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Strong pionic intermittency in 'cold' events in ^{12}C–AgBr interactions at 4.5 A GeV

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Abstract. In this paper intermittent behaviour of the pions from 'cold' and 'hot' classes of events from ^{12}C–AgBr interactions at 4.5 A GeV has been studied, separately. The results reveal strong intermittent pattern in case of 'cold' class of events.

Keywords. Pion production; 'hot' and 'cold' class of events; intermittency.

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1. Introduction

Bialas and Peschanski [1] showed the power-law dependence of the normalized scaled factorial moments on the considered phase-space bin width. This is known as intermittency that reveals the self-similar behaviour in multiparticle production process. Intermittency analysis was first applied to the pseudorapidity distribution of a single very-high-multiplicity cosmic ray event recorded in the Japanese–American Cooperative Emulsion Experiment [2]. They found indication of intermittent behaviour. This method actually measures the dynamical fluctuation present in a particle distribution. It was proved [1] that the factorial moments averaged over many events are equal to the moments of a true probability distribution of particle density without any statistical noise. Numerous experimental investigations in the framework of factorial moments during the last few years have revealed intermittent patterns in different types of interactions, e.g. hadron–hadron [3], hadron–nucleus [4], nucleus–nucleus [4–6], lepton–hadron [7], e^+e^- [8–10] interactions etc. The reason behind such a tremendous enthusiasm in self-similarity study is the failure of the existing multiparticle production models to explain this phenomenon. The power-law behaviour of the scaled factorial moments provides evidence for a self-similar cascading process of dynamical origin. Though the dynamical origin of such fluctuations is very controversial [11], and the quest for root of intermittent behaviour is still in its infancy, it is important, at this stage, to look into the problem from different angles.

Exhaustive data analysis on α-particles produced as projectile fragments from ^{56}Fe–emulsion interactions at 0.9 A GeV [12], 1.7 A GeV [13], 1.9 A GeV [14] and ^{40}Ar–emulsion interactions at 2.0 A GeV [12] shows that the transverse momentum spectrum is characterized by two distinctly different temperatures, a 'hot' (40–60 MeV) and a 'cold' (8–10 MeV) with different reaction mechanisms. Earlier work by Ghosh *et al* [15] with relativistic α-particles emitted as projectile fragments in the ^{12}C–emulsion interactions at 4.5 A GeV has also revealed that the projectile fragmentation region is characterized by two distinctly different temperatures, 10 MeV and 40 MeV, with different reaction mechanisms, i.e., there exist two different classes of events with these two temperatures. Some works on the two classes of events from ^{12}C–AgBr interactions at 4.5 A GeV have already been reported [15–24]. In this article, we have studied the intermittent behaviour of pions in ^{12}C–AgBr interactions at 4.5 A GeV and compared the result with the whole of ^{12}C–AgBr interactions at 4.5 A GeV [16], which will ultimately indicate whether pion production processes in 'cold' and 'hot' events are different or not. The method of separation of events from ^{12}C–AgBr inelastic interactions into 'hot' and 'cold' events is stated in §3.

2. Experimental data

The required data are obtained from stacks of NIKFIBR2 emulsion plates (25 cm $\times$ 10 cm $\times$ 600 μm) irradiated horizontally to ^{12}C beam at 4.5 A GeV from the JINR synchrophasotron.

Details of data and measurement are given in our early papers [15,17,18]. Primary inelastic events of ^{12}C–AgBr interactions at 4.5 A GeV have been investigated. We have classified the charged secondary particles as black (b), grey (g) and shower (s) particles following the usual nuclear-emulsion methodology:

(1) s-Particles denote relativistic charged particles of relative ionization $I/I_0 < 1.4$ (corresponding to proton energy $T_\mathrm{p} > 400$ MeV), where I_0 is the plateau grain density for singly charged particles.
(2) g-Particles denote particles with relative ionization $I/I_0 > 1.4$ and range in the emulsion $R > 3000$ μm (corresponding to proton energy 26 MeV $< T_\mathrm{p} <$ 400 MeV).
(3) b-Particles denote particles with the range $R < 3000$ μm.
(4) Projectile fragments denote the particles with emission angles $< 3^\circ$, $I \approx I_0$ and range in the emulsion $R = 2$ cm.

