system.[11] In this case the relevant parameters known at present are $E_{A^+} = 1.2$ BeV, $\Gamma_{A^+} = 0.35$ BeV, the G-parity is odd, and the isotopic spin $T = 1$ or 2. Alternatively, there may be some structure to the A^+ enhancement and our observations could arise from two unresolved peaks. Furthermore, the enhancement effects considered by Nauenberg and Pais,[12] which would not correspond to a unique isotopic spin and angular momentum state, could play a role in accounting for the lower half of the observed A^+ enhancement, i.e., in the region near 1 BeV.

We wish to thank the many members of the staff of the Brookhaven National Laboratory for their great helpfulness in making this experiment possible. In particular, we would like to express our appreciation to Dr. Hildred Blewett, Dr. Hugh Brown, Dr. Ralph Shutt, and the AGS operating crew. We also wish to thank Dr. Nicola Cabibbo, Dr. Geoffrey Chew, and Dr. Charles Zemach, for a number of helpful discussions, as well as Miss Ling-Lie Chau, Mr. Allan Hirata, Dr. Thomas O'Halloran, and Mr. Victor Seeger, who have participated in various aspects of this work. Finally, this work would not have been possible without the active help and interest of the Lawrence Radiation Laboratory scanning, measuring, and computing personnel.

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[1]R. I. Louttit, in Proceedings of the International Conference on Instrumentation for High-Energy Physics, Berkeley, California, September 1960 (Interscience Publishers, Inc., New York, 1961), p. 117.

[2]C. Baltay et al., Nucl. Instr. 20, 37 (1963).

[3]In this work we utilized a modification of the geometrical reconstruction (PANG) and kinematical fitting (KICK) programs of the Alvarez group: J. P. Berge, F. T. Solmitz, and H. D. Taft, Rev. Sci. Instr. 32, 538 (1961); A. H. Rosenfeld and J. M. Snyder, Rev. Sci. Instr. 33, 181 (1962).

[4]Identification was made by χ^2 criteria for the various hypotheses and by visual inspection of the ionization for each event. This left 6.5% of the events as ambiguous. These events are not included here.

[5]This observation was also made by C. Alff et al., Phys. Rev. Letters 9, 322 (1962), and by M. Abolins, R. L. Lander, W. A. W. Mehlhop, N. Xuong, and P. M. Yager, Phys. Rev. Letters 11, 381 (1963), who have investigated the same reaction at lower incident π^+ momenta.

[6]For type 1 the two π^+ mesons are labeled π_1^+ and π_2^+; the π_1^+ is associated with the N^{*++}. For types 2 and 3 the subscripts are assigned randomly. In general, when we wish to distinguish between the two π^+ mesons without reference to possible resonance formation, we use subscripts "a" and "b."

[7]G. Goldhaber, W. Chinowsky, S. Goldhaber, W. Lee, and T. O'Halloran, Phys. Letters 6, 62 (1963).

[8]G. Goldhaber, in Proceedings of the Athens Topical Conference on Recently Discovered Particles, Athens, Ohio, 1963 (Ohio University, Athens, Ohio, 1963), p. 80.

[9]In the reaction observed here, resonance parameters for the ρ^0 meson differ somewhat from the ones quoted in the literature. We find the central value of the experimental ρ peak to lie at $E_{\rho^0} = 770 \pm 10$ MeV with a full width at half-maximum of approximately 130 MeV. For a compilation of ρ^0-resonance parameters together with references, see M. Roos, Rev. Mod. Phys. 35, 314 (1963).

[10]We have observed f^0 production (60 ± 20 events). This process is clearly present and occurs almost exclusively with N^{*++} formation. The f^0 was originally observed in a three-particle final state: W. Selove, V. Hagopian, H. Brody, A. Baker, and E. Leboy, Phys. Rev. Letters 9, 272 (1962).

[11]In experiments at pion energies ranging from 8 to 16 BeV in a heavy-liquid bubble chamber, peaks in the 3π mass distribution have been reported in a region similar to that observed here. G. Bellini, E. Fiorini, A. J. Herz, P. Negri, and S. Ratti, Nuovo Cimento 29, 896 (1963); F. R. Huson and W. B. Fretter, Bull. Am. Phys. Soc. 8, 325 (1963).

[12]M. Nauenberg and A. Pais, Phys. Rev. Letters 8, 82 (1962).

