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Edited by

S. Bentvelsen
NIKHEF, Amsterdam
The Netherlands

P. de Jong
NIKHEF, Amsterdam
The Netherlands

J. Koch
NIKHEF, Amsterdam and University of Amsterdam
The Netherlands

and

E. Laenen
NIKHEF, Amsterdam and Utrecht University
The Netherlands

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*S. Bentvelsen, P. de Jong, J. Koch and E. Laenen (Editors)*

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# Statistical Models and Thermalization

J.Manjavidze[a]* and A.Sissakian[a]

[a]Joint Institute for Nuclear Research, Dubna, Russia

The status of thermodynamical approach is discussed. This approach is quiet 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. Existing theoretical models and corresponding generator of events are unable to predict the thermalization phenomenon. A brief review of attendant papers is given.

## 1. Introduction

The question of *applicability of thermodynamical description in hadron physics* seem crucial. Its usage in hadron dynamics is reasonable since the inelastic collisions is the typical energy dissipation processes. This point of view was explored intensively by Fermi and Landau [1] and later by other authors [2].

It must be noticed that *if the system can be described by the thermodynamical "rough" parameter, then the system is equilibrium over it.* This important observation is a theoretical basis of our approach.

So, if only the temperature is sufficient for complete definition of the energy spectrum, then the system certainly is in the thermal equilibrium. But, generally speaking, it can be outside of equilibrium relative to other parameters. Generally, the thermalized state is characterized by uniform distribution of the energy perturbation over all degrees of freedom.

The ordinary statistical models predict the mean multiplicity proportional to the its threshold value, i.e. the statistical models assume the complete thermalization.

But the experimental data on the mean multiplicity, $\bar{n}(s) \sim \ln \sqrt{s}$, where $\sqrt{s}$ is the total CM energy. This indicates that the hadron interactions final state is far from equilibrium. It is impossible to use in this case the notions of thermodynamics.

The point is that the governing hadron dynamics non-Abelian symmetry constrain prevents the thermalization at the early stage of the process. This is why the multiple production dynamics is so complicated.

Therefore, it is very important to investigate: (i) the existence of phenomenological indications of statistics and (ii) the quantitative necessary and sufficient indication that the thermalized state is produced.

These two questions are the subject of the present paper. The introduction into the thermodynamics of hadron inelastic collisions one may find in [3]. We hope that the thermodynamical approach to the hadron dynamics is applicable at least for the case of very high multiplicities (VHM).

## 2. Phenomenological indications of statistics

One should mention the growing interest in the statistical approach in the inelastic hadron collisions. The ideological basis of it was originated by the number of authors [4]. In a series of later papers, part of which were presented at this Conference, the phenomenological basis of this approach is justified.

It should be noted that most of the presented papers are devoted to the description of the heavy ion central collisions.

— It was noted that the analysis of particle production yields in central Au-Au collisions at RHIC based on the statistical thermal model is in good agreement with the experimental data,

*Permanent address: Inst. of Physics, Tbilisi, Georgia.


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see [5].

— It was shown that the improved statistical model allows one to conclude that the chemical equilibrium is reached in Pb-Pb collisions at SPS energies, see [6].

— The statistical model application indicates that the production of different particles and their momentum spectra are governed by one parameter, see [7].

## 3. Structure of the phase space

In spite of the progress of heavy ion collisions statistical description, it seems reasonable to be critical and to find the quantitative sign of its applicability.

It is useful for this purpose to have a transparent picture of the multiple production kinematics to classify various mechanisms of particle production.

One may consider the phase space projection on the longitudinal, ($p_{\|}$), vs. transverse, ($p_{\perp}$), momentum plane, see Fig.1.


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

One may extract two domain, well described by the dynamical models:

— The multiperipheral-type models belong to the "Regge" domain. This kinematic is characterized by small and independent from initial energy and multiplicity the mean value of transverse momentum;

— The region of applicability of the LLA ideologies of pQCD belongs to the "Deep Inelastic Scattering" (DIS) domain. In this case the transverse momentum of produced hadrons is larger than the longitudinal one;

— In this case the transverse and longitudinal momenta of produced particles are comparable to each other and one can expect in this case the equilibrium among these degrees of freedom. The final state of inelastic heavy ion-ion collision belongs, most likely, to the intermediate region.

So, one may assume that the place of thermodynamics lies between the "Regge" and "DIS" domains. It is the "VHM" domain. To describe this region, a new perturbation theory, "topological QCD", was developed, see [8].

## 4. Necessary and sufficient condition of thermalization

The second step toward statistical description actually is a search of the necessary and sufficient condition of thermalization.

We can argue that if the inequality:

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

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

If this condition (1) works, then it is possible to describe the system using thermodynamics.

One can observe here the analogy with the principle of "vanishing of correlations", offered by N.N. Bogolyubov for statistical physics, see [9].

It should be stressed that the conclusion (1) is general for hadron dynamics

## 5. The scenario of transition to thermalized state

We may offer a scenario as the thermalized state achieved with increasing multiplicities in hadron(ion) collisions. The Fig.2 illustrates it in terms of multiplicity distribution. So,

— Multiperipheral picture applicable up to $n \sim \bar{n}^2$ and the "hard" processes take place at larger values of $n$.

