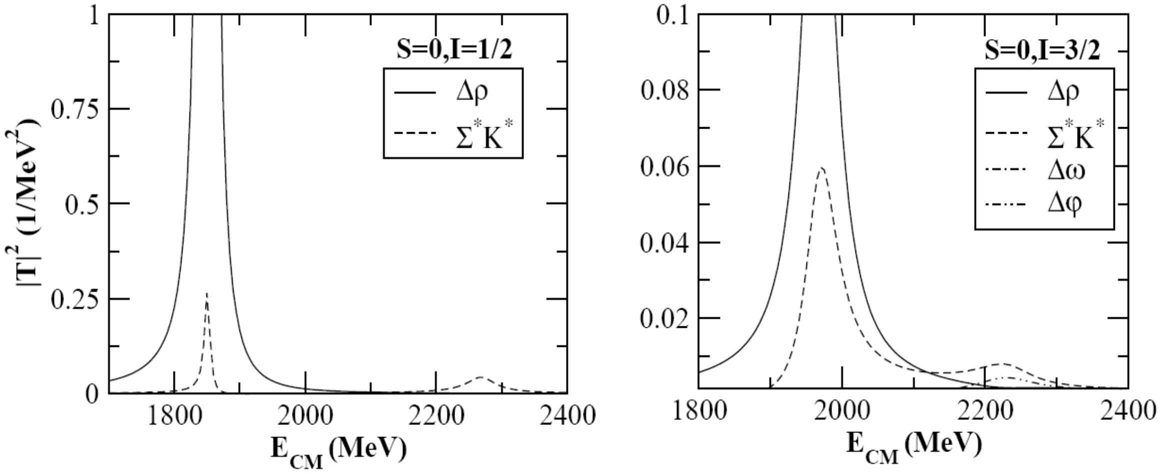
We get now three degenerate spin states for each isospin, 1/2 or 3/2

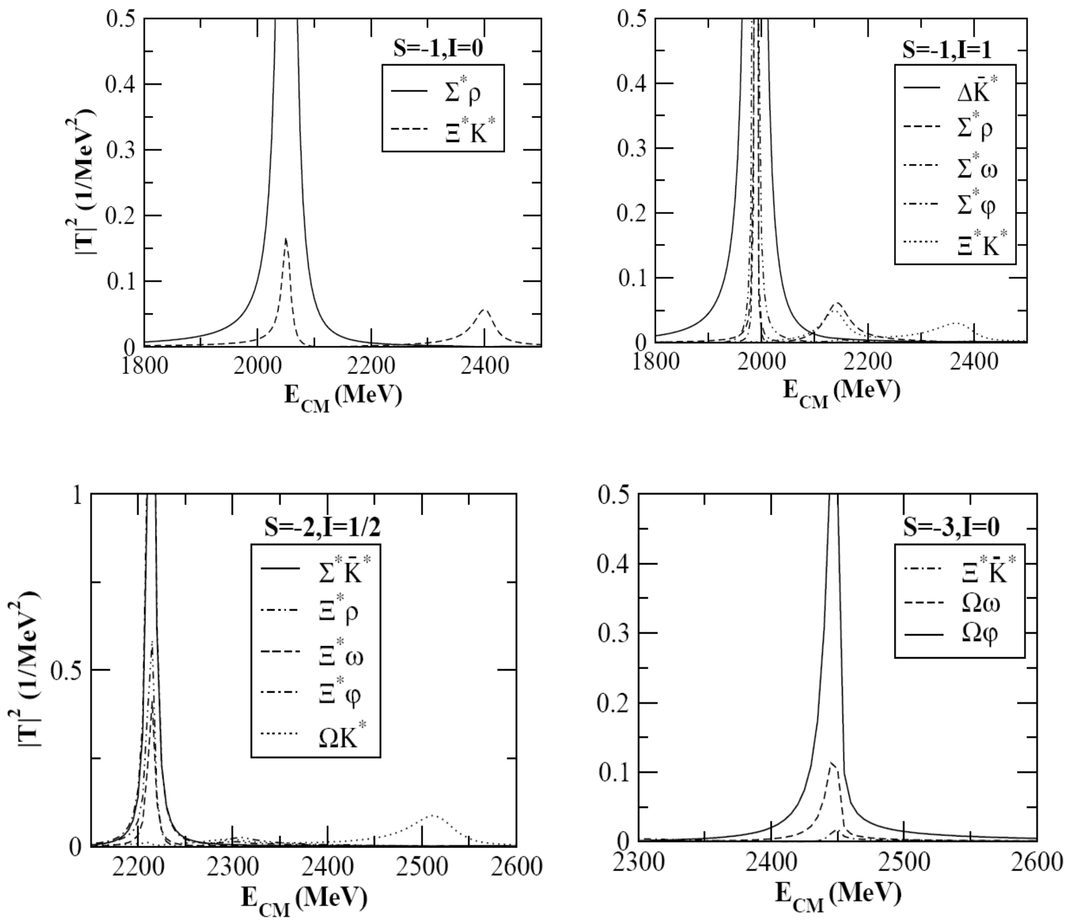
Option i) seems to be approximately at work at least for some of our degenerate $I = 3/2$, $J^P = 1/2^-, 3/2^-, 5/2^-$ states, with a mass between 1940 MeV ($q_{max} = 770$ MeV) and 1980 MeV ($q_{max} = 630$ MeV), which can be respectively assigned to $\Delta(1900)S_{31}(**)$, $\Delta(1940)D_{33}(*)$ and $\Delta(1930)D_{35}(***)$ from the Particle Data Group (PDG) Review [21].

