SLAC-PUB-1027
(TH)
March 1972

POMERON AND f EXCHANGE AMPLITUDES IN ELASTIC $\pi^{\pm}p$ SCATTERING*

Michel Davier

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

The dual absorptive model of Harari is shown to explain consistently the s ant t dependence of the sum of π^+p and π^-p elastic differential cross sections at high energy. The Pomeron amplitude shrinks at a rate similar to that of K^+p elastic scattering while the f amplitude is shown to be dominated by peripheral partial waves at a radius $\sim$ 1 fermi. Finally, the shrinkage and s dependence of the f amplitude follow a canonical Regge behavior.

(Submitted to Phys. Letters)

*Work supported by the U. S. Atomic Energy Commission.

It has always been a difficult problem to separate Pomeron (P) and f exchange amplitudes in $\pi^{\pm}p$ and $K^{\pm}p$ elastic scattering amplitudes. Owing to the fact that they have the same quantum numbers, they always appear together and their separation cannot be made without the help of a specific model. For example, duality tells us that f exchange is dual to s-channel resonances[1] while Pomeron exchange is dual to s-channel background in the FESR sense,[2] although it is perhaps most simply described at all energies in the s channel. FESR analyses[3] have already yielded interesting results on the Regge f amplitude.

In this letter we determine the Pomeron and f amplitudes from high energy $\pi^{\pm}p$ elastic scattering data using the dual absorptive model of Harari.[4] Such a model explains qualitatively all the features of πN and KN forward elastic scattering and has been successfully used to extract the imaginary part of the non-Pomeron helicity non-flip amplitude in $K^{\pm}p$ elastic scattering at 5 GeV/c.[5] The main result there was the strongly peripheral behavior of this amplitude which was parameterized by

$$\mathrm{Im}\, R_{++}(t) = A\ e^{Bt}\ J_0(R\sqrt{-t}) \tag{1}$$

with $R \simeq 1$ fermi and $B = 1.3\ \mathrm{GeV}^{-2}$. On the other hand the Pomeron amplitude as obtained from the exotic $K^{+}p$ elastic scattering had contributions from all partial waves within the interaction radius and could be represented with a simple exponential form

$$P_{++}(t) = i\,A_P\ e^{B_P t} \tag{2}$$

for $-t < 1\ \mathrm{GeV}^2$.

In the following we apply the model to πp elastic scattering, more precisely to the sum of $\pi^{+}p$ and $\pi^{-}p$ differential cross sections.† In terms of t-channel exchanges we have

$$\frac{d\sigma}{dt}(\pi p) \equiv \frac{1}{2}\left[\frac{d\sigma}{dt}(\pi^+ p) + \frac{d\sigma}{dt}(\pi^- p)\right] = \sum_{\substack{\lambda\mu \\ \text{helicities}}} \left\{|P_{\lambda\mu}+f_{\lambda\mu}|^2 + |\rho_{\lambda\mu}|^2\right\}$$

where f and ρ denote nondiffractive I=0 and 1 exchange amplitudes. At momenta above 2.5 GeV/c one can safely neglect the non-Pomeron squared terms and assuming the Pomeron amplitude to be predominantly imaginary in the forward direction and s-channel helicity conserving, we get

$$\frac{d\sigma}{dt}(\pi p) \simeq P^2 + 2P \, \mathrm{Im}\, f_{++} \tag{3}$$

where the P and f amplitudes are assumed to have the forms (2) and (1), respectively, i.e.,

$$\mathrm{Im}\, f_{++}(t) = A_f \, e^{B_f t} \, J_0(R_f \sqrt{-t}) \tag{1'}$$

We have used published differential cross sections data on $\pi^{\pm}p$ above an incident laboratory momentum of 2.5 GeV/c. Only π^+ and π^- data at the same or very nearby energies have been used.[6] The t range varied from 0.04 - 0.1 to 0.9 GeV^2.

Clearly it is impossible at any given energy to fit $\frac{d\sigma}{dt}$ alone and deduce A_P, B_P, A_f, B_f, and R_f. However A_P and A_f are related to the total cross sections through:

$$\sigma_T(\pi p) \equiv \frac{1}{2}\left[\sigma_T(\pi^+ p) + \sigma_T(\pi^- p)\right] = 4\sqrt{\pi}\,(A_P + A_f)$$

As a first-order approximation, we then assume the forward Pomeron amplitude A_P to be constant between 2.5 and 17 GeV/c — the highest momentum where both $\frac{d\sigma}{dt}(\pi^{\pm}p)$ have been measured. Although this is probably incorrect in the light of the rising K^+p total cross section,[7] it certainly appears to be a reasonable assumption when compared to the decreasing A_f amplitude.

