pp and $\overline{p}p$ scattering in finite sum of $\ln s$ powers Pomeron model

Zoltán Tarics[*], **Kornél Kontros and Alexander Lengyel** [†]

Institute of Electron Physics, Universitetska 21, 88016 Uzhgorod, Ukraine
E-mail: `iep@iep.uzhgorod.ua`, `jeno@kontr.uzhgorod.ua`, `sasha@len.uzhgorod.ua`

ABSTRACT: We assume that the Pomeron is a sum of Regge multipoles, each corresponding to a finite gluon ladder. From a fit to the diffraction cone data of $pp-$ and $\overline{p}p-$ scattering we found that the triple pole is significant for the rise of the ratio σ_{el}/σ_{tot} at high energies.

1. Introduction

It has been conjectured recently [1] that the Pomeron instead of being an infinite gluon ladder [2] may appear as a finite sum of gluon ladders corresponding to a finite sum of Regge multipoles with increasing multiplicities. The first term in the $\ln s$ series contributes to the total cross-section with a constant term and can be associated with a simple pole, the second one (double pole) goes as $\ln s$, the third one (triple pole) as $\ln^2 s$, etc. All Pomeron poles have unit intercepts. A new prong opens each time the available energy exceeds the threshold value. The values of threshold parameter were found [1] from a fit to the experimental data. Another important set of parameters is related to the coupling of the gluons to hadrons, giving the relative weight of various diagrams. In ref. [1] they were fitted to the forward scattering data and subsequently they were also calculated in QCD. Below we study this problem both in the forward and non-forward directions. Because of its complexity, we do not consider here the effect of the progressively opening channels as it was done in ref. [1]. Instead we first consider a model with a simple and dipole Pomeron [DP] contribution used earlier to fit elastic hadron scattering [3], low-x structure functions [4] and photoproduction of vector mesons at HERA [5].

The DP ansatz reads [3]

$$P(s,t) = isg_0 \sum_{i=1}^{2} c_i R_i^2(s) e^{R_i^2(s)t}, \tag{1.1}$$

---

where $c_1 = 1$, $c_2 = \lambda b - 1 = -\varepsilon$; $R_1^2(s) = \alpha'(b + \ln(-i\frac{s}{s_0}))$; $R_2^2(s) = \alpha'\ln(-i\frac{s}{s_0})$. Apart from the normalization factor g_0, this model contains 4 adjustable parameters: λ, b, s_0 and α', moreover their number can be still reduced within the cone region (i.e. $|t| \leq 1\ GeV^2$ by setting $\lambda = \frac{1}{b}$). Here a linear Pomeron trajectory, $\alpha(t) = 1 + \alpha' t$ is implied. Generalization to include nonlinear trajectory is straightforward. The model is strongly constrained by an integral relation between the residue at the simple and double poles [3], that produces the observed dip-bump structure in the differential cross-section in accordance with the experimental data.

The Dipole Pomeron model with a unit Pomeron intercept [6] was used to describe successfully $pp-$ and $\overline{p}p-$ elastic scattering at the ISR and the Collider energies, however the ratio σ_{el}/σ_{tot} was found [3] to decrease asymptotically for all physical values of the parameters. To obtain an increasing function for this ratio the authors of [3] introduced a factor corresponding to the supercritical Pomeron behavior [7]. However in this case the unitarity is broken. It was shown [8] that the unitarity violation occurs at energies only slightly above the Tevatron energy of 1.8 TeV, and therefore it is a problem of the present and not of the future. To avoid this problem, we consider a model containing a finite series of Pomeron terms up to $\ln^2 s$, in accordance with the unitarity constrains.

