$(s_{nn})^{1/2}$=7-39 GeV ENERGIYA ORALIG'IDA Au+Au TO'QNASHUVLARIDA PION, KAON, PROTON VA ANTIPROTONLARNI O'RTACHA KO'NDALANG IMPULSLARINING EVOLYUTSIYASI

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Annotatsiya: *Maqolada oddiy darajali funktsiya modeli yordamida* $(s_{nn})^{1/2}$*=7-39 GeV energiya oralig'idagi Au+Au to'qnashuvlarida pion, kaon, proton hamda antiprotonlarning o'rtacha ko'ndalang impulslari evolyutsiyasi to'qnashuv markaziyligi va energiya funktsiyasi tariqasida tadqiq qilingan.*

Kalit so'zlar: *RHIC dagi og'ir ionlar to'qnashuvlari, zarrachalarning o'rtacha ko'ndalang impulslari, zarrachalar hosil bo'lish mexanizmlari, deconfinement fazaviy o'tishni boshlanishi, Kvark-glyuon plazma (KGP) va adronlarning aralash fazasi.*

EVOLUTION OF THE AVERAGE TRANSVERSE MOMENTA OF PIONS, KAONS, PROTONS AND ANTIPROTONS IN Au+Au COLLISIONS AT $(s_{nn})^{1/2}$=7-39 GeV ENERGY RANGE

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Annotation: *In the article, using the simple power model, evolution of the average transverse momenta of pions, kaons, protons and antiprotons was investigated as a function of centrality and energy of Au+Au collisions at* $(s_{nn})^{1/2}$*=7-39 GeV energy range.*

Keywords: *heavy-ion collisions at the RHIC, average transverse momenta of particles, mechanisms of particle production, onset of deconfinement phase transition, mixed phase of Quark-gluon plasma (QGP) and hadrons.*

ЭВОЛЮЦИЯ СРЕДНИХ ПОПЕРЕЧНЫХ ИМПУЛЬСОВ ПИОНОВ, КАОНОВ, ПРОТОНОВ И АНТИПРОТОНОВ В Au+Au СОУДАРЕНИЯХ В ИНТЕРВАЛЕ ЭНЕРГИЙ $(s_{nn})^{1/2}$=7-39 ГэВ

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Аннотация: *В статье с помощью модели простой степенной функции исследована эволюция экспериментальных значений средних поперечных импульсов пионов, каонов, протонов и антипротонов в зависимости от центральности и энергии Au+Au соударений в интервале энергий* $(s_{nn})^{1/2}$*=7-39 ГэВ.*

Ключевые слова: *соударения тяжёлых ионов на RHIC, средние поперечные импульсы частиц, механизмы образования частиц, начало фазового перехода деконфайнмента, смешанная фаза Кварк-глюонной плазмы (КГП) и адронов.*

Introduction

In present work we investigate the particle species and collision energy dependencies of an important variable – the average transverse momentum (<p_t>) of identified charged particles in Au+Au collisions from the BES program at the RHIC in $(s_{nn})^{1/2}$=7-39 GeV energy range. This variable was first proposed by Van Hove [1] to identify the deconfinement phase transition in high energy proton-antiproton collisions with an anomalous behavior – a plateau-like structure of the average transverse momentum as a function of multiplicity of hadrons. Van Hove suggested [1] that the observed flattening of dependence of the experimental average transverse momentum at midrapidity versus the particle multiplicity per unit rapidity should indicate the deconfinement phase transition (the growth of entropy density at constant temperature) in a system with high energy density. Initially Van Hove's idea was suggested to investigate the correlations between <p_t> and hadron multiplicity in high-energy proton-antiproton collisions [1,2]. Nowadays we can analyze such correlations in high-statistics heavy-ion collisions at the RHIC and LHC energies [3-7].

