INTERMITTENCY '93

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An optimistic view on recent studies of intermittency
in high-energy collisions is presented.

1. Introduction

In the context of high-energy collisions, "intermittency" means self-similarity of multiparticle spectra measured at varying resolution [1]. For illustration, imagine a (hypothetical) event of so large a multiplicity that one does not need to worry about statistical fluctuations. The spectrum is called self-similar if its structure is (up to a possible scaling factor) independent of the size of the bin (Fig. 1).

Since in the real world the events do not have infinite multiplicities, one has to worry about statistical fluctuations, so that other, more refined methods of searching for self-similarity had to be devised. One well-known property of self-similar spectra, the so called "anomalous scaling laws" [2] which connect the moments of such distributions measured at different resolutions

$$F_q(\delta) = (\Delta/\delta)^{f_q} F_q(\Delta) \quad ; \quad f_q > 0 \tag{1}$$

turned out to be particularly useful [1]. Here $F_q(\delta)$ denotes, e.g., a normalized factorial moment of rank q [1] calculated at a resolution δ. Eq. (1.1) states an important fact:

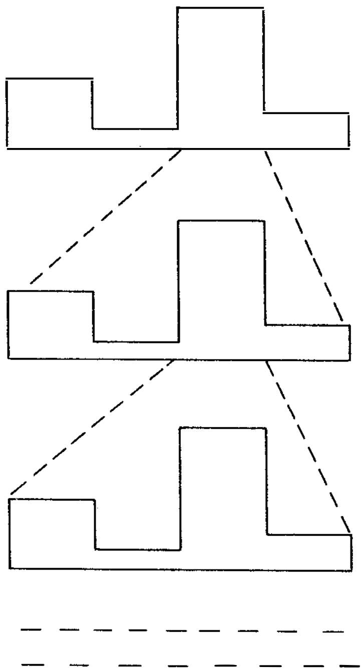

Fig. 1. Idealized self-similar spectrum

the moments of a self similar distribution measured at different resolutions are related by a power law.

Since the intermittency exponents f_q are positive numbers, (1) implies that the moments $F_q(\delta)$ are divergent in the limit $\delta \to 0$. This means that the distribution must be discontinuous (i.e. very bumpy) in this limit (distributions satisfying (1) are called fractals and f_q's are related to fractal dimensions).

The next important step is to observe that the moments of the distribution are in fact integrals of the multiparticle densities over the relevant regions of phase-space. It is thus clear that, if a moment develops a power law singularity at $\delta \to 0$, the corresponding multiparticle density, and thus also the multiparticle correlation function must be singular in the limit of vanishing momentum differences [3]. For example,

$$C_2(p_1, p_2) \sim |p_1 - p_2|^{-f_2} \tag{2}$$

Why is this interesting? It is interesting because such a power law singularity of the correlation function is characteristic of critical phenomena. Searching for intermittency, one therefore searches for critical features of particle production at high energies [4].

2. Experimental evidence

The power law (1) was observed in several experiments with an increasing precision and seems now a well-established property of multiparticle production. An example is shown in Fig. 2 where the factorial moment F_2 measured by UA1-MB collaboration [5]

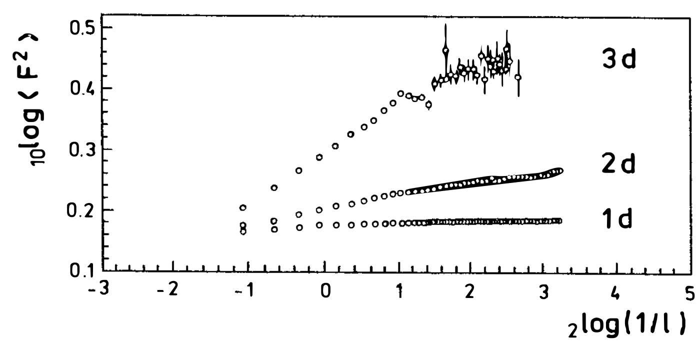

Fig. 2. Normalized factorial moments observed by UA1-MB collaboration [5].

