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MEASUREMENT OF PARTICLE AND ANTIPARTICLE ELASTIC SCATTERING ON PROTONS BETWEEN 6 AND 14 GeV *

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ABSTRACT

Differential cross sections in the t-range between 0.02 and 1.5 GeV^2 have been measured for the elastic scattering of particles and antiparticles on protons at 6.4, 10.4 and 14 GeV for $K^{\pm}p$ and 10.4 GeV for $\pi^{\pm}p$ and $p^{\pm}p$. Large statistics have been achieved and systematic uncertainties have been minimized. The relative systematic uncertainty between particle and antiparticle data is less than 0.5%. Accurate measurements of the position of the first crossover between particle and antiparticle differential cross sections have been performed. As the energy increases from 6.4 to 14 GeV the $K^{\pm}p$ crossover moves to smaller values by 0.010 GeV^2 with a statistical error of 0.006 GeV^2 and a systematic uncertainty of 0.005 GeV^2. The crossover positions at 10.4 GeV for $\pi^{\pm}$, $K^{\pm}$ and $p^{\pm}$ scale approximately with the interaction radii.

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In this letter we present new results on the differential cross sections for elastic scattering on protons of $K^{\pm}$ at 6.4, 10.4 and 14 GeV, and $\pi^{\pm}$ and $p^{\pm}$ at 10.4 GeV. These data were obtained using a wire spark chamber spectrometer system and comprise altogether about 2×10^6 events. A particular emphasis was placed on precise comparisons of the particle and antiparticle scattering and to that effect a relative normalization uncertainty of less than 0.5% has been achieved.

The goals of this experimental program were two-fold: (a) to provide accurate data on the logarithmic slopes of the elastic differential cross sections in an energy region where both the Regge and diffractive contributions are important [1], and (b) to study the C=-1 exchanges and isolate in a clean way the imaginary part of the helicity nonflip amplitude through precise measurement of the difference between particle and antiparticle cross sections. The extraction of the C=-1 amplitudes from these data is presented in the following Letter [2].

The experiment was performed at SLAC in an rf-separated secondary beam with a purity of typically 90%. The schematic layout of the apparatus [3] is shown in fig. 1. The trigger required one beam particle labelled with two Cerenkov counters and only one forward particle scattered at an angle larger than 7 mr. Multiparticle events were suppressed by veto counters placed against the inside surfaces of the magnet gap. Beam particle directions were measured with counter hodoscopes and proportional chambers. The forward spectrometer used proportional chambers, magnetostrictive-readout wire spark chambers, picket-fence hodoscopes and a bending magnet with 17.5 kG-m. A large aperture Cerenkov counter using Freon 12 was used in anticoincidence for the $K^{\pm}$ measurements to provide a substantial suppression of the triggers from $K^{\pm} \rightarrow \mu^{\pm}\nu$, $\pi^{\pm}\pi^{0}$ decays. A steel-scintillator telescope was used for further μ

identification behind the spectrometer. K decays collected below μ, π Cerenkov threshold were very useful for calibration and monitoring purposes. Spark chambers placed parallel to the 1 meter-long liquid hydrogen target detected recoil protons for $|t| > 0.07$ GeV^2 and permitted the reconstruction of three-constraint elastic events which were very important in providing a direct measurement of the shape of the missing mass resolution function and a check of the inelastic background subtraction.

The angular resolution was 1 mr and the missing mass resolution had a standard deviation of respectively 50, 105 and 130 MeV at beam momentum of 6.4, 10.4 and 14 GeV.

Elastic events were identified using the missing mass (M) distributions. Detailed fits of the M^2 spectra, as a function of momentum transfer t, were performed using the resolution function as determined from constrained elastic events (with recoil proton). The inelastic background, within the M^2 cuts, was typically 1 to 2% and could be reliably subtracted out. The final elastic scattering sample is shown in Table 1 for all the reactions and energies measured in this experiment.

The acceptance of the spectrometer was determined largely by the magnet aperture. Full azimuthal coverage was provided for momentum transfer less than 0.13, 0.25, 0.45 GeV^2 at 6.4, 10.4 and 14 GeV respectively. Since the beam passed through the spectrometer we desensitized the spark chambers in small areas around the beam and left holes of similar size in the trigger hodoscopes. The effect of the deadened regions on the small t acceptance was accounted for in the Monte Carlo acceptance program. The Monte Carlo program made use of a continuously measured sample of actual beam tracks as input and allowed for the possibility of spatially-dependent apparatus efficiency factors.

