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Status of Very High Multiplicity Physics

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Abstract

The to-day status of the problem of investigation of the very high multiplicity phenomenon is discussed. The main purpose is to show importance of the quantitative condition when the system of interacting fields becomes equilibrium. The theoretical problem with very high multiplicity events description is explained. The number of new experimentally observable effects are offered.

1 Introduction

First of all, we would like to note that, of course, "the main road" of present particle physics development is connected with the "Standard Model" and with the questions beyond it (may be SUSY, and so on). But we would like to stress also that there are other "roads" which lead to understanding of other aspects of Nature.

The topic of present note is to describe a general situation around the phenomenon, now known as the Very High Multiplicity (VHM) physics. We would discuss both, the status of theory and the experimental perspectives.

We will based mainly on the papers shown in the References. So, the phenomenology of the Very High Multiplicity events was formulated in the papers [1]. The review paper [2] contains mainly the qualitative features of the VHM physics. It contains also a large number of Appendices with mathematics. The mathematical papers [3] contain the formalism of future VHM events generator.

2 Definitions of the VHM domain

Generally, we would like to consider the processes with multiplicity

$$n >> \bar{n}(s),$$

where $\bar{n}(s)$ is the mean multiplicity, see Fig.1. The VHM domain can be specified more carefully considering the details of production processes. We will discuss this question later.

One may introduce also the inelasticity coefficient

$$\kappa = \frac{E - \epsilon_{\max}}{E},$$

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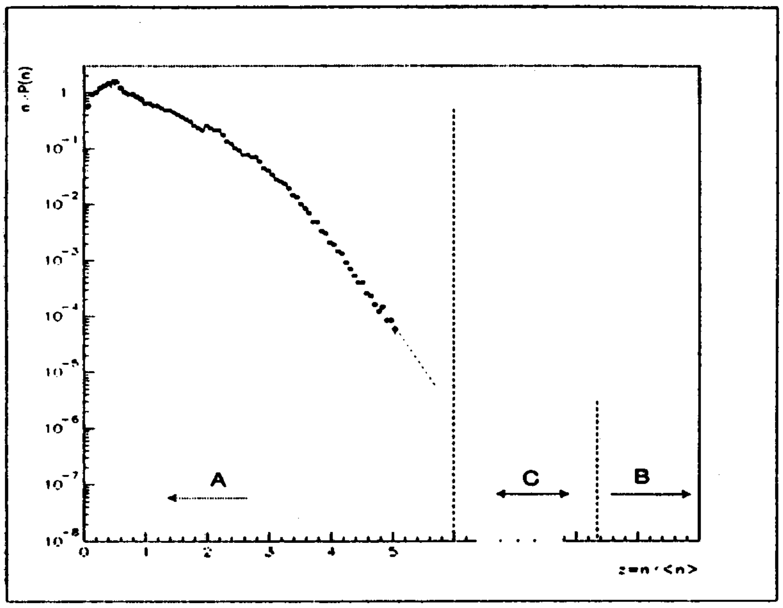

Figure 1: Multiplicity distribution $P(n) = \sigma_n/\sigma_{tot}$; points E-735 data; A: Multiperipheral domain; B: Thermodynamical domain; C: $A \Leftrightarrow B$ is the VHM domain

where E - total energy in the given frame, $\epsilon_{\max}$ - energy of the fastest particle in the same frame. Then, VHM event means that

$$1 - \kappa << 1.$$

So, the produced particles momentum is comparatively small. Roughly speaking, the VHM final state

At the same time, it is reasonable to exclude the influence of the phase space boundaries. For this reason, we would like to assume that the multiplicity can not be too large:

$$n << n_{\max} = \frac{E}{m}, \quad m \approx 0.2 \text{ GeV}.$$

From experimental point of view VHM includes the extremely rear processes, at LHC energies:

$$\sigma_n << 10^{-7}\sigma_{tot},$$

see Fig.1. At all evidence, the cross sections fall down faster then any power of $1/n$:

$$\sigma_n < O(1/n).$$

This estimation is natural in the ordinary S-matrix formalism frame, assuming that the radii of interactions is finite. But the cross section may fall down as the any inverse power of multiplicity: $\sigma_n \sim 1/n$, or even temporary rise with multiplicity in the VHM domain. This regime is out of the traditional S-matrix formalism, where the final-state interactions are excluded. Anyway, the B domain of multiplicity on the Fig.1 will be considered as the unattainable one.