For I=1/2 the candidates could be a block of non catalogued states around 1900 MeV found in the entries of N* states with these quantum numbers around 2100 MeV

Extension to the
octet of vectors
and decuplet of
Baryons

S. Sarkar, Bao Xi Sun
E. O, M.J. Vicente Vacas
09





$S,\ I$	Theory			PDG data				
	pole position	real axis		name	J^P	status	mass	width
		mass	width					
$0, 1/2$	$1850 + i5$	1850	11	$N(2090)$	$1/2^-$	$\star$	1880-2180	95-414
				$N(2080)$	$3/2^-$	$\star\star$	1804-2081	180-450
$0, 3/2$	$1972 + i49$	1971	52	$\Delta(1900)$	$1/2^-$	$\star\star$	1850-1950	140-240
				$\Delta(1940)$	$3/2^-$	$\star$	1940-2057	198-460
				$\Delta(1930)$	$5/2^-$	$\star\star\star$	1900-2020	220-500
$-1, 0$	$2052 + i10$	2050	19	$\Lambda(2000)$	$?^?$	$\star$	1935-2030	73-180
$-1, 1$	$1987 + i1$	1985	10	$\Sigma(1940)$	$3/2^-$	$\star\star\star$	1900-1950	150-300
	$2145 + i58$	2144	57	$\Sigma(2000)$	$1/2^-$	$\star$	1944-2004	116-413
	$2383 + i73$	2370	99	$\Sigma(2455)$	$?^?$	$\star\star$	2455±10	100-140
$-2, 1/2$	$2214 + i4$	2215	9	$\Xi(2250)$	$?^?$	$\star\star$	2189-2295	30-130
	$2305 + i66$	2308	66	$\Xi(2370)$	$?^?$	$\star\star$	2356-2392	75-80
	$2522 + i38$	2512	60	$\Xi(2500)$	$?^?$	$\star$	2430-2505	59-150
$-3, 1$	$1888 + i219$	1914	262					
	$2449 + i7$	2445	13	$\Omega(2470)$	$?^?$	$\star\star$	2474±12	72±33

Table 1: The properties of the 11 dynamically generated resonances and their possible PDG counterparts.

