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SCALING FEATURES OF HADRON PRODUCTION IN $\pi^- - p$ AND $\pi^- - A$ COLLISIONS AT HIGH p_T

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1 Introduction

Particle production with a high transverse momentum is traditionally connected with fundamental phenomena of elementary constituent interactions. The hypothesis of parton-hadron duality [1] states, in particular, that the features of high-p_T hadron spectra reflect the features of hard parton-parton interactions. It means that partons retain information about the collision during particle formation. Therefore, the features of single inclusive particle spectra in hadron-hadron and hadron-nucleus collisions of particle having a different flavour content are of interest to search for unusual properties of particle itself and its formation. Such features could be very useful to search for complementary signatures of unusual phenomena such as the phase transition of nuclear matter, new type of particle interactions and quark compositeness.

One of the methods to study the properties of nuclear matter is to search for the violation of known scaling laws established in elementary collisions ($l-p$, $p-p$, $\bar{p}-p$ etc.) such as the Bjorken and Feynman scalings.

In this paper we study the z-scaling features of hadron production in $\pi^- - p$ and $\pi^- - A$ collisions over a high p_T range. The scaling was proposed in [2] to describe the features of charged hadron production in $p-p$ and $\bar{p}-p$ collisions. The idea of the scaling was developed for the analysis of direct photon production in $p-p$ [3], $\bar{p}-p$ [4] and $p-A$ [5] collisions. The scaling properties of jet production in $\bar{p}-p$ and $p-p$ collisions were analyzed in [6]. The scaling features of π^0-meson production in $p-p$, $p-A$ and $A-A$ collisions were established in [7, 8].

The general concept of the scaling is based on the fundamental principles of self-similarity, locality, fractality and scale-relativity. The first one reflects the dropping of certain dimensional quantities or parameters out of a physical picture of interactions. The second principle concludes that the momentum-energy conservation law is locally valid for interacting constituents. The fractality principle says that both the structure of interacting particles and their formation mechanism are self-similar over a kinematic range. The fourth one, the scale relativity principle, states that the structures of interaction and interacting objects reveal self-similarity and fractality on any scale [9, 10]. The z-scaling relevance to the fractal structure of space-time is discussed in [12, 13].

New presentation (z-presentation) of experimental data can be obtained using the experimental observables, the inclusive cross section $Ed^3\sigma/dq^3$ and the multiplicity density of charged particles $dN/d\eta|_{\eta=0} = \rho(s)$, as shown in [2, 10, 14, 11]. The scaling function $\psi(z)$ is found to be independent of center-of-mass energy $\sqrt{s}$ and the angle of produced particle θ over a wide kinematic range. The scaling function $\psi(z)$ describes the probability density to form a particle with formation length z. The scaling variable z reveals the property of fractal measure $z = z_0\epsilon^{-\delta}$, where ϵ is the scale resolution, and has a relevance to the geometry of space-time [12, 13]. It was shown [11] that the A-dependence of high p_T hadron production in the framework of z-presentation is described by the function α depending on the single parameter, the atomic weight A.

The existence of the scaling and its properties is assumed to reflect the fundamental features of particle structure, constituent interaction and particle production such as self-similarity, locality, fractality and scale-relativity.

The z-scaling features of $\pi^{\pm,0}, K^{\pm}, \bar{p}$ hadrons produced in $\pi^- - p$ and $\pi^- - A$ collisions are studied in this paper. Experimental data on cross section [15, 16, 17, 18] and [19, 20] are used for the analysis. The energy dependence of the $\pi^- - p$ experimental data is used to find the anomalous dimension δ_π. To compare the scaling function $\psi(z)$ for different nuclei the value of δ_π and the dependence $\alpha = \alpha(A)$ determined in[11] were used.

The paper is organized as follows. A general concept of z-scaling and the method of constructing the scaling function for hadron production in $h - A$ collisions is shortly described in Section 2. New results of our analysis of experimental data on $\pi^{\pm,0}, K^\pm, \bar{p}$ hadrons produced in $\pi^- - p$ and $\pi^- - A$ collisions, a comparison with $p-p$ case, discussion of the obtained results, physical interpretation of the scaling function, the variable z and the anomalous dimension are presented in Section 3. Conclusions are summarized in Section 4.

2 Method. Properties of z-scaling

In this section, we would like to remind the basic ideas of z-scaling dealing with the investigation of the inclusive process

$$P_1 + P_2 \to q + X. \tag{1}$$

The momenta and masses of colliding nuclei and inclusive particles are denoted by P_1, P_2, q and M_1, M_2, m_1, respectively. The gross features of the inclusive particle distributions for reaction (1) at high energies are assumed to be described in terms of the corresponding kinematic characteristics of the exclusive subprocess written in the symbolic form [21],

$$(x_1M_1) + (x_2M_2) \to m_1 + (x_1M_1 + x_2M_2 + m_2). \tag{2}$$

The parameter m_2 is introduced to satisfy the internal conservation laws (for isospin, baryon number, and strangeness). The x_1 and x_2 are the scale-invariant fractions of the incoming four-momenta P_1 and P_2 of colliding objects. The cross section of process (1) is assumed to be expressed via the cross section of the corresponding parton subprocesses depending on a minimum energy, which is necessary for the production of the secondary particle with mass m_1 and four-momentum q.

2.1 Fractions x_1 and x_2

The elementary parton-parton collision is considered as a binary sub-process which satisfies the condition

$$(x_1P_1 + x_2P_2 - q)^2 = (x_1M_1 + x_2M_2 + m_2)^2. \tag{3}$$

The equation reflects minimum recoil mass hypothesis in the elementary sub-process. To connect kinematic and structural characteristics of the interaction, the coefficient Ω is introduced. It is chosen in the form

$$\Omega(x_1, x_2) = m(1 - x_1)^{\delta_1}(1 - x_2)^{\delta_2}, \tag{4}$$

where m is a mass constant and δ_1 and δ_2 are factors relating to the fractal structure of the colliding objects [10][1]. The fractions x_1 and x_2 are determined to maximize the value

[1] The anomalous dimensions are found to be $\delta_{1,2} = \delta_h$ and $\delta_1 = \delta_h$, $\delta_2 = \delta_A = \delta_N \cdot A$ for $h - h$ and $h - A$ collisions, respectively.

of $\Omega(x_1, x_2)$, simultaneously fulfilling condition (3)

$$d\Omega(x_1, x_2)/dx_1|_{x_2=x_2(x_1)} = 0. \tag{5}$$

Expressions for x_1 and x_2 as a function of the momenta and masses of the colliding and produced particles are given in [10]. The variables $x_{1,2}$ are equal to unity along the phase space limit and cover the full phase space accessible at any energy. The threshold condition for the process (1) can be written as follows

$$(M_1 + M_2 + m_2)^2 + E^2 - m_1^2 \leq (\sqrt{s_A} - E)^2. \tag{6}$$

Here $\sqrt{s_A}$ is the total center-of-mass energy. The inequality bounds kinematically the maximum energy E of the inclusive particle m_1 in the c.m.s. of the reaction (1).

2.2 Scaling function $\psi(z)$ and variable z

In accordance with the self-similarity principle, we search for the solution depending on a single scaling variable z in the form

$$\psi(z) \equiv \frac{1}{< N > \sigma_{inel}} \frac{d\sigma}{dz}. \tag{7}$$

Here, σ_{inel} is the inelastic cross section and $< N >$ is the average multiplicity of charged particles. The function $\psi(z)$ has to be dependent of the scaling variable z. We would like to note that the existence of such a solution is not evident in advance. All the quantities refer to $p - A$ interactions. The function ψ expressed via the invariant differential cross section for the production of the inclusive particle m_1 is introduced as follows (see [10])

$$\psi(z) = -\frac{\pi s_A}{\rho_A(s,\eta)\sigma_{inel}} J^{-1} E \frac{d\sigma}{dq^3}. \tag{8}$$

Here, $s_A \simeq s \cdot A$ and s are the center-of-mass energy squared of the corresponding $h - A$ and $h - N$ systems and A is the atomic weight. The factor J is a known function of kinematic variables [10]. The expression (8) relates the inclusive differential cross section and the average multiplicity density $\rho_A(s, \eta) = d < N > /d\eta$ to the scaling function $\psi(z)$.

The invariant differential cross section for the production of inclusive particle is normalized as

$$\int_{z_{min}}^{\infty} \psi(z) dz = 1. \tag{9}$$

According to the choice of $\hat{s}_{\perp}^{1/2}$ described below we have $z_{min} = 0$. The equation allow us to give the physical meaning of the scaling function ψ as a probability density to form a particle with a corresponding value of the variable z.

Here we would like to argue that the variable z can be interpreted as a particle formation length. We choose z as a physically meaningful variable that could reflect self-similarity (scale invariance) as a general pattern of hadron production in accordance with the ansatz suggested in [10]

$$z = \frac{\sqrt{\hat{s}_{\perp}}}{\Omega \cdot \rho_A(s)}, \tag{10}$$

where $\hat{s}_\perp^{1/2}$ is the transverse kinetic energy of subprocess (2), defined by the expression $\hat{s}_\perp^{1/2} = \hat{s}_\lambda^{1/2} + \hat{s}_\chi^{1/2} - m_1 - (M_1x_1 + M_2x_2 + m_2)$; Ω is the measure given by (4) and $\rho_A(s) = \rho_A(s, \eta = 0)$.

The transverse energy consists of two parts

$$\hat{s}_\lambda^{1/2} = \sqrt{(\lambda_1 P_1 + \lambda_2 P_2)^2}, \qquad \hat{s}_\chi^{1/2} = \sqrt{(\chi_1 P_1 + \chi_2 P_2)^2}, \tag{11}$$

which represent the transverse energy of the inclusive particle and its recoil, respectively[2]. We would like to note that the form of z determines its variation range. The boundaries of the range are 0 and ∞, as defined by (10) and (4). These values are scale independent and kinematically accessible at any energy.

