Effect of $I=1$ dibaryon resonances on the n-p total cross section

R. E. Shamu, M. Soga, and R. L. Shilts
Physics Department, Western Michigan University, Kalamazoo, Michigan 49008

P. W. Lisowski
Los Alamos National Laboratory, Los Alamos, New Mexico 87545
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Evidence is presented that the well-known anomaly in the n-p total cross section near 1.4 GeV/c may be interpreted as the $I_z=0$ analog of the proposed $I=1$, $^3F_3$ dibaryon resonance. Resonance parameters have been deduced using the Breit-Wigner approximation.

Numerous studies of the nucleon-nucleon system have been reported[1] since the observation at Argonne of significant structure in $\Delta\sigma_L(pp)$, that is, the p-p total-cross-section difference between antiparallel and parallel longitudinally polarized states.[2] The results of many of the p-p studies have been interpreted in terms of dibaryon resonances.[1] Such resonances are of considerable current interest because it may be possible to explain them in terms of simple excitations of six quarks.[3] Two possible $I=1$ states for which evidence is particularly strong are a $^1D_2$ state at 2.14 GeV and a $^3F_3$ state at 2.22 GeV.[1,4]

Even though a variety of p-p studies suggest the presence of these two states,[1] their existence nevertheless remains controversial. There are inconsistencies in the data as well as disagreements on interpreting the observed effects.[5] Thus, quantitative evidence for these states from other two-baryon systems clearly is desirable.

Conservation of isospin dictates that if a state exists for a N-N system with $I=1$, an analog state should be observable for the N-N system with $I_z=0$, i.e., the n-p system.[6] A review of existing n-p data near $E_{\text{c.m.}}=2.2$ GeV reveals pronounced structure in the n-p total cross section.[7] It is a remarkable fact that even though this anomaly was first reported over 10 years ago, no interpretation of this structure in terms of a dibaryon resonance has been published until just recently.[8] A Breit-Wigner analysis is presented herein.

The n-p total-cross-section data of Devlin *et al.*[7] over the energy range of interest are plotted in Fig. 1 as a function of c.m. energy. Since total-cross-section analyses are particularly simple, a graphical analysis near 2.2 GeV (1.35-GeV/c incident neutron momentum) was performed first. The observed anomaly was approximated as the incoherent sum of a resonance (× symbols) and a linearly increasing background (long dashes).[9] Figure 1 shows that the peak energy and width of the resultant resonance are about 2.2 and 0.1 GeV, respectively. Each of these values is within the range deduced for the proposed $I=1$, $^3F_3$ dibaryon resonance.[1,4]

It is well known that the elasticity x_e may be deduced from neutron total-cross-section data using the expression[10]

$$\sigma_R(\max)=\frac{2\pi\lambda\!\!\!^{-}_n{}^2(2J_0+1)x_e}{(2b+1)}\ , \tag{1}$$

where $\sigma_R(\max)$ is the *change* in total cross section over the resonance, J_0 is the angular momentum of the state, and b is the spin of the target particle. If it is assumed that the resonance is indeed a $^3F_3$ state, the observed value of 2 mb for $\sigma_R(\max)$ (see Fig. 1) yields $x_e=0.08$.

