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Intermittent and scaling behaviour of shower particles produced in the collsions of ^{28}Si-Em at 14.6A GeV

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Abstract : In the present paper an attempt has been made to study the intermittent and scaling behaviour of particles produced in the interactions of ^{28}Si-Em at 14.6A GeV. For this purpose, the method of normalized scaled factorial moments, F_q, has been utilized. We have also studied some interesting features regarding the occurence of non-thermal phase transition and scaling nature of F_q -moments.

Keywords : Relativistic heavy ion collisions, nuclear emulsion, scaling behaviour, scaled factorial moments

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1. Introduction

During the last couple of years, the study of relativistic nuclear collisions has provided unique opportunity to investigate about a hot new matter state, *i.e.*, quark-gluon plasma (QGP), which might be formed in the early stage of collision and the system will cool with its subsequent expanding and will undergo a phase transition from deconfined QGP to confined hadrons. It might be possible to search for the signals about the phase transition from the study of final state particles, because only the final particles in such collisions are observable in the experiments. The hadrons are emitted out in the freeze-out process and may carry some valuable information about the evolution of the system and interactions. A variety of possible signatures for the transient existence of non-thermal phase transition, such as J/ψ suppression, strangeness, fluctuation *etc* has been proposed theoretically and studied experimentally by various workers[1,2].

It has been suggested [3] that a promising signal for the presence of a QGP is the observation of event-by-event fluctuations. The study of dynamical fluctuations of relativistic shower particles have attracted a lot of attention. Understanding the origin of these large

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fluctuations may provide new insights into the underlying mechanisms responsible for the particle production. Therefore, the study of dynamical fluctuations has acquired importance using normalized scaled factorial moments (SFMs).

In this paper we have made a modest attempt to study the some features of intermittent and scaling behaviour of secondary charged particles produced in the interactions of ^{28}Si-Em collisions at 14.6A GeV. Analysis of experimental data has been done in terms of scaled factorial moments (SFMs), of the multiplicity distribution through successive partitions in pseudo-rapidity, η-space and azimuthal angle, ϕ-space respectively.

2. Method of analysis

It should be pointed out that the single charged particle pseudorapidity distribution is non-uniform. In order to reduce the effects of non-uniformity of the single charged particle distribution $\rho(\eta)$, we have used a new scaled variable [4], defined as:

$$X(\eta) = \int_{\eta_1}^{\eta} \rho(\eta')\, d(\eta') \Big/ \int_{\eta_1}^{\eta_2} \rho(\eta')\, d(\eta') \tag{1}$$

where η_1 and η_2 are the minimum and maximum values of the pseudorapidity distribution for a given value of the pseudorapidity η falling in the interval $\Delta\eta = \Delta\eta_2 - \Delta\eta_1$ of individual shower tracks in an event. The variable $X(\eta)$ corresponding to single particle density distribution is uniformly distributed from 0 to 1 in X-space. In terms of a new scaled variable, $X(\eta)$, the single particle density distribution is always uniform and both horizontal and vertical averaging should produce the same result. Similar procedure has been adopted in azimuthal phase-space.

An effective method to study the nature of the multiplicity fluctuations in high-energy heavy-ion collisions is to examine the dependence of the normalized scaled factorial moments (SFMs) on the bin width, which is given as:

$$F_q^H(\delta\eta) = \frac{M^{q-1}}{N_{ev}} \sum_{i-1}^{N_{ev}} \sum_{m=1}^{M} \frac{n_{m,i}\left(n_{m,i}-1\right)\ldots\left(n_{m,i}-q+1\right)}{\langle N \rangle_q} \tag{2}$$

where M is the number of bins, n_{mi} is the number of relativistic charged particles in the m^{th} bin (m =1,2,3...M) of the event and < N > represents the mean multiplicity of the hadrons. The pseudorapidity interval $\Delta\eta$ is divided into M bins of uniform width $\delta\eta = \Delta\eta/M$. It has been observed that for purely statistical fluctuations, saturation of <F_q > with decreasing resolution, $\delta\eta$, is expected, whereas for the presence of non-statistical self-similar fluctuations of many different sizes in rapidity space follows the power law behaviour of < F_q > on M given as:

