Average formation lengths of baryons and antibaryons in string model

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In this work it is continued the investigation of the space-time scales of the hadronization process in the framework of string model. The average formation lengths of several widely using species of baryons (antibaryons) such as $p$ ($\bar{p}$), $n$ ($\bar{n}$), $\Delta$ ($\bar{\Delta}$), $\Lambda$ ($\bar{\Lambda}$) and $\Sigma$ ($\bar{\Sigma}$) are studied. It is shown that they depend from electrical charges or, more precise, from quark contents of the hadrons. In particular, the average formation lengths of positively charged hadrons, for example protons, are considerably larger than of their negatively charged antiparticles, antiprotons. This statement is fulfilled for all nuclear targets and any value of the Bjorken scaling variable $x_{Bj}$. The main mechanism is direct production. Additional production mechanism in result of decay of resonances gives small contribution. It is shown that the average formation lengths of protons (antiprotons) are slowly rising (decreasing) functions of $x_{Bj}$, the ones of neutrons and antineutrons are slowly decreasing functions of $x_{Bj}$. The shape and behavior of average formation lengths for baryons qualitatively coincide with the ones for pseudoscalar mesons obtained earlier.

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I. INTRODUCTION

In any hard process the initial interaction takes place between partons which then turn into the final hadrons by means of hadronization process. The space-time evolution of the hadronization process, despite on its importance, is known relatively little. In particular in Refs. [1,2] the average formation lengths of high-energy hadrons was studied based on the Lund model of hadronization [3]. The ambiguity in the concept of formation length for composite particles was pointed out. Two different formation lengths were defined and their distributions calculated. The results were compared with the data which allowed to choice suitable form for average formation length.

In the Ref. [4] the investigation of the space-time scales of the hadronization process was continued for the concrete case of pseudoscalar mesons, produced in semi-inclusive deep inelastic scattering (DIS). It was shown that the average formation lengths of these hadrons depend from their electrical charges. In particular the average formation lengths of positively charged mesons are larger than of negatively charged ones. This statement was verified for $z$ (the fraction of the virtual photon energy transferred to the detected hadron) in the current fragmentation region, for cases of different scaling functions, for all nuclear targets and any value of the Bjorken scaling variable $x_{Bj}$. In all cases, the main mechanism was the direct production of pseudoscalar mesons. Including in consideration the additional mechanism of pseudoscalar mesons production in result of decay of resonances, leaded to the decrease of average formation lengths. It was shown that the average formation lengths of positively (negatively) charged mesons were slowly rising (decreasing) functions of $x_{Bj}$.

The investigation of average formation lengths of baryons and antibaryons is the next step in the study of space-time structure of hadronization process. The mechanism for meson production follows rather naturally from the simple picture of a meson as a short piece of string between $q$ and $\bar{q}$ endpoints. There is no unique recipe to generalize this picture to baryons. In the framework of Lund model [3] the baryon in DIS can be produced in three scenarios: (i) diquark scenario; (ii) simple popcorn scenario; (iii) advanced popcorn scenario. (i) Diquark picture. Baryon production may, in its simplest form, be obtained by assuming that any flavor $q_i$, produced from color field of string, could represent either a quark or an antidiquark in a color triplet state. Then the same basic formalism can be used as in case of meson production, supplemented with the probability to produce various diquark pairs. In this simple picture the baryon and the antibaryon are produced as neighbours in rank $^1$ in a string breakup.

The experimental data indicate that occasionally one or a few mesons may be produced in between the baryon and the antibaryon ($BB$) along the string. This fact was used for development the so called popcorn model. The popcorn model is a more general framework for baryon production, in which diquarks as such are never produced, but rather baryons appear from the successive production of several $q_i\bar{q}_i$ pairs. It is evident the density and the size of the color fluctuations which determine the properties of the $BB$ production process. The density determines the rate of baryon production but in case the fluctuations are large on the scale of the meson masses it is possible that one or more mesons are produced between the $BB$-pair. Taking into account the uncertainty principle we can estimate the value of the color fluctuations. It turn out that there

$^1$ Rank denotes the order in which the hadrons are produced, counting from the string end.
is a fast fall-off with the size of the space-time regions inside which color fluctuations may occur. Therefore, in a model of this kind, $BB$ produced in pair are basically either nearest neighbours or next nearest neighbours in rank. (ii) Simple popcorn. In this model it is assumed that at most one meson could be produced between the baryon and antibaryon. It is assumed that $BB$ and $BM\bar{B}$ (with additional meson between $B$ and $\bar{B}$) configurations occur with equal probability. (iii) Advanced popcorn. It is assumed that several mesons could be produced between the baryon and antibaryon. This model has more complicated set of parameters. In this work, for the sake of simplicity, the diquark picture will be used.