The spectrometer efficiencies were measured directly from the data using the constrained elastic events which permitted a determination of the sum of hardware and software losses in a very reliable fashion. The efficiency calculations were performed for each hour-long run making it possible to monitor the stability of the data in a continuous way. Corrections for decays in flight and nuclear absorption were also included in the Monte Carlo acceptance program.

The differential cross sections have been corrected for the effects of double scattering and Coulomb interference. The correction for double nuclear scattering is straightforward and is only significant for the $\bar{p}p$ and pp data. As for the Coulomb interference our data extend down to $t = -.005\ \mathrm{GeV}^2$, thus providing a measurement [4] of the ratio, α, between real and imaginary parts of the nuclear scattering amplitude at $t=0$. We used these real part values at 10.4 and 14 GeV for $K^{\pm}p$ to correct the measured data for $|t| > 0.02\ \mathrm{GeV}^2$ while for the other cases we used the dispersion relation values [5].

Great care has been taken in this experiment to minimize the systematic uncertainties between the particle and antiparticle data. At each energy the data-taking was split into several cycles with alternating beam polarities so that long-term drifts in the apparatus could be monitored and cancelled. Beam fluxes for both polarities were kept as close as possible to avoid large rate corrections and the instantaneous rates and accidentals were carefully monitored and recorded. This information was used to compute the small rate corrections. The data have been corrected for the following effects and the uncertainties in these corrections have been carefully studied: inelastic background subtraction, monitoring of hydrogen density, monitoring of all efficiencies including reconstruction, and nuclear absorption in the target and the spectrometer. The latter effect can be straightforwardly calculated while we have the necessary data to evaluate the other effects. Adding all these uncorrelated uncertainties in quadrature we evaluate the relative particle-antiparticle normalization uncertainty to be less than 0.5%.

The absolute normalization, on the other hand, is known only to an accuracy of about 5%. Since our data extend into the Coulomb region and since precise total cross sections measurements [6] exist in our energy range we have chosen to normalize our differential cross sections for each pair of particles jointly to the corresponding optical points corrected with our own real part measurements. Using this procedure we can quote an absolute normalization uncertainty of typically 2%, limited by the accuracy on total cross sections and real parts measurements. Since we have normalized our cross sections in pairs we have retained their intrinsic 0.5% relative uncertainty.

The measured differential cross sections are shown in figs. 2 and 3. They display the qualitative features of lower energies but with a smaller difference between particle and antiparticle cross sections. Each pair of cross sections exhibit two crossovers: the first crossover near $t=-0.2\ \mathrm{GeV}^2$ is very clear and accurately measured. The second crossover is seen and moves between -1.0 and $-1.3\ \mathrm{GeV}^2$ for the different reactions studied. The large statistics and the good systematic understanding of the data allow an accurate study of the logarithmic slopes to be performed [1].

From the data of this experiment we can extract the precise location of the crossover point between particle X^+ and antiparticle X^- cross sections. The relationship between this "raw" crossover point and the zero structure of the underlying amplitudes is discussed in detail in the following Letter [2]. To measure the crossover point t_c, we fit the difference of the $X^{\pm}$ differential cross sections over a small t interval around $t=-0.2\ \mathrm{GeV}^2$. By restricting the fit to small intervals within the range -0.1 to -0.35 GeV^2, we achieved stable results with the parametrization

$$\frac{d\sigma}{dt}(X^-p) - \frac{d\sigma}{dt}(X^+p) = A\,e^{Bt}\sinh\left[C(t-t_c)\right]$$

corresponding to exponential behavior for the cross sections in the fit interval. We have separated the uncertainty in the determination of t_c into a statistical error and a systematic error dominated by the relative normalization uncertainty. For a relative error $\frac{d\sigma}{\sigma}$ between $\frac{d\sigma}{dt}(X^{\pm}p)$ we expect a systematic shift

$$\delta t_c = \frac{d\sigma}{\sigma(B_- - B_+)}$$

where $B_{\pm}$ are the logarithmic slopes for $\frac{d\sigma}{dt}(X^{\pm}p)$ at the crossover point. The results of our determinations are shown in table 2.

