Correlations at RHIC and the Clustering of Color Sources

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Abstract. We present our results on transverse momentum fluctuations and multiplicity fluctuations in the framework of the clustering of color sources. In this approach, elementary color sources - strings - overlap forming clusters, so the number of effective sources is modified. These clusters decay into particles with mean transverse momentum that depends on the number of elementary sources that conform each cluster and the area occupied by the cluster. We find a non-monotonic dependence of the \( p_T \) and multiplicity fluctuations with the number of participants. In our approach, the physical mechanism responsible of these fluctuations is the same: the formation of clusters of strings that introduces correlations between the produced particles.

Non-statistical event-by-event fluctuations in relativistic heavy ion collisions have been proposed as a probe of phase instabilities near de QCD phase transition. In a thermodynamical picture of the strongly interacting system formed in heavy-ion collisions, the fluctuations of the mean transverse momentum or mean multiplicity are related to the fundamental properties of the system, such the specific heat, so they may reveal information about the QCD phase boundary. In particular, a phase transition in the evolution of the system created in relativistic heavy ion collisions may lead to a divergence of the specific heat which could be observed as event-by-event fluctuations. Here I am going to present our results, in the framework of clustering of color sources, concerning event-by-event \( p_T \) and multiplicity fluctuations.

Event-by-event fluctuations of the transverse momentum have been measured at SPS and RHIC energies. The non-statistical fluctuations show a particular behaviour as a function of the centrality of the collision: they grow as the centrality increases, achieving a maximum at mid centralities, followed by a decrease at larger centralities. Different mechanisms have been proposed in order to explain those data: complete or partial equilibration, critical phenomena, as string clustering or string percolation, and jets production.

Let us concentrate on the results obtained in the framework of clustering of color sources [1]. In this framework, we consider that in each collision color strings are stretched between the projectile and the target. Those strings act as the sources of particle production: particles are created via sea \( q \bar{q} \) production in the field of the string. Moreover, in the transverse space, the color strings correspond to small areas filled with the color field created by the colliding partons.

With growing energy and/or atomic number of the colliding nuclei, the number of sources grows, so the elementary color sources start to overlap, forming clusters, very much like disk in the 2-dimensional percolation theory. The density of strings is
expressed by $\eta = N_{st} \frac{S_1}{S_A}$, where $N_{st}$ corresponds to the total number of strings, $S_1 = \pi r_0^2$ with $r_0 = 0.2$ fm is the area of each individual string and $S_A$ is the nuclear overlap area. In particular, at a certain critical density, $\eta_c = 1.1 \div 1.2$, a macroscopic cluster appears, which marks the percolation phase transition. Percolation means that a cluster is formed through the whole collision area.

Taking into account that the color charge of a cluster is the vectorial sum of the string charges that come into the cluster, one can calculate, for a cluster of $n$ overlapping strings covering an area $S_n$, the multiplicity and $p_T$ of the produced particles:

$$Q_n = \sqrt{\frac{nS_n}{S_1}} Q_1, \quad \mu_n = \sqrt{\frac{nS_n}{S_1}} \mu_1, \quad \langle p_T^2 \rangle_n = \sqrt{\frac{nS_1}{S_n}} \langle p_T^2 \rangle_1. \quad (1)$$

In the clustering approach, the behaviour of the transverse momentum fluctuations can be understood as follows: at low density, most of the particles are produced by individual strings with the same $<p_T>_1$, so fluctuations are small. At large density, above the critical point, we have only one cluster, so fluctuations are not expected either -equilibration-. The fluctuations will be maximal just below the percolation critical density, where there are a large number of clusters formed by different number of strings with different size and different $<p_T>_n$.

In order to measure the event-by-event $p_T$ fluctuations, the proposed variables are $F_{p_T}$ and $\phi$, which quantify the deviation of the observed fluctuations from statistically independent particle emission:

$$F_{p_T} = \frac{\omega_{\text{data}} - \omega_{\text{random}}}{\omega_{\text{random}}}, \quad \omega = \frac{\sqrt{<p_T^2> - <p_T>^2}}{<p_T>}, \quad \phi = \sqrt{\frac{<Z^2>}{<\mu>}} - \sqrt{<z^2>}.$$

$z_i = p_{Ti} - <p_T>$ is defined for each particle, and $Z_i = \sum_{j=1}^{N_i} z_j$ is defined for each event.

Both variables are related: $F_{p_T} = \phi \sqrt{<z^2>} / \sqrt{<\mu>}$, $\phi = 1 / \sqrt{<z^2>} - 1$. We have computed $F_{p_T}$ using a Monte Carlo code to evaluate the cluster formation and the analytical expressions (1) for the transverse momentum and the multiplicities of the clusters. The behaviour of the transverse momentum fluctuations with the centrality of the collision shown by the RHIC data is naturally explained by the clustering of color sources. In this framework, elementary color sources -strings- overlap forming clusters, so the number of effective sources is modified. These clusters decay into particles with mean transverse momentum that depends on the number of elementary sources that conform each cluster, and the area occupied by the cluster. The transverse momentum fluctuations in this approach correspond to the fluctuations of the transverse momentum of these clusters, and they behave essentially as the number of effective sources. In a jet production scenario, the mean $p_T$ fluctuations are attributed to jet production in peripheral events, combined with jet suppression at larger centralities.

A way to discriminate between the two approaches is to study the fluctuations at SPS energies [3], where jet production cannot play a fundamental role. Recently, the NA49 Collaboration have presented their data on multiplicity fluctuations as a function of centrality at SPS energies. In order to measure these fluctuations, the variance of the multiplicity distribution scaled to the mean value of the multiplicity, $\text{Var}(N) = \frac{<N^2> - <N>^2}{<N>}$,
has been used. A non-monotonic centrality -system size- dependence was found. In fact, its behaviour is similar to the one obtained for $\Phi(p_T)$ -used by the NA49 Collaboration to quantify the $p_T$-fluctuations-, suggesting that they are related to each other. We find a non-monotonic dependence of the multiplicity fluctuations with the number of participants. The centrality behaviour of these fluctuations is very similar to the one found for the mean $p_T$ fluctuations. In our approach, the mechanism responsible for multiplicity and mean $p_T$ fluctuations is the formation of clusters of strings that introduces correlations between the produced particles. On the other hand, the mean $p_T$ fluctuations have been also attributed to jet production in peripheral events, combined with jet suppression in central events. However, this hard-scattering interpretation, based on jet production and jet suppression, can not be applied to SPS energies, so it does not explain the non-monotonic behaviour of the mean $p_T$ fluctuations neither the relation between mean $p_T$ and multiplicity fluctuations at SPS energy. Other possible mechanisms are: combination of strong and electromagnetic interaction, dipole-dipole interaction and non-extensive thermodynamics. Still, it is not clear if these fluctuations have a kinematic or dynamic origin, but clustering of colour sources remains a good possibility.

REFERENCES

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