Dynamically generated resonances

E. Oset , IFIC and Theory Department, Valencia
A. Ramos, S. Sarkar, Bao Xi Sun and M.J. Vicente Vacas,
P.Gonzalez, J. Vijande, D. Jido, T.Sekihara, A. Martinez,
K. Khemchhandani, U.G. Meissner

Dynamically generated resonances

Further steps to identify extra nonmeson baryon components

More on the two $\Lambda(1405)$

Dynamically generated states of two mesons and one baryon

Hidden gauge formalism for vector mesons, pseudoscalars and photons

Vector baryon molecules:

from octet of vectors and octet of baryons

from octet of vectors and decuplet of baryons

General scheme *Oller, Meissner PL '01* (meson baryon as exemple)

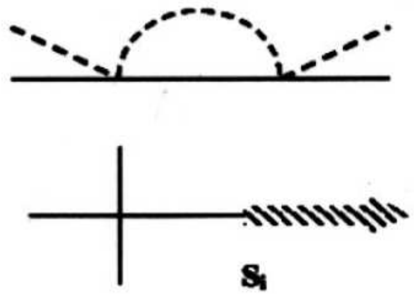
- **Unitarity** in coupled channels $\bar{K}N$, $\pi\Sigma$, $\pi\Lambda$, $\eta\Sigma$, $\eta\Lambda$, $K\Xi$, in $S=-1$

$$
\begin{aligned}
\mathrm{Im}T_{ij} &= T_{il}\sigma_{ll}T^*_{lj} \\
\sigma_l &\equiv \sigma_{ll} \equiv \frac{2Mq_l}{8\pi\sqrt{s}} \\
\sigma &= -\mathrm{Im}T^{-1}
\end{aligned}
$$

- Dispersion relation

$$
\begin{aligned}
T^{-1}_{ij} &= -\delta_{ij}\left\{\hat{a}_i(s_0) + \frac{s-s_0}{\pi}\int_{s_i}^{\infty} ds' \frac{\sigma(s')_i}{(s-s')(s'-s_0)}\right\} + \\
&+ V^{-1}_{ij} \equiv -g(s)_i\delta_{ij} + V^{-1}_{ij}
\end{aligned}
$$

g(s) accounts for the right hand cut



V accounts for local terms, pole terms and crossed dynamics. V is determined by matching the general result to the χPT expressions (usually at one loop level)

$$
\begin{aligned}
g(s) &= \frac{2M_i}{16\pi^2}\left\{a_i(\mu) + \log\frac{m_i^2}{\mu^2} + \frac{M_i^2 - m_i^2 + s}{2s}\log\frac{M_i^2}{m_i^2} + \right. \\
&+ \left. \frac{q_i}{\sqrt{s}}\log\frac{m_i^2 + M_i^2 - s - 2q_i\sqrt{s}}{m_i^2 + M_i^2 - s + 2q_i\sqrt{s}}\right\}
\end{aligned}
$$

μ regularization mass
a_i subtraction constant

Inverting T^{-1}:

$$T = [1 - Vg]^{-1}V$$

Example 1: Take $V \equiv$ lowest order chiral amplitude

In meson-baryon S-wave

$$[1 - V\,g]\,T = V \rightarrow T = V + V\,g\,T$$

Bethe Salpeter eqn. with kernel V

This is the method of *E. O., Ramos '98* using cut off to regularize the loops

Oller, Meissner show equivalence of methods with

$$a_i(\mu) \simeq -2\ln\left[1 - \sqrt{1 + \frac{m_i^2}{\mu^2}}\right] ;$$

μ cut off

$$a_i \simeq -2 \rightarrow \mu \simeq 630\,\text{MeV in } \bar{K}N$$

If higher order Lagrangians not well determined then fit a_i to the data

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?

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

WT for Weinberg Tomozawa

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

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

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

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

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

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

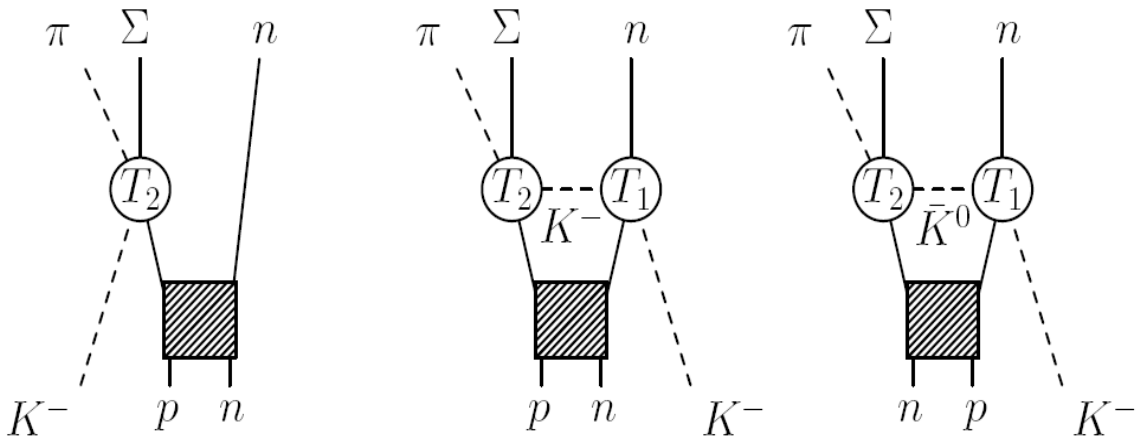
They conclude that the two Λ(1405) are basically meson baryon states, but the N*(1535) needs some extra component.

More of the two Λ(1405)

In all unitary chiral dynamical calculations two Λ(1405) appear,
One, wide, around 1395 MeV couples strongly to πΣ
The other one, narrow, around 1420 MeV, couples strongly to Kbar N

To see the one around 1420 MeV one must create it wit Kbar N

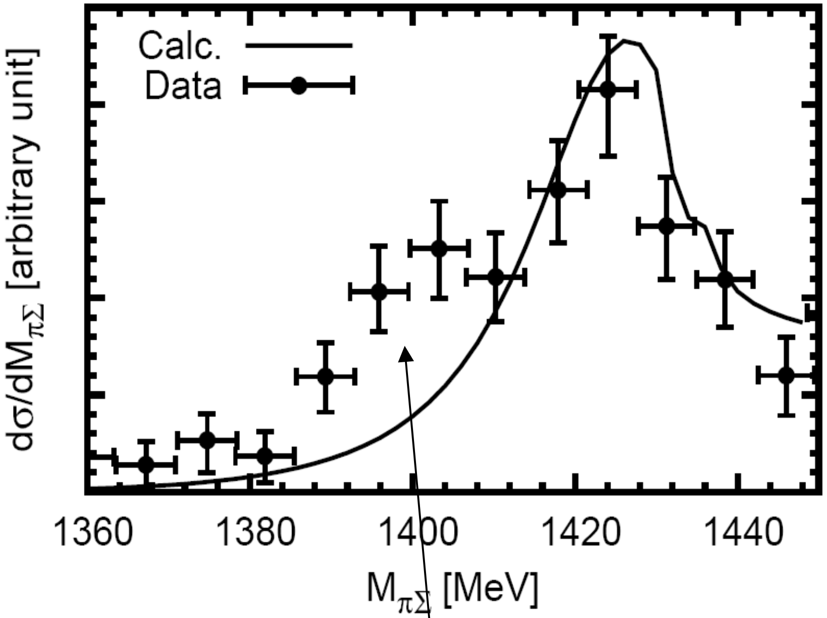
Fortunate finding: data from 1977, Braun et al, NPB129,1:
K^- d → n Λ(1405) (n πΣ)
How can that be? K^- N threshold (1432 MeV) is above the Λ(1405)!



