Elastic Scattering of Hadrons at 50 to 200 GeV*

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(Received 21 August 1975)

The differential cross section for $\pi^\pm$, $K^\pm$, and $p^\pm$ on hydrogen have been measured in the range $0.07 < -t < 1.6$ $(\mathrm{GeV}/c)^2$. The dependence on momentum, momentum, transfer, and particle type are discussed.

In an experiment at Fermi National Accelerator Laboratory we have measured the differential cross section for $\pi^\pm$, $K^\pm$, and $p^\pm$ on hydrogen at momenta of 50, 100, and 200 GeV/c. These measurements extended from $-t = 0.07$ to 1.6 $(\mathrm{GeV}/c)^2$. The data for pp scattering for $-t > 0.8$ $(\mathrm{GeV}/c)^2$ will be reported elsewhere.

The experiment was performed in the $M1$ beam in the meson area. Scintillation-counter hodoscopes were used in the beam to define the particle direction to ± 0.07 mrad and positions to ± 1 mm. The beam momentum spread was $\pm 0.5\%$. Two differential and one threshold Cherenkov counters were used in the beam to identify π, K, and p. The contamination of one particle type by another was negligible except for K^- at 200 GeV/c where a contamination of π's as large as 5% could have been present.

The apparatus downstream from a 30-cm-long hydrogen target detected both the forward-scattered particle and the recoil particle. The forward spectrometer arm measured momentum and angle of the scattered hadron to accuracies which matched those of the beam. Spark chambers spaced at 500 in. before and after bending magnets with an $\int Bdl = 3500$ kG in. were used. The recoil-arm measurement accuracy was dominated by multiple scattering in the hydrogen target and spark chambers at low t and was ± 1 mrad at larger t values.

The spark-chamber trigger in addition to a beam particle required one particle in the forward arm and a second particle in the recoil arm. In the forward arm, a veto counter with a hole through which forward elastic particles could pass was placed 4 m downstream of the hydrogen target to reduce spurious triggers from events with more than one forward particle. Approximately 40% of the triggers were identified as elastic scattering.

The azimuthal acceptance was defined by a spatial cut well inside the active region of the recoil chambers. It was approximately 5% of 2π and varied by less than 20% over the t range covered.

An elastic scattering event was identified by three criteria: coplanarity of the incoming and scattered particles, opening angle of the recoil and forward particles, and missing mass of the recoil as measured by the momentum and angle of the forward particle. When applying all three criteria, the background of inelastic events was found to be small except at the largest t values where background subtractions as large as 20% had to be made.

In addition to the azimuthal acceptance, corrections were made to the data for μ's and electrons in the beam, decay in flight of particles, absorption and scattering in the forward and recoil arms, and spark chamber and hodoscope efficiences. The uncertainties in these corrections lead to an overall $\pm 7\%$ uncertainty in the normalization. To facilitate comparison of the cross sections, an exponential fit e^{bt} was made to the data for $0.1 < -t < 0.4$ $(\mathrm{GeV}/c)^2$ and the resulting curves were used to normalize the data to the optical point. The renormalizations needed were consistent with the ±7% uncertainty quoted above. Such a normalization procedure has the obvious problem of improperly handling curvature in the cross section at small t which is known to be present in pp scattering and is perhaps significant in other reactions as well.

The particle and antiparticle cross sections are shown in Figs. 1(a)–1(c). For the sake of clarity not all the data points are shown on the graphs. A fit has been made to the data of the form $\exp(bt+ct^2)$. The 50- and 100-GeV/c data fit well. However, the 200-GeV/c πp and pp data display too sharp a break near $-t=0.4$ $(\mathrm{GeV}/c)^2$ to fit. An evaluation of the tangential slope at $-t=0.2$ $(\mathrm{GeV}/c)^2$ is given in Table I.

