Intermittent type fluctuation of target fragments produced in ^{16}O-AgBr interactions at 4.5 AGeV/c*

LI Jun-Sheng(李俊生)[1,2;1)] ZHANG Dong-Hai(张东海)[1] LIU Fu-Hu(刘福虎)[2]

1 (Institute of Modern Physics, Shanxi Normal University, Linfen 041004, China)
2 (Institute of Theoretical Physics, Shanxi University, Taiyuan 030006, China)

Abstract A study of intermittency of target associated fragments produced in the interactions of ^{16}O-AgBr at 4.5 AGeV/c with nuclear emulsion using the method of factorial moments, F_q, has been performed. The dependence of the moments on the number of bins M is found to follow a power law behavior for the experimental data in terms of new scaled variable $\chi(z)$ suggested by Bialas and Gazdzicki. The anomalous dimensions, d_q, increase linearly with the order of moments, q. This observation indicates the association of multifractility with production mechanism of target associated fragments.

Key words intermittency, target associated fragments, nuclear emulsion, factorial moments, anomalous dimensions

PACS 24.60.Ky, 25.70.Mn, 25.75.-q

1 Introduction

Fluctuation is a general characteristic of the spatial distribution of secondary charged particles emitted from high energy nucleus-nucleus collisions. Fluctuation of the produced particles in high energy nucleus-nucleus collisions includes statistical fluctuation and non-statistical fluctuation, and the latter one relates with the underlying mechanism responsible for particle production and may also indicate a phase transition. To extract non-statistical fluctuations after eliminating the statistical part through the analysis of the distribution of produced particles from a cosmic ray event by JACEE Collaboration[1], a power growth of the scaled factorial moments(SFM) with decreasing phase space bin size has been proposed by Bialas and Peschanski[2], which was made in analogy with the phenomenon known as intermittency in the hydrodynamics of turbulent fluid flow. Also, the anomalous scaling of factorial moments with phase space bin size is known as intermittency. The power law behavior of SFM is related with the self similarity and fractal properties of the underlying production processes.

So far, the intermittency phenomenon has been observed in various experiments, such as the electron-positron annihilation[3—6], the hadron-hadron[7—11], the hadron-nucleus[12, 13], and the nucleus-nucleus collisions[14—34]. It seems that the intermittency may be a general property of multiparticle production. However, a definite conclusion about the origin of intermittency is not given at present. To arrive at it, more and more data analyses are necessary.

It is interesting to note that most of these analyses have been performed on the studies of pions and little attention has been paid to the analysis of the target fragments. But the target fragmentation process may also take important information for the forces and dynamics during and immediately after nuclear impact. The evaporation model predicts an isotropic emission of target fragments in the laboratory system. But the isotropic emission of target fragments is not supported by different work[25, 33]. So the target fragmentation process should be studied by the available tools to explore the underlying mechanism in the process.

Received 29 July 2007

* Supported by National Natural Science Foundation of China (10675077, 10475054), Shanxi Provincial Natural Science Foundation (2007011005) and Shanxi Provincial Science Foundation for Youths (20051002)

1) E-mail: lijs@dns.sxnu.edu.cn

Nuclear emulsion covers 4π geometry and provides very good accuracy in the angle measurements of produced particles and fragments due to high spatial resolution and thus is suitable as a detector for the study of fluctuations in the fine resolution interval of the considered phase space.

In this work, the variation of SFM with the bin size in target fragmentation of ^{16}O-AgBr interactions at 4.5 AGeV/c in emission angle space is investigated. It is a further investigation of our previous work[35].

2 Experimental details

Stacks of NIKFI BR-2 nuclear emulsion plates horizontally exposed to the 4.5 AGeV/c ^{16}O beam at Synchro-phasotron of the Joint Institute of Nuclear Research(JINR), Dubna, are used in this work. The flux intensity is 10^3 particles/cm^2. The scanning of the plates, 600 μm in thickness, is performed by the along-the-track method using XSJ-1 and XSJ-2 microscopes under 100× oil immersion objectives and 16× eyepieces.

According to the standard emulsion terminology, all the tracks of the emitted secondary charged particles in each collision are classified into the following types:

(a) Shower tracks, which are single-charged relativistic particles having relative velocity $\beta = v/c \geqslant 0.7$ and with ionization less than $1.4I_0$ (I_0 is the minimum ionization). Most of these tracks belong to pions contaminated with small proportions of fast protons and K mesons. Their multiplicity is denoted by n_s.

(b) Grey tracks, which are mainly from protons having velocity $0.3 \leqslant \beta \leqslant 0.7$ and range >3 mm. Their multiplicity is denoted by n_g.