Dia. 1 Dia. 2 Dia. 3

Rescattering reduces the energy of the K^- and the reaction can occur, and is produced by the KN

D.Jido, E. O, T. Sekihara



Note the peak around 1420 MeV

Normalization is also obtained correctly

This is related to the Σ(1385), now clearly separated from the Λ(1405) which is narrow and peaks at 1420 MeV

Important new developments generating resonances from systems of two mesons and one baryon in L=0.

Low lying 1/2 + resonances are generated like that (exception of Roper)

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

Faddeev equations with the coupled channels allowed in SU(3)

All states found can be associated to known resonances,

Λ(1600), Λ(1810), Σ(1660), Σ(1770) ….

In strangeness zero also 1/2 + states are generated

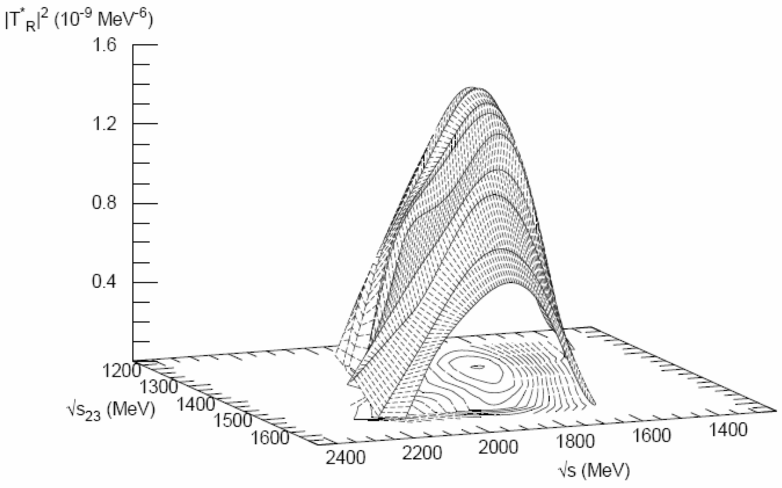
See talk of A. Martinez

The $\pi\pi N$ system
and
its coupled channels

- We consider 5 coupled channels

$$\pi^0\pi^0 n,\ \pi^+\pi^- n,\ \pi^-\pi^+ n,\ \pi^0\pi^- p,\ \pi^-\pi^0 p$$

- Negligible effect of the channels $\pi K\Sigma$, $\pi K\Lambda$ in this energy region.



- We find a peak around 1704 MeV with a width of 375 MeV in the isospin configuration I=1/2, $I_{\pi\pi}=0$.

- We identify this peak with the N*(1710) (width 50-500 MeV).

BUT .....

New state, noncatalogued, found as a K Kbar N bound state using chiral dynamics and variational method, mostly $a_0(980)$ N

Jido, Eny'o 2008

Results corroborated by A. Martinez Torres, K. Khemchandani with Faddeev equations, mixture of $a_0(980)$N , $f_0(980)$ N

The state is a $1/2^+$ apearing around 1920 MeV and we think is the peak seen in $\gamma\, p \rightarrow K^+ \Lambda$

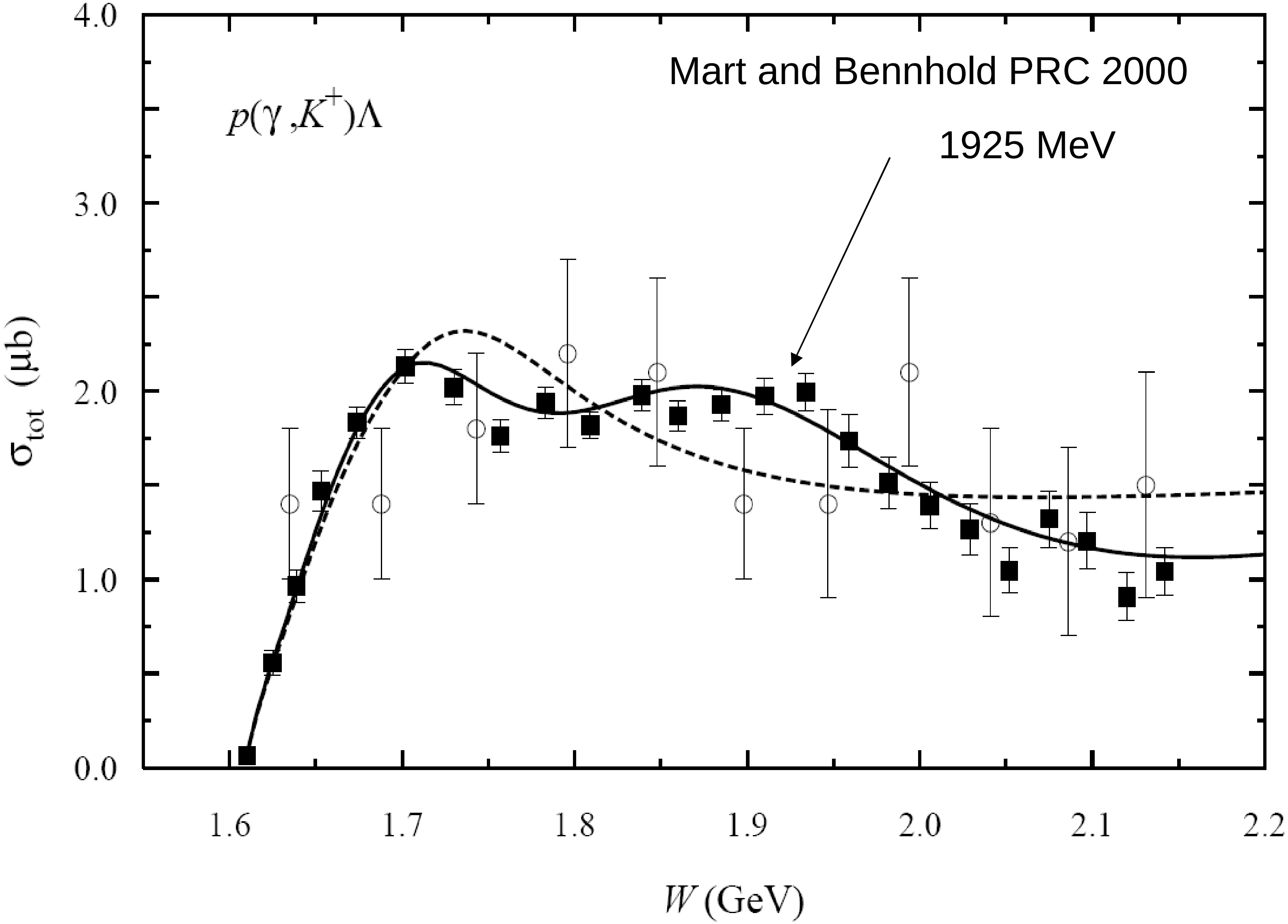
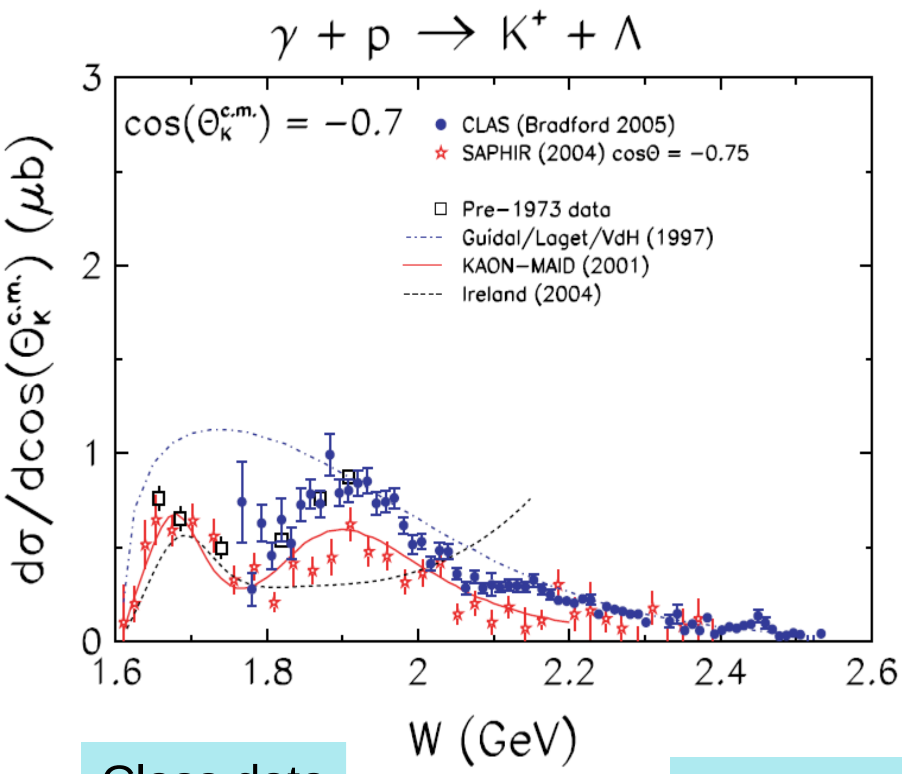
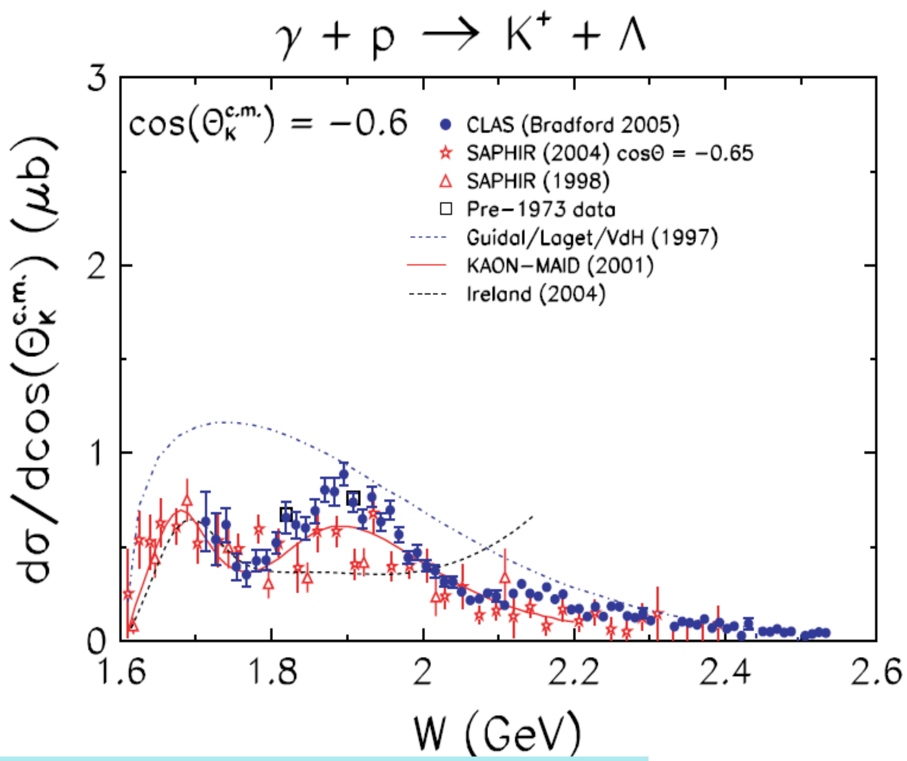