A comparison of the energy dependence for π^-p and pp is shown in Figs. 1(d) and 1(e). In each case the slope in the small $-t$ region becomes steeper with increased momentum. However, beyond $-t=0.4$ $(\mathrm{GeV}/c)^2$ the slope of the differential cross sections changes markedly so that the cross sections are energy independent within the accuracy of the data beyond $-t=0.8$ $(\mathrm{GeV}/c)^2$.

In Fig. 1(f) this is illustrated over a wide energy range by superposing our data with lower-energy data.[1] Only the π^-p and K^+p data are shown for clarity. The π^+p and K^-p exhibit the same behavior. The cross sections are independent of meson type over two decades within the accuracy of the data. Whether this is related to the saturation of the unitarity bound for low angular momentum[2] or to some fundamental hadronic symmetry of the core region would be interesting to know.

Because of the paucity of $\bar{p}$ at high energy we have limited information on the $\bar{p}p$ slope except

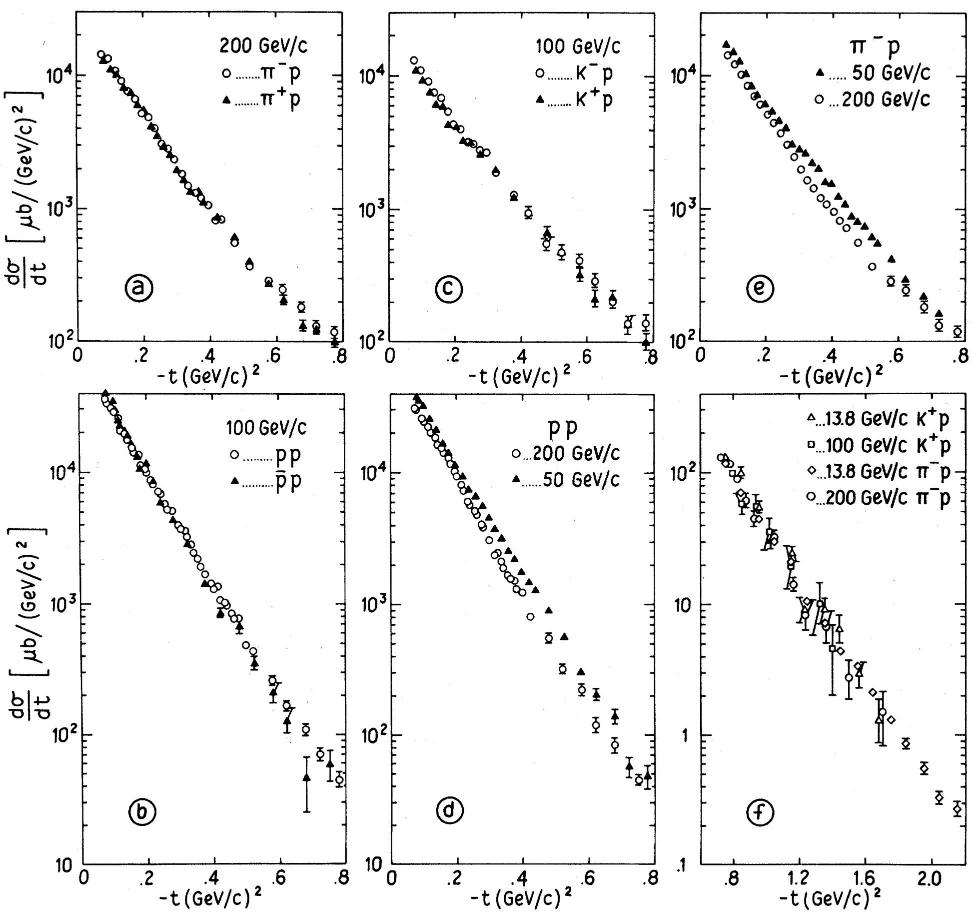

FIG. 1. (a)–(c) Comparison of particle-antiparticle cross sections; only some of the data points are shown for clarity. (d), (e) Energy dependence of cross sections. (f) Comparison of meson cross sections at large $-t$.

