# Dynamically generated resonances*

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**Abstract** In this talk I report on recent work related to the dynamical generation of baryonic resonances, some made up from pseudoscalar meson-baryon, others from vector meson-baryon and a third type from two meson-one baryon systems. We can establish a correspondence with known baryonic resonances, reinforcing conclusions previously drawn and bringing new light on the nature of some baryonic resonances of higher mass.

**Key words** dynamically generated resonances, chiral dynamics, hidden gauge formalism for vector meson interaction

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## 1 Introduction

The topic of dynamically generated resonances is bringing new light into the interpretation of many mesonic and baryonic resonances[1, 2]. Considering the case of the baryons, the underlying physics can be depicted in a schematic picture. It is well known that quarks can not be directly seen because when we give energy to the nucleon to break it, the excitation energy goes into creating meson pairs, mostly pions. This could equally happen even if we just want to excite the nucleon, not to break it. Indeed, the two first excitations of the nucleon correspond to the Roper, N*(1440) and the N*(1535). This means 500—600 MeV energy excess over the nucleon mass, which in the quark model would correspond to the excitation energy of one quark. However, the creation of one or two pions costs less energy than this. So, why should not many baryon resonances correspond to bound states or resonant states of a meson and a ground state of the baryons, or even two mesons and one baryon? The possibility that this occurs depends on whether the dynamics of the meson baryon interaction provides enough attraction to stabilize the system. Fortunately there is an excellent theory to study these interactions at low energies which is based on effective chiral Lagrangians that implement the chiral symmetry of the underlying QCD[3, 4]. In the present case we shall also report on recent results for the interaction of vector mesons with baryons, which require new Lagrangians. Here again one is lucky that such information is available in a scheme which is an extension of the chiral Lagrangians to incorporate vector mesons. The formulation starts by demanding invariance of these latter Lagrangians under local gauge transformations, that require the introduction

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of vector mesons which obtain their mass through the mechanism of spontaneous symmetry breaking. This scheme is known as the hidden gauge formalism which we shall use here too[5—8].

The novel topics that I will report about are developments on learning about the nature of resonances, which has been recently described in Ref. [9], the recent work showing extra evidence for the existence of two $\Lambda(1405)$ states[11], the generation of resonances from two mesons and a baryon[12, 13], particularly one around 1920 MeV[14—16] that could have been observed experimentally, and finally the novel work on the generation of resonances from the interaction of vector mesons with baryons, either from the octet[17] or the decuplet[18] of ground state baryons.

## 2 Searching for the nature of resonances

In this section I will report upon the work of Ref. [9]. In this work one considers the scattering of a pseudoscalar meson with mass $m$ from a target baryon with mass $M_{\rm T}$. The $s$-channel two-body unitarity condition for the amplitude $T(\sqrt{s})$ can be expressed as

$$\mathrm{Im}T^{-1}(\sqrt{s}) = \frac{\rho(\sqrt{s})}{2}, \tag{1}$$

where $\rho(\sqrt{s}) = 2M_{\rm T}\bar{q}/(4\pi\sqrt{s})$ is the two-body phase space of the scattering system with $\bar{q} = \sqrt{[s-(M_{\rm T}-m)^2][s-(M_{\rm T}+m)^2]}/(2\sqrt{s})$. This is the so-called elastic unitarity. Based on the $N/D$ method[19, 20], the general form of the scattering amplitude satisfying Eq. (1) is given by

$$T(\sqrt{s}) = \frac{1}{V^{-1}(\sqrt{s}) - G(\sqrt{s})}, \tag{2}$$

where $V(\sqrt{s})$ is a real function expressing the dynamical contributions other than the $s$-channel unitarity and will be identified as the kernel interaction. $G(\sqrt{s})$ is obtained by the once subtracted dispersion relation with the phase-space function $\rho(\sqrt{s})$. An analytical expression for this $G(\sqrt{s})$ function can be found in[20] which shows explicitly the subtraction constant $a(\mu)$ of the dispersion relation:

