Can NN and $N\bar{N}$ resonances have similar structures?

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We propose that if the NN and $N\bar{N}$ interactions are the same for $R > 1$ fm, then NN-$N\bar{N}$ pairs of resonances which have similar structures may exist. Evidence is presented that the proposed ${}^3F_3$ dibaryon and $T_1(2190)$ meson may be examples of such a pair. Some consequences of our proposal are discussed.

It is generally believed that under certain conditions the nucleon-nucleon (NN) and nucleon-antinucleon ($N\bar{N}$) interactions are identical.[1] In this paper we present arguments that as a consequence of this equality resonances may exist in the NN and $N\bar{N}$ systems which have similar structures. In particular, we give evidence that the proposed $I=1$, ${}^3F_3$ dibaryon resonance and the $T_1(2190)$ meson[2] are probable candidates for such states. A fundamental assumption of the present proposal is the concept of peripherality[3]; i.e., that resonance formation is peripheral and that the relationship between the dominant L value and the interaction radius R is given by the semiclassical expression $L(L+1) \simeq (kR)^2$, where k is the c.m. wave number.[4]

Phenomenological analyses of high-energy data on particle and antiparticle reactions indicate that the essential differences between NN and $N\bar{N}$ interactions are the roles played by two vector mesons: the ω meson and, to a lesser extent, the ρ meson. For the pp interaction, for example, the forces mediated by the ω and ρ mesons are repulsive, whereas for the $p\bar{p}$ interaction these forces are attractive.[5]

In accord with theoretical expectations, there is increasing evidence that the ranges of these two mesons are small. The Yukawa approximation $R_Y = \hbar/mc$ yields for these mesons, which are almost equal in mass, a range of 0.25 fm. Such a short range is consistent with the size of the repulsive core for NN potentials, about 0.5 fm,[6] as well as with *recent* estimates of the annihilation range for the $N\bar{N}$ interaction.[1,7]

Thus, convincing evidence exists which indicates that NN and $N\bar{N}$ forces indeed are *different* for about $R < 0.5$ fm. In the following paragraph we attempt to establish, as quantitatively as possible, the range of interaction for which these forces may be the same.

It is generally accepted that the long-range part of the NN interaction is mediated by single-pion exchange ($R_Y = 1.4$ fm). The intermediate-range portion of this interaction is not as well understood; however, a recent experiment on the electrodisintegration of the deuteron may be interpreted as evidence that at intermediate range the NN interaction is dominated by two-pion exchange ($R_Y = 0.7$ fm).[8,9] Since pions are pseudoscalar particles, they mediate attractive forces for NN and $N\bar{N}$ interactions alike. Consequently, NN and $N\bar{N}$ forces are expected to be the same for $R \simeq 1$ fm and greater. Resonances for which $R > 1$ fm in the NN or $N\bar{N}$ channel would be expected to be loosely bound and thus to have large widths. Strong experimental evidence for such NN and $N\bar{N}$ states presently exists.[10]

The dibaryon resonance which is most firmly established is the $I=1$, ${}^3F_3$ state[10] first observed by Auer *et al.*[11] Evidence for this resonance has been found in a number of pp studies, including measurements of $\Delta\sigma_L$, P, and C_{LL}.[12] Recently we have pointed out that the well-known anomaly[13] in $\sigma_t(np)$ near 1.4 GeV/c also may be a manifestation of this state.[14] Parameters for this resonance as determined in different analyses are listed in Table I.[15,16] Here the np study was a Breit-Wigner (BW) analysis of the data of Ref. 13 using a BW resonance equation identical to that of Coupland *et al.*[17] It is noted that the agreement among the various determinations is excellent. If one assumes $M = 2.20$ GeV for this state, the interaction radius in the NN channel is 1.2 fm, a value which is consistent with our range requirement.