A fit to the total cross section data[6] gives

$$A_P = 4.82 \pm 0.14$$

$$A_f = (5.41 \pm 0.46)\ s^{-(0.56\pm0.08)}$$

in $(\mathrm{mb})^{\frac{1}{2}}/\mathrm{GeV}$ and s in GeV^2.

We then proceed to fit the differential cross section data where at every energy, B_P, B_f, and R_f are left as free parameters. We also fit for the absolute normalization of the cross section since there could be systematic deviations between different experiments.[††] We examine in turn our results for the Pomeron and the f amplitudes.

The Pomeron Amplitude

The slope B_P of the Pomeron amplitude (see Fig. 1) shows a large shrinkage effect. This is expected since we know that in exotic channels like K^+p and pp, where the imaginary part of the forward amplitude should be pure Pomeron exchange, the elastic differential cross section shrinks. What is interesting, however, is that the rate of shrinkage is quite similar for πp and K^+p showing that the Pomeron amplitudes are very much alike in the two cases. The s dependence of the pp slope is also quite comparable but the interaction radius is larger.

The shrinkage character of the Pomeron in πp elastic scattering is shadowed by the behavior of the f amplitude: indeed the s dependence of the slope of the differential cross section is very flat. The fact that we could get a shrinking Pomeron amplitude is a consequence of the peripherality of the f exchange.[†††]

The f Amplitude

The present fit makes sense only if the radius R_f turns out to be in the neighborhood of 1 fermi $\simeq$ 5 GeV^{-1}. Figure 2 shows that it is indeed the case, thus providing strong support for the model. There is some evidence for a slight energy dependence of the radius although we believe this effect is quite sensitive to details — like the exact s-dependence of the forward Pomeron amplitude. Indeed, the fact that $\sqrt{B_P}$ (which is proportional to the diffraction radius) increases with energy, intuitively calls for a similar dependence for R_f.

We now turn to the slope of the f amplitude. It is shown in Fig. 3 to be increasing roughly linearly with lns. This approximate Regge behavior is made even more suggestive by the value of ~ 1.1 GeV^{-2} for the coefficient of lns and the intercept of 0.56 at t=0. Given the radius, the slope B_f defines the width of the peripheral impact parameter distribution.[5] We note that the values for R and B at $P_{lab} \sim 5$ GeV/c are almost the same for f exchange in $\pi^{\pm}p$ scattering (this analysis) and $\omega+\rho$ exchange in $K^{\pm}p$ scattering[5] indicating closely similar impact parameter distributions.

The emerging character of an exchange amplitude with no helicity-flip is therefore definitely peripheral; nevertheless the Regge behavior is still present and $J_0(R\sqrt{-t})$ seems to merely play the role of a residue function; however this would imply a constant radius. It is therefore crucial to determine experimentally the energy dependence of R as measured more directly in elastic cross-overs for odd-crossing amplitudes.

Measurements of elastic $\pi^- p$ differential cross sections have recently been performed at 25 and 40 GeV/c.[8] It is interesting to extrapolate our numbers to these energies and see if we can explain the measured slopes. Neglecting the small ρ-exchange amplitude, we obtain the following values for the slopes: $(7.9 \pm 0.2)\ \mathrm{GeV}^{-2}$ at 25 GeV/c and $(7.8 \pm 0.3)\ \mathrm{GeV}^{-2}$ at 40 GeV/c in excellent agreement with the measured numbers (8.17 ± 0.14) and (7.82 ± 0.12), respectively. This is important since it confirms the fact that the s dependence of the peripheral f amplitude almost exactly cancels the shrinkage of the Pomeron amplitude so as to produce a nearly constant overall slope.

It is interesting to note that if the energy dependence of R_f and B_f continue to be different at higher energies, then peripherality will eventually be lost. However using the present trend (R_f = constant, $B_f \sim \ln s$) this will not happen before $P_{lab} \gtrsim 10^4$ GeV/c, so that no conclusion can reasonably be drawn at this point.

We finally state our findings:

(a) the dual absorptive model of Ref. 4 consistently explains the sum of differential cross sections for π^+p and π^-p elastic scattering. It allows a separation between the central Pomeron amplitude and the peripheral f amplitude.

(b) the slope in t of the Pomeron amplitude increases with energy at a rate similar to the one observed in K^+p elastic scattering, thus giving strong support to the model.

