FLUCTUATIONS AND INTERMITTENCY IN 200 A GeV $^{16}O+(C, Au)$ REACTIONS

WA80 Collaboration

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Fluctuations in the pseudo-rapidity density of charged particles in $^{16}O+(C, Au)$ reactions at 200 A GeV were analyzed with the method of scaled factorial moments The extracted moments are proportional to a power of the pseudo-rapidity bin size, which is consistent with intermittent behaviour The dependence on target and on impact parameter are studied The fluctuations are stronger for systems with fewer participating nucleons.

Unusually large fluctuations in the rapidity density of charged particles have been observed in hadronic interactions [1]. Several theoretical interpretations for the origin of the large fluctuations have been proposed. It has alternatively been suggested that the fluctuations are: a consequence of a rather violent transition from a quark–gluon plasma back into the hadronic phase [2]; an effect of hadronic Čerenkov radiation [3]; a result of cascading or branching mechanisms [4]; consistent with jet models with scale invariant branching structure [5]. Another interpretation is based on the formation of globs of nonthermal quark–gluon plasma of sizeable parton number density but with very low mean energy per parton [6].

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The method of analyzing particle fluctuations by using scaled factorial moments was proposed and developed in a series of papers by Białas and Peschanski [4]. For the analysis of fluctuations in pseudorapidity, $\eta=-\ln[\tan(\theta/2)]$, the original pseudorapidity interval, $\Delta\eta$, is divided into M smaller bins of size $\delta\eta=\Delta\eta/M$. When events of varying multiplicity are analyzed, the definition of the ith moment is given by [4]

$$F_i=M^{i-1}\sum_{m=1}^{M}\frac{k_m(k_m-1)...(k_m-i+1)}{\langle N\rangle^i}, \qquad (1)$$

where k_m is the number of particles in the mth bin and $\langle N\rangle$ is the multiplicity of particles, $N=\sum_{m=1}^{M}k_m$, in the interval $\Delta\eta$, averaged over the event sample under study. The moments are studied as a function of the bin size $\delta\eta$. Białas and Peschanski showed that if the scaled factorial moments F_i are averaged over many events they are equal to the scaled

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moments, C_i, of the parent probability distribution of particles in phase space, and that the averaged quantities, $\langle F_i \rangle$, do not show any dependence on $\delta\eta$ if the bin size is smaller than the typical range over which the parent rapidity distribution changes appreciably. Dynamical fluctuations, characterized by a given correlation length, saturate the moments if $\delta\eta$ is smaller than this length. Therefore, resonance decays and other known sources which give rise to correlations on rather large scales can be neglected if one studies the moments for sufficiently small $\delta\eta$-values.

Fluctuations which are observed at all rapidity scales and which increase with a decrease in bin size are consistent with intermittent behaviour [4]. The name "intermittency" is borrowed from the phenomenological description of a type of fluctuation in fully-developed turbulent flow of fluids [7]. It can be shown [4] that intermittent behaviour leads to a power-law dependence on $\delta\eta$:

$$\langle F_i \rangle = b_i (\Delta\eta/\delta\eta)^{\phi_i} \tag{2a}$$

or

$$\ln(\langle F_i \rangle) = a_i - \phi_i \ln(\delta\eta) . \tag{2b}$$

In ref. [4], a type of cascade or branching model which leads to intermittent behaviour is discussed. In the limit of a large number of cascade steps the following relation for the slopes of the higher moments to the second moment is derived [4]:

$$\phi_i = \binom{i}{2} \phi_2, \quad i \geqslant 2 . \tag{3}$$

The 200 A GeV oxygen + nucleus data used in the analysis were obtained with the WA80 set-up at the CERN SPS [8]. The multiplicity data were recorded by the large Iarrocci-type streamer-tube detectors with pad read-out [9]. Each such plane has an average detection efficiency for charged particles of 85% and only particles seen in at least two planes were used in the analysis. The η-distribution is studied in the interval $2.4 \leqslant \eta \leqslant 4.0$. The lower cut-off was chosen to exclude the target-fragmentation region and the upper limit is dictated by the geometrical acceptance of the detectors. Within this η-window the average resolution, σ_η, was estimated by Monte Carlo calculations to be $\sigma_\eta = 0.07 \pm 0.01$. In the present analysis the bin size was varied down to $\delta\eta = 0.1$ corresponding to $M = 16$.

