Are multiple parton interactions important at high energies? New types of hadrons production processes

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Hadrons interaction at high energies is carried out by one color gluon exchange. All quarks and gluons contained in colliding hadrons take part in interaction and production of particles. The contribution of multiple parton interactions is negligible. Multiple hadrons production at high energies occurs only in three types of processes. The first process is hadrons production in gluon string, the second is hadrons production in two quark strings and the third is hadrons production in three quark strings. In proton-proton interaction production of only gluon string and two quark strings is possible. In proton-antiproton interaction production of gluon string, two quark strings and three quark strings is possible. Therefore multiplicity distributions in proton-proton and proton-antiproton interactions are different.

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I. INTRODUCTION

We will consider possible types of processes (or, more accurately, subprocesses) of hadrons production that give contribution to multiple production. The main picture of hadrons interaction at high energies in the last 40 years is picture of multiple interactions. It is based on Gribov reggeon theory [1] in which hadrons interaction is described by multiple reggeon exchange between components of hadrons. Many experimental data were described in this theory. It is important for us that absorbtive parts of every reggeon diagram correspond to definite type of inelastic process, namely to multiple pomeron showers. These sub-processes widen multiplicity distribution function of secondary hadrons \( P_n = \sigma_n/\sigma_{tot} \) and in idealized case at asymptotic high energies lead to oscillations [2]. This behavior is characteristic to any models of multiple scattering no matter how they are named or what hadrons constituents are discussed.

The low Constituents Number Model (LCNM) was proposed in 1980 [3]. Introduction of this model was caused by the fact that it is impossible to adjust low reduction of elastic scattering diffractive cone with energy increase and large mean multiplicity in models, based on cascades of particles both colorless and quarks and gluons.

II. LCNM AND QUASI-EIKONAL APPROACH

In the LCNM gluons density in rapidity space is low in wave function of initial state and real hadrons are produced by decay of tubes (strings) of color field. Interaction results from gluon exchange, hadrons gain color charge. Color field tube is formed between flying hadrons and than it decays to secondary hadrons. Since transverse gluons have sense only in region of weak connection \( \alpha_s(k_{g\perp}^2) \ll 1 \) then values of transverse momenta of these gluons are large, \( k_{g\perp} \sim 2 \text{ GeV} \). So probability of gluon appearance in spectrum of projectiles is low and thus smallness of \( \alpha'_p \) is explained.

It was shown in [4] that total cross sections of \( pp \) and \( p\bar{p} \) are well described in LCNM by contributions of initial state configurations corresponding to only valent quarks, valent quarks with one or two additional gluons.

\[
\sigma_{tot}^{p(p)p} = 63.52 s^{-0.358} \pm 35.43 s^{-0.56} + \sigma_0 + \sigma_1 \ln s + \sigma_2 (\ln s)^2 \tag{1}
\]

The values of parameters are \( \sigma_0 = 20.08 \pm 0.42, \sigma_1 = 1.14 \pm 0.13, \sigma_2 = 0.16 \pm 0.01 \).
Model parametrization of multiple exchange is quasi-eikonal model in which formula of total cross section can be written as

\[ \sigma_{\text{tot}} = \frac{8\pi(\alpha'_{p}\ln s + R^2)} {c} F\left(\frac{z}{2}\right), \]  

where \( F(z) = \sum_{m=1}^{\infty} (-1)^{m-1} z^m / (m \cdot m!) \), \( z/2 = g^2s^2\Delta c/(8\pi(\alpha'_{p}\ln s + R^2)) \).

We place parameters corresponding to the following sets [5]

I. \( \Delta = \alpha_{p}(0) - 1 = 0.21, \quad g^2/8\pi = 1.5 \text{ GeV}^{-2} \);
II. \( \Delta = \alpha_{p}(0) = 0.12, \quad g^2/8\pi = 2.4 \text{ GeV}^{-2} \);
III. \( \Delta = \alpha_{p}(0) = 0.07, \quad g^2/8\pi = 3.64 \text{ GeV}^{-2} \),

and \( c = 1.5, \alpha'_{p} = 0.25 \text{ GeV}^{-2}, \quad R^2 = 3.56 \text{ GeV}^{-2} \).

These corresponding graphs are presented in Fig. 1, data were taken from [6].