Thus, one of the features of the procedure described above is the joint use of the experimental observables characterizing hard and soft processes. The scaling variable z and the scaling function $\psi(z)$ are expressed via experimental quantities, inclusive cross section and multiplicity particle density. The first one describes the hard and the second one describes the soft regimes of particle formation. The physical features of hard and soft processes are very different. Therefore there is a real problem for the theoretical description of z-scaling in the framework of perturbative QCD. We would like to note that z-construction is not direct mathematical consequence of parton model of strong interaction but this is a new data presentation motivated by parton-parton and string-like scenarios of particle interactions.

Let us consider the definition of the variable $z = \sqrt{\hat{s}_\perp}/(\Omega\rho_A)$ more closely and clarify its physical meaning. We assume that the gross features of the inclusive particle distribution for the reactions (1) at high energies can be described via the corresponding characteristics of exclusive subprocess (2). The value $\sqrt{\hat{s}_\perp}$ is the minimal transverse energy of colliding constituents necessary to produce a real hadron in the reaction (1). It is assumed that two point-like and massless elementary constituents interact each other in the initial state and convert into real hadrons in the final state. The conversion is not instant process and is usually called hadronization. Space-time microscopic picture of the process is not understood enough at present time. We assume that a number of hadrons produced in the hard interaction of constituents is proportional to ρ_A. Therefore the value $\sqrt{\hat{s}_\perp}/\rho_A$ corresponds to the energy density per one hadron produced in the subprocess. The factor $\Omega \simeq M_1 + M_2 - x_1M_1 - x_2M_2$ is the missing mass for the process (1) expressed via the kinematic characteristics of the subprocess (2). It corresponds to the energy consumed on creation of the associative particle multiplicity and characterizes the property of hadron environment such as energy tension of nuclear matter. Taking into account the qualitative scenario of hadron formation as a conversion of a point-like constituent into a real hadron we interpreted the value z as a hadron formation length. It increases with $p_\perp$ at fixed $\sqrt{s}$ and takes into account kinematic and dynamic features of hadron formation in the elementary subprocess (2).

2.3 Fractality and scale-relativity

Fractality in particle and nuclear physics concerns the internal structure of particles and their interactions. It is manifested by their self-similarity on any scale. This general

[2] The fractions χ_i and λ_i are known functions of momenta P_1, P_2, q and masses M_1, M_2, m_1, m_2 of initial and produced particles [10].

principle is described by power law dependencies of the corresponding quantities [9, 10]. The equation (3) written in the form $x_1x_2 - x_1\lambda_2 - x_2\lambda_1 = \lambda_0$, does not change under the scale transformation

$$\lambda_{1,2} \to \rho_{1,2} \cdot \lambda_{1,2}, \quad x_{1,2} \to \rho_{1,2} \cdot x_{1,2}, \quad \lambda_0 \to \rho_1 \cdot \rho_2 \cdot \lambda_0. \tag{12}$$

The transformation with the scale parameters $\rho_{1,2}$ allows us to consider the collisions of the complex objects in terms of suitable sub-processes of the interacting elementary constituents. It is reasonable to use $\rho_1 = 1$, $\rho_2 = 1$ and $\rho_1 = 1$, $\rho_2 = A$ for the description of $p - p$ and $p - A$ interactions, respectively. Here, A is the corresponding atomic weight. The coefficient Ω, given by (4), connects the kinematic and fractal characteristics of the interaction. The factors δ_1 and δ_2 are anomalous fractal dimensions of the colliding objects. The fractal structure itself is defined by the structure of the interacting constituents, which is not an elementary one either. In this scheme, high energy hadron-hadron, hadron-nucleus and nucleus-nucleus interactions are considered as interactions of fractals.

For the collisions of pions with nuclei we have $\delta_\pi = \delta_1 << \delta_2 = \delta_A$, what is demonstrated on the experimental data below. In this case, the factor Ω can be approximated as follows

$$\Omega = m(1 - x_1)^{\delta_1}(1 - x_2)^{\delta_2} \simeq m(1 - x_2)^{\delta_2}. \tag{13}$$

When introducing the notation $z_0 = \sqrt{s_\perp}/\rho_A(s)$, the scaling variable z can be written in the form

$$z = z_0 \cdot V^{-\delta}. \tag{14}$$

The variable has character of a fractal measure where δ is the anomalous fractal dimension describing the intrinsic structure of the interaction constituents revealed at high energies. The factor V is the relative part of the full phase-space volume corresponding to such parton-parton collisions in which the inclusive particle can be produced. The fractal property of the collision reveals itself so that only the part of all multi-scattering corresponding to the phase space V^δ produces the inclusive particle.

3 $\pi^- p$, π^-–nucleus collisions and z-scaling

Experimental data sets [15, 16, 17, 18] and [19, 20] of cross sections for $\pi^{\pm,0}, K^\pm, \bar{p}$ hadrons produced in $\pi^- - p$ and $\pi^- - A$ collisions at high transverse momentum p_T are analyzed.

The set of experimental data [15] includes the cross sections for $\pi^- - p$ and π^-–nucleus collisions for $\pi^\pm, K^\pm, p^\pm$ hadrons produced at 200 and 300 GeV/c over the range $0.8 < p_T < 6.4\ GeV/c$. The nuclear targets Be, Cu and W were used. The measurements were made at three laboratory angles corresponding to approximately 67^0, 79^0, and 90^0 in the pion-single nucleon c.m. frame.

The next set of experimental data [16] used in our analysis corresponds to cross sections for π^0-meson production in $\pi^- - p$ collisions at $p_{lab} = 100, 200\ GeV/c$. The produced π^0-mesons were registered over the transverse momentum range of $p_T = 0.2 - 5.0\ GeV/c$ and at $\theta_{cm}^{\pi N} \simeq 90^0$.

Inclusive cross sections $Ed^3\sigma/dq^3$ for π^0-meson production in $\pi^- - p$ collisions at $p_{lab} = 300\ GeV/c$ and over the central rapidity $-0.65 < y < 0.52$ and the transverse momentum $1.25 < p_T < 7.0\ GeV/c$ ranges were taken from [17].

The set experimental data [18] including the invariant cross sections for $\pi^{\pm}, K^{\pm}, p^{\pm}$ production in $\pi^- - p$ collisions were measured at the angle $\theta_{cm}^{\pi N} = 49^0, 62^0, 73^0, 83^0, 93^0$ and the pion momentum $p_{lab} = 40\ GeV/c$. The measurements were performed over the transverse momentum range $1.35 < p_T < 3.75\ GeV/c$.

The data set [19] obtained by Collaboration E706 includes the results of measurements of the invariant cross section $Ed^3\sigma/dq^3$ for the production of π^0-mesons at a large transverse momentum and incident pion momentum $p_{lab} = 500\ GeV/c$ on the Be and Cu targets. The measurements were made over the rapidity range of $-0.7 < y < 0.7$. The p_T range for the data is $3.625 \leq p_T \leq 9.0\ GeV/c$. The same Collaboration measured the inclusive production of high-p_T neutral mesons by 515 GeV/c π^--mesons on Be target over the kinematic range of $3. < p_T < 10\ GeV/c$ with the central rapidities $-0.75 < y < 0.75$ to a high accuracy [20].

It is essential that all the cross section data demonstrate a non-exponential behavior as a function of p_T and the dependence on the incident pion momentum p_{lab} is visible.

3.1 $\pi^- - p$ collisions

In this section we study the properties of z-scaling for $\pi^{\pm,0}, K^{\pm}, \bar{p}$ produced in $\pi^- - p$ collisions. General formulas (8) and (10) are used to calculate the scaling function $\psi(z)$ and the variable z. The quantities $\rho(s,\eta)$ and σ_{inel} are the average charged particle multiplicity density and the inelastic cross section of $\pi^- - p$-collisions, respectively.

The charged particle density in $\pi^- - p$ collisions was simulated by PYTHIA [42] in the energy range $\sqrt{s} = 10 - 200\ GeV$. The results of simulations show that the energy dependence of the density $\rho(s)$ for processes $\pi^- - p$ and $p - p$ is practically the same one (taking into account the errors) and can be parameterized in the form $\rho = as^b$. The values of the parameters were found to be $a = 0.74 \pm 0.12$, $b = 0.105 \pm 0.011$ and $a = 0.59 \pm 0.08$, $b = 0.126 \pm 0.017$ for $p - p$ and $\pi^- - p$, respectively. The PYTHIA results give the relation $\sigma_{\pi p} = 0.67\sigma_{pp}$ expected from quark counting rule too. We do not have enough experimental data for $\rho(s)$ of $\pi^- - p$ at high $\sqrt{s}$ and p_T and the available experimental data [43] are not in disagreement with MC results. Therefore we use in our analysis of z-scaling in $\pi^- - p$ collisions the experimentally measured dependence of the average charged particle multiplicity density for $p - p$ collisions. As we will show later the replacement does not destroy the general properties of z-scaling in $\pi^- - p$ particle production.

The results presented in the paper were obtained at $m = 1\ GeV$, $\delta_N = 0.5$, $\delta_A = \delta_N \cdot A$, where A is the atomic weight. The values of the parameter m_2 are defined by the internal conservation laws for baryon number, electric charge, isospin, strangeness of corresponding exclusive process $\pi + p \to h + X$ and are taken to be 0., 0.140., 0., 0.178, 0.494, 0.938 for $\pi^+, \pi^-, \pi^0, K^+, K^-$ and $\bar{p}$, respectively. The dimension of the quantity m_2 is GeV.