2. The model

Our ansatz for the scattering amplitude is:

$$A_{pp}^{\overline{p}p} = P + R_f \pm R_\omega, \tag{2.1}$$

where we introduce a tripole contribution to the DP in the simplest way (see also [9]):

$$P(s,t) = isg_0 \left[b + \ln\left(-i\frac{s}{s_0}\right) + c\ln^2\left(-i\frac{s}{s_0}\right) \right] e^{\left[b + \ln\left(-i\frac{s}{s_0}\right)\right][\alpha_P(t)-1]}. \tag{2.2}$$

The Pomeron trajectory:

$$\alpha_P(t) = \alpha_P(0) + \alpha_P' t + \gamma_P \left(\sqrt{t_P} - \sqrt{t_P - t} \right), \tag{2.3}$$

where the two-pion threshold $t_P = 4m_\pi^2$.

In (2.1) the R_f, R_ω contains the subleading Reggeon contributions (f and ω) to the scattering amplitude:

$$Rj(s,t) = g_j \left(-i\frac{s}{s_0} \right)^{\alpha_j(t)} e^{b_j t}, \quad \alpha_j(t) = 1 + \alpha_j' t, \quad j = f, \omega; \quad s_0 = 1 GeV^2. \tag{2.4}$$

Recently in paper [10] the contribution of truncated BFKL Pomeron series to the σ_{tot} of $pp-$ and $\overline{p}p-$ scattering was studied and it was shown that a reliable description can be obtained by using two orders in this series. As a by-product, the elastic differential cross section was obtained for the diffraction cone at low and high energies with a qualitative description of the experimental data. Contrary to [10], in our model we performed a simultaneous fit to the σ_{tot} and $d\sigma/dt$ data as follows.

3. Comparison with experiment. Conclusion

In order to determine the parameters that control the s-dependence of $A\left(s,0\right)$ in a wide energy range $4GeV \leq \sqrt{s} \leq 1800GeV$, we used the available data for total cross sections (see the refs. in paper [11]). A total of 66 experimental data has been included for $t = 0$. For the differential cross sections we selected the data at the energies $\sqrt{s} = 19; 23; 31; 44; 53; 62 GeV$ (for $pp-$scattering) and $\sqrt{s} = 31; 53; 62; 546; 1800 GeV$ (for $\overline{p}p-$scattering). The squared 4-momentum has been limited by $0.00065 GeV^2 < |t| < 0.5 GeV^2$, because at larger $|t|$ the influence of the dip region becomes visible (in particular, it can be seen quite clearly at the Collider energy $\sqrt{s} = 546 GeV$). The total of 1383 experimental points have been used in the overall fit.

In the calculations we use the following normalization for the dimensionless amplitude:

$$\sigma_{tot} = \frac{4\pi}{s} ImA\left(s, t=0\right), \quad \frac{d\sigma}{dt} = \frac{\pi}{s^2}\left|A\left(s,t\right) + A_c\left(s,t\right)\right|^2,$$

where $A_c(s,t)$ is the Coulomb amplitude [12].

The resulting fits for σ_t, $\frac{d\sigma}{dt}$ are shown in Figs. 1-3,5,6 with the values of the fitted parameters quoted in Table 1. From these figures we conclude that the multipole Pomeron model corresponding to a sum of gluon ladders up to two rungs fits the data perfectly well in a wide energy region within the diffraction cone. As result, the model gives a good behavior for the ratio σ_{el}/σ_{tot} for $\overline{p}p-$scattering (see Fig. 4).
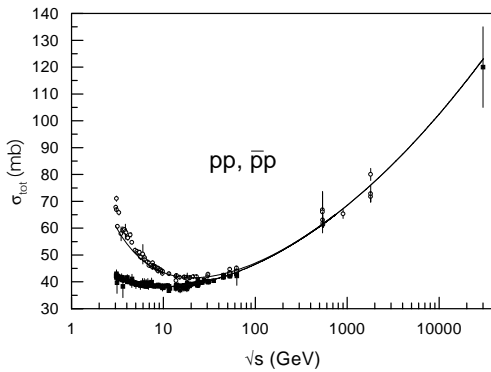