(c) Black tracks, which are the fragments emitted from the excited target nuclei. The energy of a black track is less than 30 MeV and the range is less than 3 mm in emulsion. Their multiplicity is denoted by n_b.

(d) Projectle fragments, which are the noninteracting projectile fragments with an emission angle $\theta \leqslant p_{\rm f}/p_{\rm beam}$ ($p_{\rm beam}$ stands for the beam momentum and $p_{\rm f}$ for the Fermi momentum of the nucleon; the latter is estimated to be 200 MeV/c) with respect to the incident direction and characterized by no change in its ionization for at least 2 cm from the interaction point. Their multiplicity is denoted by n_f.

The grey and black tracks together are called heavy ionizing particles. Their multiplicity is denoted by $n_h = n_g + n_b$. The total number of heavy tracks in an event can be used to decide the type of the target nucleus, e.g., a criterion of $n_h > 8$ will ensure an interaction with AgBr. Using this criterion, 848 events were chosen for analysis as ^{16}O-AgBr interactions in this work. Further detail of the experiment may be found in Refs. [36—40].

3 Method of analysis

The intermittency phenomenon is expressed as the power law behavior of SFMs with decreasing phase space bin size. To avoid the influence on the scaling behavior of SFMs from the non-uniformity of particle spectra, Bialas and Gazdzicki[41] proposed a method to construct a set of variables which drastically reduces the distortion of intermittency due to non-uniformity of single particle density distribution. The new scaled variable $\chi(z)$ related to the single particle density distribution $\rho(z)$ as,

$$\chi(z) = \frac{\int_{z_1}^{z} \rho(z)\mathrm{d}z}{\int_{z_1}^{z_2} \rho(z)\mathrm{d}z} \tag{1}$$

where z_1 and z_2 are the two extreme points of the distribution. The variable $\chi(z)$ varies between 0.0 to 1.0 keeping $\rho(\chi)$ almost constant. In $\cos\theta$ space the values of z_1 and z_2 are -1 and 1, respectively.

The qth-order normalized scaled factorial moments are given by

$$\langle F_q \rangle = \left\langle M^{q-1} \sum_{m=1}^{M} \frac{n_{\rm jm}(n_{\rm jm}-1)\cdots(n_{\rm jm}-q+1)}{\langle N \rangle^q} \right\rangle, \tag{2}$$

Here, $\langle N \rangle = \left\langle \frac{1}{M} \sum_{m=1}^{M} n_{\rm jm} \right\rangle$; M is the number of bins (the full $\chi(z)$ range is divided into M bins of size $\delta\chi(z) = \Delta\chi(z)/M$); $n_{\rm jm}$ is the multiplicity of grey or tracks in the mth bin of the jth event; The average $\langle \cdots \rangle$ is over all the events in the sample.

It has been shown[2] that the values of $\langle F_q \rangle$ for purely statistical fluctuation saturate with decreasing phase space size, whereas in dynamical fluctuation, the values of $\langle F_q \rangle$ are supposed to increase with decreasing phase space size and exhibit a power law behaviour of SFMs, which is given by

$$\langle F_q \rangle \propto M^{\alpha_q} , \tag{3}$$

The exponent, α_q, which increases with increasing order q of the moment for the existing dynamical fluctuation, is the slope characterizing a linear rise of $\ln\langle F_q \rangle$ with $\ln M$ for all number of bins. The strength of intermittency is characterized by this exponent. To obtain it, a linear fit of the form,

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

is performed, where a is a constant.

From this intermittency exponent, α_q, one can calculate the anomalous fractal dimension which obeys the relation[42]

$$d_q = \frac{\alpha_q}{q-1} \tag{5}$$

4 Results

To probe the intermittent pattern the SFMs for the varying values of M from 2 to 26 in emission angle space are calculated. The variation of $\ln\langle F_q\rangle$ against $\ln M$ for different orders ($q=2,3,4$) for black particles and grey particles produced in the interaction of ^{16}O-AgBr at 4.5 AGeV/c is shown in Fig. 1 and Fig. 2, respectively.

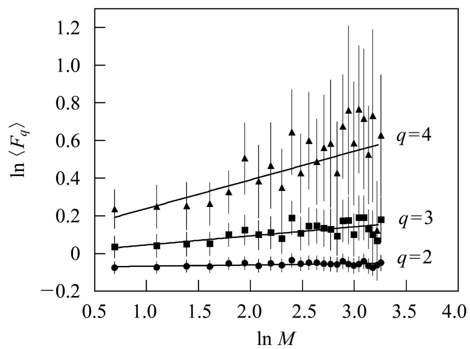

Fig. 1. Variation of $\ln\langle F_q\rangle$ vs $\ln M$ for black particles in the interactions of ^{16}O-AgBr at 4.5 AGeV/c.