In Ref. [6] the experimental spectra of <p_t> versus the average pseudorapidity multiplicity density, average number of binary collisions (<N_{coll}>), and the average number of participant nucleons (<N_{part}>) dependencies of the identified charged particles at midrapidity in Au+Au and Pb+Pb collisions at RHIC and LHC in $(s_{nn})^{1/2}$= 62-5020 GeV energy interval were reproduced very well with the proposed simple power model function. The degree of flattening of ¿p_t>¿ of the charged pions and kaons, protons and antiprotons in heavy-ion collisions at RHIC and LHC in $(s_{nn})^{1/2}$=62-5020 GeV energy range were investigated from analysis of the dependencies of the extracted exponent parameter α of the simple power function on the particle species and collision energy $(s_{nn})^{1/2}$. The coincidence of the parameter α for pions and kaons in Pb+Pb collisions at $(s_{nn})^{1/2}$=5.02 TeV, reflecting practically identical shapes of ¿p_t>¿ versus the average pseudorapidity multiplicity density, ¿N_{coll}>¿, and ¿N_{part}>¿ spectra for pions and kaons in these collisions, was obtained. This result was interpreted as being due to the creation of the highly thermalized QGP, where the difference between *u*, *d*, and *s* flavors almost disappears, which results in the similar mechanisms of production of pions and kaons in Pb+Pb collisions at $(s_{nn})^{1/2}$=5.02 TeV.

In present work we have performed the minimum $\chi 2$ fits of the experimental dependencies [7] of the average transverse momentum (¿p_t>¿) on ¿N_{part}>¿ of the charged pions, charged pions, and protons+antiprotons, produced at midrapidity (|*y*| < 0.1) in Au+Au collisions at $(s_{nn})^{1/2}$=7.7, 11.5, 19.6, 27, and 39 GeV, with the proposed simple power model function:

$$¿p_t \geq C¿N_{part}>¿^{\alpha}¿, \qquad (1)$$

where α is the exponent parameter, *C* is the fitting constant, and <N_{part}> is the average number of participant nucleons.

Analysis and Results

The minimum $\chi 2$ fit curves along with the experimental ¿p_t>¿ versus ¿N_{part}>¿ dependencies, obtained [7] by STAR Collaboration at midrapidity in Au+Au collisions from

BES program, are shown in Fig. 1. As seen from Fig. 1, the simple power function in Eq. (1) reproduces very well all the studied experimental ¿ p_t>¿ versus ¿ N_{part}>¿ dependencies.

Figure 2 shows the collision energy, $(s_{nn})^{1/2}$, dependencies of the power parameter □ for the charged pions, charged kaons, protons+antiprotons produced at midrapidity in Au+Au collisions at BES energies, extracted in present work. The corresponding results, obtained in Ref. [6] from analysis of the experimental ¿ p_t>¿ data of STAR Collaboration for midrapidity Au+Au collisions at $(s_{nn})^{1/2}$=62.4, 130 and 200 GeV, and those of ALICE collaboration for midrapidity Pb+Pb collisions at $(s_{nn})^{1/2}$=2.76 and 5.02 TeV, are also presented in Fig. 2 for a comparison. As observed from Fig. 2, we have α(pion) < α(kaon) < α((anti)proton) inequality in the whole BES energy range. A similar hadron mass dependence for the parameter α of the simple power function was obtained in Ref. [6] from analysis of the experimental ¿ p_t>¿ data of STAR Collaboration for midrapidity Au+Au collisions at $(s_{nn})^{1/2}$=62.4, 130 and 200 GeV, and those of ALICE collaboration for midrapidity Pb+Pb collisions at $(s_{nn})^{1/2}$=2.76 and 5.02 TeV. Since the degree of flattening of the spectrum rises as exponent α approaches zero, the largest degree of flattening is observed for the pion spectra − hadrons with the lowest mass, and the lowest degree of flattening is obtained for (anti)protons – hadrons with the largest mass among the studied particles. As observed from Fig. 2, the α values (and corresponding degree of flattening) of kaon spectra are located in between those for pions and (anti)protons at the BES energy range. As stated in Ref. [6], the power parameter α should contain the combined information for both the degree of thermalization and particle production mechanism(s). Then we can understand that the pions, hadrons with the lowest production threshold energy, should have the largest degree of thermalization and thermalize at the significantly smaller system temperature (smaller energy density) compared to kaons and (anti)protons, which are characterized by the significantly larger production threshold energies. This can be seen from the observed higher degree of flattening, reflected by the smaller α values, of the charged pion spectra in Fig. 1 compared to those for the charged kaons and (anti)protons.