3 Phenomenology

One may expect that various mechanisms of particle production would realized with rising multiplicity [4]. This is natural since the kinematics conditions would changed with multiplicity.

⋆ It can be shown that only three asymptotic classes exist:

— The cross section falls down faster then any power of exponent of $(-n)$:

$$\mathbf{I}: \quad \sigma_n < O(e^{-n}) : \text{ multiperipheral interactions}$$

— The cross section falls down as the exponent:

$$\mathbf{II}: \quad \sigma_n = O(e^{-n}) : \text{ hard processes}$$

— The cross section falls down slowly then any power of exponent:

$$\mathbf{III}: \quad \sigma_n > O(e^{-n}) : \text{ vacuum instability}$$

⋆ Having in mind the fact that the cross sections are extremely small in the VHM domain, it is natural to estimate them only with logarithmic accuracy. In other words, we offer to measure following quantity

$$\mu =< \varepsilon > \frac{1}{n} \ln \frac{\sigma_{tot}}{\sigma_n}$$

then, in the VHM region, see **Fig.2**,

$$\mathbf{I}: \frac{\partial}{\partial n}\mu(n) > 0, \quad \mathbf{II}: \frac{\partial}{\partial n}\mu(n) = 0, \quad \mathbf{III}: \frac{\partial}{\partial n}\mu(n) < 0.$$

If $< \varepsilon >$ is the mean energy of produced particles, then μ is a work needed for one more particle production, i.e. μ would be considered as the chemical potential.

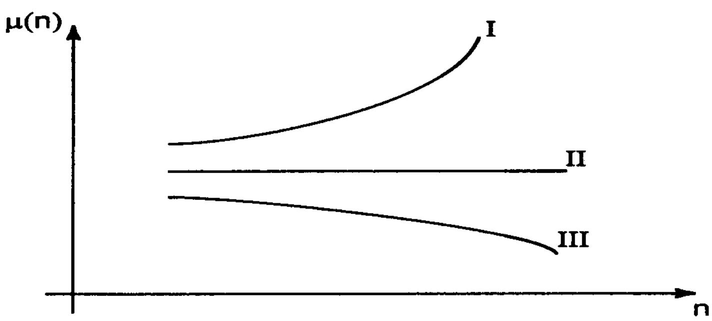

Figure 2: "Chemical potential" vs. multiplicity

⋆ Therefore, one may expect transition from regime **I** to **II** in the VHM domain.

Case **I** means that the difficulty of particle production rise with rising multiplicity. **II** means that there is a "macho" parent and it easily, without problems, produces particle. **III** is realized if the ground state is unstable against particle production.

It should be stressed once more that there is not any other possibility in the ordinary S-matrix formalism.

4 Thermodynamics

It should be mentioned that the multiple production amplitude is a function of $(3n-4)$ variables. On other hand, we know that the "statistical system" can be described by a few variables only. The powerful inclusive method [5] may be extremely important for thss problem.

⋆ So, the thermodynamics method would be necessary to describe the system completely.

Considering the multiple production process as the example of ordinary cooling, number of produced particles n measures the thermalization rate. The produced particles are the "evaporated" ones and the statistical interpretation of the VHM events may be available for this reason.

Therefore, we may conclude that

— The VHM final state should be close to the "equilibrium", i.e. be "calm" and "cold".

⋆ Notice that just this conditions are necessary for observation of the collective phenomena: phase transition in the colored plasma, for instance.

Thus, it is extremely important to know where the thermodynamic description is valid. It was shown in our paper [?] that the corresponding necessary and sufficient condition looks as follows:

$$|K_l(E,n)|^{2/l} << K_2(E,n),$$

where K_l are the ordinary l-particle energy central moments. For instance,

$$K_2(n,E) = K_2(n,E) =< \varepsilon^2; n, E > - < \varepsilon^1; n, E >,$$

and

$$K_3(n,E) = K_3(n,E) =< \varepsilon^3; n, E > -$$
$$-3 < \varepsilon^2; n, E >< \varepsilon^1; n, E > +2 < \varepsilon^1; n, E >^3,$$