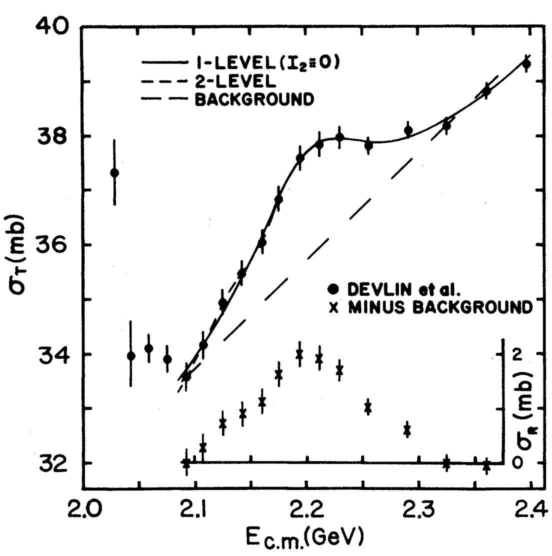

FIG. 1. Neutron total cross section near the anomaly at 1.4 GeV/c ($E_{\text{c.m.}}=2.2$ GeV). The ● are the data of Devlin *et al.* (Ref. 7). The × were determined by subtracting an assumed background (long-dashed curve) from these data. The two smooth curves through the data represent least-squares fits. A single-level fit with $I_2\neq0$ (not shown) gave results essentially identical to the one-level ($I_2=0$) curve given. See text for details.

TABLE I. Results of one and two-level fits to n-p total-cross-section data (see Ref. 7).

Type	χ_ν^2	B (mb)	C (mb/GeV)	R_1 (10^{-4} mbGeV^2)	I_1 (10^{-2} mbGeV)	E_1 (GeV)	Γ_1 (MeV)	R_2 (10^{-2} mbGeV^2)	I_2 (10^{-2} mbGeV)	E_2 (GeV)	Γ_2 (MeV)	σ_R(max) (mb)
One level ($I_2 \equiv 0$)	0.34	35.1 ±0.2	20.0 ±1.4					1.13 ±0.13		2.20 ±0.01	134 ±9	2.5 ±0.3
One level	0.35	35.0 ±0.2	19.7 ±1.4					1.36 ±0.14	1.6 ±2.8	2.20 ±0.01	145 ±10	2.6 ±0.3
Two levels	0.40	34.8 ±0.1	20.1 ±1.0	0.6 ±1.1	−1.0 ±0.8	2.14 ±0.02	39 ±55	1.40 ±0.10	5.4 ±1.9	2.19 ±0.01	140 ±7	2.8 ±0.2

Next, a least-squares analysis of the n-p data from 2.09 to 2.40 GeV was performed using the multilevel expression

$$\sigma_T(E) = \sigma_B(E) + \sum_r \frac{R_r}{(E-E_r)^2 + (\Gamma_r/2)^2} + \sum_r \frac{I_r(E-E_r)}{(E-E_r)^2+(\Gamma_r/2)^2} \qquad (2)$$

for which the total cross section at energy E is the sum of background scattering, Breit-Wigner (BW) resonance terms, and interference terms. Here R_r, I_r, E_r, and Γ_r were assumed energy independent and σ_B, the background scattering cross section, was assumed to vary smoothly with energy. Equation (2) was derived assuming that for each partial wave the scattering amplitude may be written as the sum of a potential part and a summation of BW amplitudes.[11] In the present analysis σ_B was given the linear dependence $\sigma_B = B + C(E - E_M)$, where $E_M = 2.194$ GeV.

Three types of least-squares analyses using Eq. (2) were carried out: (1) a single-level analysis ($E_2 \approx 2.22$ GeV) assuming no interference with background scattering ($I_2 \equiv 0$); (2) a single-level analysis ($E_2 \approx 2.22$ GeV) allowing interference; and (3) a two-level analysis ($E_1 \approx 2.14$ GeV, $E_2 \approx 2.22$ GeV) with interference, where the subscripts 1 and 2 refer to the proposed $^1D_2$ and $^3F_3$ states, respectively. Initial values for B and C were taken from our preliminary analysis. For the other parameters, initial values were chosen which were consistent with p-p analyses.[1]

The results of these three analyses are shown in Fig. 1 and tabulated in Table I. The two single-level analyses resulted in essentially identical cross-section values. It is observed in Fig. 1 that all three analyses provide excellent fits to the data.

In Table I, χ_ν^2 is the reduced χ^2 and the σ_R(max) value given is that of resonance 2. The uncertainty listed for each parameter is a measure of the change of that parameter required to vary χ_ν^2 by unity, where the given value is an average of plus and minus values. The small values obtained for χ_ν^2 suggest that Devlin *et al.* may have overestimated experimental uncertainties. Changing the data base near 2.4 GeV as well as including the datum at 2.075 GeV had negligible effects on the level parameters. Drastic changes in the initial parameters resulted in minima with substantially larger χ_ν^2.

