PROCEEDINGS OF SCIENCE

Self-similarity of cumulative hadron production in pA collisions at low and high $\mathrm{p_T}$

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Data on momentum spectra of charged hadrons produced in pA collisions at U70 and FNAL at low and high p_T are analyzed in the framework of z-scaling approach. The kinematic region studied covers the region forbidden for particle production in nucleon-nucleon interactions. This phenomenon is known as a cumulative production and can be only observed in processes with participation of nuclei. Inclusive cross sections are analyzed in terms of scaling function $\psi(z)$ depending on self-similar parameter z. The function expressed via invariant cross section $Ed^3\sigma/dp^3$ and average multiplicity density $dN_{ch}/d\eta(\sqrt{s},\eta)$ of charged particles is constructed. Results of analysis are compared with the data for noncumulative hadron production at high p_T obtained by J.Cronin and D.Jaffe groups at FNAL and by R.Suliaev group at IHEP. Universality of the shape of scaling function $\psi(z)$ is verified. The concept of z-scaling is discussed. Self-similarity of hadron production in pA collisions over a wide kinematic range is confirmed.

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1. Introduction

Heavy ion experimental programs at RHIC [1], SPS [2] and LHC [3] are of great interest and aimed to study nuclear matter at the extremal conditions (high collision energy and multiplicity density). It is expected that in the heavy ion collisions collective phenomena should play an important role in particle formation. Special interest is devoted to searching for signatures of phase transitions and a critical point. The phase transitions of nuclear matter are new phenomena related to collective interactions of quarks and gluons. General concepts of the critical phenomena are related to the notions of "scaling" and "universality" [4]. The high density nuclear matter can also be produced in cumulative processes. Production of any inclusive particle with a momentum beyond the free nucleon-nucleon kinematics is accompanied by cumulation of a nucleus. That is the reason to investigate a special type of particle production - cumulative production in heavy ion collisions. In present work we analyze such processes in pA collisions with a phenomenological approach, z-scaling.

2. z-Scaling

Concept of z-scaling [5, 6] is based on general principles of self-similarity, locality and fractality of constituent interactions at high energies. It is assumed that the main feature of the inclusive particle distribution of process $P_1+P_2 \to p+X$ can be described in terms of corresponding kinematic characteristics of a constituent subprocess. The subprocess satisfies the following condition [7]: $(x_1P_1+x_2P_2-p)^2 = (x_1M_1+x_2M_2+m_2)^2$. This equation is the expression of locality of the hadron interaction at a constituent level. The x_1 and x_2 are fractions of incoming momenta P_1 and P_2 of the colliding objects with masses M_1 and M_2, respectively. They determine the minimal energy which is necessary to produce the secondary particle with mass m_1 and four-momentum p. Parameter m_2 is chosen to satisfy the internal conservation laws (for charge, baryon, isospin, strangeness number etc.). The equation reflects the minimum recoil mass hypothesis of the elementary subprocess.

Based on above mentioned we construct a self-similarity parameter z which has the following form:

$$z = z_0\Omega^{-1}. \tag{2.1}$$

Here, $z_0 = \sqrt{\hat{s}_\perp}/[m(dN_{ch}/d\eta)]$ is the finite part of z. It is expressed via the ratio of the transverse energy $\sqrt{\hat{s}_\perp}$ released in the binary collision of constituents to the average multiplicity density of charged particles $dN_{ch}/d\eta$ at $\eta = 0$ and the nucleon mass m. The divergent part Ω^{-1} describes the resolution at which the collision of the constituents can be singled out of this process. Quantity Ω is introduced to connect kinematical and structural characteristics of the interaction. It is chosen in the following form: $\Omega(x_1,x_2) = (1-x_1)^{\delta_1}(1-x_2)^{\delta_2}$. Parameters δ_1 and δ_2 are the fractal dimensions of the colliding objects. Fractions x_1 and x_2 are determined to maximize the value of $\Omega(x_1,x_2)$, simultaneously fulfilling the momentum conservation law: $d\Omega(x_1,x_2)/dx_1|_{x_2=x_2(x_1)} = 0$. These fractions change over the range $0 < x_{1,2} < 1$ and cover the full phase space which is accessible at any collision energy. Function $\Psi(z)$ is written in the following form:

$$\psi(z) = -\frac{\pi s}{(dN/d\eta)\sigma_{in}} J^{-1} E\frac{d^3\sigma}{dp^3}. \tag{2.2}$$

