Title
TRANSVERSE ENERGY AND MULTIPLICITY FROM HEAVY ION COLLISIONS AT SOO A GEV

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Transverse Energy and Multiplicity from Heavy Ion Collisions at 200 A GeV

WA80 Collaboration

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1. INTRODUCTION

The successful acceleration of light ions at the CERN SPS and at the Brookhaven AGS opened the exciting field of ultra-relativistic heavy ion collisions for systematic studies. The first experiments were designed mainly to survey the reactions and to establish the essential features of the collisions.

In this paper results from the WA80 experiment on transverse energy and charged particle multiplicity are reported. These two quantities are determined by most of the experiments and can be used to characterize the events. Large multiplicities and large transverse energies are correlated with violent collisions or with small impact parameters. In addition, an estimate of the energy density reached in the collision can be derived from those two measurements. One would like to know if the energy density necessary for the transition to the quark gluon plasma has been reached. The results of the first round of experiments with oxygen ions at 60 and 200 GeV per nucleon are collected in the proceedings of the Quark Matter 88 conference [1]. Some of these results are summarized here together with new results on multiplicity fluctuations.

The data can be compared with predictions from different models. Their common feature is the assumption that the properties of the nucleus-nucleus collisions can be calculated from a superposition of nucleon-nucleon collisions (independent strings) if the nuclear geometry is treated correctly and if the known physics of N-N collisions is properly taken into account. It is hoped that deviations from the "normal" behavior predicted by those models will show characteristic properties of nucleus-nucleus collisions, like collective phenomena. However, the definition of "normal" behavior is far from being final and will require many iterations.

One of the design goals of the WA80 experiment was to be able to look for fluctuations in the number of particles produced per unit rapidity. Such fluctuations had been suggested by van Hove and others [1,2] as a possible signal for the transition from a quark-gluon plasma back into a hadronic state. Work by Hwa [3] and by Bialas and Peschanski [4] has suggested that moments of the multiplicity distribution could show the existence of dynamical correlations. If those moments are studied as a function of the rapidity interval, the onset of correlations could reveal the characteristic scale for such phenomena.

2. EXPERIMENT

Figure 1 shows the experimental setup of WA80. It has been described in detail in the References [5,6,7]. The transverse energy is measured with the mid-rapidity calorimeter (MIRAC) [5], that covers the pseudo-rapidity interval of η = 2.4 to 5.5. The charged particle

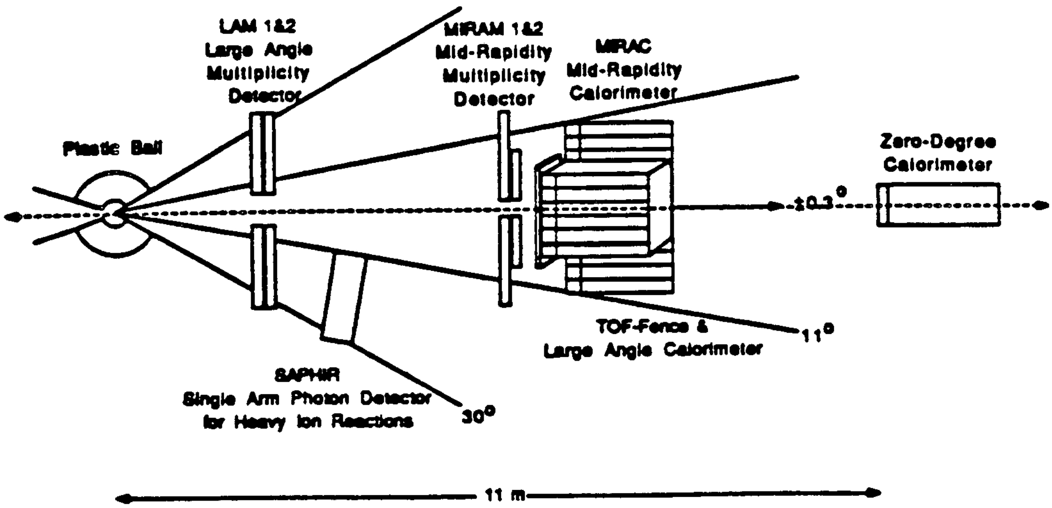

Figure 1: WA80 experimental setup

multiplicity is determined with the Plastic Ball [8] and with large arrays of streamer tubes [6] which are read out by pads of a few cm^2 in size. A good measurement of the multiplicity of charged particles emitted as a function of pseudo-rapidity η and azimuth is obtained. Averaged over the range $2.4 < \eta < 4.0$ the pseudo-rapidity resolution of the counters is 0.067 units (rms).

3. TRANSVERSE ENERGY

The transverse energy spectra for $E/A = 200$ GeV ^{32}S induced reactions are shown in Figure 2. The data span the range from 10.5 to 0.5 degrees, or 2.4 to 5.5 in pseudo-rapidity, where the mid-rapidity calorimeter (MIRAC) has full azimuthal coverage. The shapes of these spectra are determined primarily by nuclear geometry. The rise at low E_T is caused by the large differential cross section for large impact parameters, while the apparent dip at low E_T is due to trigger bias. The plateau region arises from the fact that the participant volume grows only very slowly with decreasing impact parameter if the two nuclei overlap. Thus broader and broader ranges of impact parameters produce a similar value of E_T with roughly the