In section 2 the theoretical framework is briefly presented. In section 3 the obtained results are presented and discussed. The section 4 contains conclusions.

II. THEORETICAL FRAMEWORK

In Refs. [7–9] it was shown that a ratio of multiplicities for the nucleus and deuterium can be presented in the form of a function of single variable which has the physical meaning of the formation length (time) of the hadron. This scaling was verified, for the case of the physical meaning of the formation length (time) of hadron multiplicity for the nucleus and deuterium can be presented. In section 3 the obtained results are presented.

In section 2 the theoretical framework is briefly presented. The functions $C_{p1}^h$ and $C_{p2}^h$ are the probabilities that in electroproduction process on proton target the valence quark compositions for leading (rank 1) and subleading (rank 2) hadrons will be obtained. Similar functions were obtained in [12] for more general case of nuclear targets. In eq.(3) $\delta$- and $\theta$-functions arise as a consequence of energy conservation law. The functions $D_L^h(L, z, l)$ are distributions of the constituent formation length $l$ of the rank $i$ hadrons carrying fractional energy $z$. For calculation of distribution functions we used recursion equation from Ref. [2].

The simple form of $f(z)$ for standard Lund model allows to sum the sequence of produced hadrons over all ranks ($n = \infty$). The analytic expression for the distribution function in this case was presented in [4].

Unfortunately, in case of more complicated scaling function presented in eq.(1) the analytic summation of the sequence of produced hadrons over all ranks is impossible. Therefore, we limited ourself by $n = 10$ in eq.(3).

In the Ref. [4] the essential contributions in the spectra of pseudoscalar mesons from the decays of vector mesons were obtained. Now, using the same formalism we will calculate the contribution of baryonic resonances in the average formation lengths of baryons.

The distribution function of the constituent formation length $l$ of the daughter hadron $h$ which arises in result of decay of parent resonance $R$ and carries away the fractional energy $z$ is denoted $D_R^{h,i}(L, z, l)$. It can be computed from the convolution integral:

$$D_R^{h,i}(L, z, l) = dR/h \int_{Z_{down}}^{Z_{up}} dR/h \int_{Z_{down}}^{Z_{up}} dz z D_R^{h,i}(L, z, l) \times$$

$$f(R/h) = \langle z \rangle, \quad (4)$$

where $Z_{up} = \min(1, z/R_{max})$ and $Z_{down} = \min(1, z/R_{min})$, $Z_{max}$ and $Z_{min}$ are maximal (minimal) fraction of the energy of parent resonance, which can be carried away by the daughter baryon.

Let us consider the two-body isotropic decay of resonance $R, R \rightarrow h_1h_2$, and denote the energy and momentum of the daughter hadron $h (h = h_1$ or $h_2)$, in the rest system of resonance, $E_h^{(0)}$ and $p_h^{(0)}$, respectively. In the coordinate system where resonance has energy and momentum equal $E_R$ and $p_R$,

$$z_{R/h}^{R/h} = \frac{1}{m_R} \left( E_h^{(0)} + \frac{p_R}{E_R} E_h^{(0)} \right), \quad (5)$$

$$z_{R/h}^{R/h} = \frac{1}{m_R} \left( E_h^{(0)} - \frac{p_R}{E_R} E_h^{(0)} \right), \quad (6)$$

$$C_{p1}^h \sum_{i=2}^{n} D_L^h(L, z, l) \theta(l) \theta(L - zL - l). \quad (3)$$
where $m_R$ is the mass of resonance $R$. In the laboratory (fixed target) system the resonance usually fastly moves, i.e. $p_R/E_R \to 1$.

The constants $d_R/h$ can be found from the branching ratios in the decay process $R \to h$. We will present their values for interesting for us cases below.

The distributions $f_R^{h}(z)$ are determined from the decay process of the resonance $R$, with momentum $p$ into the hadron $h$ with momentum $z p$. We assume that the momentum $p$ is much larger than the masses and the transverse momenta involved.