$$\begin{aligned}G(\sqrt{s}) = \frac{2M_{\rm T}}{(4\pi)^2}\Big\{ & a(\mu) + \ln\frac{M_{\rm T}^2}{\mu^2} + \frac{m^2 - M_{\rm T}^2 + s}{2s}\ln\frac{m^2}{M_{\rm T}^2} + \\ & \frac{\bar{q}}{\sqrt{s}}[\ln(s - (M_{\rm T}^2 - m^2) + 2\sqrt{s}\bar{q}) + \\ & \ln(s + (M_{\rm T}^2 - m^2) + 2\sqrt{s}\bar{q}) - \\ & \ln(-s + (M_{\rm T}^2 - m^2) + 2\sqrt{s}\bar{q}) - \\ & \ln(-s - (M_{\rm T}^2 - m^2) + 2\sqrt{s}\bar{q})]\Big\}.\end{aligned} \tag{3}$$

One usually assumes $V$ to be given by the Weinberg-Tomozawa interaction and then one has

$$T(\sqrt{s}) = \frac{1}{V_{\rm WT}^{-1}(\sqrt{s}) - G(\sqrt{s}; a_{\rm pheno})}, \tag{4}$$

with the subtraction constant $a_{\rm pheno}$ in the loop function $G$ being a free parameter to reproduce experimental data. This scheme can describe various phenomena well, but the subtraction constant does not always satisfy the natural renormalization condition of Ref. [20], which corresponds to having an equivalent $G$ function using a cut off of the order of 700—1000 MeV, the scale of the effective theory.

One can achieve an equivalent scattering amplitude, using a different interaction kernel $V_{\rm natural}$ as

$$T(\sqrt{s}) = \frac{1}{V_{\rm natural}^{-1}(\sqrt{s}) - G(\sqrt{s}; a_{\rm natural})}. \tag{5}$$

The interaction kernel $V_{\rm natural}$ should be modified from $V_{\rm WT}$ in order to reproduce experimental observables. Thus, equating the denominators of Eqs. (4) and (5) one obtains[9]:

$$V_{\rm natural}(\sqrt{s}) = -\frac{C}{2f^2}(\sqrt{s} - M_{\rm T}) + \frac{C}{2f^2}\frac{(\sqrt{s} - M_{\rm T})^2}{\sqrt{s} - M_{\rm eff}}. \tag{6}$$

In Eq. (6) the first term represents the Weinberg-Tomozawa interaction, the seed to generate dynamically the resonances, and the second term would represent the contribution to account for a genuine part of the wave function. The findings of Ref. [9] indicate that, while the $\Lambda(1405)$ is essentially a pure dynamically generated state, the $\mathrm{N}^*(1535)$ demands also a genuine component, probably a three quark component.

A very recent work in which a pole to account for a possible genuine component of the $\mathrm{N}^*(1535)$ is considered together with the driving Weinberg-Tomozawa term, reinforces the leading role of the dynamically generated $\mathrm{N}^*(1535)$ component, once another pole to account for a genuine $\mathrm{N}^*(1650)$ (non pseudoscalar-baryon state for this purpose) is considered[21].

## 3 The $\mathbf{K^-d \to n\Lambda(1405)}$ reaction and further evidence for the existence of two $\mathbf{\Lambda(1405)}$ states

