HIGH-ENERGY HADRON PRODUCTION IN THE DIPOLE POMERON MODEL OF DIFFRACTION

V.K. TARTAKOVSKY, O.I. IVANOVA, V.I. KOVALCHUK, I.V. SHARF[1]

Department of Physics, Taras Shevchenko Kyiv National University
(6, Academician Glushkov Ave., Kyiv 03127, Ukraine; e-mail:O_Ivanova@univ.kiev.ua),

[1]Department of Theoretical and Experimental Nuclear Physics,
Odesa National Politechnical University
(1, Shevchenko Ave., Odesa 65044, Ukraine)

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Multiple hadron production is studied in high-energy pp and p$\bar{\text{p}}$ scattering within the dipole pomeron model. Two-cascade multiplicity distributions of secondaries are calculated with and without diffraction. Reasonable agreement with data is obtained.

Introduction

It is well known [1, 2] that many details of the multiplicity distribution are well described by cascade models, in particular within the framework of the standard Regge pole approach [3–5], where one assumes that the proton in the laboratory reference system decays virtually generating showers of secondaries. These showers correspond to exchanges of reggeons with contributions of inelastic processes to the imaginary part of the scattering elastic amplitude. It allows one to compute the probability of the generation of a number of showers ν due to ν reggeon exchanges contributing to the imaginary part of the elastic scattering amplitude ("cutting" of unitary diagrams). Instead of the first stage of the process (decay of a virtual proton into constituent parts), we introduce a proton vertex interacting with ν reggeons [5]. This vertex, for instance in the eikonal approximation, is modeled as a product of simple proton-reggeon vertices. As a result, the difference between reggeons vanishes, and we can raise a question about the energy distribution according to showers corresponding to these reggeons. The probability distribution of the number of particles generated by a shower essentially depends upon the shower energy. So, in such "cutting" models, the showers with different characteristics are substituted for showers with certain averaged characteristics that will allow one to ensure the correct resulting multiplicity and rapidity distribution.

Our aim is to construct an essentially nonuniform model that should take into consideration the difference between showers. So we will try to model the vertex of proton interaction with an arbitrary quantity of showers and to put the model parameters under the unitary condition. We will also require that every shower in unitary condition have to correspond to not an "ordinary" but to dipole pomeron.

1. Representation of a Dipole Pomeron with the Help of a Sequence of Ladder Diagrams

The model of dipole pomeron suggested in [6] well describes experimental data on elastic scattering, so it's interesting to apply this model for the description of inelastic processes and the experimental multiplicity distribution of secondary particles [9]. To do it, one has to consider the question about a dipole pomeron representation with the help of a sequence of ladder diagrams.

Let's consider the standard diagram of comb type, see Fig. 1. The scattering amplitude for this diagram reads

$$A = \lambda_\alpha D\left(q_1^2\right)\lambda D\left(q_2^2\right)\dots\lambda D\left(q_{\varepsilon-1}^2\right)\lambda_b =$$

$$= \lambda_a\lambda_b\lambda^{\varepsilon-2}\prod_{k=1}^{\varepsilon-1} D(q_k^2), \tag{1}$$

where λ, λ_a, λ_b — effective couplings for a diagram vertex, $D(q_k^2)$ — effective propagators of virtual particles (here we take into account the possible vertex dependence on particle momenta at every vertex).

Since a propagator in the laboratory frame depends on rapidity as

$$D(g_k^2) = D\left(y_k, -\left(\sum_{l=1}^{k}\vec{p}_{l\perp}\right)^2\right), \tag{2}$$

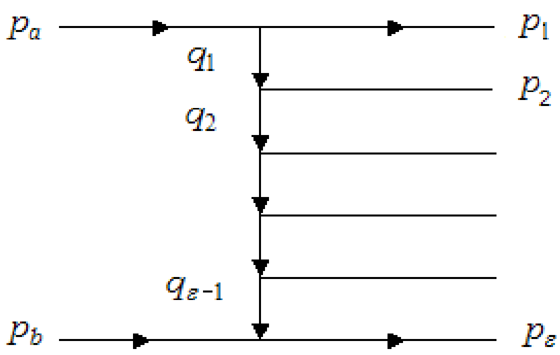

Fig.1. Comb-type diagram

where y_k is the rapidity, one can compute the contribution of this diagram to the inelastic scattering section. Then one can obtain the probability of generating ε secondaries in this process. This probability has the Poisson form:

