INTERPRETATION OF THE BERKELEY ANOMALY IN HIGH-ENERGY p - d COLLISIONS*

Arnold Tubis and Jack L. Uretsky
Physics Department, Purdue University, Lafayette, Indiana
(Received October 31, 1960)

We should like to offer an alternate explanation of the "bump" observed in the recent Berkeley experiments[1] on double-pion production in proton-deuteron collisions. It will be recalled that these experiments consisted of an examination of the momentum spectrum of the final He^3 or H^3 nucleus at a fixed laboratory angle and in a momentum range corresponding to double-pion production. Evidence was found for a strong peaking in the momentum spectrum of the final nucleus at a momentum corresponding to a total energy of about 310 Mev of the two pions in their own center-of-momentum system. Abashian et al. found that they could fit this peaking to a p-wave resonance in the $T=1$ state of the outgoing meson pair.

We shall proceed according to the rules set up in reference 1; that is to say, we shall consider a generalization of the statistical model to allow for p-wave scattering between the final-state mesons. We do this by writing the production matrix element,[2] in the system where the center-of-momentum of the two pions is at rest, in the form

$$\mathfrak{M}'(\vec{q}) = M\vec{q}\cdot\vec{\lambda}_3, \qquad (1)$$

where M is a constant, $\vec{q}$ the momentum of one of the pions, and $\vec{\lambda}_3$ the momentum of the final nucleus. Final-state scattering is accounted for by writing the total matrix element as

$$\mathfrak{M}(\vec{q}) = \int d^3q' \ \psi^*(\vec{q},\vec{q}\,')\mathfrak{M}'(\vec{q}\,'). \qquad (2)$$

The wave function $\psi^*(\vec{q},\vec{q}\,')$ describes the elastic π - π scattering from a state of relative momentum $\vec{q}\,'$ to one of momentum $\vec{q}$. We use the asymptotic form of the wave function (in configuration space) and invoke a minimum "radius of interaction," R. The transition probability is then found to be

$$d^2W/dp_3d\Omega_3 \propto p_3^{\,2}\lambda_3^{\,2}E_3^{\,-1}t[(t-4)/t]^{3/2}$$

$$\times(q^3\cot\delta_1 - R^{-3})^2(q^6\cot^2\delta_1+q^6)^{-1}. \qquad (3)$$

The last equation introduces p_3 and E_3, the laboratory momentum and energy, respectively, of the outgoing nucleon, t is the square of the energy of the two outgoing pions in their own rest system in units of the pion mass, and δ_1 is the π - π p-wave scattering phase shift for a c.m. energy of $\sqrt{t}$. Let us now make the simplest possible assumption concerning $\cot\delta_1$, namely that the scattering length approximation is valid over most of the energy range in question. We write, then, that

$$q^3\cot\delta_1 = a^{-3}, \qquad (4)$$

and choose the scattering length, a, to give the production cross section a maximum at about 300-Mev total energy in the two-pion rest system. The scattering length turns out to be about 2.5 meson Compton wavelengths. The corresponding momentum dependence of the outgoing nucleus ($T_{\text{proton}}=743$ Mev) is shown in the solid curve of Fig. 1. The dashed curve, shown for

