E2-2011-10

M. Tokarev [1], I. Zborovský [2]

ENERGY SCAN IN HEAVY-ION COLLISIONS AND SEARCH FOR A CRITICAL POINT

Presented at the 6th Workshop «Critical Point and Onset of Deconfinement», August 23–29, 2010, JINR, Dubna, Russia

[1] E-mail: tokarev@jinr.ru
[2] Nuclear Physics Institute, Academy of Sciences of the Czech Republic, 25068 Řež, Czech Republic
E-mail: zborovsky@nif.cas.cz

Токарев М., Зборовский И. E2-2011-10
Энергетическое сканирование в столкновениях тяжелых ионов
и поиск критической точки

Проведен анализ экспериментальных данных по инклюзивным спектрам частиц, рожденных в столкновениях тяжелых ионов на RHIC и SPS в широком диапазоне энергии $\sqrt{s_{NN}} = 9 - 200$ ГэВ в рамках теории z-скейлинга. Обсуждается микроскопический сценарий взаимодействия конституентов. Изучена зависимость потерь энергии конституента от центральности и энергии столкновения ионов и поперечного импульса инклюзивного адрона. Образующаяся ядерная среда описана в терминах «удельной теплоемкости» и фрактальных размерностей сталкивающихся ядер. Обсуждается кинематическая область реакции, предпочтительная для поиска сигнатур фазовых переходов в ядерной материи. Скачок «удельной теплоемкости» рассматривается как указание на существование фазового перехода и критической точки.

Работа выполнена в Лаборатории физики высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2011

Tokarev M., Zborovský I. E2-2011-10
Energy Scan in Heavy-Ion Collisions and Search for a Critical Point

Experimental data on inclusive spectra measured in heavy-ion collisions at RHIC and SPS over a wide energy range $\sqrt{s_{NN}} = 9{-}200$ GeV are analyzed in the framework of z-scaling. A microscopic scenario of constituent interactions in the framework of this approach is discussed. Dependence of the energy loss on the momentum of the produced hadron, energy and centrality of the collision, is studied. Self-similarity of the constituent interactions in terms of momentum fractions is used to characterize the nuclear medium by «specific heat» and colliding nuclei by fractal dimensions. Preferable kinematic regions for search for signatures of the phase transition of the nuclear matter produced in heavy-ion collisions (HIC) are discussed. Discontinuity of «specific heat» is assumed to be a signature of the phase transition and the Critical Point.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 2011

1. INTRODUCTION

The measurements of particle spectra at the Relativistic Heavy Ion Collider (RHIC) led to the discovery of the substantial suppression of hadron yields in nucleus–nucleus collisions relative to the proton–proton data [1–4]. The suppression is observed in the region of high transverse momenta, typically more than a few GeV/c. It is related with the energy radiations of the outgoing high-p_T partons propagating through the dense matter formed in the central collisions of heavy nuclei. The energy loss in the dense medium is substantially larger than in the vacuum. As noted in [5], this can essentially modify the behavior of the system near the Critical Point. In dependence on collision energy, the energy loss can differently smear signals which could indicate the characteristic changes in the thermodynamic properties of the system. Therefore the Energy Scan Programm carried out at SPS [6] and RHIC [7] is of great importance to search for and study of signatures of the phase transition and the Critical Point of the nuclear matter produced in heavy-ion collisions. In the contribution we use z-scaling approach for estimation of the energy loss as a function of the collision energy, transverse momentum and centrality.

2. z-SCALING

A regularity of the hadron production in high-energy proton–(anti)proton collisions, known as z-scaling, has been established in papers [8, 9]. It manifests itself in the fact that the inclusive spectra of various types of hadrons can be described by a universal scaling function. It holds over a wide range of transverse momenta, registration angles, collision energies and secondary particle multiplicities. The scaling function $\psi(z)$ depends on the single scaling variable