It should be mentioned that a resonance interpretation of the NN data mentioned above is not without controversy.[10] Some time ago Brayshaw demonstrated in connection with the proposed ${}^1D_2$ dibaryon state ($M \simeq 2.14$ GeV) that resonancelike phenomena can arise from dynamical effects alone.[18] Others have suggested that the resonancelike structure in the ${}^3F_3$ NN partial wave also can be explained in terms of a dynamical model. (See Ref. 19 and references therein.) However, a recent analysis by VerWest indicates that, for the ${}^3F_3$ channel, existing data are not sufficient to preclude a resonance interpretation.[20]

The $I=1$ meson which couples to $N\bar{N}$ and which has a mass near 2200 MeV is the $T_1(2190)$.[2,10] Various determinations of the resonance parameters for this proposed meson are listed in Table II.[17,21–23] Unfortunately, present data on the spin and parity of this meson are inconclusive.[2,10] A comprehensive analysis of $\bar{p}p \to \pi\pi$ data by Martin and Morgan, for

TABLE I. Parameters of the proposed $I=1$, $^3F_3$ dibaryon resonance.

Mass (MeV)	Γ (MeV)	$(2J+1)x_e$	Data	Analysis
2220	125 ± 25	≈ 1.4	pp phases	Breit-Wigner[a]
2190 ± 10	130 ± 10	1.1 ± 0.3	pp phases	K matrix[b]
2209 ± 7	119 ± 48	1.1 ± 0.4	$\sigma_t(np)$	Breit-Wigner[c]

[a]Reference 15.
[b]Parameters given are those of the K-matrix solution of Bhandari *et al.* See Ref. 16.
[c]Present work.

example, indicates that in the mass range of interest one can assign only broad limits to the spins of states.[24] They conclude that values of J from 1 to 5 are possible.[24]

It is observed in Table II that the spread among values of parameters is substantially larger than for the NN case, particularly for Γ. This range in Γ can be associated in part with the correction for the nonresonant background, which was very large for all these analyses. The $\sigma_1(\bar{p}N)$ analysis required, in addition, screening and Fermi-momentum corrections to $\sigma_t(\bar{p}d)$ data[21]; thus the significant difference in width with the $\sigma_t(\bar{p}p)$ result[17] is not surprising. In contrast, the low mass value determined from $\sigma_{el}(\bar{p}p)$ data[17] could be a real effect, since under certain conditions the elastic cross section can peak at a lower energy than either the total or absorption cross sections.[25]

In view of the above considerations, it is clear that any detailed comparison with the parameters listed in Table II should be made with caution. Nevertheless, we believe that meaningful comparisons can be made between the $\sigma_t(np)$ results of Table I and the $\sigma_t(\bar{p}p)$ parameters of Table II because the two studies have many common features. Important similarities are as follows: (i) total-cross-section data were analyzed, (ii) $\sigma_t(np)$ and $\sigma_t(\bar{p}p)$ data both include equal $I=0$ and $I=1$ components, (iii) identical forms of the BW resonance equation were employed, and (iv) the nonresonant background was assumed to vary smoothly with energy.

We see from Tables I and II that the agreement is very good between resonance parameters for the $^3F_3$ dibaryon and $T_1(2190)$ meson deduced from data on $\sigma_t(np)$ and $\sigma_t(\bar{p}p)$, respectively.[26] The equivalence of the masses, which are defined to about 10 MeV, is particularly noteworthy. We propose that this remarkable agreement in resonance parameters represents strong evidence that these two states have similar structures.

If our proposal is correct, then one can infer the following about these two resonances:

(i) The spin and parity of the $T_1(2190)$ meson should be $J^\pi=3^+$, provided that in the $N\bar{N}$ channel

TABLE II. Parameters of the proposed $T_1(2190)$ meson.

