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Proton fluctuation in nuclear collisions at a few GeV–self-similar or self-affine ?

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Abstract : An investigation on experimental data of the medium energy target protons (grey particles) emitted in ^{12}C -AgBr interactions at 4.5 A GeV and in ^{24}Mg-AgBr interactions at 4.5 A GeV reveals that a better power - law behaviour is exhibited in self affine analysis at $H = 0.4$ in carbon beam and at $H = 0.8$ in magnesium beam. This work reveals that the multiplicity fluctuation at this energy is not self similar but self-affine.

Keywords : Nuclear collisions, proton fluctuation

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1. Introduction

To know more about the dynamics of multiparticle production process, a very useful and interesting probe is the investigation of actual non-statistical fluctuation in narrow regions of phase space. Among the various approaches, the formalism of intermittency, which involves computation of normalized scaled factorial moments in different phase space intervals, has created a great deal of interest in recent years. This formalism was first proposed by Bialas and Peschanski in a pioneering work [1] through the analysis of the distribution of produced particles in a cosmic ray event [2]. Subsequent analysis of high energy data of various collision process in the available accelerator energy range, repeated the basic observations and intermittency appears to be a general phenomenon in the multiparticle production process in relativistic high energy interactions.

Most of the intermittency analysis performed so far, is in one-dimension though the actual process is in three-dimension. Even in two-dimensional analyses, the usual process was to divide the corresponding phase space subsequently into sub-cells by shrinking equally in each dimension.

However, the phase space in high energy multiparticle production process is anisotropic[3].

Experimental observations regarding the momentum values also support this idea.

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The fluctuation or scaling properties are expected to be anisotropic as the longitudinal momentum values are large in contrary to small transverse momentum values. Hence, the scaling behaviour should also be different in longitudinal and transverse direction resulting in anisotropic scaling.

A pattern, scaled differently in different directions is called self-affine fractal[4] whereas those scaled similarly in different directions, are called self-similar. The idea can be illustrated diagramatically as follows.

In case of Figure 1(a), the curve is made up of four identical parts all of which seem to be identical to the entire curve. Again

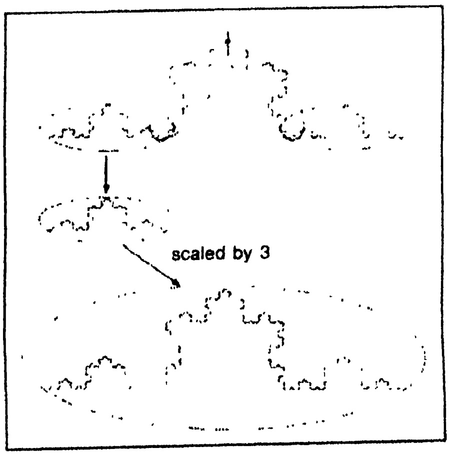

Figure 1. (a)

Hurst component.The following two diagrams (Figure 2) are self-explanatory.

Figure 2(a) shows similar scaling pattern in different directions corresponding to self-similar scaling whereas Figure 2(b) shows different scaling pattern in different directions corresponding to self-affine fractal structure.

We have plotted the natural logarithm of $\left(\delta X_{\varphi}.\delta X_{\cos\theta}\right)$ along X axis and the natural lograrithm of average value of factorial moments (ln<F_2>) along Y axis for ^{12}C - AgBr interactions at 4.5 A GeV and ^{24}Mg - AgBr interactions at 4.5 A GeV for different Hurst exponent values *e.g.* (0.4, 0.6, 0.8); linear behaviour is observed. In order to find the partitioning condition at which the scaling behaviour is best revealed, we have performed linear fit, and have estimated the χ^2 per degrees of freedom (DoF) for each linear fit. Tables 1 and 2 represent the value of χ^2/DoF and the intermittency exponent for ^{12}C-AgBr interactions and ^{24}Mg-AgBr interactions respectively for different values of H.

Table 1. The values of χ^2/DoF and intermittency exponents for particular values of Hurst exponent H in ^{12}C – AgBr interactions at 4 5 AGeV

Value of H	Order	χ^2/ DoF value of ^{12}C -AgBr interactions at 4 5v AGeV	Intermittency exponent (α_q)
	2	0.661	0.481
0.4	3	0.737	1.173
	4	1.019	1.951
	2	0.790	0.537
0.6	3	0.810	1.339
	4	1.046	2.370
	2	0.596	0.537
0.8	3	1.309	1.451
	4	1.736	2.550
	2	0.410	0.536
1.0	3	1.203	1.503
	4	1.571	2.612

