INTERMITTENCY-TYPE FLUCTUATIONS
IN HIGH ENERGY COLLISIONS *)

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ABSTRACT

This brief review concerns the phenomenon of intermittency in multiparticle production at high energies, characterized by the growth of the normalized factorial moments of multiplicity distributions in decreasing domains of phase space. We relate it to the behaviour of the probabilities for the various multiplicities in very small domains.

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never be reached experimentally). In (1) n denotes the multiplicity in the interval δy (usually the multiplicity of charged metastable hadrons, which are mostly pions). The prediction made in ref.6 on the basis of a selfsimilar random cascade model inspired by turbulence theory is that the growth of F_q may follow a power law

$$F_q \propto \langle n \rangle^{-f_q} \propto \delta y^{-f_q} \text{ for } \delta y \rightarrow 0 \quad (2)$$

with the scaling exponent f_q a positive constant for sufficiently small δy . In (2) we used the proportionality of $\langle n \rangle$ and δy at small δy ,

$$\langle n \rangle = (dn/dy) \delta y \quad (3)$$

with dn/dy the inclusive rapidity distribution at the centre of the interval δy .

3. Up to 1988, before data on factorial moments were available, the general expectation was that F_q would become constant for δy below 0.5-1, the range of the well known two-body correlations mainly due to resonances. Since that time, several experiments have shown that F_q increases continually as δy decreases down to the limit which can be reached with their present resolution and/or statistics, usually around 0.1⁷⁾. The data are not yet sufficient to establish the validity of the power law (2).

So far sufficient statistics is obtained by taking a rather large overall rapidity interval Δy , dividing it in small bins of size δy and averaging over all the latter bins for each event and over all events. This method, which is usually justified for other intermittency situations in physics (where the systems are homogeneous over large space or time intervals), is questionable for high energy collisions when dn/dy is not constant over the interval Δy , since the degree of intermittency is likely to depend on the average multiplicity (3).

As far as the experimental resolution is concerned, it puts of course a limit on the measurable narrowness of spikes, and F_q is not expected to grow when δy gets smaller than the resolution. But even if the experimental resolution could be made arbitrarily small, intermittency may also disappear (i.e., the F_q 's may become constant) below a certain domain size for dynamic reasons, as is the case for example in turbulence.

4. The strongest intermittency signals (i.e., the strongest increases of the F_q 's for decreasing δy) in accelerator experiments are observed

1. For some time there has been evidence for the sporadic occurrence of large fluctuations in the (pseudo)rapidity distributions of hadrons produced in high energy collisions; striking examples from cosmic ray and accelerator experiments were published in refs.1 and 2. The fluctuations manifest themselves in single events as peaks, often called spikes, in narrow (pseudo)rapidity intervals ($\delta y=0.10$ in the π^+p event at c.m. energy 22 GeV reported in ref.2, y being the longitudinal rapidity). Random occurrence of peaks is familiar in other parts of physics, particularly in hydrodynamic turbulence where it was observed a long time ago in velocity and temperature distributions and where it was given the name of intermittency³⁾.

Over the years, theoretical work on turbulence and other classical systems showed that intermittency could be studied through the scaling properties of the moments of the relevant random variables in decreasing domains (see ref.4 for a comprehensive review). This approach introduces a set of generalized scaling exponents associated with the name of the A. Renyi⁵⁾.

2. In a pioneering paper⁶⁾, A. Biaľas and R. Peschanski adapted the method of generalized scaling exponents to the study of intermittency, i.e., of sporadic "spiking", in multihadron production phenomena. Their main point is that one should study the scaling properties of the factorial moments of the multiplicity distribution in decreasing phase space domains. For the latter one usually takes decreasing intervals δy of (pseudo)rapidity, but it will be important also to consider the length and direction of the transverse momentum vector (e.g., spiking is not expected to be equally strong in rapidity and pseudorapidity).

Intermittency can be said to occur if the normalized factorial moments

$$F_q = \langle n(n-1)\dots(n-q+1) \rangle / \langle n \rangle^q \quad (1)$$

increase indefinitely for $\delta y \rightarrow 0$ (a limit which strictly speaking can

so far in e^+e^- annihilation and hadron-hadron collisions, which have $dn/dy \lesssim 1$. From (3) the value of $\langle n \rangle$ is therefore $\lesssim 0.1$ when $\delta y \sim 0.1$. For $\langle n \rangle \ll 1$ one can express intermittency directly in terms of the probabilities P_n for the various multiplicities in the interval δy . By means of the relations

$$\langle n(n-1)\dots(n-q+1) \rangle = q! P_q + \dots + n(n-1)\dots(n-q+1) P_n + \dots$$

for $q=1, 2, \dots$ and using the experimental fact that the f_q are $\ll 1$, one can rewrite (2) in terms of the P_n :

$$P_1 \ll \langle n \rangle, \quad P_q \ll \langle n \rangle^{q-1} \quad (q=2, \dots) \quad (4)$$

for $\delta y \ll \langle n \rangle \rightarrow 0$. In this limit, intermittency amounts to a continued increase of P_n / P_1^n ($n=2, 3, \dots$) for decreasing δy , i.e., an attractive multiparticle correlation which becomes very strong at very short range δy . In this low $\langle n \rangle$ limit, it becomes obvious why the use of normal moments is inappropriate, since to leading order they reduce to

$$\langle n^q \rangle \ll P_1^q \ll \langle n \rangle^q$$

without appearance of the intermittency exponents f_q .

5. The question of the dynamical explanation of intermittency in high energy physics is unsolved. Except for e^+e^- annihilation⁸⁾, existing models do not account for the data so far and will undoubtedly need important modifications. By the introduction of additional gluon activity, the most recent modification of the FRITIOF model goes in the right direction⁹⁾ and QCD parton shower models offer the possibility of a common mechanism for intermittency and other "ultrasoft" effects recently observed¹⁰⁾. A natural thought expressed by many people is that Bose-Einstein correlations between equal charge pions could play a role. This would make intermittency stronger for negatives than for all charged particles; according to the data of NA22¹¹⁾, UA1¹²⁾ and TASSO⁹⁾ this does not appear to be the case. Also jets or minijets can produce intermittency, but except for UA1 no jets or minijets are seen to occur in the hadronic data reported in ref.7. For all possible explanations mentioned above, intermittency would disappear for sufficiently small δy .

Following ref.6, various random cascade models were constructed to create intermittency. So far such models are exclusively aimed at giving intermittency and lack sufficient links with the vast body of knowledge on the other features of multiparticle production. While cascades are natural at QCD parton level, it is for the final state hadrons that inter-

mittency must be explained. We can therefore expect from future experimental and theoretical studies of intermittency a welcome source of new information on the hadronization process of quarks and gluons, by now the most important unsolved problem of QCD.

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