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Dipole Pomeron and Proton–Proton Elastic Scattering at High Energies

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Abstract

The differential and total cross sections for high energy pp elastic scattering in the energy range $30\cdot8 \leqslant s^{\frac{1}{2}} \leqslant 62$ GeV, with $-t$ extending up to 8 $(\mathrm{GeV}/c)^2$, have been fitted with a dipole pomeron model.

Introduction

Measurements of proton–proton elastic scattering at very high energies (Amaldi *et al.* 1973*a*, 1973*b*; Bohm *et al.* 1974; Kwak *et al.* 1975; Akerlof *et al.* 1976) have indicated dip and bump structure in the differential cross section $\mathrm{d}\sigma/\mathrm{d}t$ at $-t = 1\cdot3$ and $1\cdot8$ $(\mathrm{GeV}/c)^2$ respectively. However, conventional Regge models (e.g. Rarita *et al.* 1968; Austin *et al.* 1970) when applied to pp elastic scattering do not lead to such a structure. Theoretical treatments by Chou and Yang (1968) and Durand and Lipes (1968) have given a qualitative description of pp elastic scattering at high energies but these models did not involve any energy dependence. Henzi and Valin (1973) as well as Buras and Dies de Deus (1974) have tried to fit the data using the idea of geometrical scaling but the agreement that they obtained in the vicinity of the dip was not good. Gotsman and Maor (1975) have attempted to improve the geometrical model for pp elastic scattering by parameterizing the data with a more complicated form but they still failed to describe the dip structure quantitatively. Ng and Sukhatme (1973) and Pajares and Schiff (1973) have explained one or more characteristics of the scattering by employing Gribov's reggeon calculus (Gribov *et al.* 1968*a*, 1968*b*; Baker 1973), while Saleem *et al.* (1975) and Kamran and Saleem (1977) have explained several of the features by using a dual absorptive model with a peripheral pomeron. Phillips and Barger (1973) have made an empirical study of pp elastic scattering in terms of two exponential amplitudes plus interference.

Recently De Kerret *et al.* (1976, 1977), Hartmann *et al.* (1977) and Conetti *et al.* (1978) have measured the angular distribution for pp elastic scattering up to $-t \lesssim 14$ $(\mathrm{GeV}/c)^2$ and it has been found that no further dip occurs in this region. This is a very unexpected result because the aforementioned models predict a second dip in the vicinity of $-t = 4$ $(\mathrm{GeV}/c)^2$. Sukhatme (1977) has emphasized that the t dependence of the new data must lead to a modification of current ideas on diffraction scattering. Araki *et al.* (1977) have tried to fit the data with a model based upon the Van der Waals equation of state. This model suggests the existence of a kind of phase transition in the pp elastic scattering, and the second dip is absent up to $-t = 8$ $(\mathrm{GeV}/c)^2$. However, the model not only involves a number of parameters but also just yields qualitative agreement between theory and experiment over the entire range. More recently Shiohara and Yano (1978) and Saleem and Aleem (1979) have tried to improve this model.

Another unexpected feature was found in the total cross section σ_{T} for high energy pp elastic scattering. It was thought previously that σ_{T} would eventually become constant at high energies, but in 1973 an increasing total cross section was observed for the first time (Amaldi *et al.* 1973*a*, 1973*b*; Amendolia *et al.* 1973). Later measurements made by the CERN–Rome–Stony Brook Collaboration (1976, 1978) up to $s^{\frac{1}{2}} = 62$ GeV confirmed a continuous rise of σ_{T} with energy.

In this paper, we will show that at high energy the angular distribution and the total cross section for pp elastic scattering can be fitted up to $-t = 8$ $(\mathrm{GeV}/c)^2$ by using a dipole pomeron model.

Dipole Pomeron Model

The relevance of the double pomeron pole to diffraction phenomena has been emphasized by several authors (Burgi *et al.* 1973; Jenkovszky 1974; Joshi 1974; Phillips 1974; Kwak *et al.* 1975). Jenkovszky and Wall (1976) have tried to fit pp elastic scattering data at high energy for $0 \leqslant -t < 4$ $(\mathrm{GeV}/c)^2$. We use their formalism here and, with a suitable choice of parameters, find that we are able to obtain a very good fit to most of the presently available experimental data.

