PHYSICAL REVIEW C **84**, 045203 (2011)

Nuclear attenuation of high-energy multihadron systems in a string model

L. Grigoryan*
Yerevan Physics Institute, Brothers Alikhanian 2, 375036 Yerevan, Armenia
(Received 9 June 2011; published 11 October 2011)

Nuclear attenuation of the multihadron systems in the string model is considered. The improved two-scale model with a set of parameters obtained recently for the single-hadron attenuation is used to calculate the multiplicity ratios of the one-, two-, and three-hadron systems electroproduced on nuclear and deuterium targets. A comparison of the features of the one-, two-, and three-hadron systems is performed. The predictions of the model for multiplicity ratios of multihadron systems as functions of different convenient variables are presented.

DOI: 10.1103/PhysRevC.84.045203 PACS number(s): 13.87.Fh, 13.60.Le, 21.65.−f

I. INTRODUCTION

In any hard process an initial interaction takes place between partons, which then turn into the final hadrons by means of the hadronization process. However, the hadronization process cannot be described in the framework of the existing theory of the strong interactions (perturbative QCD) because of the essential role of the "soft" interactions. Therefore, the experimental and theoretical (on the level of phenomenological models) studies of all the aspects of the transition from partons to hadrons are very important. The space-time evolution of the hadronization process, despite its importance, has been studied relatively little. The study of the early stage of the hadronization process can shed additional light on the further development of the process. Semi-inclusive reactions with nuclear targets give a possibility to study the development of the hadronization process on distances of a few Fermi from the point of initial interaction.

In particular, the nuclear attenuation (NA) of the high-energy hadrons is the well-known tool for investigation of the early stage of the hadronization process.[1] There are many phenomenological models, which describe, rather qualitatively, existing experimental data for single-hadron NA [1–11]. Also some predictions were done for the attenuation of multihadron systems leptoproduced in nuclear matter in the framework of the string model [12,13]. It was argued that measurements of NA of multihadron systems can remove some ambiguities in the determination of the parameters describing strongly interacting systems at the early stage of particle production: formation time of hadrons and the cross section for the intermediate state to interact inside the nucleus. Then, the data were obtained using the multiplicity ratio of the two-hadron system in electroproduction [14]. The experiment was performed in specific conditions. The multiplicity ratio of the charged hadrons was measured as a function of the fractional energy of the subleading hadron z_2, whereas over the fractional energy of the leading hadron z_1 the integration in the region $0.5 < z_1 < 1 - z_2$ was performed. Later, the data on the ratio of the multiplicities of the two-hadron system in neutrino production were presented by another experiment [15].

The data on the ratio of the multiplicities of the two-hadron system [14] were described in the framework of some theoretical models: the probabilistic coupled-channel transport model [16], the so-called energy-loss model [17], and the string model [18]. In particular, we showed [15,18] that, based on the two-scale model (TSM) [4] and improved two-scale model (ITSM) [10], it is possible to describe these data quantitatively in the framework of the string model. We presented also predictions for the dependence of the NA of the two-hadron system on the virtual photon's energy in the same model. The possible mutual screening of the hadrons occurring from the same string and its experimental verification were discussed.

In this work we continue to study the electroproduction of multihadron systems in cold nuclear matter. The main goal of the present paper is to consider the mutual screening of the prehadrons and hadrons in string (jet).[2] We compare one-, two-, and three-hadron systems and show that the mutual screening of prehadrons and hadrons plays an essential role and can be measured experimentally. For instance, such data can be obtained from the HERMES experiment, SKAT experiment, and JLab after upgrading to an energy of 12 GeV. We suppose that the investigation of the mutual screening of prehadrons and hadrons in cold nuclear matter can help to establish initial conditions for the study of similar processes in hot nuclear matter arising at high energies in hadron-nucleus and nucleus-nucleus interactions at the BNL Relativistic Heavy Ion Collider (RHIC) and CERN Large Hadron Collider (LHC).

This paper is organized as follows. In Sec. II the theoretical framework is briefly described. Results and discussion as well as the necessary ingredients for calculations are presented in Sec. III. Our conclusions are given in Sec. IV.

II. THEORETICAL FRAMEWORK

In Refs. [12,13] the process of leptoproduction of multihadron systems on a nucleus with atomic mass number A was considered theoretically. Although in these papers discussions were presented for the general case of the n hadrons observed in the final state and some formulas were

*leva@mail.desy.de

[1]NA is the difference of the ratio of the multiplicities (per nucleon) on the nucleus to those on deuterium R_M^h from unity, i.e., $1 - R_M^h$.