— The LLA ideology of pQCD is applicable up to $n \sim n_h$.

— **B** is the VHM region, where thermalization

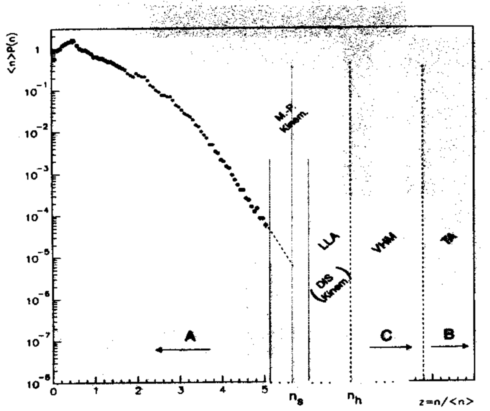


Figure 2. The multiplicity distribution. Dots from E-735 (FNAL) data.

occurs and all the secondary particles momentum are comparable to each other.

— **C** is the domain of the "ideal gas approximation".

## 6. Prediction of generators of events

It is interesting to investigate prediction of the generators of events.

— Fig.3 presents prediction of the generator PYTHIA for LHC energy. As follows from Fig.3, one may conclude that the dynamical models underlying the PYTHIA can not predict thermalization. This conclusion confirms our general prediction that no thermalization may occur in the "Regge" and "DIS" domains.

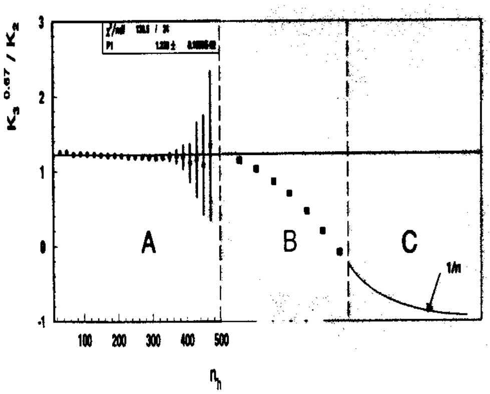


Figure 3. PYTHIA prediction for $|K_3|^{3/2}/|K_2|$ in the domain $A$.

— Fig.4 shows the prediction of the generator HIJING. It shows tendency to equilibrium since it takes re-scattering into account.

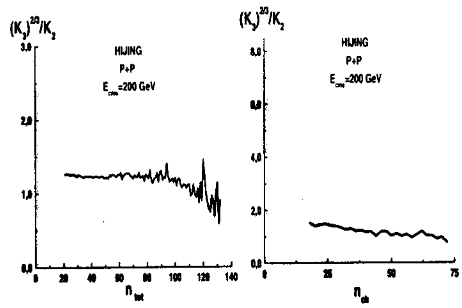


Figure 4. HIJING prediction for $|K_3|^{3/2}/|K_2|$

This shows that, presumably, the effect of thermalization may be seen in the heavy ion collisions at smaller multiplicities.

## 7. Toward the experiment

The problem of thermalization seems as a priority program in description of inelastic hadron reactions. For this purpose one must measure the ratio $|K_3|^{2/3}/|K_2|$, see (1).

It is important investigate the ratio of the mean values of the produced particles momentum $(\bar{p}_{\|}(E,n)/\bar{p}_{\perp}(E,n))$. If our conclusion about of dominance of central collisions in the VHM region then this ratio must tend to $\pi/4$ from above.

In conclusion, one may introduce also the "chemical potential" [3]

$$\mu(E,n) = - < \epsilon > \ln \frac{\sigma_n(E)}{\sigma_{tot}(E)} \qquad (2)$$

if "the ratio $K_3$ to $K_2$" less than one. This interpretation of $\mu$ will allow to observe the first order phase transitions.

## 8. Conclusion

A few notes as conclusion.

— Definite indications of thermalization phenomena exist in the heavy ion collisions.

— Besides, some resent publications on $p\bar{p}$ collisions contains an interesting attempt of experimental observation of the colored plasma-like state which can be described by the "rough" parameters like temperature [10]

— The elaboration of quantitative estimations in the VHM kinematical region is outside of the LLA of pQCD abilities. Moreover, the ordinary dynamical models can not predict even the tendency to equilibrium.

— It is important that we have found the necessary and sufficient condition of thermalization and its $S$-matrix interpretation. This gave us a possibility to show that the thermalization must occur, at least, in a deep asymptotics over multiplicity.

— A new strong coupling perturbation theory, the "topological QCD", was offered. It is important that it includes the pQCD as the definite approximation.

— The experimental side of VHM physics is discussed intensively from various points of view by the ATLAS, CDF, STAR Collaborations.

— From the practical point of view, the tQCD "fast" generator of VHM events is the most important problem. The experimental side of this issue includes the problems of the trigger and absence of any experience in the analysis of the VHM events.

And at the very end, we would like to notice that only the statistical approach can give a chance of complete description of inelastic hadron collisions.

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