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ON THE STATUS OF VHM PHYSICS*

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The status of thermodynamical approach in the multiple production processes and especially for very high multiplicity (VHM) domain is discussed. This approach is quite popular in the heavy ion collision physics. It is argued that the "principle of vanishing of correlations" must be used for quantitative estimations of the rate of thermalization. A review of present experimental information is offered.

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1. Introduction

We will start from a brief review of statistical models. For this purpose the "very high multiplicity" (VHM) physics domain in the phase space is defined. We will find the necessary and sufficient condition of thermalization. The multiple production is considered as a process of dissipation of initial energy into produced mass. Corresponding scenario of transition to thermalized state is discussed. It is based on the existing multiple production models.

To compare our theoretical results with experiment, we consider the events generator adopted to the concrete experiments. Namely, the PYTHIA predictions adopted to the ATLAS, DELPHI experiments will be shown. The NA49 data also will be demonstrated.

The general conclusions are the following: *(i)* there is no indication of thermalization in the existing no-bias experimental data and the special trigger should be used to have the thermalized states; *(ii)* it is most probable

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that the thermalization can be seen in the hard $e^+e^- \to$ hadrons processes; *(iii)* the high energy heavy ion collisions are also important because of the rescattering phenomenon.

In more details this questions will be considered in the concluding section.

2. Phenomenology indications of statistics

The rising interest to the statistical approach in the inelastic hadron and heavy ion collisions should be mentioned first of all. In a series of later papers the phenomenological basis of this approach is justified.

It must be mentioned that the statistical thermal model is in good agreement with experimental data of heavy ion collisions [1]. The "improved" statistical model shows that the chemical equilibrium is reached in heavy ion collisions [2]. Statistical methods in multiple production phenomenon were considered in [3].

Our main idea is based on the natural question: can given inelastic experiment be described "roughly" in terms of some average quantities? Such "rough" parameter can be the mean energy of produced particles. It can be shown that the thermodynamical description is available if and only if the answer to the above question is positive. Our aim is to check this question from experimental point of view.

Observed agreement of thermodynamical formulae with experiment can be used as the starting information for further investigations.

3. The structure of phase space

Three domains can be extracted in the phase space, see Fig. 1. They are the "Regge" domain, the "deep inelastic scattering" (DIS) domain and the "very high multiplicity" domain.

The "Regge" is the soft hadron dynamics. It was considered by Gribov, Ter-Martirosyan, Kaidalov, Landshoff, see list of references in [4]. The pQCD background of this approach is well described by the BFKL evolution equation [4]. "DIS" is the hard hadron dynamics described by the DGLAP equation [4]. "VHM" is the hard low-x hadron dynamics [4].

It must be noted that the symmetry constraints are not important outside "Regge" domain and the LLA ideology can not be used outside the "DIS" domain. The strong coupling tQCD was built to describe the "VHM" domain [5].

The structure shown in Fig. 1 gives a transparent picture of the multiple production kinematics classifying various mechanisms of particle production.

Thermodynamics assumes the uniform distribution of the energy over all degrees of freedom. Then, one may assume that the place of thermodynamics lies between "Regge" and "DIS" domains, where the longitudinal and

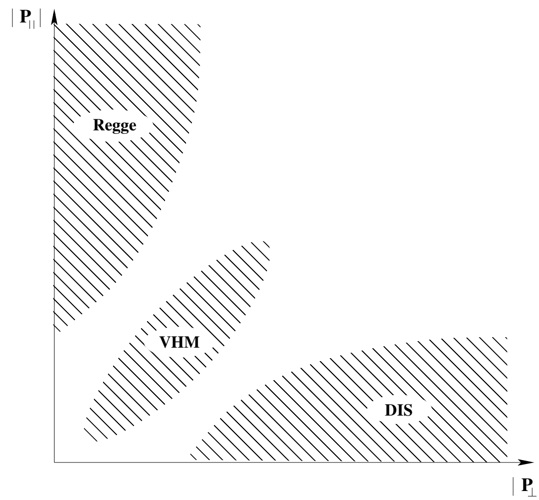

Fig. 1. The $(p_{\|}, p_{\perp})$ plane.

transverse momenta are approximately equal to each other. It must be noted that the BFKL approach in Regge domain and DGLAP in the DIS domain assumes the LLA accuracy. In the VHM domain this approximation did not work because of the approximate equality of produced particles momenta. At the same time the next-to- and so on calculations are too complicated. Just this is a main theoretical problem in the VHM domain.

For this reasons a new type perturbation theory for ordinary Yang–Mills field was constructed. It describes the conserving fields topology excitations and was called the topological QCD.

4. Necessary and sufficient condition of thermalization

One can prove [4,6]: if the inequality

$$|K_l(n,E)|^{2/l} \ll |K_2(n,E)|, \; l = 3, 4, \ldots l \tag{1}$$

does hold, then the thermalization occurs.