FIG. 1. Total cross section for $K^+\Lambda$ photoproduction on the proton. The dashed line shows the model without the $D_{13}(1960)$ resonance, while the solid line is obtained by including the $D_{13}(1960)$ state. The new SAPHIR data [6] are denoted by the solid squares, old data [22] are shown by the





Class data

Similar in LEPS, Sumihama, Nakano …

A recent paper by A. Martinez Torres, K. Khemchandani, U.G. Meissner and E. C suggest that this peak is due to the state found theoretically of $1/2^+$

Yet, the final answer is experimental: Separate the S_z=3/2 component, if the peak corresponds to $1/2^+$ it should disappear there

Since K Kbar N are all in L=0, and energy is below K Kbar N threshold, it should appear as an enhancement of the cross section of
γ p → K Kbar p close to threshold Nakano et al …..analysing

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

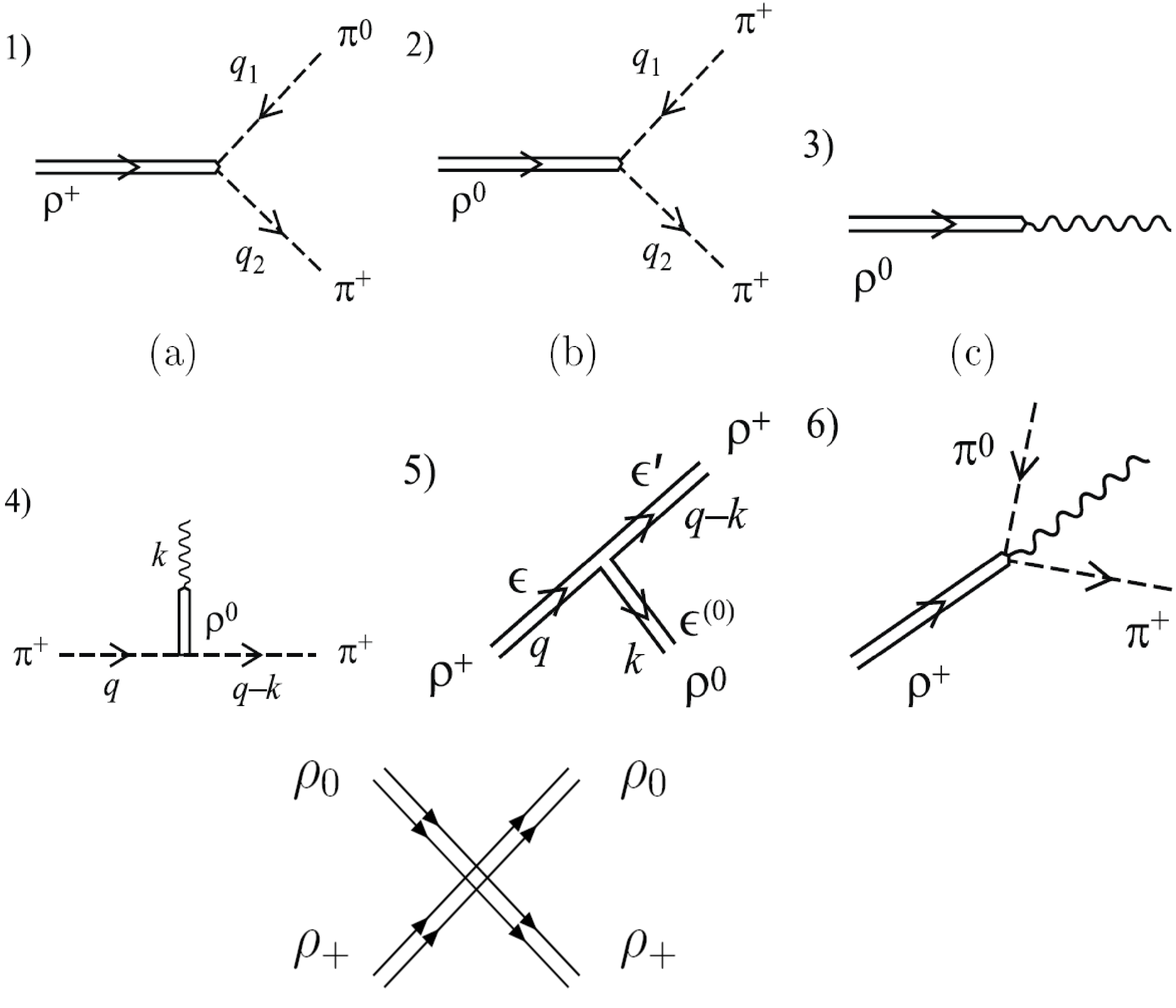
$$\Gamma_\mu = \frac{1}{2}[u^\dagger(\partial_\mu - ieQA_\mu)u + u(\partial_\mu - ieQA_\mu)u^\dagger] \tag{10}$$

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

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

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

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


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

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.

