EFFECTS OF THE INCLUSIVE DIPOLE-POMERON TO EXCLUSIVE PROCESSES

N.G. ANTONIOU, C.B. KOURIS and G.M. PAPAIOANNOU
Nuclear Research Center "Demokritos", Aghia Paraskevi Attikis, Greece

and

E.K. MANESIS
Physics Department, University of Ioannina, Greece

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The consequences of the inclusive dipole-Pomeron for the exclusive processes are investigated. In the weak coupling limit a two component picture for the production mechanism is obtained and self-consistency of the inclusive Pomeron dipole is found.

In a previous work [1] we have shown that the exchange of a dipole-Pomeron in the Mueller-Regge diagrams cannot be factorizable if the g_{dd} coupling (fig. 1) is not zero. On the other hand there is evidence that the dipole structure of the Pomeron is in agreement with recent data for elastic scattering [2]. It is therefore obvious that this structure may play a significant role in the Mueller diagrams especially for describing scaling breaking effects in inclusive distributions [3].

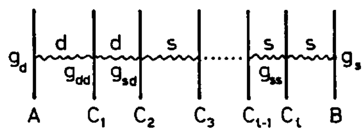

Fig. 1. Mueller-Regge diagram for the inclusive production of i particles with single and double Pomeron exchanges.

In order to maintain factorization we have to assume that only the g_{ss} and g_{sd} couplings are different from zero and $g_{dd} = 0$. With this assumption we expect that the factorization of the dipole-Pomeron in the Mueller diagrams is consistent with s-channel unitarity since the arguments of ref. [1] do not hold any more. It is analogous to the assumption that the triple Pomeron coupling is zero at $t = 0$ usually made in order that a simple factorizable Pomeron with $\alpha_p(0) = 1$ be consistent with unitarity.

We consider therefore the model in which the dominant singularity structure of the Mueller-Regge diagrams is the exchange of a simple and double pole $\alpha_p(0)$ and $g_{dd} = 0$ for large rapidity differences. Due to the factorization property of this model we can try a reverse-bootstrap of the dipole-Pomeron within the framework of the Bardeen-Peccei formalism [4]. Namely from the knowledge of the inclusive distributions for any number of particles we can draw conclusions for the exclusive production of these particles.

Following ref. [4] we write the generating function

$$I(z, Y) = \sum_{n=0}^{\infty} \sigma_n(Y)\,(1+z)^n, \tag{1}$$

where $\sigma_n(Y)$ denotes the partial cross-section for the n particle production and $Y = Y_b - Y_a$ is the rapidity difference of the initial particles. From (1) we get the well-known relations

$$I(z=0, Y) = \sigma_{tot}, \qquad \left(\frac{\partial^i I(z, Y)}{\partial z^i}\right)_{z=0} = \rho_i(Y), \tag{2, 3}$$

where

$$\rho_i(Y) = \langle n(n-1)\,\ldots\ldots\,(n-i+1)\rangle\,\sigma_{tot}. \tag{4}$$

In terms of the inclusive distributions

$$\rho_i(Y) = \int \frac{d^3p_1}{E_1} \cdots \frac{d^3p_i}{E_i} \left(\frac{E_1 \cdots E_i \, d\sigma_{in}}{d^3p_1 \cdots d^3p_i} \right). \tag{5}$$

Similarly at $z = -1$ we have

$$I(z=-1, Y) = \sigma_0, \qquad \frac{1}{n!}\left(\frac{\partial^n I(z,Y)}{\partial z^n}\right)_{z=-1} = \sigma_n(Y). \tag{6, 7}$$

Using (5) one can write the following formula (4)

$$\rho_i(Y) = \exp(-Y)\, i! \int_0^Y dz_1 \int_0^{Y-z_1} dz_2 \cdots \int_0^{Y-\sum_{\mu=1}^{i-1} z_\mu} dz_i \, g^+ S(z_1) G S(z_2) \cdots S\left(Y - \sum_{\mu=1}^{i} z_\mu\right) g, \tag{8}$$

where g^+ is the row matrix of the external couplings of the exchanged factorizable singularities, G the square matrix of the internal couplings and $S(z)$ is the square matrix of the propagators of those singularities.

In our model we consider two leading singularities at $j = \alpha_P(0)$, one simple and one double-pole with $g_{dd} = 0$. Hence the input matrices are

$$G = \begin{pmatrix} g_{ss} & g_{sd} \\ g_{sd} & 0 \end{pmatrix}, \qquad S(z) = \begin{pmatrix} 1 & 0 \\ 0 & z \end{pmatrix} \exp(z\alpha_p(0)), \qquad g^+ = (g_s, g_d). \tag{9}$$

Then the generating function $I(z, Y)$ satisfies the following integral equation

$$\tilde{I}(z,Y) = \tilde{\rho}_0(Y) + z \int_0^Y dy \, \tilde{\rho}_0(y) G \tilde{I}(z, Y-y), \tag{10}$$

where

$$I(z,Y) = g^+ \tilde{I}(z,Y) g, \tag{11}$$

and

$$\rho_i(Y) = g^+ \tilde{\rho}_i(Y) g, \qquad \tilde{\rho}_0(Y) = \exp(-Y) S(Y). \tag{12}$$