Figure 2 shows the clear dependencies of the exponent α on collision energy, $(s_{nn})^{1/2}$, for the charged pions, charged kaons, and (anti)protons in Au+Au collisions at BES energy range, $(s_{nn})^{1/2}$ = 7−39 GeV. Generally, the power parameter α for the charged kaons, and (anti)protons shows a noticeable decreasing behavior with increasing collision energy from $(s_{nn})^{1/2}$= 7 to 39 GeV. For the charged pions, as observed from Fig. 2, the exponent parameter α decreases quite weakly in range $(s_{nn})^{1/2}$=7-19 GeV and then remains constant within uncertainties in region $(s_{nn})^{1/2}$ = 19-39 GeV, and further up to 62 GeV. It is necessary to mention that in Ref. [7] STAR Collaboration obtained a linear increase in pion yields as a function of collision energy, $(s_{nn})^{1/2}$, in range up to around 19.6 GeV with a subsequent kink structure seen at about 19.6 GeV. It was interpreted [7] as a substantial change in particle production mechanism in Au+Au collisions at $(s_{nn})^{1/2} \approx$ 19.6 GeV. The energy dependence of pion yields has changed a slope: the slope below 19.6 GeV is significantly different from that above 19.6 GeV [7]. It agrees with the significant change of the $(s_{nn})^{1/2}$ dependence of the power parameter α for the charged pions obtained at $(s_{nn})^{1/2} \approx 19.6$ GeV in Fig. 2 in present work.

