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**INTERMITTENCY PARAMETERS AS A POSSIBLE SIGNAL
FOR QUARK-GLUON PLASMA FORMATION**

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ABSTRACT

It is suggested that measurements of anomalous dimensions in the spectra of particles produced in high-energy heavy ion reactions, obtained from studies of intermittency, can serve as a possible signal of the formation of quark-gluon plasma and its subsequent phase transition into hadrons. Existing data suggest a quark-gluon plasma signal for 200 GeV/nucleon S-Ag, Br central collisions.

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Recently, several experiments [1- 6] confirmed the power law behaviour of normalized factorial moments predicted by the hypothesis of intermittency [7]. The relation

$$F_p(\delta) = F_p(\Delta) (\Delta/\delta)^{d_p} \quad (1)$$

where $F_p(\delta)$ is the normalized factorial moment of rank p and δ is the interval considered, was observed in the region $1 \gtrsim \delta \gtrsim 0.1$ (both in rapidity and in azimuthal angle).

The intermittency exponents f_p determined from (1) are related to anomalous fractal dimensions d_p of the distributions [8] by the relation [9,10]

$$d_p = f_p / (p - 1) \quad (2)$$

These anomalous fractal dimensions describe how the distribution changes with increasing resolution.

The relation (1) is characteristic for systems which are scale invariant in the region where (1) is observed. It was pointed out by several authors [11] that there are two natural scenarios which can explain (1) in particle production processes.

1. Second-order phase transition [12-14]. At the critical point the correlation length diverges and the system becomes scale invariant. If there are no long-range interactions we then expect that all anomalous fractal dimensions are equal to each other, i.e., the system is a simple fractal, as demonstrated explicitly for the Ising model [13] and for Feynman-Wilson fluid [14]. The value of d_p can be related to a critical exponent for the phase transition.
2. Self-similar cascade [7,15]. In this case anomalous fractal dimensions are sensitive to the details of the vertex describing the cascade and there is no reason to expect d_p to be independent of p in general [7,16].

Thus the measurements of p dependence of d_p can give an indication which one of the two scenarios is at work. In particular, an observation of d_p independent of p would indicate a phase transition in the system.

In the present note we like to suggest that this argument may serve as a possible signature for production of quark-gluon plasma. Indeed, if a quark-gluon plasma in thermodynamic equilibrium is created in a high-energy collision, a phase transition to the hadron phase must take place. If this transition is sufficiently close to the second order (i.e., if the latent heat is sufficiently small), we expect that the final hadron system should show intermittency with anomalous fractal dimensions d_p approximately independent of p . If, on the other hand, the final hadron system is created as a result of a cascading process (partonic and/or hadronic) one rather expects d_p to be approximately linear in p [16].

In Fig. 1 the anomalous fractal dimensions d_p as observed in (pseudo)-rapidity distributions of particles produced in lepton-hadron, hadron-hadron and nucleus-nucleus interactions at $\sqrt{s} \simeq 20\text{GeV}$ are plotted versus p . In both figures one sees that the p dependence of d_p weakens when one passes consecutively from muon-hadron to hadron-hadron and nucleus-nucleus interactions. Furthermore, while for 0-Ag, Br collisions some residual p dependence can still be seen, no significant p dependence is observed in S-Ag, Br central collisions. It therefore seems reasonable to suggest that constancy of d_p in the case of S-Ag, Br collisions may be interpreted as a possible indication for the formation of quark-gluon plasma [17]. It would of course be interesting to see if this picture is confirmed in collisions of heavier nuclei.

One sees also in Fig. 1 that the anomalous fractal dimensions generally decrease when one passes from μp to hadron-hadron and heavy-ion collisions. This trend was observed and explained already some time ago [9] as a consequence of a growing complexity of the process. What we would like to emphasize here, however, is that, as seen from Fig. 1, this effect is substantially weaker at small p ($p = 2$) than at large p . Thus the approximate independence of d_p on p for S-Ag, Br central collisions is a genuine effect, which cannot be attributed to a general decrease of all d_p 's.

At this point it seems interesting to speculate what trend is to be expected for behaviour of intermittency parameters in collisions of heavier nuclei. We see two possible scenarios:

1. If the phase transition from plasma to hadrons is sufficiently close to second-order (i.e., if the correlation length at the transition is larger than the size of the largest system produced) we expect d_p to reach a limiting value for central collisions of heavy nuclei [18].

2. If, on the other hand, the phase transition is of first order with a large latent heat and a short correlation length, the system is no longer self-similar at large scales and one thus expects all anomalous fractal dimensions to vanish for central collisions of heavy nuclei.

Our conclusions can be summarized in three points.

1. Intermittency parameters can serve as a signal of second-order phase transition in a statistical system.
2. The existing data show that the p dependence of intermittency parameters measured in different high-energy processes is not universal, thus indicating various production mechanisms at work.
3. The observed pattern is rather suggestive of a self-similar cascade mechanism for lepton-hadron and hadron-hadron interactions, whereas a phase transition seems to be present in the S-Ag, Br central collisions.

We would like to end this paper with the following comments.

1. The parameters of the self-similar cascade can be chosen in such a way that also in this case the anomalous dimensions d_p do not depend on p (β model of Ref. [7]). Therefore the condition $d_p = \text{const.}(p)$ is not sufficient to prove the phase transition is taking place.
2. One may ask whether the dimensions d_p can be altered by evolution of the hadronic system after phase transition. This may only happen, however, if the evolution process involves a substantially long cascading. Although some cascading may certainly take place, we do not expect it to be long enough to alter significantly the constancy of d_p .
3. As seen from Fig. 1, the proton-emulsion data of Ref. [1] do not show a significant p dependence, within rather large experimental errors. We do not have an explanation of this anomaly.
4. If further measurements confirm our observations, this will be a suggestion not only that quark-gluon plasma is indeed produced in heavy ion collisions but also that the correlation length in the phase transition from plasma to hadrons is large and comparable to the size of the system.

5. An obvious consequence of our argument, which should be investigated when more data are available, is that if quark-gluon plasma is indeed produced in central collisions of heavy ions, we expect constancy of d_p at high transverse energies and multiplicities, whereas p dependence of d_p can develop as transverse energy and multiplicity decrease.

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Anomalous dimensions of (pseudo) rapidity spectra at $\sqrt{s} \approx 20$ GeV

FIGURE CAPTIONS

1) Anomalous dimensions of pseudorapidity spectra at $\sqrt{s} \approx 20$ GeV.

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17. We have checked that the data on intermittency in $(\delta y \delta \varphi)$ binning [1,5], although less complete, show the same tendency as the δy data plotted in Fig. 1.
18. In the case of a genuine second-order transition this limit value can be related to the critical exponents of the transition.