[2]The term "string" here means the object arising because of deep inelastic scattering (DIS), which, during its space-time evolution, turns into states consisting of strings, prehadrons, and hadrons. After all this, the object turns into the jet of hadrons.

written for this general case, the basic formulas and numerical calculations were performed for the case of two observed hadrons. In this work we take the next step in this direction and consider three-hadron systems observed in the final state of the high-energy semi-inclusive lepton-nucleus interactions.

We do not give the equations for the cases of one and two hadrons, which also will be used for calculations and discussions in here because the conversion of these formulas to the cases of one and two hadrons is very simple. The semi-inclusive reaction of the leptoproduction of three hadrons on a nuclear target is

$$l_i + A \to l_f + h_1 + h_2 + h_3 + X, \tag{1}$$

where l_i (l_f) is the initial (final) lepton and h_1, h_2, and h_3 are the observed hadrons. The hadrons h_1, h_2, and h_3 carry fractions z_1, z_2, and z_3 of the total available energy (the energy conservation implies the condition $z_1 + z_2 + z_3 \leqslant 1$). The multiplicity ratio for that process is defined as (it is assumed that averagings over transverse momenta of the final hadrons are performed)

$$R_M^{3h} = \frac{2d\sigma_A(\nu, Q^2, z_1, z_2, z_3)}{Ad\sigma_D(\nu, Q^2, z_1, z_2, z_3)}, \tag{2}$$

where $d\sigma_A$ and $d\sigma_D$ are the cross sections for reaction (1) on the nuclear and deuterium targets, respectively, ν denotes the energy of the virtual photon, and $Q^2 = -q^2$, where q^2 is the square of the four-momentum of the virtual photon. One can imagine reaction (1) as shown in Fig. 1. The interaction of the lepton with the intranuclear nucleon occurs at the point (b, x) from which the intermediate state q begins its propagation (b and x are the impact parameter and the longitudinal coordinate of the DIS point, respectively). Initially, the intermediate state q presents itself as an object like a string with a knocked-out quark on the fast end and a nucleon remnant on the slow end, which are connected by means of a string consisting of gluons. During further movement the string breaks into smaller pieces, and as a result at the points (b, x_{c1}), (b, x_{c2}), and (b, x_{c3}) the first constituents (valence quarks or antiquarks) of the hadrons h_1, h_2, and h_3 are produced, and at the points (b, x_1), (b, x_2), and (b, x_3) the second constituents are produced, and the yo-yos of the hadrons h_1, h_2, and h_3 arise (the term "yo-yo"

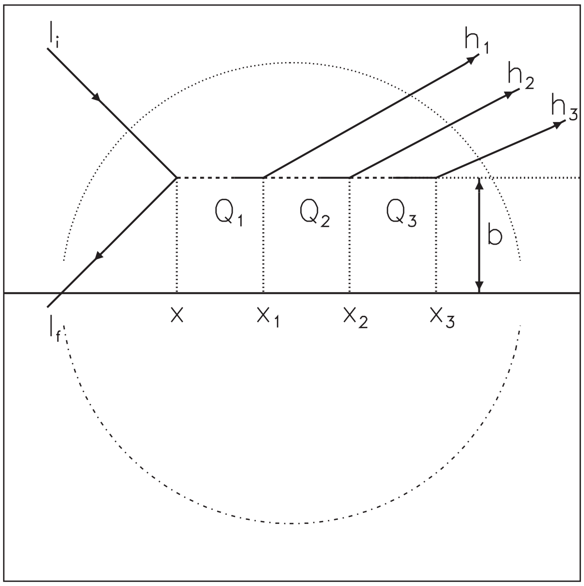

FIG. 1. Leptoproduction of three-hadron system on a nuclear target. For details see the text.

means that the colorless system with valence contents and quantum numbers of the final hadron is formed, but without its "sea" partons). The points (b, x_{c1}), (b, x_{c2}), and (b, x_{c3}) are not represented in Fig. 1, but they are used properly in the calculations. In Fig. 1, for the sake of simplicity, we represent the case of three adjacent hadrons. In fact, all the possibilities have been considered in the calculations with both adjacent and nonadjacent hadrons.

We do not take into account the hadrons produced as a result of the decay of the resonances. This factor could lead to an increase in nuclear attenuation if taking into account only one hadron from each resonance and a decrease in nuclear attenuation if taking into account that two or three hadrons can be produced from the same resonance. We think that the overall effect is small.

