Lawrence Berkeley National Laboratory

Recent Work

Title

THREE-PION RESONANCE OR BOUND STATE

Permalink

<https://escholarship.org/uc/item/0qj5839d>

Author

Chew, Geoffrey P.

Publication Date

1959-12-16

UNIVERSITY OF
CALIFORNIA

Ernest O. Lawrence

*Radiation
Laboratory*

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545

BERKELEY, CALIFORNIA

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

for pub. Phys. Rev. Letters

UCRL-9015

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

THREE-PION RESONANCE OR BOUND STATE

Geoffrey F. Chew

December 16, 1959

Printed for the U. S. Atomic Energy Commission

THREE-PION RESONANCE OR BOUND STATE*

Geoffrey F. Chew

Lawrence Radiation Laboratory and Department of Physics
University of California, Berkeley, California

December 16, 1959

It has been shown by Frazer and Fulco¹ that a two-pion P-wave resonance at a total energy between three and four pion rest masses can account for the isotopic vector component of nucleon electromagnetic structure. The mean square radius both of the isovector charge and the anomalous magnetic moment is essentially determined by the energy of this resonance ($\bar{r}^2 \approx 6 E_R^{-2}$). It continues to be a mystery, however, why the isotopic scalar charge experimentally should have nearly this same radius again, since the isoscalar electromagnetic structure is presumably dominated by a three-pion configuration.^{2,3} The purpose of this note is to point out that it is not unreasonable to expect a three-pion resonance or even a bound state at roughly the same energy as the two-pion resonance. According to an argument given earlier by the author in terms of unsubtracted dispersion relations,⁴ such a circumstance might explain the experimental absence of neutron charge structure.

The essential point is that in the particular three-pion state involved in nucleon electromagnetic structure, each pair of pions feels the same strong attractive force as that producing the

* This work was done under the auspices of the U.S. Atomic Energy Commission.

two-pion resonance. The three-pion state has $I = 0$, $J = 1$, and odd parity.^{2,3} It is easy to verify that the isotopic spin function is antisymmetric under exchange of any pair, and therefore each pair is in a pure $I = 1$ state. The relative angular momentum of any pair can be 1, 3, 5 ..., etc., but the proportion of $l = 1$ at low energies must be very large.⁵ Thus the strong attractive force between P-wave pions occurs in all three pairs of the three-pion state of interest, and it seems not unlikely that the extra potential energy could compensate for the rest mass of the third pion and produce a resonance at about the same total energy as that of the two-pion system.

In fact the attraction might easily be so great as to produce a bound state, that is, a particle of mass slightly less than $3m_\pi$, with $I = 0$, $J = 1$, and odd parity. Such a vector meson has been discussed by Nambu,⁶ who proposed it as a new elementary particle. However, the effect on nucleon electromagnetic structure would be the same for the three-pion bound state, and so would the other experimental manifestations of the vector meson discussed by Nambu.

The question naturally arises as to whether further resonances or bound states could result from configurations of still higher pion number. First of all, such configurations would not be stable unless they had energies less than $2m_\pi$ if the G parity is even or $3m_\pi$ if the G parity is odd. Furthermore, it is unlikely that the rest energy of additional pions can continue to be compensated by potential energy of attraction because the strong attractive force occurs in only one particular pair configuration. This configuration happens

-3-

to occur almost with 100% probability for all pairs of our particular three-pion state, but such a circumstance probably cannot be repeated with higher pion numbers.

It is to be hoped that when the detailed nature of the force between two pions has been understood, one can make at least a crude calculation of the three-pion system. A relativistic three-body problem, however, is sure to be very difficult, and confirmation of the resonance or bound state must come from other sources. Should the state actually be bound, then the decay products discussed by Nambu⁶ may be sought.⁷ A resonance will be more difficult to establish but will have the same virtual manifestations as a bound state. For example, there will be a strong short-range contribution to the nuclear force which may, as Nambu suggested, have something to do with the hard core. Similar short-range interactions due to the exchange of the three-pion state will occur in many other situations. Really convincing evidence could come from some reaction in which three pions are produced electromagnetically, say by a high-energy photon in a Coulomb field or by the clashing positron-electron beams envisaged at Stanford. Here a resonance could be unmistakably established.

The author is grateful to Drs. Robert Karplus, Stanley Mandelstam, and Ben Mottelson for discussion of these ideas, which are about one year old. They have not been published previously, partly because the author's preoccupation with another problem prevented a careful investigation and partly because experimental consequences seemed remote. Recently, however, Dr. Barton J. Moyer in a private conversation informed the author that an experimental search for the Nambu particle is quite feasible. If these superficial remarks serve to encourage such a search, they are perhaps justified.

FOOTNOTES

1. W. R. Frazer and J. R. Fulco, Effect of a Pion-Pion Scattering Resonance on Nucleon Structure, UCRL-8880, August 1959, and Phys. Rev. Lett. 2, 365 (1959).
2. Chew, Karplus, Gasiorowicz, and Zachariasen, Phys. Rev. 110, 265 (1958).
3. Federbush, Goldberger, and Treiman, Phys. Rev. 112, 642 (1958).
4. Geoffrey F. Chew, The Bare Particle Concept and Nucleon Electromagnetic Structure, UCRL-8194, February 1958.
5. It was pointed out to the author by Ben Mottelson that a three-pion state with $J = 1$ and odd parity can be constructed which has only $\ell = 1$ relative angular momentum for each pair.
6. Yohjiro Nambu, Phys. Rev. 106, 1366 (1957).
7. Presumably, the most important decay modes are $(\Xi)_B \rightarrow \pi^0 + \gamma$ and $(\Xi)_B \rightarrow \pi^+ + \pi^- + \gamma$, with rates $\sim 10^{20} \text{ sec}^{-1}$.