

## Fractal measures in multiparticle production

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A new set of moments  $G_l$  of the multiplicity distribution in a narrow rapidity window is suggested for analysis so that the chaotic fluctuations of the rapidity distribution can be described in the formalism of multifractals. Phenomenological evidence is given to show that there is a fractal structure in the data of multiparticle production at high energy. The fractal dimension and its generalizations can be determined to provide a description of the spectrum of scaling indices. The implication on the emergence of a new approach to the study of multiparticle production in the framework of multifractals in the theory of chaos is discussed.

### I. INTRODUCTION

The study of multiparticle production at high energies has recently entered into a new phase. For many years the emphasis has been placed on Koba-Nielsen-Olesen (KNO) scaling and its violation, forward-backward multiplicity correlation, representation of data by negative-binomial distribution, etc. (For recent reviews, see Refs. 1 and 2.) Many models have been suggested to interpret the data; all of them claim impressive successes.<sup>3</sup> More recent experiments on relativistic heavy-ion collisions produced multiplicity (or transverse-energy) distributions that are no more successful than those from hadronic collisions in discriminating among the various models that describe the basic collision process.<sup>4</sup> However, the scenario changed dramatically when data on intermittency appeared last year,<sup>5</sup> showing clear discrepancies from the predictions of some standard models, according to existing Monte Carlo codes. Recent results from high-energy nuclear collisions<sup>6</sup> having even better statistics have reinforced the discrepancy. In the area of multiparticle production we have finally found a disagreement between theory and experiment that cannot be eliminated by the adjustment of some parameters. It is a signal for the discovery of some very basic issues that have escaped notice thus far.

In the past the models were constructed to explain average features in the data. Bialas and Peschanski<sup>7</sup> were the first to raise questions about the significance of sharp spikes in the cosmic-ray data.<sup>7</sup> Having in mind the analogous bursts of turbulence in the theory of chaos,<sup>8</sup> they proposed the investigation of intermittency in multiparticle production. Specifically, they suggested that, if intermittency exists, the normalized factorial moments of multiplicity distribution should exhibit power-law dependences on the width  $\delta y$  of the rapidity window, as  $\delta y \rightarrow 0$ . The most significant aspect of their work is to steer people away from studying average phenomena, and to emphasize the importance of understanding the chaotic structure of the rapidity distribution from event to event.

The point of view of Bialas and Peschanski received a tremendous boost of support when intermittent types of behavior were observed in  $e^+e^-$  annihilation,<sup>9</sup> hadron-

hadron,<sup>10</sup> hadron-nucleus,<sup>11</sup> and nucleus-nucleus collisions.<sup>3,11</sup> Numerous theoretical models have also been proposed to account for intermittency, or more broadly, the power-law behavior of the factorial moments:<sup>12-17</sup>

$$F_l \sim (\delta y)^{-\alpha_l}, \quad \delta y \rightarrow 0, \quad (1.1)$$

where the exponent  $\alpha_l$  increases with the order  $l$  of the moment. Indeed, there are proposals, such as that in Ref. 15, which dispute the necessity of invoking intermittency as understood in the theory of deterministic chaos<sup>18</sup> to account for the behavior of (1.1). Given (1.1) as a summary of the phenomenological fact about particle production at small  $\delta y$ , the pressing theoretical question is then the interpretation of the exponents  $\alpha_l$ . This paper is directed toward answering that question, but in so doing we have found that  $F_l$  are not the optimal moments to investigate. An alternative set of moments  $G_l$  are far more direct in exhibiting an order in the seemingly random fluctuations in the rapidity distributions.

The study of deterministic chaos in nonlinear physics is now a well-developed branch of science.<sup>3,19,20</sup> In particular, the behavior of strange attractors in chaotic dynamical systems has been investigated extensively. It has come to be recognized that the characterizations of the attractors, as well as many other similar objects in dissipative systems, can best be done in terms of fractal measures.<sup>20</sup> The most notable property of fractals is their dimensions.<sup>21</sup> A formalism for treating the fractal dimension and its generalization has recently been developed,<sup>22-25</sup> and has been applied effectively to the study of intermittent behavior in turbulent fluids and other transitions to chaos, such as through period doubling and quasiperiodicity. We shall adapt that formalism for the treatment of our problem in multiparticle production.

It should be mentioned that there is a sharp distinction between the nature of problems in deterministic chaos and the one that we encounter in particle production. In the former case the problem is usually set up in the form of a set of coupled, nonlinear differential equations. One attempts to find efficient ways to solve the problem and to present the nature of the solution and its critical properties in some compact and, if possible, universal form.

# Theory Of Multiparticle Production Procebes

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