In the chiral $SU(3)$ framework for meson-baryon interaction one has the interaction of one octet of mesons with the octet of baryons, which leads to a singlet, a symmetric octet and an antisymmetric octet in which the interaction is attractive, while it is repulsive in the other multiplets[22]. This leads to two octets and a singlet of dynamically generated states and the two octets are degenerate in the $SU(3)$ limit when the masses of the mesons are made equal as well as those of the baryons. As the physical masses are gradually restored, the two octets split apart and one of them approaches the pole of the singlet at energies around 1400 MeV, such that they overlap and the physical $\Lambda(1405)$ is a superposition of the two resonances. Yet, there are some differences between the two states: the one at 1395 MeV is wide and couples strongly to $\pi\Sigma$, while that at 1420 MeV is narrow (around 30 MeV) and couples mostly to $\bar{K}N$. These findings have been corroborated by all following chiral dynamical works on this issue[23—29]. Because of the different shape of the two states and the different coupling to $\bar{K}N$ or $\pi\Sigma$, one expects that the $\Lambda(1405)$ will show up with different positions and widths in different experiments, depending on whether it is produced by an initial $\bar{K}N$ or $\pi\Sigma$ state. The first evidence for this was seen in the $K^-p \to \pi^0\pi^0\Sigma^0$ experiment[30] where a narrow peak was found around 1420 MeV. The reaction was studied theoretically in[31], where it was shown that the resonance was indeed excited from the $\bar{K}N$ channel and this was responsible for the experimental shape as predicted in Ref. [22].

A further evidence for it has come from the analysis of the experiment of Ref. [32] done recently in Ref. [11]. The reaction is $K^-d \to n\Lambda(1405)$, but the peak of the resonance is seen clearly at 1420 MeV. It is curious to see how the $\Lambda(1405)$ can be made in a $K^-p$ reaction when the resonance is below the $K^-p$ threshold. The answer is found in[11], where the reaction was studied taking into account single and double scattering of the $K^-$, as depicted in Fig. 1.

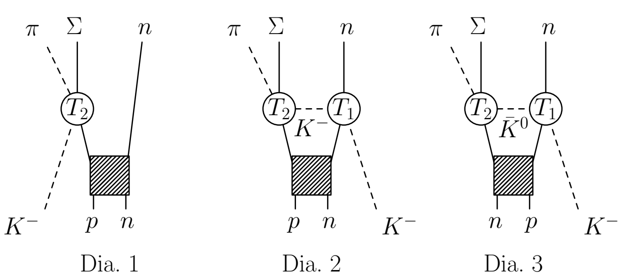


Fig. 1. Diagrams for the calculation of the $K^-d \to \pi\Sigma n$ reaction. $T_1$ and $T_2$ denote the scattering amplitudes for $\bar{K}N \to \bar{K}N$ and $\bar{K}N \to \pi\Sigma$, respectively.

The reaction proceeds basically by double scattering: in a first scattering there is a collision of the $K^-$ which gives energy to a neutron and brings the $K^-$ below threshold to produce the $\Lambda(1405)$ in the second collision. The calculated cross section of Ref. [11] agrees well with experiment in shape and size, leaving apart a bump around 1385 MeV that in Ref. [11] is found to come from $\Sigma(1385)$ excitation (Fig. 2), the inclusion of which does not distort the shape of the $\Lambda(1405)$. Experiments in this line are planned for J-PARC.

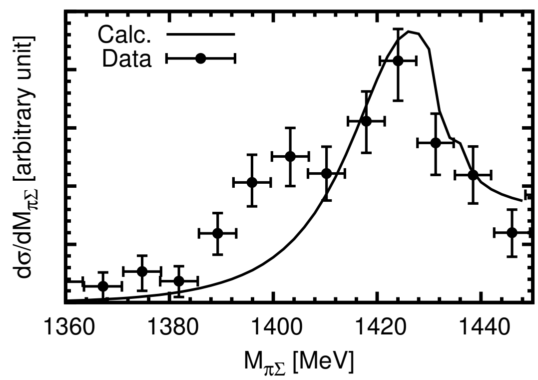


Fig. 2. $\pi\Sigma$ invariant mass spectra of $K^-d \to \pi^+\Sigma^-n$ in arbitrary units at 800 MeV/$c$ incident $K^-$ momentum. The solid line denotes the present calculation. The data are taken from the bubble chamber experiment at $K^-$ momenta between 686 and 844 MeV/$c$, see text.