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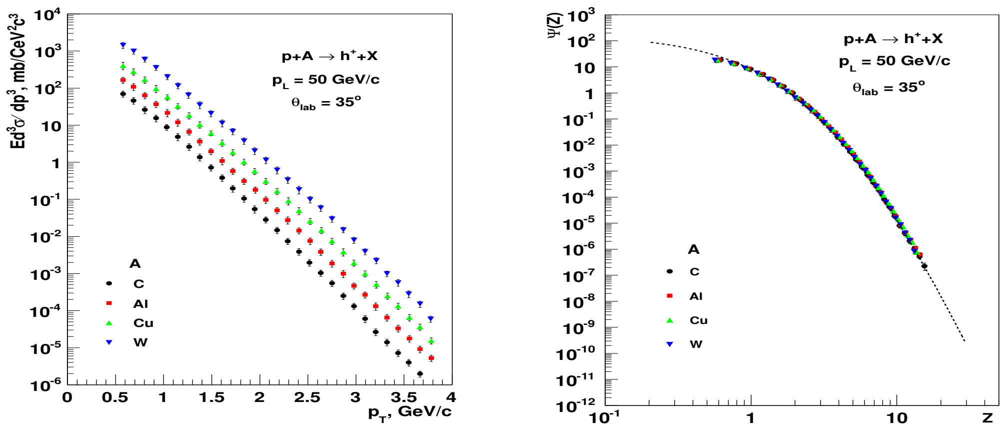
Here, $Ed^3\sigma/dp^3$ is the invariant cross section, $dN/d\eta$ is the multiplicity density as a function of collision energy and pseudorapidity, σ_{in} is the inelastic cross section, J is the corresponding Jacobian [6]. Factor J is known function of the kinematic variables the momenta and masses of the colliding and produced particles. Function $\psi(z)$ normalized as follows:

$$\int_0^\infty \psi(z)dz = 1. \qquad (2.3)$$

It is interpreted as a probability density to produce a particle with corresponding value of variable z. One should note that ψ and z are scale dependent quantities. They both depend on the dimensional variables $\sqrt{s}$ and p_T. It is assumed that in this region the internal structure of hadrons, interactions of their constituents and mechanism of hadronization should reveal self-similarity.

3. Cumulative hadron production in pA collisions

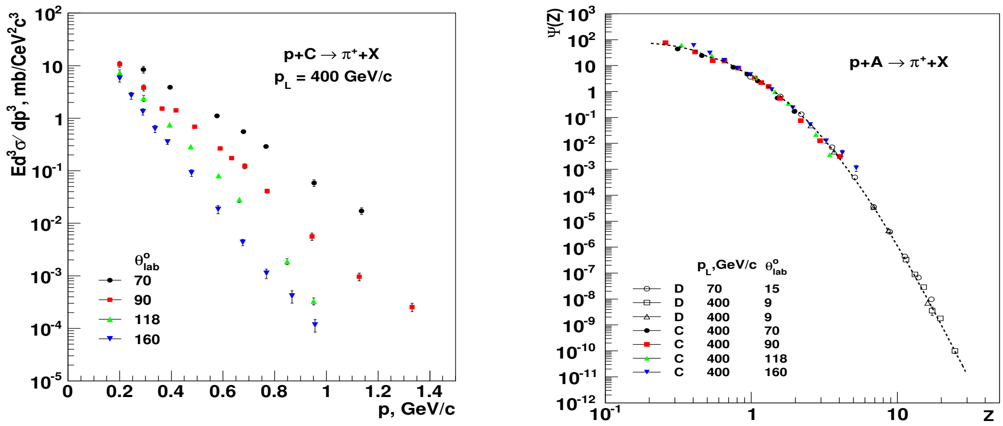
Cumulative particles are particles produced in the kinematical region forbidden for free nucleon-nucleon interactions. Such particles can be produced only in the processes with participation of nuclei. Production of such particles does not contradict with momentum conservation laws. Cumulative processes taken place in collisions of protons with nuclei are of great interest.



a) b)

Figure 1: Transverse momentum spectra of positively charged particles produced in pA collisions at incident proton momentum $p_L = 50$ GeV/c and angle $\theta_{lab} = 35^0$ in p_T (a) and z (b) presentations. The data are taken from [8].

