Lawrence Berkeley National Laboratory

Recent Work

Title

WILSON-PEIERLS AMBIGUITY IN HIGH-ENERGY PHOTOPRODUCTION

Permalink

<https://escholarship.org/uc/item/4345p1cd>

Author

Sakurai, J.J.

Publication Date

1958-09-02

UNIVERSITY OF
CALIFORNIA

*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.

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

WILSON-PEIERLS AMBIGUITY IN HIGH-ENERGY
PHOTOPRODUCTION

J. J. Sakurai

September 2, 1958

WILSON-PEIERLS AMBIGUITY IN HIGH-ENERGY PHOTOPRODUCTION

J. J. Sakurai*

Radiation Laboratory
University of California
Berkeley, California

September 2, 1958

Recent experiments at Cornell University and at the California Institute of Technology have revealed the presence of a second peak in photoproduction of a single pion.¹ It has been suggested by R. R. Wilson that this peak corresponds to a resonance in an excited isobaric state of the proton with $T = \frac{1}{2}$ and $J = \frac{3}{2}$.² The parity of the isobaric state was originally assigned by him to be even so that the isobar decays into a p-wave pion and a nucleon. However, in a more recent letter R. F. Peierls has pointed out that the π^+ production can be more readily understood in terms of a resonance in a $T = \frac{1}{2}$, $J = \frac{3}{2}$ state with odd parity,³ which means that the proposed isobar has a symmetry property required of a nucleon plus a d-wave pion. Arguments based on the angular distribution of the π^+ production are not very conclusive, since there are many nonresonant states which are expected to be important for photoproduction of charged pions. The purpose of this letter is to point out that there exists a very definite possibility of resolving this $p_{3/2}$ vs. $d_{3/2}$ ambiguity by measuring the polarization of the recoil proton in the reaction

$$\gamma + p \rightarrow p + \pi^0, \quad (1)$$

and that such an experiment is indeed feasible.

Let us recall that the $p_{3/2}$ state of the pion-nucleon system can be reached from the magnetic dipole channel of the γp system and the $d_{3/2}$

* On leave of absence from the University of Chicago.

-2-

state from the electric dipole channel. We construct the production matrix M for Eq. (1) under the assumption that only these two channels contribute, since other nonresonant states are expected to be relatively unimportant for photo-production of neutral pions. provided that either of the resonance models is correct.⁴ We have⁵

$$M = A \left[2\hat{q} \cdot (\hat{k} \times \hat{\epsilon}) - i(\sigma \cdot \hat{k} \hat{q} \cdot \hat{\epsilon} - \sigma \cdot \hat{\epsilon} \hat{q} \cdot \hat{k}) \right] + iB(3\sigma \cdot \hat{q} \hat{\epsilon} \cdot \hat{q} - \sigma \cdot \hat{\epsilon}), \quad (2)$$

where $\hat{\epsilon}$, $\hat{k}$ and $\hat{q}$ are unit vectors along the photon polarization, the photon momentum, and the pion momentum respectively, and A and B are the transition amplitudes for $M1 \rightarrow p_{3/2}$ and for $E1 \rightarrow d_{3/2}$ respectively. In Wilson's $p_{3/2}$ model B is 0 and $|A|^2$ is essentially proportional to the total π^0 production cross section at all energies up to $E_\gamma = 800$ Mev. In Peierls's $d_{3/2}$ model A is dominant in the first resonance region ($E_\gamma \approx 320$ Mev), both A and B contribute in the transition region ($450 \text{ Mev} < E_\gamma < 600 \text{ Mev}$), and B is dominant in the second resonance region ($E_\gamma \approx 700$ Mev). From Eq. (2) we obtain the angular distribution

$$I(\theta) \sim (|A|^2 + |B|^2) \left(1 + \frac{3}{2} \sin^2 \theta \right) - 2 \text{Re}(AB^*) \cos \theta. \quad (3)$$

From the experimental point of view the most striking feature of Reaction (1) is that the π^0 angular distribution is forward-backward symmetric in the entire region up to 800 Mev and is consistent with the $1 + \frac{3}{2} \sin^2 \theta$ distribution. Hence unless one has

$$2 \text{Re}(AB^*) \approx 0 \quad (4)$$

at all energies Peierls's model is untenable—a point already noted by Peierls himself. Note that Peierls's model implies that A and B are about 90° out of phase in the transition region where we know both A and B contribute substantially.