## 4 States of two mesons and a baryon

There are two specific talks on this issue in the Workshop[33, 34]. I will summarize a bit the important findings in this area by different groups. In Refs. [12, 13] a formalism was develop to study Faddeev equations of systems of two mesons and a stable baryon. The interaction of the pairs was obtained from the chiral unitary approach, which proves quite successful to give the scattering amplitudes of meson-meson and meson-baryon systems in the region of energies of interest to us. The spectacular finding is that, leaving apart the Roper resonance, whose structure is far more elaborate than originally thought[35, 36], all the low lying $J^P = 1/2^+$ excited states are obtained as bound states or resonances of two mesons and one baryon in coupled channels.

It is rewarding to see that the idea is catching up and an independent study, using variational methods found a bound state of $K\bar{K}N$, with the $K\bar{K}$ being in the $a_0(980)$ state[14]. The system was studied a posteriori in[16] and it was found to appear at the same energy and the same configuration, although with a mixture of $f_0(980)N$, see Fig. 3. This state appears around 1920 MeV with $J^P = 1/2^+$. In a recent paper[37] some arguments were given to associate this state with the bump that one sees in the $\gamma p \to K^+\Lambda$ reaction around this energy, which is clearly visible in recent accurate experiments[38, 39]. If this association was correct there would be other experimental consequences, as an enhanced strength of the $\gamma p \to K^+K^-p$ cross section close to threshold, as well as a shift of strength close to the $K\bar{K}$ threshold in the invariant mass distribution of the kaon pair. This experiment is right now under study and preliminary results corroborate our predictions[40].

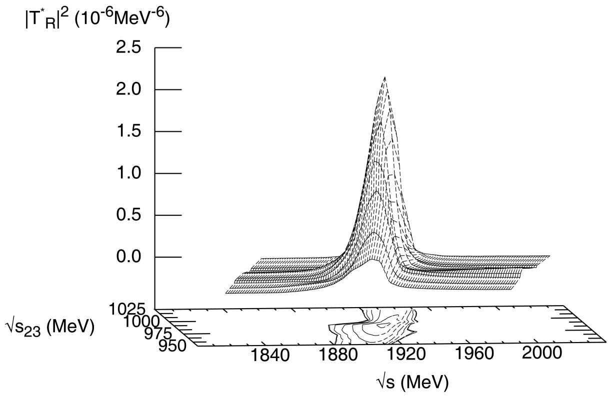


Fig. 3. A possible $N^*(1910)$ in the $NK\bar{K}$ channels.

## 5 Resonances from the interaction of vector mesons with baryons

This is a very novel development since, as we shall see, some of the high mass baryon resonances can be represented like bound states of vector mesons and baryons, either from the octet of stable baryons or the decuplet.

### 5.1 Formalism

We follow the formalism of the hidden gauge interaction for vector mesons of[5—8] (see also Ref. [41] for a practical set of Feynman rules). The Lagrangian involving the interaction of vector mesons amongst themselves is given by

$$\mathcal{L}_{III} = -\frac{1}{4}\langle V_{\mu\nu}V^{\mu\nu}\rangle \ , \tag{7}$$

where the symbol $\langle\rangle$ stands for the trace in the $SU(3)$ space and $V_{\mu\nu}$ is given by

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - \mathrm{i}g[V_\mu, V_\nu] \ , \tag{8}$$

where $g$ is

$$g = \frac{M_V}{2f} \ , \tag{9}$$

with $f = 93$ MeV the pion decay constant. The magnitude $V_\mu$ is the $SU(3)$ matrix of the vectors of the octet of the $\rho$

$$V_\mu = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu \ . \tag{10}$$

The lagrangian $\mathcal{L}_{\rm III}$ gives rise to a contact term coming from $[V_\mu, V_\nu][V_\mu, V_\nu]$

$$\mathcal{L}^{(c)}_{\rm III} = \frac{g^2}{2}\langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu\rangle \ , \tag{11}$$

as well as to a three vector vertex which can be conveniently rewritten as

$$\mathcal{L}^{(3V)}_{\rm III} = \mathrm{i}g\langle(V^\mu\partial_\nu V_\mu - \partial_\nu V_\mu V^\mu)V^\nu\rangle \ . \tag{12}$$

