term larger than the limit set by Gerhart.

*Research supported by the U. S. Atomic Energy Commission.

¹J. B. Gerhart and R. Sherr, Bull. Am. Phys. Soc. Ser. II, 1, 195 (1956); J. B. Gerhart, Phys. Rev. 109, 897 (1958).

²W. M. MacDonald, Phys. Rev. 110, 1420 (1958).

ELECTROMAGNETIC MASS CORRECTION FOR SPIN 0 PARTICLES

S. Gasiorowicz* and A. Petermann
Theoretical Study Division, CERN,
Geneve, Switzerland

(Received November 20, 1958)

Because of the requirement of gauge invariance, the electromagnetic coupling of a charged spin-zero field consists of two terms,

$$-ie\left(\varphi^*(x)\cdot\partial_\mu\varphi(x)-\partial_\mu\varphi^*(x)\cdot\varphi(x)\right)A_\mu(x) \quad (1a)$$

$$-e^2\varphi^*(x)\varphi(x)A_\mu(x)A_\mu(x). \quad (1b)$$

In lowest-order perturbation theory (ignoring for the moment all strong interactions) the two self-energy terms are represented by the diagrams in Fig. 1.

To separate the contributions of the two terms (each of which is gauge dependent), it is useful to choose the gauge in which the photon Green's function in momentum space takes the form

$$D_{F\mu\nu}(K) = \frac{1}{K^2} \left(\delta_{\mu\nu} - \frac{K_\mu K_\nu}{K^2} \right). \quad (2)$$

With this choice, the contribution of the terms (1a) to the self-energy are seen to be logarithmically divergent, since

$$\begin{aligned} \int d^4K (q - \tfrac{1}{2}K)_\mu \frac{1}{(q-K)^2 + \mu^2} (q - \tfrac{1}{2}K)_\nu \frac{1}{K^2} \left(\delta_{\mu\nu} - \frac{K_\mu K_\nu}{K^2} \right) \\ = \int d^4K \frac{1}{K^2} \frac{1}{(q-K)^2 + \mu^2} \left(q^2 - \frac{(q \cdot K)^2}{K^2} \right). \end{aligned} \quad (3)$$

FIG. 1. Lowest order electromagnetic effect.

The contribution of the term (1b) is quadratically divergent. It is proportional to

$$3e^2 \int \frac{d^4K}{K^2}, \quad (4)$$

which behaves as Λ^2 , if Λ is a cutoff momentum for the photon. With this choice of gauge, the familiar result that the spin-zero boson electromagnetic self-energy is quadratically divergent¹ is made very transparent. As would be expected on dimensional grounds, it is also clear that the dominant term [(1b) in this gauge], which is the quadratically divergent one, is independent of the mass of the boson. On these grounds, if it is assumed that the mass difference between charged and neutral members of the same multiplet is purely electromagnetic, one might expect the result

$$\frac{m_{K^+} - m_{K^0}}{m_{\pi^+} - m_{\pi^0}} = \frac{m_\pi}{m_K} \quad (5)$$

to hold to good accuracy.

It is of course necessary to enquire how this result is affected by the inclusion of strong interactions. The terms of the type shown in Fig. 2 (a) correspond to taking into account, for example, the fact that in the strong interaction "box," which changes the boson mass from the bare to the physical mass, the masses of intermediate charged and neutral members of a multiplet are their physical (slightly unequal) masses. We expect the contribution of these terms to the electromagnetic mass difference to be rather small. There are also terms of a type exhibited in Fig. 2 (b). We do not, of course, know how to calculate these terms but, if we assume that the vertex operator behaves in a way similar to that indicated by perturbation

FIG. 2. Strong interactions corrections.

theory (for strong interactions), then these terms are again no more than logarithmically divergent. Thus again Fig. 1 (b) represents the leading contribution to the electromagnetic mass difference and again Eq. (5) may be expected to hold for very large Λ^2 .

For a photon cutoff momentum of the order of 1 BeV/c, deviation from (5) will occur that we cannot estimate, whereas for point interactions (5) is exact up to finite α corrections to m_π/m_K .²

It is a pleasure for one of us (S.G.) to thank Professor Ferretti and CERN for their hospitality

*National Science Foundation Fellow. On leave from the Radiation Laboratory, Berkeley, California.

¹R. Feynman and G. Speisman, Phys. Rev. 94, 500 (1954); A. Petermann, Helv. Phys. Acta 27, 441 (1954).

²One can actually show that terms $\sim (\Lambda^2/m)\log(\Lambda^2/m^2)$ do never occur.

PHOTOPRODUCTION OF SINGLE POSITIVE PIONS FROM HYDROGEN IN THE 600- TO 1000-Mev REGION*

F. P. Dixon and R. L. Walker
California Institute of Technology,
Pasadena, California
(Received November 17, 1958)

The earlier magnetic spectrometer measurements¹ of pions from the reaction $\gamma + p \rightarrow \pi^+ + n$, initiated by the bremsstrahlung beam of the Cal-Tech Synchrotron in a liquid hydrogen target, have been extended to cover a range of 20° to about 163° in the center-of-momentum system for laboratory photon energies of 600, 700, 800, 900, and 1000 Mev. The experimental technique was improved by the placement of veto counters along the pole faces of the magnet to eliminate counts from scattered particles and from showers produced in the iron. Also, a Lucite Čerenkov counter was used to discriminate against protons, which could not be clearly separated from pions at momenta above 800 Mev/c by a pulse-height analysis. New data at angles greater than 135° were taken with the same medium-momentum spectrometer used for the previous measurement. However, for pion momenta greater than 600 Mev/c (forward angles) the high-momentum spectrometer described by Vette² was employed with the addition of the pole face veto counters and a front "aperture" counter located near the magnet entrance.

FIG. 1. Angular distributions of pions from $\gamma + p \rightarrow \pi^+ + n$ for 600- and 800-Mev photons. The solid curves in Figs. 1-3 are least-squares fits to the data, of the form $d\sigma/d\Omega = \sum_{n=0}^4 A_n \cos^n \theta$. The dashed curves are fits of the form $(1 - \beta \cos \theta)^2 (d\sigma/d\Omega) = \sum_{n=0}^6 B_n \cos^n \theta$ following Moravcsik.⁴

The data presented in this report have been corrected for empty-target backgrounds, pion decay in flight, absorption of pions in the system, and muon contamination. The background was found to be about 10% of the total counting rate. The worst case was 13% at 11.3° in the laboratory system. Negative-field runs at this position showed no contribution from the hydrogen, since empty- and full-target runs gave equal counting rates amounting to 4% of the total positive-field run with hydrogen in the target. The absorption correction was 14%, where the geometrical value was used for the counters and the attenuation in the half-inch Pb absorber was measured. A preliminary estimate of muon contamination was used and gave 4 ± 2 to $8 \pm 4\%$ correction for this effect. With the pion decay loss this resulted in a net correction of 8 to 19% for effects associated with pion decay.

Angular distributions in the center-of-momentum system for each of the five photon energies investigated are shown in Figs. 1-3. In these figures the previous cross sections of reference 1 have been increased about 4% as a result of a recent beam monitor calibration.³ None of the data should be considered as final, since we plan to make an improved calculation of the corrections for muon contamination, and a future detailed measurement of the bremsstrahlung spectrum could result in some changes in the cross sections. We have used essentially a thin-