

An Investigation of Intermittency in the Reactions $^{16}\text{O} + ^{197}\text{Au}$ and $^{32}\text{S} + ^{32}\text{S}$ at 200 GeV per Nucleon

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Abstract

Fluctuations in the rapidity density of charged particles in nucleus-nucleus reactions were analyzed by the method of normalized factorial moments. The "intermittent" correlations are much weaker than in hadron-hadron interactions, but are still present. No evidence of Quark-Gluon plasma is observed.

The main objective of nucleus-nucleus interactions at high energy is the investigation of the nuclear matter under extreme conditions of density and temperature [1]. Recent QCD calculations on extended lattices have reaffirmed the existence of a deconfined quark-gluon (QG) plasma state at a critical energy density of about $2.5 - 3 \text{ GeV}/\text{fm}^3$ [2].

The experimental investigations of the QG plasma pose many problems which one can summarize by the two following questions:

- i) Is it possible in nucleus-nucleus collisions to produce the critical energy density within a large enough volume and during a long enough time to produce a QG plasma?
- ii) What are the QG plasma signals?

To answer these questions one needs a precise knowledge of the space-time development of the nucleus-nucleus interaction. Direct calculations of this process in QCD are not possible and only in the framework of some thermodynamical models one can say something about possible QG plasma signals. Despite the fact that thermodynamics deals with average quantities this simple approach to complicated phenomena still has led to many important results in very different branches of physics. We hope to have a similar success in the studies of nuclear matter despite the obvious limitations of the models.

So far experimental investigations have not given any clear indications of the QG plasma and observations in nucleus-nucleus collisions are more or less consistent with the picture of the Glauber model superposition of nucleon-nucleon interactions.

In this paper we report the preliminary investigations of the rapidity fluctuations in oxygen gold and sulfur sulfur interactions. More about the experiment and other results are published in [3]. Large fluctuations in the rapidity density $\rho(y) = \frac{1}{N} \frac{dn}{dy}$ (average multiplicity per rapidity bin), where $y = \frac{1}{2} \ln \frac{E+p_{\parallel}}{E-p_{\parallel}}$ ($E = p^2 + m^2$ and $p_{\parallel} = p \cos \Theta$, Θ scattering angle) were predicted in these models as possible consequence of a rather violent transition from a QG plasma back into the hadronic phase [4]. In order to investigate these fluctuations we adopted the method of normalized factorial moments as proposed and developed in the series of papers by Bialas and Peschanski [5]. The authors call this specific type of correlations intermittency. The phenomenon of intermittency was originally observed and investigated in studies of turbulent flow [6]. Intermittency basically means random deviation from smooth or regular behaviour.

We have investigated the rapidity fluctuations in the rapidity region $1.5 < y < 3.5$. In this Δy interval we considered only part of the azimuthal ϕ region (ϕ is the rotation angle around the beam axis) where our acceptance was about 90 percent. In total we have 163 OAu events, in which we measured only negative particles and 59 OAu and 363 SS events in which we measured all charged particles.

The Δy interval was divided into smaller bins of length in $\delta y = \frac{\Delta y}{M}$, where $M = 1, 2, \dots$. The smallest bin width for SS was 0.03 and for OAu and negative particles it was 0.05. Over the whole rapidity interval Δy our rapidity resolution was 0.01. In practice the

range of δy is not only limited by resolution but also by the finite number of particles per event. In order to be outside the correlation length induced from resonance decays we consider only bins $\delta y \leq 1$. For each bin width δy , we found the multiplicity distributions by grouping all δy bins in the Δy interval together. From these multiplicity distributions we calculated normalized factorial moments

$$(1) \quad F_i(\delta y) = \frac{1}{M} \frac{\langle \sum_{k=1}^M n_k (n_k - 1) \dots (n_k - i + 1) \rangle}{\left(\frac{\langle n \rangle}{M}\right)^i}$$

where n_k is the number of particles in the δy window, n is the total number of particles in the Δy interval, and $\langle \rangle$ denotes averaging over all events. As argued in [5] the factorial moments are sensitive to dynamical correlations and not to the statical fluctuations.