In the string model there are simple connections between the above-mentioned points $x_1 - x_{c1} = z_1 L$, $x_2 - x_{c2} = z_2 L$, and $x_3 - x_{c3} = z_3 L$, where L is the full hadronization length, $L = \nu/\kappa$, and κ is the string tension ($\kappa = 1$ GeV/fm). The multiplicity ratio for the case of three hadrons observed in the final state can be presented in the form

$$\begin{aligned}
R_M^{3h} \approx \frac{1}{6}\int d^2b \int_{-\infty}^{\infty} dx \int_x^{\infty} dx_1 \int_{x_1}^{\infty} dx_2 \int_{x_2}^{\infty} dx_3 \rho(b,x)[D(z_1, z_2, z_3, x_1 - x, x_2 - x, x_3 - x)\\
\times W_0(h_1, h_2, h_3; b, x, x_1, x_2, x_3) + D(z_1, z_3, z_2, x_1 - x, x_2 - x, x_3 - x)\\
\times W_0(h_1, h_3, h_2; b, x, x_1, x_2, x_3) + D(z_2, z_1, z_3, x_1 - x, x_2 - x, x_3 - x)\\
\times W_0(h_2, h_1, h_3; b, x, x_1, x_2, x_3) + D(z_2, z_3, z_1, x_1 - x, x_2 - x, x_3 - x)\\
\times W_0(h_2, h_3, h_1; b, x, x_1, x_2, x_3) + D(z_3, z_1, z_2, x_1 - x, x_2 - x, x_3 - x)\\
\times W_0(h_3, h_1, h_2; b, x, x_1, x_2, x_3) + D(z_3, z_2, z_1, x_1 - x, x_2 - x, x_3 - x)\\
\times W_0(h_3, h_2, h_1; b, x, x_1, x_2, x_3)] \div \frac{1}{6}\int_x^{\infty} dx_1 \int_{x_1}^{\infty} dx_2 \int_{x_2}^{\infty} dx_3
\end{aligned}$$

$$\times [D(z_1, z_2, z_3, x_1 - x, x_2 - x, x_3 - x) + D(z_1, z_3, z_2, x_1 - x, x_2 - x, x_3 - x) + D(z_2, z_1, z_3, x_1 - x, x_2 - x, x_3 - x) + D(z_2, z_3, z_1, x_1 - x, x_2 - x, x_3 - x) + D(z_3, z_1, z_2, x_1 - x, x_2 - x, x_3 - x) + D(z_3, z_2, z_1, x_1 - x, x_2 - x, x_3 - x)], \quad (3)$$

where $D(z_1, z_2, z_3, l_1, l_2, l_3)$ (with $l_1 < l_2 < l_3$) is the distribution of the constituent formation lengths l_1, l_2, and l_3 of the hadrons and $\rho(b, x)$ is the nuclear density function normalized to unity. W_0 is the probability that neither the hadrons h_1, h_2, h_3 nor the intermediate states leading to their production (initial strings) interact inelastically in nuclear matter:

$$W_0(h_1, h_2, h_3; b, x, x_1, x_2, x_3) = (1 - Q_1 - \{H_1 + Q_2 + H_2 + Q_3 + H_3 - H_1[Q_2 + H_2 + Q_3 + H_3 - H_2(Q_3 + H_3)] - H_2(Q_3 + H_3)\})^{(A-1)}, \quad (4)$$

where Q_1, Q_2, and Q_3 are the probabilities for the initial strings of the corresponding hadrons to be absorbed in the nucleus within the intervals (x, x_1), (x_1, x_2), and (x_2, x_3), respectively. H_i $(i = 1, 2, 3)$ is the probability for h_i to interact inelastically in nuclear matter, starting from point x_i. The probabilities $Q_1, Q_2, Q_3, H_1, H_2, H_3$ can be calculated using the general formulas:

$$P(x_{\min}, x_{\max}) = \int_{x_{\min}}^{x_{\max}} \sigma_P \rho(b, x) dx, \quad (5)$$

where the subscript P denotes the particle (initial string or hadron), σ_P is its inelastic cross section on the nucleon target, and $x_{\min}$ and $x_{\max}$ are the end points of its path in the x direction, as shown in Fig. 1.

We use the scaling function of the standard Lund model for calculations. The simple form of this function $f(z) = (1 + c)(1 - z)^c$, where $c \approx 0.3$ is the parameter that controls the steepness of the standard Lund model's fragmentation function, allows us to sum the sequence of produced hadrons over all the ranks and to obtain the analytic expression for any number of particles observed in the final state. In the general case of n hadrons the distribution $D(z_1, \ldots, z_n; l_1, \ldots, l_n)$ of the constituent formation lengths $l_1, \ldots, l_n$ is