Let us now study the energy dependence of the scaling function $\psi(z)$ of hadrons produced in $\pi^- - p$ collisions. For analysis, we use the sets of cross section data [15, 16, 17] and [18]. It should be noted that a strong dependence of the cross section on energy $\sqrt{s}$ was experimentally found. The similar feature was also observed for hadron production in $p-p$ collisions [24, 31]. The effect increases with transverse momentum.

We verify the hypothesis of energy scaling for data z-presentation for $\pi^{\pm,0}, K^{\pm}, \bar{p}$ production in $\pi^- - p$ collisions using the available experimental data.

Figures 1(a)-5(a) show the dependence of the cross section $Ed^3\sigma/dq^3$ of charged hadrons ($\pi^{\pm}, K^{\pm}, \bar{p}$) produced in $\pi^- - p$ on transverse momentum p_T at $p_{lab} = 40, 200, 300\ GeV$ and the produced angle θ_{cm} near 90^0. Note that the data cover the wide transverse momentum range, $p_T = 1 - 6\ GeV/c$.

The similar energy dependence of cross section for π^0-mesons produced in $\pi^- - p$ collisions at $p_{lab} = 100, 200$ and $300\ GeV/c$ and the angle $\theta_{cm}^{\pi N}$ of 90^0 is shown in Figure 6(a).

Some features of hadron spectra should be stressed. The first one is the strong energy dependence of the cross section on transverse momentum. The second feature is a tendency that difference between hadron yields increases with transverse momentum and energy $\sqrt{s}$. The third one is a non-exponential behavior of the spectra at $p_T > 1\ GeV/c$.

Figures 1(b)-6(b) show z-presentation of the same data sets. Taking into account the experimental errors we can conclude that the scaling function $\psi(z)$ of $\pi^{\pm,0}, K^{\pm}, \bar{p}$ produced in $\pi^- - p$ collisions demonstrates an energy independence over a wide energy and transverse momentum range at $\theta_{cm}^{\pi N} \simeq 90^0$.

Figures 7-10 demonstrate the energy dependence of $\psi(z)$ for $\pi^{\pm}, K^{\pm}$ produced in $p-p$ collisions, as a comparison with the $\pi^- - p$ case. Experimental cross section data were obtained at Batavia [24] and Protvino [31]. One can see that both data z-presentations reveal similar properties.

To analyze the angular dependence of the scaling function $\psi(z)$ of charged hadrons $\pi^{\pm}, K^{\pm}, \bar{p}$ produced in $\pi^- - p$ collisions we use the data set obtained at Protvino [18]. The data set includes the results of measurements of the invariant cross section $Ed^3\sigma/dq^3$ at the pion incident momentum $p_{lab} = 40\ GeV$ over the momentum and angular ranges of $p_T = 1.05 - 3.75\ GeV/c$ and $\theta_{cm}^{\pi N} = 49^0 - 93^0$. A dependence of the cross section on the angle of the produced hadrons was experimentally found. The general feature of a spectrum angular dependence is the decreasing of the cross section with an angle. However we would like to note that the experimental errors of data [18] are large enough and do not allow us to make strong statement about the angular dependence of $\psi(z)$. The points corresponding to the transverse momentum $p_T > 2\ GeV/c$ and the incident momentum $p_{lab} = 40\ GeV/c$ dispose upper than the corresponding points at $p_{lab} = 200$ and $300\ GeV/c$. Moreover the difference between points corresponding to the different p_{lab} increases with a transverse momentum. From our point of view it means the existence of the considerable systematic errors of cross section measurements over a high p_T range.

Thus the obtained results show that more high accuracy data on the cross section angular dependence are necessary to verify carefully the angular independence of the scaling function $\psi(z)$ of hadrons produced in $\pi^- - p$ collisions as a function of energy $\sqrt{s}$ and transverse momentum p_T.

3.2 $\pi^- - A$ collisions

In this section, we study the properties of z-scaling for $\pi^{\pm,0}, K^{\pm}, \bar{p}$ production in π^-–nucleus collisions. The experimental data sets [15, 19] and [20] are used in the analysis.

According to the procedure of z-analysis of the $p - A$ experimental data, the function ψ is calculated for every nucleus using the normalization factor $\sigma^{pA}_{inel}/\sigma^{pp}_{inel}$ [11] in the expression for the inclusive cross section[3]. The factor σ^{pA}_{inel} is the total inelastic cross section for pA interactions. The A-dependence of the ratio $\sigma^{pA}_{inel}/\sigma^{pp}_{inel}$ is taken from [38]. The relevant multiplicity densities of charged particles obtained by the Monte Carlo simulation generator HIJING [39, 40] for different nuclei ($A = 7 - 197$) are taken in the form $\rho_A(s) \simeq 0.67 \cdot A^{0.18} \cdot s^{0.105}$ [10]. In the present analysis we use for the multiplicity density $\rho_A(s)$ and the A-dependence of the ratio $\sigma^{\pi A}_{inel}/\sigma^{\pi p}_{inel}$ of $\pi^- - A$ the results obtained for $p - A$ collisions. The possibility of such replacement will be argued by obtained results for data z-presentation.

The symmetry transformations

$$z \to \alpha(A) \cdot z, \quad \psi \to \alpha^{-1}(A) \cdot \psi \tag{15}$$

of the function $\psi(z)$ and the argument z are used to compare the functions ψ for different nuclei.

Figures 11(a)-15(a) show the dependence of the inclusive cross section $Ed^3\sigma/dq^3$ for $\pi^{\pm}, K^{\pm}, \bar{p}$ produced in $\pi^- - Be, Cu$, and W collisions on the transverse momentum p_T at $p_{lab} = 200$ and 300 GeV/c.

Figure 16(a) presents cross sections for π^0-mesons produced on Be and Cu nuclear targets at $\sqrt{s} \simeq 31$ GeV.

The incisive cross section data obtained at two incident pion momentum 200 and 300 GeV/c for W nucleus demonstrate the energy dependence, which enhances as the transfers momentum of produced particle increases.

The dependencies of the scaling function ψ on z of the same experimental data are shown in Figures 11(b)-16(b). The results presented in Figures 11(b)-15(b) confirm the validity of energy independence of $\psi(z)$ for heavy W nucleus for different types of produced hadrons, $\pi^{\pm}, K^{\pm}, \bar{p}$.

The function characterizing the influence of nuclear matter on hadron formation, $\alpha = \alpha(A)$, found in [10] for pA collisions was used in our calculation. It was parameterized as follows $\alpha(A) \simeq 0.9A^{0.15}$. The function is independent of energy $\sqrt{s}$ and transverse momentum of produced particle p_T.

It should be noted that the slope parameter β of $\psi(z) \sim z^{-\beta}$ increases with z. As seen from Figure 16(b) the asymptotic regime (the power law for $\psi(z) \sim z^{-\beta}$) is achieved over a high-p_T range for π^0-meson production on nuclei Be and Cu at $\sqrt{s} \simeq 31$ GeV. The value of the slope parameter β is found to be $\simeq 9.37$ over a wide range of high transverse momentum ($3 < q_T < 7.5$ GeV/c). The range corresponds to the change of the scaling variable z from 6.1 to 12.2. This is a confirmation of self-similarity and fractality of particle formation.

Thus, the results presented in Figures 11(b)-16(b) illustrate the existence of the A-dependence of z-scaling for $\pi^{\pm,0}, K^{\pm}, \bar{p}$ produced in π^-–nucleus collisions at a high colliding energy $\sqrt{s}$ over a high transverse momentum range and a central rapidity range. They are in a good agreement with the results obtained for charged hadrons produced in $p - A$ collisions [11].

[3] The other normalization factor, σ_{inel}, was used in [10].

All of these allow us to say that the mechanism of hadron formation demonstrates a feature depending on general properties of nuclear matter described by the function $\alpha = \alpha(A)$.

We use the properties of z-scaling to calculate the cross section of π^0-meson production in π^-—nucleus collisions at high energies. Figures 17(a-c) show the dependence of the inclusive differential cross section of π^0-mesons produced in $\pi^- - Be$, $\pi^- - Cu$ and $\pi^- - Au$ collisions on transverse momentum p_T at energy $\sqrt{s}$ and $\theta_{cm}^{\pi N} \simeq 90^0$. The points and solid lines are the results obtained at different $\sqrt{s}$ ($\diamond - 60\ GeV, \circ - 200\ GeV, + - 500\ GeV$). The experimental data ($\triangle$) are taken from [19, 20] and shown for comparison.

It is usually assumed that high energy-density nucleon matter produced in heavy-ion collisions could give an indication of phase transition to a quark-gluon plasma and high-p_T π^0-meson spectra should be sensitive to the transition [41]. Therefore the verification of the predicted results is of interest for a more detailed study of the A-dependence of π^0 spectra over a high-p_T range and for a search for signatures of nuclear matter phase transition.

4 Discussion

In this section we discuss the obtained results. First of all, it should be emphasized that the scaling properties of $\pi^{\pm,0}, K^{\pm}, \bar{p}$ produced in $\pi^- - p$ and $\pi^- - A$ collisions were observed at a high colliding energy and transverse momentum of produced hadron. This means that the scaling function describes the fragmentation process of point-like produced partons into observable hadrons.

In Section II we described the qualitative scenario that is useful to construct the scaling function ψ and variable z. In the scenario the reaction $P_1 + P_2 \to q + X$ is treated as a binary parton-parton collision process which leads to (3). The remnant X is treated as an elementary particle with a mass $x_1M_1 + x_2M_2 + m_2$. The 4-momentum conservation law (3) is an important part of the construction. We show that z-presentation of experimental data demonstrate self-similarity of particle production. This fact is independent of theoretical scenario of constituent interaction. In the analysis we use the experimental data but not the results of microscopic calculations. However there are and widely used different string-like models (Lund model [44], Dual Parton Model [1], Monte Carlo String Fusion Model [45] etc.). Such string-like models of particle production allow ones to describe satisfactorily different experimental data, as well [25, 26, 27, 28, 29, 30]. It means that string-like scenarios of particle formation reflect also some features of particle structure, constituent interaction and particle formation. At present time we do not know the real mechanism of particle formation. We assume that the process can reveal different features corresponding to binary parton-parton and string-like interactions. Therefore we hope that such joint models can be developed in future to describe, in particular, z-scaling too.