There is a slight energy dependence of the "raw" crossover point in $K^{\pm}p$ scattering: as the energy increases from 6 to 14 GeV, the crossover appears to move to smaller t-values. The variation amounts to 0.010 GeV^2, where the statistical error is 0.006 GeV^2 and the systematic uncertainty is 0.005 GeV^2. These results are of course consistent with no energy dependence but imply that a trend to larger t values is unlikely. This behavior appears to be in slight contradiction to the trend observed at lower energies [7]. However we believe there is probably no disagreement since dynamical effects, which are important at low energies and which cause shifts in the crossover position, have to be taken into account in any discussion of the crossover phenomenon [2].

In general the $\pi^{\pm}p$ crossover is difficult to measure because of the small slope difference between π^-p and π^+p differential cross sections. In this experiment the $\pi^{\pm}p$ crossover point is accurately measured for the first time and is seen to be close to the $K^{\pm}p$ value. On the other hand the $p^{\pm}p$ crossover occurs at a substantially smaller t-value, reflecting the larger interaction radius.

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References

[1] R. K. Carnegie et al., to be published, SLAC-PUB-1609 (1975).

[2] R. K. Carnegie et al., to be published, SLAC-PUB-1608 (1975).

[3] G. W. Brandenburg et al., to be submitted to Nucl. Instr. and Methods.

[4] R. K. Carnegie et al., to be published, SLAC-PUB-1606 (1975).

[5] R. E. Hendrick and B. Lautrup, Rockefeller University preprint, COO-2232B-62

[6] W. Galbraith et al., Phys. Rev. 138B, 913 (1965);
K. J. Foley et al., Phys. Rev. Letters 19, 330 (1967).

[7] I. Ambats et al., Phys. Rev. 9D, 1179 (1974).

TABLE 1

Summary of the data taken in this experiment.

Reaction	Momentum (GeV)	t range (GeV^2)	Number of elastic events/beam polarity
$K^{\pm}p$	6.4	.03 - .4	55,000
$K^{\pm}p$	10.4	.02 - 1.5	150,000
$K^{\pm}p$	14	.02 - 1.5	250,000
$\pi^{\pm}p$	10.4	.02 - 1.0	300,000
$p^{\pm}p$	10.4	.02 - 1.5	185,000

TABLE 2

The measured crossover positions as obtained from a fit to the difference between particle and antiparticle differential cross sections.

Reaction	Momentum (GeV)	t range used in the fit	t_c	Δt_c statistic	Δt_c systematic
$K^{\pm}p$	6.4	.1 - .35	.219	.005	.002
$K^{\pm}p$	10.4	.1 - .34	.211	.004	.0025
$K^{\pm}p$	14	.1 - .34	.209	.004	.003
$\pi^{\pm}p$	10.4	.04 - .40	.231	.007	.005
$p^{\pm}p$	10.4	.08 - .21	.146	.002	.0015

Figure Captions

1. Layout of the experimental setup. Scintillator hodoscopes and proportional chambers are labelled H_i and PC_i, respectively.
2. The differential cross sections for $K^{\pm}p \rightarrow K^{\pm}p$ at 6.4, 10.4 and 14 GeV.
3. The differential cross sections for $\pi^{\pm}p \rightarrow \pi^{\pm}p$ and $p^{\pm}p \rightarrow p^{\pm}p$ at 10.4 GeV.