$$D(z_1 \cdots z_n; l_1 \cdots l_n) = L^n (1 + c)^n \frac{(l_1 \cdots l_n)^c}{[(l_1 + z_1 L) \cdots (l_n + z_n L)]^{1+c}} \times \left[\delta(l_n - (1 - z_n)L) + \frac{1 + c}{l_n + z_n L}\right] \times \left[\delta(l_n - l_{n-1} - z_{n-1} L) + \frac{1 + c}{l_{n-1} + z_{n-1} L}\right] \cdots \left[\delta(l_2 - l_1 - z_1 L) + \frac{1 + c}{l_1 + z_1 L}\right], \quad (6)$$

where $l_n \leqslant (1 - z_n)L$, $l_{n-1} \leqslant l_n - z_{n-1}L, \ldots,$ and $0 \leqslant l_1 \leqslant l_2 - z_1 L$. Equation (6). was obtained in Ref. [13]. Unfortunately, the corresponding equation (2.21) from Ref. [13] contains some mistakes and uncertainties.

III. RESULTS AND DISCUSSION

The production of multihadron systems depends on many variables. This complicates the study of such systems. For example, in the electroproduction process, when in the final state n hadrons are observed, even after averaging over the virtuality of photon and transverse momenta of hadrons, the ratio of multiplicities depends on $n + 1$ variables (the fractional energies of hadrons and energy of photon). Although we restrict ourselves in this paper to three hadrons observed in the final state, the simultaneous consideration of four variables is a very difficult task, especially in experimental study. We escape this difficulty by including some additional averagings. We consider the following combinations of fixed and averaged values of variables: (i) The dependence on the fractional energy of one of the hadrons, the "trigger" hadron z_{tr}, is studied, where integrations are performed over the fractional energies of other hadrons, and the energy of virtual photon ν is kept at a fixed value (in this paper it is fixed at a value of 10 GeV). (ii) The dependence on the number of observed hadrons n is studied, where the integrations are performed over some regions of z_{tr}, and ν is kept fixed. (iii) The ν dependence is studied at a fixed value of the "trigger" hadron fractional energy $z_{tr} = 0.3$. (iv) The dependence on the fractional energy of the multihadron system $Z = \sum_{i=1}^{n} z_i$ is studied, where z_i is the fractional energy of ith hadron and $n = 1, 2, 3$ is the number of hadrons observed in the final state. (v) The dependence on n is studied, where the fractional energies of all the observed hadrons are integrated in the region $0.1 < z < 0.33$.

At present it is assumed that hadrons produced from the same string attenuate independently (full attenuation). This seems strange for the following reason. String has transverse dimensions comparable to the transverse size of the hadrons (no more). Therefore, it is natural to suppose that hadrons produced from the same string may partially screen one another, which as a result must lead to the weakness of NA (partial attenuation). To study this effect and to compare with the basic supposition that hadrons attenuate independently (full attenuation), we consider partial attenuation in the extreme case, when hadrons fully screen one another, and as a result the multihadron system attenuates as a single hadron. In accordance with the above-mentioned suppositions we consider four different cases for nuclear attenuation: (i) All the parts of the string and all the produced hadrons are absorbed in the nuclear medium independently (full attenuation). Full attenuation corresponds to Eq. (4) (in all figures, full attenuation is denoted by solid lines). (ii) Only the initial string for the first produced hadron and the first produced hadron itself attenuate (partial attenuation). Here the first produced hadron means the hadron that was produced earlier than others among all the observed hadrons. Partial attenuation corresponds to Eq. (4) with the corresponding