The differential cross section of elastic scattering at high energies (\( \sqrt{s} \geq 53 \text{ GeV} \)) in LCNM is described as following

\[ \frac{d\sigma^{el}}{dt} = \frac{1}{16\pi} \left[ \sigma_0 + \sigma_1 \ln s + \sigma_2 (\ln s)^2 \right]^2 \times \]  

\[ \times \left( 1 + \rho^2 \right) \exp\left\{ -(B(s)|t|) \right\} \]  

(3)

Experimental data at \( \sqrt{s} = 53, 62, 546, 1800 \text{ GeV} \) [7] were fitted using this formulae. Only parameter \( B(s) \) was varied.

In quasi-eikonal model \( d\sigma^{el}/dt \) is defined as follows

\[ \frac{d\sigma^{el}}{dt} = \frac{4\pi(\alpha'_{p}\ln s + R^2)^2} {c^2} \left[ \sum_{m=1}^{\infty} (-1)^{m-1} (z)^m (m \cdot m!) \right] \times \]  

\[ \times \exp\left\{ -\left( \frac{(\alpha'_{p}\ln s + R^2)} {m} \right)|t| \right\} \]  

(4)

We took parameters from II set which give good description of total cross sections. The comparison of fits is given in Fig. 2 and 3.

Values of \( B(s) \) obtained from fitting of
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\[ \frac{d\sigma^{el}}{dt} \] were then fitted by quadratic function with the following parameters

\[ B(s) = 7.12 + 0.34 \ln s + 0.02 \ln^2 s. \]

Elastic cross sections at high energies are described by the following formulae in LCNM (5) and quasi-eikonal (6).

\[ \sigma^{el} = \frac{1}{16\pi} \left( \sigma_0 + \sigma_1 \ln s + \sigma_2 \ln^2 s \right)^2 B(s) \] (5)

\[ \sigma^{el} = \frac{4\pi(\alpha')^2 \ln s + R^2}{c^2} \left[ 2F\left(\frac{z}{2}\right) - F(z) \right] \] (6)

Graphs are shown in Fig. 4. Thus we can state that LCNM gives better description of experimental data than the best set of parameters in quasi-eikonal approach.

**III. GLUON STRING**

There are no other characteristic sizes for configuration with only valence quarks but hadrons sizes. Value of chromodynamics constant \( \alpha_s \) is large at these sizes. After color gluon exchange two objects with gluon charges move apart, their sizes coincide with colliding hadrons sizes. Large number of gluons is produced in gluon string because of running constant \( \alpha_s \) large value. This process can be shown in diagrams like the one shown in Fig. 5. Gluon pairs production continues until pair masses approaches hadrons masses. There is no suppression on energy because exchange is of vector type. All these diagrams have the same order of magnitude in given order of coupling constant and every one of them corresponds to definite final hadrons state. Number of these diagrams is infinite in principle. Hence secondary hadrons multiplicity in final state as random variable has to obey normal distribution because of central limit theorem of probability theory.

**IV. QUARK STRING**

In configuration with one and two transverse gluons scale is defined by large transverse momentum \( k_T^2 \approx 2 \text{ GeV} \) and running constant \( \alpha_s \) is low. Quarks in moving apart hadrons are greatly separated and quark strings are produced. Quark-antiquark pairs produced in string field are virtual and they come out on mass shell by tunneling. Momenta of these quarks appearing at mass shell are equal to zero in center-of-mass system of moving apart quarks. The break-up of string in models of Lund type is schematically described by diagram in Fig. 6a. Let us associate this diagram to diagram in Fig. 6b. Diagram is Lorenz invariant, that is in any reference system string break-up begins from slow quarks. Color and spin correlations are essential. So secondary hadrons multiplicity distribution will vary from Poisson and normal distributions.

Transverse sizes of string arising in configurations with one and two gluons are small because they have to consume these gluons. Let us consider \( pp \) scattering. One additional gluon is consumed by quark string arising between quark and diquark thereby the second quark string is allocated. Corresponding inelastic process is hadrons production in two indepen-
dent quark strings. Since in \( pp \) interaction quark strings production is possible only between quark and diquark, configuration with two additional quarks leads to the same result.

In \( pp \) interaction configuration with one gluon leads to hadrons production in two quark strings. Also there is the same process of hadrons production in two quark strings when two gluons are consumed by the same quark string. However, if two gluons are consumed by different quark strings, they allocate the third quark string thereby. So one more type of inelastic process is possible in \( pp \) interaction, it is hadrons production in three quark strings.

We would like to stress out that there are no other inelastic processes. There have to be four additional gluons in initial state in order to produce two pomeron showers. Probability of this is negligible.

In this way there are three types of inelastic processes at high energies: 1) hadrons production in gluon string; 2) hadrons production in two quark strings; 3) hadrons production in three quark strings. There are no other processes in our opinion.