$$\left\langle F_q(\delta X)\right\rangle \propto (\delta X)^{-\alpha_q}, \quad (\delta X \to 0)$$

or,

$$\langle F_q(M)\rangle \propto (M)^{\alpha_q}, \quad (M \to \infty) \tag{3}$$

where α_q is called intermittency index, which can be determined from the slopes of the relations between ln< F_q > and ln M. If the non-statistical fluctuations are self-similar in nature, the factorial moment is given by:

$$\ln \langle F_q \rangle = \alpha_q \ln M + C. \tag{4}$$

With the knowledge of intermittency index, α_q, the possibility of detecting a non-thermal phase transition can be obtained by calculating the relevant parameter, λ_q, using the following relation:

$$\lambda_q = (\alpha_q + 1)/q. \tag{5}$$

3. Experimental details

In the present work, we have analyzed data from two emulsion stacks exposed to 14.6A GeV/c silicon beam from Alternating Gradient Synchrotron at Brookhaven National Laboratory. 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^o 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[5,6]. The space angles (θ_s) with respect to the beam direction and azimuthal angle (ϕ) of shower tracks were determined by measuring the coordinates of the vertex and points on the primary and shower tracks. The pseudo-rapidity of the relativistic shower particles was found using the relation, $\eta = -\ln\tan(\theta_s/2)$. In the present investigation, only interactions with $N_s \geq 8$ are considered, since the events with low multiplicity (N_s < 8) would have large statistical fluctuations. The numbers of interactions with $N_s \geq 8$ for silicon beam with emulsion nuclei are found to be 923. Only these events with $N_s \geq 8$ were considered to maximize the contribution of dynamical fluctuations [6]. The fluctuations are studied in the range of pseudorapidity, $\Delta\eta$ = 0.25 to 6.5, leaving out the fragmentation tails where statistics are low.

4. Results and discussions

The normalized scaled factorial moments method has been used to study the intermittent behaviour of multiparticle production in high-energy heavy-ion collisions. We have investigated the experimental data in pseudorapidity (η) and azimuthal angle (ϕ) spaces respectively using eq.(1) in terms of the cummulative variable (X). The range of ΔX = 1 was divided into M bins, each of size $\Delta X/M$, where M varies from 2 - 35. The average values of, $\left\langle F_q^H(\eta \; or \; \phi)\right\rangle$, using eq. (2) have been calculated for all the events corresponding to q = 2 – 6. The variation of ln< F^H_q > as a function of ln M in the η and ϕ - spaces respectively for each order of moments are depicted in Figures 1(a) and (b) along with the corresponding UrQMD predictions. The error bars associated are statistical in nature.The linear rise in the values of ln< F_q > with increasing ln M in Figures 1(a and b) show a power law dependence in η and ϕ - spaces. This trend gives an evidence of intermittent behaviour. Similar trend is observed in the corresponding UrQMD generated data shown by an open circles in Figure 1(a). It may be further seen from the figure that the experimental values of ln< F_q > are somewhat larger than the events simulated using UrQMD model. In order to check the presence of the dynamical fluctuations, uncorrelated Monte Carlo events generated randomly are also shown in the