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

where

$$z_0 = \frac{\sqrt{s_\perp}}{(dN_{\rm ch}/d\eta|_0)^c\, m} \tag{2}$$

and

$$\Omega(x_1, x_2, y_a, y_b) = (1-x_1)^{\delta_1}(1-x_2)^{\delta_2}(1-y_a)^{\epsilon}(1-y_b)^{\epsilon} \tag{3}$$

are the functions of kinematic quantities. The value of z_0 is proportional to the transverse kinetic energy $\sqrt{s_\perp}$ of the constituent binary subprocess required for production of an inclusive particle (m_1) and its recoil partner (m_2). The parameter c, which has the meaning of the specific heat of the produced medium, determines the functional dependence of z_0 on the multiplicity density $dN_{\rm ch}/d\eta|_0$ of the charged particles produced in the central rapidity region $\eta = 0$. The constant m is fixed at the value of the nucleon mass. Quantity Ω is interpreted as a relative number of the constituent configurations which include binary subprocesses corresponding to the fractions x_1 and x_2 of colliding hadrons momenta and to the momentum fractions y_a and y_b of the secondary objects produced in these subprocesses. The selected binary subprocess, in terms of which the variable z is defined, is determined by the maximum of $\Omega(x_1, x_2, y_a, y_b)$ with the kinematic constraint

$$(x_1P_1 + x_2P_2 - p/y_a)^2 = M_X^2. \tag{4}$$

The mass of the recoil system in the production of an inclusive particle with the momentum p is written in the following form:

$$M_X = x_1M_1 + x_2M_2 + m_2/y_b. \tag{5}$$

Equation (4) accounts for the locality of the constituent interactions and sets a kinematic restriction on the momentum fractions x_1, x_2, y_a, and y_b.

The variable z has a property of the fractal measure. It diverges in the power-like manner with the increased resolution relative to the constituent subprocesses $(x_1, x_2, y_a, y_b \to 1)$. The parameters δ_1 and δ_2 are the corresponding fractal dimensions of the colliding objects. For nuclear collisions we set $\delta_{1,2} = A_{1,2}\delta$, where δ is the nucleon fractal dimension. The parameter ϵ stands for the fractal dimension of the fragmentation process. The parameter c is interpreted as «specific heat» of the medium produced with the production of the inclusive particle. In *pp* collisions the parameters δ, ϵ, and c were found to be independent of kinematic variables over a wide energy range $\sqrt{s} = 19-200$ GeV. The determination of the fractions x_1, x_2, y_a, y_b corresponding to the selected binary subprocess allowed us to develop a microscopic scenario of the interaction at a constituent level. The dependences of the momentum fractions and the recoil mass M_X on the transverse momentum p_T of the inclusive particle, as well as on the energy and centrality of the collisions represent important features of the constituent interactions.

The scaling function $\psi(z)$ is expressed in terms of experimentally measurable inclusive cross section for the reaction $P_1 + P_2 \to p + X$. It can be written in the following form:

$$\psi(z) = -\frac{\pi s}{(dN/d\eta)\sigma_{\rm inel}} J^{-1}\, E\frac{d^3\sigma}{dp^3}, \tag{6}$$

where $\sigma_{\rm in}$ is the total inelastic cross section, $dN/d\eta$ is the multiplicity density of registered particles and J is the Jacobian for the transformation from $\{p_T^2, y\}$ to $\{z, \eta\}$. The normalization equation

$$\int_0^\infty \psi(z)dz = 1 \tag{7}$$

allows us to interpret $\psi(z)$ as the probability density of production of the inclusive particle with the corresponding value of variable z.

3. ENERGY SCAN IN AA COLLISIONS

The phase transition into the QGP state produced in the central collisions of heavy nuclei is among most dramatic many-body effects. This phenomenon is expected to be manifested as a change in the properties of the system with modification of the constituent interactions and subsequent fragmentation processes. At a microscopic level it is related with dissipative parton dynamics by formation of the observed hadrons. The energy dissipation significantly changes in ultra-dense nuclear environment characterized by high multiplicity of the secondary particles. It depends on the collision energy and can be sensitive to the type of the phase transition or location of the Critical Point on the phase diagram. Besides the energy losses of the secondary partons in the produced medium, the behavior of the multi-parton system is characterized by thermodynamical quantities. One of the most important is specific heat which reveals a discontinuity at the second-order phase transition of a thermodynamic system. The effects can be however much diminished when smeared by the processes with the large energy loss in the nuclear collisions. Nevertheless, search for a unique description of the hadron spectra expressed in terms of parameters which have analogy in the thermodynamic quantities is of great importance. Possible change of the quantities corresponding to such parameters could be studied in the Energy Scan Programs carried out at current relativistic colliders [6,7]. Such a change with the collision energy or multiplicity would indicate to a phase transition or location of the Critical Point in AA interactions.