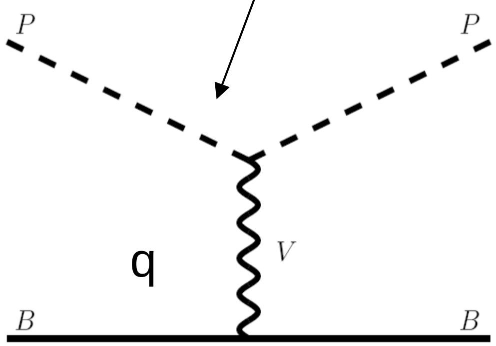
Extension to the baryon sector

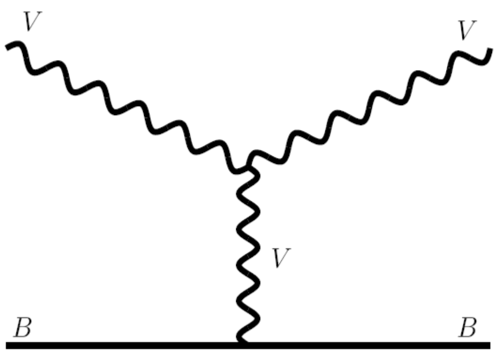
$$\mathcal{L}_{BBV} = -\frac{g}{2\sqrt{2}}\left(tr(\bar{B}\gamma_\mu[V^\mu, B] + tr(\bar{B}\gamma_\mu B)tr(V^\mu)\right)$$

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

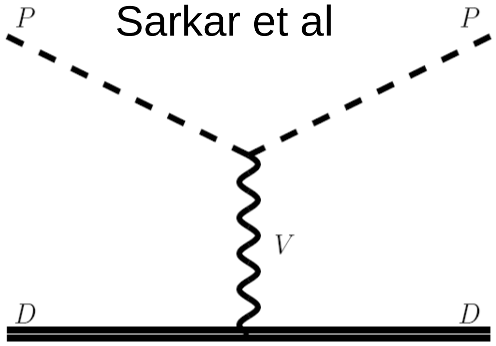
> 200 works

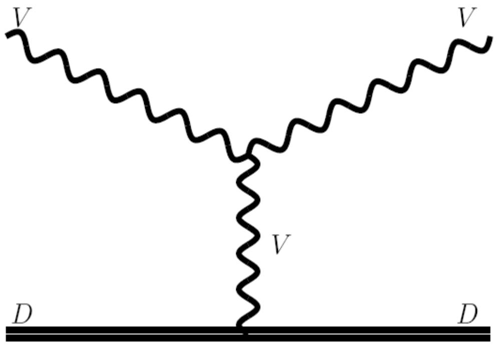




New: A. Ramos, E. O.

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

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

K^0 energy of vector mesons

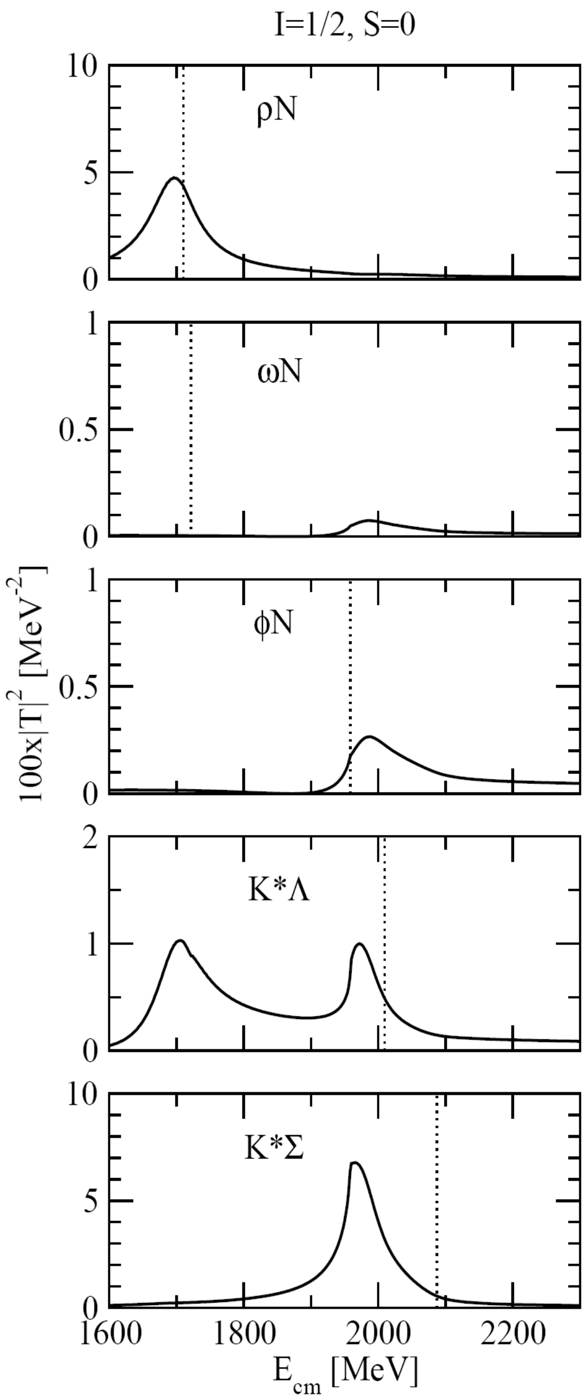
We solve the Bethe Salpeter equation in coupled channels Vector-Baryon octet.

