ELASTIC SCATTERING OF MUONS IN NUCLEAR EMULSION*

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In the past 10 years several experiments have been performed to measure the nuclear scattering of cosmic-ray muons.[1] Many of these experiments are claimed to show, in addition to the Coulomb interaction, an anomalous muon-nuclear interaction. These cosmic-ray experiments suffer from several difficulties: (1) They measure inelastic as well as elastic scatterings; (2) the pion background is uncertain and difficult to correct for; (3) the incoming muon energy is not known; and (4) the use of thick scattering plates requires serious corrections for multiple scattering (also for successive single scatterings combined with multiple scattering). At high momentum transfer these scattering corrections require knowledge of the elastic and especially the inelastic cross sections. Such theoretical knowledge is yet only approximate.[2] Masek, Heggie, Kim, and Williams[3] have recently performed an experiment which overcomes most of the above difficulties. They measured a mixture of elastic and inelastic scattering of 2-Bev μ^- on carbon using a Bevatron separated muon beam; most of their scatterings with high momentum transfer should be inelastic, and their results are in agreement with the inelastic cross section estimates of Drell and Schwartz.[4]

Our experiment, on the other hand, measures only elastic scatterings as do the electron scattering experiments of Hofstadter.[5] The corresponding calculations can be done precisely so that detailed information on the charge distribution of the nucleus can be obtained from the elastic scattering measurements. A departure of the muon elastic scattering from these precise calculations would reveal a nonelectromagnetic muon-nuclear interaction, or a difference between the mean radii of the muon and electron charge distributions.

In this Letter we report the final results of our μ^+ scattering experiment and preliminary results of our μ^- scattering experiments. The μ^+ stack was exposed to 3.5×10^6 muons in the 43-Mev separated muon beam of the Carnegie Tech synchrocyclotron and the μ^- stack was exposed to 2.5×10^7 muons in the 60-Mev separated muon beam of the CERN synchrocyclotron. In the μ^+ experiment the small pion background is eliminated by observation of the π-μ decay. In the μ^- experiment the ratio of muon endings to pion endings is greater than 1000 to 1. Negative pions are also eliminated by observation of prongs at either the scattering or the ending. We have observed no inelastic scatterings. Most inelastic scatterings in our energy region would be expected to excite the giant resonance and thus show up as a large increase in grain density at the scattering.[6] Other inelastic scatterings could be distinguished by proton or conversion-electron prongs at the scattering.

Large effective path lengths are achieved by area scanning for muon endings in the region where muons are not supposed to end and tracing these endings back to a possible large-angle scattering. Since the geometry of the stack is known precisely, it is possible to make numerical calculations of the effective muon path scanned.

In our μ^+ experiment we have restricted our data to 14- to 40-Mev muons scattering at angles between 80° and 180°. Our energy and angle limits correspond to momentum transfers of 80 to 160 Mev/c. Figure 1 shows the number of events observed having a momentum transfer greater than the value q. The curve is the number of events predicted from the elastic scattering calculations of Rawitscher,[7] who used the nuclear charge distributions obtained by Hofstadter.[5] Figure 2 shows our experimental cross sections plotted against momentum transfer q, together with Rawitscher's calculated cross sections for 27-Mev μ^+ scattering elastically on Ag ($Z=47$) and Br ($Z=35$) averaged together. Rawitscher's cross sections when plotted against q are virtually independent of muon energy in the energy region studied. The statistical standard deviations are shown in Figs. 1 and 2, and it appears that the data are consistent with Rawitscher's calculations. The predicted number of events depends both on our geometry calculation and interpolations of Rawitscher's cross sections. We estimate an over-all accuracy of ±10% for our calculation of the predicted number of events. This possible systematic error is not shown in Figs. 1 or 2.

Early scanning on our μ^- experiment has yielded 10 events so far with $q>100$ Mev/c and this also appears to be consistent with Rawitscher's calculations.