In this contribution we analyze the spectra of the charged hadrons produced in the central collision of heavy nuclei in z-scaling approach. The analysis includes the data obtained at different energies. Figure 1 shows the p_T-dependence of the spectra of the charged hadrons produced in the central AuAu [1, 10–12] and PbPb [13] collisions at $\sqrt{s_{NN}} = 9.2, 62.4, 130, 200$ and 17.3 GeV, respectively. The centrality is characterized by the corresponding multiplicity density $dN_{\rm ch}/d\eta|_0$ of the charged particles produced in the mid-rapidity region. The spectra cover a wide range of the transverse momentum, $p_T = 0.35{-}10.8$ GeV/c.

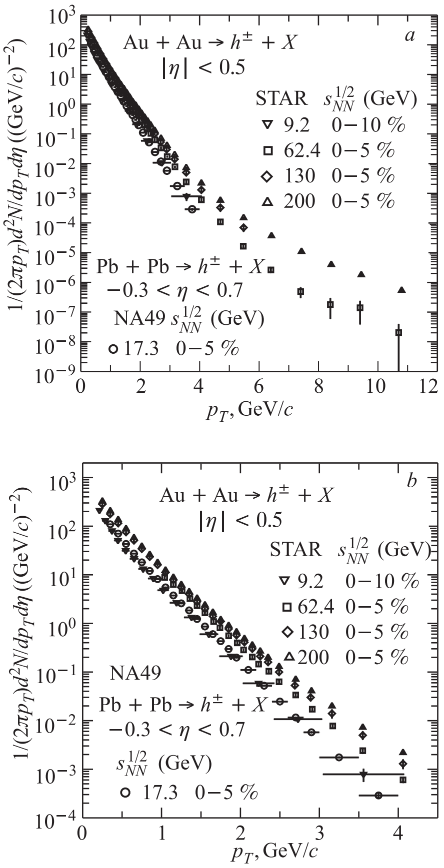

Fig. 1. The transverse momentum spectra of the charged hadrons produced in central AuAu and PbPb collisions at different energies $\sqrt{s_{NN}} = 9.2, 62.4, 130, 200$, and 17.3 GeV, and the central rapidity range in high (*a*) and low (*b*) p_T-range. The experimental data are taken from [1, 10–13]

The yields change more than eight orders of magnitude in this range. The dependence on the collision energy for the high and low momenta is demonstrated in Fig. 1, *a* and *b*, respectively.

Figure 2 shows the same data in z-presentation. The structure of the gold nuclei is characterized with the fractal dimension $\delta_{\rm AuAu} = 197 \cdot \delta$, where $\delta = 0.5$ has the same constant value as in proton–proton collisions. The independence of $\psi(z)$ on the collision energy and centrality for AuAu collisions at $\sqrt{s_{NN}} = 62.4, 130$, and 200 GeV is consistent with the constant value of the specific heat $c_{\rm AuAu} = 0.11$ provided the multiplicity dependence of the fragmentation

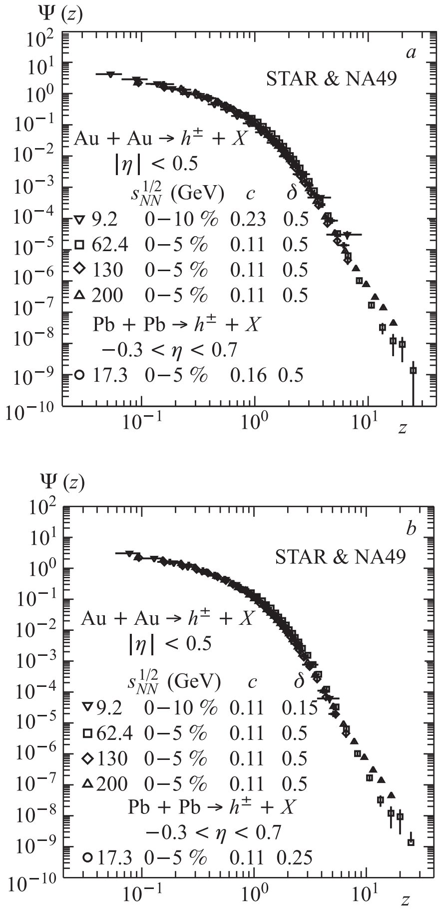

Fig. 2. z-presentation of the transverse momentum spectra of the charged hadrons produced in central AuAu and PbPb collisions at different energies $\sqrt{s_{NN}} = 9.2, 62.4, 130, 200$, and 17.3 GeV, and the central rapidity range. The experimental data are taken from [1,10–13]. *a*) — scenario I; *b*) — scenario II

dimension ϵ_{AA} in the following form:

$$\epsilon_{AA} = \epsilon_0(dN_{\rm ch}^{AA}/d\eta) + \epsilon_{pp}. \tag{8}$$

The value of $\epsilon_{pp} = 0.2$ has been obtained from z-scaling analysis of the charged hadrons produced in pp collisions [8,9]. Allowing the coefficient ϵ_0 to be dependent on the collision energy, one can obtain the identical $\psi(z)$ for pp and AuAu interactions for all centralities in the considered energy range.