Figure 1: Predictions of the model with the parameters from Table 1 compared to the experimental data on σ_{tot}.
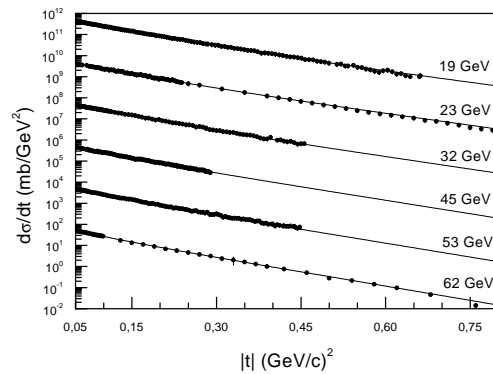
Figure 2: Differential cross-section for $pp-$scattering (a factor 10^2 between successive curves is present). The solid curves are fits of the model.

The rapid decrease of the coefficients of the first three terms in the Pomeron series in (2.2) provides the fast convergence of the series and ensures the applicability of this approximation at still much higher energies.

In this paper we have explored only the simplest extension of the dipole Pomeron to a tripole. In fact, the scattering amplitude is much more complicated than just a simple power series in $\ln s$.
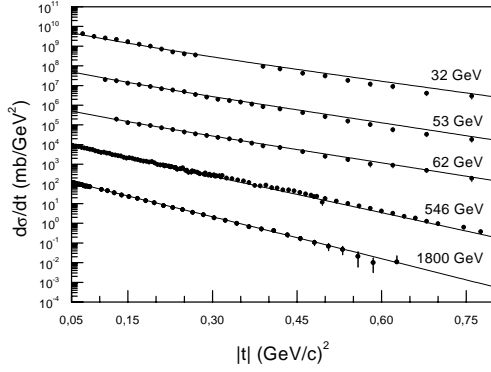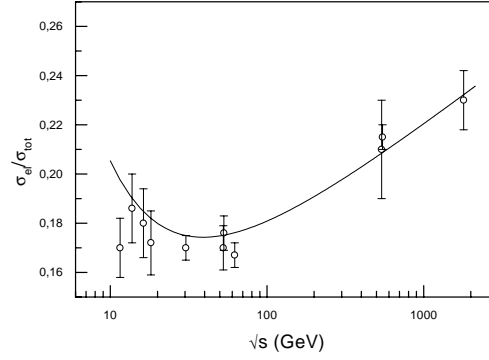
Figure 3: The same as in the Fig. 2 for $\overline{p}p$−scattering.

Figure 4: Calculated ratio of σ_{el}/σ_{tot} for $\overline{p}p$−scattering compared with experiment.
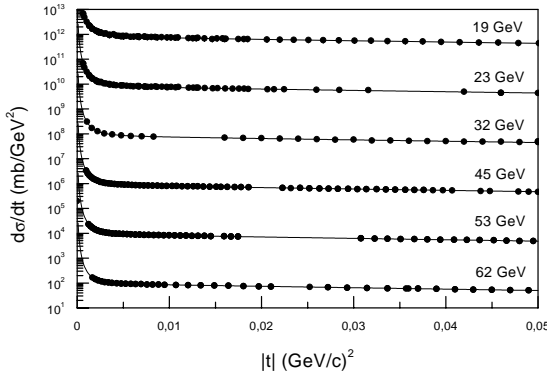
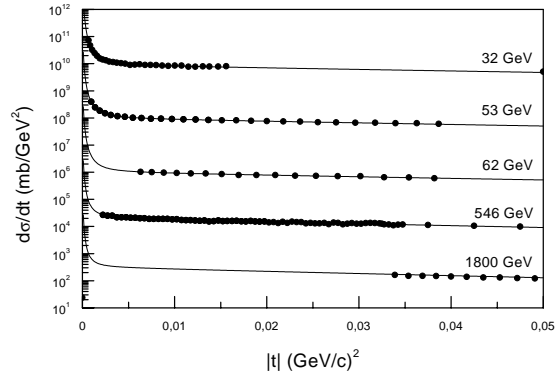**Figure 5:** The same as in the Fig. 2 for very small $|t| < 0.05$.