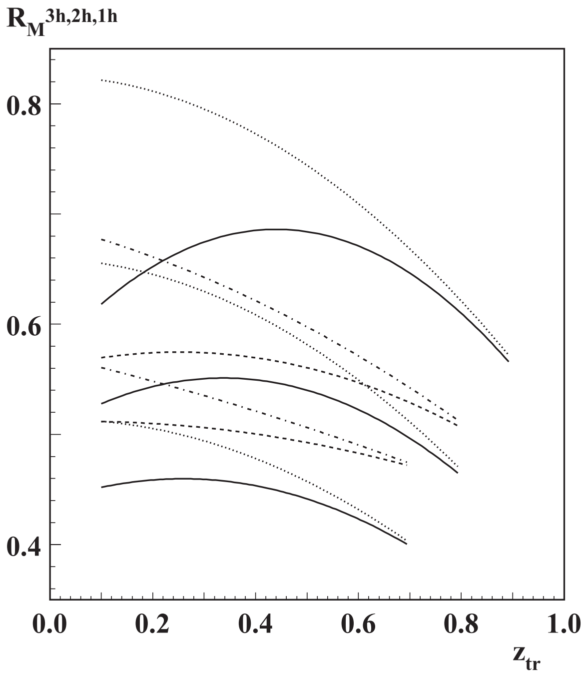

FIG. 2. Ratio $R_M^{3h,2h,1h}$ for a krypton target as a function of the fractional energy of the trigger hadron z_{tr}. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. Solid lines correspond to the case of full attenuation. From top to bottom the ratios R_M^{1h}, R_M^{2h}, and R_M^{3h} are presented, respectively. Dashed lines correspond to the case of partial attenuation. From top to bottom the ratios R_M^{2h} and R_M^{3h} are presented, respectively. Dotted lines correspond to the case of full attenuation and adjacent hadrons produced on the fast end of the string. From top to bottom the ratios R_M^{1h}, R_M^{2h}, and R_M^{3h} are presented, respectively. Dot-dashed lines correspond to the case of partial attenuation and adjacent hadrons produced on the fast end of the string. From top to bottom the ratios R_M^{2h} and R_M^{3h} are presented, respectively.

replacements $Q_2 = H_2 = Q_3 = H_3 = 0$ (in all figures, partial attenuation is denoted by dashed lines). (iii) It is supposed that n observed hadrons ($n = 1, 2, 3$) are adjacent ones and also that they are produced on the fast end of the string. It is assumed additionally that this system suffers full attenuation in nuclear matter.[3] The case of n adjacent hadrons produced on the fast end of the string corresponds to Eq. (6), where only δ functions in square brackets are taken into account (in all figures, n adjacent hadrons on the fast end of the string and full attenuation are denoted by dotted lines). (iv) Only n adjacent hadrons produced on the fast end of the string are taken into account. It is supposed also that only the initial string for the first produced hadron and the first produced hadron itself attenuate (in all figures, n adjacent hadrons on the fast end of the string and partial attenuation are denoted by dot-dashed lines).

Results of the calculations with these conditions are shown in Figs. 2–6. The nuclear density functions and the set of parameters used in the calculations were taken from our recent work [11].[4]

In Fig. 2 the multiplicity ratios $R_M^{3h,2h,1h}$ for a krypton target as a function of the fractional energy of the trigger hadron z_{tr} are presented. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. Solid lines correspond to the case of random selection of hadrons from the jet and full attenuation. From top to bottom the ratios R_M^{1h}, R_M^{2h}, and R_M^{3h} are presented, respectively. Dashed lines correspond to the case of random selection of hadrons from the jet and partial attenuation. From top to bottom the ratios R_M^{2h} and R_M^{3h} are presented, respectively. Dotted lines correspond to the case of adjacent hadrons produced on the fast end of the string and full attenuation. From top to bottom the ratios R_M^{1h}, R_M^{2h}, and R_M^{3h} are presented, respectively. Dot-dashed lines correspond to the case of adjacent hadrons produced on the fast end of the string and partial attenuation. From top to bottom the ratios R_M^{2h} and R_M^{3h} are presented, respectively. From Fig. 2 it is easy to see that large values of z_{tr} ($z_{tr} \geqslant 0.7$) are very convenient for studying the mutual screening of the hadrons. For these values of z_{tr} the positions of the particles in the string do not play an essential role. Mutual screening leads to the curves corresponding to the full and partial screenings being quite substantially different. The difference for the three-particle case is more than for the two-particle case. The positions of the particles in the string become significant in the case of small values of z_{tr} ($z_{tr} \leqslant 0.3$). Particles produced on the fast end of the string are attenuated less than others. The largest difference occurs in the case of a single hadron, and the smallest difference occurs in the case of three hadrons.

In Fig. 3 the ratio R_M^{nh} for the krypton target as a function of n are presented, where $n = 1, 2, 3$ is the number of hadrons observed in the final state. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. The fractional energy of the trigger hadron is restricted in the following regions: $0.1 < z_{tr} < 0.25$ in Fig. 3(a), $0.25 < z_{tr} < 0.4$ in Fig. 3(b), $0.4 < z_{tr} < 0.55$ in Fig. 3(c), and $0.55 < z_{tr} < 0.7$ in Fig. 3(d). The fractional energies of other hadrons are integrated over kinematically allowed regions. The notations are the same as in Fig. 2. From Fig. 3 we see that in the case of $n = 1$ the study of small and medium z_{tr} [Figs. 3(a)–3(c)] can provide information about the observed hadron. In particular, is it a leading hadron or not? The term "leading hadron" means that the hadron was produced on the fast end of the string and contains a knocked-out quark. In the case of $n = 2$ it is convenient to study positions of hadrons in the string at small and medium z_{tr} [Figs. 3(a)–3(c)]. In the case of $n = 3$ the study of medium and large z_{tr} [Figs. 3(c) and 3(d)] can reveal the presence of the mutual screening in the three-particle system.

In Fig. 4 the ratios $R_M^{3h,2h,1h}$ for the krypton target as a function of the energy of the virtual photon ν are presented. The fractional energy of the trigger hadron z_{tr} is fixed at $z_{tr} = 0.3$.

