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DETERMINATION OF THE PION-NUCLEON COUPLING CONSTANT FROM PHOTOPRODUCTION ANGULAR DISTRIBUTION

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ABSTRACT

It is conjectured that the amplitude for photoproduction of π-mesons from nucleons possesses certain reasonable analyticity properties as a function of the invariant momentum transfer. If the conjecture is correct it is possible to continue an angular distribution to a pole lying just outside the physical region. The residue at the pole can be evaluated and provides a determination of the pion-nucleon coupling constant. A preliminary determination gives $f^2 = 0.0716 \pm 0.0302$.

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It has been conjectured by one of us (J.G.T.)[1] that the pion photoproduction amplitude is an analytic function of the momentum transfer in a cut plane. We here apply this conjecture to a determination of the pion-nucleon coupling constant. It will be seen that our method defines a coupling constant which is essentially different from the one obtained from the usual low-energy considerations.

Because a detailed discussion of the conjecture has been given elsewhere, we will content ourselves with a brief description of the region of analyticity of the photoproduction amplitude. We denote by $\underline{k}$ and $\underline{q}$ the photon and pion four-momenta, and by Δ^2 the invariant momentum transfer $(\underline{k} - \underline{q})^2$. The amplitude is expected to have a pole at the value of Δ^2 that corresponds to a one-pion intermediate state. Furthermore, we expect branch points at the values of Δ^2 that correspond to two-pion and one-pion one-nucleon intermediate states. In the center-of-mass

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system. we find that the pole coccurs at a value of $\cos\theta$ equal to β^{-1}, where β is the center-of-mass pion velocity, and θ is the angle between the three-vectors $\underline{k}$ and $\underline{q}$. The branch point corresponding to the two-pion state lies at

$$\cos\theta = \beta^{-1}\left(1 + \frac{3}{2k\,q_o}\right) . \tag{1}$$

The other branch point corresponds to a large (nonphysical) negative value of $\cos\theta$ and is not of interest in this discussion. We shall expect, as a consequence, that the differential cross section multiplied by $(1 - \beta\cos\theta)^2$ can be analytically continued to the pole. The continued differential cross section itself may be expressed in the form

$$\frac{d\sigma}{d\Omega} = \frac{g(\cos\theta)}{(1 - \beta\cos\theta)^2} + f(\cos\theta) , \tag{2}$$

where g and f are analytic in the cut plane. The residue at the pole is given by

$$g(\beta^{-1}) = 147\, f^2 \frac{q}{f} (1 + q_o/M)^{-2}\, k^{-2}\, (1 - \beta^2) \quad \text{(microbarns/sterad)}. \tag{3}$$

The behavior of the residue as a function of photon energy is shown in Fig. 1.

We assume[2] that g is a cubic and f is a quadratic function of $\cos\theta$. In the physical region this corresponds to the assumption that terms arising from the nucleon current are due to S and P waves only, while all the angular momentum states arising from the meson current are included.

A plot of $\frac{d\sigma}{d\Omega}(1 - \beta\cos\theta)^2$ at 260-Mev laboratory photon energy is shown in Fig. 2. Our assumptions imply that this quantity can be expressed as a quartic polynomial in $\cos\theta$. We have determined the coefficients of this polynomial by least-squares fit. This could be done in a significant way only at energies where experimental data at forward angles are available. Furthermore, because the error increases very fast with the size of the range to be extrapolated over, it is advantageous to choose those energies for which the range of extrapolation is small, that is, at as high energies as possible. On the other hand, we deduce from Fig. 1 that for a given percentage error in the residue the data must be obtained with increased accuracy at higher energies.

Experimentalists will want to know how precisely they will have to measure angular distributions in order to obtain a coupling constant determined to within a given specified error. We are investigating this question and expect that our results will be quite energy-dependent.