It is observed that for ^{12}C-AgBr and ^{24}Mg-AgBr data, best linear fit occurs at H = 0.4 and H=0.8 respectively. Figure.3 and 4 represent the variation of ln<F_2> with ln[$\delta(\cos\theta)\delta\theta$] at H=0.4 for carbon and at H=0.8 for magnesium initiated interactions respectively. This result shows that the anisotropic scaling behaviour is best revealed at H = 0.4 for carbon beam and at H=0.8 for magnesium beam. H<0.4 was not considered since in these cases, number of bins in one of the phase spaces becomes very small and consequently, anisotropy can not be studied. Thus, we can conclude that the emission process of medium energy protons is not self-similar but self-affine. This work

Table 2. The values of χ^2/DoF and intermittency exponents for particular values of Hurst exponent H in ^{24}Mg - AgBr interactions at 4.5 AGeV

Value of H	Order	χ^2/ DoF value of ^{24}Mg - AgBr interactions at 4 5 AGeV	Intermittency exponent (α_q)
	2	2.216	0.447
0.4	3	3.283	1.118
	4	4.062	1.805
	2	1.267	0.504
0.6	3	2.027	1.317
	4	2.795	2.218
	2	0.862	0.498
0.8	3	0.690	1.201
	4	0.523	1.851
	2	0.747	0.487
1.0	3	1.066	1.000
	4		

reports the first ever evidence of self-affine behaviour of medium energy knocked out protons in ultra-relativistic nucleus - nucleus collisions and this information is extremely useful for understanding the emission of this protons.

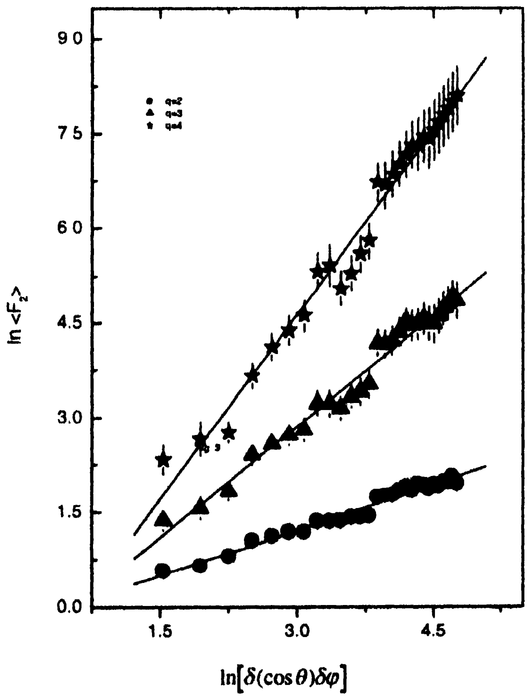

Figure 3. Plot of ln<F_2> *vs.* ln[$\delta(\cos\theta)\delta\varphi$] for H = 0.4 in two dimensional space of $\cos\theta$ and φ for ^{12}C – AgBr interactions at 4.5 AGeV.

Further works with medium energy protons at different energies are essential to ascertain the degree of anisotropy in phase space in different nucleus - nucleus interactions.

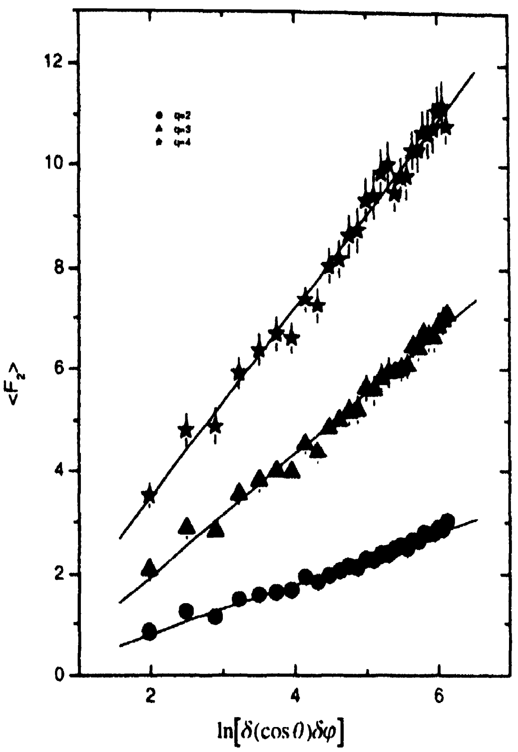

Figure 4. Plot of $\ln<F_2>$ *vs.* $\ln[\delta(\cos\theta)\delta\varphi]$ for $H = 0.4$ in two dimensional space of $\cos\theta$ and φ for ^{24}Mg – AgBr interactions at 4.5 AGeV.

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