Intermittency Approach in the Nuclear Collisions of ^{28}Si + AgBr at 14.6A GeV - *Nuclear Emulsion Experiment a Particle Detector*

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Abstract

A new method has been applied for the study of intermittency in the collisions of ^{28}Si + AgBr at 14.6 A GeV for the produced relativistic charged particles by using the method of mixed factorial moment (MFM). In this paper an analysis has been made for the presence of fractal behavior with three different approaches of Scaled factorial Moments (SFMs) named as- horizontal, vertical and mixed (horizontal and vertical together). The non-statistical fluctuations of relativistic charged particles have been calculated on events with different degree of centrality. These results have been compared with the results of simulated data obtained from UrQMD model and we find a good agreement between experimental data and simulated data.

Keywords: multiplicity fluctuation;, UrQMD simulation technique; scaled factorial moemnts component; charged particle production

Introduction

A phase transition from hadron gas to quark gluon-plasma (QGP) is expected to occur at high energy densities ($\approx 1 GeV/fm^3$). There are some signals at the maximum SPS energies that quark-gluon-plasma is created at the early stage of heavy ion collisions [1-4]. Various theoretical models predict an increase of multiplicity fluctuations near the onset of deconfinement state [5, 6]. An approach of 'intermittency' phenomenon [7 and references therein] belongs to scaled factorial moment (SFM) and its scaling nature with diminishing phase-space interval size (δX), which is mainly an arrangement with the short-range correlations among the produced particles in heavy ion collisions at high-energies. Analysis of SFM is also capable of suppressing any Poisson-type statistical noise present in the local density fluctuations and of characterizing the non-statistical component of the same in terms of a finite set of parameters. The experimental data on particle fluctuations in small space domains has been presented for different collisions at different energies [4, 6-8]. We are studying here the intermittent behaviour of multiparticle production can be related to the formation of mini-jets, a second order phase transition from quark gluon plasma to the normal hadronic matter or the random cascading process [6-9].

It has been found that the intermittency is a general property of multiparticle production in relativistic heavy ion collisions [6-9]. The intermittent behavior of multiparticle production can be related to the formation of mini-jets, a second order phase transition from quark gluon plasma to the normal hadronic matter or the random cascading process [9]. In this paper we draw some results of the analysis of the multiplicity fluctuations in pseudo-rapidity scale for ^{28}Si (projectile) + AgBr (target) collisions at 14.6 A GeV. It has been proposed to study the dependence of scaled factorial moments F_q, on the order of the moment, q, as a function of the bin width $\delta\eta$ [6-9], the pseudo-rapidity interval is $\Delta\eta$. The intermittent behavior should a clue of a power law dependence of the scaled factorial moments on the bin size such as follow:

$$F_q = \left(\frac{\Delta\eta}{\delta\eta}\right)^{\alpha_q}, \text{ where } \alpha_q > 0 \qquad (1)$$

I. Data collections and experimental details

In the present experiment, FUJI nuclear emulsion pellicles were irradiated horizontally with a beam of ^{28}Si nuclei at 14.6A GeV at Alternating Gradient Synchrophasotron (AGS) of Brookhaven National Laboratory (BNL), NewYork, USA. The method of line scanning has been adopted to scan the stacks, which was carried out carefully using Japan made NIKON (LABOPHOT and Tc-BIOPHOT) high-resolution microscopes with 8 cm movable stage using 40X objectives and 10X eyepieces by two independent observers, so that the bias in the detection, counting and measurements can be minimized.

The interactions due to beam tracks making an angle < 2° to the mean direction and lying in emulsion at depths > 35 μm from either surface of the pellicles were included in the final statistics. The other relevant details about the present experiments and target identifications may be seen in our earlier publications [10-17]. In the measured interactions all charged secondary particles were classified according to the commonly accepted emulsion experiment terminology into following groups:

A. Black track producing particles (N_b)

The tracks with specific ionization $g^* > 10$ ($g^* = g/g_0$, where g_0 is the Plateau ionization of a relativistic singly charged particle and g is the ionization of the charged secondary) have been taken as black tracks. These correspond to protons of relative velocity $\beta < 0.3$ and range in emulsion L < 3.0 mm [11].