The measure $\Omega(x_1, x_2)$ defining the scaling variable z given by (4) determines all possible configurations of elementary interactions that lead to the production of the inclusive particle. In our case, the measure is factorized: $\Omega(x_1, x_2) = \Omega_1(x_1) \cdot \Omega_2(x_2)$ [4]. A single measure $\Omega_i(x_i)$ described by a power dependence in the space of fractions $\{x_1, x_2\}$ reflects

[4] The factorization of $\Omega(x_1, x_2)$ is assumed to be violated for the cumulative processes [21, 32, 33, 34].

the number of constituent configurations in the colliding object involved in the production of the inclusive particle. The measure is characterized by the fractal dimension δ_i. The z-presentation of experimental data for $\pi^{\pm,0}, K^{\pm}, \bar{p}$ produced in $\pi^- - p$ collisions and presented in Figures 1(b)-6(b) corresponds to the anomalous dimensions $\delta_N = 0.5$ and $\delta_\pi = 0.1$. The fractal dimension of the nucleus δ_A is expressed via the nucleon fractal dimension $\delta_A = \delta_N \cdot A$.

We would like to note that the same values of δ_N (see Figure 7(b)-10(b)) and δ_A were used in our previous analysis of charged and neutral hadrons produced in $p-p$ and $p-A$ collisions [8, 11]. The relation $\delta_\pi < \delta_N < \delta_A$ means that a fractal structure of nucleon and nucleus is more richer than a pion one. We assume that the dimension of a point-like particle should be zero. In reality the point-likeness of the interacting constituents is defined by a colliding energy $\sqrt{s}$ and a transverse momentum of a registered particle. Therefore the determination of the anomalous dimension δ_h of different kind of particles $(p, \pi, K, \gamma, e, \mu$ etc.) is of interest to study elementary constituents and search for quark and gluon substructure.

The property of scale covariance of the function ψ under scale transformation (12) shows that hadron formation (hadronization) as a process reveals self-similarity in a nuclear environment. The fractal dimension δ_A is a quantitative characteristic of the hadron structure in surrounding matter. Therefore, the change of the fractal dimension of particle formation is assumed to be a signature of new physics phenomena (quark compositeness, new type of interaction, phase transition etc.).

In the framework of the proposed scenario, the interaction of colliding objects is the interaction of fractals and the mechanism of hadron formation is considered as a process of construction of complex fractal (hadron) from elementary fractal blocks. The size and structure of blocks depend on the colliding energy and transverse momentum of the produced hadron. The multiple scattering of elementary constituents is the main feature of heavy ion collisions. Fractality is the reflection of this property described by a power law.

One of the important properties of the scaling function $\psi(z)$ is the power law, $\psi(z) \sim z^{-\beta}$. The power regime is found for π^0-meson production in $\pi^- - A$ collisions at a high transverse momentum of $p_T > 2\ GeV/c$ and $\sqrt{s} \simeq 31\ GeV$ and shown in Figure 16(b). The asymptotic value of the slope parameter $\beta \simeq 9.37$ is determined over the transverse momentum range $3 < p_T < 7.5\ GeV/c$.

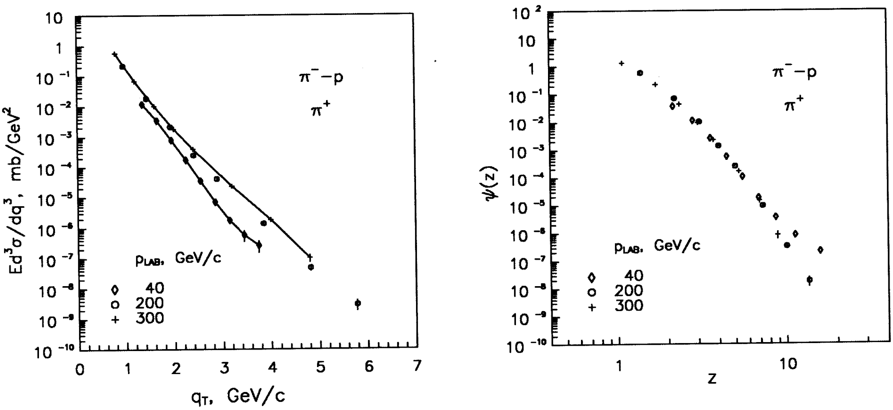
The A-dependence of z-scaling obtained in our analysis confirms the general features of z-scaling construction found for charged hadron production in $p-p$ and $p-A$ collisions [2, 10]. Thus, the influence of surrounding matter on the mechanism of particle formation both in $\pi^- - A$ and $p - A$ is described by a smooth function $\alpha(A)$ depending on the atomic weight A. The obtained results give indication that the fractal dimension is not changed by a nuclear medium and the relation $\delta_A = \delta_N \cdot A$ is valid for hadron production in $\pi^- - A$ collisions too.

We would like to note that the different data presentations are used to study the A-dependence of particle production. One of them is $\sigma_A = \sigma_N \cdot A^{\alpha(x_F, p_T)}$. Here σ_A, σ_N and x_F are the cross section for nucleus, nucleon and Feynman scaling variable, respectively; A is the atomic weight. The function $\alpha(x_F, p_T)$ describes the nuclear matter influence and reveals a nontrivial x_F and p_T dependence as found for example in [24] (see [28, 29] also). There are the problem how to normalize the experimental nucleus cross section in order to compare the cross sections (or the scaling functions as in the present paper) for different nuclei. One can use the normalization per pair participants in soft region (low p_T) or per one collisions in hard region (high p_T). Both of them are model dependent and there are not strong criteria for the procedure. Therefore in the paper we described one of the possible procedures to study the A-dependence of z-scaling. The normalization per nucleon for z (not per nucleus ρ_A as in the present paper) and per nucleus cross section σ_{pA}^{inel} for $\psi(z)$ were used in [10]. In the present paper we used the normalization conditions for z and ψ as in [8].

The other problem for data analysis is due to multiplicity selection of events. In the paper we presumably treat the minimum bias data of $\pi - A$ collisions. The A-dependence of the parameter α is found by the fit. It is the same as for $p - A$ collisions [11]. The comparison of ψ for the different nuclei is performed by "shifting" of $z \to \alpha z$ and the scaling function $\psi \to \alpha^{-1}\psi$. We would like to note that the centrality of the collision is characterized by the multiplicity of particles produced. It corresponds to the different value of the impact parameter. The impact parameter is the model dependent quantity and characterizes the collision geometry. We do not have enough information (cross section data and corresponding multiplicity particle density data) for analysis. Therefore we use the procedure to construct data z-presentation without taking into account the multiplicity selection. We assume that high-p_T collisions over a central rapidity range for different nuclei can be described by the same function $\alpha(A)$. The obtained results shown in Figures 11(b)-16(b) confirm the assumption. In the general case the multiplicity independence of $\alpha(A)$ for the particle production in collisions with different multiplicity at the same energy $\sqrt{s}$ can be violated due to spectator contribution. However there is the indication [36, 37] that the shape of p_T spectra of π^0-mesons produced in the central and minimum bias nucleus-nucleus collisions is practically the same. It is not true for the peripheral collisions. It means that the dynamic mechanism describing the particle formation is the same for different multiplicity too. The multiplicity (or impact parameter) selection from this point of view is the some kind of cross section renormalization. Therefore we consider that for construction of z-presentation the inclusive cross section and multiplicity particle density should be taken in a consistent manner. The change of the p_T spectrum shape as a function of multiplicity at the same $\sqrt{s}$ and different atomic weight A can indicate the modification of nuclear matter state and can be one of the complementary criteria to search for nuclear phase transition.

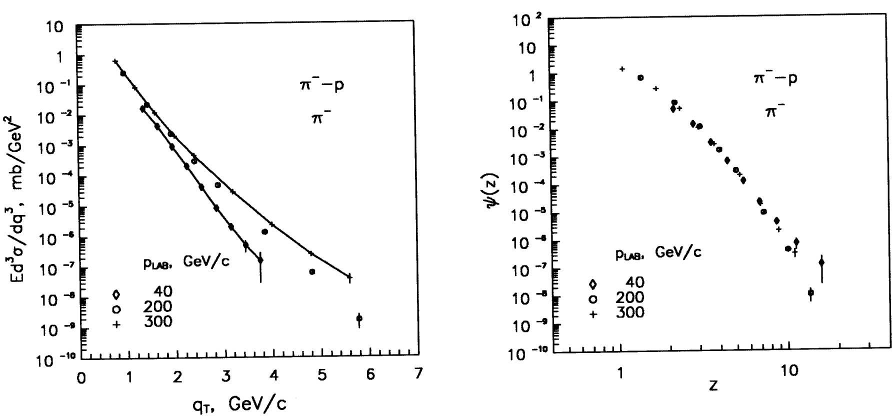
We emphasize that the scaling function $\psi(z)$ describes the transformation (or hadronization) of point-like partons to real particles $\pi^{\pm,0}, K^{\pm}, \bar{p}$. Therefore, we assume that the search for scaling violation of hadron production in $\pi - A$ collisions at high energies, especially in the region of high transverse momenta, could be very interesting for our understanding of a π-meson substructure itself, interaction of pion and nucleon elementary constituents and mechanism of particle formation in nuclear medium.