(c) the peripheral f amplitude[††††] has a characteristic "absorption radius" of ~ 1 fermi showing no striking energy dependence. The slope in t of the amplitude, together with the s dependence of the t=0 amplitude is compatible with standard Regge behavior.

We would like to thank Y. Avni, F. Gilman and J. Matthews for interesting discussions.

REFERENCES

1. R. Dolen, D. Horn, and C. Schmid, Phys. Rev. 166 (1968) 1768.
2. H. Harari, Phys. Rev. Letters 20 (1968) 1395;
   P.G.O. Freund, Phys. Rev. Letters 20 (1968) 235.
3. F. Gilman, H. Harari, and Y. Zarmi, Phys. Rev. Letters 21 (1968) 323;
   H. Harari and Y. Zarmi, Phys. Rev. 187 (1969) 2230.
4. H. Harari, Ann. Phys. 63 (1971) 432.
5. M. Davier and H. Harari, Phys. Letters 35B (1971) 239.
6. G. Giacomelli et al., Compilation of πN scattering data, CERN-HERA 69-1 (1969).
7. S. P. Denisov et al., Phys. Letters 36B (1971) 415.
8. W. Kienzle et al., to be published;
   A. Weitsch, private communication.
9. V. Barger and F. Halzen, University of Wisconsin preprint (1972).
10. V. Barger and D. Cline, Nucl. Phys. B23 (1970) 227.
11. H. A. Gordon et al., BNL preprint (1971).
12. T. Lasinski et al., Nucl. Phys. B37 (1972) 1.

FOOTNOTES

† The same model can also be applied to the difference of π^+p and π^-p differential cross sections which would project out Im ρ_{++}. However this is a very small amplitude at high energy and the analysis is not meaningful due to systematic experimental errors between π^+ and π^- data.

†† The fitted normalization varies from 0.91 to 1.20.

††† We completely disagree with the analysis of Barger and Halzen[9] who claimed a nonperipheral f amplitude after having assumed an s-independent Pomeron amplitude P(t). This nonshrinking Pomeron behavior is ruled out by K^+p and pp elastic scattering data, as emphasized by Barger and Cline.[10]

†††† Gordon <u>et</u> <u>al</u>.[11] have attempted to isolate f exchange in πp scattering taking into account the Pomeron shrinkage. Although their handling of the Pomeron amplitude is incorrect, their analysis qualitatively shows the peripherality of the f amplitude.

FIGURE CAPTIONS

1. The slope of the Pomeron amplitude as a function of s. The shaded area represents the experimental values for the slope of K^+p elastic scattering for the same t range $-t < 0.9$ GeV^2.[12]
2. The absorption radius for f exchange as a function of s.
3. The slope of the f amplitude as a function of s.