In analogy with eq.~(2) we can write the expression for the average value of the formation length $L_R^{h}$ for the daughter baryon $h$ produced in result of decay of the parent resonance $R$ in form:

$$
L_R^{h} = \int_0^\infty dl \int_0^\infty dD_c^{R,h}(L, z, l) / R \int_0^\infty dl \int_0^\infty dD_c^{R,h}(L, z, l). \tag{7}
$$

Here is need to give some explanations. We can formally consider $L_R^{h}$ as the formation length of daughter baryon $h$ for two reasons: (i) the parent resonance and daughter hadron are the hadrons of the same rank, which have common constituent quark; (ii) beginning from this distance the chain consisting from pre-hadron, resonance and final baryon $h$ interacts (in nuclear medium) with hadronic cross sections.

The general formula for $L_R^{h}$ for the case when a few resonances contribute can be written in form:

$$
L_R^{h} = \int_0^\infty dl \left( \alpha_B D_c^{h}(L, z, l) + \alpha_R \sum_R D_c^{R,h}(L, z, l) \right) / \int_0^\infty dl \left( \alpha_B D_c^{h}(L, z, l) + \alpha_R \sum_R D_c^{R,h}(L, z, l) \right), \tag{8}
$$

where $\alpha_B$ ($\alpha_R$) is the probability that $qqq$ system turns into baryon (baryonic resonance). For $\Delta$ and $\Sigma$ resonances, taking into account the decuplet/octet suppression and the extra $\Sigma/\Lambda$ suppression following from the mass differences $[5,13]$, the condition $\alpha_R=\alpha_B=0.5$ is used.

Let us now discuss the details of model, which are necessary for calculations. We will consider several species of widely using baryons (antibaryons) such as $p$ ($\bar{p}$), $n$ ($\bar{n}$), $\Delta$ ($\bar{\Delta}$), $\Lambda$ ($\bar{\Lambda}$) and $\Sigma$ ($\bar{\Sigma}$) electroproduced on proton, neutron and nuclear targets. The scaling function $f(z)$ in eq.~(1) has two free parameters $a = 0.8$, $b = 0.58$GeV$^{-2}$. Next parameter, which is necessary for the calculations in the framework of string model is the string tension. It was fixed at a static value determined by the Regge trajectory slope $[8,14]$

$$
\kappa = 1/(2\pi a_R') = 1$GeV$/fm. \tag{9}
$$

Now let us turn to the functions $C_{p1}^h$ and $C_{p2}^h$, which have the physical meaning of the probabilities to produce on proton target hadron $h$ of first and second ranks, respectively. For pseudoscalar mesons they were presented in Ref.~[4]. For baryons these functions have more complicate structure, therefore it is convenient to present here final expressions which were obtained after small calculations. For protons and antiprotons of first and second ranks they have the form

$$
C_{p1}^h = \frac{\frac{4}{9}u(x_{Bj}, Q^2)\cdot 1.05 + \frac{1}{9}d(x_{Bj}, Q^2)}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))} \gamma_{qqq}, \tag{10}
$$

$$
C_{p2}^h = \frac{\frac{4}{9}u(x_{Bj}, Q^2)\cdot 1.05 + \frac{1}{9}d(x_{Bj}, Q^2) - \bar{u}(x_{Bj}, Q^2)\cdot 1.05 + \bar{d}(x_{Bj}, Q^2)}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))} \gamma_{qqq}, \tag{11}
$$

The coefficients for first rank neutron (antineutron) $C_{n1}^h$ ($C_{n1}^h$) can be obtained from corresponding expressions for proton (antiproton) by means of changing distribution functions in nominators ($u, d \to \bar{u}, d, u \to \bar{u}, d, u \to \bar{d}, u \to \bar{d}$); coefficients for second rank are equal to them for proton $C_{p2}^h = C_{n2}^h = C_{p2}^h$. For $\Delta$ and $\Lambda$ they are:

$$
C_{p1}^\Lambda = \frac{\frac{4}{9}u(x_{Bj}, Q^2)\cdot 0.5 + \frac{1}{9}s\gamma_{qqq}}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))}, \tag{12}
$$

$$
C_{p1}^\Lambda = \frac{\frac{4}{9}u(x_{Bj}, Q^2)\cdot 0.5 + \frac{1}{9}s\gamma_{qqq}}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))}. \tag{13}
$$