In this case one finds an analogy to the coupling of vectors to pseudoscalars given in the same theory by

$$\mathcal{L}_{\rm VPP} = -\mathrm{i}g\langle[P, \partial_\nu P]V^\nu\rangle \ , \tag{13}$$

where $P$ is the $SU(3)$ matrix of the pseudoscalar fields.

In a similar way, one obtains the Lagrangian for the coupling of vector mesons to the baryon octet given by[42, 43] ;1)

$$\mathcal{L}_{\rm BBV} = g\left(\langle\bar{B}\gamma_\mu[V^\mu, B]\rangle + \langle\bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle\right) \tag{14}$$

where $B$ is now the $SU(3)$ matrix of the baryon octet

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix} . \tag{15}$$

With these ingredients we can construct the Feynman diagrams that lead to the $PB \to PB$ and $VB \to VB$ interaction, by exchanging a vector meson between the pseudoscalar or the vector meson and the baryon, as depicted in Fig. 4.

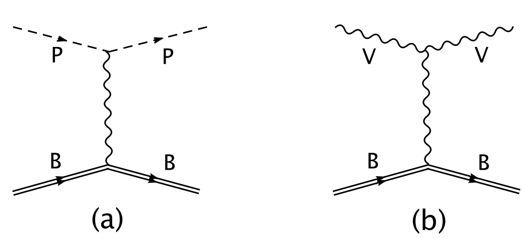


Fig. 4. Diagrams contributing to the pseudoscalar-baryon (a) or vector- baryon (b) interaction via the exchange of a vector meson.

1) Correcting a misprint in Ref. [42]

From the diagram of Fig. 4(a), and under the low energy approximation of neglecting $q^2/M_V^2$ in the propagator of the exchanged vector, where $q$ is the momentum transfer, one obtains the same amplitudes as obtained from the ordinary chiral Lagrangian for pseudoscalar-baryon octet interaction[3, 4], namely the Weinberg-Tomozawa terms. The approximation of neglecting the three momenta of the vectors implies that $V^\nu$ in Eq. (12) corresponds to the exchanged vector and the analogy with Eq. (13) is more apparent. Note that $\epsilon_\mu\epsilon^\mu$ becomes $-\vec{\epsilon}\vec{\epsilon}'$ and the signs of the Lagrangians also agree.

A small amendment is in order in the case of vector mesons, which is due to the mixing of $\omega_8$ and the singlet of $SU(3)$, $\omega_1$, to give the physical states of the $\omega$ and the $\phi$ mesons:

$$\omega=\sqrt{\frac{2}{3}}\omega_1+\frac{1}{\sqrt{3}}\omega_8\ ,\quad \phi=\frac{1}{\sqrt{3}}\omega_1-\sqrt{\frac{2}{3}}\omega_8\ . \quad (16)$$

Given the structure of Eq. (16), the singlet state which is accounted for by the $V$ matrix, $\mathrm{diag}(\omega_1,\omega_1,\omega_1)/\sqrt{3}$, does not provide any contribution to Eq. (12), in which case all one must do is to take the matrix elements known for the PB interaction and, wherever P corresponds to the $\eta_8$, the amplitude should be multiplied by the factor $1/\sqrt{3}$ to get the corresponding $\omega$ contribution, and by $-\sqrt{2/3}$ to get the corresponding $\phi$ contribution. Upon the approximation consistent with neglecting the three momentum versus the mass of the particles (in this case the baryon), we can just take the $\gamma^0$ component of Eq. (14) and then the transition potential corresponding to the diagram of 4(b) is given by

$$V_{ij}=-C_{ij}\,\frac{1}{4f^2}\,(k^0+k'^0)\ \vec{\epsilon}\vec{\epsilon}'\ , \quad (17)$$

where $k^0,k'^0$ are the energies of the incoming and outgoing vector meson.