If we neglect spin, the scattering amplitude for pp elastic scattering can be written (in units of $\mathrm{mb}^{\frac{1}{2}}(\mathrm{GeV}/c)^{-1}$)

$$\begin{aligned} T(s,t) &= \frac{\mathrm{d}}{\mathrm{d}\alpha}\Big(\exp(-\mathrm{i}\tfrac{1}{2}\pi\alpha)\,(s/s_0)^{\alpha}\,G(\alpha)\Big) \\ &= \exp(-\mathrm{i}\tfrac{1}{2}\pi\alpha)\,(s/s_0)^{\alpha}\,G'(\alpha)\big[1+\phi(\alpha)\ln(s/s_0)-\mathrm{i}\tfrac{1}{2}\pi\,\phi(\alpha)\big], \end{aligned} \tag{1}$$

where $\alpha = \alpha(t)$ is the pomeron trajectory, s_0 is a constant, $\phi(\alpha) = G(\alpha)/G'(\alpha)$ and the factor $1/\sin(\frac{1}{2}\pi\alpha)$ has been absorbed in $G(\alpha)$. In their analysis Jenkovszky and Wall (1976) took $\sin(\frac{1}{2}\pi\alpha)$ to be approximately constant, but this is not valid because $\alpha(t)$ varies from $+1$ to -1 as $-t$ goes from zero to 8 $(\mathrm{GeV}/c)^2$. From the structure of equation (1) we note that the first term in the square brackets gives the contribution from the simple pole, $G(\alpha)\sin(\frac{1}{2}\pi\alpha)$ being the residue at this pole. The function $G'(\alpha)$ is assumed to fall exponentially. If we take the pomeron trajectory as linear, say $\alpha(t) = \alpha_0 + \alpha' t$, we may write

$$G'(\alpha) = A\exp[b\{\alpha(t)-\alpha_0\}] = A\exp(b\alpha' t), \tag{2}$$

where A and b are free parameters to be fixed from experiment. The function $G(\alpha)$ is then obtained by integrating the above equation:

$$G(\alpha) = (A/b)\exp(b\alpha' t)+\gamma, \tag{3}$$

where γ is a constant. From equations (2) and (3), we get

$$\phi(\alpha) = G(\alpha)/G'(\alpha) = b^{-1}+(\gamma/A)\exp(-b\alpha' t). \tag{4}$$

The parameter γ can be determined from the condition

$$\phi(\alpha(t=0)) = \lambda,$$

where λ is the coefficient of the logarithmic term in the total cross section.

By using the norm

$$d\sigma/dt = (s_0^2/s^2)\,|\,T(s,t)\,|^2 \qquad \mathrm{mb\,(GeV}/c)^{-2},$$

we get the following forms for the differential and total cross sections respectively:

$$\begin{aligned} d\sigma/dt &= (s/s_0)^{2\alpha-2}\,G'^2(\alpha) \\ &\quad \times[\{1+\phi(\alpha)\ln(s/s_0)\}^2 + \tfrac{1}{4}\pi^2\,\phi^2(\alpha)] \qquad \mathrm{mb\,(GeV}/c)^{-2}, \end{aligned} \tag{5a}$$

$$\sigma_{\mathrm{T}} = 4\surd(0\cdot389\,\pi)\,(s_0/s)\,\mathrm{Im}\big(T(s,t=0)\big) \qquad \mathrm{mb}. \tag{5b}$$

Equations (5a) and (5b) can be rewritten as

$$\begin{aligned} d\sigma/dt &= A^2\exp[2\alpha'\{b+\ln(s/s_0)\}t][1+\{b^{-1}+(\lambda-b^{-1})\exp(-b\alpha' t)\}\ln(s/s_0) \\ &\quad +\tfrac{1}{4}\pi^2\{b^{-1}+(\lambda-b^{-1})\exp(-b\alpha' t)\}^2] \qquad \mathrm{mb\,(GeV}/c)^{-2}, \end{aligned} \tag{6a}$$

$$\sigma_{\mathrm{T}} = -4\cdot42\,A\{1+\lambda\ln(s/s_0)\} \qquad \mathrm{mb}. \tag{6b}$$