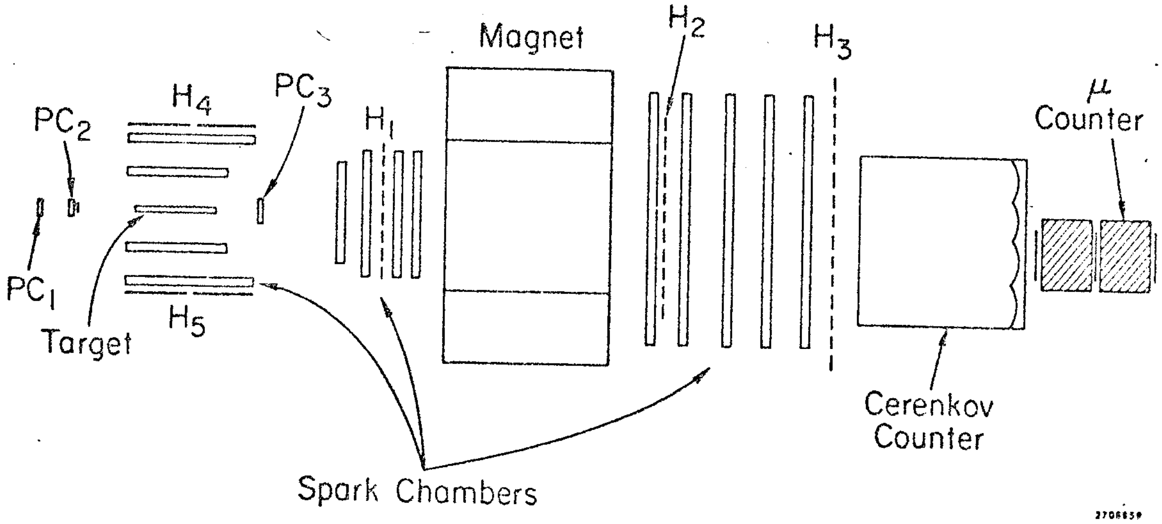

Magnet
H2
H3
H4
PC3
PC2
H1
μ
Counter
PC1
Target
H5
Cerenkov
Counter
Spark Chambers