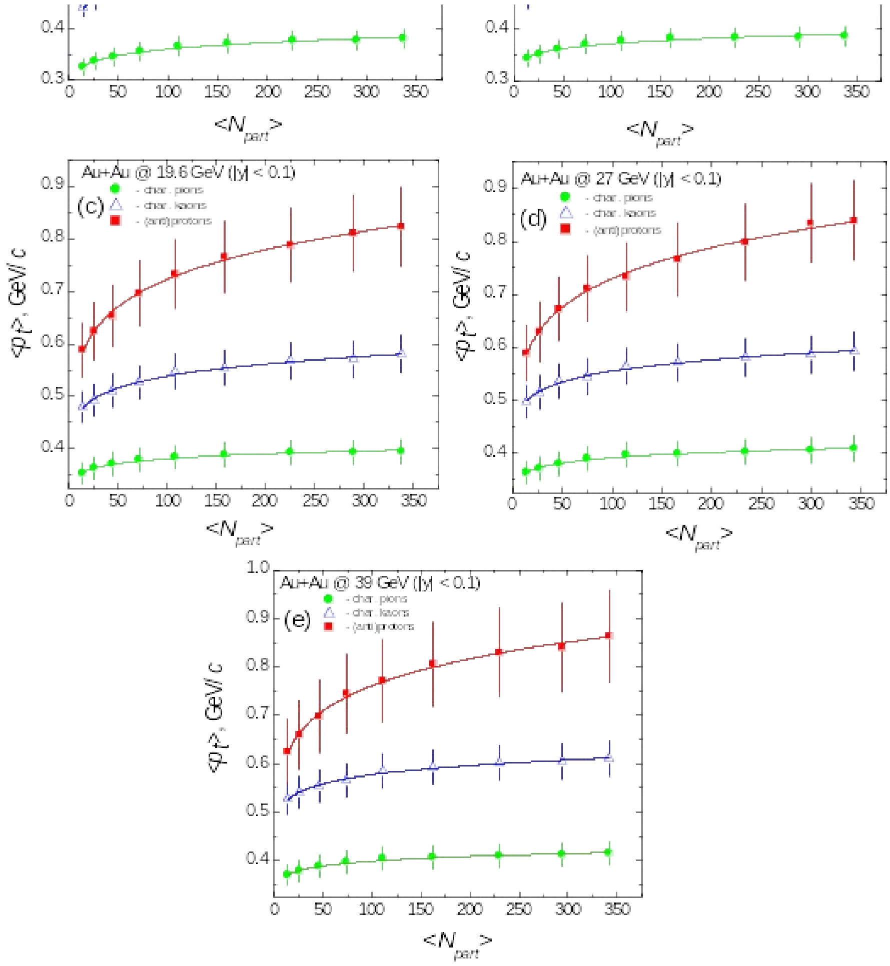

Figure 1. Minimum $\chi 2$ fits (solid curves) with the simple power model function (Eq. (1)) of the experimental average transverse momentum, ¿ p_t>¿, versus ¿ N_{part}>¿ dependencies for the charged pions, charged kaons, protons+antiprotons produced at midrapidity ($|y| < 0.1$) in Au+Au collisions at $(s_{nn})^{1/2}$=7.7 (a), 11.5 (b), 19.6 (c), 27 (d), and 39 (e) GeV.

Even though the exponent α demonstrates generally a decrease with an increase in $(s_{nn})^{1/2}$ energy for both charged kaons and (anti) protons in $(s_{nn})^{1/2}$ = 7−39 GeV energy range, the small kinks are observed in regions 19−27 GeV and 11−19 GeV in Fig. 2 for (anti)protons and the charged kaons, respectively. Figure 2 demonstrates that the power parameter α for (anti)protons does not change within uncertainties in the wide energy range $(s_{nn})^{1/2}$ = 62−5020

GeV. In present work we observe that parameter α for the charged kaons increases substantially in region $(s_{nn})^{1/2}$ = 39−62 GeV after an overall decrease in range $(s_{nn})^{1/2}$ = 7−39 GeV, which can also reflect a significant change in production mechanism(s) of the charged kaons in Au+Au collisions at $(s_{nn})^{1/2} \approx$ 39−50 GeV. We observe the anticorrelated behavior of the parameter α for the charged pions and charged kaons in regions $(s_{nn})^{1/2} \approx$ 62−130 GeV and $(s_{nn})^{1/2} \approx$ 62−130 GeV: in these two regions an increase of the parameter α for one particle species goes along with a decrease of the α for the second particle species, and vice versa.