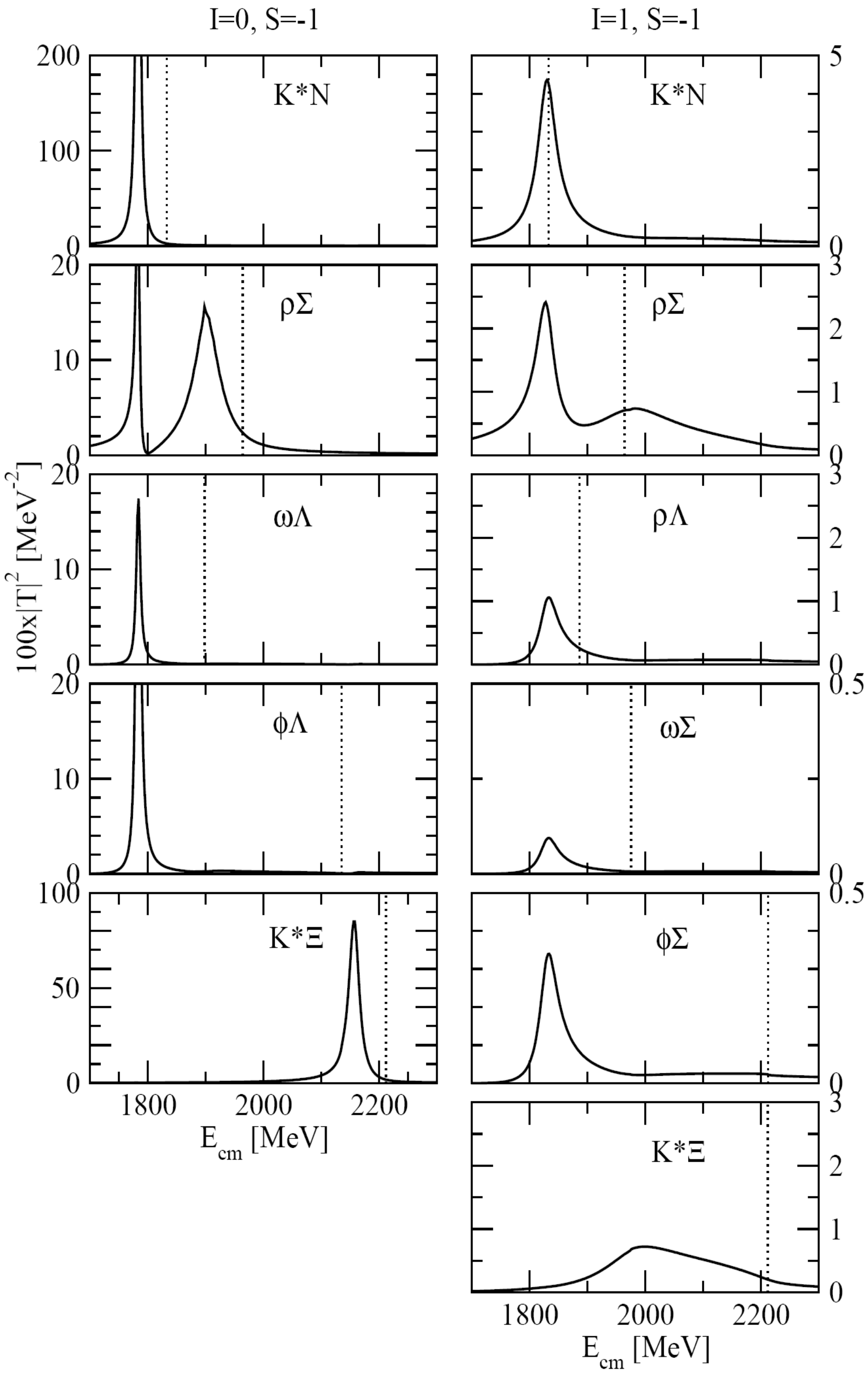
$T= (1-GV)^{-1} V$

with G the loop function of vector-baryon

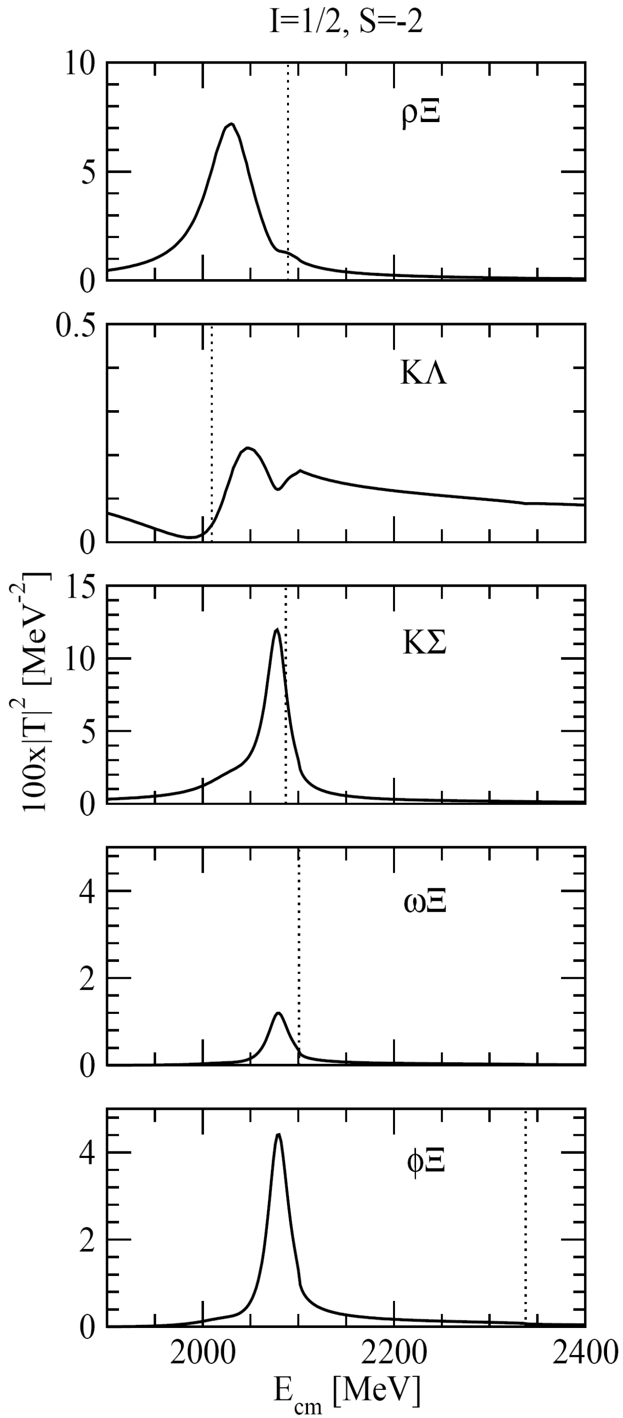
Apart from the peaks, poles are searched In the second Riemann sheet and pole positions and residues are determined.

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
K*N
ρΣ
ρΛ
ωΣ
φΣ
K*Ξ
100x|T|^2 [MeV^-2]
E_cm [MeV]
E_cm [MeV]



I=1/2, S=-2
ρΞ
KΛ
KΣ
ωΞ
φΞ
100x|T|^2 [MeV^{-2}]
E$_{cm}$ [MeV]
0
5
10
0.5
15
2
4
2000
2200
2400

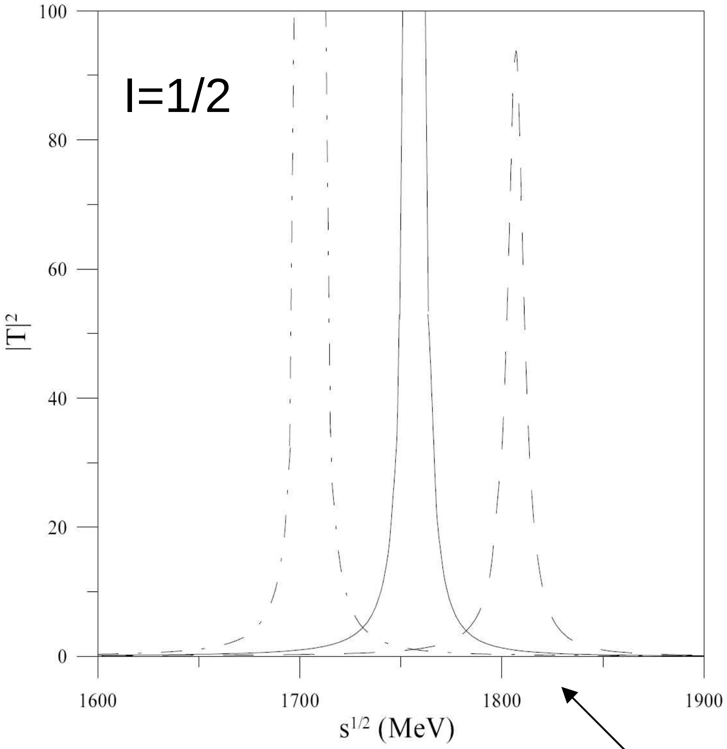
S, I	Theory		PDG data				
	(real axis)		name	J^P	status	mass	width
	mass	width					
$0, 1/2$	1699	84	$N(1650)$	$1/2^-$	$\star\star\star\star$	1645-1670	145-185
			$N(1700)$	$3/2^-$	$\star\star\star$	1650-1750	50-150
	1967	82	$N(2080)$	$3/2^-$	$\star\star$	≈ 2080	180-450
			$N(2090)$	$1/2^-$	$\star$	≈ 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