Correlation between the parameters c and δ for AuAu collisions at $\sqrt{s_{NN}} = 9.2$ GeV and for PbPb collisions at $\sqrt{s_{NN}} = 17.3$ GeV was found. The restoration of the universal shape of $\psi(z)$ at these energies can be reached in two scenarios: I — $c_{\rm AuAu} = 0.23$, $\delta = 0.5$; $c_{\rm PbPb} = 0.16$, $\delta = 0.5$; and II — $c_{\rm AuAu} = 0.11$, $\delta = 0.15$; $c_{\rm PbPb} = 0.11$, $\delta = 0.25$. The first scenario (Fig. 2, *a*) corresponds to the large and the second one (Fig. 2, *b*) to the small (energy independent) values of the «specific heat» c. The z-presentations of the spectra at $\sqrt{s_{NN}} = 9.2$ and 17.3 GeV are described by the same curve as for higher energies. The measured p_T-range of the spectra and the large errors at high p_T do not allow us to discriminate between the both scenarios. Measurement of the hadron distributions at $\sqrt{s_{NN}} = 9.2$ and 17.3 GeV versus centrality for $p_T > 4$ GeV/c is desirable to resolve the problem and to study the dependence of the energy loss in this region. More detailed investigations could provide future analysis of the spectra obtained by the Energy Scan Program at SPS [6] and RHIC [7].

4. ENERGY LOSS IN AA COLLISIONS

The microscopic scenario of the particle production based on z-scaling is used for estimation of the energy loss of the produced particles in the nuclear medium. Energy loss during formation of the inclusive hadron is given by the momentum fraction y_a. It varies with the transverse momentum, energy and centrality of the collisions. The value of y_a depends on the fragmentation dimension ϵ. The increase of ϵ_{AA} with the multiplicity density (centrality) in nuclear collisions is related with decrease of the momentum fraction y_a. This corresponds to the larger energy loss by formation of the inclusive hadron. On the other hand, the energy loss depends on the traversed medium which converts it into the multiplicity of the associated particles. The larger ϵ_{AA} the more energy loss consumed to production of secondary particles. In such a way the produced medium is characterized by the amount of the energy loss.

Figure 3, *a* shows the dependence of the fraction y_a on the transverse momentum of the charged hadrons produced in the central AuAu collisions at $\sqrt{s}_{NN} = 62.4, 130, 200$ GeV in the mid-rapidity range. The energy loss by the formation of the inclusive particle is proportional to $(1 - y_a)$. As seen from Fig. 3, *a*, the energy loss decreases with the increasing momentum p_T and increases with the collision energy. The similar trends (Fig. 3, *b*) are seen in AuAu and PbPb collisions at lower energies $\sqrt{s}_{NN} = 9.2$ and 17.3 GeV for the both scenarios. The energy loss is smaller for the scenario I (the empty symbols) in comparison with the scenario II (the full symbols). The energy loss in the central AuAu collisions at $p_T = 4$ GeV/c was found (Fig. 3, *a*) to be about 70, 82, and 87% at $\sqrt{s} = 62.4, 130$, and 200 GeV, respectively. At the energy $\sqrt{s_{NN}} = 9.2(17.3)$ GeV and $p_T = 4$ GeV/c the energy loss in the central colli-