EVIDENCE FOR A P_{11} PION-NUCLEON RESONANCE AT 556 MeV†

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The purpose of this note is to report strong evidence for the existence of a resonance in the P_{11} state of the pion-nucleon system. Previous pion-nucleon resonances were discovered from observations on the qualitative behavior of experimental observables. The resonance suggested in this paper, however, is not associated with conspicuous features in the observables measured so far and has been inferred from a more quantitative analysis.

In the course of an energy-dependent pion-nucleon phase-shift analysis,[1] an unexpected behavior of the P_{11} phase shift has been observed. It was previously reported[1,2] that the P_{11} phase shift is small and negative at low energies, and becomes very large ($\approx 80°$) at 700-MeV pion laboratory kinetic energy when a parametrization is used that restricts the phases to lie between -90° and +90°. Another parametrization which allows the phases to go through 90° has since been used, and, indeed, the P_{11} phase does go through 90° at 550 MeV. The former parametrization is

$$\tan\delta_l = k^{2l+1}\sum_{m=0}^{l_m - l} a_n k^n,$$

and the latter is

$$\delta_l = k^{2l+1}\sum_{n=0}^{l_m - l} a_n k^n, \tag{1}$$

where l_m is the maximum value of the orbital angular momentum l used in the analysis and k is the c.m. pion momentum.

Layson and Feld[3] reported a possible P_{11} resonance at ≈ 900 MeV. The original plans for the present investigation called for searching for this P_{11} resonance around 900 MeV. The fact that it appears at a much lower energy came as a surprise, but is consonant with the less extensive analysis of Bareyre et al.[4]

The best solution obtained is shown in Fig. 1. This solution represents a fit to 1170 pieces of data between 0 and 700 MeV, including much recent data made available by private communication. All the phases were parametrized according to Eq. (1), except P_{33} and D_{13}. Layson's[3] relativistic Breit-Wigner resonance form, with a small background in the D_{13} case, was used for these two states. The elastic reduced width was not allowed to vary from the value given by Layson. It is not believed that this constraint could have caused the observed P_{11} resonance behavior, because the P_{11} state began showing this behavior in the 0- to 350-MeV analysis where the D_{13} resonance is not important. The analysis will soon be modified to allow the elastic reduced width to vary.

Attempts to fit the P_{11} phase with the Layson form fail because the P_{11} phase is negative below 150 MeV. One can achieve a slightly better fit to the data by using for the P_{11} state a resonance

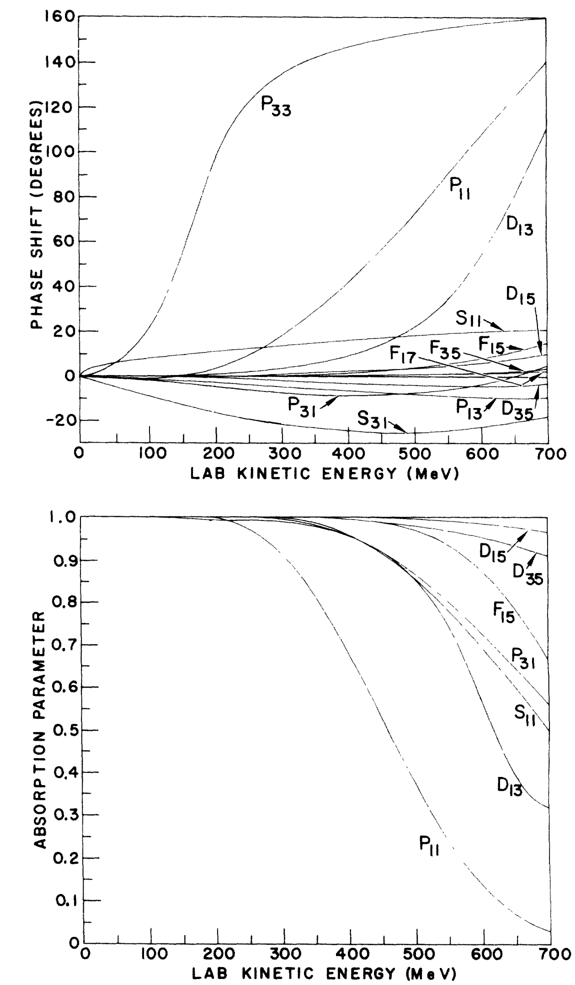

FIG. 1. Pion-nucleon phase shifts and absorption parameters for $l_m = 3$ as functions of energy from 0 to 700 MeV. All data available to the author at the time of writing were used in obtaining this solution.

form that has a zero,[5] instead of Eq. (1); namely,

$$\tan\delta = -\frac{q_{0z} - q_0}{q_{0r} - q_0}(a_1 k^3 + a_2 k^4 + a_3 k^5 + a_4 k^6),$$

where the zero $q_{0z} = 1.73$, the resonance position $q_{0r} = 3.242$, $a_1 = 0.335$, $a_2 = -0.229$, $a_3 = 0.0544$, and $a_4 = -0.00449$. (Here q_0 is the total pion c.m. energy, and energies and momenta are in units of the pion mass.)

