EVIDENCE FOR AN $I=\frac{5}{2}$ BARYON RESONANCE OF MASS 1640 MeV/c^2 †

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(Received 19 December 1968)

Evidence is presented to confirm the existence of an $I=\frac{5}{2}$ baryon resonance at 1640 MeV/c^2. The resonance is observed in the reaction $\pi^-d\to pn\pi^-\pi^-\pi^+$ at 2.6 GeV/c^2 and is found to decay into $n\pi^-\pi^-$ possibly via $\Delta^-(1236)\pi^-$. It is shown that the observed peak cannot be due to kinematical effects such as those responsible for the $I=\frac{5}{2}$ enhancement at $\simeq$1580 MeV/c^2 observed earlier.

A possible $I=\frac{5}{2}$ baryon resonance of mass 1650 MeV/c^2 has been reported by Banner et al.,[1] who studied the reaction $\pi^+p\to\pi^-+$(missing mass) at 1.9 GeV/c. An enhancement of 4 standard deviations was seen in the missing-mass distribution, but it was not possible to determine if the observed enhancement was due to the production of a baryon resonance or to kinematical effects, such as a reflection of ρ production, as was shown[2,3] to be the case for a previously reported $I=\frac{5}{2}$ resonance at ~1580 MeV/c^2. Similarly, Vishnevskiĭ et al.[4] reported an enhancement of 3 standard deviations in the region 1600-1700 MeV/c^2 in the $I=\frac{5}{2}$ states of the reactions $np\to pn\pi^+\pi^+\pi^-\pi^-$ and $np\to pn\pi^+\pi^+\pi^-\pi^-\pi^0$ with beam-neutron energies of 2-10 GeV; but because of statistical limitations they could not investigate the possibility that they too were dealing with kinematical effects.

In this paper, we present new evidence for an $I=\frac{5}{2}$ baryon resonance of mass 1640 MeV/c^2 and show that the kinematical effects which gave rise to the 1580-MeV/c^2 peak cannot be responsible for the peaking we observe.

Our results are based on a study of the reactions

$$\pi^-d\to pp\pi^-\pi^-, \tag{1}$$

$$\to pp\pi^-\pi^-\pi^0, \tag{2}$$

$$\to pn\pi^-\pi^-\pi^+, \tag{3}$$

produced by 2.26-GeV/c π^- mesons in the 72-in. Lawrence Radiation Laboratory bubble chamber filled with deuterium. The evidence for the $I=\frac{5}{2}$ resonance was found in the $n\pi^-\pi^-$ system of Reaction (3). A total of 2447 three-prong events[5] (i.e., with "spectator" protons of range too small to produce a visible track) was found to fit Reaction (3) with a χ^2 probability greater than 4%. The Lawrence Radiation Laboratory versions of TVGP and SQUAW were used for the geometrical reconstruction and kinematical fitting. In SQUAW the unmeasured spectator protons are assigned, on the basis of the impulse approximation, values of 0 ± 30, 0 ± 30, and 0 ± 40 MeV/c for the x, y, and z components of the momentum, respectively, in the chamber coordinate system. The ionization of the positive track was checked for consistency with that of a π^+ meson. Those cases where π^+ could not be distinguished from a proton by ionization were not included in the analysis if the χ^2 probability for fits to Reactions (1) or (2) was greater than 1%. A total of 93 events was in this latter category.

Figure 1(a) shows the effective mass of the $n\pi^-\pi^-$ system. The peak at 1640 MeV/c^2 rises to 4 standard deviations above background when we select those events for which the four-momentum transfer from the beam π^- meson to the outgoing π^+ meson is less than 0.6 (GeV/c)^2 [shaded area in Fig. 1(a)]. In Fig. 1(b) we have plotted the $n\pi^-\pi^-$ distribution for those events with at least one $n\pi^-$ combination falling in the region of the Δ(1236). From the fact that the peak in Fig. 1(b) appears to contain approximately the same number of events as in the shaded area of Fig. 1(a), it might be concluded that the peak is associated with Δ(1236) events. However, because of the limited phase space available, it is difficult, on the basis of the present statistics, to determine if the decay proceeds via $\Delta^-\pi^-$ rather than directly into $n\pi^-\pi^-$.

