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Fluctuations and correlations in the string clustering approach

L. Cunqueiro[a], E.G. Ferreiro, and C. Pajares

Instituto Galego de Física de Altas Enerxías and Departamento de Física de Partículas, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain

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Abstract. The fluctuations due to the clustering of color sources can explain the behaviour of the scaled multiplicity variance and transverse momentum fluctuations with centrality. They also predict a nonmonotonic behaviour with centrality for the multiplicity associated to high-p_T events. The clustering of color sources gives rise to an increase in the long-range correlations with centrality as well as to a supression at high centrality with respect to superposition models.

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The NA49 Collaboration has presented its data on multiplicity fluctuations as a function of centrality for Pb-Pb collisions [1]. A nonmonotonic centrality (system size) dependence of the multiplicty scaled variance was found. Concretely, the nonstatistical normalized fluctuations grow as the centrality increases, with a maximum around $N_{part} \simeq 100$, followed by a decrease at large centralities. This behaviour is similar to the one obtained for the $\Phi(p_T)$ and for the $F_{P_T}(p_T)$ measure, used to quantify the p_T fluctuations by the NA49 Collaboration [2,3] and by PHENIX Collaboration [4,5] respectively. This suggests that multiplicity and transverse momentum fluctuations are related [6]. Moreover, the $\Phi(p_T)$ variation with impact parameter implies that the collision is not a simple superposition of nucleon-nucleon collisions but rather collective effects are at work. In the framework of string clustering [7] such a behaviour is naturally explained [8,9]. The fluctuations in the size of the color clusters govern the behaviour of both multiplicity and transverse momentum fluctuations.

In a nucleus-nucleus collision strings are streched between partons from the projectile and the target [10–12]. With the increase of energy and/or the the atomic number of the colliding nuclei, the number of strings grows and so does its density in the nuclear overlap area: $\eta = N_S \frac{S_1}{S_A}$, being $S_A = \pi R_A^2$ for central collisions and S_1 the area of a single string. As the density grows, strings begin to overlap forming clusters. At a certain critical density a macroscopic cluster appears marking the percolation phase transition. A cluster consisting of n strings will have an area S_n and and a color charge which corresponds to the vectorial sum of the charges of each individual string: $\langle Q_n \rangle = \sqrt{\frac{nS_n}{S_1}} Q_1$. Clusters fragment via the Schwinger mechanism. The fragmentation is controlled by the cluster tension that is related to the composed color field of the cluster. According to the Schwinger mechanism, we obtain the average multiplicity and p_T of a cluster composed by n strings: $\langle \mu \rangle_n = \sqrt{\frac{nS_n}{S_1}} \langle \mu \rangle_1$ and $\langle p_T^2 \rangle_n = (\frac{nS_1}{S_n})^{\frac{1}{2}} \langle p_T^2 \rangle_1$, being $\langle \mu \rangle_1$ and $\langle p_T \rangle_1$ the mean multiplicity and transverse momentum of a single string. In [9] we derive the analytical expression for the scaled multiplicity variance:

$$\frac{Var(\mu)}{\langle \mu \rangle} = 1 + \frac{\left\langle \left(\sum_j \langle \mu \rangle_n j \right)^2 \right\rangle - \left\langle \sum_j \langle \mu \rangle_n j \right\rangle^2}{\left\langle \sum_j \langle \mu \rangle_n j \right\rangle} \qquad (1)$$

that is essentially a measure of the fluctuations in $\sum_j \sqrt{\frac{n_j S_{nj}}{S_1}}$. The sum over j goes over all individual clusters j, each one formed by n_j strings and occupying an area S_{nj}.

We use a Monte Carlo code based on the QSM [11] to obtain the different cluster configurations at a fixed number of participants. Once we know the number of clusters, the area occupied by each of them and the number of strings they contain, we apply the analytical formula in eq. (1). Our results for the scaled variance for negative particles are presented in fig. 1. The agreement with experimental data is acceptable. However, there is a discrepancy at the most central region where our results are well above the data. The reason for this are the simplifications coming from the use of analytical expressions.