We have studied the interactions of 200 A GeV ^{16}O with light and heavy targets, C and Au, in order to study the fluctuations as a function of the size of the reacting system. The forward energy of projectile fragments and produced particles is measured by the Zero-Degree Calorimeter [10], ZDC, for $\eta \geqslant 6.0$ ($\theta \leqslant 0.3°$). This energy can operationally be correlated to the number of participating nucleons or to the impact parameter [11] Two different event classes, corresponding to central collisions and to events of medium centrality, were selected for the C and Au targets, respectively. The cuts on the energy measured in the ZDC, the number of analyzed events, and the average multiplicity of each data sample are presented in table 1.

Monte Carlo calculations were made in order to study the influence of background sources such as resonance decays, gamma conversion and secondary hadronic interactions. 5435 central (15–16 projectile participants) and 3986 more peripheral (7–11 projectile participants) 200 A GeV ^{16}O+Au events were generated with the nucleus–nucleus event simulator Fritiof, version 1.6 [12]. These events were analyzed with the same routines which were employed for the analysis of the WA 80 data after including:

(1) the acceptance, response and granularity of the multiplicity detectors;

(2) photon conversion in the material in front of the detectors, and

(3) hadronic interactions which produce secondary particles in the material in front of the detectors.

Fig. 1 shows the result of these studies. The dependence of $\ln(\langle F_i \rangle)$ on $-\ln(\delta\eta)$ is displayed for the second, third, fourth, fifth and the sixth moments. As can be seen, the simulated detector effects, the produced secondary particles, as well as the decay particles produced by the Fritiof event generator do not

Table 1
Characteristics of the analyzed data sets.

Data set	E_{ZDC} (TeV)	# of events ($\times 10^3$)	Mean multiplicity
^{16}O+C	2.2–2.4	38	23.0±0.1
^{16}O+C	≤1.7	114	45.5 ±0.1
^{16}O+Au	1.0–1.8	31	61.1±0.4
^{16}O+Au	≤0.4	92	117.9±0.7

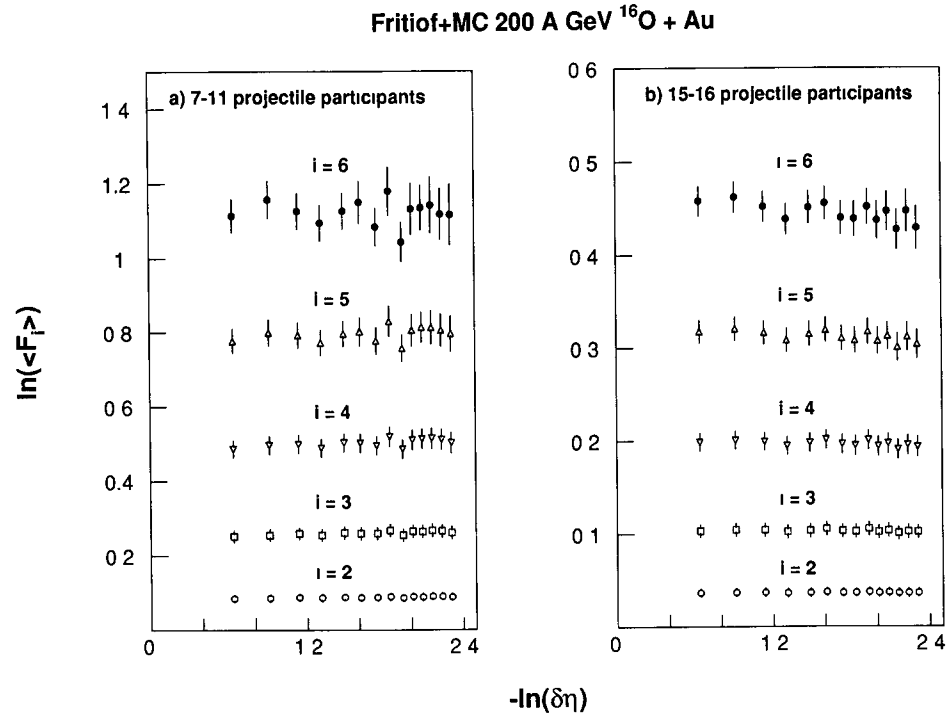

Fig 1 Scaled factorial moments as a function of bin size, $\delta\eta$, for 200 A GeV ^{16}O+Au events simulated with Fritiof 1.6, filtered by a Monte Carlo algorithm which simulates detector effects and secondary interactions. (a) shows the result for 7–11 projectile participants and (b) shows central events with 15–16 projectile participants.

result in any appreciable $\delta\eta$ dependence for the moments. The displayed error for fixed M and i represents the dispersion of the logarithm of the average moment. If we denote the dispersion in the average moment as $\delta(\langle F_i\rangle)$, then the error in $\ln(\langle F_i\rangle)$ is calculated as $\delta(\langle F_i\rangle)/\langle F_i\rangle$ according to ordinary error propagation. Since the same data is used to calculate $\ln(\langle F_i\rangle)$ for each M, the errors do not reflect the interdependence of the different points.