Using Laplace transforms we find that the solution of (10) is [4]

$$I(z,Y) = \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} d\theta \exp(\theta Y) g^+ \frac{1}{\tilde{\rho}_0^{-1}(\theta) - zG} g, \tag{13}$$

where

$$\tilde{\rho}_0(\theta) = \int_0^\infty dY \exp(-\theta Y) \tilde{\rho}_0(Y). \tag{14}$$

Using our input (9) and (12) we get

$$g^+ \frac{1}{\tilde{\rho}_0^{-1}(\theta) - zG} g = \frac{g_s^2(\theta + 1 - \alpha_p)^2 + 2 g_s g_d g_{sd} z + g_d^2(\theta + 1 - \alpha_p - z g_{ss})}{(\theta + 1 - \alpha_P - z g_{ss})(1 + \theta - \alpha_P)^2 - z^2 g_{sd}^2}. \tag{15}$$

The integral (13) is evaluated from the contribution of the poles of (15).

It is obvious that we have three poles. On physical grounds we expect that the coupling g_{sd} is small because it gives a measure of the scaling breaking effects in the inclusive distribution. In fact the observed small rising of the plateau in the one particle distribution is given in this model by a term of the form $g_{sd} \ln s$ [3].

As a first approximation it is reasonable to keep in (15) only linear terms with respect to g_{sd}. With this approximation we have one simple pole at $\theta = \alpha_P + z g_{ss} - 1$ and a double pole at $\theta = \alpha_P - 1$.

From (13) we therefore obtain

$$I(z,Y) = \exp\left(Y(\alpha_P - 1)\right)\left[g_s^2 \exp\left(z g_{ss} Y\right) + g_d^2 Y - \frac{2 g_s g_d g_{sd}}{g_{ss}}\left(Y - \frac{\exp\left(z g_{ss} Y\right) - 1}{z g_{ss}}\right)\right]. \tag{16}$$

From this formula we can now draw conclusions for the exclusive cross sections $\sigma_n(Y)$ and ask for self-consistency for the singularities. For the elastic cross section $\sigma_0(Y)$ we get

$$\sigma_0(Y) = I(z=-1, Y)$$

$$= \left(g_d^2 - \frac{2 g_s g_d g_{sd}}{g_{ss}}\right) Y \exp\left(Y(\alpha_P - 1)\right) + \frac{2 g_s g_d g_{sd}}{g_{ss}^2} \exp\left(Y(\alpha_P - 1)\right) + \left(g_s^2 - \frac{2 g_s g_d g_{sd}}{g_{ss}^2}\right) \exp\left(Y(\alpha_P - 1 - g_{ss})\right). \tag{17}$$

The first two terms are obviously identified with the contribution of the exclusive Pomeron (simple and double pole) to the elastic cross section. The third term must be identified with the interference of the meson and dipole Pomeron exchange.

From the above identification, self-consistency leads to the following conditions

$$\alpha_P(0) - 1 = 2\,\alpha_P(0) - 2 \quad \text{or} \quad \alpha_P(0) = 1, \text{ and}$$

$$\alpha_P(0) + \alpha_R(0) - 2 = \alpha_P(0) - 1 - g_{ss} \quad \text{or} \quad \alpha_R(0) = 1 - g_{ss}. \tag{18}$$

where $\alpha_R(0)$ is the intercept of the meson trajectory.

This result shows that the dipole structure of the inclusive facorizable Pomeron generates in a self-consistent way the exclusive Pomeron with $\alpha_P(0) = 1$ and the exclusive meson trajectory with $\alpha_R(0) = 1 - g_{ss}$.

This result has to be compared with the Chew-Pignotti model [5] in which a simple Pole for the Pomeron with intercept one cannot bootstrap itself. With the above values of the intercepts we have from (2), (16), (17) for the elastic and total cross sections the following asymptotic expressions

$$\sigma_0(Y) = \frac{2 g_s g_d g_{sd}}{g_{ss}^2} + \left(g_d^2 - \frac{2 g_s g_d g_{sd}}{g_{ss}}\right) Y, \tag{19}$$

and

$$\sigma_{tot} = I(z=0, Y) = g_s^2 + g_d^2\, Y. \tag{20}$$

These expressions are known to give a good description of the experimental data in proton-proton collisions at the ISR. In fact we can have an estimate of the couplings g_s, g_d, g_{ss}, g_{sd} from the phenomenological expressions [2]. We find

$$g_s = 5.3\ (\text{mb})^{1/2}, \qquad g_d = 1.4\ (\text{mb})^{1/2}, \qquad g_{ss} = 0.33, \qquad g_{sd} = 0.036. \tag{21}$$

We find a reasonable value for the meson intercept ($\alpha_R(0) = 0.67$) and a small value for the coupling g_{sd} justifying a posteriori the weak coupling approximation.