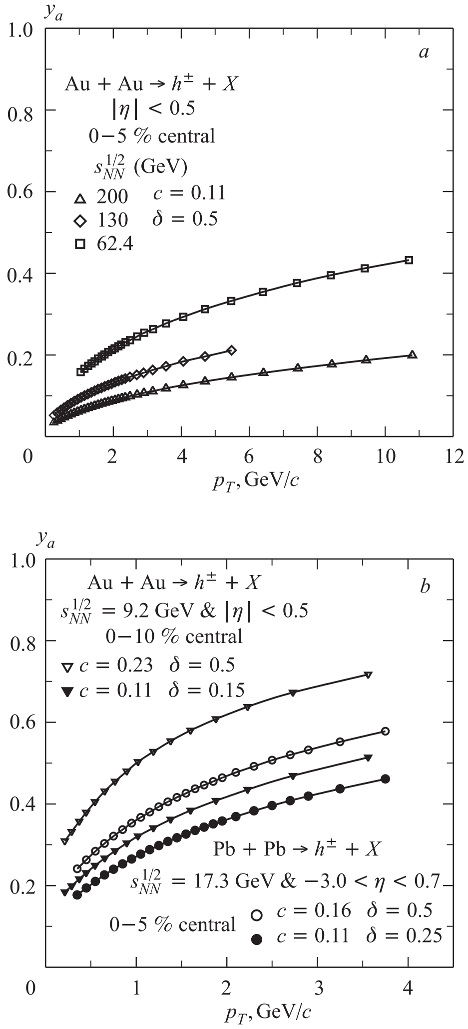

Fig. 3. The dependence of the fraction y_a on the transverse momentum p_T for the charged hadrons produced in AuAu and PbPb collisions in the central rapidity range at different energies $\sqrt{s_{NN}} = 62.4, 130, 200$ (*a*), and 9.2, 17.3 GeV (*b*). The empty and full symbols in (*b*) correspond to scenarios I and II of the hadron production, respectively

sions is estimated (Fig. 3, *b*) to be about 25 (40%) and 45 (55%) for the scenarios I and II, respectively.

The recoil object in the constituent subprocess moving in the away side direction of the inclusive particle is characterized by the recoil mass M_X. It depends on the momentum fractions x_1 and x_2 of the interacting hadrons (or nuclei) with the masses M_1 and M_2. The dependence of M_X on y_a and y_b is determined by (5) with $x_{1,2} = x_{1,2}\ (y_a, y_b)$ given in [8]. This includes the dependence of M_X on the fractal dimensions δ_1, δ_2, and ϵ. The recoil mass reflects an internal connection to the structure of the colliding objects, constituent interactions, and process of formation of the individual hadrons. In the considered analysis there are relations $M_1 = M_2 = M_A$, $\delta_1 = \delta_2 \equiv \delta_A$, and $x_1 \simeq x_2$.

Figure 4, a shows the dependence of the recoil mass M_X on the transverse momentum of the charged hadrons produced in the central AuAu collisions at $\sqrt{s_{NN}} = 62.4, 130$, and 200 GeV in the mid-rapidity range $|\eta| < 0.5$. All curves demonstrate growth with p_T which is followed by a successive flattening. The values of the recoil mass reveal a characteristic increase with the collision energy. The similar dependences of M_X on p_T in AuAu and PbPb collisions at $\sqrt{s_{NN}} =$ 9.2 and 17.3 GeV for the scenarios I and II are depicted in Fig. 4, b. Here, in contrast to higher energies, one can see the sharp growth of M_X with p_T in the range $p_T = 0.3{-}4$ GeV/c without any indication on a flattening. The scenario with the large specific heat (the empty symbols) corresponds to smaller values of M_X in comparison with the scenario II (the full symbols). Consequently, the large specific heat scenario at the energies $\sqrt{s_{NN}} = 9.2$ and 17.3 GeV would reflect the production of more compact subsystems in the constituent interactions with smaller energy loss.

The monotonous dependence of M_X on the collision energy demonstrated in Fig. 4, a at high $\sqrt{s_{NN}}$ is preserved in the scenario I at lower energies as well (Fig. 4, b). It results from the energy independent value of the fractal dimension $\delta = 0.5$. However in the region of large p_T, the values of M_X for $\sqrt{s_{NN}} =$ 9.2 GeV become larger than M_X for $\sqrt{s_{NN}} = 17.3$ GeV, as indicated by the empty symbols in Fig. 4, b. This behavior follows from formula (4) which consists of two parts. At high energies the recoil mass is well approximated by $M_X \simeq m_2/y_b$. At lower energy, the fractions x_1, x_2 and y_b become larger and the «constituent part» of the recoil mass, $x_1M_1 + x_2M_2$, gets important. For heavy nuclei, the recoil mass becomes dominated by the «constituent part», $M_X \simeq x_1M_1 + x_2M_2$, at very low $\sqrt{s_{NN}}$ and high p_T. This trend is visible in Fig. 4, b for the scenario II (the full symbols) in which M_X becomes slightly larger at $\sqrt{s_{NN}} = 9.2$ GeV than at $\sqrt{s_{NN}} = 17.3$ GeV as p_T increases. Here it is related with the relative enhancement of the fractions x_1 and x_2 as follows from a decrease of the fractal dimension δ.