Fig. 1

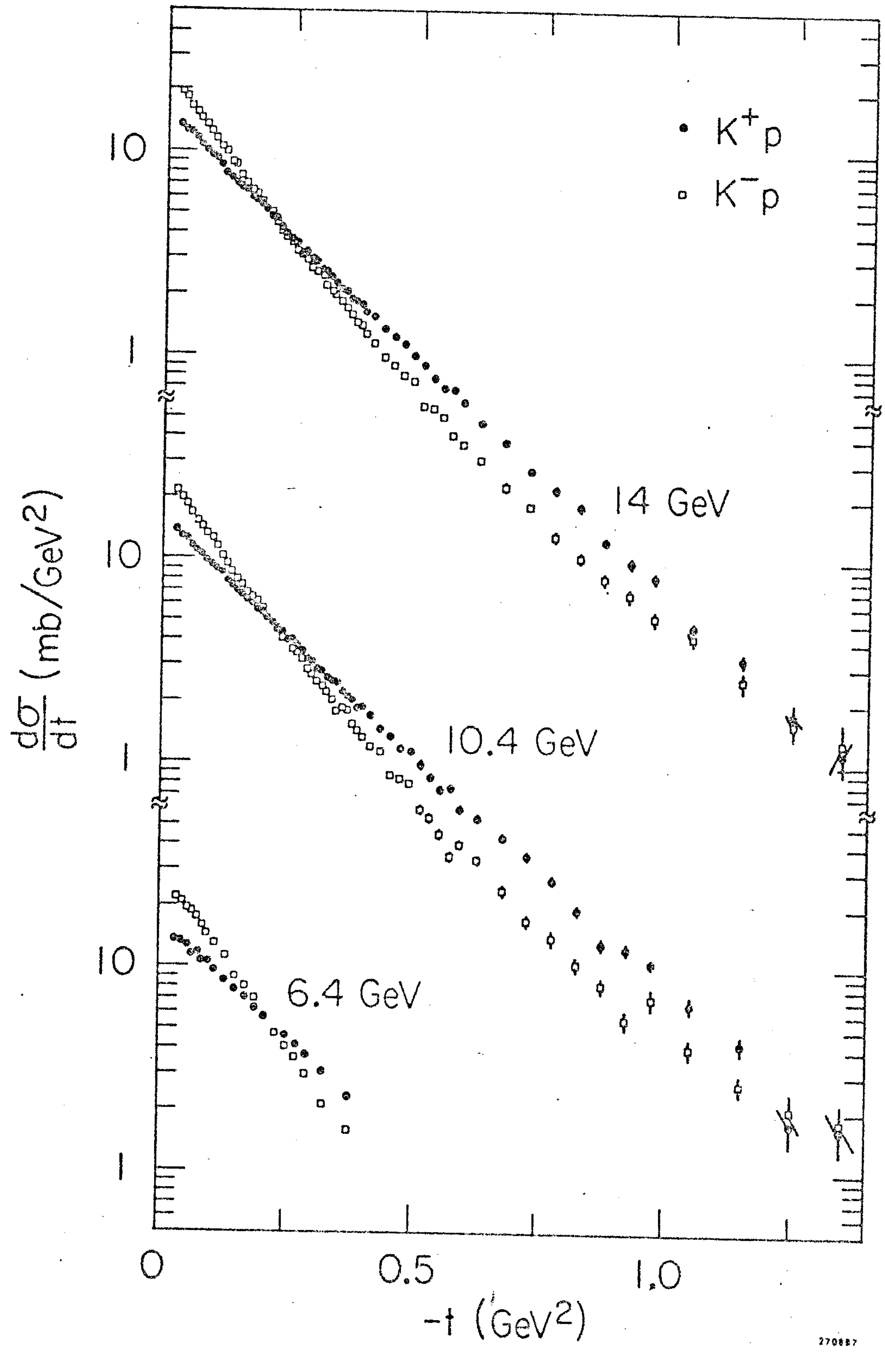
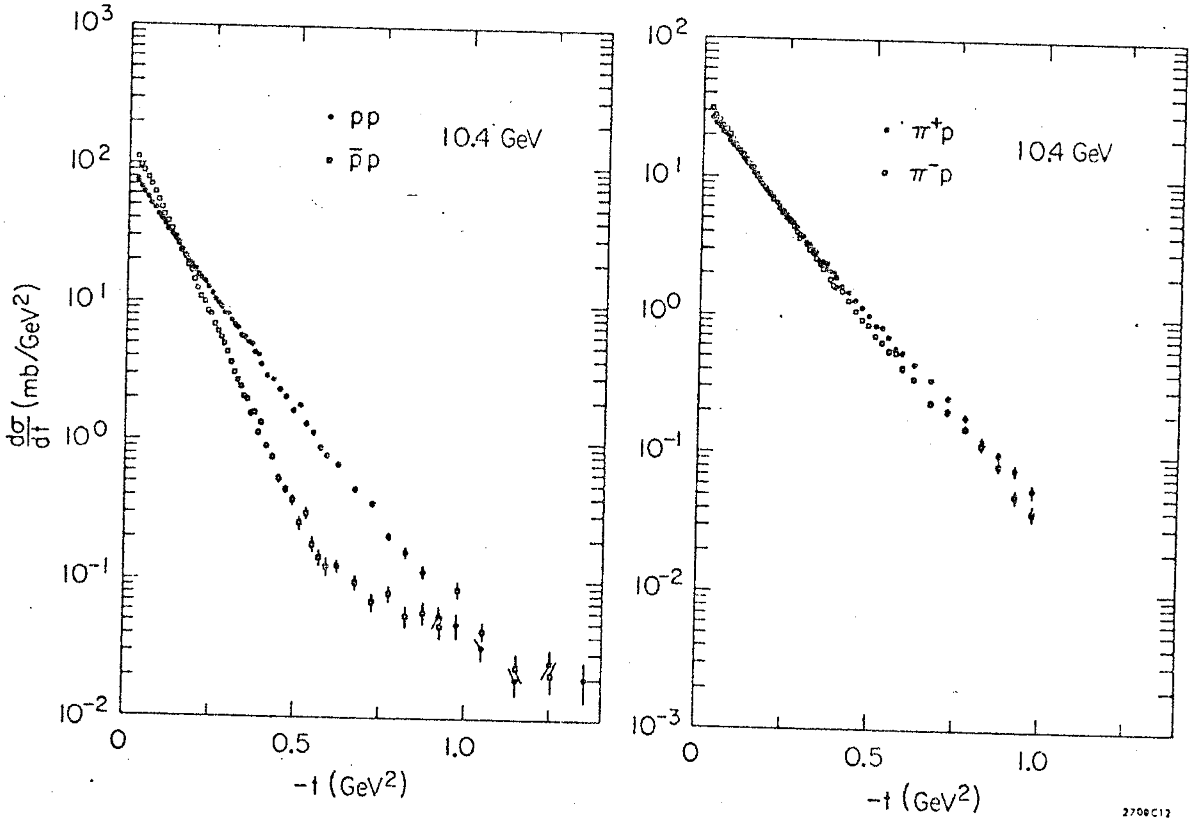

K+p
K−p
14 GeV
10.4 GeV
6.4 GeV
10
1
10
1
10
1
dσ/dt (mb/GeV2)
0
0.5
1.0
−t (GeV2)
270887

Fig. 2



$\frac{d\sigma}{dt}$ (mb/GeV^2)
• pp
∘ $\bar{p}$p
10.4 GeV
−t (GeV^2)
• π^+p
∘ π^-p
10.4 GeV
−t (GeV^2)

Fig. 3