[3] It is supposed that the n hadrons observed in the final state are neighbors over the time of production, i.e., additional hadrons are not produced between them. The phrase "hadrons produced on the fast end of the string" means a sequence of hadrons having the lowest ranks in the string.

[4] See the functions and parameters corresponding to the minimum value of the quantitative criterium $\hat{\chi}^2$ in Table 2 of [11].

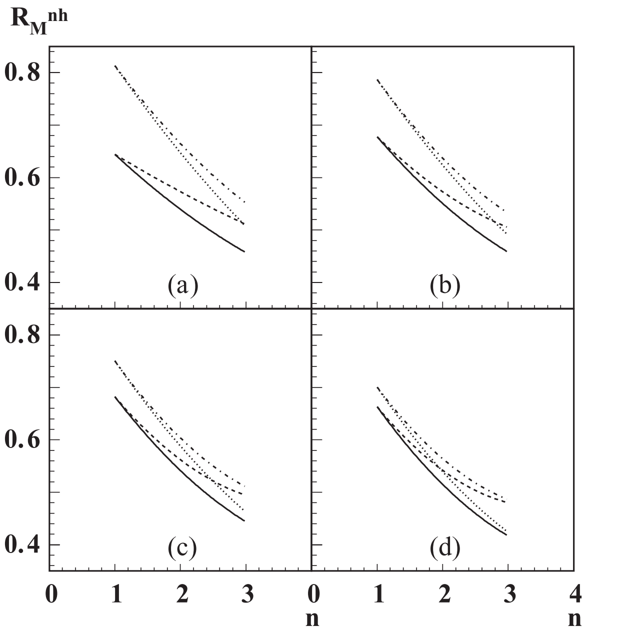

FIG. 3. Ratio R_M^{nh} for the krypton target as a function of n, where $n = 1, 2, 3$ is the number of hadrons observed in the final state. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. The fractional energy of the trigger hadron is restricted in the range (a) $0.1 < z_{tr} < 0.25$, (b) $0.25 < z_{tr} < 0.4$, (c) $0.4 < z_{tr} < 0.55$, and (d) $0.55 < z_{tr} < 0.7$. The fractional energies of other hadrons are integrated over kinematically allowed regions. The notations are the same as in Fig. 2.

The notations are the same as in Fig. 2. Figure 4 shows that our questions, (i) is attenuation full or partial and (ii) are observed particles neighbors produced on the fast end of the string or not, can be examined in the entire region considered energies. However, question (i) is convenient to consider in the region of relatively low energies ($\nu \sim 5$ GeV), and question (ii) is convenient to consider in the region of relatively high energies ($\nu \sim 20$ GeV).

In Fig. 5 the ratios $R_M^{3h,2h,1h}$ for the krypton target as a function of $Z = \sum_{i=1}^{n} z_i$, where z_i is the fractional energy of ith hadron, are presented. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. The notations are the same as in Fig. 2. Through this variable it is convenient to explore the question, are the produced particles neighbors produced on the fast end of the string or not? The behavior of the systems containing only the neighboring particles on the fast end of the string is qualitatively different from the behavior of the systems that contain them among others.

In Fig. 6 the ratios R_M^{nh} as a function of n are presented. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. The fractional energies of all the observed hadrons are integrated in the region $0.1 < z < 0.33$. The results for different nuclei are presented: helium [Fig. 6(a)], neon [Fig. 6(b)], krypton [Fig. 6(c)], and xenon [Fig. 6(d)]. The notations are the same as in Fig. 2. It is easy to see that nuclear effects are amplified with the increase in the atomic mass number A. Joint experimental study of the one-, two-, and three-hadron systems can be very helpful. We want to note that in the energy region studied in