The $C_{ij}$ coefficients of Eq. (17) can be obtained directly from[44—46] with the simple rules given above for the $\omega$ and the $\phi$ mesons, and substituting $\pi$ by $\rho$ and K by $K^*$ in the matrix elements. They can be found in the appendix of[17] where one can see that the cases with $(I,S)=(3/2,0)$, $(2,-1)$ and $(3/2,-2)$, the last two corresponding to exotic channels, have a repulsive interaction and do not produce poles in the scattering matrices. However, the sectors $(I,S)=(1/2,0)$, $(0,-1)$, $(1,-1)$ and $(1/2,-2)$ are attractive and one finds bound states and resonances in these cases.

The scattering matrix is obtained solving the coupled channels Bethe Salpeter equation in the on shell factorization approach of[20, 44]

$$T=[1-VG]^{-1}V, \quad (18)$$

with $G$ being the loop function of a vector meson and a baryon of Eq. (3). This function is convoluted with the spectral function of the vector mesons to take into account their width as done in Ref. [47].

In this case the factor $\vec{\epsilon}\vec{\epsilon}'$, appearing in the potential $V$, factorizes also in the $T$ matrix for the external vector mesons. This trivial spin structure is responsible for having degenerate states with spin-parity $1/2^-,3/2^-$ for the interaction of vectors with the octet of baryons and $1/2^-,3/2^-,5/2^-$ for the interaction of vectors with the decuplet of baryons.

What we have done here for the interaction of vectors with the octet of baryons can be done for the interaction of vectors with the decuplet of baryons, and the interaction is obtained directly from that of the pseudoscalar-decuplet of baryons studied in[48, 49]. The study of this interaction in[18, 50] leads also to the generation of many resonances which are described below.

We search for poles in the scattering matrices in the second Riemann sheet, as defined in previous works[51], basically changing $\bar{q}_l$ by to $-\bar{q}_l$ in the analytical formula of the $G$ function, Eq. (3), for channels where $\mathrm{Re}(\sqrt{s})$ is above the threshold of the corresponding channel. From the residues of the amplitudes at the poles one obtains the couplings of the resonances to the different channels. Alternatively, one can obtain these couplings from the amplitudes in the real axis as follows. Assuming these amplitudes to behave as

$$T_{ij}=\frac{g_ig_j}{\sqrt{s}-M_R+i\Gamma/2}\ , \quad (19)$$

where $M_R$ is the position of the maximum of $|T_{ii}|$, with $i$ being the channel to which the resonance couples more strongly, and $\Gamma$ its width at half-maximum, one then finds

$$|g_i|^2=\frac{\Gamma}{2}\sqrt{|T_{ii}|^2}\ . \quad (20)$$

Up to a global phase, this expression allows one to determine the value of $g_i$, which we take to be real. The other couplings are then derived from

$$g_j=g_i\frac{T_{ij}(\sqrt{s}=M_R)}{T_{ii}(\sqrt{s}=M_R)}\ . \quad (21)$$

This procedure to obtain the couplings from $|T|^2$ in the real axis was used in Ref. [52] where it was found that changes in the input parameters which lead to moderate changes in the position and the width of the states affected the couplings more smoothly.