The position of the dip is given by

$$-t = \frac{1}{\alpha' b}\ln\left(\frac{1-\lambda b}{1+b/\ln(s/s_0)}\right) \qquad (\mathrm{GeV}/c)^2.$$

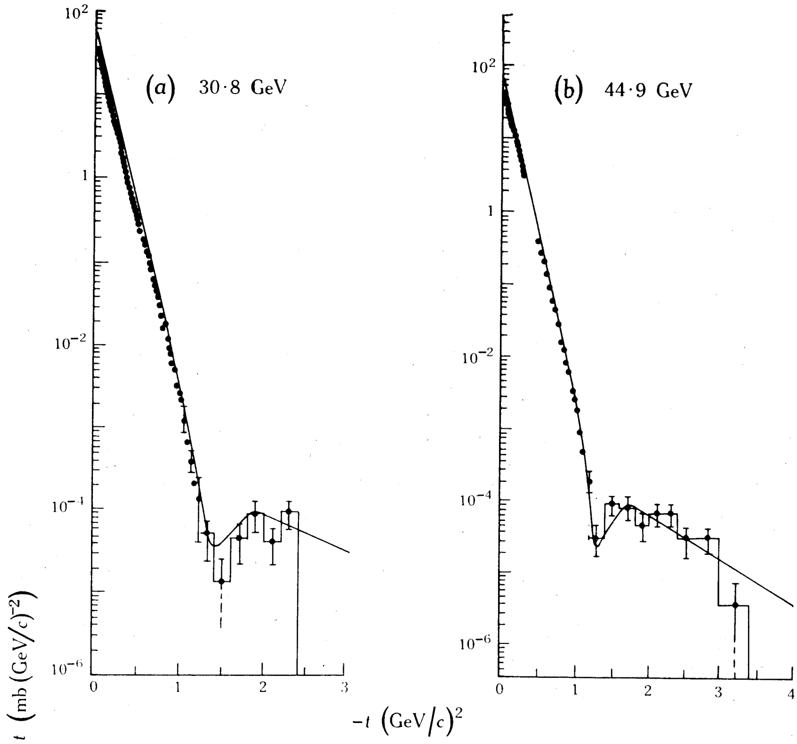
Results and Discussion

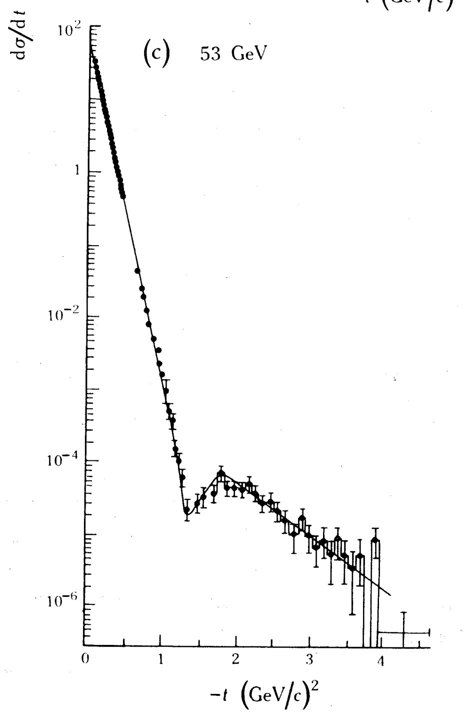
We find that at high energies a very good fit with experiment is obtained by taking the pomeron trajectory as $\alpha(t) = 1+0\cdot21\,t$ with the following choice of parameters:

$$A = -8\ \mathrm{mb}^{\frac{1}{2}}\,(\mathrm{GeV}/c)^{-1}, \qquad b = 19\cdot9, \qquad s_0 = 50\ \mathrm{GeV}^2, \qquad \lambda = 0\cdot04895.$$