Several experiments were made fulfilling these conditions. In the present paper data obtained in [9, 8, 10] are analyzed. Figures 1a, 2a, and 3a show dependence of the particle cross sections on atomic weight A, angle θ_{lab} and momentum of incident proton p_L. However, one can see from Figs. 1b, 2b and 3b that the data in z-presentation demonstrate universality of the shape of $\Psi(z)$ as a function of an angle, collision energy and type of nuclear target. The function reveals two regimes of behavior: soft regime at low z and hard regime at high z. The region of high z is expected to be preferable in searching for critical phenomena in hot and dense nuclear matter.



a) b)

Figure 2: Transverse momentum spectra of the π^+ mesons produced in pA collisions at incident proton momentum $p_L = 400$ GeV/c and angle $\theta_{lab} = 70^0, 90^0, 118^0, 160^0$ in p (a) and z (b) presentations. The data are taken from [9].

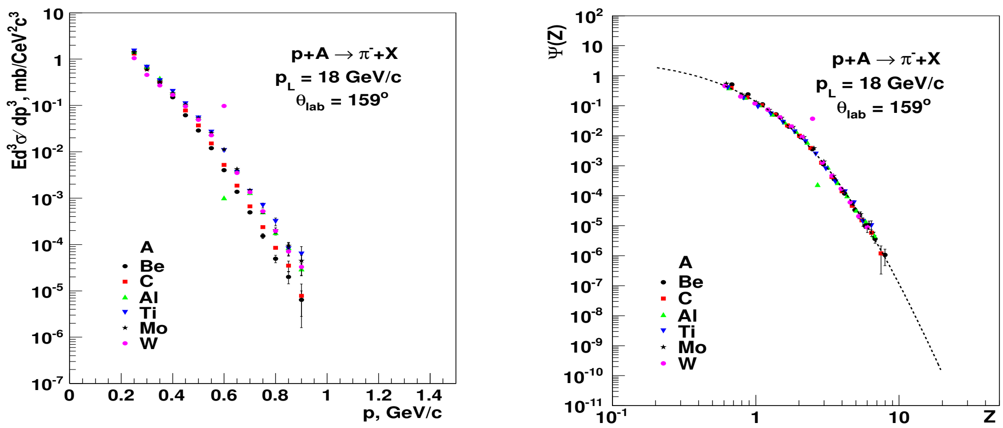


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Figure 3: Spectra of π^- pions produced in pA collisions at $p_L = 18$ GeV/c and angle $\theta_{lab} = 159^0$ in p (a) and z (b) presentations. The data are taken from [10].

The main physical motivation to investigate the cumulative processes is related to the assumption that the cumulative region corresponds to the regime of particle production in which nuclear matter is strongly compressed. The determination of properties of scaling function in this range is of interest especially to verify the hypothesis of the universality of $\Psi(z)$. In this case we could use it to calculate inclusive spectra in the region which has not been experimentally available up to now.

4. Conclusions

The experimental data on inclusive spectra of charged hadrons produced in pA collisions at incident proton momentum $p_L = 18, 50$ and 400 GeV/c were analyzed in the framework of z-

scaling. No evidences on violation of the shape of $\Psi(z)$ in the cumulative regions which could be possible due to phase transition in the nuclear matter were found. Nevertheless, self-similarity of the cumulative hadron production in low- and high-p_T regions was confirmed. Universality of the shape of $\psi(z)$ for different nuclei was used to predict the momentum spectra of $\pi^{\pm}$ mesons and $h^{\pm}$ hadrons produced in pA collisions in the deep-cumulatice region.

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