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THE STRUCTURE OF THE FORWARD ELASTIC CROSS SECTION IN (10-14) GeV RANGE*

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ABSTRACT

The logarithmic slope of the differential cross section for $K^{\pm}p$ elastic scattering at 10 and 14 GeV, and for $\pi^{\pm}p$ and $p^{\pm}p$ at 10 GeV has been measured. Rich structure is observed in the forward slope for all processes, which is well accounted for by the properties of a peripheral exchange amplitude for the nonexotic reactions, and by a peripheral component of the diffractive amplitude as clearly seen in the exotic processes, $K^{+}p$ and pp.

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In this letter we report on structure observed in the forward elastic scattering cross sections in the (10-14) GeV energy range, through a detailed analysis of the logarithmic slope. The data come from an experiment using a wire spark chamber spectrometer at SLAC to study with high statistics the systematics of elastic scattering of particles and their antiparticles on protons. The properties of the spectrometer [1], and a more detailed discussion of the experiment, are reported elsewhere [2].

The data on forward differential cross sections for elastic scattering of $K^{\pm}p$ at 6.4, 10.4, and 14 GeV, and $\pi^{\pm}p$ and $p^{\pm}p$ at 10.4 GeV have already been presented [2]. These measurements were based on approximately 2×10^5 elastic scattering events for each particle and energy. In this letter we present new data on the differential cross section for elastic K^+p scattering at 14 GeV in which the statistics were increased to $\sim 6 \times 10^5$ events. This additional running was performed to search for possible small t structure in K^+p scattering comparable to that observed in elastic pp scattering at the CERN ISR [3].

The differential cross sections for K^+p scattering at 10 and 14 GeV are shown in the upper part of Fig. 1. In order to investigate possible structure we divide the data by an exponential function, e^{Bt}, which is the best fit to the cross section in the small t interval between 0.02 and 0.20 GeV^2. The resulting distributions are presented in the bottom part of Fig. 1, where the cross sections are clearly shown to deviate from a single exponential form. There is no clear evidence for a sharp break in the distributions, but rather the data implies a continuous curvature of the cross section. The deviation from a single exponential is not very pronounced at 10 GeV, but becomes rather striking by 14 GeV. In contrast, the lower energy K^+p differential cross sections are well explained by a single exponential [4]. Therefore, we see evidence for a curvature effect at small t values, growing with energy above 10 GeV. Such a curvature is unlikely to be generated by peripheral nondiffractive exchanges since the K^+p system is exotic and receives little contribution from these exchanges, and furthermore the energy dependence would be the opposite of that exhibited by the data. It is natural to ascribe this behavior to diffraction scattering, and one would then expect the phenomenon to become more pronounced at higher energies. It is interesting to remark that the energy region around 10 GeV corresponds to the onset of the rising K^+p total cross section [5] and that therefore a correlation might exist between these two phenomena. This point is further strengthened by the observation of similar phenomena in the rise of the pp total cross section [6] and the upward curvature in the forward pp elastic differential cross section [3].

To investigate the structure of the forward elastic cross sections in more detail, we examine the cross sections for $\pi^{\pm}p$, $K^{\pm}p$, and $p^{\pm}p$ differentially over the measured t-range, and fit locally for the logarithmic slope,

$$B(t) = \frac{d}{dt}\left(\ln \frac{d\sigma}{dt}\right)$$

These fits were performed over small t intervals - typically (0.1) GeV^2 in the forward direction, growing to (0.3) GeV^2 for t values near 1.0 GeV^2 - with around 50-80,000 events per fit. In addition to the statistical error, there are systematic effects due to spatial variation of the detection efficiencies. These systematic effects contribute an uncertainty of ~ 0.1 GeV^{-2} to the determination of B(t) in this experiment. The results of the fits are shown in Fig. 2, where rich and interesting structure is observed for all the scattering processes. We are able to present the data in this form not only because of the large statistical power of these measurements but also due to the good understanding that has been achieved on the details of the local and global t acceptance of the spectrometer [7].

The π^+p, π^-p, and K^-p cross sections all display similar behavior as a function of t; they have a steep slope in the very forward direction, which smoothly decreases as t increases. By contrast, the $\bar{p}p$ slope <u>increases</u> as t changes from zero to around 0.3 GeV^2, drops sharply around $t \sim 0.5$ GeV^2, and then remains constant as t increases further. These scattering processes are all nonexotic in the s-channel, and have corresponding strong imaginary (Regge) exchange amplitudes. Such scattering processes have been explained in terms of two main amplitudes [8] - the diffractive contribution, which is central and represents the absorption of the incoming particle via all the open inelastic channels, and the exchange contribution, which is strongly absorbed for small impact parameters and peaks at the edge of the interaction volume. This picture can qualitatively account for the structures observed in Fig. 2, for the nonexotic channels.