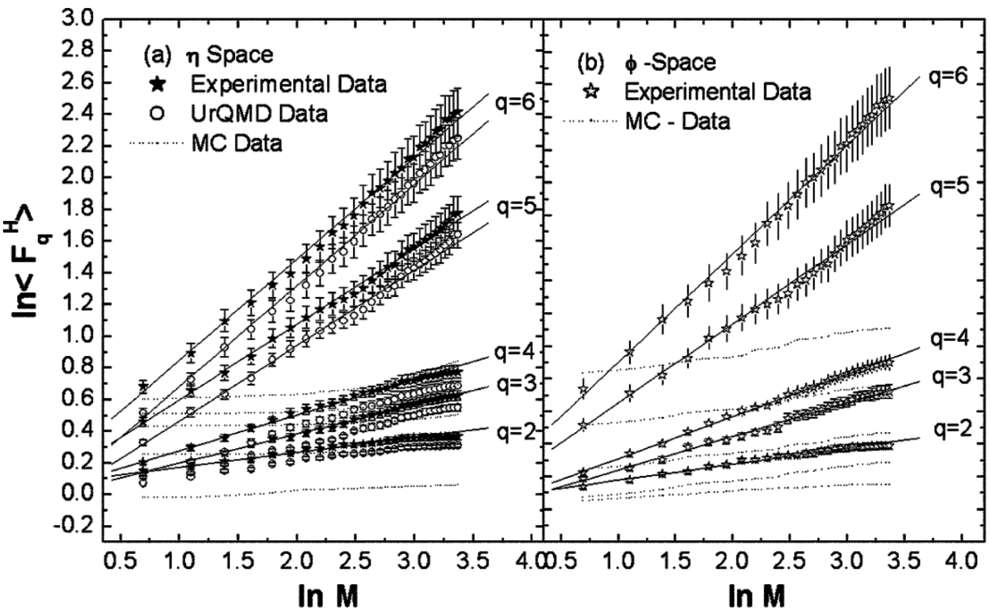

Figure 1. Variation of ln<F_q^H > as a function of ln M (a) for η-space and (b) for ϕ-space in the interactions of ^{28}Si-Em at 14.6A GeV.

same figure by dotted lines. This gives an indication for the presence of dynamical contribution into experimental data. The flat behaviour in MC events is expected for independent emssion of particle. It is also evident from the plots of ln< F_q > *vs.* ln M in Figure 1(b) that it shows a power law dependence in ϕ-space. The intermittency effect appears to be stronger in ϕ-space than in η-space. This can also be understood in terms of the intermittency index given in Table 1 in η and ϕ-spaces. The values of intermittency index, α_q, in ϕ-space shown in Table 1 are more than η-space for all values of q.

Table 1. The values of intermittency index, α_q in the interaction of ^{28}Si-Em collisions at 14.6A GeV.

Order of moments	η -space	ϕ -space
2	0.095 ± 0.004	0.099 ± 0.008
3	0.193 ± 0.004	0.237 ± 0.005
4	0.325 ± 0.005	0.358 ± 0.008
5	0.707 ± 0.015	0.726 ± 0.018
6	1.142 ± 0.021	1.265 ± 0.027

In order to study the possibility of observing a non-thermal phase transition during the collision, the function λ_q defined in eq. (5) should have a minimum at certain value of $q = q_c$. It has been shown that the self-similar multiparticle systems behave differently in the two regions $q < q_c$ and $q > q_c$. It is observed that the region $q < q_c$ is dominated by numerous small fluctuations and the region $q > q_c$ is dominated by a small number of very large fluctuations[7-9]. This situation can easily be compared with a mixture of "liquid" of large number of small fluctuations and a "dust" consisting of few grains of very large density. The "liquid" and the "dust" phases coexist. The behaviour of λ_q as a function of order of moments, q, has been shown in Figure (2) in the interaction of ^{28}Si-Em at 14.6A GeV for η and ϕ-spaces respectively. The result of ^{28}Si-Em at 4.5A GeV has also been shown for comparison purpose. From the Figure we observed that no clear cut minimum value of λ_q for certain value of q has been observed within the limit $2 \le q \le 6$ as reported by other workers [10,11]. However, a little deviation of the experimental data from the 'no intermittency' line ($\alpha_q = 0$) indicates the presence of a weak intermittency in η-space for the present data. A weak intermittency effect is found due