The fluctuations on the number of target participants at a fixed number of proyectile participants have been pointed out to be an important contribution to the scaled

[a] e-mail: leticia@fpaxp1.usc.es

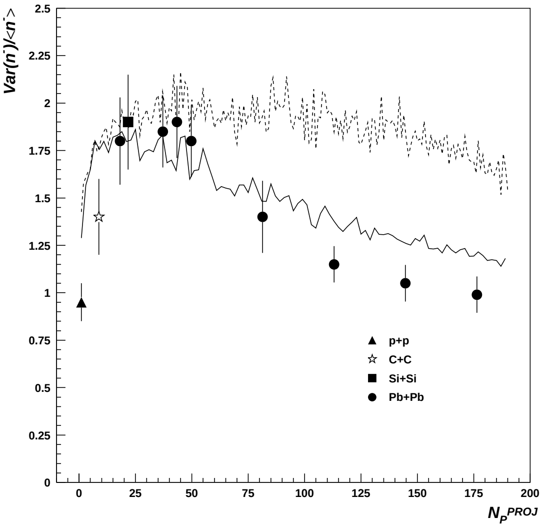

Fig. 1. Our results for the scaled variance of negatively charged particles in Pb-Pb collisions at SPS energies compared to NA49 data. Solid line: clustering of colour sources. Dashed line: independent strings.

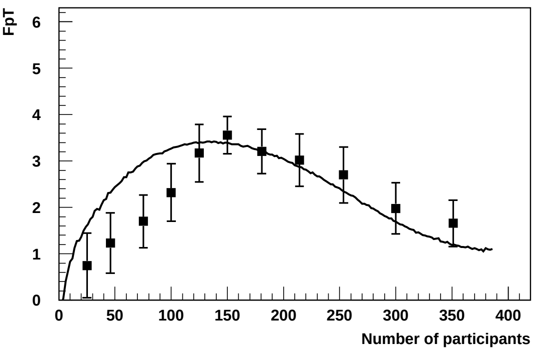

Fig. 2. F_{P_T} *versus* the number of participants. $F_{P_T} = \frac{w_{data} - w_{random}}{w_{random}}$ and $w = \frac{\sqrt{\langle p_T^2 \rangle - \langle p_T \rangle^2}}{\langle p_T \rangle}$. Experimental data from PHENIX at $\sqrt{s} = 200$ GeV are compared to our results (solid line).

multiplicity variance [13]. These fluctuations are included in our approach because most of our strings are formed between partons from the projectile and the target, conecting both hemispheres.

The PHENIX Collaboration [4,5] has measured the centrality dependence of the transverse momentum fluctuations using the observable F_{P_T} that quantifies the deviation of the observed fluctuations from statistically independent particle emission. The comparison of our results for the dependence of F_{P_T} on the number of participants N_p to the PHENIX data is shown in fig. 2. In fig. 3 our results for the observable Φ_{P_T} of charged particles in Pb-Pb central collisions at 158 AGeV are compared to the data of NA49 [2]. A good agreement is obtained.

The behaviour of the transverse momentum fluctuations as well as the behaviour of the multiplicity fluctuations can be understood as follows: at low density, most

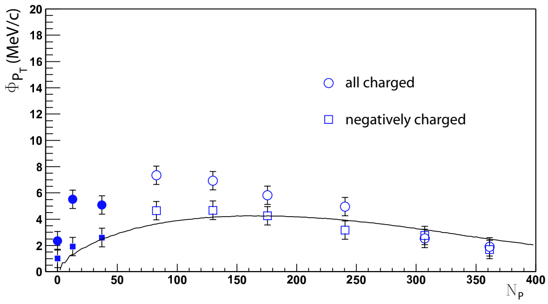

Fig. 3. Φ_{P_T} *versus* the number of participants. $\Phi_{P_T} = \sqrt{\frac{\left\langle \left(\sum_{i=1}^{\mu} (p_{T_i} - \overline{p_T}) \right)^2 \right\rangle}{\langle \mu \rangle}} - \sqrt{\overline{(p_T - \overline{p_T})^2}}$. The overline means averaging over a single-particle inclusive distribution and $\langle\ \rangle$ means an average over all events. Experimental data from NA49 at $\sqrt{s} = 158$ GeV are compared to our results (solid line).

of the particles are produced by individual strings with the same $\langle p_T \rangle$ and $\langle \mu \rangle$, so the fluctuations are small. Similarly, at large density above the percolation critical point there is essentially only one cluster formed by most of the strings created in the collision and therefore fluctuations are not expected either. There is a density in between these two limits for which the cluster configuration is the most diverse and thus the fluctuations are the highest.