etc. The l-particle mean energy is defined by well known equality:

$$< \varepsilon^l; n, E >=$$

$$= \frac{\int \varepsilon(q_1)d^3q_1\varepsilon(q_2)d^3q_2\cdots\varepsilon(q_l)d^3q_l \left\{d^{3l}\sigma_n(E)/d^3q_1d^3q_2\cdots d^3q_l\right\}}{\int d^3q_1d^3q_2\cdots d^3q_l \left\{d^{3l}\sigma_n(E)/d^3q_1d^3q_2\cdots d^3q_l\right\}}$$

where

$$d^{3l}\sigma_n(E)/d^3q_1d^3q_2\cdots d^3q_l$$

is the corresponding differential cross section.

It should be noted that derived condition of the thermodynamic description validity reminds the "correlations relaxation" principle offered by Bogolyubov for non-equilibrium thermodynamics [6] . It should be noted also here that we can show that $|K_l(E,n)|^{2/l} << K_2(E,n)$ is the *necessary and sufficient* condition and in this respect this result looks like prove of the Bogolyubov's supposition.

The PITHYA prediction for ratio K_3 to K_2 is shown on Fig.3.

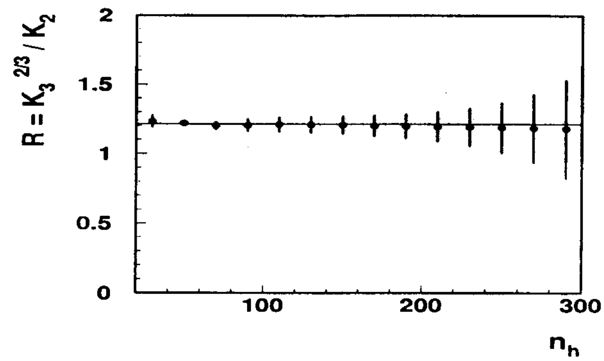

Figure 3: PYTHIA prediction for ratio $K_3^{2/3}/K_2$

Notice that it did not predicts even tendency to equilibrium. But, on other hand, we have a formal prove that the system should come to equilibrium in the deep asymptotics over multiplicity. The ratio K_3 to K_2 should tend to zero with multiplicity. This is a formal, mathematical, theorem.

Therefore, having in mind that used generator of events based on the hadron peripheral interactions phenomenology, we can conclude that investigation of the ratio K_3 to K_2 in the VHM domain will allow to define the range of applicability of the peripheral picture of hadron interactions.

I'd like to note here importance of investigation of this question in the heavy ions collisions. Indeed, there is the idea that having a large number of hadrons in the initial state, one may assume that the thermalization effect will be attained. So, measurement of the ratio K_3 to K_2 should help to check this basic idea. It is crucial for searching of the colored plasma. We start discussion of this question with the STAR (RHIC) community.

5 Model predictions

The attempts of naive transition of the existing models prediction into the VHM region was performed. Result looks as follows.

⋆ Multiperipheral kinematics. *It is known that Pomeron contributions may be used up to* $n \sim \bar{n}(s)^2$. *Out_of this range there is not predictions: model did not "work".* In the range of its applicability

— No tendency to "equilibrium" is valid

— Multiperipheral kinematics predict, see Fig.4,

$$\frac{\partial}{\partial n}\mu(n) > 0.$$

⋆ DIS kinematics predict, see Fig.5,

$$\mu(n) \to \text{const} \quad \text{for} \quad n >> \bar{n}(s).$$

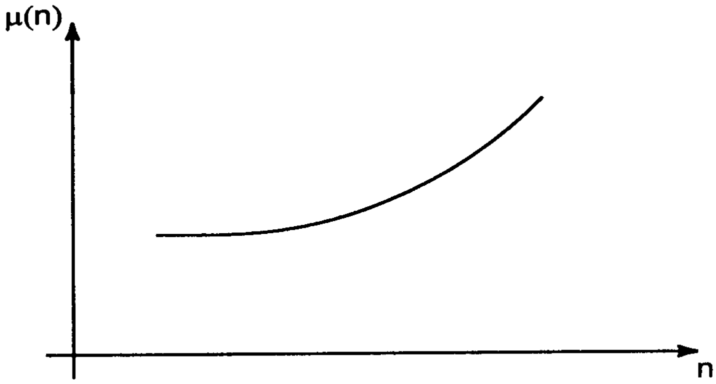

Figure 4: "Chemical potential" for multiperipheral kinematics: $\mu(n) \sim \ln n$.