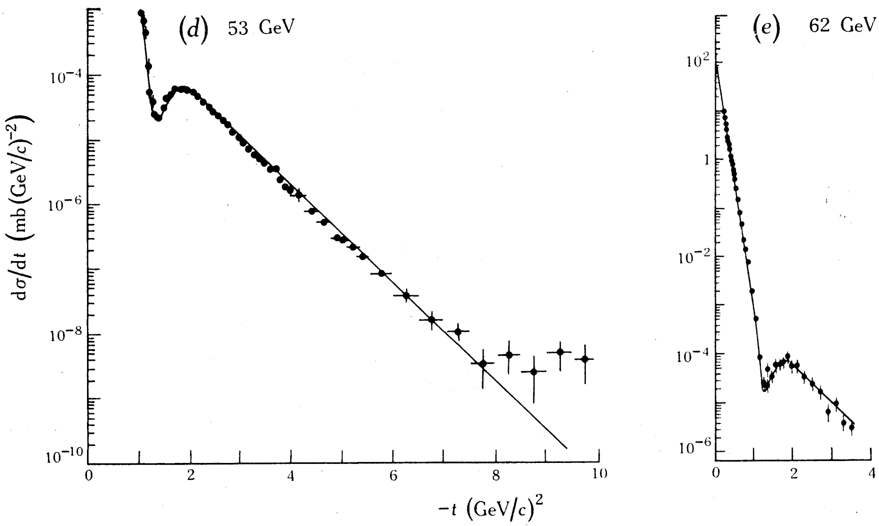
The calculated differential cross sections $d\sigma/dt$ are shown in Fig. 1. For $s^{\frac{1}{2}} = 44\cdot9$, 53 and 62 GeV (Figs 1*b*–1*e*) the agreement between theory and experiment is very good up to about $-t = 8$ $(\mathrm{GeV}/c)^2$, but for $s^{\frac{1}{2}} = 30\cdot8$ GeV (Fig. 1*a*) the agreement is not so good. The discrepancy in the latter case is probably due to a contribution from other trajectories. A second dip does not appear in the theoretical results, which is consistent with experiment. The data also show that for $s^{\frac{1}{2}} \geqslant 30\cdot8$ GeV the energy dependence of the dip is such that it moves slowly towards $t = 0$ as the energy increases. At $s^{\frac{1}{2}} = 30\cdot8$, $44\cdot9$, 53 and 62 GeV, the model predicts the dips to occur at $-t = 1\cdot36$, $1\cdot32$, $1\cdot30$ and $1\cdot28$ $(\mathrm{GeV}/c)^2$ respectively, and these values are consistent with experiment as can be seen from Fig. 1.

The calculated results for the total cross section σ_{T} are shown in Fig. 2. Once again the agreement between theory and experiment is very good. It is interesting to note that, without violating the Froissart bound, the Regge pole models cannot explain the rising cross sections. However, this rise in σ_{T} at high energies emerges as a natural consequence of the dipole pomeron model.





Figs 1*a*–1*e*. Comparison of the present theoretical results (curves) with experimental data for pp elastic scattering differential cross sections $d\sigma/dt$ plotted against $-t$, at the indicated values of $s^{\frac{1}{2}}$. The experimental data in (a, b, c, e) are from Amaldi *et al.* (1973*a*, 1973*b*) and Kwak *et al.* (1975), for $0 < -t < 4$ $(\mathrm{GeV}/c)^2$, and those in (d) are from De Kerret *et al.* (1977), for $1 < -t < 10$ $(\mathrm{GeV}/c)^2$.



Figs 1*d* and 1*e*

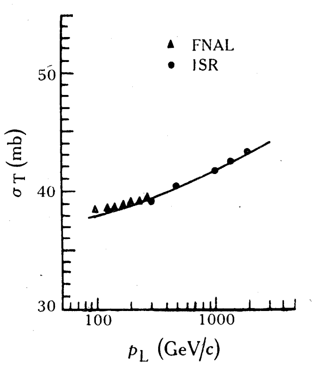


Fig. 2. Comparison of the calculated total cross section σ_T for pp elastic scattering (curve) with experimental data for a laboratory momentum p_L in the range 100–1500 GeV/*c*. The data are from (ISR) Amaldi *et al.* (1973*b*) and (FNAL) Carroll *et al.* (1976).

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