The K^+p and pp cross sections both exhibit structure in the very forward direction. The K^+p data, as discussed above, indicate a steepening of the cross section for small t, and the effect seems to grow with increasing energy. For pp, a sharp change of slope is observed for $t < 0.2$ GeV^2 with the slope increasing by $\sim 1\frac{1}{2}$ GeV^{-2} from its value at larger t. This is very similar to the behavior observed in pp scattering at the ISR [3], and is the first time that the phenomenon has been clearly observed at lower energies [9]. The K^+p and pp reactions are exotic in the s-channel, and are expected [8] to be accounted for by just one contribution - the central gaussian diffractive amplitude, leading to purely exponential behavior in t. The data for these reactions clearly do <u>not</u> support such a simple description of the exotic elastic scattering. From the observation of the small t pp elastic scattering structure, the energy dependence of that structure, and from the results of the impact parameter analysis of high energy diffractive scattering data, one is led naturally to the idea of two components for the diffractive amplitude [10]. One of the components is the classic central term which is essentially constant with energy, and the second term is a peripheral contribution in impact parameter space and grows with energy, accounting for the rapid shrinking of the small t elastic scattering cross section. Our data on K^+p and pp scattering at 10 and 14 GeV imply that such a second term is required to explain the diffractive scattering even at low energies.

Below we adopt such a picture of diffraction and attempt to describe the (10-14) GeV elastic scattering cross sections measured at SLAC [2], using

$$\frac{d\sigma}{dt} \propto \left| \mathscr{P}_1 + \mathscr{P}_2 + \mathscr{R} \right|^2 ,$$

where we have neglected the effect of small real parts.

$\mathscr{P}_1$ and $\mathscr{P}_2$ are the two diffractive components discussed above, and $\mathscr{R}$ represents the nondiffractive (Regge) exchange contribution. The t dependence of the separate contributions is defined by

$$\mathscr{P}_1 = A_P e^{B_P t}$$

$$\mathscr{P}_2 = A'_P e^{B'_P t} J_0(R_P\sqrt{-t})$$

$$\mathscr{R} = A_R e^{B_R t} J_0(R_R\sqrt{-t})$$

All of the parameters in the above amplitudes are determined from our knowledge of the total cross sections and exchange amplitudes, except for B'_P, which was set by inspection of the data. The strength of each contribution, A_P, A'_P, A_R, is determined for the $\pi^\pm p$, $K^\pm p$, and $p^\pm p$ scattering by the three different energy dependences observed in the total cross sections [11] - constant, logarithmic, and $s^{-\frac{1}{2}}$; the parameters defining the impact profile of the exchange contribution, B_R and R_R, are obtained from our study of the $C = -1$ exchange amplitudes from particle and antiparticle elastic scattering [12], B_P is set 'geometrically' from A_P (i.e., $B_P \propto A_P$) and R_P was set equal to 1 fermi.

The t dependence of the slope of the forward scattering cross section predicted by this model is shown in Fig. 3, together with the measured slopes discussed above. The agreement is good.

This simple model appears to account for all the features of the logarithmic slopes, B(t), for the six scattering processes measured. It demonstrates clearly that the diffractive amplitude is not simple and that a second component is necessary, even at energies as low as 10 GeV - the data on the K^+p and pp reactions require such a term. Extrapolating the observed energy dependence of such a diffractive amplitude provides a good description of the curvature measured in high energy K^+p and pp scattering [13]. The strong structure observed in the nonexotic scattering - where the slope grows steeper as t increases for processes with large exchange amplitudes, like $\bar{p}p$ - is well accounted for, both in magnitude and in slope, by the peripheral (Regge) exchange contribution.

Finally it is interesting to note the observation of forward structure in both the K^+p and pp scattering, and the possible correlation with the measured rise in the total cross section. The precocious K^+p system exhibits both phenomena in the 10 GeV region, while for pp scattering the structure in the elastic cross section is observed at the same low energy but the total cross section rise is masked by the power law exchange contribution until higher energies.