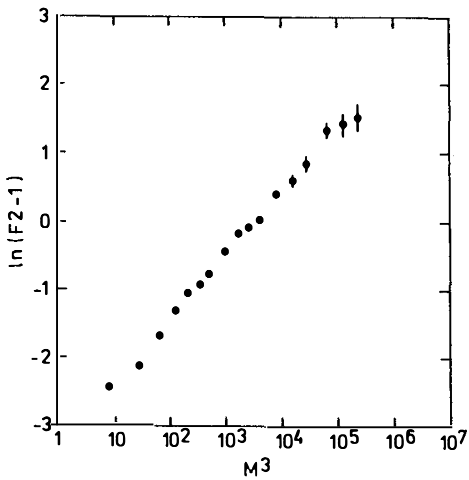

Fig. 3. Two-particle correlation function observed by EMC collaboration [8]

is plotted versus resolution. This figure documents one more point, namely a dramatic change of the intermittency exponents from one-dimensional (rapidity), to two-dimensional (rapidity and azimuthal angle) and three-dimensional spectra. This seems now well-understood as the result of washing out an intermittent structure by projection on a subspace of the three-dimensional space [6]. The conclusion is that the real strength of the effect can only be measured in three dimensional spectra or by selecting a proper variable. Fig. 3 shows another example of the power law behaviour found by EMC coll. [7] in muon-proton collisions.

3. Universality

Another important feature of the data, first investigated for three dimensional spectra by Fialkowski [8], is the universality of intermittency exponents. Comparing data for several processes, Fialkowski found that the moments of the second rank can be fitted by the formula

$$F_2(\delta) = A + B\delta^{-f_2} \tag{3}$$

with an universal value of the intermittency exponents $f_2 = 0.4 \pm 0.1$. This suggests that intermittency is related to some general features of the production process rather than specific properties of a given reaction. More work and more precise data (particularly for models of rank higher than two) are needed, however, to arrive at a firm conclusion.

4. Discovery of '92: charge dependence

Improved analysis of the data [3,9] established finally beyond any doubt a strong dependence of the intermittency exponents on particle charges. This is seen in Fig. 4, where the correlation integral measured in UA1-MB and in DELPHI experiments [10] is plotted versus $Q^2 = (p_1 - p_2)^2$ where p_1 and p_2 are four-momenta of the particles. One sees a rather dramatic difference between the particles of the same and of opposite charges. The most natural explanation of this observation is that the Hanbury-Brown and Twiss effect [11] plays a crucial role in the phenomenon of intermittency [12].

It is important to realize that this data demonstrate both the strong charge dependence and the existence of the power law. This is seen clearly in Fig. 5 where the correlation integral for same charge particles from UA1-MB experiment [13] is compared to power-law and exponential curves. One sees that the power-law dependence is preferred by this data. Similar effect is reported by NA22 collaboration [14]. It should

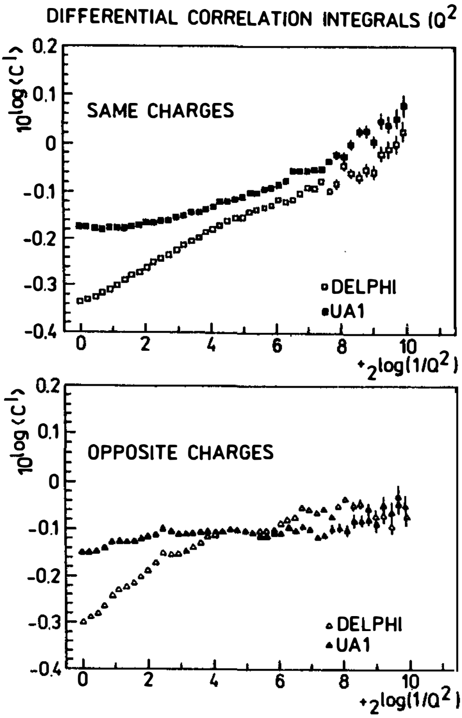

Fig. 4. Two-particle correlation functions for like-sign and unlike-sign particles measured by DELPHI and UA1-MB collaborations [11].