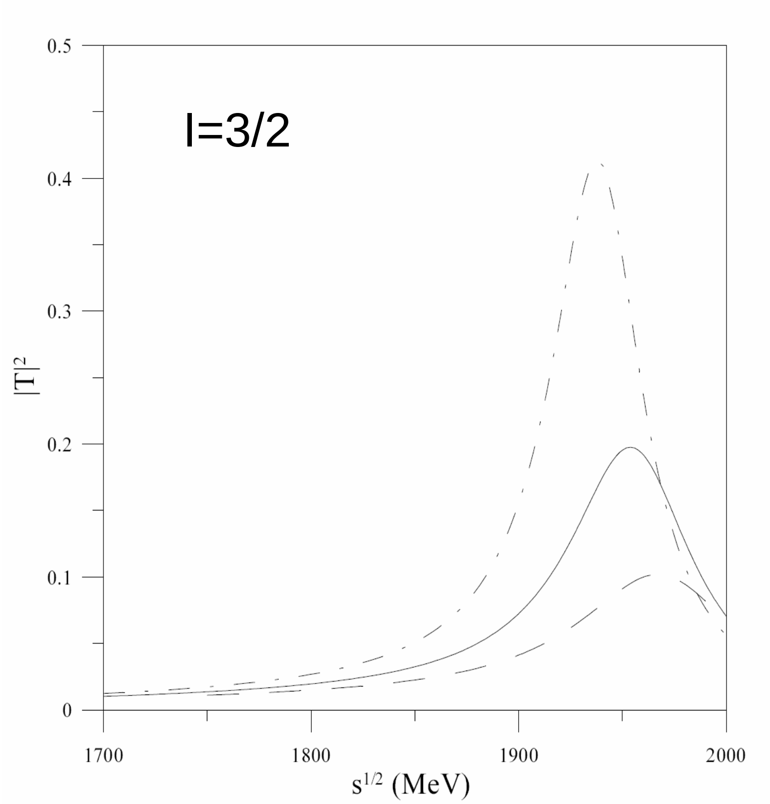


FIG. 5: $|T|^2$ for $\rho\Delta \to \rho\Delta$ in the $I = 1/2$ channel for several values of the cutoff q_{max} including ρ and Δ mass distributions: solid line $q_{max} = 770$ MeV, dashed line $q_{max} = 700$ MeV, dashed-dotted

The Vector Baryon decuplet coupling is taken from Jenkins and Manohar

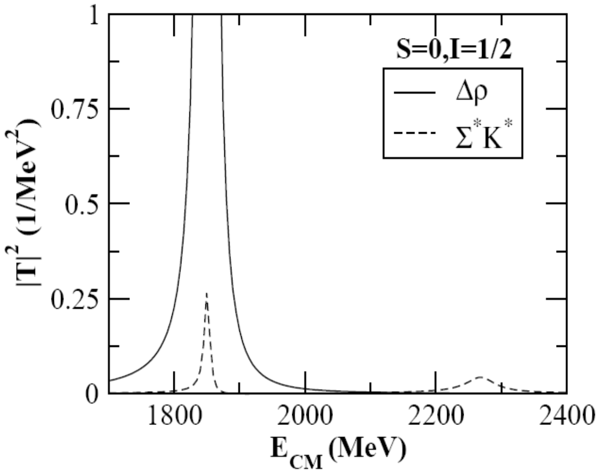
We get now three degenerate spin states for each isospin, 1/2 or 3/2

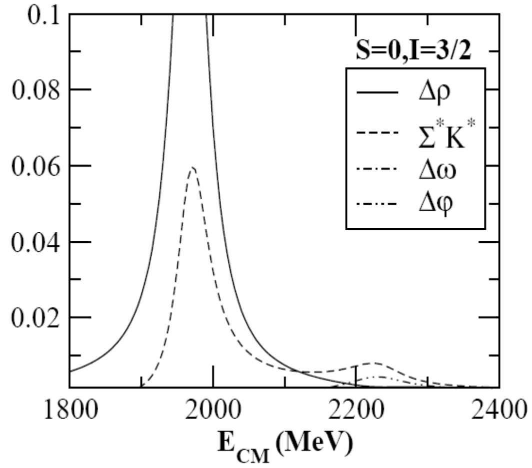
Option i) seems to be approximately at work at least for some of our degenerate $I = 3/2$, $J^P = 1/2^-, 3/2^-, 5/2^-$ states, with a mass between 1940 MeV ($q_{max} = 770$ MeV) and 1980 MeV ($q_{max} = 630$ MeV), which can be respectively assigned to $\Delta(1900)S_{31}(**)$, $\Delta(1940)D_{33}(*)$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

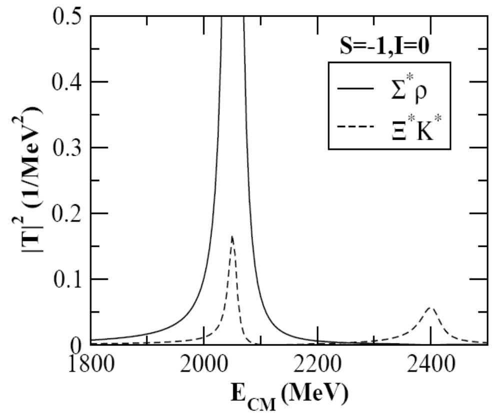
For I=1/2 the candidates could be a block of non catalogued states around 1900 MeV found in the entries of N* states with these quantum numbers around 2100 MeV

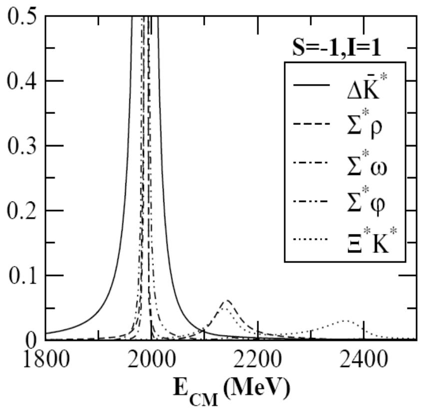
Extension to the octet of vectors and decuplet of Baryons

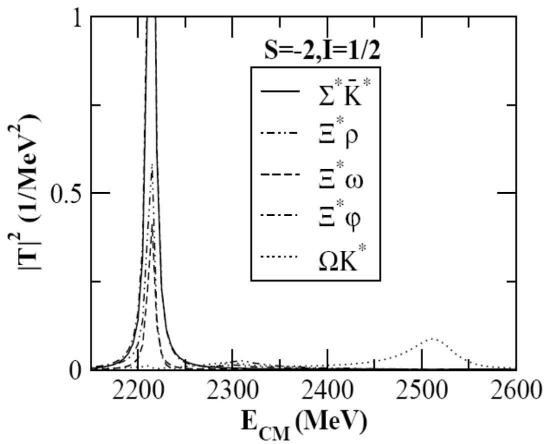
S. Sarkar, Bao Xi Sun
E. O, M.J. Vicente Vacas
09

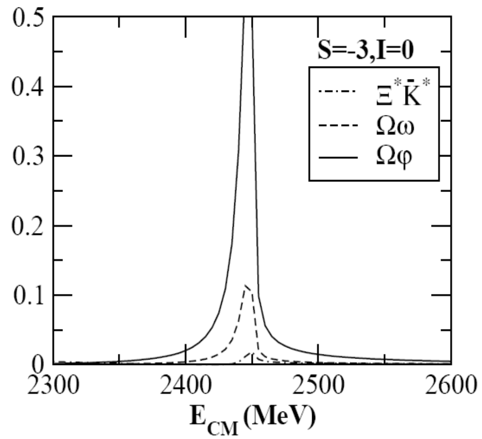












$S,\ I$	Theory			PDG data				
	pole position	real axis		name	J^P	status	mass	width
		mass	width					
$0, 1/2$	$1850 + i5$	1850	11	$N(2090)$	$1/2^-$	$\star$	1880-2180	95-414
				$N(2080)$	$3/2^-$	$\star\star$	1804-2081	180-450
$0, 3/2$	$1972 + i49$	1971	52	$\Delta(1900)$	$1/2^-$	$\star\star$	1850-1950	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