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

| $I,S$ | theory | | | PDG data | | | | |
|---|---|---|---|---|---|---|---|---|
| | pole position | real axis | | name | $J^P$ | status | mass | width |
| | | mass | width | | | | | |
| 1/2, 0 | — | 1696 | 92 | N(1650) | $1/2^-$ | ⋆⋆⋆⋆ | 1645-1670 | 145-185 |
| | | | | N(1700) | $3/2^-$ | ⋆⋆⋆ | 1650-1750 | 50-150 |
| | 1977+i53 | 1972 | 64 | N(2080) | $3/2^-$ | ⋆⋆ | ≈2080 | 180-450 |
| | | | | N(2090) | $1/2^-$ | ⋆ | ≈2090 | 100-400 |
| 0, −1 | 1784+i4 | 1783 | 9 | Λ(1690) | $3/2^-$ | ⋆⋆⋆⋆ | 1685-1695 | 50-70 |
| | | | | Λ(1800) | $1/2^-$ | ⋆⋆⋆ | 1720-1850 | 200-400 |
| | 1907+i70 | 1900 | 54 | Λ(2000) | $?^?$ | ⋆ | ≈2000 | 73-240 |
| | 2158+i13 | 2158 | 23 | | | | | |
| 1, −1 | — | 1830 | 42 | Σ(1750) | $1/2^-$ | ⋆⋆⋆ | 1730-1800 | 60-160 |
| | — | 1987 | 240 | Σ(1940) | $3/2^-$ | ⋆⋆⋆ | 1900-1950 | 150-300 |
| | | | | Σ(2000) | $1/2^-$ | ⋆ | ≈2000 | 100-450 |
| 1/2, −2 | 2039+i67 | 2039 | 64 | Ξ(1950) | $?^?$ | ⋆⋆⋆ | 1950±15 | 60±20 |
| | 2083+i31 | 2077 | 29 | Ξ(2120) | $?^?$ | ⋆ | ≈2120 | 25 |

Table 2. The properties of the 10 dynamically generated resonances and their possible PDG counterparts. We also include the N* bump around 2270 MeV and the Δ* bump around 2200 MeV.

| $S,I$ | theory | | | PDG data | | | | |
|---|---|---|---|---|---|---|---|---|
| | pole position | real axis | | name | $J^P$ | status | mass | width |
| | | mass | width | | | | | |
| 0, 1/2 | 1850+i5 | 1850 | 11 | N(2090) | $1/2^-$ | ⋆ | 1880-2180 | 95-414 |
| | | | | N(2080) | $3/2^-$ | ⋆⋆ | 1804-2081 | 180-450 |
| | | 2270(bump) | | N(2200) | $5/2^-$ | ⋆⋆ | 1900-2228 | 130-400 |
| 0, 3/2 | 1972+i49 | 1971 | 52 | Δ(1900) | $1/2^-$ | ⋆⋆ | 1850-1950 | 140-240 |
| | | | | Δ(1940) | $3/2^-$ | ⋆ | 1940-2057 | 198-460 |
| | | | | Δ(1930) | $5/2^-$ | ⋆⋆⋆ | 1900-2020 | 220-500 |
| | | 2200(bump) | | Δ(2150) | $1/2^-$ | ⋆ | 2050-2200 | 120-200 |
| −1, 0 | 2052+i10 | 2050 | 19 | Λ(2000) | $?^?$ | ⋆ | 1935-2030 | 73-180 |
| −1, 1 | 1987+i1 | 1985 | 10 | Σ(1940) | $3/2^-$ | ⋆⋆⋆ | 1900-1950 | 150-300 |
| | 2145+i58 | 2144 | 57 | Σ(2000) | $1/2^-$ | ⋆ | 1944-2004 | 116-413 |
| | 2383+i73 | 2370 | 99 | Σ(2250) | $?^?$ | ⋆⋆⋆ | 2210-2280 | 60-150 |
| | | | | Σ(2455) | $?^?$ | ⋆⋆ | 2455±10 | 100-140 |
| −2, 1/2 | 2214+i4 | 2215 | 9 | Ξ(2250) | $?^?$ | ⋆⋆ | 2189-2295 | 30-130 |
| | 2305+i66 | 2308 | 66 | Ξ(2370) | $?^?$ | ⋆⋆ | 2356-2392 | 75-80 |
| | 2522+i38 | 2512 | 60 | Ξ(2500) | $?^?$ | ⋆ | 2430-2505 | 59-150 |
| −3, 0 | 2449+i7 | 2445 | 13 | Ω(2470) | $?^?$ | ⋆⋆ | 2474±12 | 72±33 |

## 5.2 Results

In Table 1 we show a summary of the results obtained from the interaction of vectors with the octet of baryons and the tentative association to known states[53].