Figure 18 shows a $z - p_T$ plot for $\pi^- - p$, $\pi^- - Be$ and $\pi^- - Au$ collisions at $\sqrt{s} = 20, 30$ and 40 GeV. The plot allows us to determine a transverse momentum range where the scaling can be violated. The value $z = 20$ for $\pi^- - p$ collisions corresponds to the value of the transverse momentum p_T of 7.2, 9 and 10.5 GeV/c, at $\sqrt{s} =$ 20, 30 and 40 GeV, respectively. The available experimental data [16, 17] for $\pi^- - p$ (Figure 6(b)), and the data [19, 20] for $\pi^- - Be$ (Figure 16(b)) give us the indication that the kinematic range $z > 10$ is of more preferable for experimental investigations of z-scaling violation.



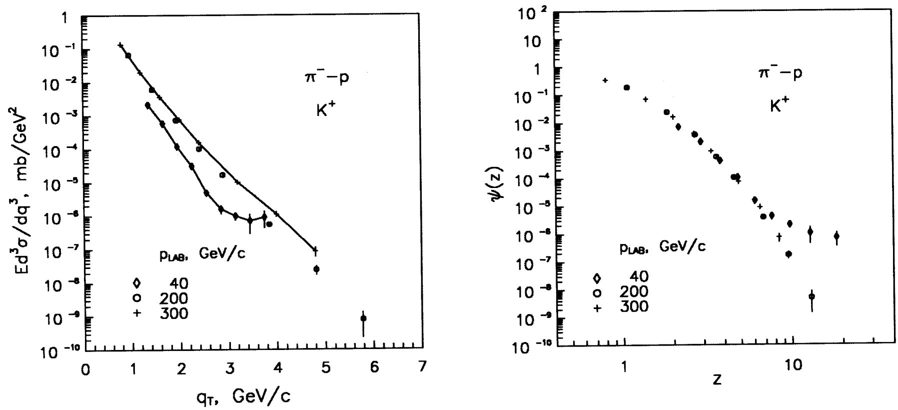
a) b)

Figure 1. (a) Dependence of the inclusive cross section of π^+-meson production on transverse momentum q_T at $p_{lab} = 40, 200$ and $300\ GeV/c$ and $\theta_{cm}^{\pi p} \simeq 90^0$ in $\pi^- - p$ collisions. Experimental data are taken from [15, 18]. (b) The corresponding scaling function $\psi(z)$.



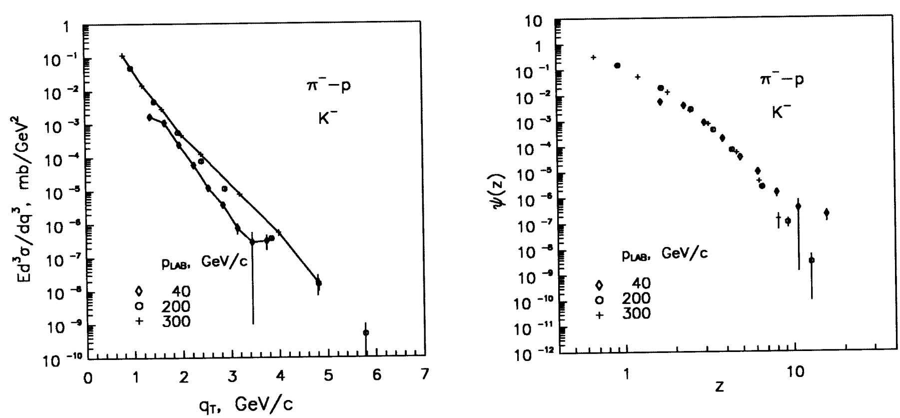
a) b)

Figure 2. (a) Dependence of the inclusive cross section of π^--meson production on transverse momentum q_T at $p_{lab} = 40, 200$ and $300\ GeV/c$ and $\theta_{cm}^{\pi p} \simeq 90^0$ in $\pi^- - p$ collisions. Experimental data are taken from [15, 18]. (b) The corresponding scaling function $\psi(z)$.



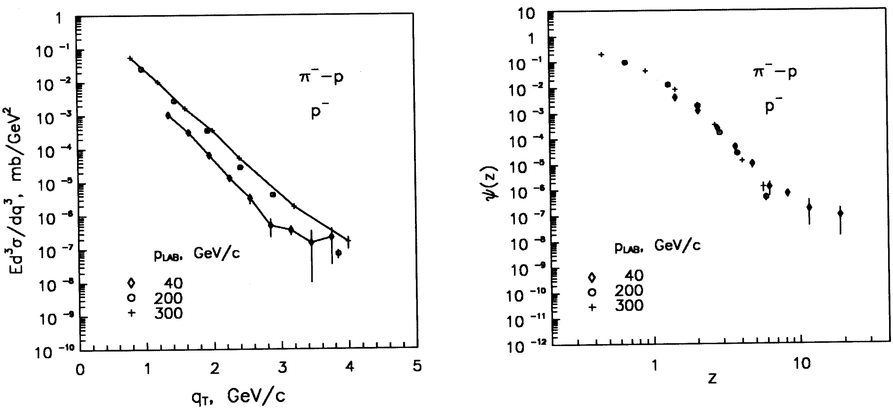
a) b)

Figure 3. (a) Dependence of the inclusive cross section of K^+-meson production on transverse momentum q_T at $p_{lab} = 40, 200$ and 300 GeV/c and $\theta_{cm}^{\pi p} \simeq 90^0$ in $\pi^- - p$ collisions. Experimental data are taken from [15, 18]. (b) The corresponding scaling function $\psi(z)$.



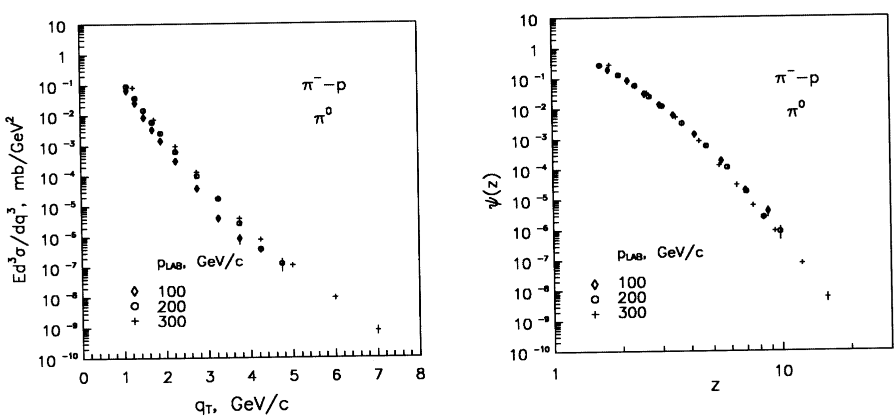
a) b)

Figure 4. (a) Dependence of the inclusive cross section of K^--meson production on transverse momentum q_T at $p_{lab} = 40, 200$ and 300 GeV/c and $\theta_{cm}^{\pi p} \simeq 90^0$ in $\pi^- - p$ collisions. Experimental data are taken from [15, 18]. (b) The corresponding scaling function $\psi(z)$.



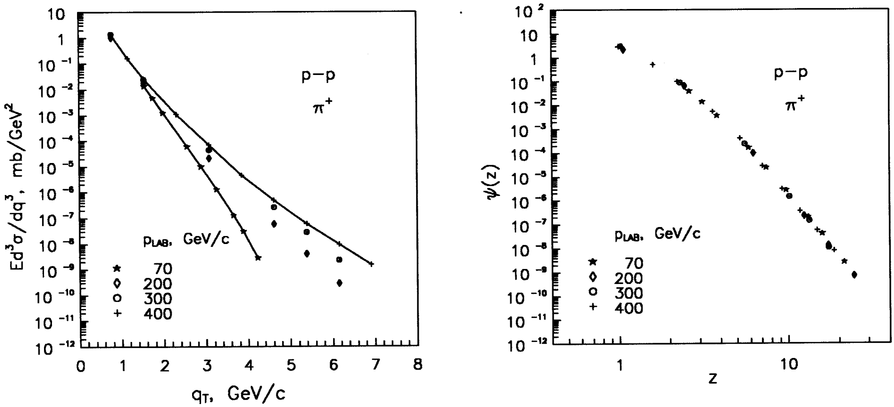
a) b)

Figure 5. (a) Dependence of the inclusive cross section of $\bar{p}$ production on transverse momentum q_T at $p_{lab} = 40, 200$ and $300\ GeV/c$ and $\theta_{cm}^{\pi p} \simeq 90^0$ in $\pi^- - p$ collisions. Experimental data are taken from [15, 18]. (b) The corresponding scaling function $\psi(z)$.



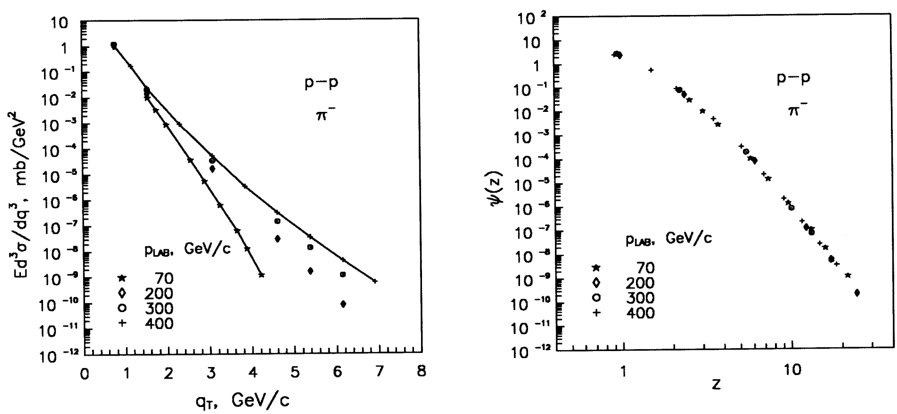
a) b)

Figure 6. (a) Dependence of the inclusive cross section of π^0-meson production on transverse momentum q_T at $p_{lab} = 100, 200$ and $300\ GeV/c$ and $\theta_{cm}^{\pi p} \simeq 90^0$ in $\pi^- - p$ collisions. Experimental data ($\diamond - 100\ GeV/c, \circ - 200\ GeV/c, + - 300\ GeV/c$) are taken from [16] and [17]. (b) The corresponding scaling function $\psi(z)$.