In figs. 2a, 2b the results for the central and medium 200 A GeV ^{16}O+Au events are displayed. The logarithm of the moments depends linearly on the logarithm of the bin size. The rise is stronger for the more peripheral events than for the central events. A similar result is obtained for the 200 A GeV ^{16}O+C data, as can be seen in figs. 3a and 3b. The slopes of the central carbon data, with a number of target and projectile participants of approximately 20–25, are steeper than the slopes for the more peripheral gold data which correspond to events with about 30–40 participants. We can hence conclude that the effect decreases with increasing number of participating nucleons. The slopes of the fitted lines for each data set are summarized in table 2. The errors in the slopes are calculated under the assumption that all the data points are independent.

In fig. 4 we examine the relations between the extracted slopes. We show the quantity $2\phi_i/i(i-1)$ as a function of the order of the moment which should be constant if eq. (3) is valid. The extracted slopes give rise to slightly decreasing values for all of the systems studied.

The NA22 Collaboration [13] (250 GeV/c π^+p and K$^+$p interactions) and the KLM Collaboration [14] (p+Em at 200 and 800 GeV and ^{16}O+Em at 60 and 200 A GeV) have shown data with a general trend towards a stronger effect, i.e. the extracted slopes are larger, for smaller interacting systems. Recently, e$^+$e$^-$ data at $\sqrt{s}=22$ GeV were reanalyzed by fitting negative binomial distributions to the multiplicity distributions in different rapidity bins and relating the aggregation parameter to the factorial mo-

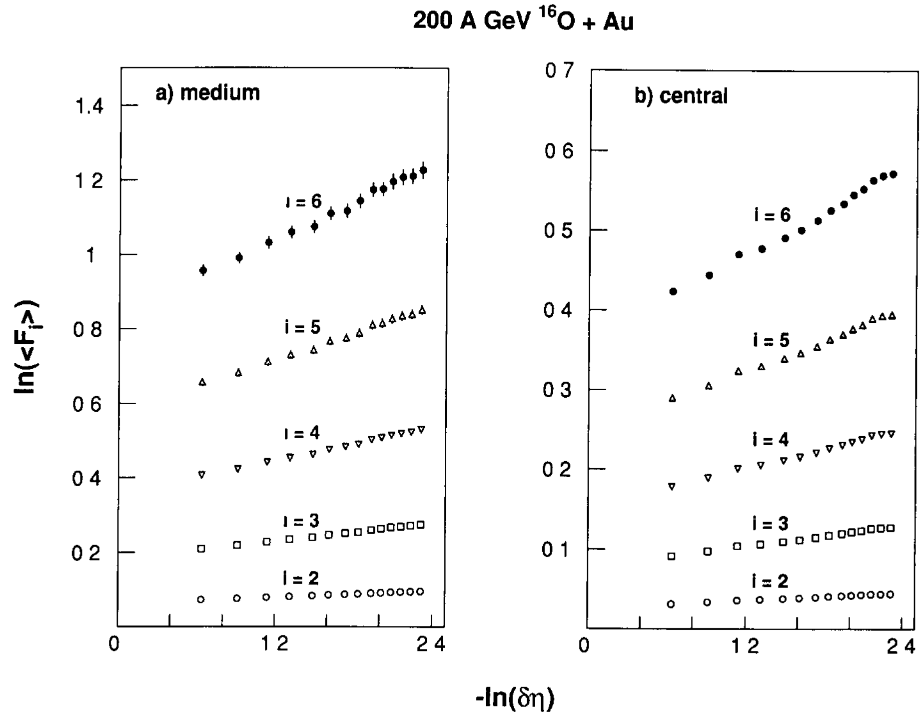

Fig 2 Scaled factorial moments as a function of the bin size, $\delta\eta$, for (a) medium and (b) central 200 A GeV ^{16}O+Au reactions.