The pseudorapidity (η) values of the s-particles (shower tracks) are calculated from the emission angles (θ) of the tracks with the help of the relation

$$\eta = -\ln\left(\tan\frac{\theta}{2}\right). \tag{1}$$

3. Separation of hot and cold events

The separation of 'cold' and 'hot' events is done following Baumgardt *et al* [14]. The transverse momentum of these α-particles was calculated from the relation

$$P_{\mathrm{T}} = \left[\frac{Am_0 v}{(1-\beta^2)^{1/2}}\right]\sin\theta, \tag{2}$$

where A is the atomic number, m_0 is the nucleon rest mass, v is the velocity of α-particle, $1/(1-\beta^2)$ is the Lorentz factor of the projectile fragment and θ is the emission angle of α-particle with the incident beam. Assuming the momentum distribution (P_{T}) to be a Maxwell–Boltzmann (M–B) distribution in the projectile rest frame at some temperature T, the integral frequency distribution of P_{T} per nucleon squared, $Q = (P_{\mathrm{T}}/A)^2$, is

$$\ln F(>Q) = -\frac{AQ}{2m_0 T}. \tag{3}$$

A cumulative plot of $\ln F(>Q)$ as a function of Q shows a non-linear distribution. It is interpreted as a mixture of two Maxwell–Boltzmann distribution components with two distinct temperatures: one is 40 MeV (the 'hot' group) and the other is 10 MeV (the 'cold' group). Details are given in our earlier work [15].

4. Methodology

The scaled factorial moment F_q of order q is defined for a fixed multiplicity event and for a particular portion of an overall rapidity interval Δy divided into M bins of width $\delta y = \Delta y/M$ as

$$F_q = \frac{1}{M}\sum_{m=1}^{M}\left[M^q \frac{k_m(k_m-1)\cdots(k_m-q+1)}{N(N-1)\cdots(N-q+1)}\right]. \tag{4}$$

For events with varying multiplicity, the normalized scaled factorial moment of order q is given by

$$F_q = \frac{M^{q-1}}{\langle N\rangle^q}\sum_{m=1}^{M}[k_m(k_m-1)\cdots(k_m-q+1)], \tag{5}$$

where k_m is the multiplicity of the mth bin, $\langle N\rangle$ is the average multiplicity of the data sample in the region Δy. Scaled factorial moments of order q of the events are averaged to obtain $\langle F_q\rangle$.

It is a fact that the factorial moments F_q averaged over many events are equal to the moments of a true probability distribution of the particle density in rapidity space [1]. Thus the problem of statistical fluctuation arising due to a finite number of particles per event, is reduced.

Intermittent behaviour of multiplicity fluctuation is provided by a power-like dependence of factorial moments on the bin width δ, as $\delta \to 0$,

$$\langle F_q \rangle = \left(\frac{\Delta}{\delta}\right)^{\alpha_q}. \tag{6}$$

The exponent α_q is the slope characterizing the linear rise of $\ln\langle F_q\rangle$ vs. $-\ln\delta$. The strength of intermittency is characterized by this exponent α_q.

We get from eq. (3),

$$\ln(F_q) = A - \alpha_q \ln(\delta\eta). \tag{7}$$

Errors in F_q's have been calculated from the dispersion of event-wise factorial moments. The anomalous fractal dimension d_q is given by

$$d_q = \frac{\alpha_q}{q-1}. \tag{8}$$

The generalized dimension is given by

$$D_q = 1 - d_q. \tag{9}$$

5. Results and discussion

The present analysis has been done using $\ln\delta\eta$ as the basic parameter, where η is the pseudorapidity defined in (1). We have studied the entire pseudorapidity region

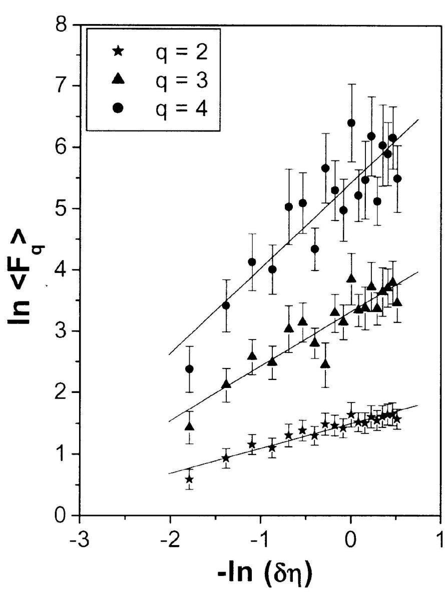

Figure 1. Plot of $\ln\langle F_q\rangle$ vs. $-\ln(\delta\eta)$ for 'cold' events from ^{12}C–AgBr interactions at 4.5 A GeV.