The momentum fractions x_1 and x_2 characterize center-of-mass energy of a subprocess which is the interaction of hadron constituents with the masses x_1M_1 and x_2M_2. In the symmetric nuclear collisions there is approximate relation $x_1A_1 \simeq x_2A_2$ for the hadron production at mid-rapidity. Figure 5, a shows the dependence of the momentum fraction x_1A_1 on the transverse momentum of the charged hadrons produced in the central AuAu collisions at $\sqrt{s_{NN}} =$

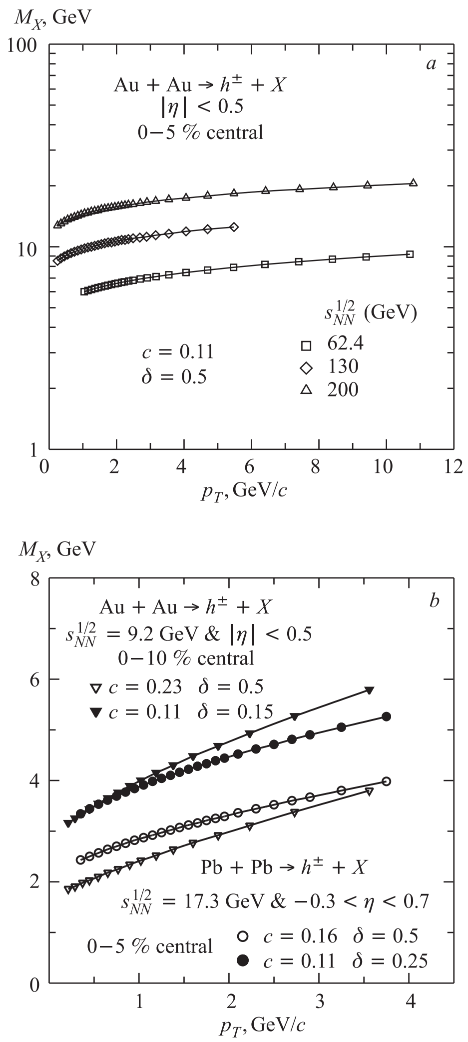

Fig. 4. The dependence of the recoil mass M_X on the transverse momentum p_T for the charged hadrons produced in central AuAu and PbPb collisions in the central rapidity range at different energies $\sqrt{s_{NN}} = 62.4, 130, 200$ GeV (*a*), 9.2, 17.3 GeV (*b*). The empty and full symbols in (*b*) correspond to scenarios I and II of the hadron production, respectively

$62.4, 130$, and 200 GeV in the mid-rapidity range. The similar trends (Fig. 5, *b*) are demonstrated for central AuAu and PbPb collisions at the energies $\sqrt{s_{NN}} = 9.2$ and 17.3 GeV for two scenarios discussed above. All curves demonstrate growth of the momentum fraction $x_1 A_1$ with p_T and a characteristic decrease with the