$$p_2(\varepsilon) = \frac{1}{\varepsilon!}\left(\frac{\lambda^2}{2(2\pi)^3}\int\limits_0^{Y_a} d\,y \int\int \left|D\left(y, -\vec{\chi}^{\,2}\right)\right|^2 d\,\vec{\chi}\right)^{\varepsilon} \times$$

$$\times \exp\left(-\left(\frac{\lambda^2}{2(2\pi)^3}\int\limits_0^{Y_a} d\,y \int\int \left|D\left(y, -\vec{\chi}^{\,2}\right)\right|^2 d\,\vec{\chi}\right)\right),$$

$$\varepsilon = 0,\, 1,\, \dots\, ,\, \infty. \tag{3}$$

This expression has a still not defined function $D(y, -\vec{\chi}^{\,2})$ that can be specified from the unitary condition.

Let's now require that the sum of contributions of comb-type inelastic processes to the imaginary part of the scattering amplitude correspond to the dipole reggeon contribution. Then

$$A(s,t) = e^{i\,\frac{\pi\alpha(t)}{2}}\left(\frac{s}{s_0}\right)^{\alpha(t)} \times$$

$$\times \left[A e^{b(\alpha(t)-1)} + \left(\ln\left(\frac{s}{s_0}\right) - i\,\frac{\pi}{2}\right) \times\right.$$

$$\left.\times\, A\left(\frac{1}{b}\,e^{b(\alpha(t)-1)} - \gamma\right)\right], \tag{4}$$

where $\alpha(t)$ is the "trajectory" of a dipole reggeon.

The first cascade distribution is expressed as

$$p_1(\nu) = \frac{1}{\nu!}\frac{F^{\nu}(\vec{p}_a,\, 0)}{e^{F(\vec{p}_a,0)} - 1} \approx \frac{1}{\nu!}F^{\nu}(\vec{p}_a, 0)e^{F(\vec{p}_a,0)}, \tag{5}$$

where $F(\vec{p}_a, 0)$ specifies the first cascade of the Poisson distribution and has the form

$$F(\vec{p}_a,\, 0) = \frac{1}{2}\int \frac{M(\vec{p}_a,\, \vec{q})}{(2\pi)^3\sqrt{m^2 + \vec{q}^{\,2}}}\, d\,\vec{q}.$$

For the full definition of expression (5), we have to assign the matrix element

$$M(\vec{p}_a,\, \vec{q}) = K\, e^{-R^2 s'}, \quad s' = \left(\vec{p}_a + \vec{q}\right)^2, \tag{6}$$

where K and R are adjusting constants. K is a characteristic vertex value for the proton radiation of primary pions and R is the characteristic dimension of the pion "coat" around the proton.

By introducing the new variables, rapidity and transverse momentum, we get the matrix element as

$$M(\vec{p}_a,\, \vec{q}) = Q\, e^{-2R^2 m_{\perp} m_a \cosh(Y_a - Y)}, \tag{7}$$

where

$$Q = K\, e^{-R^2\left(m_p^2 + m_\pi^2\right)}.$$

So we have defined the first cascade distribution.

2. Computation of a Two-cascade Distribution

Now we compute a two-cascade multiplicity distribution with the help of the dipole pomeron diagram representation. A second cascade distribution has the form:

$$p_2(\varepsilon) = \frac{1}{\varepsilon!}\left(h(\vec{q})\right)^{\varepsilon} e^{-h(\vec{q})}, \tag{8}$$

where $\vec{q}$ is the momentum of a primary pion that generates a shower.

The function $h(\vec{q})$ depends only on transverse momenta of particles (i.e. on rapidity):

$$h(Y) = \ln\left(\frac{\lambda^2 m_p m_\pi}{\pi\lambda_a^2\lambda_b^2}\right) +$$

$$+ \ln\left(A\left[1 + \left(\frac{1}{b} - \gamma\right)\ln\left(\frac{m_p m_\pi}{s_0}\right) + \left(\frac{1}{b} - \gamma\right) Y\right] \times\right.$$

$$\times e^{2Y} - \frac{A\left(\frac{1}{b}-\gamma\right)}{2}\, e^{2Y} + C\Bigg), \tag{9}$$

where A, b, γ, s_0 - the parameters of a dipole pomeron. The parameters $u = \ln\left(\frac{\lambda^2 m_p m_\pi}{\pi \lambda_a^2 \lambda_b^2}\right)$ and C are adjusting parameters of the model.