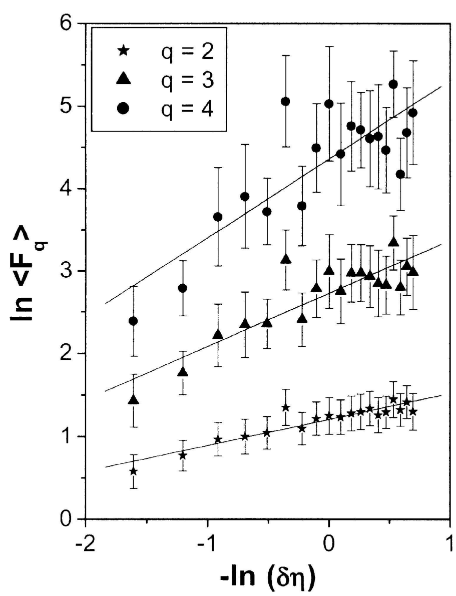

Figure 2. Plot of $\ln\langle F_q\rangle$ vs.] $-\ln(\delta\eta)$ for 'hot' events from ^{12}C–AgBr interactions at 4.5 A GeV.

Table 1. Values of α_q, χ^2/dof, d_q, D_q for 'cold' and 'hot' events from ^{12}C–AgBr interactions at 4.5 A GeV for the order of moments $q = 2, 3, 4$.

Order of moment	'Cold' events				'Hot' events			
(q)	α_q	χ^2/dof	d_q	D_q	α_q	χ^2/dof	d_q	D_q
2	0.40 ± 0.03	0.30	0.40 ± 0.02	0.60 ± 0.15	0.30 ± 0.03	0.17	0.30 ± 0.02	0.7 ± 0.02
3	0.89 ± 0.10	0.53	0.45 ± 0.05	0.55 ± 0.05	0.64 ± 0.08	0.44	0.32 ± 0.04	0.68 ± 0.04
4	1.39 ± 0.17	0.97	0.46 ± 0.09	0.44 ± 0.09	0.96 ± 0.15	0.77	0.32 ± 0.08	0.8 ± 0.08

Table 2. Values of order of moments (q) and confidence level based on χ^2 for pions from 'hot' and 'cold' events of ^{12}C–AgBr interactions at 4.5 A GeV.

	Confidence level based on χ^2	
Order of moment (q)	'Cold' events	'Hot' events
2	>99%	>99%
3	90–95%	95–98%
4	30–50%	50–70%

for both classes of events. M varies from 2 to 20. With the above specification, average scaled factorial moments of order 2, 3, 4 have been calculated separately for the 'cold' and 'hot' events. Figures 1 and 2 represent the variation of the moments on the bin size for 'cold' and 'hot' classes of events, respectively. The standard statistical errors are shown by the vertical lines in the graphs.

From the slopes of the lines of figures 1 and 2 we get α_q's for the respective cases with the help of (7). Anomalous fractal dimensions (d_q) and generalized dimensions (D_q) are obtained with the help of relations (8) and (9) respectively. Values of α_q, χ^2, d_q and D_q for 'cold' events and 'hot' events are given in table 1. Confidence level based on χ^2 is given table 2.

Intermittency exponents of the whole sample of ^{12}C–AgBr interactions at 4.5 A GeV [16] are given in table 3. Comparing the intermittency exponent of the whole sample of ^{12}C–AgBr interactions at 4.5 A GeV (table 3) with those of 'hot' and 'cold' events from ^{12}C–AgBr interactions at 4.5 A GeV (table 2) we observe that intermittency exponent is least for the whole sample at every value of q, expect at $q = 4$ of 'hot' events.

From table 1 we observe that the strength of intermittency of 'cold' events is stronger than that of 'hot' events for a fixed value of q.

Ghosh *et al*, in [19], determined D_q's of pions from 'hot' and 'cold' events obtained from the same data of ^{12}C–AgBr interactions at 4.5 A GeV by Takagi moments method, which are different from those obtained in the present work. The quantitative disagreement in the values of D_q's is due to the different approaches for determination of the generalized dimension (D_q).

It is extremely interesting to observe that the degree of intermittency of 'cold' class of events is stronger than that of 'hot' class of events for a fixed value of q, indicating that the produced pions in 'hot' events are more chaotic than those in 'cold' events.

Table 3. Values of intermittency exponents (α_q) of pions from whole sample of ^{12}C–AgBr interactions at 4.5 A GeV.

Type of interaction	Energy of projectile	Intermittency exponent (α_q)		
		$q = 2$	$q = 3$	$q = 4$
^{12}C–AgBr	4.5 A GeV	0.12 ± 0.01	0.45 ± 0.06	0.97 ± 0.13

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