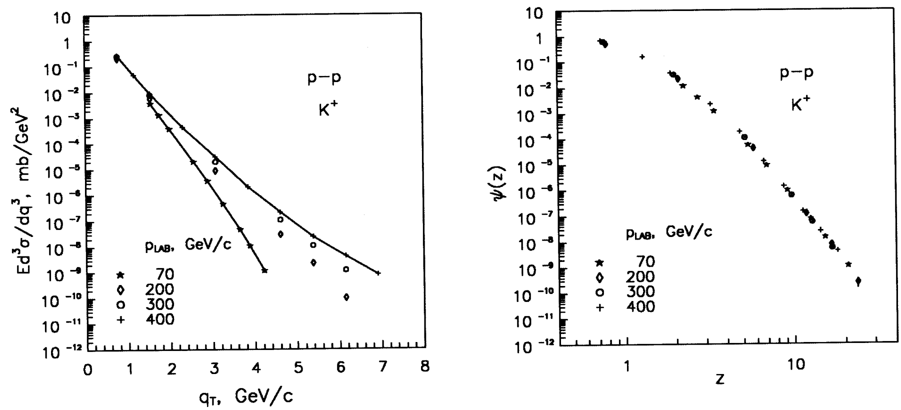
a) b)

Figure 7. (a) The inclusive differential cross sections for the π^+-mesons produced in $p-p$ collisions at $p_{lab} = 70, 200, 300$ and $400\ GeV/c$ and $\theta_{pp} \simeq 90^0$ as functions of the transverse momentum q_T. (b) The corresponding scaling function $\psi(z)$. Solid lines are obtained by fitting of the data at $p_{lab} = 70$, and 400. Experimental data are taken from [24, 31].



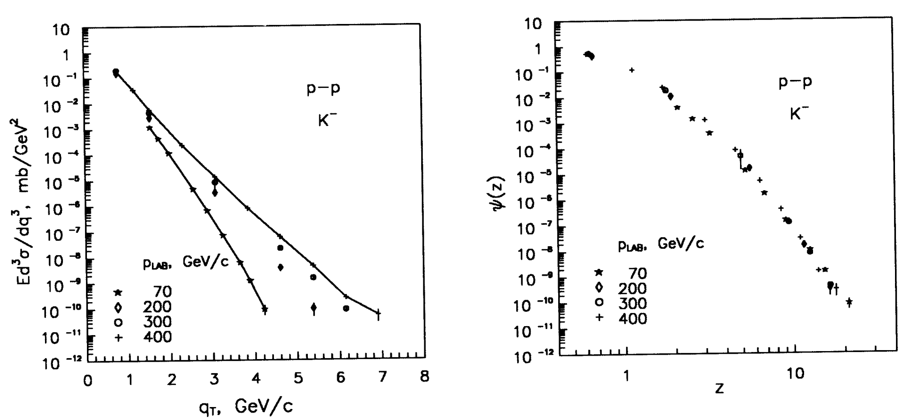
a) b)

Figure 8. (a) The inclusive differential cross sections for the π^--mesons produced in $p-p$ collisions at $p_{lab} = 70, 200, 300$ and $400\ GeV/c$ and $\theta_{pp} \simeq 90^0$ as functions of the transverse momentum q_T. (b) The corresponding scaling function $\psi(z)$. Solid lines are obtained by fitting of the data at $p_{lab} = 70$, and 400. Experimental data are taken from [24, 31].



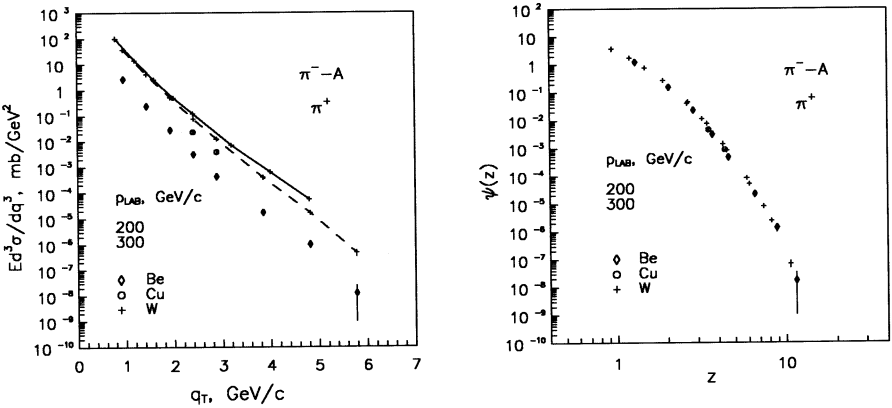
a) b)

Figure 9. (a) The inclusive differential cross sections for the K^+-mesons produced in $p-p$ collisions at $p_{lab} = 70, 200, 300$ and $400\ GeV/c$ and $\theta_{pp} \simeq 90^0$ as functions of the transverse momentum q_T. (b) The corresponding scaling function $\psi(z)$. Solid lines are obtained by fitting of the data at $p_{lab} = 70$, and 400. Experimental data are taken from [24, 31].



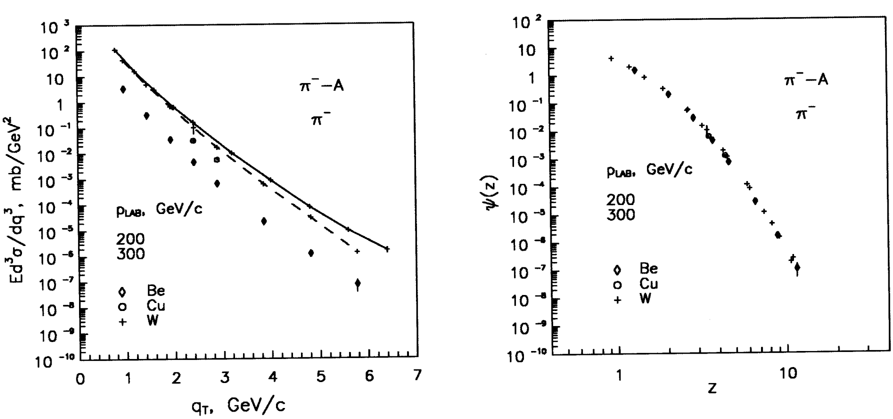
a) b)

Figure 10. (a) The inclusive differential cross sections for the K^--mesons produced in $p-p$ collisions at $p_{lab} = 70, 200, 300$ and $400\ GeV/c$ and $\theta_{pp} \simeq 90^0$ as functions of the transverse momentum q_T. (b) The corresponding scaling function $\psi(z)$. Solid lines are obtained by fitting of the data at $p_{lab} = 70$, and 400. Experimental data are taken from [24, 31].



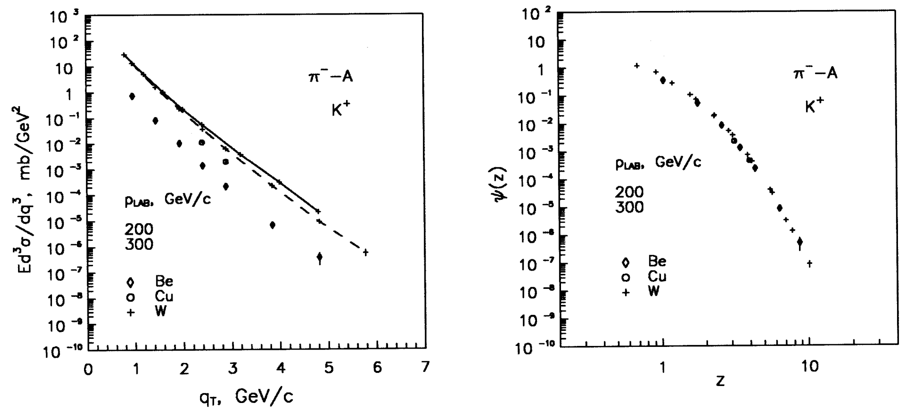
a) b)

Figure 11. (a) Dependence of the inclusive cross section of π^+-meson production on transverse momentum q_T in $\pi^- - A$ collisions at $p_{lab} = 200, 300\ GeV/c$. Experimental data are taken from [15]. (b) The corresponding scaling function $\psi(z)$.



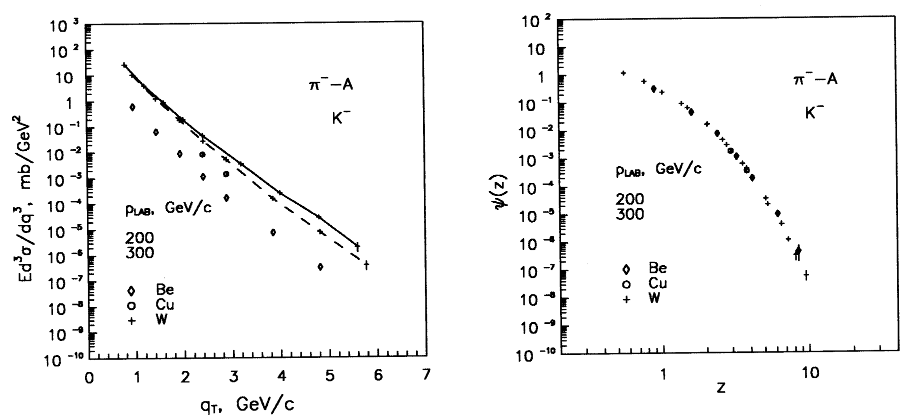
a) b)

Figure 12. (a) Dependence of the inclusive cross section of π^--meson production on transverse momentum q_T in $\pi^- - A$ collisions at $p_{lab} = 200, 300\ GeV/c$. Experimental data are taken from [15]. (b) The corresponding scaling function $\psi(z)$.