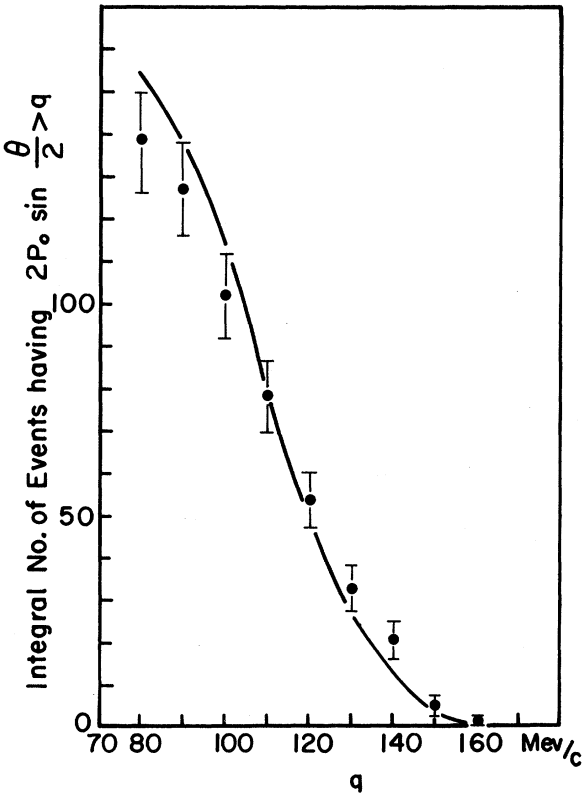

FIG. 1. The number of events having a momentum transfer greater than q is plotted vs q. The curve is the predicted number of events based on the elastic scattering cross sections calculated by Rawitscher.

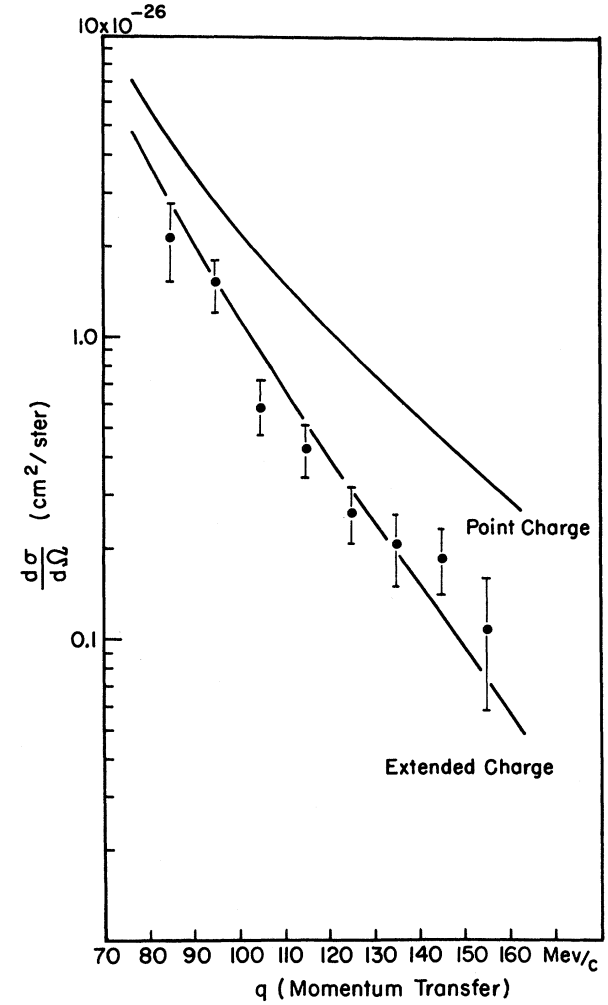

FIG. 2. One-half the sum of the differential cross sections for the elastic scattering of 27-Mev μ^+ on Ag and Br plotted against the momentum transfer q. The experimental points are based on a total of 138 observed scatters in nuclear emulsion. The curves for extended and point charge distribution are those calculated by Rawitscher.

We conclude that our positive muons behave as heavy positrons in the same momentum transfer region as was studied by the cosmic-ray experiments. We have no indication of an anomalous muon-nuclear interaction. If we make allowance for a possible finite size of the muon by multiplying Rawitscher's cross sections by $f^2(q)$, where $f(q) = (1 + \frac{1}{6}\langle R_\mu^2\rangle_{\rm av} q^2)^{-1}$ is the form factor due to the muon charge distribution,[8] we find that our data determine an upper limit of 1.7×10^{-13} cm for the rms muon radius $(\langle R_\mu^2\rangle_{\rm av})^{1/2}$.

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[1]For the most recent cosmic-ray experiments see R. L. Sen Gupta, S. Ghosh, A. Acharya, M. M. Biswas, and K. K. Roy, Nuovo cimento 19, 245 (1961). For a summary of the experiments up to 1958, see G. N. Fowler and A. W. Wolfendale, Progress in Elementary Particle and Cosmic-Ray Physics (North-Holland Publishing Company, Amsterdam, 1958), Vol. 4, p. 123.

[2]L. N. Cooper and J. Rainwater, Phys. Rev. 97, 492 (1935).

[3]G. E. Masek, L. D. Heggie, Y. B. Kim, and R. W.