The total pion-nucleon c.m. energy and pion-laboratory kinetic energy are, respectively, 1485 MeV and 556 MeV for the P_{11} resonance, 1559 MeV and 676 MeV for the D_{13} resonance, and 1234 MeV and 193 MeV for the P_{33} resonance.

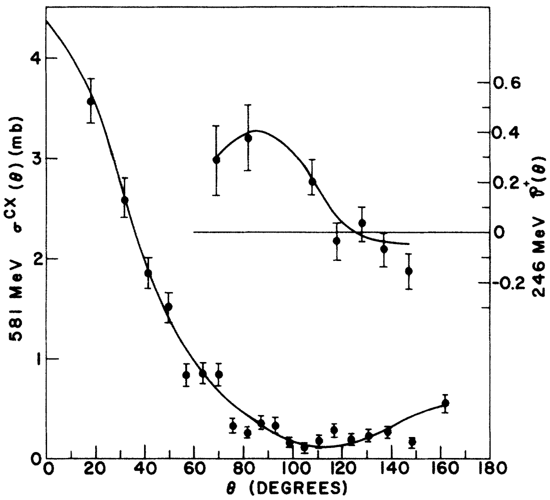

FIG. 2. Prediction of the original energy-dependent phase-shift analysis versus some new data that were not used in the original analysis. The charge-exchange differential cross section data, $\sigma^{cx}(\theta)$, are preliminary results from a recent Berkeley Bevatron experiment [C. Chiu (private communication)], and the π^+-p polarization data, $p^+(\theta)$, are the values obtained by means of the Berkeley polarized target [C. Schultz (private communication)].

Recently much new data have become available through private communication. The solution obtained without the new data is in good agreement with the new data. Examples of such agreement are shown in Fig. 2.

This work was begun while the author was with the Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts. The computations were done at the Lawrence Radiation Laboratory, University of California, Livermore, California. The details of the analysis will be published in a report presently in preparation.

The author wishes to thank Professor B. T. Feld of the Massachusetts Institute of Technology for initially suggesting this problem and for much advice during the course of the analysis. Dr. Michael Moravcsik of Lawrence Radiation Laboratory has lent much advice and encouragement to the completion of this work. Mr. Robert M. Wright, Mr. Richard A. Arndt, and Mr. Eldon J. Halda were the principals among many who were responsible for the actual computer computations.

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[4] P. Bareyre, C. Bricman, G. Valladas, G. Villet, J. Bizard, and J. Sequinot (to be published).

[5] The author wishes to thank Dr. Paul Finkler for suggesting a form of this type.

DETERMINATION OF THE SPIN OF THE f^0 RESONANCE*

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In studying $\pi^- -p$ interactions above 3 GeV/c, several groups[1-6] have reported the existence of the f^0 resonance in the $\pi^+\pi^-$ system from the reaction

$$\pi^- + p \to n + \pi^+ + \pi^-. \qquad (1)$$

The fact that the resonance does not seem to show up in the $\pi^-\pi^0$ spectrum from the reaction

$$\pi^- + p \to p + \pi^- + \pi^0 \qquad (2)$$

nor in the $\pi^+\pi^0$ spectrum from the reaction[7,8] $\pi^+ + p \to p + \pi^+ + \pi^0$ has led to the conclusion[9] that the f is an isotopic singlet ($T = 0$) and, therefore, that its spin (L) is even. This latter conclusion arises from the fact that the f^0 width is large and therefore it conserves isotopic spin in its decay.

The $L = 0$ assignment has definitely been ruled out by the published data[2,4-6] on the decay angular distribution of the f^0, thus indicating an $L = 2$ assignment, which seems to agree with the data to within the error allowed by the somewhat limited statistics available. Hagopian and Selove[4] also mentioned the fact that, disregarding the isotopic spin restriction, their data were incompatible