Mass (MeV)	Γ (MeV)	$(2J+1)x_e$	Data	Analysis
2204 ± 10[a]	85 ± 26	1.4 ± 0.2[b]	$\sigma_1(\bar{p}N)$	Breit-Wigner[c]
2193 ± 2	98 ± 8		Annihilation	Breit-Wigner[d]
2199 ± 5[a]	130 ± 30	1.3 ± 0.3[e]	$\sigma_t(\bar{p}p)$	Breit-Wigner[f]
2155 ± 15	135 ± 75		$\sigma_{el}(\bar{p}p)$	Breit-Wigner[f]

[a]Total c.m. energy given in Ref. 21 has been shifted upwards by 14 MeV in accord with the findings of Ref. 22.
[b]We have corrected the value of Ref. 21 to take into account the spins of the particles in the incident channel.
[c]Reference 21.
[d]Reference 23.
[e]This value was computed using the resonance height of 5.0 mb given in Ref. 17.
[f]Reference 17.

$J=L$, as is the case for the $^3F_3$ dibaryon in the NN channel. Since two pions can decay only into normal-parity states, as a consequence of this assignment the decay $T_1(2190)\rightarrow\pi^+\pi^-$ would be forbidden. This 3^+ assignment appears to be consistent with values of $(2J+1)x_e$ deduced for this state (see Table II) and with existing data on $\bar{p}p\rightarrow\pi^+\pi^-$ in that there is no anomaly in the total cross section for this reaction channel near $E_{\mathrm{c.m.}}=2.2$ GeV.[27]

(ii) The dominant configuration of the $T_1(2190)$ meson ought to be $\bar{N}\Delta$ (or $N\bar{\Delta}$), since the $^3F_3$ dibaryon is believed to decay predominantly into the $N\Delta$ channel.[16]

(iii) A potential-model description of these two resonances would be appropriate,[1] rather than the single-bag, multiquark models suggested for the $T_1(2190)$ meson and $^3F_3$ dibaryon by Jaffe[4] and by Mulders *et al.*,[28] respectively, since it seems improbable that two such different multiquark structures[4,28] could result in resonances with parameters which are so similar. We recall that the apparent interaction radius is relatively small, 1.2 fm in the NN channel. Thus, a two-bag picture of these resonances would appear to be consistent with a bag radius <1 fm as proposed by Brown[9] rather than the radius $\simeq 1$ fm assumed in the MIT bag model.[4]

In addition, if our peripheral model is valid, then, analogous to the $^3F_3$ dibaryon and $T_1(2190)$ meson, pairs of resonances with $L>3$ ought to exist at higher energies. Indeed, evidence for an $L=4$ dibaryon has been reported by Auer *et al.*, who have found a pronounced dip in $C_{LL}(pp)$ near 1.8 GeV/c ($E_{\mathrm{c.m.}}=2.36$ GeV), which they attribute to the $^1G_4$ partial wave.[29] The $I=1$ meson next higher in energy which has a large width and which couples to $N\bar{N}$ is the U_1 ($M=2.35$ GeV).[21] The NN (and $N\bar{N}$) interaction radius for $L=4$ and $M=2.35$ GeV is 1.2 fm, in excellent agreement with the value deduced for the $^3F_3$ dibaryon. Thus, it seems highly probable that the proposed $^1G_4$ dibaryon and U_1 meson are the members of the $L=4$ pair of states.

Finally, as indicated above, the peripheral model which we employ requires that the L value of the resonance phase shift in the NN and $N\bar{N}$ channels be the same for the proposed $^3F_3$ dibaryon and $T_1(2190)$ meson, respectively. It is generally believed that the assignment $^3F_3$ for this dibaryon is correct.[10] Thus, a decisive test of our proposal that NN and $N\bar{N}$ resonances have similar structures would be the demonstration that $L=3$ in the $N\bar{N}$ channel for the $T_1(2190)$ meson.

To summarize, since there is increasing evidence that the NN and $N\bar{N}$ interactions are the same for $R>1$ fm, we propose that short-lived NN and $N\bar{N}$ resonances may exist which have similar structures. Evidence is presented that the proposed $^3F_3$ dibaryon and $T_1(2190)$ meson are good candidates for such a pair of resonances. We point out that if our model is valid, a single-bag multiquark description of these two states may not be appropriate. A crucial test of our model would be the identification of the resonance phase shift in the $N\bar{N}$ channel for the $T_1(2190)$ meson.

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