B. Grey track producing particles (N_g)

The tracks with specific ionization $1.4 \leq g^* \leq 10$ corresponding to protons with velocity in the interval $0.3 \leq \beta \leq 0.7$ and range $L \geq 3.0$ mm in nuclear emulsion are called grey tracks [11].

C. Shower track producing particles (N_S)

The tracks with specific ionization $g^* < 1.4$ corresponding to protons with relative velocity $\beta > 0.7$ are classified as shower tracks. These tracks are mostly due to relativistic pions with small admixture of charged K-mesons and fast protons. In order to eliminate all the possible backgrounds due to γ overlap (where a γ from a π^0 decay converts into $e^+ e^-$ pair) close to shower tracks near vertex, special care was taken to exclude such $e^+ e^-$ pairs from the primary shower tracks while performing angular measurements. Usually all shower tracks in the forward direction were followed more than 100 - 200μm from the interaction vertex for angular measurement. The tracks due to $e^+ e^-$ pair can be easily recognized from the grain density measurement, which is initially much larger than the grain density of a single charged pions or proton track. It may also be mentioned that the tracks of an electron and positron when followed downstream in nuclear emulsion showed considerable amount of Coulomb scattering as compared to the energetic charged pions. Such $e^+ e^-$ pairs were eliminated from the data.

D. Projectile fragments (Z_f)

The projectile spectator fragments, singly and multiple charged, emitted inside fragmentation cone, usually we determine the number of alpha particles (n_α) and the number of fragments with Z>2, separately [9].

The polar (θ) and azimuthal (ϕ) emission angles of all tracks have been measured, and the pseudorapidity has been calculated by $\eta = -\ln\tan(\theta_S/2)$ for each shower particle.

II. Mathematical analysis

We used three methods of analysis; method of horizontal factorial moments (HFM), vertical factorial moments (VFM) and published in [6-8] and also in the present analysis we used the mixed factorial moments (MFM). The standard horizontal factorial moments $F_e^{(H)}$ characterizing the *eth* event are defined by the following relation:

$$F_e^{(H)}(q) = M^{q-1} \sum_{m=1}^{M} \frac{F(n_{me}, q)}{\left[N_e^{(H)}\right]^q}, \quad (2)$$

where M is the number of equal bins of size δη into which the pseudorapidity interval Δη has been divided, n_{me} is the number of shower particles in the m^{th} bin. Non averaging and non normalized factorial moments are given by:

$$F(n_{me}, q) = n_{me}(n_{me} - 1)\ldots(n_{me} - q + 1) \quad (3)$$

The vertical averaging of $F_e^{(H)}$ gives the full form

$$F^{(H)}(q) = \frac{1}{E} \sum_{e=1}^{E} F_e^{(H)}(q), \quad (4)$$

where E is the total number of events. The denominator of the horizontal moment (Eqn. 2) is $N_e^{(H)} = \sum_{m=1}^{M} n_{me}$. (5)

The vertical analysis is suggested in case of rare events with sharp peaks [8, 9]. The normalized standard vertical moments characterizing the m^{th} bin are given by

$$F_m^{(V)}(q) = E^{q-1} \sum_{e=1}^{E} \frac{F(n_{me}, q)}{\left[N_m^{(V)}\right]^q} \tag{6}$$

and the horizontal averaging gives the full form

$$F^{(V)}(q) = \frac{1}{M} \sum_{m=1}^{M} F_m^{(V)}(q), \tag{7}$$

where; $N_m^{(V)} = \sum_{e=1}^{E} n_{me}$ is the sum of multiplicities which appear in the m^{th} bin of all events. Besides the horizontal and vertical factorial moment methods a mixed approach is applied. The mixed factorial moments are defined such as:

$$F^{(HV)} = M^{q-1} E^{q-1} \frac{\sum_{m=1}^{M} \sum_{e=1}^{E} F(n_{me}, q)}{\left[N^{(HV)}\right]^q} \tag{8}$$

where; $N^{(HV)} = \sum_{m=1}^{M} \sum_{e=1}^{E} n_{me}$ is the total number of charged particles observed in the sample of E events.