We have looked at various kinematical effects, but none is able to produce the peaking we observe. For example, in 10% of the events we find that both $n\pi^-$ combinations fall in the Δ(1236) region (1180-1300 MeV/c^2). For these events, the $n\pi^-\pi^-$ mass is kinematically constrained,[2] but the enhancement produced by this effect occurs at a mass of ~1550 MeV/c^2 [Fig. 1(b)−shad-

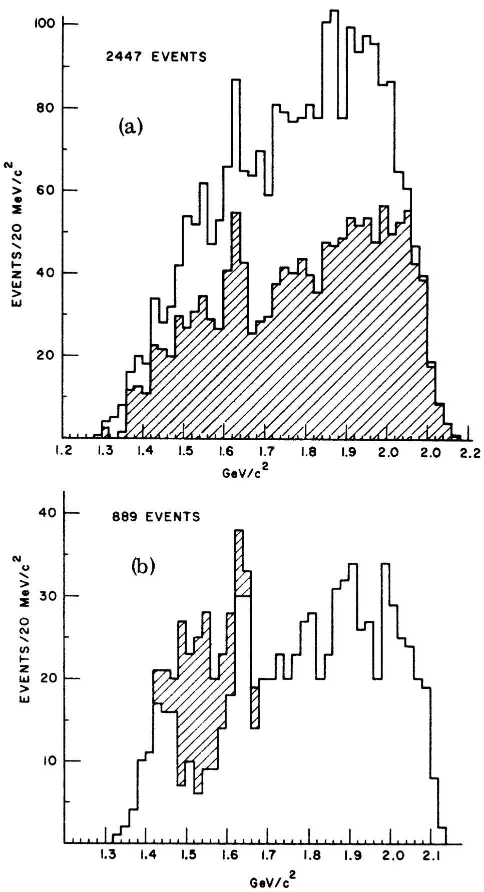

FIG. 1(a) Effective mass of the $n\pi^-\pi^-$ system. Events with four-momentum transfer $|t|$ from the beam to the π^+ less than 0.6 (GeV/c)^2 are shaded. (b) Effective mass of the $\Delta^-\pi^-$ system for events with $|t|<0.6$ (GeV/c)^2. Δ^- is defined as $1180<M(n\pi^-)<1300$ MeV/c^2; "double" Δ^- events are shaded.

ed region]. Moreover, the enhancement is much broader than the one we observe at 1640 MeV/c^2. Another possible kinematical effect is associated with $\Delta^-\rho^0$ production. Owing to the spin of the ρ^0, the π^- from the decay of the ρ^0 tends to be aligned along the axis determined by the line of flight of the ρ^0. This results in enhancements in the $\Delta^-\pi^-$ mass distribution. Thus an $I=\frac{5}{2}$ peak at ~1580 MeV/c^2 seen in the $p\pi^+\pi^+$ mass distributions for the reaction $\pi^+p\to p\pi^+\pi^+\pi^-$ at 3.65 GeV/c was found[3] to be a kinematical reflection of $\Delta^{++}\rho^0$ production. At our c.m.-system energy, this mechanism could lead to enhancements in the $\Delta^-\pi^-$ system at ~1480 and ~2000 MeV/c^2 for $\cos\theta\approx-0.8$ and $\cos\theta\approx 0.8$, respectively, where θ is the decay angle of the π^- from the ρ^0. Moreover, we find no evidence of the peak at 1640 MeV/c^2 in the $n\pi^-\pi^-$ distribution for the $\Delta^-\rho^0$ events [$680<M(\pi^+\pi^-)<840$ MeV/c^2 and $1120<M(n\pi^-)<1320$ MeV/c^2]. One must also note that neither of the two foregoing mechanisms would produce the narrow peak which we observe. If we remove from our sample the possible $\Delta^-\rho^0$ events and plot the $n\pi^-\pi^-$ effective-mass distribution (Fig. 2), we see a prominent peak of ~5 standard deviations at a mass of 1640 MeV/c^2, the peak having a width of less than 60 MeV/c^2. We are unable to determine the width more precisely because the method of treating the unseen spectator, although known to be reliable in other respects, gives rise to difficulties in unfolding the resolution function for this narrow a peak. We also considered possible effects due to contamination from the reaction $\pi^-d\to pn\pi^-\pi^-\pi^+\pi^0$. On the basis of the missing-mass distribution, we estimate this contamination to be less than 4% and find no evidence that such events are associated with the observed peak in the $n\pi^-\pi$ system.

