HIGH-p_{T} SPECTRA FROM RHIC AND QCD TEST OF z-SCALING*

M. Tokarev

Joint Institute for Nuclear Research
Joliot-Curie 6, 141980 Dubna Moscow region, Russia

I. Zborovský

Nuclear Physics Institute, Academy of Sciences of the Czech Republic
250 68 Řež, Czech Republic

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New analysis of high-p_{T} hadron spectra obtained at RHIC is performed in z-scaling scheme. The energy, angular, and multiplicity independence of the scaling function $\psi(z)$ is demonstrated. Universality of the shape of the scaling function for various types of produced hadrons $(\pi, K, \bar{p}, \Lambda)$ is shown. Results of analysis of experimental data are compared with the NLO QCD calculations in z-presentation.

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1. Introduction

Production of particles with high transverse momenta from collision of hadrons and nuclei at high energies has relevance to constituent interactions at small scales. This regime is suitable for precise tests of the perturbative QCD and searching for new phenomena in elementary processes. Production of particles with small momenta and high multiplicities has relevance to phase transitions in hadron/nuclear matter. Study of new physics in both regions is one of the main goals of investigations at Relativistic Heavy Ion Collider (RHIC) at BNL and Large Hadron Collider (LHC) at CERN.

Many approaches have been used to search for regularities reflecting general principles in these systems. One of the basic principles is the self-similarity of hadron production valid both in soft and hard physics. Other general principles are locality and fractality applied to hard processes at small scales. Numerous investigations have shown that hadrons and nuclei interact here in terms of their constituents. Fractality in hard processes is a specific feature connected with sub-structure of the constituents.

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The principles of locality, self-similarity, and fractality are manifested in the z-scaling for inclusive reactions at high energies (see Ref. [1]). The scaling variable z and the scaling function $\psi(z)$ are constructed using the experimentally measured inclusive cross-section $Ed^3\sigma/dp^3$, multiplicity density $dN/d\eta$, and some parameters which suppose reasonable physical interpretation. Analysis of data shows that simultaneous independence of $\psi(z)$ on the collision energy $\sqrt{s}$, angle θ, multiplicity $N_{\rm ch}$, and particle type can be obtained for specific values of these parameters.

2. Basics of the z-scaling

The collision of hadrons and nuclei at sufficiently high energies is considered as an ensemble of individual interactions of their constituents (Fig. 1). The interacting constituents carry the fractions x_1 and x_2 of the 4-momenta of the colliding objects. Their structure is characterized by the parameters δ_1 and δ_2, respectively. The inclusive particle carries the 4-momentum fraction y_a of the scattered constituent with a fragmentation characterized by a parameter ϵ_a. A fragmentation of the recoil constituent is described by ϵ_b and the 4-momentum fraction y_b. According to the z-scaling hypothesis, the self-similarity is manifested in spectra of inclusive particles and expressed via a scaling function $\psi(z)$ in dependence on the single variable

$$z = \frac{s_\perp^{1/2}}{(dN_{\rm ch}/d\eta|_0)^c} \cdot \Omega^{-1}\,, \tag{1}$$

$$\Omega = (1-x_1)^{\delta_1}(1-x_2)^{\delta_2}(1-y_a)^{\epsilon_a}(1-y_b)^{\epsilon_b}\,. \tag{2}$$

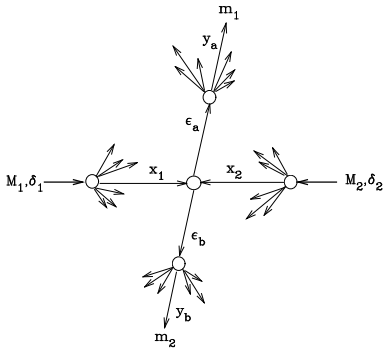


Fig. 1. Hadron/nucleus interactions at the constituent level.

For pp collisions is $\delta_1 = \delta_2 \equiv \delta$ and $\epsilon_a = \epsilon_b \equiv \epsilon$. The 4-momentum fractions are determined in a way to maximize $\Omega(x_1, x_2, y_a, y_b)$ under the condition

$$(x_1P_1 + x_2P_2 - p/y_a)^2 = (x_1M_1 + x_2M_2 + m_2/y_b)^2\,. \tag{3}$$

The transverse kinetic energy, $s_{\perp}^{1/2}$, of the constituent sub-process consumed on the production of the inclusive particle (m_1) and its counterpart (m_2) is expressed in terms of x_1, x_2, y_a, and y_b. The multiplicity density, $dN_{\rm ch}/d\eta|_0$, of charged particles in the central interaction region (at pseudorapidity $\eta = 0$) is related to a state of the medium produced in the colliding system. The parameter c characterizes properties of this medium.