For $\Delta$ resonances these coefficients are:

$$
C_{p1}^{\Delta^{++}} = \frac{\frac{4}{9}u(x_{Bj}, Q^2)}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))} \gamma_{qqq}, \tag{14}
$$

$$
C_{p1}^{\Delta^+} = \frac{\frac{4}{9}u(x_{Bj}, Q^2)\cdot \frac{1}{2} + \frac{1}{9}d(x_{Bj}, Q^2)}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))} \gamma_{qqq}, \tag{15}
$$

$$
C_{p1}^{\Delta^0} = \frac{\frac{4}{9}u(x_{Bj}, Q^2)\cdot \frac{1}{2} + \frac{1}{9}d(x_{Bj}, Q^2)\cdot \frac{1}{2}}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))} \gamma_{qqq}, \tag{16}
$$

$$
C_{p1}^{\Delta^-} = \frac{\frac{4}{9}d(x_{Bj}, Q^2)}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))} \gamma_{qqq}, \tag{17}
$$

$$
C_{p1}^{\Delta^{++}} = \frac{\frac{4}{9}u(x_{Bj}, Q^2)\cdot \frac{1}{2} + \frac{1}{9}d(x_{Bj}, Q^2)\cdot \frac{1}{2}}{\sum_{q=u,d,s} e_q^2(q(x_{Bj}, Q^2) + \bar{q}(x_{Bj}, Q^2))} \gamma_{qqq}, \tag{18}
$$

where $x_{Bj} = \frac{Q^2}{2m_p}$ is the Bjorken’s scaling variable; $Q^2 = -q^2$, where $q$ is the 4-momentum of virtual photon; $m_p$ is the proton mass; $q(x_{Bj}, Q^2)$($\bar{q}(x_{Bj}, Q^2)$), where $q = u, d, s$ are quark (antiquark) distribution functions for proton. Easily to see, that functions $C_{pn}^h$ for hadrons of higher rank ($n > 2$) coincide with ones for second rank hadron $C_{pn}^h = C_{p2}^h$. This fact was already used for construction of eq.(3). For neutron and nuclear targets more general functions $C_{fi}^h$($i = 1, 2$) from [12] are used. Similar functions can be obtained for $\Delta$, $\Sigma$ and $\Sigma$ resonances.
III. RESULTS AND DISCUSSION

All calculations were performed at fixed value of $\nu = 10 GeV$. Calculations of $z$-dependence were performed at fixed value of $Q^2 = 2.5 GeV^2$, which correspond to $x_{BF} \approx 0.133$. The parameterizations for quark (antiquark) distributions in proton in approximation of leading order were taken from [15]. We assume, that new $q\bar{q}$ pairs are $u\bar{u}$ with probability $\gamma_u d\bar{d}$ with probability $\gamma_d^u$ and $s\bar{s}$ with probability $\gamma_s$. It is followed from isospin symmetry that $\gamma_u = \gamma_d = \gamma_q$. In the diquark scenario we need also in probabilities for production in color field of string diquark-antidiquark pairs with different contents: (i) diquark-antidiquark pairs of light quarks with spin (S) and isospin (I) $S=0, I=0$ $\gamma_{u\bar{u}}=\gamma_{q\bar{q}}$, (ii) diquark-antidiquark pairs of light quarks with $S=1, I=1$ $\gamma_{u\bar{u}d}=\gamma_{d\bar{d}=q\bar{q}}$; (iii) diquark-antidiquark pairs containing strange quark (antiquark) $\gamma_{u\bar{u}d}=\bar{q} \bar{q}$. We use the connections between different quantities and set of values for $\gamma$ taken from Lund model [6]

$\gamma_{q\bar{q}}=0.15, \gamma_{d\bar{d}}=0.12, \gamma_{u\bar{u}}=0.17, \gamma_u : \gamma_d : \gamma_s = 1 : 1 : 0.3$.

We take into account that part of baryons can be produced from decay of baryonic resonances. As a possible sources of $p, n (\bar{p}, \bar{n})$ and $\Lambda (\bar{\Lambda})$ baryons we consider $\Delta (\bar{\Delta})$ and $\Sigma (\bar{\Sigma})$ baryonic resonances, respectively. The contributions of other resonances are neglected.

The decay distributions $f^{R/h}$ are determined from the decay process of the resonance $R$, with momentum $p$ into the hadron $h$ with momentum $z p$.