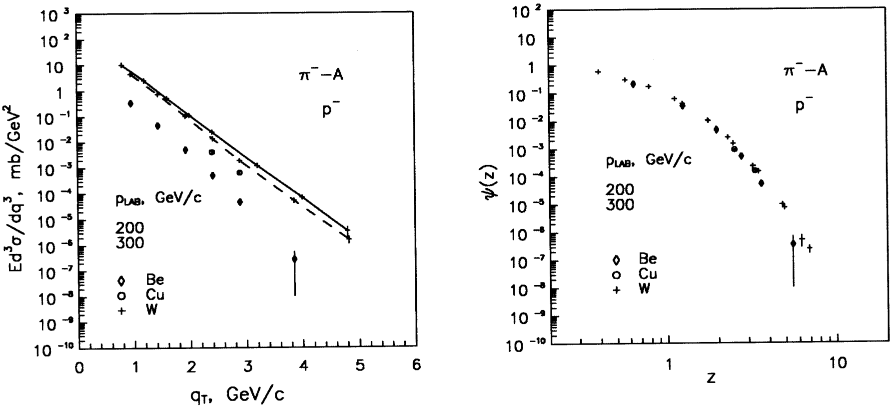
a) b)

Figure 13. (a) Dependence of the inclusive cross section of K^+-meson production on transverse momentum q_T in $\pi^- - A$ collisions at $p_{lab} = 200, 300\ GeV/c$. Experimental data are taken from [15]. (b) The corresponding scaling function $\psi(z)$.



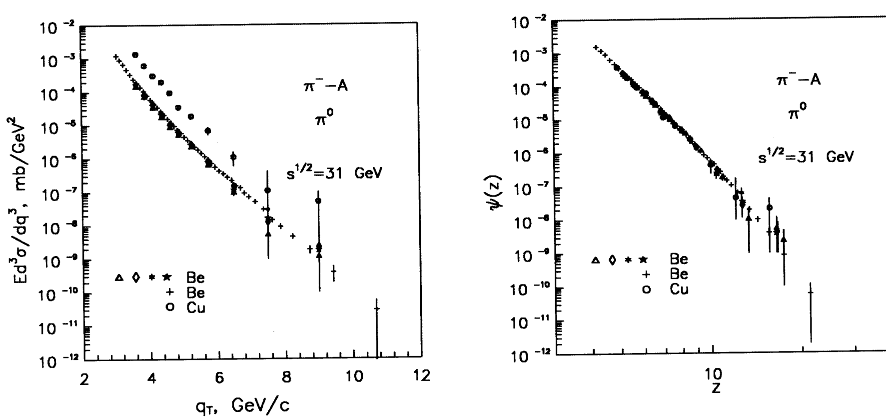
a) b)

Figure 14. (a) Dependence of the inclusive cross section of K^--meson production on transverse momentum q_T in $\pi^- - A$ collisions at $p_{lab} = 200, 300\ GeV/c$. Experimental data are taken from [15]. (b) The corresponding scaling function $\psi(z)$.



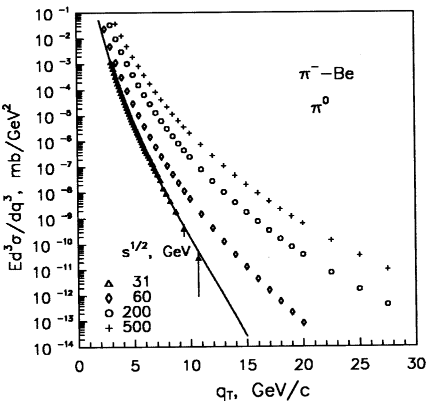
a) b)

Figure 15. (a) Dependence of the inclusive cross section of $\bar{p}$ production on transverse momentum q_T in $\pi^- - A$ collisions at $p_{lab} = 200, 300\ GeV/c$. Experimental data are taken from [15]. (b) The corresponding scaling function $\psi(z)$.

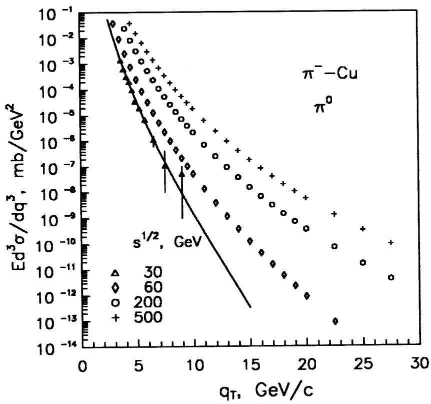


a) b)

Figure 16. (a) Dependence of the inclusive cross section of π^0-meson production on transverse momentum q_T in $\pi^- - A$ collisions at $\sqrt{s} = 31\ GeV$. Experimental data are taken from [19, 20]. (b) The corresponding scaling function $\psi(z)$.



a)



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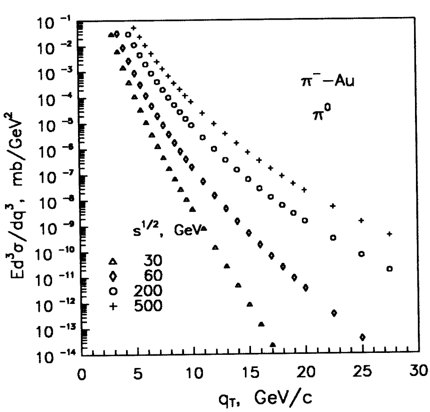
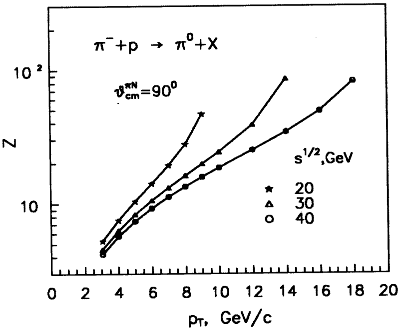
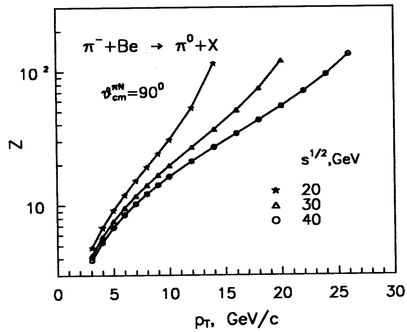


c)

Figure 17. Dependence of the inclusive cross section of π^0-meson production on transverse momentum q_T at $\theta_{cm}^{\pi N} \simeq 90^0$ in $\pi^- - Be$ (a), $\pi^- - Cu$ (b) and $\pi^- - Au$ (c) collisions. The calculated results are shown by points and solid lines ($\diamond - 60\ GeV, \circ - 200\ GeV, + - 500\ GeV$). Experimental data ($\triangle$) are taken from [19, 20].



a)



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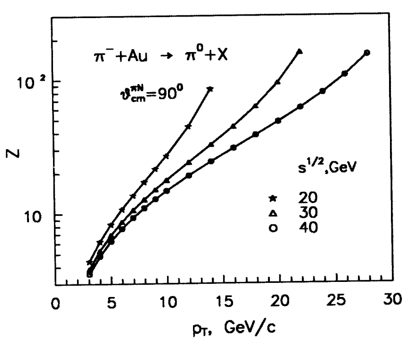

c)

Figure 18. Dependence of the variable z of π^0-meson production in $\pi^- - p$ (a), and $\pi^- - Be$ (b) and $\pi^- - Au$ (c) collisions on transverse momentum p_T at different colliding energy $\sqrt{s}$ and $\theta_{cm}^{\pi N} \simeq 90^0$. Points, $\star - 20$, $\triangle - 30\ GeV$, $\circ - 40\ GeV$, are calculated results.

5 Conclusions

The scaling features of $\pi^{\pm,0}, K^{\pm}, \bar{p}$ hadrons produced in $\pi^- - p$ and $\pi^- - A$ collisions at high energies in terms of z-scaling are considered. The experimental data sets [15, 16, 17, 18] and [19, 20] on the inclusive cross sections are used in the analysis. The momentum of incident pion beam p_{lab} changes from 40 to 515 GeV/c over the high transverse momentum range ($p_T = 0.2 - 10\ GeV/c$).

The function $\psi(z)$, describing a new presentation of experimental data, is constructed. It is expressed via the experimental observables, invariant inclusive cross section $Ed^3\sigma/dq^3$ and the multiplicity density of charged particles. From analysis of different $\pi^- - p$ data sets follows that the anomalous dimension δ_π is 0.1. The value is allowed us to reproduce the general properties of z-scaling established in $p-p$, $\bar{p}-p$ and $p-A$ collisions, namely the energy independence and the power law of the experimental data z-presentation.

The symmetry transformations of the function ψ and its argument, $\psi \to \alpha^{-1}(A)\psi$ and $z \to \alpha(A)z$, are used to compare $\psi(z)$ of different nuclei ($A = Be, Cu, W$). The A-dependence of the transformation parameter $\alpha = \alpha(A)$ and the fractal dimension of nuclei δ_A for $\pi^- - A$ are found to be the same as for the hadrons produced in $p - A$ collisions.

The asymptotic regime of the scaling function, $\psi(z) \sim z^{-\beta}$, is observed and the asymptotic value of the slope parameter β is determined to be $\simeq 9.37$ at $\sqrt{s} \simeq 31\ GeV$ and over the transverse momentum range $3 < p_T < 7.5\ GeV/c$.