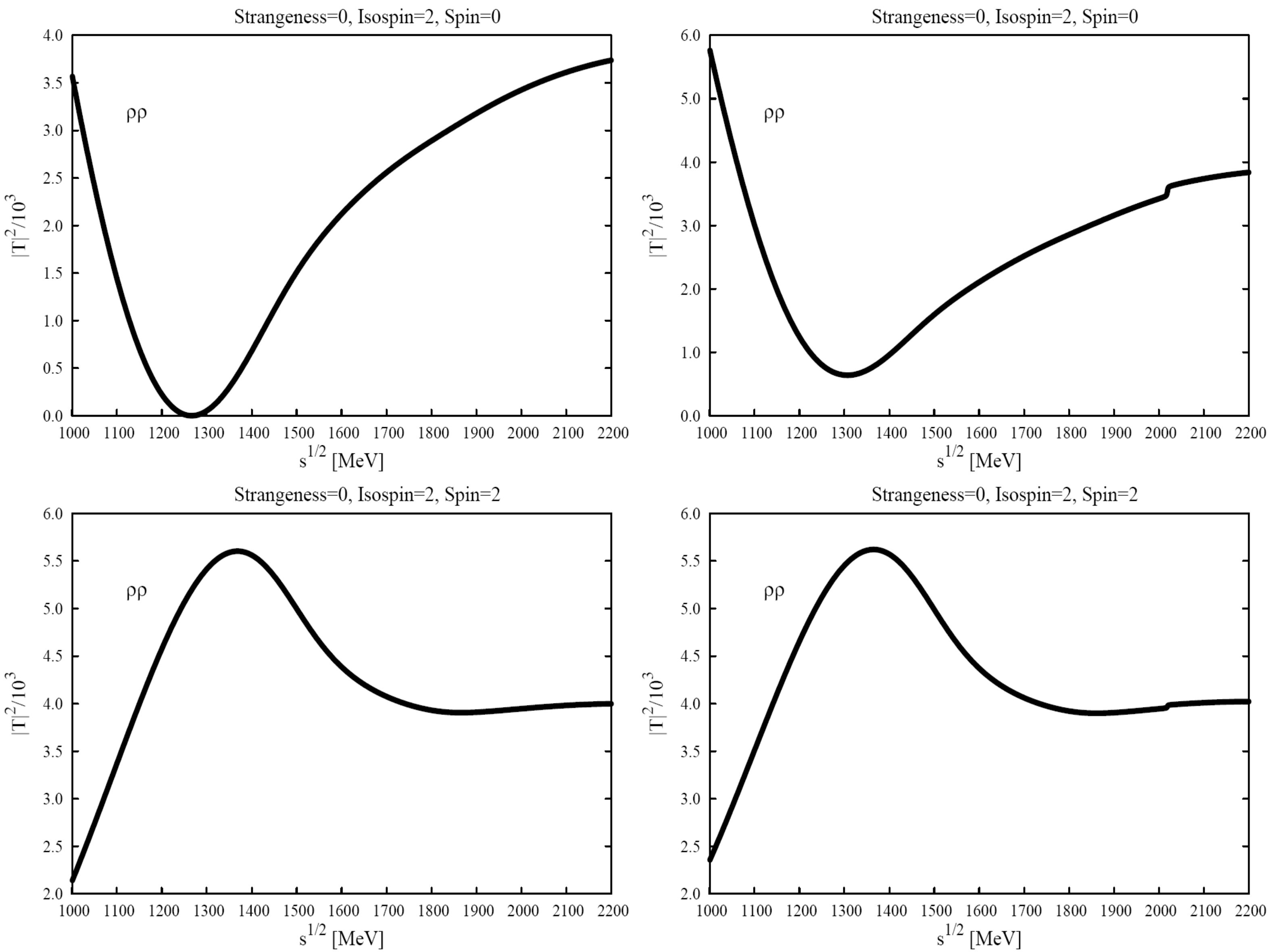
Conclusions

Chiral dynamics plays an important role in hadron physics.