In Refs. [4, 11] they were presented for case of pseudoscalar mesons, here we will use similar functions for baryons. The common expression $f^{R/h}(z) = 1/(z_{max} - z_{min}), f$ for using baryonic resonances will be used. The values of $z_{max}$ and $z_{min}$ it is easily to obtain from eqs.(5) and (6).

For protons we have $d^{\Delta^+/n}/p = \frac{1}{4}, d^{\Delta^+/n}/p = \frac{1}{4}, d^{\Delta^-}/p = \frac{1}{2}$; for neutrons $d^{\Delta^+/n}/p = \frac{1}{4}, d^{\Delta^+/n}/p = \frac{1}{4}, d^{\Delta^-}/n = \frac{1}{2}$; for $\Lambda$ from $\Sigma^0$ decay we have $d^{\Sigma^0}/\Lambda = \frac{1}{2}$.

In Fig.1 the average formation lengths for electroproduction of baryons and antibaryons on proton target, normalized on $L$, are presented as a functions of $z$. On panel a the protons and antiprotons are presented. The contributions of direct protons (dashed curves) as well as of the sum of direct and produced from decay of $\Delta$ resonances protons (solid curves) are presented. Upper curves represent the average formation lengths for protons and lower curves the same for antiprotons. On panel b the results for neutron and antineutron in the same approach are presented. On other panels the results for $\Sigma$ resonances and on panel f for $\Sigma$ resonances are presented. The results for symmetric Lund model are presented. The parameters of model also are presented.

![Fig. 1: Average formation lengths for electroproduction of baryons and antibaryons on proton target, normalized on L, are presented as a functions of z.](image)

Symmetric Lund model. In Fig.2 the average formation lengths for electroproduction of $\Lambda$ and $\bar{\Lambda}$ on proton target, normalized on $L$, are presented as a functions of $z$. The contributions of directly produced hadrons as well as of the sum of direct and produced from decay of $\Sigma^0$ ($\bar{\Sigma}^0$) resonances hadrons are presented. Upper curves represent formation lengths of $\Lambda$ and lower curves of $\bar{\Lambda}$. The first observation which can be made from Figs.1 and 2 is that the contribution of the resonances is small, so small that practically does not change result. The second observation is that for baryons having several charge states ($\Delta$ and $\Sigma$) there is following rule: larger charge corresponds larger average formation length. The third observation is that all antibaryons independent from charge and other quantum numbers have practically the same average formation lengths.

We already discussed in [4] why the average formation lengths of positively charged hadrons are larger than of negatively charged ones. It happens due to the large probability to knock out $u$ quark in result of DIS.
Let us calculate from eqs. (5) and (6) the quantities \( z_{\text{min}} \) and \( z_{\text{max}} \) for decays \( \Delta \to N\pi \) and \( \Sigma \to \Delta\gamma \). We obtain for first case \( z_{\text{min}}^{R/h} = 0.6, z_{\text{max}}^{R/h} = 0.97 \) and for second case \( z_{\text{min}}^{R/h} = 0.88, z_{\text{max}}^{R/h} = 1 \), which means that in case of baryons integration over \( z \) in eq.(4) is performed in narrow enough region, i.e. contribution of resonances does not distort the distribution of formation lengths of hadrons. For comparison, we would like to remind [4], that for decay \( \rho \to \pi\pi \) \( z_{\text{min}}^{R/h} = 0.035, z_{\text{max}}^{R/h} = 0.965 \), which leads to the distortion of pions spectra. It is worth to note, that results for deuteron coincide, in our approach, with results for any nuclei with \( Z = N \), where \( Z \) (N) is number of protons (neutrons). Average for-

**FIG. 2:** Average formation lengths for electroproduction of \( \Lambda \) and \( \bar{\Lambda} \) on proton target, normalized on \( L \), are presented as a functions of \( z \). The contributions of direct hadrons as well as of the sum of direct and produced from decay of \( \Sigma^0 \) (\( \Sigma^+ \)) resonances hadrons are presented. Upper curves represent formation lengths of \( \Lambda \) and lower curves of \( \bar{\Lambda} \).

**FIG. 3:** Average formation lengths for electroproduction of protons and antiprotons on different targets, normalized on \( L \), as functions of \( z \).