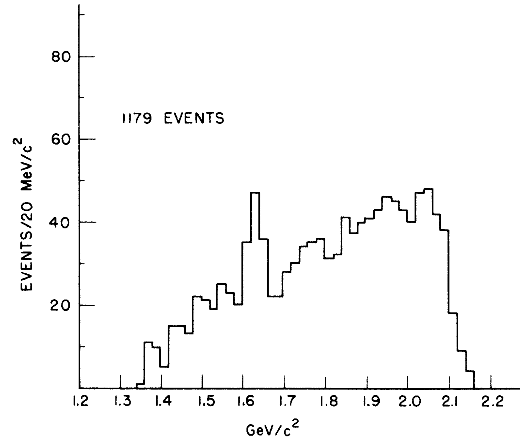

FIG. 2. Effective mass of the $n\pi^-\pi^-$ system for events with $|t|<0.6$ (GeV/c)^2, but without $\Delta^-\rho^0$ events. Δ^- defined as in Fig. 1(b), ρ^0 defined as $710<M(\pi^+\pi^-)<810$ MeV/c^2.

After normalizing the number of events from Reaction (1) to the results of Alff-Steinberger et al.,[6] we estimate that the $I=\frac{5}{2}$ isobar is produced with a cross section of ~40 μb. This differs from the value of ~5 μb found by Banner et al.[1]

We are grateful to the Lawrence Radiation Laboratory for the loan of the film and for assistance with the computer programs.

†Work supported in part by the U. S. Atomic Energy Commission and the National Science Foundation.

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FINITE- AND INFINITE-COMPONENT WAVE EQUATIONS

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We show that there exists a strong reciprocal relationship between the algebras associated with the wave equations of Bhabha and Nambu. The representations of the two groups obtained, O(6) and O(4,2), respectively, are the simplest algebras which can describe supermultiplets of relativistic particles.

With the emerging plethora of resonances of higher spin, much attention has been paid in recent years to the theoretical description of such "particles." Wave equations for higher spin have been investigated by many authors.[1,2] Such an equation is generally proposed for a specific value of maximum spin and has, accordingly, a finite spin and mass spectrum. Work has concentrated on the projection of definite spin states and on the relevant electromagnetic interactions. Furthermore, infinite-component wave equations have been developed which are able to describe an infinite tower of discrete states of a system.[3-5] This approach has generally made strong use of group theoretical considerations instead of the usual more dynamical ones. An infinite spectrum of spin states and mass levels emerges as a direct consequence of the spectra of relevant operators in an assumed symmetry group. The avoidance of dynamics in favor of group theory is particularly in line with the general trend of particle physics, shunning detailed assumptions of internal structure. We should like to report some work on the relationship between these two approaches: the finite-component wave equation of Bhabha,[6] and the infinite-component wave equation of Nambu.[3]

The first step has been to work out an algebraic approach for the Bhabha equation. This enables us to consider arbitrary spins in full generality. The result is an algebra very closely related to the algebra associated with Nambu's equation.[7] To exhibit the origin of this strong reciprocity between the two algebras, we shall show that the Nambu and Bhabha equations are the two solutions of the problem to find the simplest wave equation uniting particles of different spin into supermultiplets.

To begin, we note that all particles belong to a representation of the Lorentz group. For convenience—since we are not interested in the noncompactness in the time—we shall use the group O(4) instead. This group has the generators J_i and K_i with $i=1,\cdots,3$ and the commutation relations

$$[J_i,J_j]=i\epsilon_{ijk}J_k,$$
$$[J_i,K_j]=i\epsilon_{ijk}K_k,$$
$$[K_i,K_j]=i\epsilon_{ijk}J_k. \tag{1}$$

The two Casimir operators of O(4) completely specify the representation. If we are interested now, in combining particles of different representations in multiplets, then we have to find a larger group which includes O(4) as a subgroup, but also includes a Casimir operator of O(4) as one of its generators. We shall find explicitly the simplest such group.

For convenience we shall use the isomorphism