For the $(I,S) = (1/2,0)$ N* states there is the N*(1700) with $J^P = 3/2^-$, which could correspond to the state we find with the same quantum numbers around the same energy. We also find in the PDG the N*(1650), which could be the near degenerate spin parter of the N*(1700) that we predict in the theory. It is interesting to recall that in the study of Ref. [54] a pole is found around 1700 MeV, with the largest coupling to ρN states. Around 2000 MeV, where we find another N* resonance, there are the states N*(2080) and N*(2090), with $J^P = 3/2^-$ and $J^P = 1/2^-$ respectively, showing a good approximate spin degeneracy.

For the case $(I,S) = (0,-1)$ there is in the PDG one state, the Λ(1800) with $J^P = 1/2^-$, remarkably close to the energy were we find a Λ state. The state obtained around 1900 MeV could correspond to the Λ(2000) cataloged in the PDG with unknown spin and parity.

The case of the $\Sigma$ states having $(I,S)=(1,-1)$ is rather interesting. The state that we find around 1830 MeV, could be associated to the $\Sigma(1750)$ with $J^P=1/2^-$. More interesting seems to be the case of the state obtained around 1990 MeV that could be related to two PDG candidates, again nearly degenerate, the $\Sigma(1940)$ and the $\Sigma(2000)$, with spin and parity $J^P=3/2^-$ and $J^P=1/2^-$ respectively.

Finally, for the case of the cascade resonances, $(I,S)=(1/2,-2)$, we find two states, one around 2040 MeV and the other one around 2080 MeV. There are two cascade states in the PDG around this energy region with spin parity unknown, the $\Xi(1950)$ and the $\Xi(2120)$. Although the experimental knowledge of this sector is relatively poor, a program is presently running at Jefferson Lab to improve on this situation[55].

The case of the vector interaction with the decuplet is similar and we show the results in Table 2.

We also can see that in many cases the experiment shows the near degeneracy predicted by the theory. Particularly, the case of the three $\Delta$ resonances around 1920 MeV is very interesting. One observes a near degeneracy in the three spins $1/2^-,3/2^-,5/2^-$, as the theory predicts. It is also very instructive to recall that the case of the $\Delta(5/2^-)$ is highly problematic in quark models since it has a 3 $h\omega$ excitation and comes out always with a very high mass[50, 56].

The association of states found to some reported in the PDG for the case of $\Lambda$, $\Sigma$ and $\Xi$ states looks also equally appealing as one can see from the table.

In summary, the study of the interaction of mesons in the vector octet of the $\rho$ with baryons of the octet of the proton and the decuplet of the $\Delta$ within the hidden gauge formalism of vector mesons, using a unitary framework in coupled channels, has lead to a rich structure of excited baryons. Many of the states predicted by the theory can be associated to known states in the PDG, thus providing a very different explanation for the nature of these states than the one given by quark models as simple 3q states. One of the particular predictions of the theory is that, within the approximations done, one obtains degenerate pairs of particles in $J^P=1/2^-,3/2^-$ for the case of the interaction of vectors with the baryons of the octet and degenerate trios $J^P=1/2^-,3/2^-,5/2^-$ for the case of the interaction of vectors with the baryons of the decuplet. This behavior seems well reproduced by many of the existing data, but in some cases the spin partners do not show up in the PDG. The reasonable results reported here produced by the hidden gauge approach should give a stimulus to search experimentally for the missing spin partners of the already observed states, as well as possible new ones.

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