Using the properties of z-scaling, the dependence of the cross sections of π^0-mesons produced in $\pi^- - Be$, $\pi^- - Cu$ and $\pi^- - Au$ collisions on transverse momentum over the central rapidity range at high energy $\sqrt{s} = 60, 200$ and 500 GeV is predicted.

The dependence of z on transverse momentum p_T ($z - p_T$ plot) as a function of an atomic weight (A), an angle of produced particle (θ) and a colliding energy $\sqrt{s}$ is suggested to use as a joint kinematic and dynamic criterion to select the domain where new physical phenomena can be found.

Thus, the obtained results show that data z-presentation of $\pi^{\pm,0}, K^{\pm}, \bar{p}$ hadrons produced in $\pi^- - p$ and $\pi^- - A$ collisions demonstrates general properties of the particle formation mechanism such as self-similarity, locality, scale relativity and fractality. As one can assume the properties reflect through the anomalous dimension δ_π the features of elementary constituent substructure too.

References

[1] A. Capella, U. Sukhatme, C.I. Tan, and J. Tran Thanh Van, Phys. Rep. **236**, 225 (1994).

[2] I.Zborovský, Yu.A.Panebratsev, M.V.Tokarev, G.P.Skoro, Phys. Rev. **D54** (1996) 5548.

[3] M.V.Tokarev, JINR Preprint E2-98-92, Dubna, 1998.

[4] M.V.Tokarev, E.V.Potrebenikova, JINR Preprint E2-98-64, Dubna, 1998; Computer Physics Communications **117** (1999) 229.

[5] M.V.Tokarev, JINR Preprint E2-98-161, Dubna, 1998.

[6] M.V.Tokarev, T.G.Dedovich, JINR Preprint E2-99-300, Dubna, 1999; Int. J. Mod. Phys. **A15** (2000) 3495.

[7] M.V.Tokarev, O.V.Rogachevski, T.G.Dedovich, JINR Preprint E2-99-313, Dubna, 1999; J. Phys. G: Nucl. Part. Phys. **26** (2000) 1671.

[8] M.V.Tokarev, O.V.Rogachevski, T.G.Dedovich, JINR Preprint E2-2000-90, Dubna, 2000.

[9] L.Nottale, Fractal Space-Time and Microphysics. World Scientific Publishing Co.Pte. Ltd. 1993.

[10] I.Zborovský, M.V.Tokarev, Yu.A.Panebratsev, and G.P.Škoro, Phys. Rev. **C59**, 2227 (1999); JINR Preprint E2-98-250, Dubna, 1998.

[11] M.V.Tokarev, I.Zborovský, Yu.A.Panebratsev, G.P.Skoro, JINR Preprint E2-99-113, Dubna, 1999; Int. J. Mod. Phys. **A16** (2001) 1281.

[12] I.Zborovský, hep-ph/0101018

[13] I.Zborovský, M.V.Tokarev, Yu.A.Panebratsev, G.P.Skoro, JINR Preprint E2-2001-41, Dubna, 2001.

[14] I.Zborovsky, M.V.Tokarev, Yu.A.Panebratsev, G.P.Skoro, JINR Preprint E2-97-24, Dubna, 1997.

[15] N. D. Giokaris et al., Phys. Rev. Lett. **47**, 1690 (1981);
H. J. Frisch et al., Phys. Rev. **D27**, 1001 (1983).

[16] G. J. Donaldson et al., Phys. Rev. Lett. **36**, 1110 (1976); Phys. Rev. Lett. **40**, 917 (1978); Phys. Lett. **B73**, 375 (1978).

[17] C. DeMarzo et al., Phys. Rev. **D36**, 16 (1987).

[18] L. K. Turchanovich et al., Yad.Fiz. **56(10)**, 116 (1993).

[19] G. Alverson et al., Phys. Rev. **D48**, 5 (1993).

[20] L. Apanasevich et al. Phys. Rev. Lett. **81**, 2642 (1998).

[21] V.S. Stavinsky, Physics of Elementary Particles and Atomic Nuclei **10**, 949 (1979).

[22] V.A. Matveev, R.M. Muradyan, and A.N. Tavkhelidze, Part. Nuclei **2**, 7 (1971); Lett. Nuovo Cimento **5**, 907 (1972); Lett. Nuovo Cimento **7**, 719 (1973).

[23] S. Brodsky, and G. Farrar, Phys. Rev. Lett. **31**, 1153 (1973); Phys. Rev. **D11**, 1309 (1975).

[24] J.W.Cronin *et al.*, Phys.Rev. **D11** (1975) 3105;
D.Antreasyan *et al.*, Phys. Rev. **D19** (1979) 764.

[25] *Proceedings of the XII International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions*, Heidelberg, Germany, 1993; Nucl. Phys. **A610** (1996).

[26] *Proceedings of the X International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions*, Borlange, Sweden, 1993, edited by E. Stenlund *et al.*.

[27] For reviews see, e.g., Hot and Dense Nuclear Matter, NATO ASI Series B: Physics Vol.335, edited by W. Greiner, H. Stocker, and A. Gallmann (Plenum Press, New York, 1994).

[28] J. Schukraft, Report No. CERN-PPE/91-04, 1991 (unpublished).

[29] H. Schmidt and J. Schukraft, J. Phys. **G19**, 1705 (1993).

[30] *Proceedings of the 14th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions*, Torino, Italy, 1999, edited by L.Riccati et al.; Nucl. Phys. **A661** (1999).

[31] V.V.Abramov et al., Sov. J. Nucl. Phys. **41** (1985) 700.

[32] O.P. Gavrishchuk *et al.*, Nucl. Phys. **A523** (1991) 589.

[33] L.L. Frankfurt, M.I. Strikman, Phys. Rep. **160** (1988) 235.

[34] V.K. Bondarev, Physics of Elementary Particles and Atomic Nuclei **28** (1997) 13.

[35] A.A. Baldin, A.M. Baldin, Physics of Elementary Particles and Atomic Nuclei **29** (1998) 577.

[36] WA80 Collaboration R.Albrecht et al. Eur. Phys. J. **C5** (1998) 255

[37] WA98 Collaboration M.M. Aggarwal et al., nucl-ex/9806004;
F.J.M. Geurts, PhD Thesis, Universiteit Utrecht, The Netherlands, 1998.

[38] J. Carroll *et al.*, Phys. Lett. B **80**, 319 (1979).

[39] X.N. Wang and M. Gyulassy, Phys. Rev. D **44**, 3501 (1991).

[40] X.N. Wang and M. Gyulassy, Phys. Rev. D **45**, 844 (1992).

[41] X.-N. Wang, nucl-th/9907093, 22 July, 1999.

[42] T. Sjostrand, Computer Physics Communications, **82**, 74 (1994).

[43] M. Adamus et al., IHEP preprint 88-121, Serpukhov, 1988.

[44] B. Andersson, G. Gustafson, G. Ingelman, and T. Sjostrand, Phys. Rep. **97**, 31 (1983); B. Andersson, The Lund Model, Cambridge University Press, Cambridge, 1998; B. Andersson, In: Proc. XXII International Symposium on Multiparticle Dynamics, p.428 Edited by C.Pajares, Santiago de Compostela, Spain, July 13-17, 1992, World Scientific Publishing Co. Pte. Ltd.

[45] N.S. Amelin, M. Braun, and C.Pojares, Z. Phys. C **63**, 507 (1994).

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Токарев М. В. и др. E2-2001-282

Скейлинговые особенности рождения адронов в $\pi^- - p$- и $\pi^- - A$-столкновениях при больших p_T

Исследуются скейлинговые закономерности рождения заряженных $(\pi^\pm, K^\pm, \bar{p})$ и нейтральных (π^0) адронов с большими поперечными импульсами в $\pi^- - p$- и $\pi^- - A$-столкновениях при высоких энергиях. Анализируются, в рамках общей концепции z-скейлинга, экспериментальные данные по инклюзивным сечениям $Ed^3\sigma/dq^3$ процессов $\pi^- - p$ и $\pi^- - A$. Построена скейлинговая функция $\psi(z)$ и скейлинговая переменная z. Изучены энергетическая и угловая зависимости $\psi(z)$ и найдена аномальная размерность δ_π. Установлена A-зависимость функции $\psi(z)$ рождения частиц в пион-ядерных взаимодействиях. Скейлинговые преобразования $z \to \alpha(A) \cdot z$ и $\psi \to \alpha^{-1}(A) \cdot \psi$ использованы при сравнении $\psi(z)$ для ядерных мишеней Be, Cu и W. Предсказаны сечения рождения π^0-мезонов в $\pi^- - A$-взаимодействиях при высоких энергиях.

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Scaling Features of Hadron Production in $\pi^- - p$ and $\pi^- - A$ Collisions at High p_T

Scaling features of charged $(\pi^\pm, K^\pm, \bar{p})$ and neutral (π^0) particles produced in $\pi^- - p$ and $\pi^- - A$ collisions over a high p_T range at high energies are studied. The general concept of z-scaling is applied for the analysis of $\pi^- - p$ and $\pi^- - A$ experimental data on the $Ed^3\sigma/dq^3$ inclusive cross section. The scaling function $\psi(z)$ and scaling variable z are constructed. The energy and angular dependencies of the scaling function $\psi(z)$ are studied and the anomalous dimension δ_π is found. The A-dependence of particle production in pion-nucleus collisions is studied and the scale transformations $z \to \alpha(A) \cdot z$ and $\psi \to \alpha^{-1}(A) \cdot \psi$ are used for the analysis of $\psi(z)$ for different nucleus targets (Be, Cu, W). Using the properties of z-scaling the dependence of the cross section of the π^0-mesons produced in $\pi^- - A$ collisions on transverse momentum in the central rapidity range at high energies is predicted.

The investigation has been performed at the Laboratory of High Energies, JINR.

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