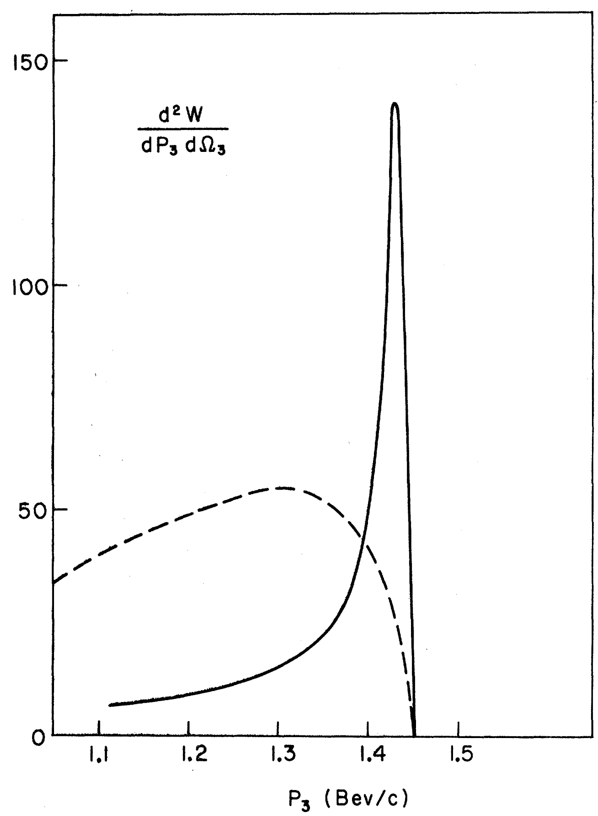

FIG. 1. Contribution of the $T=1$ two-pion production mode to the He^3 or H^3 momentum distribution function as given by Eqs. (3) and (4). The solid curve corresponds to a scattering length a of 2.5 pion Compton wavelengths while the dashed curve corresponds to a zero scattering length. The distribution functions are evaluated for an incident proton energy of 743 Mev in the laboratory and are to be compared with Figs. 3 and 4 of Abashian et al.[1] We have used arbitrary units for the ordinate scale.

purpose of comparison, corresponds to the "p-wave statistical model" obtained by allowing the scattering length to vanish.

It is our feeling that the present Berkeley data are consistent with the scattering-length model we have presented and that there is no necessity for invoking the existence of a resonance to explain the Berkeley "bumps." The validity of our approximation rests upon the assumption that the effective range and higher terms in the expansion implied by Eq. (4) are sufficiently small to warrant their neglect in the energy range under consideration. We note that if this is the case, and if the appropriate choice of signs is made for the effective-range term, it is possible, within the framework of our model, to have a high-energy resonance such as the one required by Frazer and Fulco[3] although its shape will not satisfy their requirements.

If the explanation we propose is found to be consistent with future experiments, it raises the possibility of an interesting speculation. We recall that[4] if there is a bound p state of binding energy E_B, and if the terms involving higher powers of q^2 in the expression for $\cot\delta_1$ are sufficiently small, then the binding energy is related to the scattering length by the relation ($\hbar = \mu = c = 1$)

$$E_B \approx 1/a.$$

Thus, if the scattering length in our model can be shown to be positive, we are led to consideration of a particle that is a two-meson bound state of spin and isotopic spin 1 and of a mass about equal to 450 electron masses.[5]

*This work was supported in part by the Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.

[1]A. Abashian, N. E. Booth, and K. M. Crowe, Phys. Rev. Letters 5, 258 (1960).

[2]Julius S. Kovacs, Phys. Rev. 101, 397 (1956).

[3]W. R. Frazer and J. R. Fulco, Phys. Rev. Letters 2, 365 (1959).

[4]L. D. Landau and E. M. Lifshitz, Quantum Mechanics (Pergamon Press, New York, 1958), pp. 401-2.

[5]J. L. Uretsky and T. R. Palfrey (to be published) have considered the possibility of finding a two-meson bound s-state in photoproduction. In that paper the conclusion is reached that there is at present no persuasive evidence contradicting the existence of a two-meson bound state.

RESONANT SCATTERING OF ANTINEUTRINOS

J. C. Barton
Department of Physics, Northern Polytechnic, London, England
(Received October 27, 1960)

It has recently been suggested by Glashow[1] that there might be a resonance in the scattering of antineutrinos by electrons which would lead to an appreciable production of μ mesons. It was estimated that (under the hypothesis of an intermediate charged boson of mass m_Z) the antineutrinos in the cosmic radiation would produce a meson flux of from 0.1 m^{-2} day^{-1} (for m_Z = nucleon mass) to 2 m^{-2} day^{-1} (for $m_Z = K$-meson mass); this rate should be independent of the depth below ground and should thus be distinguishable from mesons produced in the atmosphere.

While studying the intensity of cosmic radiation at various depths underground, a recorder of geometric area 0.08 m^2 has been operated for 21 days at a depth of 5050 m.w.e. No cosmic-ray events were observed. The effective area of the recorder for high-energy mesons, which would be accompanied by knockon and pair-produced electrons, is at least 25% greater than the geometric area so that the meson flux is probably less than 0.5 m^{-2} day^{-1}. According to Glashow's theory this result makes it unlikely that there is a resonance involving a virtual charged boson with mass equal to that of a K meson.

[1]S. L. Glashow, Phys. Rev. 118, 316 (1960).