From (7), (16) and (18) we obtain the following multiplicity distribution

$$\sigma_n(Y) = g_s^2 \exp\left(-g_{ss} Y\right) \frac{(g_{ss} Y)^n}{n!} + \frac{2 g_s g_d g_{sd}}{g_{ss}^2}\left[1 - \exp\left(-g_{ss} Y\right) \sum_{\kappa=1}^{n+1} \frac{(g_{ss} Y)^{n+1-\mu}}{(n+1-\mu)!}\right], \qquad (n > 0). \tag{22}$$

The first term gives a Poisson distribution corresponding to simple pole exchanges in the Mueller diagram and it represents the short range forces in the Feynman gas. The second term which is proportional to the coupling g_{sd} and corresponds to dipole exchanges gives the correction due to the long range forces. In fact this term is a diffractive component because for fixed n gives a constant contribution to $\sigma_n(Y)$ for $Y \to \infty$. It is worth noting that although the elastic cross section grows like Y due to the dipole exchange, the diffractive part of $\sigma_n(Y)$ for

$n > 0$ goes to a constant showing a diffractive dissociation by a simple Pomeron. This is consistent with unitarity since a dipole diffractive dissociation would lead to the usual disease $\sigma_D > \sigma_{tot}$, where σ_D is the diffractive part of the inelastic cross section.

Finally, the presence of long-range forces in this model can also be seen from the fact that a phase transition appears in the corresponding Feynman gas. In fact from the partition function (16) and the thermodynamic relation $\ln I(z, Y) = Yp(z)$ for $Y \to \infty$ we get the following expression for the pressure $p(z)$ as a function of the fugacity z.

$$p(z) = 0, \qquad z \leqslant 0, \qquad\qquad p(z) = zg_{ss}, \qquad z > 0. \tag{23}$$

Obviously the system undergoes a phase-transition at $z = 0$ similar to the phase transition appearing in the simple two component model [6]. The approximation made so far can be improved by taking into account higher order terms in the expressions for the poles of (15) with respect to g_{sd}.

In fact we find the following three simple poles

$$\theta_1 = \alpha_P(0) - 1 + zg_{ss}\left(1 + \frac{g_{sd}^2}{2zg_{ss}^3}\right) + O(g_{sd}^4), \qquad \theta_2 = \alpha_P(0) - 1 - zg_{ss}\left(\frac{g_{sd}}{g_{ss}^{3/2}(-z)^{1/2}} + \frac{g_{sd}^2}{4zg_{ss}^3}\right) + O(g_{sd}^3),$$

$$\theta_3 = \alpha_P(0) - 1 + zg_{ss}\left(\frac{g_{sd}}{g_{ss}^{3/2}(-z)^{1/2}} - \frac{g_{sd}^2}{4zg_{ss}^3}\right) + O(g_{sd}^3). \tag{24}$$

Hence $\theta_3 - \theta_2 \sim O(g_{sd})$ and $\theta_2 - \theta_1 \sim O(1)$, $\theta_3 - \theta_1 \sim O(1)$, namely θ_2 and θ_3 are close together and coincide for $g_{sd} = 0$.

The effect of higher order terms is to split the output leading singularity in two poles α_{P_1} and α_{P_2} close to unity and to change by a small amount the position of the meson intercept.

The self-consistency relations for the dipole are

$$2\alpha_{P_1} - 2 = \alpha_P - 1 + \frac{g_{sd}}{g_{ss}^{1/2}} - \frac{g_{sd}^2}{4g_{ss}^2} + O(g_{sd}^3), \qquad 2\alpha_{P_2} - 2 = \alpha_P - 1 - \frac{g_{sd}}{g_{ss}^{1/2}} - \frac{g_{sd}^2}{4g_{ss}^2} + O(g_{sd}^3). \tag{25}$$

Using the values of (21) for the couplings and imposing the condition $\alpha_{P_1} = 1$ for the leading partner of the output doublet we find that the imput dipole α_P should be at 0.997. For the other partner we have from (25) $\alpha_{P_2} = 0.937$. This shows that if the coupling g_{sd} is sufficiently small, the inclusive dipole Pomeron with intercept very close to unity is self-consistent in the sense that the leading output singularity is a system of two single poles in the vicinity of unity.

Concluding we have found that a factorizable pole-dipole Pomeron with $g_{dd} = 0$ and small g_{sd} coupling in the Mueller-Regge diagrams is self-consistent and leads to a two component picture for the exclusive production.

References

[1] N.G. Antoniou, C.B. Kouris and G.M. Papioannou, Phys. Lett. 52B (1974) 207.
[2] V. Barger, Invited talk, XVII Intern. Conf. on High energy physics.
[3] N.G. Antoniou, C.B. Kouris and G.M. Papaioannou, Let. Nuovo Cimento 9 (1974) 509.
[4] W.A. Bardeen and R.D. Peccei, Phys. Lett. 45B (1973) 353.
[5] C.F. Chew and A. Pignotti, Phys. Rev. 176 (1968) 2112.
[6] H. Harari, Multihadron production at high energies, Phenomenology and theory, Weizmann preprint WIS 73/32 Ph.