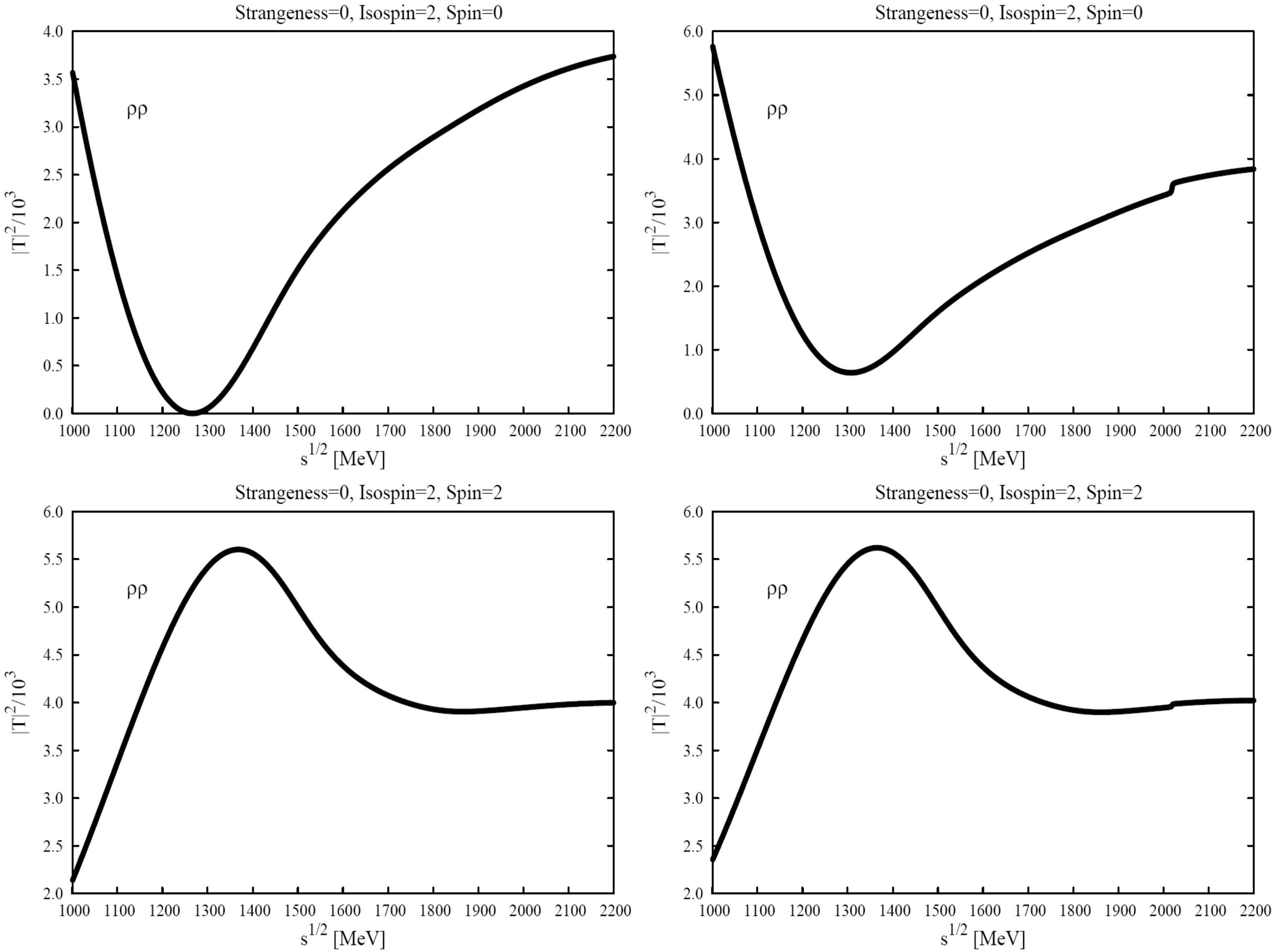
Chiral dynamics plays an important role in hadron physics.

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.

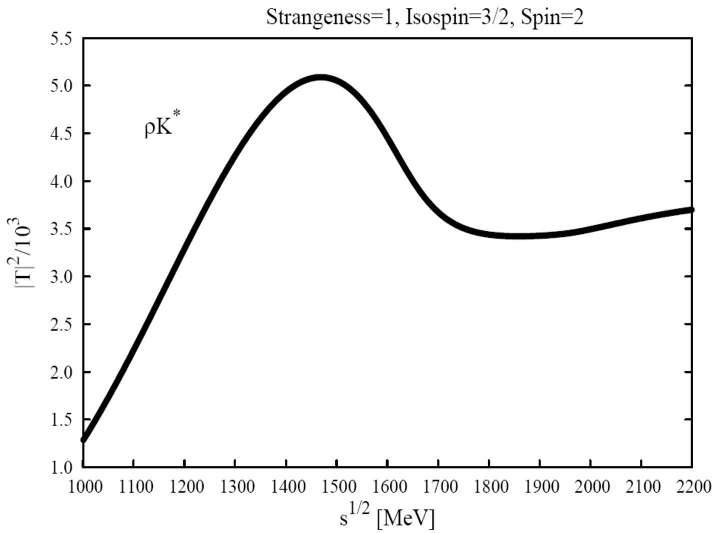
The study of systems with two mesons and a baryon has enlarged the number of dynamically generated states to new states of positive parity.

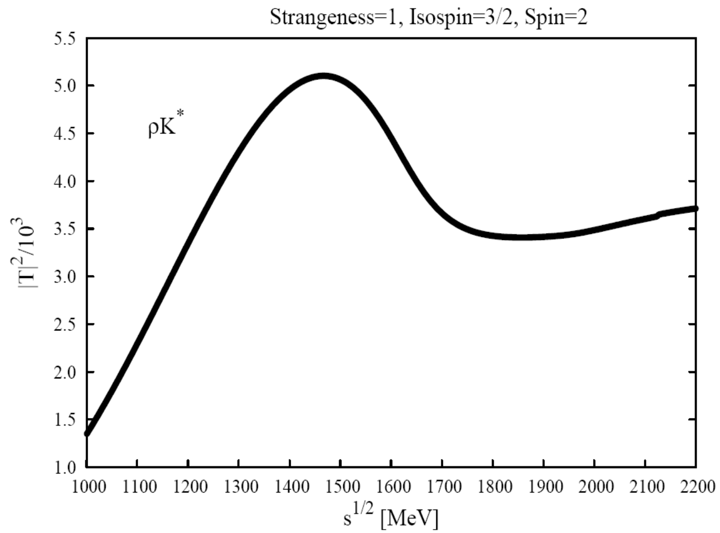
The introduction of vector mesons as building blocks brings a new perspective into the nature of higher mass mesons and baryons.