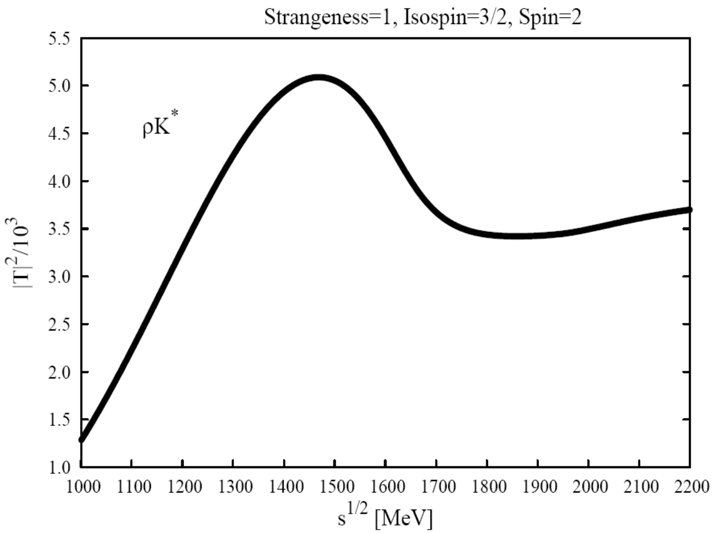
Its combination with nonperturbative unitary techniques allows to study the interaction of hadrons. Poles in amplitudes correspond to dynamically generated resonances. Many of the known meson and baryon resonances can be described in this way.

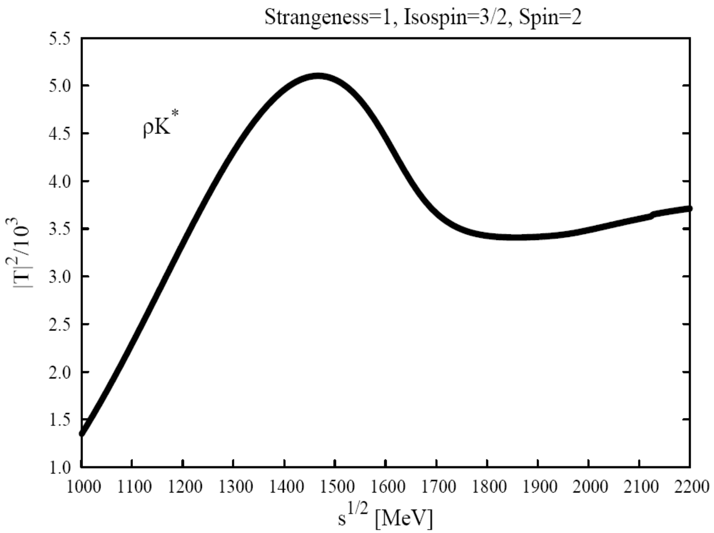
The introduction of vector mesons as building blocks brings a new perspective into the nature of higher mass mesons and baryons.

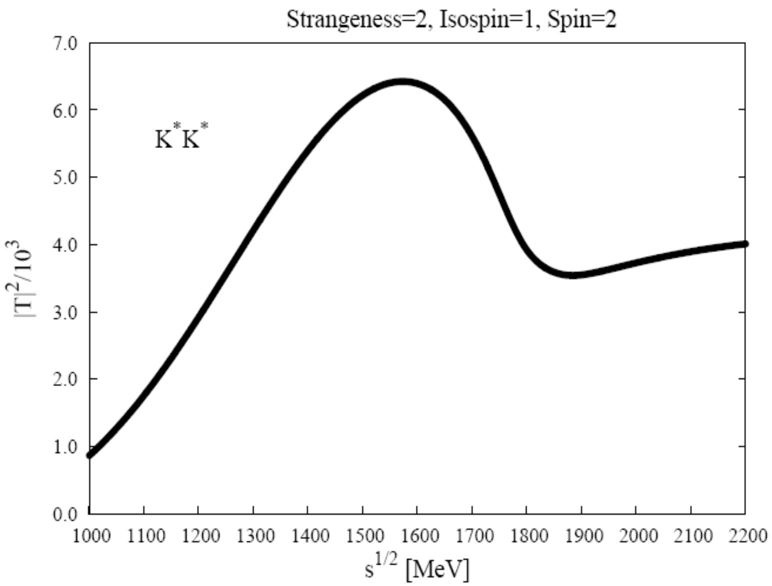
Experimental challenges to test the nature of these resonances looking for new decay channels or production modes. Plus the search for new predicted resonances.

