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Study of Levy stability and intermittent behaviour in ^{28}Si-emulsion collisions at 4.5 A GeV

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Abstract

Modified power law has been used to study the behaviour of higher order and second order scaled factorial moments of relativistic shower particles produced in ^{28}Si-emulsion collisions at 4.5 A GeV/c in pseudorapidity phase space for different N_s-intervals. The intermittency exponents, ϕ_q, are compared with the anomalous fractal dimensions, d_q. The ratios of higher order and second order anomalous fractal dimensions (d_q/d_2) expressed in terms of the Levy stable law gives an evidence of self-similar cascading mechanism responsible for multiparticle production. The experimental data within different N_s-intervals fulfills the requirement of the Levy stable region ($0 \leqslant \mu \leqslant 2$). Moreover, the value of universal scaling exponent (υ) indicates that no clear evidence of second order phase transition has been found in the interactions. Finally, Renyi dimensions, D_q, and multifractal spectrum, $f(\alpha_q)$, are determined in accordance with the Levy stable theory.

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Keywords: Multiplicity fluctuation; Scaled factorial moments; Levy stable law; Levy index; Renyi dimension; Spectral function; Quark–gluon plasma; Ginzburg–Landau theory

1. Introduction

The experimental observation of large rapidity fluctuations [1] has provided interest and excitement about their nature and origin. Bialas and Peschanski [2] have proposed the most suitable method known as scaled factorial moments (SFMs) to study the non-statistical fluctuations in

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the distributions of relativistic shower particles produced in high-energy collisions. They suggested a power law scaling behaviour of SFMs ($\langle F_q \rangle \propto M^{\phi_q}$) on the bin size and described the phenomenon as "intermittency", a term coined from hydrodynamic turbulence [3]. The SFMs method cannot only predict the existence of large non-statistical fluctuations but it could also investigate the pattern of fluctuations and their origin. There exists abundant evidence of power law behaviour in experimental data of e^+e^- annihilation [4], muon–hadron [5], ν-nucleus [6], hadron–hadron [7], hadron–nucleus [8] and nucleus–nucleus collisions [8,9]. Evidence of this behaviour has also been found in nuclear multi-fragmentation [10]. No one has claimed the existence of formation of quark matter in such experiments. Thus, intermittency seems to be a general property of multiparticle production and this effect is not fully explained by any single model proposed, so further experimental information is needed for necessary improvements.

According to the predictions of a simple scale-invariant cascade model [11], the higher order scale factorial moments are related to the second order scaled factorial moments by a modified power law, which may provide some vital information about the underlying dynamics. It has been found that the slopes of the power law between higher order and second order SFMs are independent of the phase space size and phase space dimension [11,12]. Ginzburg–Landau formalism [12–14] and the scaling exponent in relation, $\beta_q = (q-1)^{\nu}$ help to provide a useful diagnostic tool to detect the existence of second order phase transitions in hydronization process. Analysis of modified power law has been used to investigate hadronic collisions [11,15] and nuclear collisions data [8,9,12]. The dependence of ratios of higher order anomalous fractal dimension [11] on the order of moments can help to search for an intermittent type of fluctuations in the multiparticle production process. The Levy stable law [11,16] has been used to study such dependences, where multiplicity fluctuation is described quite successfully [17]. The study of variations of these ratios on the order of moments has suggested the existence of self-similar cascade processes and a second order phase transition [11,16]. If the underlying mechanism is a self-similar cascade mechanism, then it leads to intermittent fluctuations and this type of behaviour is characterized by multifractals, whereas, if it is a second order phase transition, e.g., quark gluon plasma, the behaviour is characterized by monofractals.

The aim of the present work is to investigate the behaviour of multiplicity fluctuation of relativistic shower particles produced in ^{28}Si-emulsion interactions at 4.5 A GeV in pseudorapidity phase space. The present study includes the behaviour of higher order and second order scaled factorial moments in different N_s-intervals. The ratio of anomalous fractal dimensions (d_q/d_2) as a function of order of moments, q, has been studied and Levy-stable law [11,16] has been used to find the Levy index (μ). Finally, multifractal spectra, $f(\alpha_q)$ in pseudorapidity space corresponding to negative q values has also been studied.

2. Experimental details

In the present work, one stack of BR-2 emulsion exposed to 4.5 A GeV/c silicon beam at the Synchrophasotron of the Joint Institute of Nuclear Research (JINR), Dubna, Russia, has been utilized. The method of line scanning has been adopted to scan the stacks, which were carried out with Japan made NIKON (LABOPHOT and Tc-BIOPHOT) microscopes with 8 cm movable stage using 40X objectives and 10X eyepieces. The interactions due to beam tracks with an angle $< 2^\circ$ to the mean direction and lying in the emulsion at depths > 35 μm from either surface of the pellicles were included in the final statistics. The sensitivity of nuclear emulsion used for singly charged particles was about 30 grains per 100 μm. Some other relevant details about the present experiment may be found in our earlier publications [18].