-3-

Thus from the π^0 angular distribution we cannot decide between Wilson's model with $B = 0$ and Peierls's model with $\text{Re}(AB^*) \approx 0$,⁶ and it would be nice if we could directly test Peierls's hypothesis that $|2 \text{Im}(AB^*)|$ is almost as large as $|A|^2 + |B|^2$ in the transition region where $|A| \approx |B|$. We now note that the polarization of the recoil proton is given by

$$P(\theta) = \frac{(\uparrow) - (\downarrow)}{(\uparrow) + (\downarrow)}$$

$$= 4 \text{Im}(AB^*) \sin \theta / \left[(|A|^2 + |B|^2)(1 + \frac{3}{2} \sin^2 \theta) - 2 \text{Re}(AB^*) \cos \theta \right], \quad (5)$$

where $(\uparrow)$ and $(\downarrow)$ refer to the respective probabilities for observing the proton with spin up and spin down relative to the production plane whose normal is given by $\hat{k} \times \hat{q}$. Quantitatively Peierls's model implies that with A and B 90° out of phase the polarization is as large as 80% in the angular region $40^\circ < \theta_{\text{cm}} < 140^\circ$ at about $E_\gamma = 550$ Mev (or, more precisely speaking, at that energy where $|A| = |B|$), as shown in Fig. 1. Fortunately this polarization is rather insensitive to variations in the relative phase of A and B ; even if the relative phase is 60° (which would probably give too much forward-backward asymmetry to be consistent with the angular-distribution measurements) the polarization can be still as large as 70% in the broad angular region shown in Fig. 1.

The recoil proton in Reaction (1) has a substantial laboratory-system kinetic energy in the major part of the region of our interest. Specifically at $E_\gamma = 550$ Mev, $\theta_{\text{cm}} = 55^\circ$ the proton kinetic energy is 215 Mev. As is well known, a polarized proton beam can be analyzed by a scattering from complex nuclei. In fact the situation here is extremely favorable: For 220-Mev polarized protons the analyzing power of proton-carbon scattering is essentially 100%

-4-

at optimum angles, so that at such angles the observed right-left asymmetry in the subsequent p-C scattering is the proton polarization itself.⁷ With only a few hundred events a statistically significant result can be obtained, and in spite of a low expected counting rate such an experiment is feasible.

In view of this large asymmetry expected from Peierls's model and no asymmetry expected from Wilson's model, we believe that the Wilson-Peierls ambiguity can be resolved in this manner. Should the proposed experiment indeed show a large proton polarization in the transition region (i.e. between the first and second peak), such a polarization would be a very striking confirmation of Peierls's model. Of course the possibility exists that neither Peierls's model nor Wilson's model is correct. We expect that most other models⁸ are likely to give a proton polarization substantially smaller than 80%. The energy and angular dependence of the proton polarization will throw further light on the nature of the second peak.

The investigation discussed here was sparked by stimulating conversations the author had with Dr. Oreste Piccioni. Thanks are also due to Drs. M. J. Moravcsik and T. J. Ypsilantis for helpful discussions.

This work was done under the auspices of the United States Atomic Energy Commission.

FOOTNOTES

- 1 De Wire, Jackson, and Littauer, Phys. Rev. 110, 1208 (1958);
P. C. Stein and K. C. Rogers, Phys. Rev. 110, 1209 (1958);
Heinberg, McClelland, Turkot, Wilson, Woodward and Zipoy, Phys. Rev. 110,
1211 (1958);
F. P. Dixon and R. L. Walker, Phys. Rev. Letters 1, 142 (1958).
- 2 R. R. Wilson, Phys. Rev. 110, 1212 (1958).
- 3 R. F. Peierls, (to be published).
- 4 In Wilson's model, however, the neglect of the $E2 \rightarrow p_{3/2}$ transition in the
second resonance region may not be justified on a priori theoretical grounds.
- 5 For the construction of the production matrix see, e.g., M. J. Moravcsik,
p. 15-16, Selected Topics in Low-Energy Pion Physics BNL-459 (T-100)
(Associated Universities, 1957).
- 6 In principle we can resolve the ambiguity by using a polarized γ -ray beam.
The A term gives $1 + 3 \sin^2 \theta \sin^2 \phi$, whereas the B term gives $1 + 3 \sin^2 \theta \cos^2 \phi$,
where ϕ is the angle between $\hat{e}$ and $\hat{q}$. However, the possibility of obtaining
a polarized γ -ray beam at 700 Mev seems to be rather remote at present.
- 7 See, e.g., E. M. Haffner, Phys. Rev. 111, 297 (1958).
- 8 Cf. remarks by R. L. Walker and M. Gell-Mann, Proceedings of the Eighth
Annual Conference on High Energy Nuclear Physics (CERN, Geneva, 1958; to
be published).

-6-

FIGURE CAPTION

Fig. 1. Expected proton polarization for Reaction (1) in Peierls's model in the energy region where the $p_{3/2}$ state and the $d_{3/2}$ state contribute equally under the assumption that the $p_{3/2}$ amplitude and the $d_{3/2}$ amplitude are 90° out of phase.