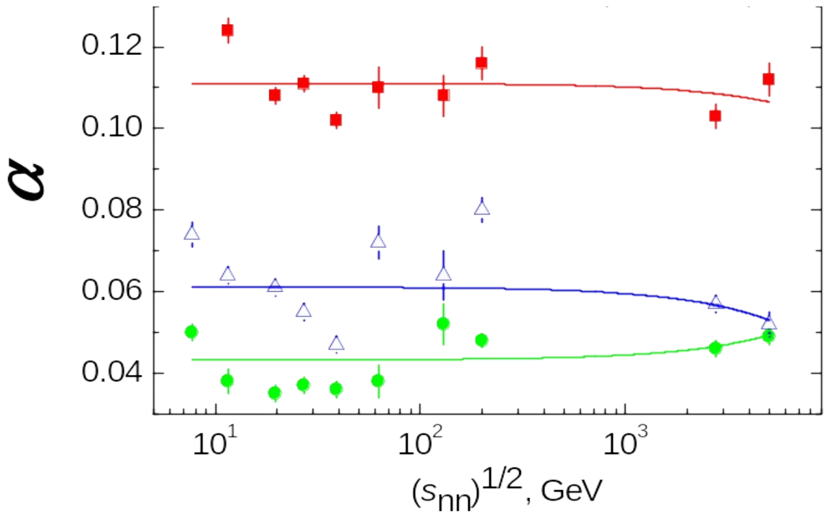

Figure 2. The dependence on collision energy $(s_{nn})^{1/2}$ of the exponent parameter α for the charged pions, charged kaons, protons+antiprotons, extracted in present work from minimum $\chi 2$ fits by $¿ p_t \geq C ¿ N_{part} > ¿^{\alpha} ¿$ (Eq. (1)) function of the experimental midrapidity $¿ p_t > ¿$ versus $¿ N_{part} > ¿$ dependencies of the charged pions and kaons, protons+antiprotons in Au+Au collisions in $(s_{nn})^{1/2}$=7−39 GeV energy range. The corresponding results, obtained in Ref. [6] from analysis of the experimental $¿ p_t > ¿$ data of STAR Collaboration for midrapidity Au+Au collisions at $(s_{nn})^{1/2}$=62.4, 130 and 200 GeV, and those of ALICE collaboration for midrapidity Pb+Pb collisions at $(s_{nn})^{1/2}$=2.76 and 5.02 TeV, are presented for a comparison. For guiding the eyes, the spectra are fitted (solid curves) by a linear function $y = Ax + B$.

Figure 2 shows that with an increase in $(s_{nn})^{1/2}$ in region $(s_{nn})^{1/2}$ > 200 GeV, the exponent α for charged kaons approaches that for charged pions, with the parameter α for kaons coinciding with that for pions at the largest collision energy $(s_{nn})^{1/2}$=5.02 TeV. The coincidence of the power parameter α for pions and kaons, produced at midrapidity in Pb+Pb collisions at $(s_{nn})^{1/2}$=5.02 TeV, reflecting practically identical shapes of $¿ p_t > ¿$ versus $¿ N_{part} > ¿$, $¿ \frac{dN_{ch}}{d} > ¿$, and $¿ N_{coll} > ¿$ spectra for pions and kaons, was obtained in Ref [6]. This result was interpreted [6] as being due to production of the highly thermalized QGP, in which the difference among *u*, *d*, and *s* flavors practically disappears, which leads to the similar mechanisms of production of pions and kaons in Pb+Pb collisions at $(s_{nn})^{1/2}$=5.02 TeV at the Large Hadron Collider.

Summary and Conclusions

The experimental spectra of the average transverse momentum, $<p_t>$, versus the average number of participant nucleons, $<N_{part}>$, dependencies of the identified charged particles at midrapidity in Au+Au collisions from the Beam Energy Scan (BES) program at the RHIC in $(s_{nn})^{1/2}$= 7-39 GeV energy range have been described very well with the proposed simple power model function. The degree of flattening of $<p_t>$ of the charged pions and kaons, protons and antiprotons in the analyzed heavy-ion collisions in $(s_{nn})^{1/2}$=7-39 GeV energy range have been investigated analyzing the dependencies of the obtained exponent parameter α of the simple power function on the particle species and collision energy. On the whole, the exponent parameter α for the charged kaons, protons and antiprotons decreases noticeably with increasing collision energy of Au+Au collisions from $(s_{nn})^{1/2}$= 7 to 39 GeV. While for the charged pions the power parameter α decreases weakly in range $(s_{nn})^{1/2}$=7-20 GeV and practically does not change in region $(s_{nn})^{1/2}$=20-39 GeV. The significant gap between parameter α for the protons and antiprotons has been observed in region $(s_{nn})^{1/2}$=7-20 GeV. The normalization fitting constant *C* and power parameter α of the simple power function have been strongly anticorrelated for all studied particle species. The differences observed between parameter α versus collision energy dependencies of the particles and antiparticles have been related to the ratios of antiparticle and particle yields and differences in the mechanisms of production of particles and antiparticles.

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