Figure 6: The same as in the Fig. 5 for $\overline{p}p$−scattering.

g_0	b (GeV^{-2})	c	α'_P (GeV^{-2})	γ_P (GeV^{-1})	$\alpha_f(0)$	b_f (GeV^{-2})	g_f	$\alpha_\omega(0)$	b_ω (GeV^{-2})	g_f
0.309	5.22	0.132	0.305	0.0864	0.786	2.54	13.0	0.491	6.41	7.39

Table 1: Values of the fitted parameters in the model.

Earlier a comprehensive analysis of the $pp-$ and $\overline{p}p-$ diffraction cone scattering using the dipole and supercritical Pomeron models was done [11].

On the one hand, though we used just a simplified t-dependence in the model reasonably good results were obtained. Because the slopes of secondary Reggeons do not influence the fit sufficiently, we have fixed them at $\alpha'_f = 0.84$ (GeV^{-2}) and $\alpha'_\omega = 0.93$ (GeV^{-2}), which correspond to the values of Chew-Frautschi plot. On the other hand, we included the curvature of the Pomeron trajectory that cannot be negligible.

The quality of our fits $\chi^2/dof = 2.05$ is comparable with the best fit [11].

Acknowledgments

References

[1] R. Fiore, L. Jenkovszky, E. Kuraev, A. Lengyel, F. Paccanoni and A. Papa, *Phys. Rev.* **D 63** (2001) 056010.

[2] E.A. Kuraev, L.N. Lipatov and V.S. Fadin, *Zh. Eksp. Teor. Fiz.* **72** (1977) 377;
Sov. Phys. JETP **45** (1977) 199;
Y.Y. Balitzkij, L.N. Lipatov, *Sov. J. Nucl. Phys.* **28** (1978) 822.

[3] A.N. Vall, L.L. Jenkovszky and B.V. Struminsky, *Yad. Fiz.* **40** (1987) 1319.

[4] L. Jenkovszky, F. Paccanoni, E. Predazzi, *Nucl. Phys.* **B 25** (1992) 80 (Conf. Suppliment);
M. Bertini, M. Giffon, L. Jenkovszky, F. Paccanoni, E. Predazzi, *Riv. Nuovo Cim.* **1** (1996) 1;
P. Desgrolard, L. Jenkovszky, A. Lengyel, F. Paccanoni, *Phys. Lett.* **B 459** (1999) 265.

[5] R. Fiore, L. Jenkovszky, F. Paccanoni, *Eur. Phys. J.* **C 10** (1999) 461.

[6] A.N. Vall, L.L. Jenkovszky, *The Dipole Pomeron and pp Scattering*, [ITP-74-166E preprint], Kiev 1974; *Czech. J. Phys.* **B 26** (1976) 447;
M. Saleem, Fazal-e-Aleem, M. Kamran, *Aus. J. Phys.* **33** (1980) 481;
M. Kamran, *J. Phys.* **G 8** (1983) 221.

[7] A. Donnachie, P. Landshoff, *Phys. Lett.* **B 296** (1992) 227.

[8] R.J.M. Covolan, J. Montanha, K. Goulianos, *Phys. Lett.* **B 389** (1996) 176.

[9] P. Desgrolard, M. Giffon, L. Jenkovszky, *Yad. Fiz.* **56** (1993) 226;
Phys. Atom. Nucl. **56** (1993) 1429.

[10] M.B. Gay Ducati, M.V.T. Machado, *Truncated BFKL Series and Hadronic Collisions*, [`hep-ph/0009011`].

[11] P. Desgrolard, A.I. Lengyel , E.S. Martynov, *Nuovo Cim.* **110A** (1997) 251.

[12] G.B. West, D.R. Yennie, *Phys. Rev.* **172** (1968) 1413.