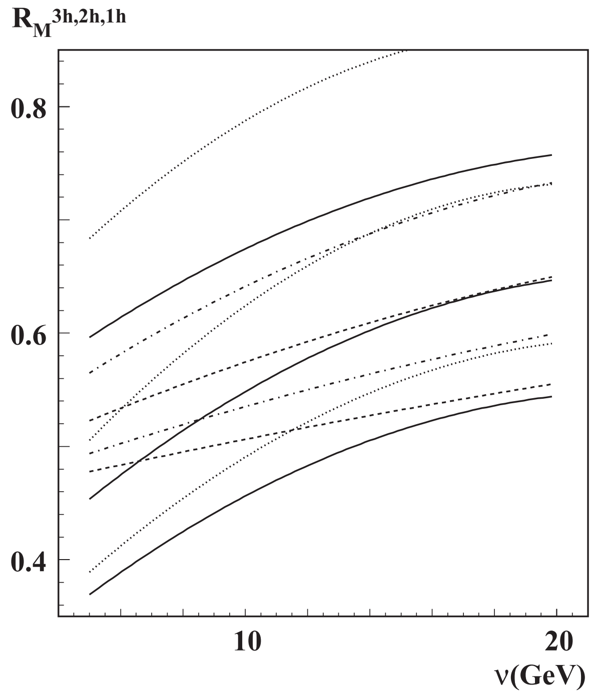

FIG. 4. Ratio $R_M^{3h,2h,1h}$ for the krypton target as a function of the energy of the virtual photon ν. The fractional energy of the trigger hadron z_{tr} is fixed at $z_{tr} = 0.3$. The notations are the same as in Fig. 2.

this work (5–20 GeV) the number of hadrons in the current fragmentation region is limited, and the probability of having among the observed hadrons two or even three adjacent ones

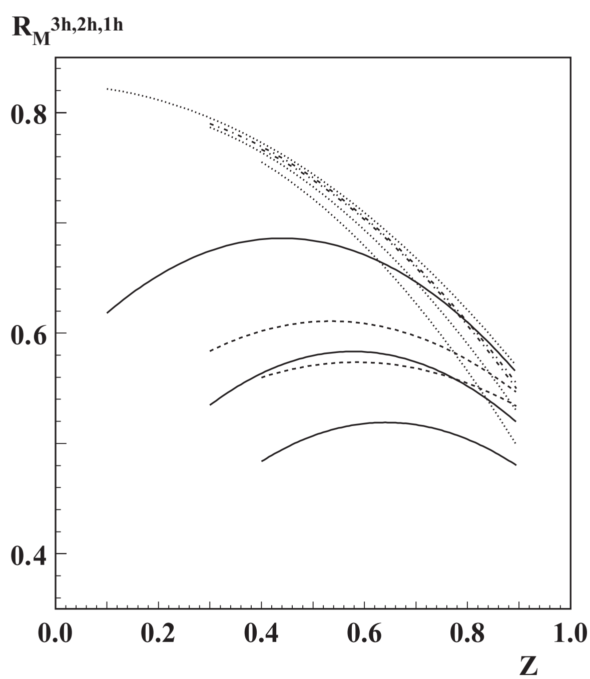

FIG. 5. Ratio $R_M^{3h,2h,1h}$ for the krypton target as a function of $Z = \sum_{i=1}^{n} z_i$, where z_i is the fractional energy of ith hadron and $n = 1, 2, 3$ is the number of hadrons observed in the final state. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. The notations are the same as in Fig. 2.

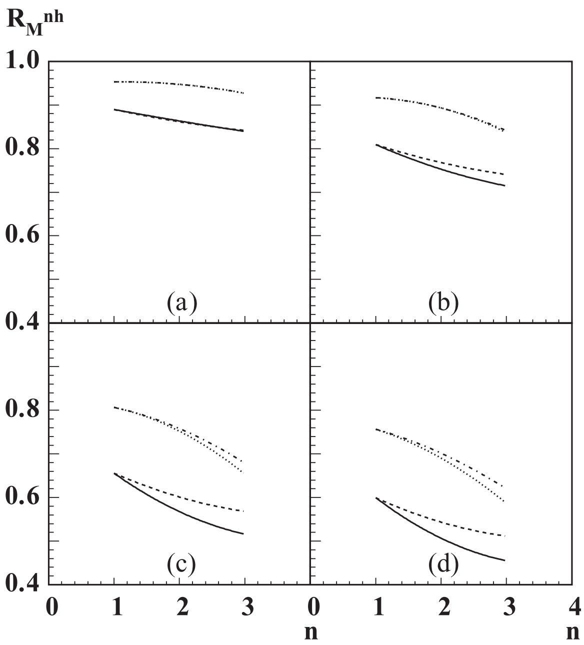

FIG. 6. Ratio R_M^{nh} as a function of n, where $n = 1, 2, 3$ is the number of hadrons observed in the final state. The fractional energies of all the hadrons are integrated in the range $0.1 < z < 0.33$. The energy of the virtual photon ν is fixed at $\nu = 10$ GeV. The results for different nuclei are presented: (a) helium, (b) neon, (c) krypton, and (d) xenon. The notations are the same as in Fig. 2.

is large. Also, it is likely that these hadrons were produced on the fast end of the string.

Also, we would like to briefly discuss why the cross section of the string-nucleon interaction may be equal to the cross section of hadron-nucleon interaction. Since the string is an object with small transverse dimensions the probability of mutual screening of the particles in the string is very large.

