Fluctuations and Transverse Momentum Distributions in the Color Clustering Approach

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We present our results on transverse momentum fluctuations, multiplicity fluctuations and transverse momentum distributions for baryons and mesons in the framework of the clustering of color sources. We determine under what conditions the initial state configurations can lead to color connection, and more specifically, if variations of the initial state can lead to a transition from disconnected to connected color clusters, modifying the number of effective sources. We find that beyond a critical point, one has a condensate, containing interacting and hence color-connected sources. This point thus specifies the onset of color deconfinement. We show that the transverse momentum and multiplicity distributions are related to each other in a defined way. We obtain a non-monotonic dependence of the $p_T$ and multiplicity fluctuations with the number of participants. We present our results for the fluctuations and the transverse momentum distributions at RHIC energies compared to the existing experimental data and our predictions for LHC energies.

I. INTRODUCTION

The main idea in the framework of the clustering of color sources is the fact that elementary color sources -strings- can overlap forming clusters, so the number of effective sources is modified. The procedure is the following: in each collision, color strings are stretched between the colliding partons. Those strings act as color sources of particles which are successively broken by creation of $q\bar{q}$ pairs from the sea. The color strings correspond to small areas in the transverse space filled with the color field created by the colliding partons. If the density of strings increases, they overlap in the transverse space, giving rise to a phenomenon of string fusion and percolation [1]. Percolation indicates that the cluster size diverges, reaching the size of the system.

Thus, variations of the initial state can lead to a transition from disconnected to connected color clusters. The percolation point signals the onset of color deconfinement.

These clusters decay into particles with mean transverse momentum and mean multiplicity that depend on the number of elementary sources that conform each cluster, and the area occupied by the cluster. For a cluster of $n$ overlapping strings, the vectorial sum of the color charges of the individual strings leads to the following values for the total color charge, the mean multiplicity and the mean transverse momentum:

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

Moreover, it is possible to obtain the following analytic expression that relates the areas with the density of strings $\eta$:

$$\langle \frac{nS_1}{S_n} \rangle = \frac{\eta}{1 - \exp(-\eta)} \equiv \frac{1}{F(\eta)^2}.$$
II. TRANSVERSE MOMENTUM DISTRIBUTIONS

The clustering reduces the average multiplicity and enhances the average $<p_T>$ of an event in a factor $F(\eta)$ with respect to those resulting from pure superposition of strings:

$$<\mu> = N_S F(\eta) <\mu>_1$$

$$<p_T^2>_1/F(\eta)$$

where $N_S$ is the number of strings and $F(\eta) = \sqrt{1 - e^{-\eta}}$ is a function of the density of strings $\eta$.

The invariant cross section can be written as a superposition of the transverse momentum distributions of each cluster, $f(x,p_T)$ - Schwinger formula for the decay of a cluster—, weighted by the distribution of the different tensions of the clusters, $W(x)$. This weight function behaves as a gamma function whose width is proportional to $1/k$ where $k$ is a determined function of $\eta$ related to the measured dynamical transverse momentum and multiplicity fluctuations $[2, 3]$:

$$dN/dp_T^2 dy = \int_0^\infty dx W(x) f(p_T, x) = \frac{dN}{dy} \frac{k - 1}{k} \frac{1}{<p_T^2>_1} F(\eta) \frac{1}{(1 + \frac{F(\eta)p_T^2}{k<p_T^2>_1})^k}.$$  

(4)

For (anti)baryons the equation (4) must be changed to $<\mu_{B,T}> = N_S^{1+\alpha} F(\eta_B) <\mu_{B,T}>_1$ to take into account the fact that baryons are enhanced over mesons in the fragmentation of a high density cluster $[4]$. The parameter $\alpha = 0.09$ is fixed from the experimental dependence of $p_T$ on $N_{part}$. The (anti)baryons probe higher densities than mesons, $\eta_B = N_S^2 \eta$. On the other hand, from the constituent counting rules applied to the high $p_T$ behavior we deduce that for baryons $k_B = k(\eta_B) + 1$. In Fig. 1, we show the ratios $R_{CP}$ and $\frac{p}{\pi^0}$ compared to RHIC experimental data for pions and antiprotons together with the LHC predictions. In Fig. 2 (left) we show the nuclear modification factor $R_{AA}$ for pions and protons for central collisions at RHIC. LHC predictions are also shown. We note that $p + p$ collisions at LHC energies will reach enough string density for nuclear like effects to occur. Because of this, in Fig. 2 (right) we show the ratio $R_{CP}$ for $pp \rightarrow \pi X$ as a function of $p_T$, where the denominator is given by the minimum bias inclusive cross section and the numerator is the inclusive cross section corresponding to events with twice the multiplicity of the minimum bias one. According to our formula (4) a suppression at large $p_T$ occurs.
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. These fluctuations show a non-monotonic behavior with the centrality of the collision: they grow as the centrality increases, showing a maximum at mid centralities, followed by a decrease at larger centralities. Different mechanisms have been proposed in order to explain those data. In the string clustering approach, the behavior of the $p_T$ and multiplicity fluctuations can be understood as follows: at low density, most of the particles are produced by individual strings with the same transverse momentum $<p_T>$ and the same multiplicity $<\mu>$, so fluctuations are small. At large density, above the critical point of percolation, we have only one cluster, so fluctuations are not expected either. Just below the percolation critical density, we have a large number of clusters formed by different number of strings $n$, with different size and thus different $<p_T>$ and different $<\mu>$ so the fluctuations are maximal.

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

$$\phi = \sqrt{\frac{<Z^2>}{<\mu>}} - \sqrt{<z^2>},$$

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

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

Moreover, in order to measure the multiplicity fluctuations, the variance of the multiplicity distribution scaled to the mean value of the multiplicity has been used. Its behavior is similar to the one obtained for $\Phi(p_T)$, used to quantify the $p_T$-fluctuations, suggesting that they are related to each other. The $\Phi$-measure is independent of the distribution of number of particle sources if the sources are identical and independent from each other. That is, $\Phi$ should be independent of the impact parameter if the nucleus-nucleus collision is a simple superposition of nucleon-nucleon interactions.
In Fig. 3 we present our results on $p_T$ fluctuations at LHC. Note that the increase of the energy essentially shifts the maximum position to a lower number of participants \[5\]. In Fig. 4 we show our values for the scaled variance of negatively charged particles at SPS, RHIC and LHC energies.

References

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