The expression for the generating function looks

$$\Phi(s) = N^{-1}\times$$

$$\times\left[\exp\left(Q\int\limits_0^\infty e^{(s-1)h(Y)}\frac{r(Y)+1}{\cosh^2(Y)}\, e^{-r(Y)} dY\right) - 1\right], \tag{10}$$

where $r(Y) = \mu\cosh(Y_a - Y)$, $\mu = R^2 m_\pi m_p$, and

$$N = \exp\left(K\int\limits_0^\infty dY\frac{r(Y)+1}{r^2(Y)}\, e^{-r(Y)}\right) - 1\,.$$

Based on the generating function, we can deduce the multiplicity distribution that can be compared with experiment.

The above expressions describe the two-cascade distribution $p(n)$ according to the multiplicity of n secondaries generated in pp and p$\bar{\text{p}}$ collisions without diffraction. Now phenomenologically we will take diffraction phenomena into account.

3. The Cascade Model with Diffraction

The diffraction mechanism consists in the following: the parton emitted by the incident proton exchanges with the target by a reggeon, see Fig. 2. As a result, the parton is "knocked out" from the proton and, having no possibility to "back" into the initial proton, decays into a group of hadrons. If the probability of the diffraction mechanism realization is denoted as D (one more adjusting parameter), then the probability of the diffraction mechanism unrealization for the multiple generation for one primary pion will be correspondingly $1-D$. As the cross section of the diffraction generation of hadrons is likely $s^{2(\alpha(0)-1)}$, then it has no energy dependence in the case of the pomeron exchange and therefore D has to be energy independent too. The average number of secondary hadrons $\langle n_d\rangle$, which were generated by one initial parton within the diffraction mechanism, will be considered as another adjusting parameter.

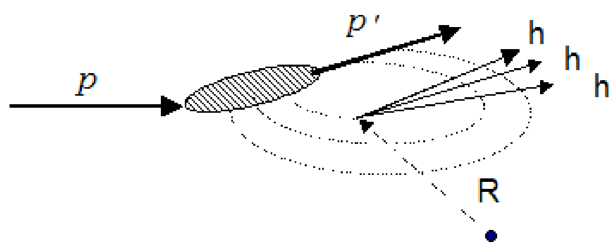

Fig.2. Diffraction mechanism of the production of secondary hadrons

Then the total probability of the generation of ε secondary hadrons by one initial parton is

$$p(\varepsilon) = D\frac{\langle n_d\rangle^\varepsilon}{\varepsilon!}e^{-\langle n_d\rangle} + (1-D)\frac{(h(y))^\varepsilon}{\varepsilon!}e^{-h(y)}. \tag{11}$$

The generating function of the cascade distribution with diffraction has the following form:

$$\Phi(s) = A\Bigg[\exp\Bigg(\int\Bigg(D\, e^{\langle n_d\rangle(s-1)} +$$

$$+(1-D)\, e^{2y(s-1)}\Bigg)dy\Bigg) - 1\Bigg], \tag{12}$$

where

$$A = \frac{1}{\exp\left(\int\limits_0^\infty f(y)dy\right) - 1}, \quad Q = \frac{K}{(m_p R^2)^2},$$

$$f(y) = Q\frac{\mu\cosh(Y_a - y) + 1}{\cosh^2(Y_a - y)}\, e^{-\mu\cosh(Y_a - y)}.$$

The results of computation of $p(n)$ with taking diffraction into account for some values of the energy of incident protons are illustrated in Fig. 3. As seen, the additional consideration of diffraction improves the agreement with experiment, see [7,8].

Summary

1. We have obtained the two-cascade multiplicity distribution of secondaries that were generated in proton-proton and proton-antiproton collisions with and without diffraction.

