Table I. Measured asymmetries and derived values of R.

$\theta_{c.m.}$	Asymmetry RP_1P_3	P_1P_3	R
24.0	-0.0421 ± 0.0095	0.188	-0.224 ± 0.051
32.7	-0.0351 ± 0.0088	0.173	-0.203 ± 0.051
45.7	-0.0249 ± 0.0044	0.140	-0.178 ± 0.031
54.4	-0.0252 ± 0.0050	0.119	-0.212 ± 0.042
67.2	-0.0187 ± 0.0035	0.088	-0.213 ± 0.040
76.1	-0.0100 ± 0.0043	0.068	-0.147 ± 0.063
84.0	-0.0084 ± 0.0080	0.059	-0.142 ± 0.136
90.0	+0.0054 ± 0.0064	0.049	+0.110 ± 0.131

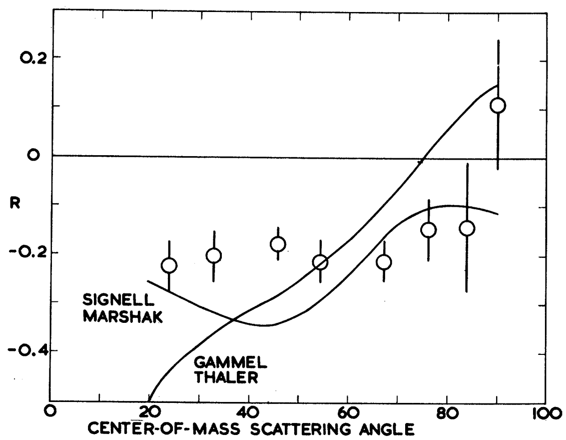

FIG. 1. R parameter in p-p scattering at 142 Mev, with earlier theoretical estimates by Signell and Marshak and by Gammel and Thaler.

The values of asymmetries, analyzing powers, and of R are given in Table I. The results are shown in Fig. 1, together with predictions from the Signell-Marshak[1] and the Gammel-Thaler[2] potentials. These are both in qualitative accord with the trend of the experimental points.

Preliminary results have been presented at the Few-Nucleon Conference, London, July, 1959 (unpublished) and at the Ninth Annual International Conference on High-Energy Physics, Kiev, 1959 (unpublished).

A full account of the experiment will be published elsewhere.

*Now at Liverpool University, Liverpool, England.

[1]P. S. Signell and R. E. Marshak, Phys. Rev. 109, 1229 (1958).

[2]J. L. Gammel and R. M. Thaler, Phys. Rev. 107, 291 (1957).

POSSIBLE NEW RESONANCE IN THE π^+-p SYSTEM

Peter Carruthers*
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York
(Received February 19, 1960)

Within the past year a great deal has been learned about the interactions of high-energy negative π mesons with protons. In particular two very striking peaks have been found to exist in the π^--p cross section at lab pion energies of about 600 and 900 Mev.[1-3] Angular distributions of elastically scattered pions in this energy range have been reported.[2,4] However, experimental data for π^+-p scattering in the same energy range are not nearly so complete. Total cross-section measurements[1,5] have indicated that in this energy region the π^+-p cross section reaches a minimum at about 650 Mev, thereafter rising slowly to the broad peak near 1.3 Bev.[5,6]

In the present note we wish to anticipate future investigations of the π^+-p system by drawing attention to some features of data already available which suggest the existence of a new resonance in the isotopic spin 3/2 (π^+-p) state at an energy of about 850-950 Mev.[7] This evidence further suggests that the favored state has negative parity and total angular momentum 3/2 ($D_{3/2}$). This is precisely the state of angular momentum and parity assigned to the 600-Mev resonance of isotopic spin 1/2 (the "second" resonance) through the work of Wilson,[8] Peierls,[9] Sakurai,[10] and Stein.[11] This assignment for the second resonance is essential to the arguments presented here and will be assumed throughout. With the notation L_{JT} (L is the orbital momentum, J the total angular momentum, T the total isotopic spin) we suggest that there is a $D_{3/2,\,3/2}$ resonance as well as the already established[8-11] $D_{3/2,\,1/2}$ resonance. Theoretical arguments are given for the particular quantum numbers of the suggested resonance, and for the different energies of the two $D_{3/2}$ resonances, at the end of this Letter.