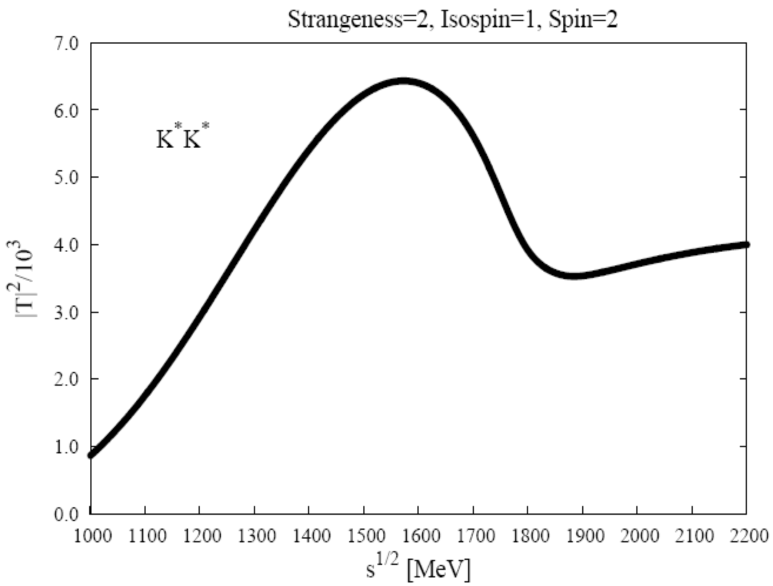


Note broad peak around 1400 MeV with I=2. A state there is claimed in the PDG. But we find no pole since the interaction is repulsive. No exotics.