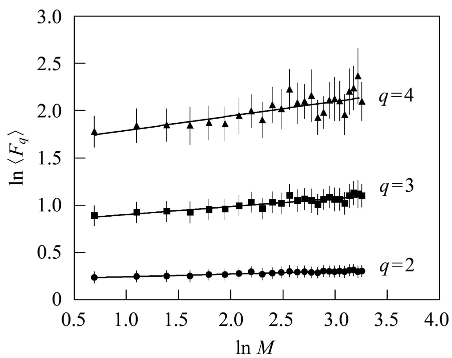

Fig. 2. Variation of $\ln\langle F_q\rangle$ vs $\ln M$ for grey particles in the interactions of ^{16}O-AgBr at 4.5 AGeV/c.

It is evident from the figures that the values of $\ln\langle F_q\rangle$ increase with increasing $\ln M$ (i.e. decreasing bin size). The linear rise in the values of $\ln\langle F_q\rangle$ with $\ln M$ indicates the power law behaviour, which clearly suggests that an intermittent behaviour is observed both for grey particles and for black particles.

The values of the intermittency exponent, α_q, from the best fitted lines of Fig. 1 and Fig. 2 are listed in Table 1. It is observed that the parameter increases with the increasing order of the moments. The values of d_q for grey particles and black particles are also listed in Table 1 and plotted in Fig. 3. Fig. 3 shows that the magnitude of the anomalous fractal dimension increases approximately linearly with the increase of the order of the moments. This indicates multifractality of the emission spectra of target fragments. This phenomenon is also reported for the interactions of ^{32}S-AgBr at 200 AGeV, ^{16}O-AgBr at 60 AGeV and 2.1 AGeV, ^{28}Si-AgBr at 14.5 AGeV[33], ^{84}Kr-AgBr at 0.95 AGeV[34].

Table 1. The values of α_q and d_q for target associated fragments in ^{16}O-AgBr interactions at 4.5 AGeV/c.

q	grey particles		black particles	
	α_q	d_q	α_q	d_q
2	0.029±0.018	0.029±0.018	0.007±0.010	0.007±0.010
3	0.085±0.033	0.043±0.017	0.048±0.023	0.024±0.012
4	0.154±0.055	0.051±0.019	0.154±0.050	0.051±0.017

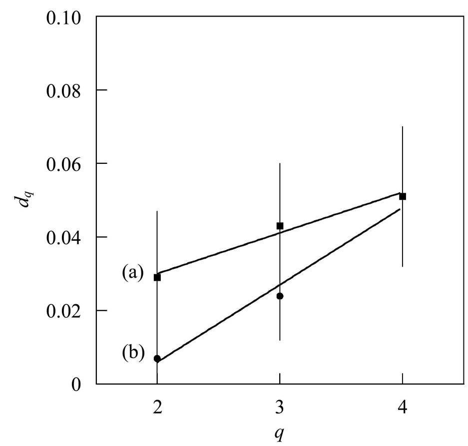

Fig. 3. Variation of d_q versus q for (a) grey particles and (b) black particles in the interactions of ^{16}O-AgBr at 4.5 AGeV/c.

5 Conclutions

A significant statistical study of 4.5 AGeV ^{16}O-AgBr interactions in nuclear emulsion has been carried out. From the present study, it may be concluded that the intermittent behaviour is observed both for grey particles and black particles in the considered reactions for the $\cos\theta$ phase space. The observed increase in the scaled factorial moments with decreasing bin size clearly contradicts the evaporation model. The anomalous fractal dimension increases with the increase of the order of the scaled factorial moment, thereby indicating multifractal geometry of the emission spectra of target fragments. This analysis will be useful to understand the emission of target fragments, especially the emission of black particles.