Unfortunately the hypothetical $D_{3/2,\,3/2}$ resonance cannot be expected to reveal itself in such a dramatic fashion as have the well-established resonances, for the following reasons. First of all at such high energies (near 900 Mev) the maximum permissible cross section for a state having $J=3/2$ is only 30 mb, and this will be further reduced by the occurrence of inelastic processes. Further, since the proposed resonance lies at the foot of the broad peak at 1.3 Bev, the amplitudes for the states composing this latter peak will already be appreciable before the $D_{3/2,\,3/2}$ resonance has subsided, preventing the appearance of a distinct peak, although one may hope that more refined experiments will reveal some structure in the cross section. (Clearly these observations do not diminish the importance of such a resonance for the understanding of the dynamics of meson-nucleon interactions.) Therefore a measurement is proposed to detect the characteristic *PD* interference in the recoil proton polarization [see Eq. (3)]. The Saclay group[3] reported π^+-p measurements up to about 850 Mev. Their data, besides displaying sharper and higher π^--p peaks, show both a lower minimum in the π^+-p cross section than previously found[1,5] and an abrupt rise in $\sigma(\pi^+-p)$ in the interval 700-850 Mev. If this curve is continued up to the points of reference 6, a distinct shoulder appears in the cross section.[12] We now discuss the possible structure of this shoulder.

First consider the remarkable behavior of the elastic charge exchange scattering ($\pi^-+p\rightarrow\pi^0+n$) in the 500-800 Mev energy range. Throughout this interval the charge exchange scattering is small and rapidly decreasing, without any sign of a peak, although the elastic scattering (π^--p) displays a sharp peak near 600 Mev.[2] This is rather surprising, since the cross sections are given in terms of the amplitudes $f_{3/2}$ and $f_{1/2}$ (the subscript denotes isotopic spin) by

$$\sigma_{\mathrm{el}}^{-}\propto|f_{3/2}|^2+4|f_{1/2}|^2+4\mathrm{Re}(f_{1/2}^{*}f_{3/2}),\qquad(1)$$

$$\sigma_{\mathrm{ex}}^{-}\propto2|f_{3/2}|^2+2|f_{1/2}|^2-4\mathrm{Re}(f_{1/2}^{*}f_{3/2}).\qquad(2)$$

[The proportionality factor is the same for (1) and (2).] Since $f_{1/2}$ is known to vary in a resonant manner, the smallness and smoothness of the charge-exchange scattering requires that the interference term $\mathrm{Re}(f_{1/2}^{*}f_{3/2})$ be large and positive, a point already noticed by Peierls.[13] Since we are concerned with total cross sections, only states having the same L and the same J survive in the interference term. Now if these $T=3/2$ states were small and nonresonant, one would expect the charge exchange cross section to rise abruptly on the high-energy side of the resonance, which is not the case. Since $D_{3/2,\,1/2}$ presumably is the most important state in this energy interval, the simplest way to prevent both the occurrence of a peak in σ_{ex} and an abrupt rise above the second resonance is to have the $D_{3/2,\,3/2}$ phase shift positive and growing rapidly above 600 Mev. (The relative phase of the states $D_{3/2,\,1/2}$ and $D_{3/2,\,3/2}$ is expected to be large and near 90° between about 600 and 900 Mev, but it must be rather less than 90° for the present argument to work.) Let us consider the other interference terms. Since the S-wave phase shifts are not too large and probably have opposite signs,[2,14,15] their interference will not help in explaining the behavior of σ_{ex}. Next consider the $P_{1/2}$ interference; α_{11} and α_{31} are both small and negative (we use $\alpha_{2T,2J}$ for the P phase shifts, and reserve $\delta_{2T,2J}$ for the D waves) at 300 Mev,[15,16] and at least α_{31} is negative at 500 Mev.[14] Hence this term will either be small or else have the wrong sign. The $P_{3/2}$ interference term will have the wrong sign as long as α_{13} is positive.[15] In any event α_{33} is varying slowly in the energy region under consideration. Accurate $T=3/2$ D-wave phase shifts have been obtained at 310 Mev by Foote et al.[16] They find that δ_{33} is positive, indicating an attractive $D_{3/2,\,3/2}$ state, consistent with the present scheme, and a negative $D_{5/2,\,3/2}$ phase (δ_{35}). The solutions f and g obtained by Willis also have this character.[14] Crittenden et al.[2] report a tentatively negative (and small) δ_{15} at 460 Mev. Thus it seems unlikely that $D_{5/2}$ interference can have the required character. There is some evidence[13] that the third resonance ($T=\frac{1}{2}$) may be associated with an $F_{5/2,\,1/2}$ state. However, since the proposed resonance is supposed to have an energy comparable to the third resonance, it seems impossible for the $F_{5/2,\,3/2}-F_{5/2,\,1/2}$ interference to be appreciable in the vicinity of the second resonance.

Further, the size of the π^+-p cross section at 900 Mev (≈ 22 mb) is compatible with a dominant $D_{3/2}$ state with an inelastic scattering of about 6 mb. (Since the other states have been ignored, this underestimates σ_{in}.) This is to be compared with $\sigma_{\text{in}}=2.8\pm0.5$ mb at 500 Mev[14] and $\sigma_{\text{in}}=10.5\pm1.5$ mb at 990 Mev.[17] Only a completely absorptive $J=5/2$ wave can have as small a total cross section as 22 mb at 900 Mev.

