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STRUCTURES IN THE NUCLEON-NUCLEON SYSTEM*

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A. Yokosawa

DE91 006598

High Energy Physics Division, Argonne National Laboratory
Argonne, Illinois 60439 USA

ABSTRACT

The status of dibaryon resonances in $I = 0$ and $I = 1$ states is discussed together with new data.

Introduction

Many structures have been found in the NN system, and they have been investigated mainly by means of phase-shift analyses. The results confirmed Breit-Wigner behavior for some of them. Structures observed in various channels are not explained by the standard theories but are well explained by adding the dibaryon admixture to theoretical models.

As evidence for the existence of dibaryons grows, it becomes crucial to understand the nature of these resonances. Earlier references to theoretical work (MIT bag model, string model, spring model, NN and $\pi\pi$ NN dynamics, Deck model, OPE three-body theory, OBE inelastic-threshold model, coupled-channels method, etc.) were discussed in Ref. 1. Recent reviews of the status of dibaryon resonances are given in, for instance, Refs. 2 to 5.

In general, dibaryon resonances are fairly well established in NN phase-shift analyses, and they are consistent with observations in πd elastic and $pp \rightarrow \pi d$ channels. However, some objections to the existence of dibaryons were raised in the study of $NN\pi$ channels. Here we review those objections and conclude that the experimental results of all the channels studied so far are consistent with the existence of dibaryons.

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$\Delta\sigma_L$ ($I = 1$) and $\Delta\sigma_T$ ($I = 1$) Measurements

A striking energy dependence has been observed in the difference between the total cross sections for pure spin states, $\Delta\sigma_L$ and $\Delta\sigma_T$. The first remarkable structures observed in the pp system were from $\Delta\sigma_L$ measurements⁶ performed at the Argonne Zero Gradient Synchrotron (ZGS). Since then, the energy-dependent data of $\Delta\sigma_L$ and $\Delta\sigma_T$ up to about 2.5-GeV/c incident proton momentum were taken at the ZGS, Los Alamos Meson Physics Facility (LAMPF), Paul Scherrer Institute (PSI), Saturne National Laboratory - Saclay (Saturne II), and TRIUMF (Vancouver, Canada).⁷⁻⁹

Many authors have attempted to interpret the nature of these structures. The bump at 1.2 GeV/c both in $\Delta\sigma_T$ and $\Delta\sigma_L$ and the dip at 1.5 GeV/c appearing in $\Delta\sigma_L$ have been interpreted as evidence for the formation of "diproton resonances" B_1^2 (2.14) with a quantum state of 1D_2 and B_1^2 (2.22) with a 3F_3 state, respectively.¹⁰⁻¹⁵

To further understand the nature of these effects, one must look for structures in energy much higher than the threshold region. New results at $P_{lab} = 2$ to 6, and 11.75 GeV/c reveal bump and dip structures in the momentum range 2.5 to 4.0 GeV/c.¹⁶ If the bumps in $(k^2/4\pi) \Delta\sigma_L$ are considered to be due to diproton resonances, the masses are about 2700 and 2900 MeV. Earlier, structure near 2700 MeV was observed in the spin-spin correlation parameter $C_{LL} = (L,L;0,0)$ and $C_{NN} = (N,N;0,0)$ in pp elastic scattering around $\theta_{c.m.} = 90^\circ$, and in other parameters.^{1,17,18} A structure centered on the mass of 2700 MeV was recently observed in the polarization measurements for $p^\dagger p + d\pi^\dagger$ carried out at Saturne II.¹⁹ We also note here that in earlier pp total-cross-section measurements there was evidence for a small, broad structure around 2750 MeV.²⁰ The second bump near 2900 MeV coincides with a dip

observed earlier in a plot of $k^2 C_{LL} (d\sigma/d\Omega)$ at $\theta_{c.m.} = 90^\circ$. The dip was claimed to be due to a spin-singlet term.¹⁷

We note that a cloudy bag model²¹ predicts six-quark-state resonances, in particular, an s-wave state near 2700-MeV mass and a singlet state near 2900 MeV. A diquark-cluster model also predicts both 2700- and 2900-MeV dibaryons.²²

$\Delta\sigma_L (I = 0)$ Measurements

Measurements of $\Delta\sigma_L(np)$ and $\Delta\sigma_T(np)$ were performed at 6 energies between 0.31 and 1.08 GeV by using Saturne II polarized neutron beams and the Saclay frozen-spin proton target.²³ Recently, by using a polarized neutron beam,²⁴

(np) was measured up to 800 MeV at LAMPF.²⁵ These data, when combined with other cross section data, show evidence of an elastic $I = 0$ spin-singlet resonance with mass ~ 2213 MeV and width ~ 70 MeV. It is important to recognize that the structure in $\Delta\sigma_L$ for the $I = 0$ channel can not be explained by threshold effect or other non-resonant contributions from the inelastic channel.

Exclusive Two-Body Reactions and $NN\pi$ Channels

The nature of N-N structures should be best studied in the elastic-scattering channel and $pp \rightarrow d\pi$ channel because of relatively much less independent amplitudes involved. The $NN\pi$ channels seem difficult ones to study in clarifying the N-N structures. The claim made by the results of $p^\dagger p^\dagger \rightarrow np\pi^+$ measurements²⁶ conflicts sharply with the conclusion of a number of analyses of the world's pp scattering data including nucleon-nucleon elastic scattering, πd elastic scattering, $pp \rightarrow \pi d$, and $\gamma d \rightarrow pn$ reaction (for instance, see Refs. 2-5). Furthermore, it is interesting to observe that

recent analyses ²⁷⁻²⁹ on the $NN\pi$ channels provide evidence for the existence of the $J^P = 2^+$ dibaryon. Their conclusions are opposite from Ref. 26.

It is significant to observe that the conclusions reached on the existence of resonances from pp elastic scattering data are consistent with those from $pp \rightarrow d\pi$ results.⁴ Candidates for the dibaryon resonances are B_1^2 (2.14), B_1^2 (2.18), B_1^2 (2.22), B_1^2 (2.43), B_1^2 (2.70), B_1^2 (2.90), and B_0^2 (2.22).⁵

Narrow Structures

In the elastic scattering narrow structures were reported in the momentum range of 1.2 to 1.4 GeV/c at KEK.³⁰ A considerable amount of experimental work has been devoted to the study of narrow resonances.³¹ Theoretically, the interest in narrow resonance with $\Gamma_{1/2} \leq 100$ MeV was stimulated by the possibility that the quark color degree of freedom might manifest itself in the form of exotic states with narrow width in the $B = 2$ system. In the $T = 1$ channel the first observations of such states in the $p^3\text{He} \rightarrow dX$ in Saturne experiments³² above the $NN\pi$ threshold were confirmed by analyzing powers deduced from an experiment, $p^3\text{He} \rightarrow dX$, at an incident proton energy of 800 MeV performed recently at LAMPF.³³

It is remarkable to note that narrow structures have been observed in the same energy region as the broad structures. Recently Hiroshige et al.³⁴ revealed the existence of the $J^P = 2^+$ resonances, both narrow and broad ones in the mass region 2.05 to 2.15 GeV.

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