TABLE I. Elasticities and fitted slopes.

	50	100	200
		b at $-t=0.2$ (GeV/c)^2	
π^+p	7.74 ± 0.10	8.16 ± 0.11	8.46 ± 0.15
π^-p	7.92 ± 0.10	8.22 ± 0.11	8.46 ± 0.10
K^+p	6.86 ± 0.45	7.38 ± 0.21	7.54 ± 0.40
K^-p	7.26 ± 0.40	7.77 ± 0.20	7.91 ± 0.55
pp	9.61 ± 0.20	10.06 ± 0.12	10.40 ± 0.15
$\bar{p}p$		11.13 ± 0.25	
		σ_{el}/σ_{tot}	
π^+p	0.155 ± 0.012	0.149 ± 0.012	0.146 ± 0.012
π^-p	0.156 ± 0.012	0.149 ± 0.012	0.145 ± 0.012
K^+p	0.139 ± 0.012	0.134 ± 0.012	0.141 ± 0.012
K^-p	0.147 ± 0.012	0.139 ± 0.012	0.142 ± 0.012
pp	0.209 ± 0.015	0.197 ± 0.015	0.192 ± 0.015
$\bar{p}p$	0.207 ± 0.015	0.196 ± 0.015	0.193 ± 0.015

at 100 GeV/c. However, comparison of our 100 GeV/c data with the data of Antipov *et al.*[3] leads one to conclude that the $\bar{p}p$ slope continues to decrease slightly with energy.

The ratio of elastic cross section to total cross sections is shown in Table I. The errors are essentially all due to the absolute-normalization uncertainty. The ratios are remarkably similar for all the mesons but differ markedly from those for pp and $\bar{p}p$ scattering.

We would like to thank the Fermilab Accelerator and Meson Lab staffs. Also we thank R. Thun, J. Koschik, and M. Zumberge who provided valuable assistance during the experiment.

*Work supported by the U. S. Energy Research and Development Administration.

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Chiral-Symmetry Breaking and the Ambiguity of Alternative Soft-Pion Approaches to Threshold $\pi N \to \pi\pi N$

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(Received 25 August 1975)

The alternative soft-pion approaches to threshold $\pi N \to \pi\pi N$ provided by the phenomenological-Lagrangian and current-commutator theories are shown to differ only in their pion-pole contributions. Since the data for the reaction $\pi^-p \to \pi^-\pi^+n$ seem well fitted by the former theory for $\xi=0$, and by the latter for $\xi=-\frac{1}{2}$, where ξ is the chiral-symmetry-breaking parameter introduced by Olsson and Turner, threshold total-cross-section data for this charge state will not be able to determine a unique ξ value.

It is well known[1-3] that chiral symmetry alone is insufficient to fix the π-π scattering lengths a_0 and a_2 without some further assumption as to how the symmetry is broken. Of all those reactions[3] which could serve to discriminate experimentally among the various chiral-symmetry-breaking models[2-4] that have been suggested, threshold $\pi N \to \pi\pi N$ has long been most favored.[3,5-7] In addressing themselves to the subject of this predictive ambiguity and its possible removal through the study of single-pion production, Olsson and Turner,[5] working in the framework of the phenomenological Lagrangian,[8] were able to show that the most general Lagrangian derived in accordance with current algebra and the hypothesis of partially conserved axial-vector current introduces a single symmetry-breaking parameter ξ into the π-π scattering lengths which can then be determined only through additional assumptions. Moreover, ξ is the *only* parameter[5] which enters the threshold one-pion production amplitude with external pions on the mass shell. In their[5] comparison with the best data then available near threshold[9] for the reaction $\pi^-p \to \pi^-\pi^+n$, Olsson and Turner[5] find that the data seem to converge to the predicted threshold curve specified by $\xi=0$ (Weinberg's model[1]) or 4.5, with the latter value apparently ruled out