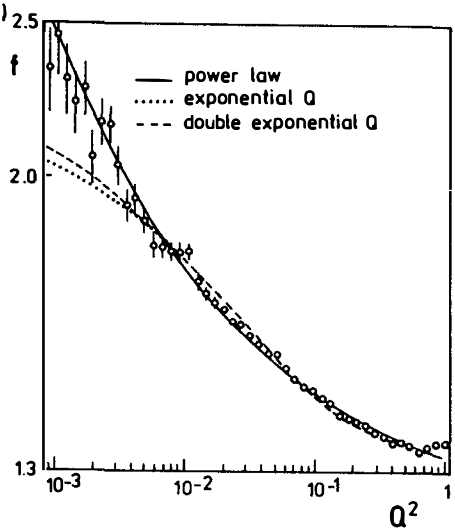

Fig. 5. Two-particle correlation function for like-sign particles measured by UA1-MB collaboration compared to power law and to an exponential [14].

be emphasized that the data extend up to $Q \sim 30$ MeV and that the region of smallest Q is crucial for determining the power law.

5. Theoretical speculations

A natural suggestion for explanation of self-similarity is the parton cascade. This was considered already some time ago, but only recently the effect was calculated in the framework of perturbative QCD [15]. The results were presented at this meeting. They show that, although the parton cascade can indeed account for the data on correlations at relatively large values of Q^2, it seems difficult to reconcile with data at high resolution. The reasons are twofold. First, since the QCD coupling varies with Q^2 (running coupling), the moments saturate at high resolution and the intermittency effect disappears. Second, the parton cascade does not explain easily the dependence of correlation functions on particle charges.

These two observations show that hadronization, i.e., non-perturbative effects must be essential for explanation of the phenomenon. This is both good news and bad news. It is good news because by studying intermittency one may hope to learn about the — till now elusive — hadronization process. It is bad news because hadronization may turn out so complicated that no useful information can be extracted from these data.

A possible solution is suggested by the observed strong HBT effect [4,16]. It implies that the measured correlation functions are just Fourier transforms of the space-time distribution of the source of particles. Thus intermittency exponents should not be sensitive to the details of the hadronizaton process, but only to its space-time structure. It follows that to understand intermittency at high resolution (in particle momenta) it is necessary to study the space-time structure of the strong interactions at large distances [17] rather than their momentum structure. This observation brings a radically novel view to our thinking about intermittency.

In this interpretation the observed power law in momentum space should be viewed as a reflection of a power-law structure in space-time. It can be shown that some detailed features of this space-time structure are simply reflected in the measured intermittency parameters. Measurements of the correlations between more than two particles are particularly important [18]. To illustrate the potential of this approach let me only mention that already the existing data allow to exclude the the simplest possibility, i.e., a superposition of sources with different radii [16]. Also independent emission from a source with density following a power law seems to be difficult to reconcile with the data of NA22 coll. [14]. It thus seems that the data point towards the fractal nature of the space-time structure of particle emission process. The story is of course at its beginning and further work is needed to understand the situation better.

6. Conclusions

The main conclusion is that the existing data definitely indicate the existence of intermittency, i.e. of self similar structures in the systems of particles created in high-energy collisions [19]. The effect seems universal: it was found in most of the processes investigated and its measured parameters depend only weakly (if at all) on the process in question. Strong HBT effect was found, suggesting that intermittency is related to space-time structure of the pion source rather than to detailed momentum structure of the production amplitudes. There are indications that this space time structure may be fractal, but more data is needed to establish this. The theoretical explanation remains obscure: it seems that both parton cascade and hadronization play an important role. Their interrelation, however, remains a mystery.

7. Apologies

This report being necessarily very short, it was impossible to give justice to many developments, even most recent and most important ones. Also the list of literature is necessarily limited. I apologize to the readers for presenting such an incomplete and perhaps too optimistic view and to my friends involved in studies of intermittency for not being able to present adequately their work.

8. Acknowledgements

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19. Other opinions also exist. See E. De Wolf, in XXII Int. Symp. on Multip. Dynamics, Santiago de Compostela (1992) and these proceedings.