**FIG. 4:** Average formation lengths for electroproduction of neutrons and antineutrons on different targets, normalized on \( L \), as a functions of \( z \).
IV. CONCLUSIONS

Main conclusions are: (i) the average formation lengths of several widely using species of baryons (antibaryons) such as \( p \) (\( \bar{p} \)), \( n \) (\( \bar{n} \)), \( \Delta \) (\( \bar{\Delta} \)), \( \Lambda \) (\( \bar{\Lambda} \)) and \( \Sigma \) (\( \bar{\Sigma} \)) for the case of symmetric Lund model are obtained for the first time; (ii) the average formation lengths of baryons and antibaryons produced in semi-inclusive deep inelastic scattering of leptons on different targets, depend from their electrical charges or, more precise, from their quark contents; (iii) the contribution of \( \Delta \) (\( \bar{\Delta} \)) resonances erably from the ones on nuclei with \( Z = N \). In Fig.3 the average formation lengths for electroproduction of protons and antiprotons on different targets, normalized on \( L \), as a functions of \( z \) are presented. From Figs.3 and 4 we have interesting information, that average formation lengths of protons (neutrons) reaches maximal value on proton (neutron) target, which is easily to explain because when the kinds of target hadron and final hadron coincide, final hadron has maximal chance be leading. Another information, which is not so obvious as in the previous case, is that antiproton has minimal average formation length on proton target (may be it is connected with large denominator in function \( C_n(L) \)). In Fig.5 the average formation lengths for electroproduction of protons and antiprotons on proton target, normalized on \( L \), as a functions of \( x_{Bj} \) are presented. In Fig.6 the same as in Fig.5 for the case of neutrons and antineutrons are presented. The average formation lengths of protons (antiprotons) are slowly rising (decreasing) functions of \( x_{Bj} \). They differ significantly at middle \( z \), i.e. when \( z \) antiprotons will attenuate in nuclei significantly stronger than protons. The average formation lengths of neutrons (antineutrons) both are slowly decreasing functions of \( x_{Bj} \), their values are close enough for all values of \( z \) and for all region of \( x_{Bj} \). We obtained, for the first time \(^2\), the average formation lengths for different baryons (antibaryons) in the eletroproduction process on proton, neutron, deuteron and krypton targets, in the framework of symmetric Lund model. It is worth to note, that results for deuteron coincide, in our approach, with results for any nuclei with \( Z = N \), where \( Z \) (\( N \)) is number of protons (neutrons). Average formation lengths of baryons on krypton nucleus, which has essential excess of neutrons, do not differ considerably from the ones on nuclei with \( Z = N \).

\(^2\) We would like to note, that in \([16]\) the attempt was made to obtain average formation lengths for proton and antiproton in the rough version of standard Lund model. Comparison is shown, that they essentially differ from our result (Fig.1a).
in case of protons (antiprotons) and neutrons (antineutrons), and \( \Sigma (\bar{\Sigma}) \) resonances in case of \( \Lambda (\bar{\Lambda}) \) are considered. It is obtained that their contributions are small, i.e. in case of baryons, production from resonances is essentially weaker than in case of mesons; (iv) the average formation lengths of protons (antiprotons) are slowly rising (decreasing) functions of \( x_{Bj} \), the average formation lengths of neutrons and antineutrons are slowly decreasing functions of \( x_{Bj} \); (v) the shape and behavior of average formation lengths for baryons qualitatively coincide with the ones for pseudoscalar mesons obtained earlier [4].

It is worth to note that in string model the formation length of the leading (rank 1) hadron \( l_{c1} = (1 - z)\nu/\kappa \) does not depend from type of process, kinds of hadron and target. Therefore, the dependence of obtained results from the type of process, kinds of targets and observed hadrons is mainly due to presence of higher rank hadrons.

Which sizes can reach the average formation length? At fixed \( x_{Bj} \) it is proportional to \( \nu \). Consequently it will rise with \( \nu \) and can reach sizes much larger than nuclear sizes at very high energies.

At present the hadronization in nuclear medium is widely studied both experimentally and theoretically. It is well known, that there is nuclear attenuation of final hadrons. Unfortunately it does not clear, which is the true mechanism of such attenuation: final state interactions of prehadrons and hadrons in nucleus (absorption mechanism); or gluon bremsstrahlung of partons (produced in DIS) in nuclear medium, whereas hadronization takes place far beyond nucleus (energy loss mechanism). We hope, that results obtained in the previous [4] and this works can be useful for the understanding of this problem.

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