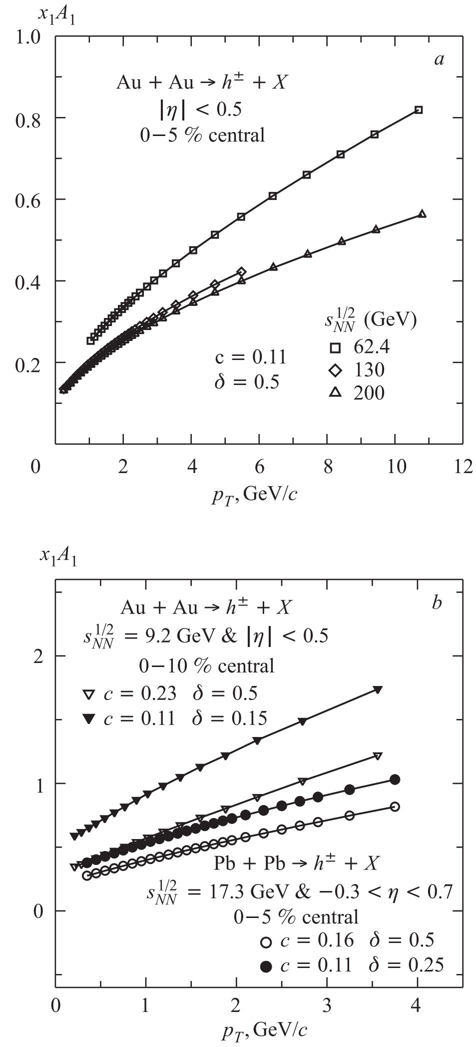

Fig. 5. The dependence of the fraction $x_1 A_1$ on the transverse momentum p_T for the charged hadrons produced in central AuAu and PbPb collisions in the central rapidity range $|\eta| < 0.5$ at different energies $\sqrt{s_{NN}} = 62.4, 130, 200$ GeV (*a*), 9.2, 17.3 GeV (*b*). The empty and full symbols in (*b*) correspond to scenarios I and II of the hadron production, respectively

collision energy $\sqrt{s_{NN}}$. The scenario with the large specific heat (the empty symbols in Fig. 5, *b*) corresponds to smaller values of $x_1 A_1$ in comparison with the scenario II (the full symbols). This would correspond to a larger values of the center-of-mass energies of the subprocesses at low $\sqrt{s_{NN}}$ in the scenario II, i.e., in the case when the constituent structure of the colliding nuclei is more smeared (small δ).

The region $x_1A_1, x_2A_2 < 1$ corresponds to the production of an inclusive hadron in a free nucleon–nucleon kinematics. The cumulative production of particles in nuclear collisions is determined by the conditions x_1A_1 or $x_2A_2 > 1$. The double (or hard) cumulative processes are defined by $x_1A_1, x_2A_2 > 1$. This corresponds to the hadron production in the nuclear collisions with extra large p_T. The cumulative processes are forbidden for free nucleon–nucleon kinematics. As seen from Fig. 5, the cumulative region for hard processes can be reached more easily at $\sqrt{s}_{NN} = 9.2$ and 17.3 GeV than at $\sqrt{s}_{NN} = 62-200$ GeV. At high collision energies the free nucleon–nucleon kinematic boundary is far enough and is experimentally not accessible. As demonstrated in Fig. 3, the energy loss $\Delta E \sim 1 - y_a$ decreases with the increasing transverse momentum p_T and is relatively small at low collision energies. In that sense the hard cumulative region is more preferable to study the hadron production with small energy loss.

5. SEARCH FOR A CRITICAL POINT IN AA COLLISIONS

The Energy Scan Program at SPS [6] and RHIC [7] is aimed to determine the phase diagram of the nuclear matter produced in heavy-ion collisions. The search for location of the Critical and Triple Critical Points is of special interest.

We assume, that localization of the Critical Point of the phase transition would be much more effective for processes with smaller loss of energy. The large energy loss can cause a «smearing out» of the behavior of parameters c, δ and ϵ close to the Critical Point. The hard cumulative production is characterized by relatively small energy loss and therefore extremely suitable for such type of investigations. The isolation of the interaction between constituents allows a direct measurement of the invariant mass M_X, which for large p_T is essentially the mass of a cumulative recoil jet. In this region (hard cumulative processes), one can investigate the structure of fluctons (the particle-like fluctuations of the nuclear matter) and fragmentation processes induced by their collisions. Besides cumulativity, selection of processes with large multiplicity is considered to be preferable to search for the Critical Point. Multiplicity, as one of the experimentally measurable quantities, can be used to control the properties of a medium in which the flucton interactions take place. Production of the compressed matter in heavy-ion collisions suggests using the special kinematic conditions ($x_1A_1, x_2A_2 > 1$) and centrality event selection ($dN_{\mathrm{ch}}/d\eta|_0 > 250-300$).

Under such conditions the discrimination between the above discussed scenarios with the energy independent or enhanced «specific heat» c at low collision energy requires more detailed analysis of high-p_T processes in the central nuclear collisions within the range $\sqrt{s_{NN}} = 9{-}20$ GeV. Because fractal dimension δ is sensitive to the behavior of the spectra at high p_T, the $\delta - c$ correlation is expected to be stronger in this region. Study of such a correlation could help to resolve possible enhancement of the «specific heat» of the produced matter and shed some light on location of the Critical Point in this region.