Now consider the available π^+-p angular distributions. At both 500 Mev[14] and 1.1 Bev[18] the most noticeable feature is the very small amount of scattering in the backwards direction. If the scattering is really strong in a $D_{3/2}$ state around 850-900 Mev, then one should expect some $1+3\cos^2\theta$ component to be detectable in the backwards hemisphere. Now in fact, at 990 Mev, where the "resonance" should still be appreciable, there is in fact an encouraging backwards maximum.[17] Photoproduction angular distributions should show signs of this state, but in the total cross section the proposed resonance probably will not be distinguishable from the third resonance, which occurs at about the same energy.

As mentioned before, the detection of a large negative (with respect to the normal to the plane of scattering) polarization for large scattering angles (forward protons) at an energy of, say, 800 Mev would be good evidence for the picture presented above. This rough choice of energy would be low enough to avoid complications from other states and the appreciable inelastic scattering which accompany the 1.3-Bev peak. It is low enough for the tail of the $P_{3/2,\,3/2}$ resonance to be large and high enough for the proposed $D_{3/2,\,3/2}$ resonance to be important. Keeping only these two states in computing the polarization, one has for the polarization of the recoil proton {the amplitudes f are $[\rho\exp(2i\delta)-1]/2ik$; $0\leqslant\rho\leqslant1$}

$$P_n k^2 d\sigma/d\Omega = 2\sin\theta(9\cos^2\theta-1)\,\mathrm{Im}(f_{P_{3/2,\,3/2}}{}^* f_{D_{3/2,\,3/2}}). \quad (3)$$

(k is the pion momentum in units of $\hbar$.) Note the large $\cos^2\theta$ term. One can see that the other states involved give interference terms which are likely to be small, and if anything, tend to offset the above polarization. [Note that if $D_{3/2,\,3/2}$ is replaced by $D_{5/2,\,3/2}$ then the right-hand side of (3) is generally smaller and more isotropic since $9\cos^2\theta-1$ becomes $\frac{3}{2}(1+\cos^2\theta)$.] The actual magnitude of P_n depends on α_{33}. The proton energy (near 400 Mev) should make the polarization experiment feasible.

The dispersion relation calculations of Sternheimer[19] show that the real part of the forward scattering amplitude for π^+-p scattering vanishes at about 900 Mev pion energy. Such a circumstance is certainly compatible with the existence of a dominant resonance state at this energy (if the real part of the phase shift is 90°, then f is purely imaginary). At this energy the S waves and some of the P waves are probably mostly absorptive, making no contribution to $\mathrm{Re}(f)$, and the cancellation of the amplitudes of the remaining states is quite plausible.

Peierls[13] has interpreted the second and third resonances in terms of two-meson states, utilizing ideas from the isobar model.[20] For instance, for the negative-parity second resonance ($D_{3/2,\,1/2}$) the S-P configuration is supposed to be important. This model had some difficulty in explaining why there was a resonance in the $D_{3/2,\,1/2}$ state but not in the $D_{3/2,\,3/2}$ state. This difficulty is resolved if the point of view of the present note is taken.

Finally it is necessary to consider why the two D-wave resonances should be so far apart (250-300 Mev in the lab; 150-175 Mev c.m.) in energy. As might be expected, this behavior is to be blamed on the 33 resonance. A partial explanation may be contained in the observation that in the partial wave dispersion relations the cross section for the 33 resonance enters with opposite signs for the $T=1/2$ and $3/2$ amplitudes.

The author would like to thank Professor H. A. Bethe for a number of enlightening discussions of this work, and Dr. A. Erwin for supplying some unpublished data.

---

*National Science Foundation Predoctoral Fellow.

[1]H. C. Burrowes, D. O. Caldwell, D. H. Frisch, D. A. Hill, D. M. Ritson, R. A. Schluter, and M. A. Wahlig, Phys. Rev. Letters 2, 119 (1959).

[2]R. R. Crittenden, J. H. Scandrett, W. D. Shephard, W. D. Walker, and J. Ballam, Phys. Rev. Letters 2, 121 (1959).

[3]J. C. Brisson, J. Detoef, P. Falk-Vairant, L. Van Rossum, G. Valladas, and L. C. L. Yuan, Phys. Rev. Letters 3, 561 (1959).