III. results and discussions

Figure 1, shows the normalized pseudorapidity distributions (i.e. the particle number densities in rapidity space) of the secondary charged shower particles emitted in the interactions of ^{28}Si-Em at 14.6A GeV. In the same figure the results obtained from the interactions of ^{28}Si-Em and ^{12}C-Em at 4.5A GeV along with the result of ^{16}O-AgBr at 3.7, 60 and 200A GeV respectively have been shown for comparison.

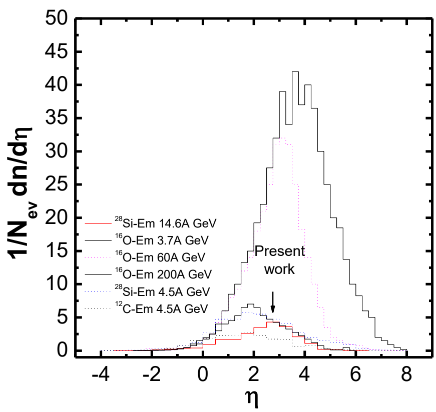


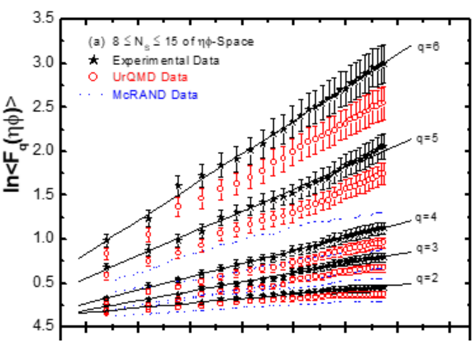
Figure 1. The pseudorapidity distributions of the shower charged particles produced at various energies

One may notice that the η-distributions are completely scaled in the region of smaller values of η and also found to be independent of mass of incident beam whereas weak energy dependence has been found in this region. The distribution is broader for higher mass as well as beam energy. The height of the centroid increases many times in the case of nucleus-nucleus collisions with respect to the proton-nucleus collisions [6-9].

It is well known that the statistical fluctuations are suppressed in the study of scaled factorial moments (SFMs), whereas, ordinary multiplicity moments $(<n^q>/<n>^q)$ is unable to reveal the existence of dynamical fluctuation due to significant contribution of the purely statistical fluctuations. The SFMs are capable of measuring the large-scale fluctuations and provide information about the pattern of these fluctuations. The cumulative interval of $X(\eta)$ or $X(\phi)$ variable, is successively divided into M = 2-30 bins. Recently, it has been suggested to study the interaction dynamics and sources of the multiplicity fluctuations and power-law scaling behaviour of SFMs in the multi-dimensional $(\eta, \phi.....)$ phase-space. Thus analysis of the data has been performed to check the existence of intermittency signal from one-dimensional η or ϕ variable to the two-dimensional $(\eta\phi)$ variable. One started with a rectangle in $(\eta\phi)$-space. The rectangle was divided into $M_{\eta,\phi}$ bins each of size $(\delta\eta\delta\varphi) = (\Delta\eta/M_\eta)(\Delta\varphi/M_\varphi)$. Fig. 2 (a-c) shows the plots of $\ln<F_q>$ as a function of $\ln M_\eta M_\phi$ in the interactions of ^{28}Si-Em collisions at 14.6A GeV for q = 2-6 for different N_S -intervals. A linear rise of SFMs is seen from the figure and a larger value of α_q is reported in Table I. A stronger intermittency effect is observed in 2D, in comparison with a weak signal observed in one-dimension (1D). Result obtained using UrQMD model is also shown in Fig. 2 (a-c) for comparison, which also follows the similar trend. The individual analysis in pseudorapidity or azimuthal space may not be favourable to detect the existence of quark-gluon plasma. Instead of QGP, intermittent behaviour is observed. The analysis of experimental result in two-dimensions is more effective than the one-dimension in different N_S -intervals. Finally, it may be concluded that the results in nucleus-nucleus interactions with ^{28}Si beam at 14.6A GeV fulfil the predictions of the self-similar cascade model in observing the intermittency.

