EVENT-BY-EVENT CLUSTER ANALYSIS OF FINAL STATES FROM HEAVY ION COLLISIONS

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We present an event-by-event analysis of the cluster structure of final multihadron states resulting from heavy ion collisions. A comparison of experimental data with the states obtained from Monte Carlo generators is shown. The analysis of the first available experimental events suggests that the method is suitable for selecting some different types of events.

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1. Introduction

In many scenarios of heavy ion collisions, such as Quark Gluon Plasma (QGP)[1] or Disoriented Chiral Condensate (DCC) [2] formation, one expects an appearance of groups of particles, which differ somehow from the majority of produced hadrons. In particular, such groups are often characterized by small momenta in the rest frame of the group forming a sort of a cluster. Therefore it seems to be interesting to develop procedures looking for clusters in single events.

We analyze the cluster structure of events resulting from the heavy ion collisions and from the Monte Carlo (MC) generators. In particular, we investigate, for single events, the dependence of the multiplicity distributions of charged hadrons in clusters on the parameter defining a cluster size. The procedure is presented in next section. We employ the cluster definition used in the procedure implementing the Bose–Einstein (BE) effect in MC [3]. We consider only clusters containing at least two hadrons and investigate the average multiplicity and the second normalized factorial moment, defining them with "two subtracted", *i.e.* $\overline{n}-2$, and

$$\tilde{F}_2 = \frac{\overline{(n-2)(n-3)}}{(\overline{n}-2)^2}. \qquad (1)$$

This choice of moments is motivated by three facts. First, in our procedure each cluster contains by definition at least one hadron. Second, the percentage of "one hadron clusters" is not expected to obey any smooth multiplicity distribution (*e.g.* due to the contributions of "leading particles"). Therefore only the distribution for $n \geq 2$ may be expected to follow from some smooth formula. Moreover, if we consider the limit for $\tilde{F}_2$ at $\overline{n}-2 \to 0$ for Negative Binomial Distribution in $n-2$ with different values of the parameter k, we find it is finite and depends on k. Thus, in principle, our choice of moments allows to investigate the cluster structure in the limit of very small clusters, where other definitions lead to divergencies or to results independent of the shape of the distribution.

In this note we work in a two-dimensional momentum space $(\eta - \phi)$ to be able to use the available experimental data of the KLM collaboration [4]. In principle, however, the data with full measurement of momenta are preferred, as they should allow to identify clusters better suited for the analysis of QGP or DCC signals.

In the next section we present in more detail our procedure and the form in which the data are presented. We discuss also some modifications and generalizations of our approach. In the third section we compare the results of our analysis for the real- and MC-generated events. The last section contains conclusions and outlook.

2. Clustering procedure

To start the clustering procedure we have to define the distance in the momentum space. Since in the data set [4] only the pseudorapidity η and the azimuthal angle ϕ are given, we use

$$d^2 = (\Delta\eta)^2 + (\Delta\phi)^2 \tag{2}$$

as a distance measure. An introduction of different coefficients in front of the two terms in this definition (with their ratio between 0.5 and 2.0) does not change significantly the final results. Obviously, for data with full momenta measurement we would use some other measures, *e.g.* three momentum or four momentum difference squared.

In our procedure originally each particle is considered as a single cluster. We fix the value of a "cluster size parameter" ε and perform the clustering procedure for all pairs of particles. The particle is assigned to a given cluster if its distance d^2 to at least one particle from this cluster is smaller than ε. Obviously for very small ε values we have very few (or no) clusters with at least two particles. On the other hand, for large ε values almost all particles must fall into a single large cluster.

Our procedure is different from the clustering procedure applied in [4]. We do not define the "global cluster size" in the $(\eta - \phi)$ space but consider only distances between particles. Moreover, the results are analyzed differently. In Ref. [4] one asks what is the percentage of particles in clusters; we investigate the multiplicity distribution of particles in different clusters for single events. The results are significant if we have a sufficiently large number of clusters (with at least two particles). This limits the possible range of ε values, which must be neither too small nor too large. Thus our analysis is in fact complementary to the "intermittency analysis" performed in Ref. [4], where only very small bins in momentum space are relevant (corresponding to small ε values). At the lower end of our range most of the clusters contain just two particles; at the higher one, as we shall see, there are typically a few tens of particles in a cluster. To characterize the muliplicity distribution we calculate for each event the average multiplicity of a cluster and the second scaled factorial moment, as defined in the Introduction.

3. Results: comparison of MC with data

We performed the clustering procedure for the four KLM events presented in Ref. [4] and for the events obtained from the VENUS generator [5]. In addition we use the "random events" of similar multiplicities obtained with a uniform random generation of (η, ϕ) points (SERENE events). The results are shown for the range of ε values for which there are at least 40 clusters (with more than one particle) in the event. We checked that the results do not depend on the order in which the data are read in, as expected.