In the case that the considered rapidity interval Δy is not in the plateau of a rapidity distribution, as is the case for our Δy interval, one has to divide (1) by

$$(2) \quad R_i(\delta y) = \frac{\frac{1}{M} \sum_{k=1}^M \rho_k^i}{\left(\frac{1}{M} \sum_{k=1}^M \rho_k\right)^i}$$

Dividing (1) by (2) one reduces F_i because, for finite bin width δy , $R_i(\delta y) \geq 1$.

By definition a process shows intermittency if fluctuations are present at all scales (δy) and the moments rise with decreasing δy like a power

$$(3) \quad \frac{F_i(\delta y)}{R_i(\delta y)} = a_i \delta y^{-b_i}$$

Fitting the calculated reduced moments for different order i in dependence of δy with formula (3) we obtain the slopes b_i . Through our subdividing procedure the F_i for different δy are correlated and these correlations are reflected in especially good fits. Therefore the errors on b_i , obtained by the fitting procedure have been multiplied by $\sqrt{\frac{\chi^2}{\nu}}$, where χ^2 is the *chi*-square value and ν is the number of degrees of freedom. These errors are only statistical and the systematic errors could be larger than the statistical ones.

Table 1 shows the values of the slopes b_i obtained for charged particles and for negative particles in OAu and SS interactions..

	O + Au, $1.5 < y < 3.5$				S + S, $1.5 < y < 3.5$			
	CHARGED PART.		NEGATIVE PART.		CHARGED PART.		NEGATIVE PART.	
	SLOPES	χ^2/ν	SLOPES	χ^2/ν	SLOPES	χ^2/ν	SLOPES	χ^2/ν
b_2	0.0011 ± 0.0006	7.1/39	0.0041 ± 0.0009	15.8/39	0.0053 ± 0.0004	25.0/64	0.0052 ± 0.0008	19.3/49
b_3	0.0031 ± 0.0022	9.1/39	0.0185 ± 0.0037	19.1/39	0.0197 ± 0.0013	29.7/64	0.0310 ± 0.0029	21.4/49
b_4	0.0041 ± 0.0075	14.8/39	0.0140 ± 0.0100	22.8/39	0.0343 ± 0.0031	31.6/64	0.0675 ± 0.0080	24.0/49
b_5	0.0037 ± 0.0192	14.2/39	-0.0489 ± 0.0274	24.5/29	0.0287 ± 0.0053	15.8/40	0.0809 ± 0.0210	32.2/49

TABLE 1: The slopes b_i , extracted from the fits to the expression $a_i \delta y^{-b_i}$ (3) for oxygen Gold and Sulfur Sulfur interactions (i , is the order of factorial moment). The errors are only statistical ones. χ^2 is the chi-square value of the fit, and ν is the number of degrees of freedom.

The slopes are small indicating weak intermittent behaviour. The slopes for OAu are smaller than for SS and for charged particles smaller than for only negative particles. For both reactions we selected central collisions, by vetoing the events with total energy larger than 200 GeV in the very forward region $\Theta < 0.3^\circ$. In OAu reactions, with small impact parameter, all projectile nucleons interact several times (~ 3 times) inside the target. That is not the case for SS interaction. The decrease in intermittency for reaction types in which one has an occurrence of more subprocesses is expected and observed [7]. The observation of somewhat larger b_i for negative particles than for charged particles could indicate possible effects from Bose-Einstein correlations. This effect is also observed in muon-proton interactions. However, this effect is not observed in hadron-hadron and e^+e^- reactions [7]. Omitting at random half the tracks in each event for charged particles we obtained $b_i < 0$; the TASSO collaboration [8] claims an increase of b_i with this procedure.

In conclusion we see weak intermittent behaviour in nucleus-nucleus interactions. It is much weaker than in more elementary interactions, indicating that the phenomenon is not connected with QG plasma.

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