TABLE I. THE VALUES OF INTERMITTENCY INDICES IN TWO DIMENSIONAL (2D) PHASE SPACES FOR NUCLEAR COLLISIONS AT AN ENERGY 14.6 A GEV/C

Order of Index	Values of Intermittency Indices		
	$8 \le N_S \le 15$	$8 \le N_S \le 15$	$N_S \ge 24$
α_2	0.175±0.010	0.155±0.013	0.195±0.012
α_3	0.395±0.011	0.295±0.012	0.425±0.017
α_4	0.689±0.014	0.578±0.013	0.798±0.032
α_5	1.183±0.018	1.091±0.027	1.257±0.039
α_6	1.767±0.025	1.356±0.034	1.953±0.051



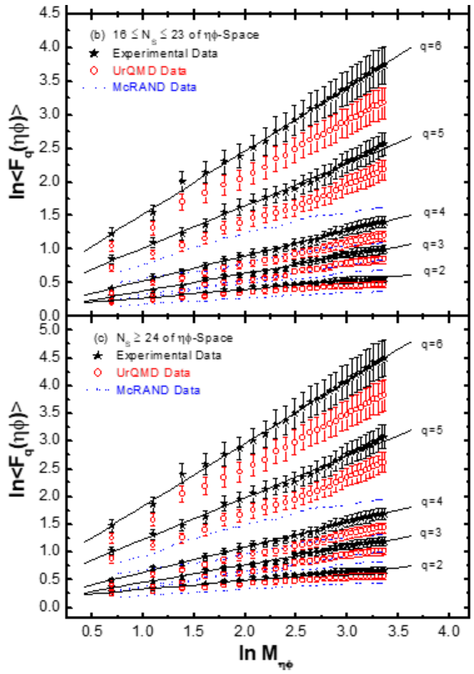


Figure 2. The Variations of $\ln\langle F_q(\eta\phi)\rangle$ as a function of $\ln M_{\eta\phi}$ in $\eta\phi$-phase space for different N_S -intervals in the interactions of ^{28}Si-Em with UrQMD and MC-RAND model

The error bars in Figs. 2 (a-c) are estimated by considering them as independent statistical errors only and the solid lines drawn indicate the least squares fit to the respective experimental data points. Though the effect of point-to-point correlations of the statistical errors for different bin sizes has not been taken into consideration in the present study, it is expected that the exclusion of the correlation of the statistical errors will not change the main result appreciably. For better understanding of intermittency indices, α_q , it has been calculated using least square fitting of the data points in Figs. 2 (a-c). The values obtained experimentally in different N_S -intervals are reported in Table I in $\eta\phi$ -phase (2D) space respectively. It is observed from the table that the exponent, α_q , in Eqn. (1) increases with increasing order of moments, q, for different sets of data samples in 2-D phase space.

The values of α_q in are consistently higher for multiplicity interval $N_S \geq 2l$ than rest of another two intervals values in $\eta\phi$ -space (2D). It is also observed that the intermittency effect is not independent of the phase space variable. The intermittency effect is more pronounced in $\eta\phi$ -space (2D) than in one-dimension. The observation of experimental results clearly indicates a stronger intermittency signal in $\eta\phi$ -space. The higher values of α_q in $\eta\phi$ -space is consistent with the interpretation that the increase in factorial moments is due to clusters of particles yielding a correlation between local η and ϕ -fluctuations. However, a constant and small values of α_q are seen for MC generated events.