The average cluster multiplicity (or, to be more precise, its excess over the minimal value of 2) increases monotonically with ε. It is interesting to note that the value of ε for which the increase becomes faster than linear is the same as a value for which the number of clusters with at least two particles starts to decrease (for smaller ε the decrease resulting from joining small clusters into the large ones is compensated by formation of small clusters from single particles). As shown in Fig. 1a), the increase is faster for events with larger global multiplicity N. Two lower data sets correspond to $N = 742$ and $N = 743$, and the two higher ones to $N = 926$ and $N = 986$, respectively. If the distance ε is scaled by the average distance ε_0 between neighbouring particles (inversely proportional to N, $\varepsilon_0 \simeq 12\pi/N$), differences between events disappear as shown in Fig. 1b).

In the MC generated events a similar increase occurs. The corresponding plots (not presented here) show no clear differences between the experimental and VENUS events, although the latter ones have typically higher global multiplicities resulting in higher average multiplicities of clusters. In random events there seems to be a larger spread of data points for fixed global multiplicity, but again no clear difference shows up.

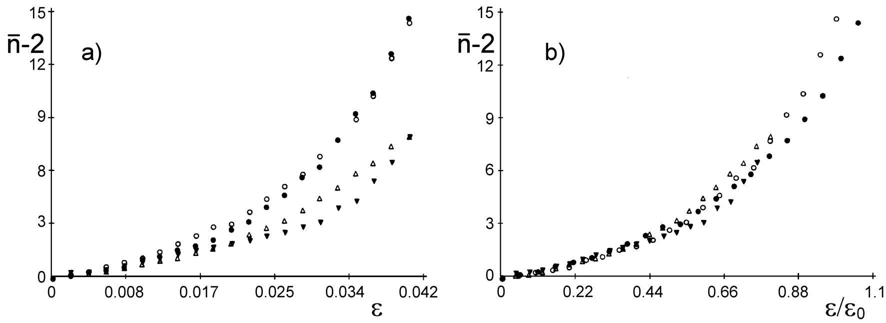

Fig. 1. The average hadron multiplicity of a cluster $\overline{n}-2$ (for clusters with at least two particles) as a function of a)the parameter ε defining the maximal distance in the $(\eta-\phi)$ space, for which two particles are joined into a cluster, b)the same parameter scaled by $\varepsilon_0 = 12\pi/N$. Data are taken from Ref. [4]. Four kinds of symbols correspond to four different events.

On the other hand the analysis of the second scaled factorial moment as a function of average multiplicity shows a striking differentiation of events. For small $\overline{n}-2$ (below 4) it rises irregularly to the values of a few units. Then in all the VENUS events we see a much faster rise to the values of about 30–40 as shown in Fig. 2. For transparency only five out of twenty analyzed events are shown.

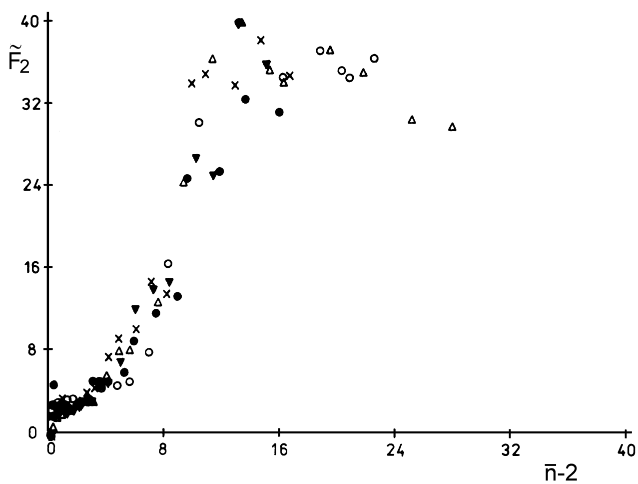

Fig. 2. The second scaled factorial moment (Eq. (1)) as a function of average multiplicity $\overline{n}-2$ for the events obtained from the VENUS generator. Each symbol corresponds to one event.

In the random events the rise is much slower (Fig. 3), although we selected multiplicities corresponding to the maximal multiplicity of the VENUS events. Out of four KLM events two seem to follow the "VENUS pattern" and two look like "SERENE events", as seen in Fig. 4.