We have used data at 230,[3,4,5,6] 260,[5,6,8] 265,[3,7] and 290 Mev[5,6,9]. Table I gives the values of the residue as obtained by extrapolation from experiments and the corresponding coupling constants, both including and excluding the 290-Mev data. With the 290-Mev data, we obtain $f^2 = 0.0716 \pm 0.0302$, and without the 290-Mev data, we get $f^2 = 0.111 \pm 0.039$. These values should not be considered final, because the experimental data we used will undoubtedly be improved in the future. We are encouraged to think, however, that when more accurate data are available on the angular distribution of positive-pion photoproduction from hydrogen, our method will give an accurate determination of the coupling constant. This determination will be independent of the assumption of charge independence and will give a coupling constant for the interaction of positive pions with nucleons.

Our tentative value of the coupling constant (with the 290-Mev data) agrees well with the value obtained by one of us (J.L.U.) from an application of dispersion relations to photoproduction.[8] It might be worth pointing out, however, that our method is independent of the details of the dispersion-relation approach. We could, of course, obtain the coefficients of the powers of cos θ in f and g by such an approach. However, we chose to use the experimental data instead in order to avoid assumptions about scattering phase shifts and high-energy behavior of scattering.

A more detailed discussion, possibly with more complete data, will be published at a later time.

It is our pleasure to acknowledge stimulating discussions with Professor Geoffrey Chew. This work was performed under the auspices of the United States Atomic Energy Commission.

TABLE I

Values of the residue as obtained from experimental extrapolation, and the corresponding coupling constants, at various photon energies, given in the laboratory system.

E_{γ}	Experimental residue (microbarns/sterad)	Coupling constant f^2
235	1.43 ± 0.90	0.078 ± 0.050
260	1.70 ± 0.52	0.136 ± 0.048
265	1.79 ± 1.25	0.133 ± 0.093
290	0.287 ± 0.350	0.0278 ± 0.0340
Average of all data		0.0716 ± 0.0302
Average without the 290-Mev data		0.111 ± 0.039

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FIGURE LEGENDS

Fig. 1: Value of the residue vs. the photon energy in the laboratory system.

Fig. 2: The quantity $\frac{d\sigma}{d\Omega}(1 - \beta \cos \theta)^2$ vs. $\cos \theta$ in the center-of-mass system, for 265-Mev photon energy in the laboratory system, as obtained from the polynomial fit of all experimental data at this energy. The figure shows the extrapolated part of the curve in the unphysical region which leads to the value of the residue at $\cos \theta = 1.31$, together with the forward half of the physical angular region.