References and Footnotes

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Figure Captions

1. The differential cross section for K^+p elastic scattering at 10.4 and 14 GeV. Below the cross sections are divided by the function Ae^{Bt}, where A and B were evaluated in a best fit for $0.02 < t < 0.2$ GeV^2. ($B = 5.94 \pm .04$ at 14 GeV and $5.49 \pm .06$ at 10 GeV.)

2. The logarithmic slopes as a function of momentum transfer, t, for $\pi^{\pm}p$, $K^{\pm}p$, and $p^{\pm}p$ elastic scattering.

3. The momentum transfer dependence of the slope of the forward scattering cross section, as predicted from a simple model incorporating a two-component diffractive amplitude and a peripheral exchange amplitude. (For details see text.) The t range of the $\pi^{\pm}p$ curve extends only to $t \sim 0.75$ GeV^2 as limited by the data, while that for $p^{\pm}p$ was limited to the t interval in which the exchange amplitude is well understood (see Ref. 12).

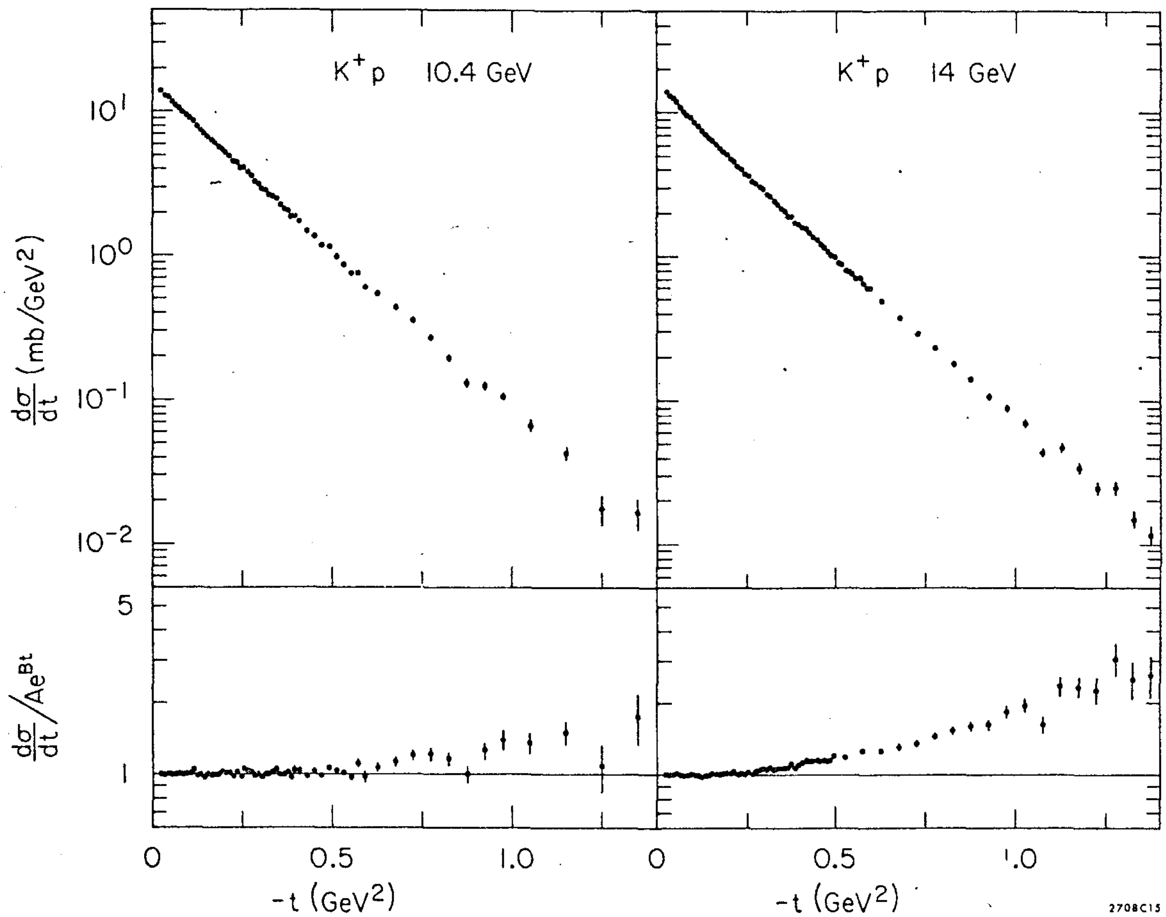