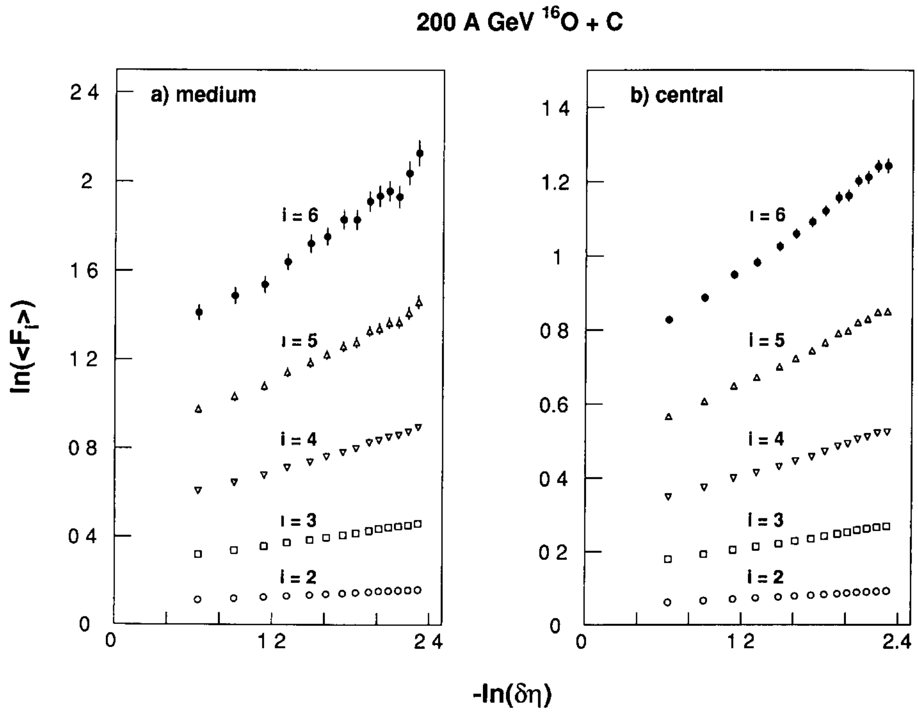

Fig 3 Scaled factorial moments as a function of the bin size, $\delta\eta$, for (a) medium and (b) central 200 A GeV ^{16}O+C reactions.

Table 2
Extracted slopes from fits of eq (2) to the various data sets Statistical errors are given

Data set	E_{ZDC} (TeV)	i	Slope
$^{16}O+C$	2.2–2.4	2	0 029 $\pm$ 0 001
		3	0 087 $\pm$ 0 003
		4	0 171 $\pm$ 0.005
		5	0 278 $\pm$ 0.012
		6	0 399 $\pm$ 0.025
$^{16}O+C$	$\leqslant$1.7	2	0.019 $\pm$ 0 001
		3	0.056 $\pm$ 0 001
		4	0 107 $\pm$ 0.003
		5	0 174 $\pm$ 0 006
		6	0 255 $\pm$ 0 013
$^{16}O+Au$	1.0–1 8	2	0 014 $\pm$ 0.001
		3	0.040 $\pm$ 0.002
		4	0.075 $\pm$ 0.003
		5	0.118 $\pm$ 0 005
		6	0.166 $\pm$ 0.008
$^{16}O+Au$	$\leqslant$0 4	2	0 008 $\pm$ 0 001
		3	0 022 $\pm$ 0.001
		4	0.041 $\pm$ 0 001
		5	0 067 $\pm$ 0 002
		6	0.090 $\pm$ 0 003

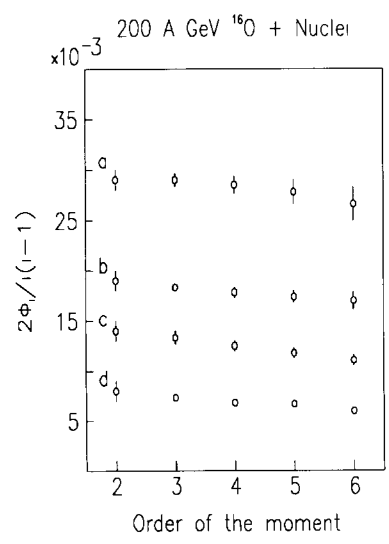

Fig 4 The extracted slopes from 200 A GeV ^{16}O+nucleus interactions are compared to eq. (3). We show $2\phi_i/i(i-1)$ as a function of the order of the moment which should be constant if eq. (3) is valid. The data points marked with (a) and (b) represent the medium and central $^{16}O+C$ reactions, respectively, and the data marked with (c) and (d) are the corresponding quantities for medium and central $^{16}O+Au$ reactions

ments [15]. Even steeper slopes than in hadron–hadron interactions were extracted for the second and third moments for the so-called "two-jet" events.

In summary, we have studied the behaviour of the scaled factorial moments, in the pseudo-rapidity range $2.4 \leqslant \eta \leqslant 4.0$, for 200 A GeV ^{16}O+ (C, Au) interactions. Centrality selections were made by applying cuts on the measured forward energy. A clear linear increase of $\ln(\langle F_i \rangle)$ as a function of $-\ln(\delta\eta)$, characteristic of intermittency, is observed. The extracted slopes increase with a decrease in the number of participating nucleons.

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