References

1 Burnett T H, Dake S, Fuki M et al. Phys. Rev. Lett., 1983, **50**(26): 2062
2 Bialas A, Peschanski R. Nucl. Phys. B, 1986, **273**(3-4): 703; 1988, **308**(4): 857
3 Buschbeck B, Lipa R, Peschanski R. Phys. Lett. B, 1988, **215**(4): 788
4 Abreu P, Adam W, Adami F et al. (DELPHI Collaboration). Phys. Lett. B, 1990, **247**(1): 137
5 Braunschweig W, Gerhards R, Kirschfink F J et al. (TASSO Collaboration). Phys. Lett. B, 1989, **231**(4): 548
6 Gustafson G, Sjögren C. Phys. Lett. B, 1990, **248**(3-4): 430
7 Ajinenko I V, Belokopytov Yu A, Böttcher H et al. (NA22 Collaboration). Phys. Lett. B, 1989, **222**(2): 306; Ajinenko I V, Belokopytov Yu A, Böttcher H et al. (NA22 Collaboration). Phys. Lett. B, 1990, **235**(3-4): 373
8 Albajar C, Albrow M G, Allkofer O C et al. (UAI Collaboration). Nucl. Phys. B, 1990, **345**(1): 1
9 Alner G J, Alpgard K, Ansorge R E et al. Phys. Rep., 1987, **154**(5): 247
10 Adamus M, Ajinenko I V, Amato S F et al. Phys. Lett. B, 1987, **185**(1): 200
11 Agababyan N M, Atayan M R, Chen G et al. (NA22 Colaboration). Phys. Lett. B, 1996, **382**(3): 305; 1998, **431**(3-4): 451
12 Holynski R, Jurak A, Olszewski A et al. Phys. Rev. Lett., 1989, **62**(7): 733
13 Holynski R, Jurak A, Olszewski A et al. (KLM Collaboration). Phys. Rev. C, 1989, **40**(6): R2449
14 Adamovich M I, Aggarwal M M, Arora R et al. (EMU01 Collaboration). Phys. Lett. B, 1988, **201**(3): 397
15 Sengupta K, Jain P L, Singh G et al. Phys. Lett. B, 1990, **236**(2): 219
16 Adamovich M I, Aggarwal M M, Alexandrov Y A et al. Phys. Rev. Lett., 1990, **65**(4): 412—415
17 Åkesson T, Almehed S, Angelis A L S et al. (HELLOS Emulsion Collaboration). Phys. Lett. B, 1990, **252**(2): 303
18 Ghosh D, Ghosh P, Deb A et al. Phys. Lett. B, 1991, **272**(1-2): 5—10
19 Ghosh D, Ghosh P, Roychowdhury J et al. Phys. Rev. C, 1993, **47**(3): 1120
20 Jain P L, Shing G. Nucl. Phys. A, 1996, **596**(3-4): 700
21 Smolarleiewicz M M, Kirejczyk M, Sikora B et al. Acta Phys. Pol. B, 2000, **31**(2): 385
22 Janik R A, Beata Z. Acta Physica Polonica B, 1999, **30**: 259
23 Bialas A, Ziaja B. Phys. Lett. B, 1996, **378**(1-4): 319
24 Das G, Shivpuri R K, Soni S K et al. Phys. Rev. C, 1996, **54**(4): 2081
25 Ghosh D et al. J. Phys. G: Nucl. Phys., 1994, **20**(1): 1077; 2003, **29**: 983; 2003, **29**: 2087
26 Ghosh D, Ghosh P, Ghosh A. Phys. Rev. C, 1994, **49**(4): R1747
27 Ahmad S, Ayaz Ahmad M. Nucl. Phys. A, 2006, **780**: 206
28 Hasan R, Saiful Islam, Mohib-ul Haq M. Chaos, Solitons and Fractals, 2005, **25**: 1029
29 Ahmad S, Ayaz Ahmad M. J. Phys. G: Nucl. Part. Phys., 2006, **32**: 1279
30 Ghosh D, Deb A, Lahiri M B et al. Phys. Rev. C, 2004, **70**(5): 054903
31 Ghosh D, Deb A, Chattopadhyay R. Phys. Rev. C, 1998, **58**(6): 3553
32 Ghosh D, Deb A, Mondal M et al. Eur. Phys. J. A, 2002, **14**: 77
33 Ghosh D, Deb A, Bhattacharyya S et al. Int. J. Mod. Phys. E, 2003, **12**(3): 407
34 Bhattacharjee B. Nucl. Phys. A, 2005, **748**(3-4): 641—648
35 LI J S, ZHANG D H. HEP & NP, 2006, **30**(5): 398 (in Chinese)
36 ZHANG D H, SUN H C. HEP & NP, 2001, **25**(7): 651 (in Chinese)
37 WU F J, ZHANG D H, LI J S et al. Chin. Phys., 2004, **13**(5): 646
38 LI J S, ZHANG D H, LI Z Y et al. Chin Phys., 2004, **13**(6): 836
39 ZHANG D H, LI Z Y, LI J S et al. Chin. Phys., 2004, **13**(8): 1239
40 SONG F, ZHANG D H. Chin. Phys., 2005, **14**(5): 942
41 Bialas A, Gazdzicki M. Phys. Lett. B, 1990, **252**: 483
42 Hwa R C. Phys. Rev. D, 1990, **41**(5): 1456