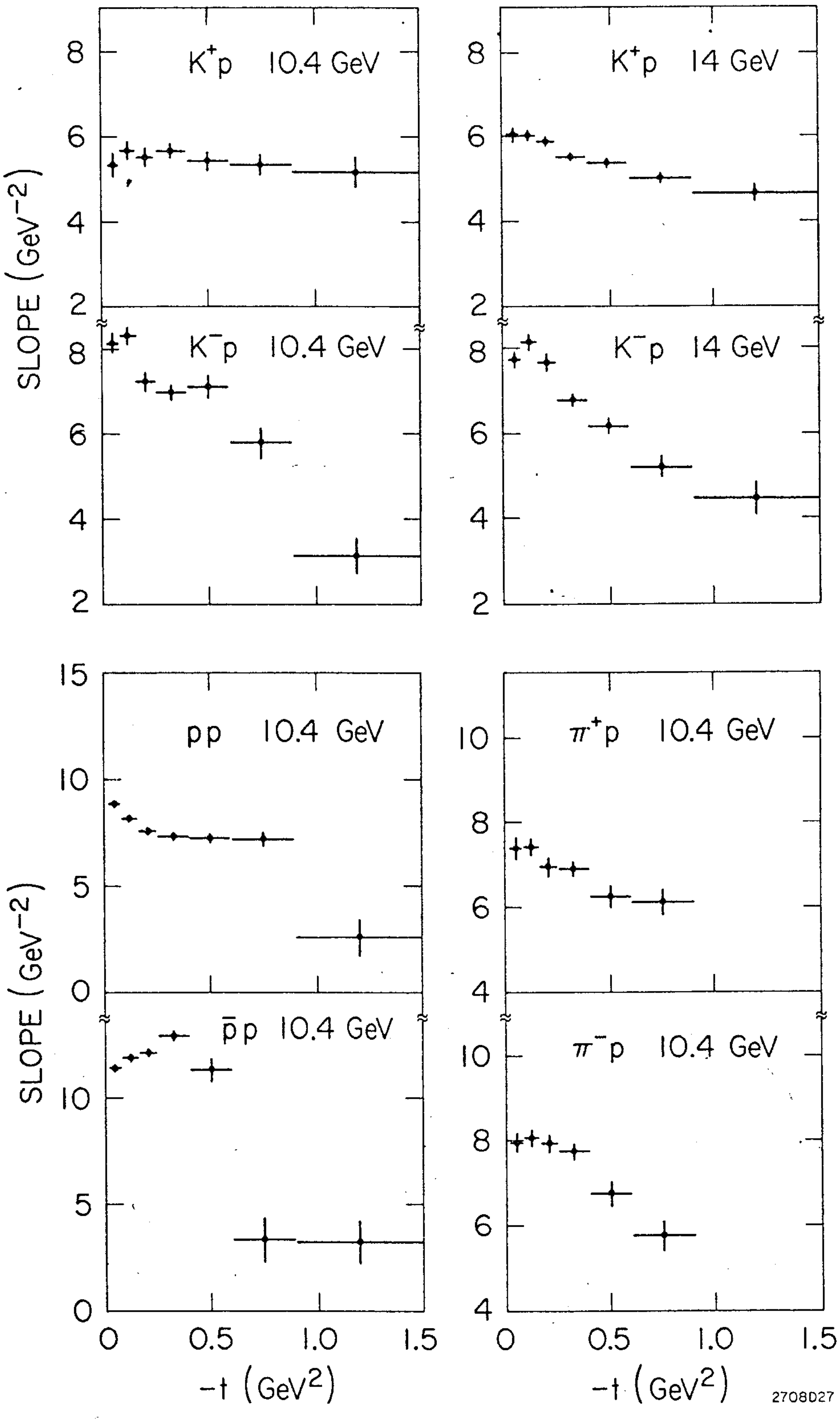
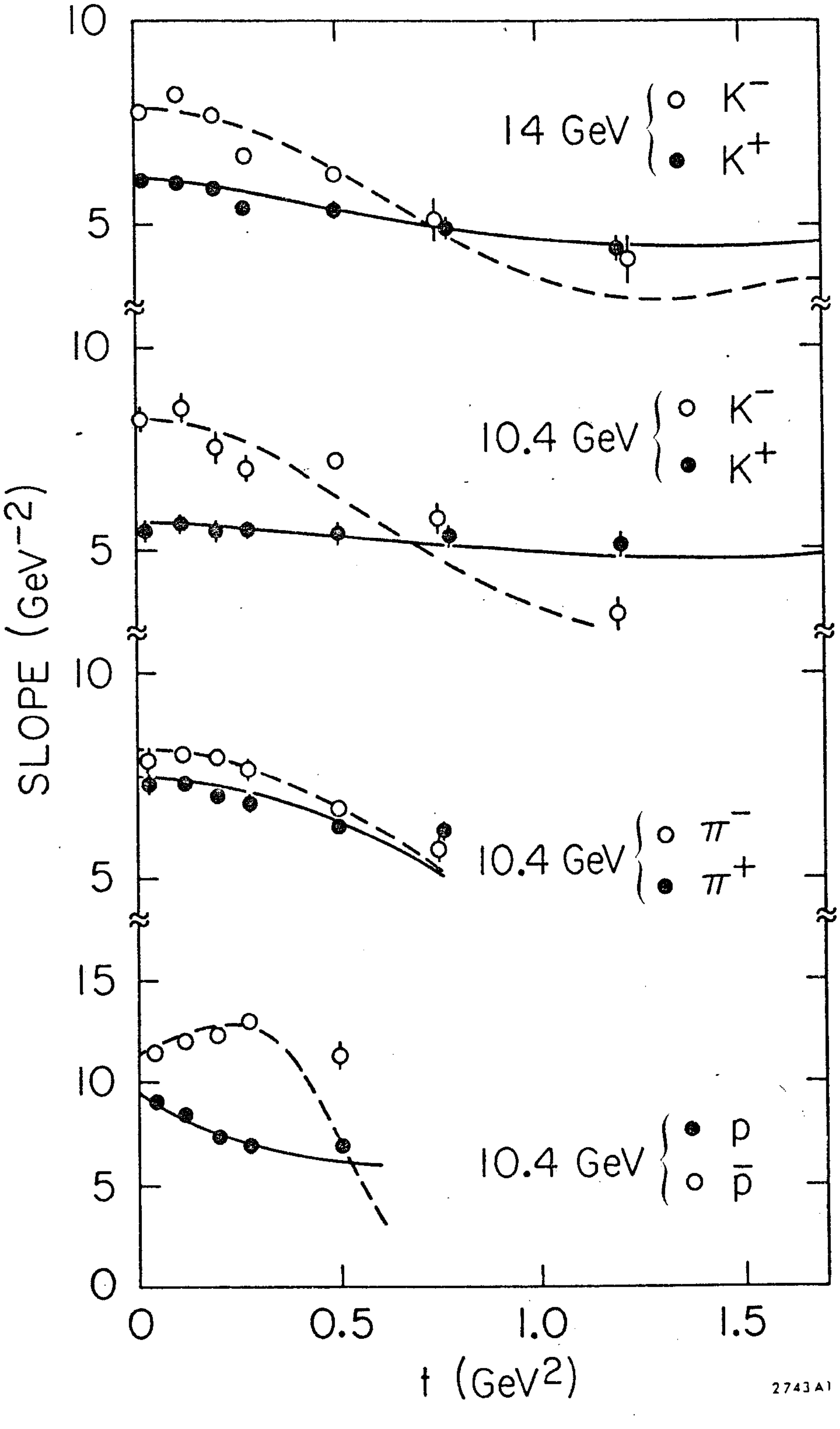

K+p 10.4 GeV
K+p 14 GeV
$\frac{d\sigma}{dt}$ (mb/GeV^2)
$\frac{d\sigma}{dt}/Ae^{Bt}$
-t (GeV^2)
-t (GeV^2)
2708C15

Fig. 1



K⁺p 10.4 GeV
K⁺p 14 GeV
K⁻p 10.4 GeV
K⁻p 14 GeV
pp 10.4 GeV
π⁺p 10.4 GeV
p̄p 10.4 GeV
π⁻p 10.4 GeV
SLOPE (GeV⁻²)
−t (GeV²)
2708D27

Fig. 2



SLOPE (GeV^{-2})
10
5
10
5
10
5
15
10
5
0
14 GeV
○ K$^-$
● K$^+$
10.4 GeV
○ K$^-$
● K$^+$
10.4 GeV
○ π^-
● π^+
10.4 GeV
● p
○ $\bar{p}$
0
0.5
1.0
1.5
t (GeV^2)
2743A1

Fig. 3