POSSIBLE EXISTENCE OF KINKS IN HIGH-ENERGY ELASTIC pp SCATTERING CROSS SECTION*

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Using a model proposed earlier and experimental proton form factors, the high-energy elastic pp scattering cross section is computed.

About a year ago we proposed[1] a model for high-energy scattering which gave a relationship between form factors and high-energy elastic scattering. The relationship was used to compute the proton form factor from high-energy pp elastic data. The mathematics of the model was developed further in a recent paper,[2] where the following equivalent relationships were obtained:

$$[F(\kappa^2)]_p{}^2 = (\text{constant})[a_{pp}(\vec{\kappa}) + \tfrac{1}{2}a_{pp}(\vec{\kappa})\otimes a_{pp}(\vec{\kappa}) + \tfrac{1}{3}a_{pp}(\vec{\kappa})\otimes a_{pp}(\vec{\kappa})\otimes a_{pp}(\vec{\kappa}) + \cdots], \quad (1)$$

$$a_{pp}(\vec{\kappa}) = \Delta_p(\vec{\kappa}) - \frac{1}{2!}\Delta_p(\vec{\kappa})\otimes\Delta_p(\vec{\kappa}) + \frac{1}{3!}\Delta_p(\vec{\kappa})\otimes\Delta_p(\vec{\kappa})\otimes\Delta_p(\vec{\kappa}) - \cdots, \quad (2)$$

where

$$\Delta_p(\vec{\kappa}) = (\text{constant})[F(\kappa^2)]_p{}^2, \quad (3)$$

$F(\kappa^2)p$ is the proton form factor, and a_{pp} the elastic amplitude for pp scattering at infinite energy. The symbol $\otimes$ means convolution integral. The vector $\vec{\kappa}$ in a_{pp} is the two-dimensional momentum transfer at infinite energies in a plane perpendicular to the incoming momentum.

In II we took some possible limiting scattering amplitudes a_{pp} and computed the form factor from (1). Since there are now available accurate data on the form factors, we could also use (2) to compute the limiting scattering amplitude a_{pp}, adjusting the constant in (3) so that $d\sigma/dt$ at $t=0$ agrees with its experimental value. The result of such a calculation is shown in Fig. 1.

The agreement of the curves of Fig. 1 with experimental data for low values of $-t$ is expected, since papers I and II already demonstrated this point conclusively. The most interesting new point of the curves of Fig. 1 lies in the zeros of $d\sigma/dt$. Mathematically they came about because of the terms of different signs in (2) [which, in turn, as emphasized in II, originate from shielding effects of the back of a particle by its front, and which have their exact counter parts in Glauber's theory of particle-nucleus scattering]. In this connection we note that in contrast, (1) has only one sign for its terms so that if a_{pp} is a monotonically decreasing function of κ^2 with no zeros, so is F.