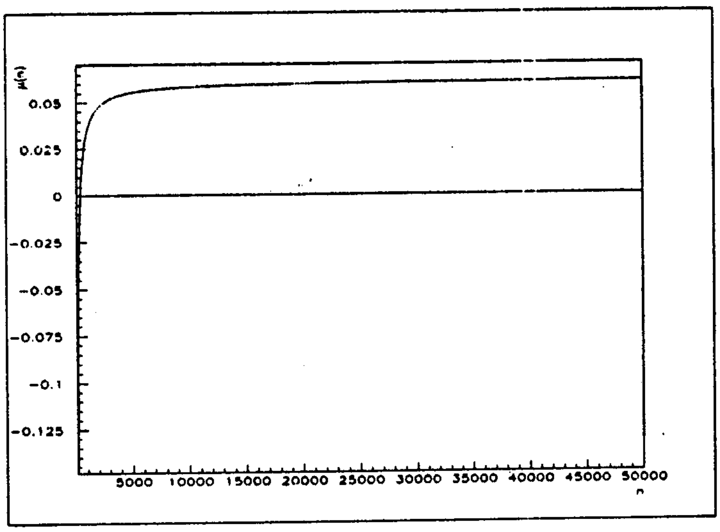

Figure 5: $\mu(n)$ for DIS kinematics

This proves the offered above idea that the VHM processes should be hard. But nevertheless,

— *The effect of softening of the spectra in the VHM domain makes problematic the Leading Logarithm ideology, ordinary used, for instance, for verification of the multiperipheral picture. This is the general (model-free) conclusion.* It means practically that the perturbative QCD calculations in the VHM region are out the human opportunity.

For this reason the experimental information in the VHM region seems from this point of view extremely important.

6 Ion collisions

We know well that it is necessary to have definite formation length for particle production in the hadron-ion collision. The formation length is proportional to the particle energy ε. The mean multiplicity in the hadron-ion collision is comparatively small, it is proportional to the radii of ion. Then the corresponding total cross section would be proportional to the surface of ion.

Let us consider the VHM in such reactions. To have such final state one should have enormous reproduction. So, the VHM final state may produced in hadron-ion collisions if the formation radii is always smaller than the ion radii. In this case all nucleon work in the process of particles production. So, the VHM states production is the "volume effect": the measurable should dependent on the whole number of the ion constituents, see also [7].

The detailed investigation of the VHM states in the ion-ion collision is intensively performed.

7 Experiment

⋆ *Rough description*

We should take into account that the VHM cross sections are extremely small. Moreover

(i) The multiplicity is the hardly measurable parameter.

For this reason we trying to formulate the VHM theory without notion of multiplicity n.

(ii) It is practically impossible to restore the VHM kinematics completely.

For this reason, the "rough measurements" only can be performed. It was offered for this reason to consider the correlation among the "groups" of particles.

— The VHM Generator of Events (VHMGE) should be constructed.

Developed new perturbation QCD theory includes the perturbative QCD as an approximation.

⋆ *Toward the experiment*

We would like like to extract following mostly important, the first stage, problems. They are

— The thermalization problem.

— The problem of quantitative definition of the range of validity of the LLA in VHM domain.

The VHM problem highlights the mostly painful questions of the hadron physics.

(A) Phase transition in the colored state.

The VHM gives a good chance for it since the state is "calm" and "cold". Last one means that the interaction energy is larger then the kinetic one if we have the VHM final state.

(B) The "pre-confinement" VHM state presents the **equilibrium** colour plasma [7]. This means that it can be characterized by few global parameters. In this sense it will be the "state".

(C) The ratio $R = < p_{\|} >/< p_{\perp} > = \pi/4$ for isotropic case, when the end of produced particle momenta locate on the sphere.

(D) The process of VHM production is "fast" and "hard". In this case *the isotope spin orientation may be frozen randomly.* Experimentally it looks like large fluctuations of the charge: if $C = n_c/n_0$ is the ratio of charged to neutral particle number then the "anomalous" (non-Gaussian) distribution over C may be expected.

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