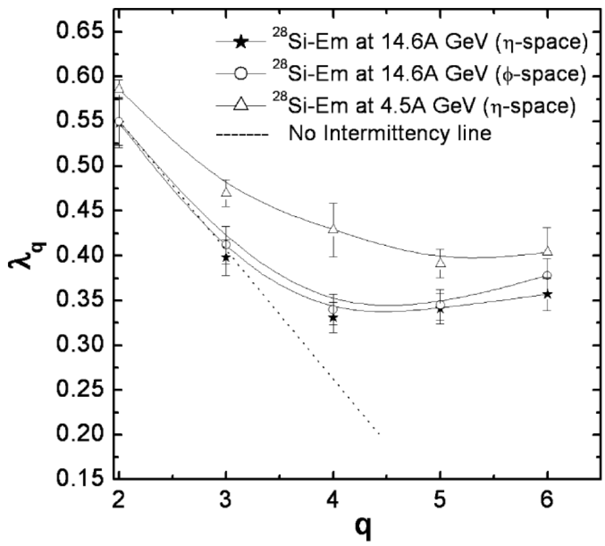

Figure 2. Plot of λ_q *vs* order of moments. *q*. The dotted line represents no intermittency line (α_q = 0).

to intermixing of many subprocesses during multiparticle production of cascade mechnism. A large deviation from the 'no intermittency' line is found in the ϕ-space. Thus it may be concluded that our data do not support a clear evidence for the existance of non-thermal phase transition. To get more unambiguous evidence, the analysis should be done upto q = 8 with large statistics at high energies and with different projectiles.

Another consequence of intermittency is a scaling property of SFM(s) in multiparticle production. Seibert[12] proposed that higher order scaled factorial moments, F_q, to the second order factorial moments, F_2, are observed to obey the scaling law. The higher order scaled factorial moments can be expressed in terms of second order moments by the relation:

$$(F_q - 1)/q(q-1) = (F_2 - 1)/2. \tag{6}$$

Thus the entire functional form of the q^{th}-order scaled factorial moments is determined by the second order factorial moments. It has been reported [8,13] that instead of expanding (F_q–1) as a function of (F_2–1) $\ln F_q$ can also be expanded as a function of $\ln F_2$, giving the scaling law for F_q by using the eq. (6) in the following form:

$$\ln F_q/q(q-1) = F_2/2 \tag{7}$$

or,

$$2\ln F_q/q(q-1) = F_2. \tag{8}$$

In order to check the validity of the above scaling law, the values of 2 $\ln F_q/q(q-1)$ for different values of q as a function of lnM are plotted in Figure 3 for our data in η-space.

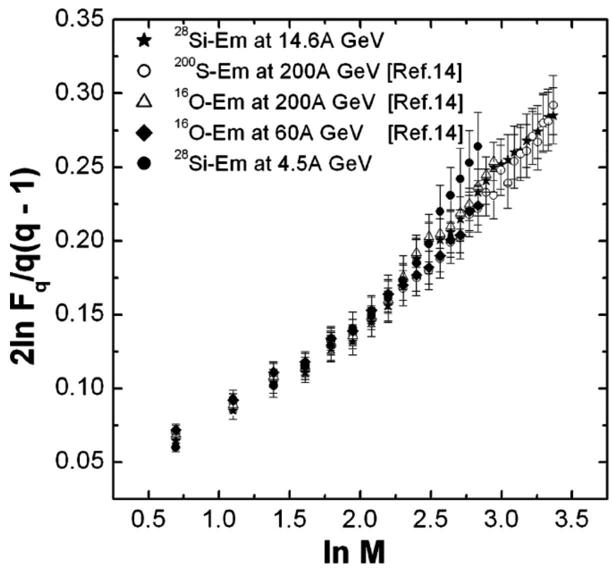

Figure 3. Variation of $2\ln F_q/q(q-1)$ as a function of ln M (a) at different energies.

This Figure also includes the results at 60 and 200A GeV [14] respectively. It can be concluded that it favours the scaling behaviour, but it is too early to say the universality of the scaling law. To see importance of the scaling behaviour it would be interesting to further study the scaling law with different projectiles and energies.

5. Summary and conclusions

On the basis of the results presented, the following conclusions may be drawn:

(i) A generalized power law behaviour of scaled factorial moments in η-space as well as in ϕ-space has been observed in the interactions of ^{28}Si-Em collisions at 14.6A GeV. Thus, an intermittent behaviour in multiparticle production may support a cascade mechnism.

(ii) No clear evidence for the existance of non-thermal phase transition is observed from the study of λ_q vs q graph in η-space as well as in ϕ-space.

(iii) A scaling behaviour may be observed for SFMs.

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