1 Multiplicity associated to high-p_T events and multiplicity fluctuations

Assuming nuclear collisions to be a superposition of elementary interactions, a universal relation between the multiplicity distribution associated to the production of rare and self-shadowed events [14] and the total multiplicity distribution is obtained [15]:

$$P_C(n) \simeq \frac{nP(n)}{\langle n \rangle} \,. \tag{2}$$

In [16] we argue that, although eq. (2) has been obtained in a superposition scheme, it remains approximately valid in a more general frame. From eq. (2) we derive [16] the following relation between the average multiplicity associated to rare events, the average total multiplicity and the scaled multiplicity variance:

$$\langle n \rangle_C - \langle n \rangle = \frac{\langle n^2 \rangle - \langle n \rangle^2}{\langle n \rangle} \,. \tag{3}$$

High-p_T events are rare and self-shadowed. This means that their associated multiplicity distribution will satisfy eq. (2)and that their mean associated multiplicity will also satisfy eq. (3). The average multiplicity associated to high-p_T events will show a nonmonotonic behaviour with centrality due to the nonmonotonic centrality dependence of the scaled multiplicity variance at the right-hand side of eq. (3) This can be checked experimentally.

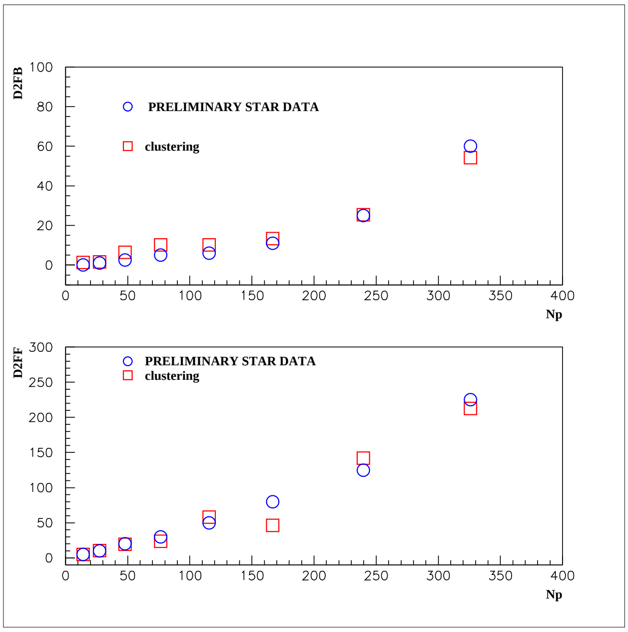

Fig. 4. DFB^2 and DFF^2 *versus* the number of participants compared to PRELIMINARY STAR data.

2 Forward-backward long-range correlations

In any model based on a superposition of elementary and statistically independent collisions, the squared forward-backward dispersion is proportional to the squared dispersion of the number of elementary collisions [17]. In fact, we have

$$D_{FB}^2 \equiv \langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle = \langle N \rangle (\langle n_{0F} n_{0B} \rangle - \langle n_{0F} \rangle \langle n_{0B} \rangle) + (\langle N^2 \rangle - \langle N \rangle^2) \langle n_{0F} \rangle \langle n_{0B} \rangle, \quad (4)$$

where N stands for the number of elementary interactions, n_{0F} (n_{0B}) for the number of forward (backward) produced particles in an elementary interaction and n_F (n_B) for the total number of forward (backward) particles. The first term of eq. (4) is the correlation between particles produced in the same elementary interaction. Assuming these correlations to have short range in rapidity, if one takes a rapidity gap between the forward and backward rapidity intervals large enough (1–1.5 units) this first term vanishes. In this way, one is left with the last term in eq. (4). This long-range rapidity correlation is due to the fluctation in the number of elementary interactions, controlled by unitarity. It increases with the number of elementary interactions, therefore we expect it to increase with energy and the size of the nucleus in the collision. However, if there are interactions among strings, the number of independent elementary interactions translates approximately into the number of clusters of strings. Therefore a clear supression of long-range correlations relative to the expected in a superposition picture is predicted [18,19]. Preliminary STAR data show that there is in fact a strong supression of long-range correlations. In fig. 4 we compare the preliminary data, obtained with a rapidity gap of 1.6 units in the central rapidity region, and a forward and backward intervals of 0.2 units, to our results [20] of percolation of strings. A good agreements is obtained.

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