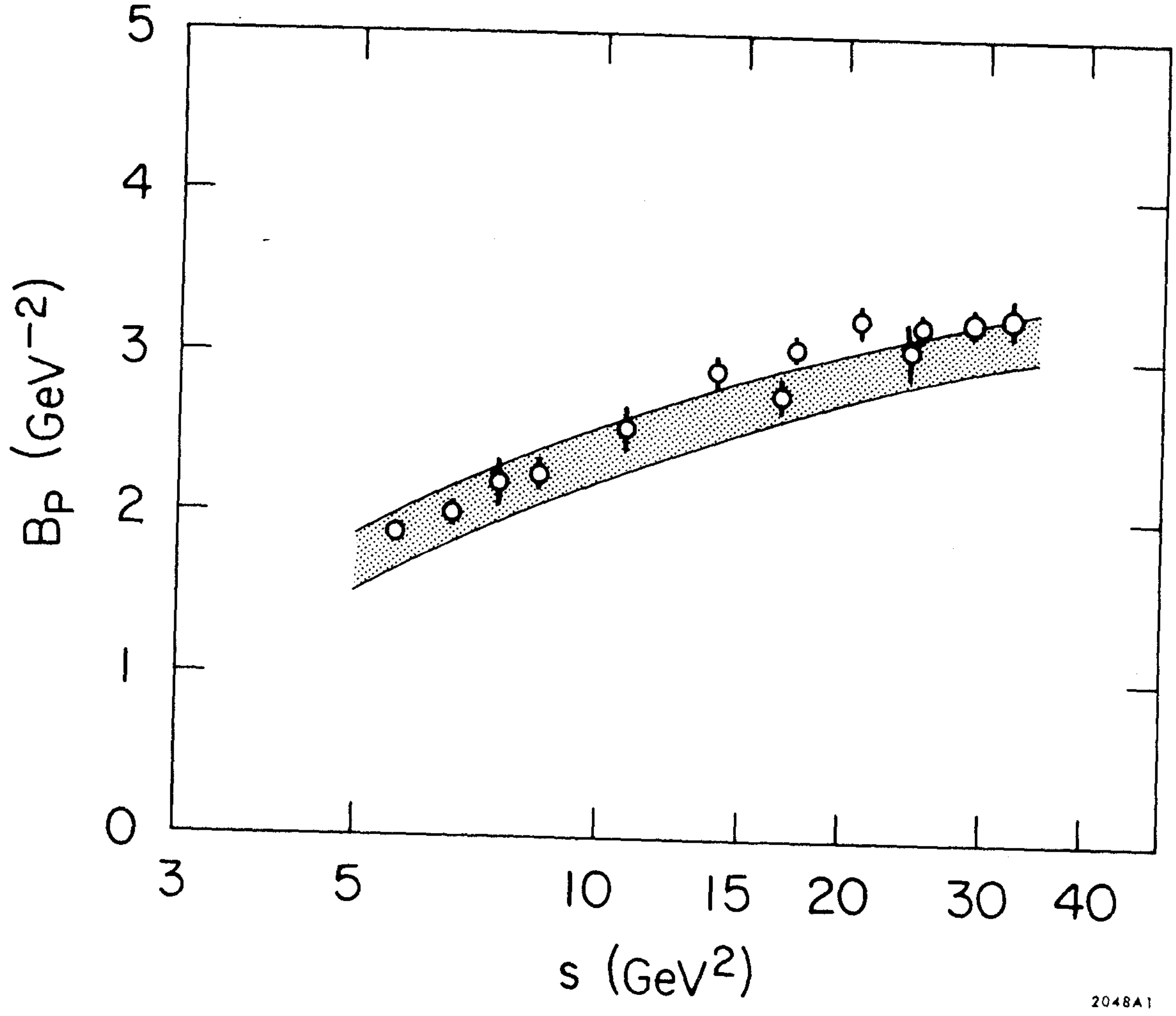

Fig. 1

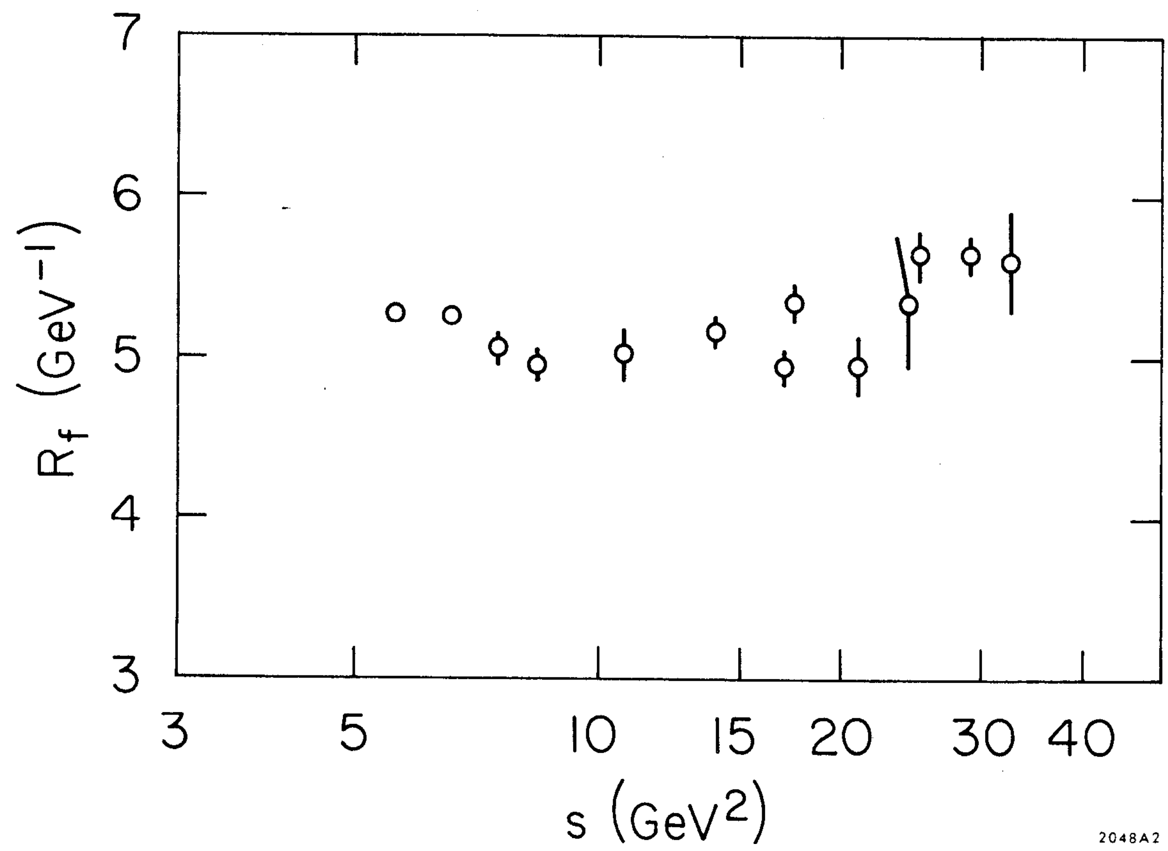