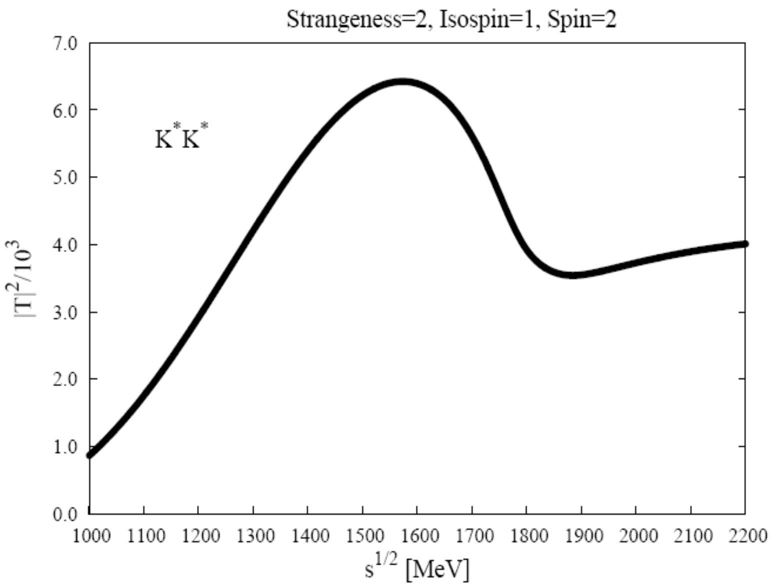
Experimental challenges to test the nature of these resonances looking for new decay channels or production modes. Plus the search for new predicted resonances.

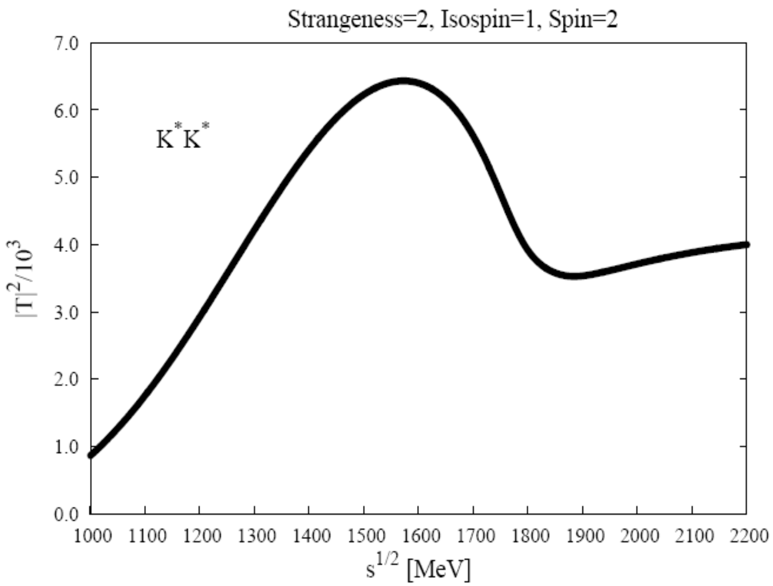


Note broad peak around 1400 MeV with I=2. A state there is claimed in the PDG. But we find no pole since the interaction is repulsive. No exotics.







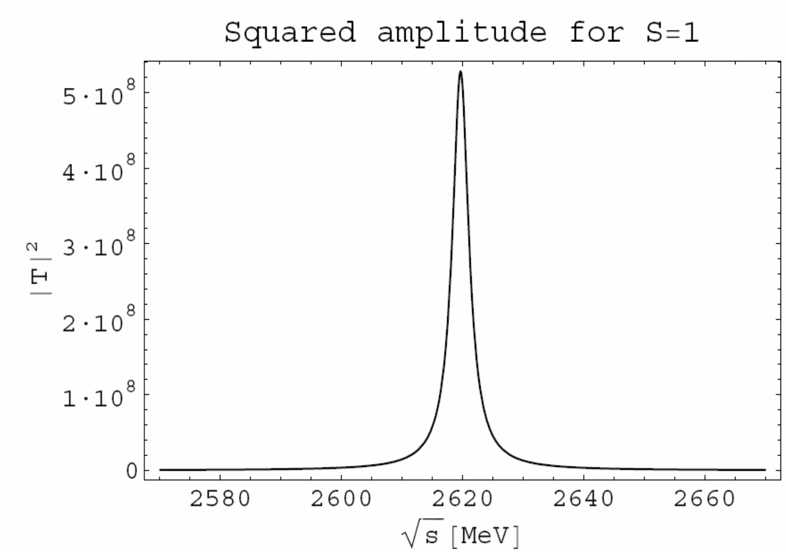


No claims of states there in the PDG. BEWARE: these are no poles

ρ D* interaction, R. Molina, E.O 2009

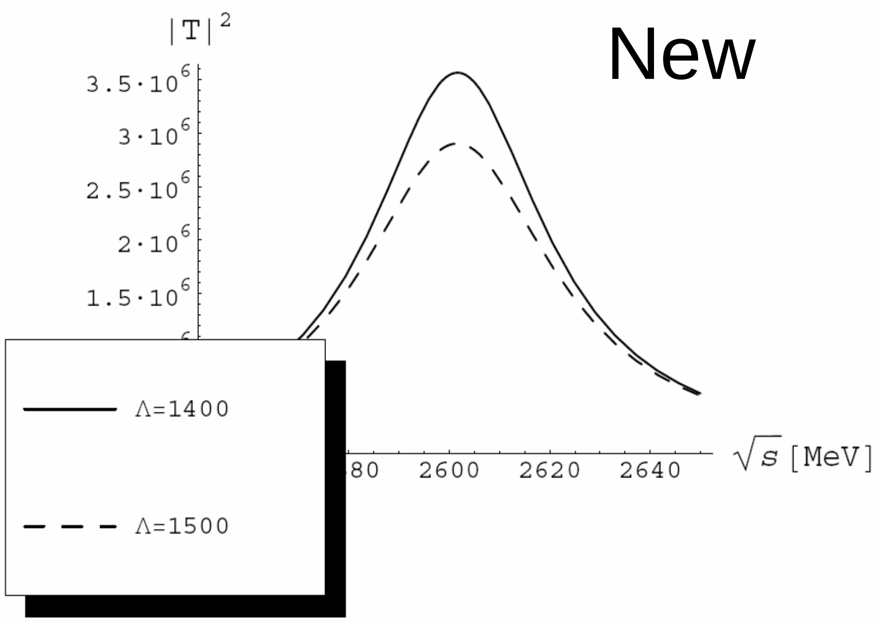
We also allow for decay into π D

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

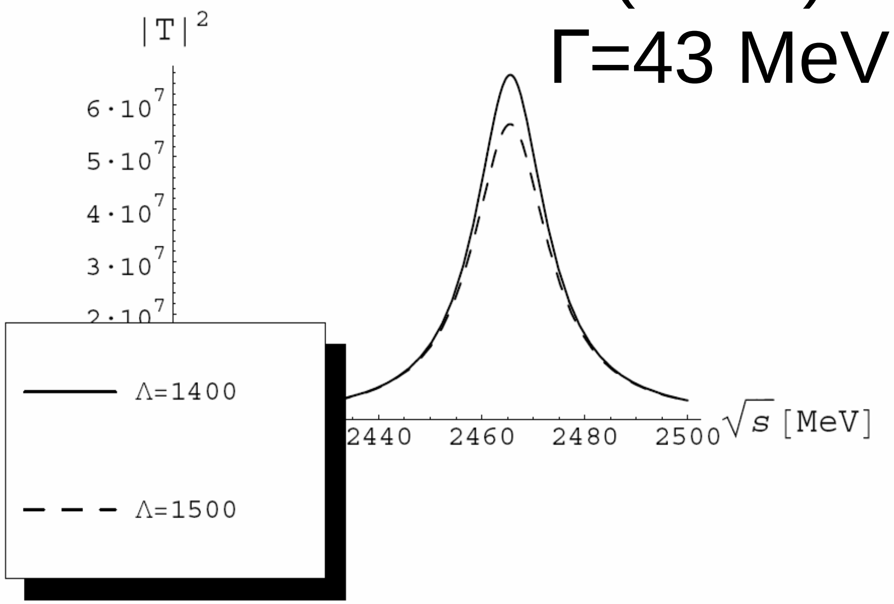


Figure 11: Squared amplitud for $S = 0$ and $S = 2$ including the convolution of the ρ-mass