The central energy correlation functions are:

$$K_l(n,E) = \left\langle \prod_{k=1}^{l} (e_k - \langle e \rangle) \right\rangle ,$$
$$e_k = (q_k^2 + m^2)^{1/2} , \quad \langle 1 \rangle = 1 . \tag{2}$$

Averaging is performed over the semi-exclusive cross sections

$$\frac{d^l \sigma_n}{dq_1 dq_2 \cdots dq_l} = \int \prod_{k=l+1}^{n} \frac{d^3 q_k}{(2\pi)^3 2e_k} |A_n(q_1, \ldots, q_l, q_{l+1}, \ldots, q_n)|^2,$$

where A_n is the n-particle production amplitude.

The second step toward statistical description consists in observation that latter means necessity to have the well defined thermodynamical parameters.

Therefore, if the inequality is satisfied then the statistical description actually occurs. To have a right to introduce, for example, the temperature and to use the statistical models, one must check the experimental data from this point of view.

It should be stressed that the given inequality is necessary and sufficient for thermalization. We understand this phenomenon as the transition to the uniform distribution of the perturbation over all degrees of freedom. It is practically independent of the type of Lagrangian, on symmetries and other details. One can observe here the analogy with the principle of "vanishing of correlations", offered by Bogolyubov for statistical physics [7]. This conclusion is general, it weakly depends on details of dynamics.

The following scenario to thermalized state has been derived in [4] (see Fig. 2). The multiperipheral kinematics for $n < n_{\rm s} \sim \bar{n}(s)^2$, is satisfied in the domain A in Fig. 2. With rising $n > n_{\rm s}$ the hard (multi)-jet kinematics must dominate and the $n_{\rm h} > n_{\rm s}$ is the LLA kinematics threshold. The VHM domain B is the region of thermalization.

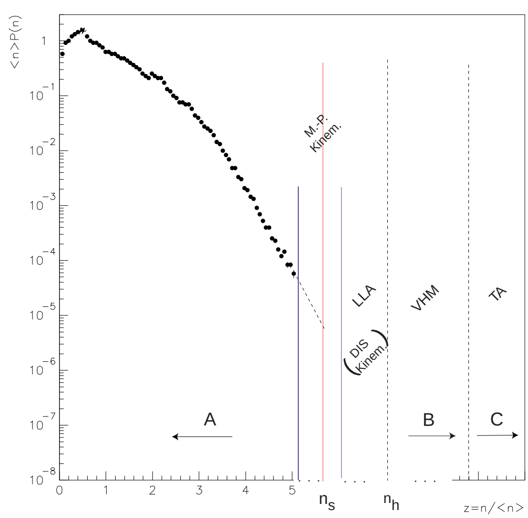

Fig. 2. The multiplicity distribution. Dots are from E-735 (FNAL) data.

It is important to note that in the multiplicity domain C, where the produced particle momenta are small, $|q_k| < m$ — hadron mass, the thermalization *must* occur. This domain is not interesting from dynamical point of view, but is interesting for investigation of the Bose–Einstein correlations.

On the to-day level of theory we can not prove that the VHM region is not empty in the high energy experiments. Existing experimental data will be shown. Just the question of thermalization will be investigated by the new experiment at U70 in Protvino. More details about this experiment were given on previous ISMD Symposium [8] in the talk of Vladimir Nikitin, the head of this experiment. He can not come here to present the to-day status of the experiment

5. Prediction of generators: PYTHIA

We are starting now to consider the predictions of the most popular generators of events. By definition, the generators absorb all existing experimental and theoretical information concerning multiple production events. For this reason this information must be important.

Fig. 3 presents the PYTHIA prediction for LHC energy. (To have sufficiently large multiplicity, it was assumed that the produced particle transverse momentum is larger than 0.3 GeV.)

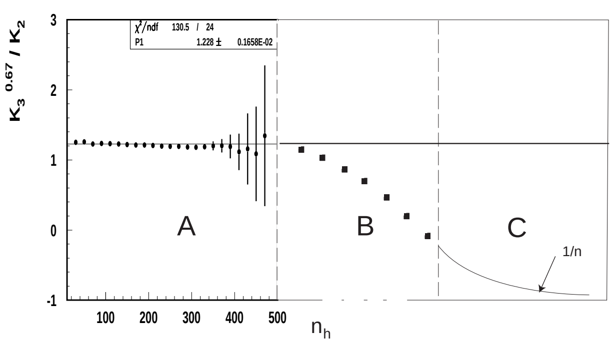

Fig. 3. PYTHIA prediction for $|K_3|^{2/3}/|K_2|$ in the domain A.