We conclude the following from Table I.

(1) Our two-level analysis of these data provides no evidence for a resonance at 2.14 GeV since the values of R_1 and I_1, and therefore x_e, are consistent with zero [see Eqs. (1) and (2)]. The negligible change in χ_ν^2 between the one-level and two-level analyses supports this conclusion.[12]

(2) The one-level analyses provide strong evidence

for a resonance of energy and width consistent with those of the proposed $I=1$, $^3F_3$ state, 2.18–2.22 GeV and 0.12–0.16 GeV, respectively.[1,4]

(3) The one-level analysis with $I_2 \neq 0$ indicates that interference between level 2 and background scattering is negligible since I_2 is consistent with zero. This conclusion is supported by the one-level ($I_2 \equiv 0$) analysis for which χ_ν^2 is essentially the same. Also, this result is consistent with existing N-N phase-shift analyses, for which the $^3F_3$ phase is very small below the proposed $^3F_3$ resonance.[4,13]

The elasticity of level 2 may be obtained directly from the value of $\sigma_R(\max)$ since $I_2 \approx 0$. We find $x_e = 0.096 \pm 0.012$, which is in agreement with values for the $I=1$, $^3F_3$ resonance.[1,4] This value is equivalent to $x_e(pp) = 0.19 \pm 0.02$, since $\sigma_T(np) = \frac{1}{2}[\sigma(0)+\sigma(1)]$ and $\sigma(1) = \sigma_T(pp)$.

To summarize, evidence has been presented that the anomaly in the n-p total-cross-section data of Devlin *et al.*[7] may be interpreted as the analog resonance of the $I=1$, $^3F_3$ dibaryon resonance proposed on the basis of p-p analyses. The resonance parameters obtained in the present analysis are $E = 2.20 \pm 0.01$ GeV, $\Gamma = 134 \pm 9$ MeV, and $x_e(pp) = 0.19 \pm 0.02$, where the quoted uncertainties do not take into account the limitations of the BW approximation. These parameters are in good agreement with values deduced from BW analyses of p-p data.[1,13] No evidence was obtained in the present analysis for the proposed $^1D_2$ resonance.

Auer *et al.*[14] have noted an unexpected difference between n-p and p-p data near 2.2 GeV. For the n-p system there is an anomaly in $\sigma_{\mathrm{tot}}(np)$ and an apparent lack of structure in $\Delta\sigma_L(pn)$.[14] Conversely, p-p studies show no obvious structure in $\sigma_{\mathrm{tot}}(pp)$ but significant structure in $\Delta\sigma_L(pp)$.[1] If the $I=1$, $^3F_3$ dibaryon state exists, one would expect from naive considerations to find structure in all four cross sections. The reason for these apparent differences among N-N data near 2.2 GeV is not understood at present.

The present analysis is in disagreement with the work of Hashimoto and Hoshizaki, who interpret the n-p total-cross-section anomaly in terms of an $I=0$, $^1F_3$ state.[8] If published values[1,4,13] for the resonance parameters of the proposed $^3F_3$ state are correct, as our analysis indicates, then it is clear from Fig. 1 that the proposed $I=1$, $^3F_3$ resonance *alone* can account for the anomaly in the n-p data of Devlin *et al.*[7]

Finally, it is straightforward to generalize Eq. (2) to take into account a nonlinear background and the energy dependence of Γ near threshold. Each of these improvements requires the addition of one or more adjustable parameters. These refinements were not applied to our analysis of the Devlin *et al.* data because there were only 13 data over the energy range of interest. Nevertheless, we believe that a more general treatment would not have altered the major conclusion of the present work, i.e., that the n-p total-cross-section anomaly near 1.4 GeV/c is a manifestation of the proposed $I=1$, $^3F_3$ dibaryon resonance. Extensive new n-p total-cross-section measurements are in progress at Los Alamos National Laboratory.

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