It has been observed [7-9] that if the dynamics of intermittency is due to self-similar cascading, then there is a possibility of observing a non-thermal phase transition, which is believed to occur during the collision. If such a non-thermal phase transition is present then the function λ_q should have a minimum at certain value of q = q_c, where q_c is some minimum point in the distribution [7-9]. The region with $q < q_c$ is dominated by numerous small fluctuations, whereas the region with $q > q_c$ is due to rarely large fluctuations. 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 variation of λ_q as a function of q for grey and black particles produced in ^{28}Si-Em interactions at 14.6A GeV has been shown in Fig. 3. The result of ^{16}O-AgBr 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 $2 \leq q \leq 6$ as reported by other workers [16,17]. However, a little deviation of the experimental data from the "no intermittency" line (α_q = 0) indicates the presence of a weak intermittency effect in $\cos\theta$ -space for the present data. A weak intermittency effect is found due to intermixing of many subprocesses during multiparticle production of cascade mechanism. Thus it may be concluded that data for grey and black particles do not support a clear evidence for the existence 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.

IV. conclusions and final remarks

With an outlook of the present article entitled "Intermittency Analysis by Mixed Scaled Factorial Moments in the Nuclear Collisions of ^{28}Si + AgBr at 14.6A GeV" describes the study about the dynamics of multiparticle production in nucleus-nucleus collisions. The analysis is based on 951 interactions of ^{28}Si+AgBr collisions at 14.6A GeV using nuclear emulsion. One can conclude the followings from the present article:

The generalized power law behaviour of mixed scaled factorial moments in in two-dimension (2D), $\eta\phi$ phase space reflects an evidence for an intermittency pattern of fluctuations in all the above mentioned interactions at 14.6A GeV for shower particles.The present study also gives a strong evidence of self-similar structure in multiparticle production in such collisions at 14.6A GeV for two-dimensional $\eta\phi$ -phase space. The values of the intermittency indices, α_q , in two dimensional-space show a strong dependence on N_S -multiplicity as well as phase-space dimension.

Some significant results have been obtained for dynamical fluctuations in present work. It is believed that these fluctuations may be a weak signal of QGP formation in such experiment. Further, evidence of these fluctuations has also been observed in low energy nuclear collisions, whereas the formation of QGP is not expected. Even in target fragmentation process, where the QGP phase transition is most unlikely, some physicists have reported evidence of dynamical fluctuations in earlier work.

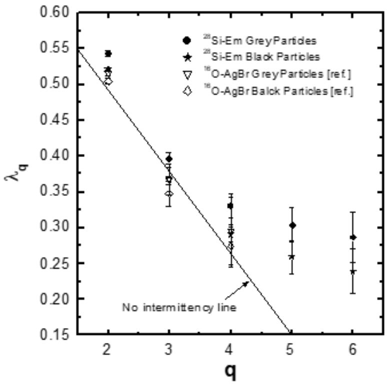


Figure 3. The Dependence of λ_q on the order of moments, q in the collisions of ^{28}Si+AgBr nuclei at 14.6A GeV.

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References

[1] Miklos Gyulassy, "Signatures of new phenomena in ultrarelativistic nuclear collisions." Nuclear Physics A418, 1984, pp. 59-85.

[2] M. Stephanov, K. Rajagopal and E. Shuryak, "Event-by-Event fluctuations in heavy ion collisions and the QCD crititical point." - art. No. 114028. Physical Review D60 (11), 1999, pp. 4028

[3] J. D. Bjorken, "Highly relativistic nucleus-nucleus collisions: The central rapidity region." Physical Review D27, 1983, pp.140-151.

[4] Mir Hashim Rasool, M. Ayaz Ahmad and Shafiq Ahmad. "Signal of Unusual Large Fluctuations in ^{32}S-Em Interactions at SPS Energies." Journal of Korean Physical Society 67 (2015): 448-457.