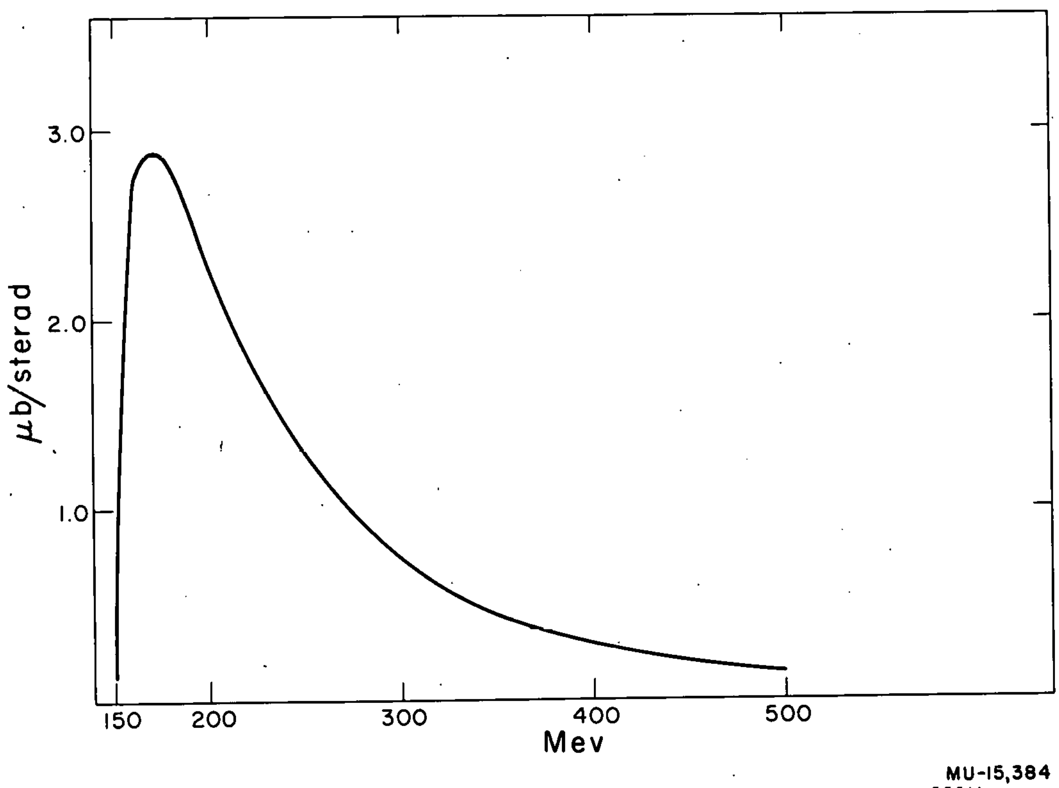

Fig. 1

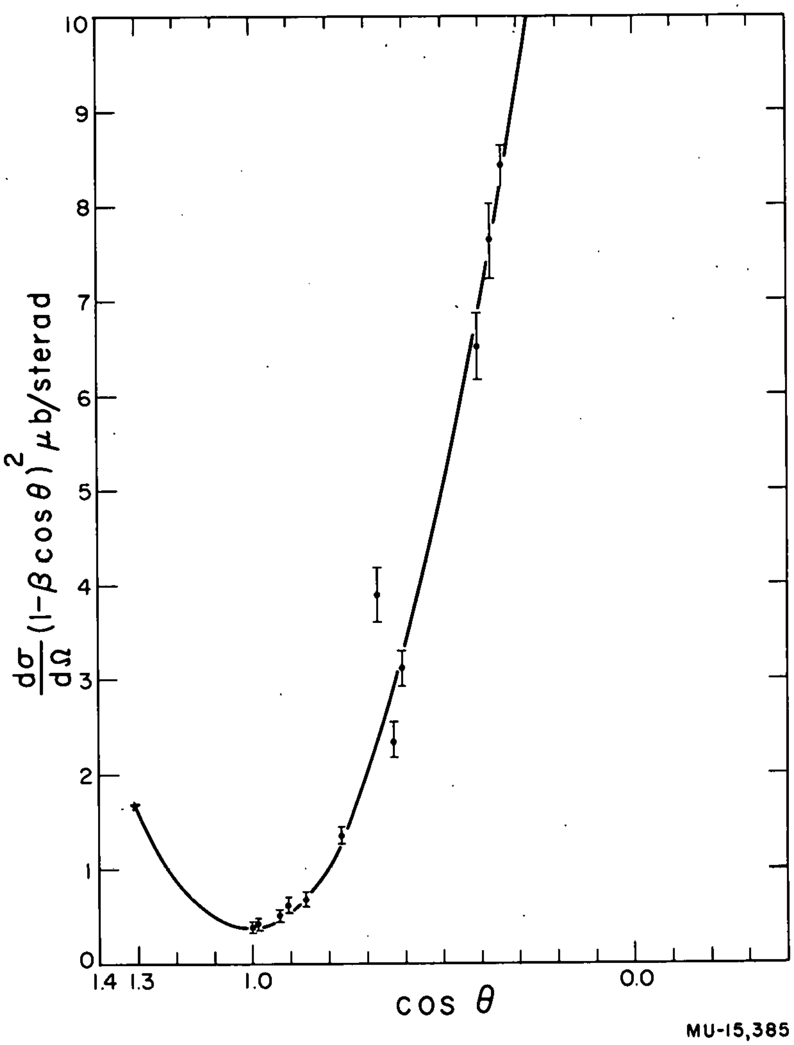
10
9
8
7
6
5
4
3
2
1
0
1.4
1.3
1.0
0.0
cos θ
dσ/dΩ (1-β cos θ)² μb/sterad
MU-15,385

Fig. 2