[4]A. Erwin and J. Kopp, Phys. Rev. 109, 1364 (1958); W. D. Walker, F. Hushfar, and W. D. Shephard, Phys. Rev. 104, 526 (1956).
[5]R. Cool, O. Piccioni, and D. Clark, Phys. Rev. 103, 1082 (1956).
[6]M. J. Longo, J. A. Helland, W. N. Hess, B. J. Moyer, and V. Perez-Mendez, Phys. Rev. Letters 3, 568 (1959).
[7]Most of the ideas in this note were summarized by the author in a post-deadline paper given at the 1960 New York Meeting of the American Physical Society.
[8]R. R. Wilson, Phys. Rev. 110, 1212 (1958).
[9]R. F. Peierls, Phys. Rev. Letters 1, 174 (1958).
[10]J. J. Sakurai, Phys. Rev. Letters 1, 258 (1958).
[11]P. C. Stein, Phys. Rev. Letters 2, 473 (1959).
[12]This continuation may be done, for example, with recent unpublished data, the authors of which may be found in reference 6. (The cross sections of all three experiments join smoothly.)
[13]R. F. Peierls, thesis, Cornell University, 1959 (unpublished).
[14]W. J. Willis, Phys. Rev. 116, 753 (1959).
[15]H. Y. Chiu and E. L. Lomon, Ann. Phys. 6, 50 (1959).
[16]J. H. Foote, O. Chamberlain, E. H. Rogers, H. M. Steiner, C. Wiegand, and T. Ypsilantis, Phys. Rev. Letters 4, 30 (1960).
[17]A. Erwin, J. Kopp, and A. M. Shapiro (private communication from Dr. Erwin).
[18]L. O. Roellig and D. A. Glaser, Phys. Rev. 116, 1001 (1959).
[19]R. M. Sternheimer, Phys. Rev. 101, 384 (1956).
[20]R. M. Sternheimer and S. J. Lindenbaum, Phys. Rev. 109, 1723 (1958).

FEASIBILITY OF USING HIGH-ENERGY NEUTRINOS TO STUDY THE WEAK INTERACTIONS

M. Schwartz*
Columbia University, New York, New York
(Received February 23, 1960)

For many years, the question to how to investigate the behavior of the weak interactions at high energies has been one of considerable interest. It is the purpose of this note to show that experiments pointed in this direction, though not quite feasible with presently existing equipment, are within the capabilities of present technology and should be possible within the next decade.

We propose the use of high-energy neutrinos as a probe to investigate the weak interactions.

A natural source of high-energy neutrinos are high-energy pions. Such pions will produce neutrinos whose laboratory energy will range with equal probability from zero to 45% of the pion energy, and whose direction will tend very much toward the pion direction. For example, 1-Bev/c pions will emit neutrinos with an average energy of ~220 Mev in such a way that ~$\frac{1}{2}$ of the neutrinos will fall within a cone of half-angle 7°. For orientation purposes, the mean decay distance for such a pion would be 50 meters.

The best known source of pions is a proton accelerator where the beam is allowed to impinge on a target. Let us assume that we have available a 3-Bev proton beam and 10 000 kilograms of material for sensing a neutrino interaction. We may then estimate the proton flux necessary to produce one interaction per hour with a cross section of σ cm^2. To do this, let us consider the simple setup shown in Fig. 1.

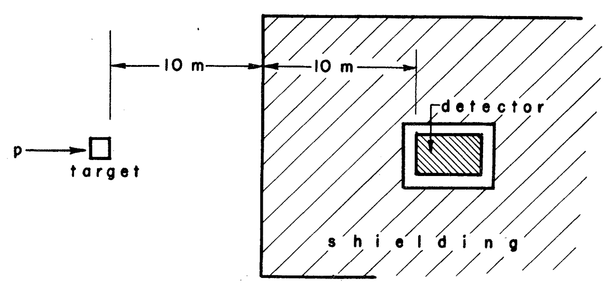

FIG. 1. Proposed experimental arrangement.

Let I be the number of incident protons per unit time, and let, say, $I/10$ charged pions with energy $\geqq 2$ Bev be produced at the target. These pions emerge in a cone of about 45° half-angle, or in about 2 steradians of solid angle. We now let them travel for a distance of 10 meters before hitting a 10-meter shielding wall in front of the detector. Approximately 10% of the pions will decay with an average neutrino energy of about 400 Mev. Each square centimeter of detector subtends a solid angle of $\frac{1}{4}\times10^{-6}$ steradian. Hence, the high-energy neutrino flux at the detector is $(\frac{1}{10}I)(\frac{1}{4}\times10^{-6})(\frac{1}{10})(\frac{1}{2})\cong1\times10^{-9}I$. If there are 10 000 kilograms of detector present, the number of events per unit time is given by

$$N\sim(10^7)(6\times10^{23})(10^{-9}I)\sigma=6\times10^{21}I\sigma.$$

For an intensity of $I=5\times10^{12}$ protons/sec $=1.8\times10^{16}$