Are there experimental indications of the exis-

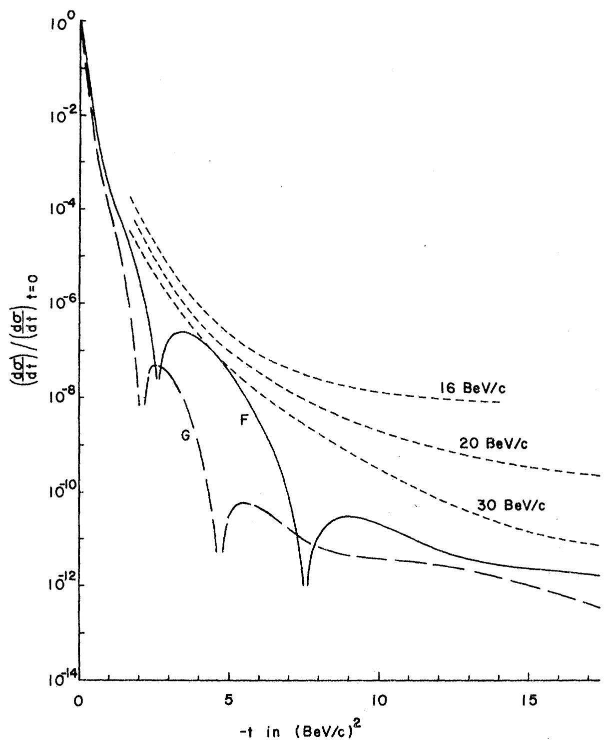

FIG. 1. Elastic pp scattering cross section $(d\sigma/dt)/(d\sigma/dt)_{t=0}$ vs $-t$ at infinite energy is calculated from Eq. (2). Curves F (solid) and G (long-dashed) are obtained by using F_1 and G_M/μ form factors of the proton, respectively. To facilitate computations, we used the following fits for the form factors: $[F_1(\kappa^2)]_p{}^2 = 0.81135 \times \exp(-5.26\kappa^2) + 0.18\exp(-1.36\kappa^2) + 0.0085\exp(-0.500\kappa^2) + 0.00015\exp(-0.163\kappa^2)$ and $[G_M(\kappa^2)/\mu]_p{}^2 = 0.79 \times \exp(-6.50\kappa^2) + 0.1999\exp(-2.07\kappa^2) + 0.01\exp(-0.779\kappa^2) + 0.0001\exp(-0.227\kappa^2)$. These fits are good. Although they are not least-squares fits, they are consistent with the spread of experimental form-factor data. Existing experimental data of scattering cross sections for large $-t$ values [G. Cocconi et al., Phys. Rev. 138, B165 (1965)] are also shown (short-dashed curves).

tence of such zeros of $d\sigma/dt$? In Fig. 2 we show curve F of Fig. 1 together with the experimental points plotted by Krisch.[3] (We have in this plot taken $\beta^2 p_\perp^2 = -t$ since at infinite energies $\beta^2 p_\perp^2 \to -t$.) It is interesting that the "kink" near $-t = 1$, as shown in Krisch's plot, seems also to exist in curve F. Another experimental indication[4] of "kinks" has been reported at the CERN conference on high-energy scattering.

One must remember, of course, that the differential cross sections near these kinks are very small, and in our theory their exact positions sensitively depend on form factors at smaller values of $-t$. Furthermore, the model of papers I and II is heuristically derived, and should not quantitatively give exact results, except where $d\sigma/dt$ and form factors are quite large (i.e., at small $-t$). In addition there is the uncertainty about which form factors to use, F_1 or G_M/μ, and there is the uncertainty about spin-flip contributions and imaginary parts of a_{pp} (real part in the usual terminology).

The possible existence of zeros for $d\sigma/dt$, i.e., $-\infty$ for $\ln(d\sigma/dt)$ is, however, quite independent of the specific details of our model. Indeed, if it is true at high energies that (i) only one amplitude contributes[1] for the elastic-scattering process, and (ii) that amplitude becomes purely real (imaginary in the usual terminology), then $d\sigma/dt$ may have zeros.

We note that in p-α elastic scattering a very good fit[5] to experimental data is obtained with Glauber's theory. The dips in such a case are indeed due to zeros in the real part (imaginary part in the usual terminology) of the scattering amplitude.

It would be very interesting to test for the existence of zeros of $d\sigma/dt$ in elastic differential cross sections between hadrons at high energies. A good region to focus one's attention is the region of $-t$ values, where there is a known "shoulder," "kink," or "dip," such as[6] near $-t = 1$ $(\mathrm{BeV}/c)^2$ and 3 $(\mathrm{BeV}/c)^2$ for πp scattering. If one observes a deepening of the dip as the incoming energy increases, one may be observing a zero for $d\sigma/dt$ at infinitely high energies.