Williams, Phys. Rev. 122, 937 (1961).
[4]S. D. Drell and C. L. Schwartz, Phys. Rev. 112, 568 (1958).
[5]R. Hofstadter, Ann. Rev. Nuclear Sci. 7, 231 (1957).
[6]Hans Bethe (private communication).
[7]G. H. Rawitscher, Phys. Rev. 112, 1274 (1958); also Bull. Am. Phys. Soc. 6, 301 (1961).
[8]S. D. Drell, Ann. Phys. 4, 75 (1958).

PROPOSED METHOD OF MEASURING THE SPIN OF THE K' MESON

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The recent discovery[1] of the K' meson with a mass of about 880 Mev has led to considerable speculation about its role in strange particle reactions. A knowledge of its spin is hence of obvious importance. It has already been verified that the K' has isotopic spin 1/2 and decays via the modes $K' \to K + \pi$. At the moment, one possibility for determining whether its spin is 0 or 1 is by observing the occurrence (or nonoccurrence) of the decay mode $K' \to K + \gamma$. It is the purpose of this note to point out another method of measuring the spin of the K', which, although no better than the above, is rather unique and perhaps somewhat elegant.

The reaction we shall consider is $\bar{p} + p \to K^0 + \bar{K}^{0\prime}$ or $K^{0\prime} + \bar{K}^0$, where the antiproton capture takes place at rest. Only one assumption will be made here—namely that the capture proceeds from an S state. The justification for this assumption rests on the recent arguments of Day, Snow, and Sucher.[2] At any rate, there is an inherent check of this assumption in the experiment as will be seen below.

Subject to the above assumption, the initial state can be either the triplet or the singlet state. The triplet state is odd under charge conjugation and the singlet state is even. The parity of the initial system is odd.

The reaction $\bar{p} + p \to K^0 + \bar{K}^0$. It is well known that if the above conditions are satisfied, then the outgoing $K^0\bar{K}^0$ system must be odd under charge conjugation. If this is so, the outgoing wave function will have the factor $K_{1a}{}^0K_{2b}{}^0 - K_{2a}{}^0K_{1b}{}^0$. Hence one K^0 will always decay via the $K_1{}^0$ mode and the other will decay via the $K_2{}^0$ mode. The observation of this effect serves then as a check on the assumption of S-state capture.

The reaction $\bar{p} + p \to K^0 + \bar{K}^{0\prime}$ or $K^{0\prime} + \bar{K}^0$, in the event that the $K^{0\prime}$ has spin zero. In this case, the outgoing state must be an S state (since the relative parity of the K and K' is odd). Hence the initial state must be the singlet S state. Therefore it is even under charge conjugation. Hence the final state must be of the form $K^0\bar{K}^{0\prime} + K^{0\prime}\bar{K}^0$. The $K^{0\prime}$ (or $\bar{K}^{0\prime}$) decays via the mode

$$K^{0\prime} \to (\tfrac{1}{3})^{1/2}K^0\pi^0 - (\tfrac{2}{3})^{1/2}K^+\pi^-,$$
$$(\bar{K}^{0\prime} \to (\tfrac{1}{3})^{1/2}\bar{K}^0\pi^0 - (\tfrac{2}{3})^{1/2}K^-\pi^+).$$

If we now adopt the notation that subscript a refers to the primary K^0 or $\bar{K}^0$ and b refers to the other, we can rewrite our outgoing state as

$$\psi = \psi_1 + \psi_2 = (\tfrac{1}{3})^{1/2}\left\{\frac{K_a{}^0\bar{K}_b{}^0\pi^0 + \bar{K}_a{}^0K_b{}^0\pi^0}{\sqrt{2}}\right\} - (\tfrac{2}{3})^{1/2}\left\{\frac{K_a{}^0K_b{}^-\pi^+ + \bar{K}_a{}^0K^+\pi^-}{\sqrt{2}}\right\}.$$

We shall deal now only with the first part of this state. Let us substitute

$$K^0 = (K_1{}^0 + K_2{}^0)/\sqrt{2}, \quad \bar{K}^0 = (K_1{}^0 - K_2{}^0)/\sqrt{2}.$$

We then have

$$\psi_1 = (K_{1a}{}^0K_{1b}{}^0 - K_{2a}{}^0K_{2b}{}^0)/\sqrt{2}.$$

Hence we will observe either a two-$K_1{}^0$ type of decay or a two-$K_2{}^0$ type of decay, but no events in which we have both a $K_1{}^0$ and a $K_2{}^0$.

The reaction $\bar{p} + p \to K^0 + \bar{K}^{0\prime}$ or $K^{0\prime} + \bar{K}^0$, in the event that the spin of the K' is 1. In this case the outgoing state must be a p state. Hence we can have either $J=0$ or $J=1$. $J=2$ is forbidden