The scaling function $\psi(z)$ is expressed in terms of the inclusive cross-section $Ed^3\sigma/dp^3$ and the multiplicity density $dN/d\eta$ as follows

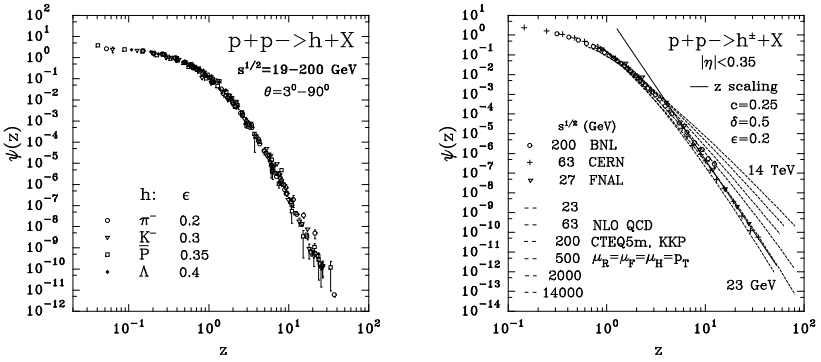
$$\psi(z) = -\frac{\pi s A_1 A_2}{(dN/d\eta)\sigma_{\rm inel}} J^{-1} E\frac{d^3\sigma}{dp^3}\,. \tag{4}$$

Here s is the square of the center-of-mass energy of the corresponding NN system, A_1 and A_2 are atomic weights, $\sigma_{\rm inel}$ is inelastic cross-section, and J is the corresponding Jacobian.

3. Data analysis and QCD test of *z*-scaling

We have analyzed experimental data [2] on inclusive hadron ($h^{\pm}$, π^-, K^-, and $\bar{p}$) production in pp collisions at FNAL, ISR, and RHIC energies in z presentation. Performed analysis includes the multiplicity dependence of the K_S^0-meson and Λ-baryon spectra [3] in the central pseudorapidity range $|\eta| < 0.5$ at $\sqrt{s} = 200$ GeV measured by STAR collaboration. The assumption of self-similarity of the spectra transforms to the requirement of simultaneous description of the data sets by a scaling function $\psi(z)$. Independence of $\psi(z)$ on $\sqrt{s}$, θ, and $N_{\rm ch}$ is consistent with the values of $c = 0.25$ and $\delta = 0.5$ for all analyzed particles. The values of ϵ increase with particle mass. None of these parameters depends on $\sqrt{s}$, θ, or $N_{\rm ch}$. Energy, angular, and multiplicity independence of $\psi(z)$ gives the same shape of the scaling function for different particle species (Fig. 2(a)). Fig. 2(b) shows z presentations of the charged particle spectra. The NLO QCD calculations depicted by the dashed lines were performed with the parton distribution functions CTEQ5m and the fragmentation functions KKP. Experimental data are shown by symbols. The NLO QCD predictions demonstrate deviation from the asymptotic behavior of the z-scaling in the TeV energy region where measurements are not performed yet.

We conclude that z-scaling in pp collisions is a regularity which reflects the self-similarity, locality, and fractality of the hadron interaction at the constituent level. The variable z depends on the parameters c, δ, and ϵ, interpreted as a specific heat of the produced medium, a nucleon fractal dimension, and a fractal dimension of the fragmentation process, respectively. Energy, angular, and multiplicity independence of the scaling function constrains these parameters and gives flavor independence of $\psi(z)$. Asymptotic



(a) (b)

Fig. 2. (a) The spectra of $\pi, K, \bar{p}$, and Λ produced in pp collisions in z presentation. (b) The NLO QCD predictions of the spectra of charged hadrons produced in pp collisions over a range $\sqrt{s} = 23 - 14000$ GeV and $|\eta| < 0.35$ with CTEQ5m parton distributions and KKP fragmentation functions in z presentation. Experimental data are shown by the points. The solid line depicts asymptotic behavior of $\psi(z)$.

behavior of the z-scaling is not reproduced in the TeV energy range by the NLO QCD calculations with the distribution and fragmentation functions used in the present calculations. The obtained results may be of interest to search for new physics phenomena at LHC energies.

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