2. Reasonable agreement of computations with experimental data is obtained.

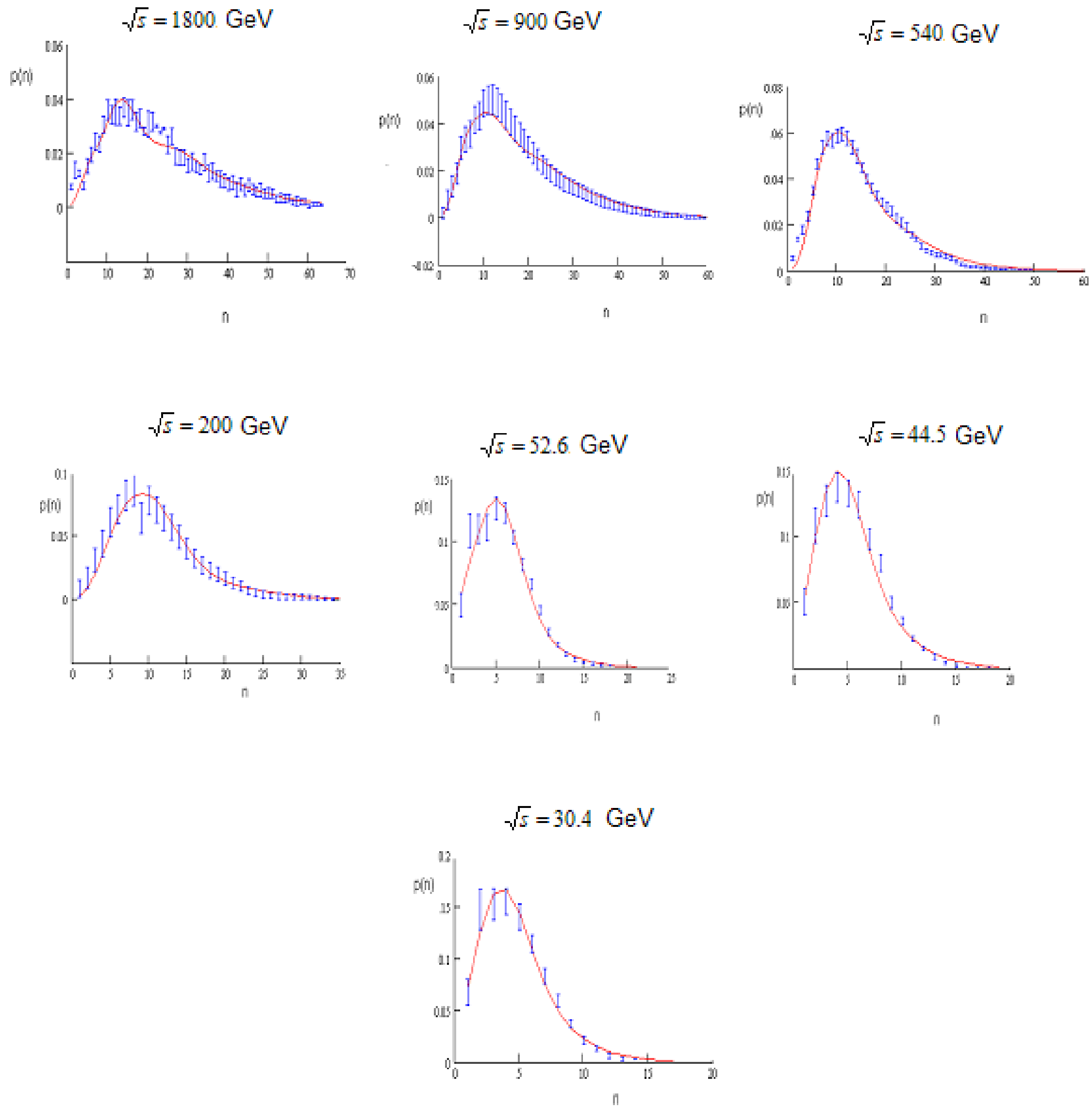

Fig.3. Comparison with experimental data

3. The distribution parameters connected with effective coupling have characteristic point at a collision energy of 200 GeV.

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НАРОДЖЕННЯ АДРОНІВ
ПРИ ВИСОКИХ ЕНЕРГІЯХ В МОДЕЛІ ДИПОЛЬНОГО
ПОМЕРОНА З УРАХУВАННЯМ ДИФРАКЦІЙНИХ ЯВИЩ

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Р е з ю м е

В межах моделі дипольного померона розглянуто множинне утворення адронів при високоенергетичному непружному pp- та p$\bar{\text{p}}$-розсіянні. Розраховані двокаскадні розподіли по множинності вторинних адронів з урахуванням та без урахування дифракційних явищ. Результати розрахунків задовільно узгоджуються з експериментом.

РОЖДЕНИЕ АДРОНОВ
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Р е з ю м е

В рамках модели дипольного померона рассмотрено множественное рождение адронов при высокоэнергетическом неупругом pp- и p$\bar{\text{p}}$-рассеянии. Рассчитаны двухкаскадные распределения по множественности вторичных адронов с учетом и без учета дифракции. Результаты расчетов удовлетворительно согласуются с экспериментом.