There are three domains:

A. One may conclude from Fig. 3 that the dynamical models built into the PYTHIA can not predict thermalization.

B. The transition region to thermalized state. VHM may belong to it.

C. The limiting thermalization region:

$$\frac{|K_3(n,E)|^{2/3}}{|K_2|} \sim \frac{1}{n}\,. \tag{3}$$

The ratio of mean values of longitudinal to the transverse momenta (see Fig. 4)

$$r = \frac{\langle p_{\|}\rangle}{\langle p_{\perp}\rangle} \tag{4}$$

is one of the indicators of thermalization. Indeed, in the thermalized state the mean values of the momenta components must be of the same order. This means that the values of the produced particle momenta must be the same. Just this condition gives the ratio r equal to $4/\pi$.

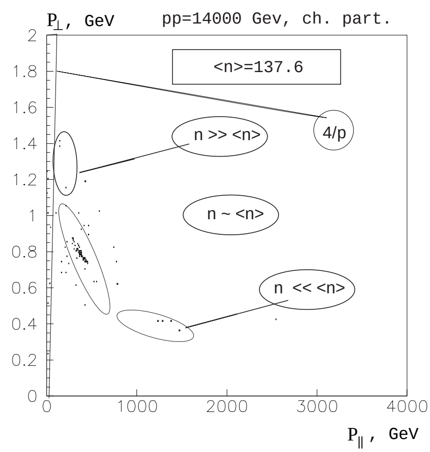

Fig. 4. PYTHIA prediction for r

The same conclusion holds for the ion–ion collisions. The HIJING generators prediction is presented in Fig. 5 and the experimental information from NA49 is given in Fig. 6.

We have to use the PYTHIA accommodated to the DELPHI data, see Fig. 7. It must be noted that there is some tendency to thermalization. This is in accord with our prediction that the VHM final state must be result of hard interactions. So, it is important to continue the study of $K_3^{2/3}/K_2$ in the hard processes.

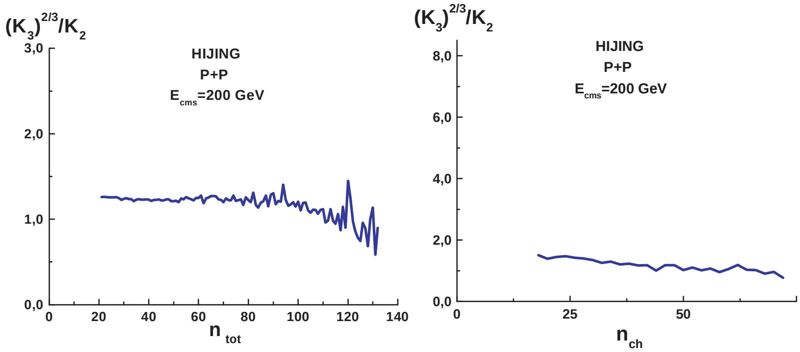

Fig. 5. HIJING prediction for $|K_3|^{2/3}/|K_2|$.

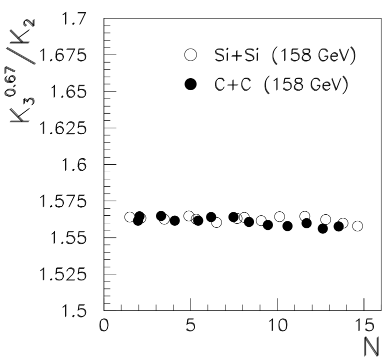

Fig. 6. NA49 data (unpublished).

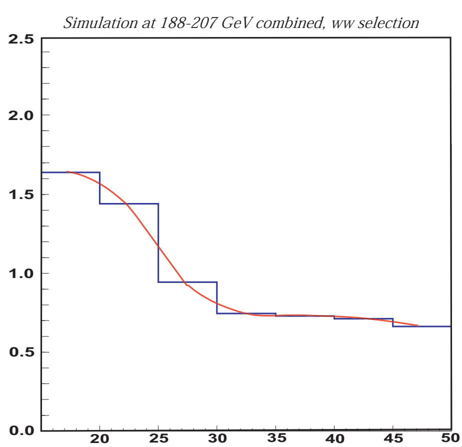

Fig. 7. PYTHIA prediction for the "K_3 to K_2" ratio.

6. Conclusions

Our S-matrix interpretation of thermodynamics shows that the thermalization must occur, at least, for high multiplicity. There is a method that makes it possible to find the necessary and sufficient conditions for a thermodynamic description to be valid.

Ordinary ("Regge", pQCD in LLA) theoretical models can not predict even the tendency to equilibrium. Our approach helps to answer the question: is it possible to use the thermodynamics in hadron collisions? The fact that we have a multiparticle system is not enough to justify the use of the thermodynamics.

The experimental data presented above are in good, at least qualitative, agreement with predictions of theory. Experiment shows that there is not justified to use thermodynamical description for the data of existing multiplicities. Nevertheless, some very weak tendency to thermalization in the hard collisions is observed. Now we investigate heavy ions inelastic collisions at STAR. We are planning also to continue these investigations on CDF and future ATLAS data.

One may conclude that we are far from the interesting physical VHM region. The special experiment with larger multiplicity seems extremely important.

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