[5] S. A. Bass et. al., "Microscopic Models for Ultrarelativistic Heavy Ion Collisions." Progress Part. Nuclear Physics 41, 1998, pp. 255-369 arXiv:nucl-th/9803035v2

[6] Shafiq Ahmad and M. Ayaz Ahmad, "A comparative study of multifractal moments in relativistic heavy-ion collisions." Journal of Physics G: Nuclear and Particle Physics 32(9), 2006, pp. 1279-1293.

[7] Shafiq Ahmad, M. Ayaz Ahmad, M. Irfan and M. Zafar, "Study of non-statistical fluctuations in relativistic nuclear collisions." Journal of the Physical Society of Japan, Vol. 75(6), 2006, pp. 064604(1-9).

[8] Shafiq Ahmad and M. Ayaz Ahmad, "Some observations related to intermittency and multifractality in ^{28}Si and ^{12}C-nucleus collisiond at 4.5A GeV." Nuclear Physics A780, 2006, pp. 206-221.

[9] M. Ayaz Ahmad, "A Study of Intermittency and Multifractality in ^{28}Si-emulsion Collisions at 14.6A GeV." [Ph.D. thesis], Aligarh Muslim University, Aligarh, Indiat, 2010.

[10] Mir Hashim Rasool, M. Ayaz Ahmad, Muzamil Ahmad Bhat and Shafiq Ahmad, "Study of compound particle production in ^{28}Si and ^{32}S-emulsion collisions at 14.6 and 200 A GeV." World Journal of Nuclear Science and Technology 5 (2015): 208-220.

[11] M. Tariq, M. Ayaz Ahmad, Shafiq Ahmad and M. Zafar. "Analysis of high N_S-multiplicity events produced in relativistic heavy ion collisions at 4.5A GeV/c." Romanian Reports in Physics Vol. 59(3), 2007, pp. 773-790.

[12] Mir. Hashim Rasool, M. Ayaz Ahmad, Omver Singh and Shafiq Ahmad, "Some inportant features of relativistic charged particles produced in 32S-Emulsion interactions at 200A GeV/c." Journal of Modern Physics 6, 2015, pp.1498-1509 DOI:10.4236/jmp.2015.611154

[13] M. Ayaz Ahmad, Mir Hashim Rasool, Shafiq Ahmad, Jamal H. Madani and Rachid Ayad' "Study of Deconfinement Phase Transition in Heavy Ion Collisions at BNL Energies." International Journal of Applied Physics and Mathematics, (IJAPM) 4, 2013, pp. 289-292. DOI: 10.7763/IJAPM.2013.V3.223

[14] M. Ayaz Ahmad, Mir Hashim Rasool and Shafiq Ahmad. "Scaling nature of target fragments in the interactions of ^{28}Siemulsion at energy 14.6A GeV." Ukrainian Journal of Physics. 58(10), 2013, pp. 944-955

[15] M. Ayaz Ahmad and Shafiq Ahmad. "Study of Angular Distribution and KNO Scaling in the Collisions of ^{28}Si with Emulsion Nuclei at 14.6A GeV." Ukrainian Journal of Physics. 57(12) (2012): 1205-1213.

[16] Mir H. Rasool, M. Ayaz Ahmad, Shafiq Ahmad, "Multifractal study and multifractal specific heat of singly charged particles produced in ^{32}S-Em interactions at 200A GeV." Chaos Solitons & Fractal Vol. 81, 2015, pp. 197-202. DOI:10.1016/j.chaos.2015.08.027

[17] Mir Hashim Rasool, M. Ayaz Ahmad, Omveer Singh, Shafiq Ahmad. "Multiplicities of Forward -Backward Relativistic Charged Particles Produced in ^{32}S-Emulsion Interactions at 200 A GeV/c." Chinese Journal of Physics- Taipei- 53(5), 2015, pp. 100302-1-11.