The experimental data on the inclusive spectra of the charged hadrons produced in central AuAu and PbPb collisions at energies $\sqrt{s_{NN}} = 9.2, 62.4, 130, 200$, and 17.3 GeV were analyzed in the framework of z-scaling. The experimental data in z-presentation indicate similarity as a characteristic feature of mechanism of the hadron production. This property includes structure of the colliding objects, interaction of their constituents, and character of the fragmentation process. The microscopic scenario of nucleus–nucleus interactions at a constituent level in terms of the momentum fractions was used to estimate the energy loss of the secondary partons passing through the medium produced in heavy-ion collisions. It was shown that the energy loss increases with the collision energy, and decreases with p_T.

It was demonstrated that the universality of the shape of $\psi(z)$ of the hadron production in AuAu collisions at $\sqrt{s}_{NN} = 62.4, 130, 200$ GeV can be preserved for the constant value of the «specific heat» $c_{\mathrm{AuAu}} = 0.11$ for all centralities, provided the fragmentation dimension ϵ_{AuAu} increases with multiplicity. The correlation between the parameters c_{AuAu} and δ with change of their values at lower energies $\sqrt{s}_{NN} = 9.2$ and 17.3 GeV was found. Two scenarios (with the large and small «specific heat») of the hadron production at these energies were suggested. The scenarios differently describe behavior of the energy loss, recoil mass and cumulative number (x_1A_1) on the transverse momentum. It was noted that a preferable kinematic region to discriminate between the both scenarios corresponds to measurements of the charged hadron spectra in the cumulative region ($p_T > 4$ GeV/c, $x_1A_1 > 1$). We assume that this is the region where the $c - \delta$ correlation should be strengthened and signatures of existence of the Critical Point should be manifested more clearly. Therefore forthcoming data of the Beam Energy Scan Program at SPS and RHIC are of great interest.

The obtained results may be exploited to search for the phase transition and the Critical Point and to study of new physics phenomena in the hadron production in heavy-ion collisions.

Acknowledgements. The investigations have been supported by the IRP AVOZ10480505, by the Ministry of Education, Youth and Sports of the Czech Republic grants LA08002, LA08015 and by the special program of the Ministry of Science and Education of the Russian Federation, grant RNP.2.1.1.2512.

REFERENCES

1. *Adams J. et al.* (*STAR Collab.*) // Phys. Rev. Lett. 2003. V. 91. P. 172302.
2. *Arsene I. et al.* (*BRAHMS Collab.*) // Phys. Rev. Lett. 2003. V. 91. P. 072305.
3. *Adler S. S. et al.* (*PHENIX Collab.*) // Phys. Rev. C. 2004. V. 69. P. 034910.
4. *Back B. B. et al.* (*PHOBOS Collab.*) // Phys. Rev. Lett. 2005. V. 94. P. 082304.
5. *Tokarev M. V., Zborovský I.* // Phys. Part. Nucl. Lett. 2010. V. 7(3). P. 160.
6. *Gazdzicki M.* (*for the NA61/SHINE Collab.*) // J. Phys. G. 2009. V. 36. P. 064039.
7. *Caines H.* (*for the STAR Collab.*). arXiv:0906.0305v1 [nucl-ex];
   Abelev B. I. et al. (*STAR Collab.*). http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493;
   Abelev B. I. et al. (*STAR Collab.*) // Phys. Rev. C. 2010. V. 81. P. 024911.
8. *Zborovský I., Tokarev M. V.* // Phys. Rev. D. 2007. V. 75. P. 094008.
9. *Zborovský I., Tokarev M. V.* // Int. J. Mod. Phys. A. 2009. V. 24. P. 1417.
10. *Adler C. et al.* (*STAR Collab.*) // Phys. Rev. Lett. 2002. V. 89. P. 202301.
11. *Gagliardi C. A.* (*for the STAR Collab.*) // Eur. Phys. J. C. 2005. V. 43. P. 263.
12. *Tokarev M. V.* (*for the STAR Collab.*). arXiv:1004.5582 [nucl-ex].
13. *Alt C. et al.* (*NA49 Collab.*) // Phys. Rev. C. 2008. V. 77. P. 034906.

Received on February 3, 2011.

Корректор *Т. Е. Попеко*

Подписано в печать 29.04.2011.
Формат $60 \times 90/16$. Бумага офсетная. Печать офсетная.
Усл. печ. л. 1,18. Уч.-изд. л. 1,59. Тираж 375 экз. Заказ № 57316.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@jinr.ru
www.jinr.ru/publish/