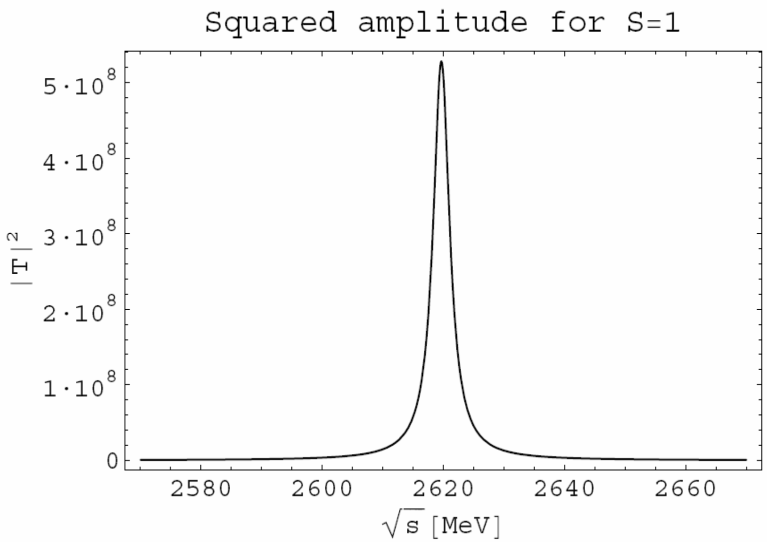


No claims of states there in the PDG. BEWARE: these are no poles

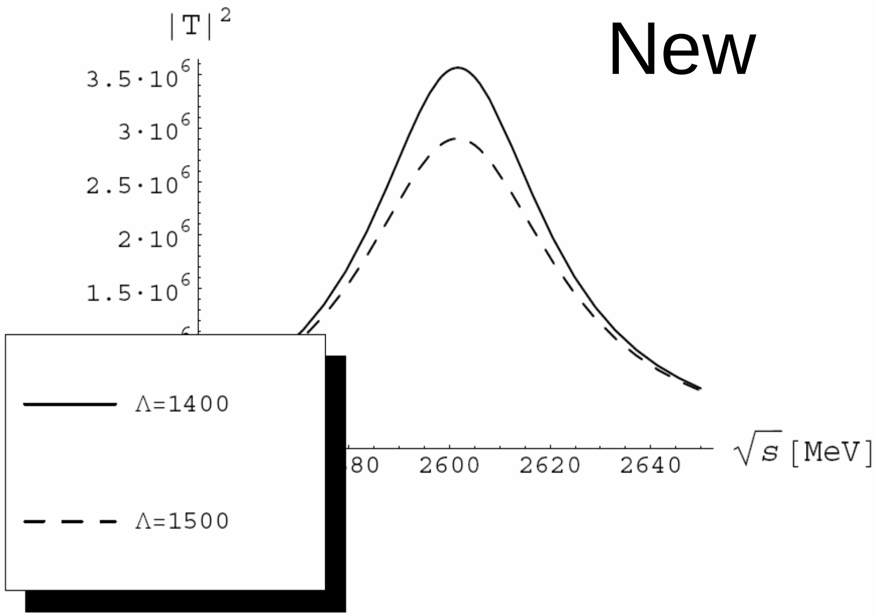
ρ D* interaction, R. Molina, E.O 2009

We also allow for decay into π D

VV in L=0
has P=+
Decay into
π D forbidden
since L’ should
be equal to S=1
and this has
negative parity



D*(2640) ?
$I(J^P)=1/2(?^?)$
Γ<15 MeV



New

D2*(2460)
Γ=43 MeV

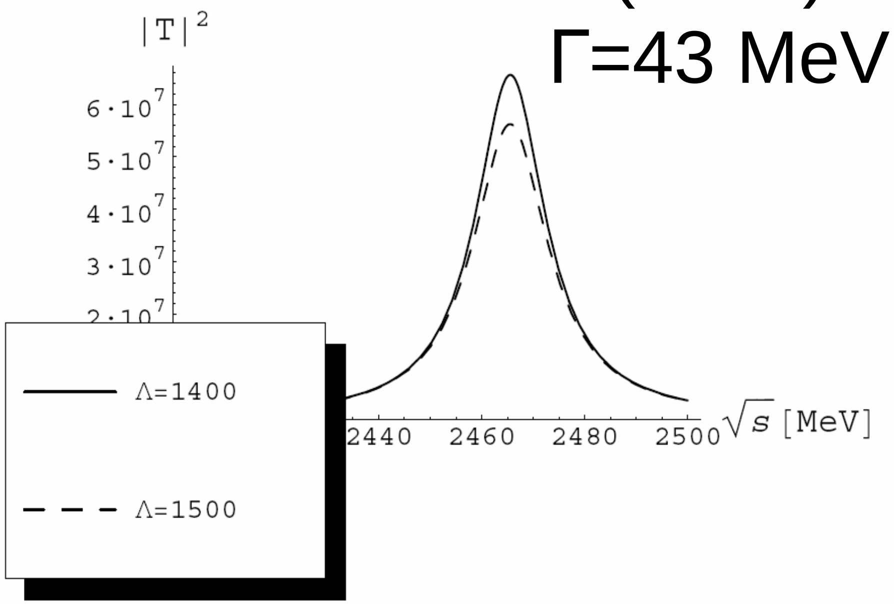


Figure 11: Squared amplitud for $S=0$ and $S=2$ including the convolution of the ρ-mass

CHIRAL LAGRANGIANS FOR MASSIVE SPIN-1 FIELDS ☆

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The paper establishes the equivalence of the chiral lagrangian method together with the tensor representation for the vectors with the hidden gauge formalism of vector mesons and vector representation for the vectors.

This is good news