Fig. 2

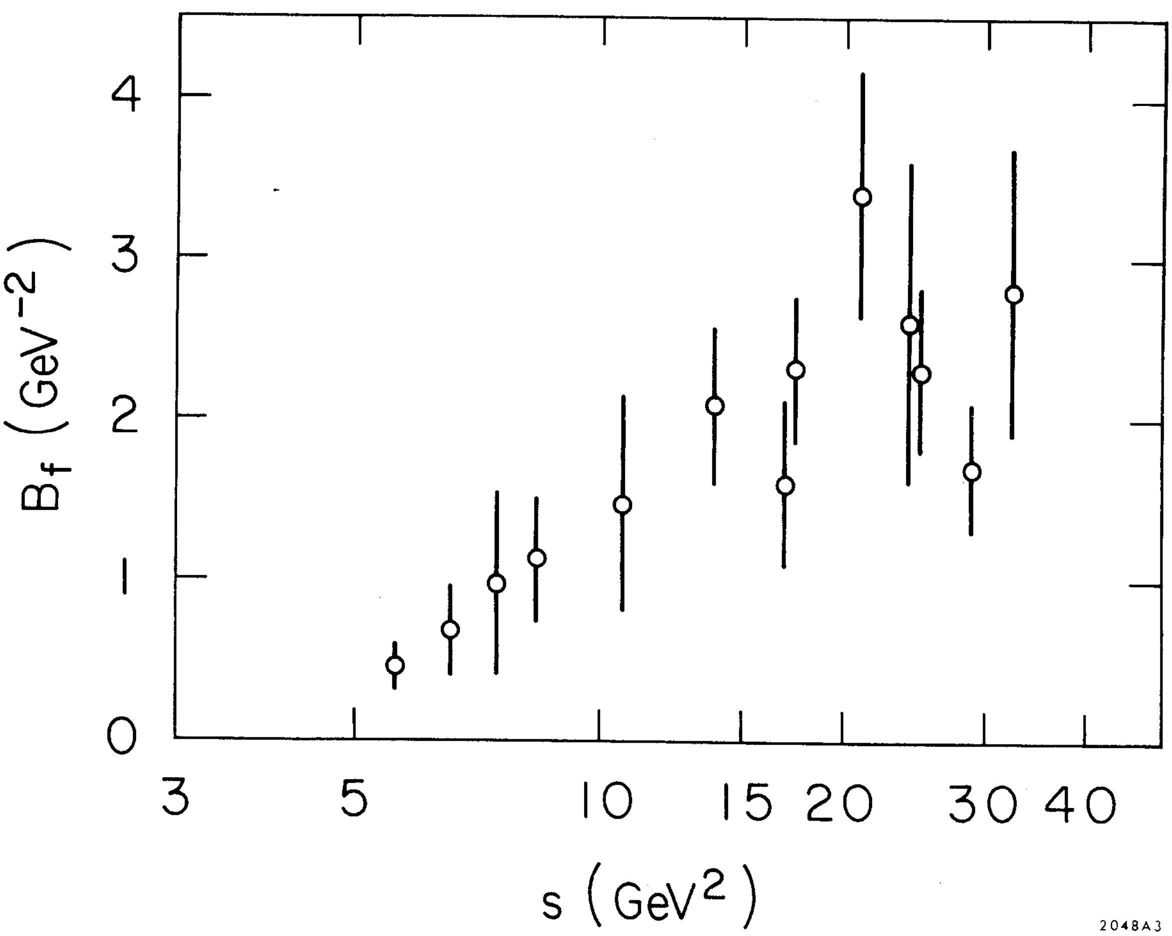

Fig. 3