The existence of zeros in $d\sigma/dt$ for pp scattering according to the model of papers I and II was discussed by us at the CERN conference on high-energy scattering in January 1968. At the same conference it was reported[7] that Durand and Lipes have also found these zeros in $d\sigma/dt$ for pp scattering according to our model. We have subsequently received a preprint[8] of these authors giving their detailed curves. We note that while the formulas used by these authors are the same as ours, the input for the proton form factor used by us is the experimental data,[9] while in Ref. 8 a dipole fit is used, resulting in considerable numerical differences.

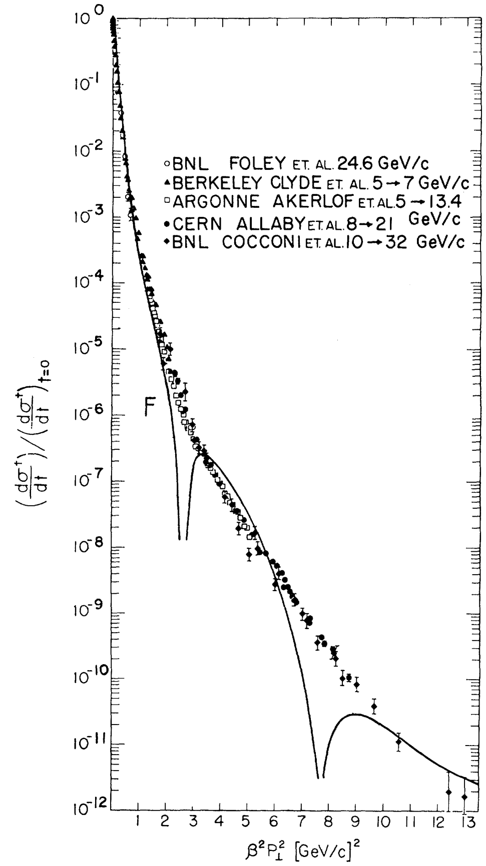

FIG. 2. Curve F of Fig. 1 is compared with Krisch's plot of $(d\sigma^+/dt)/(d\sigma^+/dt)_{t=0}$ vs $\beta^2 p_\perp^2$ with $\beta^2 p_\perp^2 = -t$ (see text). We emphasize that in Krisch's plot, data at not very high energies are used which, strictly speaking, should not be compared with our model for scattering at infinite energies.

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[1]T. T. Chou and C. N. Yang, in Proceedings of the Second International Conference on High Energy Physics and Nuclear Structure, Rehovoth, Israel, 1967, edited by G. Alexander (North-Holland Publishing Company, Amsterdam, The Netherlands, 1967), pp. 348-359; hereafter referred to as I.

[2]T. T. Chou and C. N. Yang, Phys. Rev. (to be published); hereafter referred to as II.

[3]A. D. Krisch, Phys. Rev. Letters 19, 1149 (1967).

[4]J. V. Allaby, A. N. Diddens, A. Klovning, E. Lillethun, E. J. Sacharidis, K. Schlüpmann, and A. M.

Wetherell, in Proceedings of the Topical Conference on High Energy Collisions of Hadrons, CERN, 15-18 January 1968 (to be published).

[5]W. Czyż and L. Leśniak, Phys. Letters 24B, 227 (1967); R. H. Bassel and C. Wilkin, Phys. Rev. Letters 18, 871 (1967); T. T. Chou, Phys. Rev. 168, 1594 (1968).

[6]R. Rubinstein, A. Ashmore, C. J. S. Damerell, W. R. Frisken, J. Orear, D. P. Owen, F. C. Peterson, A. L. Read, D. G. Ryan, and D. H. White, in Proceedings of the Topical Conference on High Energy Collisions of Hadrons, CERN, 15-18 January 1968 (to be published).

[7]V. Barger, in Proceedings of the Topical Conference on High Energy Collisions of Hadrons, CERN, 15-18 January 1968 (to be published).

[8]L. Durand, III, and R. Lipes, Phys. Rev. Letters 20, 637 (1968).