There are other reasons why multihadron systems can attenuate as a single hadron. The two- or three-hadron systems will attenuate as a single hadron when the final hadrons appear as a result of the decay of one resonance. For instance, combinations of two or three pions can be obtained as a result of the decay of a single vector meson that was produced in the nucleus and decayed behind it.

IV. CONCLUSIONS

In this paper the problem of the mutual screening of the prehadrons and hadrons in the string has been considered in the framework of the standard Lund model. We have shown that if the relevant data are obtained, they will allow us to assess the degree of mutual screening of the particles in the string. From our point of view, such information would be very useful for understanding the behavior of jets in high-energy hadron-nucleus and nucleus-nucleus interactions. Unfortunately, many questions remained beyond the scope of this work: (i) How strongly do the results depend on the chosen model? As mentioned above, a simple formula for the scaling function in the standard Lund model allows us to obtain expressions for any number of hadrons in a compact form. Such a compact expression cannot be obtained in the case of more complex scaling functions (for instance, a symmetric Lund's model scaling function). (ii) How do the results change if we consider different kinds of hadrons having different charges and cross sections? We can choose a combination of particles that cannot be neighbors in the string or that have very different cross sections. Experimental study of such combinations can be very useful for the development of the model. (iii) How do the results change if we consider that two or three hadrons could be produced as a result of the decay of the single resonance? Above we tried qualitatively to answer this question, but a quantitative study is needed. (iv) In this work the basic case was considered, where as a result of DIS in the direction of the virtual photon only one string arises. In Ref. [19] we considered the more general case, where in the direction of the virtual photon both one and two strings arise. The contribution of the events with two strings is relatively small in the case when a single hadron is observed in the final state. However, it can essentially increase if in the final state are observed two or three hadrons. These questions will be discussed in future presentations.

ACKNOWLEDGMENTS

The author would like to thank H. Gulkanyan for fruitful discussions. This work has been partially supported by a cooperation agreement between DESY and YerPhI.

[1] G. Davidenko and N. Nikolaev, Nucl. Phys. B **135**, 333 (1978).
[2] A. Bialas, Acta Phys. Pol. B **B11**, 475 (1980); M. Gyulassy and M. Pluemer, Nucl. Phys. B **346**, 1 (1990).
[3] J. Czyzewski and P. Sawicki, Z. Phys. C **56**, 493 (1992).
[4] J. Ashman *et al.*, Z. Phys. C **52**, 1 (1991).
[5] A. Accardi, V. Muccifora, and H. J. Pirner, Nucl. Phys. A **720**, 131 (2003).
[6] T. Falter *et al.*, Phys. Lett. B **594**, 61 (2004).
[7] X.-N. Wang and X. Guo, Nucl. Phys. A **696**, 788 (2001); E. Wang and X.-N. Wang, Phys. Rev. Lett. **89**, 162301 (2002).
[8] B. Kopeliovich, J. Nemchik, and E. Predazzi, in *Proceedings of the Workshop on Future Physics at HERA*, edited by G. Ingelman, A. De Roeck, and R. Klanner (Deutsches Elektronen-Synchrotron, Hamburg, 1996), Vol. 2, p. 1038; B. Kopeliovich *et al.*, Nucl. Phys. A **740**, 211 (2004).
[9] N. Akopov, G. Elbakian, and L. Grigoryan, arXiv:hep-ph/0205123v2 May 2002.
[10] N. Akopov, L. Grigoryan, and Z. Akopov, Eur. Phys. J. C **44**, 219 (2005).
[11] N. Akopov, L. Grigoryan, and Z. Akopov, Eur. Phys. J. C **70**, 5 (2010).
[12] A. Bialas and J. Czyzewski, Z. Phys. C **47**, 133 (1990).
[13] J. Czyzewski, Phys. Rev. C **43**, 2426 (1991).

[14] P. Di Nezza (HERMES Collaboration), J. Phys. G **30**, S783 (2004); A. Airapetian *et al*., Phys. Rev. Lett. **96**, 162301 (2006).

[15] N. M. Agababyan *et al*. (SKAT Collaboration), Phys. At. Nucl. **74**, 246 (2011).

[16] T. Falter, W. Cassing, K. Gallmeister, and U. Mosel, Phys. Rev. C **70**, 054609 (2004).

[17] A. Majumder, E. Wang, and X.-N. Wang, Phys. Rev. Lett. **99**, 152301 (2007); A. Majumder, Eur. Phys. J. C **43**, 259 (2005).

[18] N. Akopov, L. Grigoryan, and Z. Akopov, Eur. Phys. J. C **49**, 1015 (2007).

[19] N. Akopov, L. Grigoryan, and Z. Akopov, Eur. Phys. J. C **52**, 893 (2007).