V. SINGLE DIFFRACTION CROSS SECTION

In LCNM single diffraction to large masses can be described as follows. From all possible gluon exchanges on Fig. 7a we will choose the one that leads to colorless configuration from three leading quarks. Color string arises between system of three antiquarks and additional gluon. It is double quark string.

Diagrams in Fig. 7a and 7b correspond to spectrums \( dn/dy \), \( y \) means rapidity, in figures Fig. 7d and 7e. In Fig. 7e beam with large mass \( M \) and beam of small mass \( \mu \) from diffractive proton are shown. If three quarks system does not diffract then leading proton arises, which is shown in Fig. 7c, spectrum is shown in Fig. 7f.

Value of diffractive gap in rapidity space is defined by energy of additional gluon \( \omega \), which has spectrum \( d\omega/\omega \). This corresponds to three pomerons term in inclusive transverse cross section

\[
\frac{d^2\sigma}{dtdM^2} \sim \frac{1}{1 - x}.
\]

A qualitative result comes after this assumption. Multiplicity distribution in diffractive beam will be different from multiplicity distributions in \( pp \) and \( pp \) interactions.

Quite evidently that contribution from diagram in Fig. 7b equals to contribution from diagram in Fig. 7c multiplied by coefficient of shower enhancement proposed by Kaidalov. Moreover, since only one gluon from eight in Fig. 7a gives colorless quark system, then contribution from diagram in Fig. 7c equals to one twelfth contribution from diagram in Fig. 7a. The same arguments are correct to configuration with two additional gluons.

We estimate the upper limit of \( \sigma^{sd} \) by taking one twelfth from contributions to total cross sections of configurations with one and two addi-
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FIG. 7: Color diagrams and rapidity spectrums

FIG. 8: Fitting of $\sigma^{sd}$ of $pp$ and $p\bar{p}$ collisions in LCNM

\[ \sigma^{sd} = \sigma^{sd}_0 + \frac{1}{12} \sigma^{tot}_1 \ln s + \frac{1}{12} \sigma^{tot}_2 (\ln s)^2, \]
\[ \sigma^{sd}_0 \simeq 4.2 \text{ mb}, \quad \sigma^{sd} \simeq 11 \text{ mb at 14 TeV} \]

Configuration with one additional gluon corresponds to super hard component $\delta(1-z)$ in pomeron structure function, since all longitudinal momentum that is used for diffractive beam production is carried by gluon; $z$ - part of pomeron momentum carried by gluon.

Configuration with two additional gluons corresponds to hard component $z(1-z)$.

[1] Gribov V.N. Sov.Phys.JETP (1968) 26:414-422.
[2] Abramovsky V.A., Kancheli O.V. (1972) Pisma Zh.Eksp.Teor.Fiz.15:559-563
[3] Abramovsky V.A., Kancheli O.V. (1980) JETP Letters 31:566-569, 32:498-501.
[4] Abramovsky V.A., Radchenko N.V. (2009) Particles and Nuclei, Letters 6:607-619 (in russian).
[5] Kaidalov A.B., Ter-Martirosyan K.A. (1984) Sov.J.Nucl.Phys. 40:135-140; Kaidalov A.B., Ponomarev L.A., Ter-Martirosyan K.A. (1986) Sov.J.Nucl.Phys. 44:468-471.
[6] Amsler C. et al. (2008) Phys. Lett. B 667:1-6.
[7] Breakstone A. et al. (1984) Nucl. Phys. B 248:253-260; Amos N. et al. (1985) Nucl. Phys. B 262:689-714; Bozzo M. et al. (1984) Phys. Lett. B 147:385-391; Bozzo M. et al. (1985) Phys. Lett. B 155:197-202; Bernard D. et al. (1987) Phys. Lett. B 198:583-589; Abe F. et al. (1994) Phys. Rev. D 50:5518-5554; Amos N. et al. (1990) Phys. Lett. B 247:127-130.
[8] Armitage J.C.M. et al. (1982) Nucl. Phys. B 194:365-372; Barish S. et al. (1974) Phys. Rev. D 9:2689-2691; Ansorge R.E. et al. (1986) Z. Phys. C 33:175-185; Shamberger R.D. et al. (1975) Phys. Rev. Lett. 34:1121-1124; Aler G.J. et al. (1987) Phys. Rept. 154:247-283; Bernard D. et al. (1987) Phys. Lett. B 186:227-232; Amos N.A. et al. (1993) Phys. Lett. B 301:313-316; Abe F. et al. (1994) Phys. Rev. D 50:5535-5549.