[9]D. H. Coward, H. DeStaebler, R. A. Early, J. Litt, A. Minten, L. W. Mo, W. K. H. Panofsky, R. E. Taylor, M. Breidenbach, J. I. Friedman, H. W. Kendall, P. N. Kirk, B. C. Barish, J. Mar, and J. Pine, Phys. Rev. Letters 20, 292 (1968); M. Goitein, R. J. Budnitz, L. Carroll, J. Chen, J. R. Dunning, Jr., K. Hanson, D. Imrie, C. Mistretta, J. K. Walker, R. Wilson, G. F. Dell, M. Fotino, J. M. Paterson, and H. Winick, Phys. Rev. Letters 18, 1016 (1967); W. Albrecht, H. J. Behrend, F. W. Brasse, W. Flauger, H. Hultschig, and K. G. Steffen, Phys. Rev. Letters 17, 1192 (1966); W. Bartel, B. Dudelzak, H. Krehbiel, J. M. McElroy, U. Meyer-Berkhout, R. J. Morrison, H. Nguyen-Ngoc, W. Schmidt, and G. Weber, Phys. Rev. Letters 17, 608 (1966); L. N. Hand, D. G. Miller, and R. Wilson, Rev. Mod. Phys. 35, 335 (1963).

DOUBLE CHARGE EXCHANGE IN π^+–HELIUM SCATTERING*

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It has been suggested by several authors that the double-charge-exchange reaction might supply information on nucleon-nucleon correlations in nuclei.[1] In the course of an experiment on π^+ interactions in helium we have obtained a limited sample of double-charge-exchange events. Although the number of events is rather small, a simple analysis gives a qualitative picture of the process involved.

The data were obtained from an exposure of 610-MeV/c π^+ in the 10-in. superconducting-magnet bubble chamber at the Argonne National Laboratory. About 17 300 frames were scanned for events in which negative pions were produced, with a scanning efficiency of 97%. Of the 269 events found, 42 fitted the double-charge-exchange hypothesis:

$$\pi^+ + \mathrm{He} \to \pi^- + 4p. \qquad (1)$$

The remainder were distributed among various two-pion final states. The observed rate corresponds to a cross section of 1.20 ± 0.21 mb.

Since there are no theoretical calculations of double charge exchange in the energy range covered by this experiment, the data are compared with a phase-space model. The model is based on the assumption that the process involved is

$$\pi^+ + 2n \to \pi^- + 2p \qquad (2)$$

with two spectator protons. Further assumptions include the following: (a) There is no spin flip. (b) The transition amplitude for Reaction (2) is not a function of the momenta of the particles. (c) The spectator protons have a momentum distribution given by the square of the Fourier transform of the nuclear charge density; the kinetic energy of the spectators is neglected.

The fact that the final state contains four protons—two of each spin—is taken into account by using antisymmetrical wave functions in the fi-

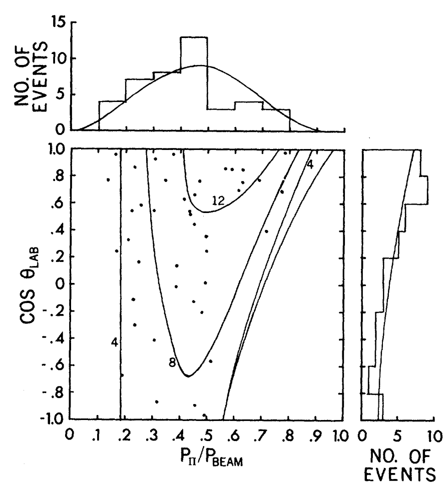

FIG. 1. The ratio of the laboratory momentum of the π^- to the beam momentum plotted against the cosine of the angle between the π^- and the beam. The curves show lines of equal density, on an arbitrary scale, as predicted by the phase-space model. The curve on the extreme right-hand side is the kinematic limit. The curves on the histograms are predictions normalized to the observed number of events.