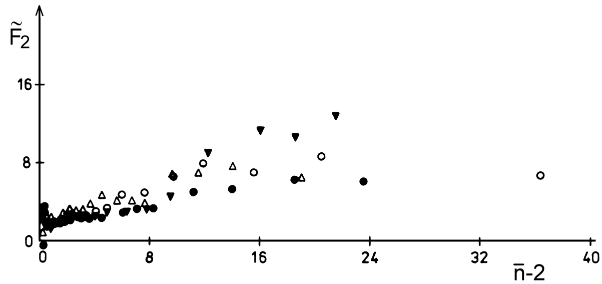

Fig. 3. The second scaled factorial moment as a function of average multiplicity $\overline{n} - 2$ for the events obtained from a uniform random numbers generator. Each symbol corresponds to one event.

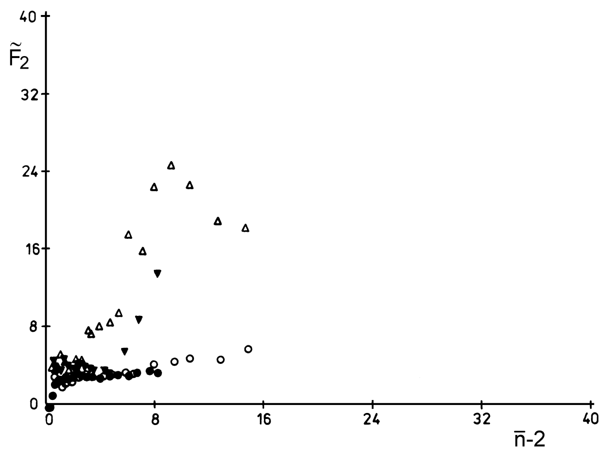

Fig. 4. The second scaled factorial moment as a function of average multiplicity $\overline{n} - 2$ for the KLM events. Each symbol corresponds to one event.

The irregularity of $\tilde{F}_2$ for small $\overline{n} - 2$ shows that for the events with global multiplicity of the order of 10^3 we cannot draw any significant conclusions about the limit $\overline{n} - 2 \to 0$. Our choice of the definition of $\tilde{F}_2$ "with 2 subtracted" (1) is found *a posteriori* not too relevant. However, the situation may be different at higher multiplicities expected at RHIC energies.

One should stress that large values of $\tilde{F}_2$ signal large fluctuations of the cluster multiplicities (as compared to the average value). The violent growth observed in VENUS events suggests an occurrence of one or a few clusters with multiplicity of the order of 100 when the average is close to 10. Apparently this does not occur in the randomly sampled events and only two out of four KLM events show such behaviour. It is interesting to note that these two events are the same which show fast “intermittent” rise of the scaled factorial moments in small bins of the phase-space; this rise was interpreted as a manifestation of “strong dynamical correlations” [4].

It is, in fact, rather surprising that the same events seem to be “special” in the limit of very small bins (“intermittency analysis”) and for a quite large average cluster size in our analysis.

Even more surprising is the fact that in our analysis all the “VENUS events” look like “special” KLM events. It may be so that fixing the parameters of the VENUS generator by fitting the averages over many experimental events induces such cluster structure in all single events, whereas the data are more differentiated. It will be really interesting to repeat this analysis on a much larger sample of events (both experimental and MC generated) and for other choices of variables and clustering procedures.

4. Conclusions and outlook

We have applied a simple cluster analysis to single events of heavy ion collisions, both experimentally and MC generated. Analyzing the multiplicity distributions of charged hadrons in clusters we found two different patterns of behaviour already in the first four published experimental events. On the contrary, all the VENUS generated events follow one pattern. Thus the reasonable agreement of MC description with the inclusive features of data (obtained by averaging over many events) does not apply for single events.

We conclude that the cluster analysis of single events may allow to select special classes of events signalling, *e.g.*, the formation of some exotic states (QGP, DCC). Obviously our results present only a preliminary evidence; similar analysis should be performed using different variables. In particular, data with full momentum measurements and particle identification should be compared with the MC results. Different clustering procedures should also be introduced. The results may help to improve our understanding of multiple production in heavy ion collisions.

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REFERENCES

[1] M. Jacob, J. Tran Thanh Van (eds.), *Phys. Rep.* **88**, 321 (1982); E.V. Shuryak, *Phys. Rep.* **115**, 151 (1984).

[2] A. Anselm, M.G. Ryskin, *Phys. Lett.* **B266**, 482 (1991); J.D. Bjorken, *Int. J. Mod. Phys.* **A7**, 4189 (1992); J.-P. Blaizot, A Krzywicki, *Phys. Rev.* **D46**, 462 (1992); K. Rajagopal, F. Wilczek, *Nucl. Phys.* **B399**, 395 (1993).

[3] K. Fiałkowski, R. Wit, J. Wosiek, *Phys. Rev.* **D58**, 094013 (1998).

[4] M.L. Cherry *et al.* (KLM Collaboration), *Acta Phys. Pol.* **B29**, 2129 (1998).

[5] K. Werner, *Phys. Rep.* **232**, 87 (1995).