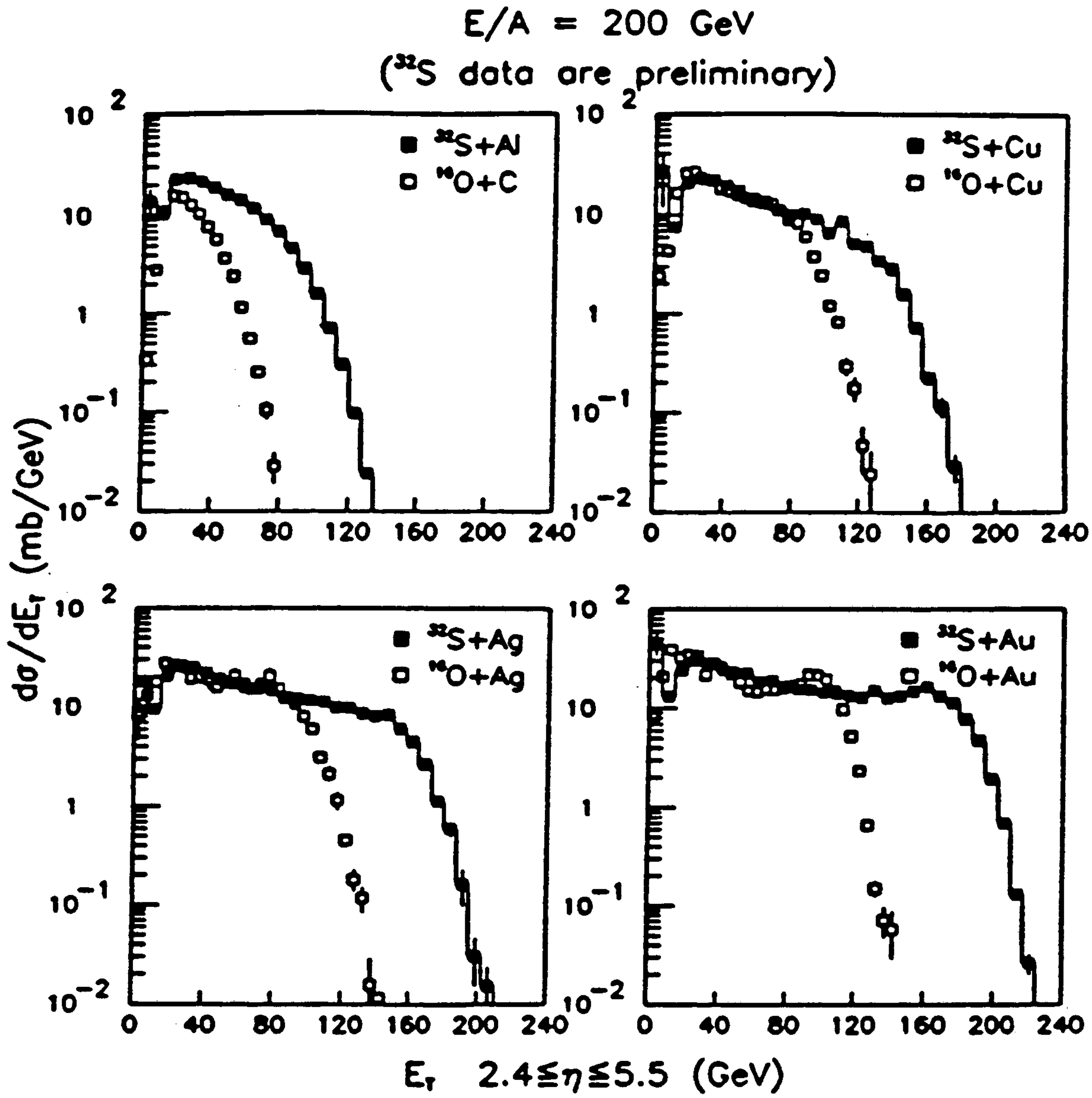

Figure 2: Transverse energy spectra for E/A = 200 GeV ^{16}O and ^{32}S induced reactions on various targets

same incremental probability. At very high E_T there is a Gaussian tail that comes from fluctuations in the violence of collisions at nearly zero impact parameter. The ^{16}O data, also shown in Figure 2, exhibit similar features. For the heavy targets, an enhancement at high E_T is visible. This bump is less prominent for the ^{32}S data because there is a larger fraction of the total cross section for the smaller ^{16}O nucleus to completely dive into the large target nucleus and to generate a roughly constant and large E_T.

Because the transverse energy and the energy density are related, it is interesting to study, how E_T scales with increasing projectile mass. As can be extracted from Figure 2 for the example of the Au target, E_T scales with a factor of 1.6 when going from the ^{16}O to the ^{32}S projectile. This shows that doubling the projectile mass and thus the total energy produces an increase in E_T of about a factor of $2^{2/3}$. This is close to the increase in the number of participant baryons that would be expected in a simple geometrical picture. This scaling suggests that the transverse energy per participant might be roughly constant, in accord with the earlier conclusions of Reference [9].

There is no precise way to determine the energy density reached in high energy heavy ion collisions. A procedure generally applied at 200 GeV per nucleon is to use the Bjorken formula [10], that is derived for the case of a large, baryon free central region, a condition certainly not fulfilled at SPS energies. The energy density ε is given by

$$\varepsilon = \frac{1}{\tau \pi R^2} \frac{dE_T}{d\eta},$$

where τ is the proper formation time, and R is the projectile radius. With $\tau = 1$ fm/c and a radius of 3 fm for the oxygen projectile, energy densities of the order of 2 to 3 GeV/fm^3 have been determined [11,12]. When the energy density for ^{32}S is calculated, the increase by a factor $2^{2/3}$ cancels with the increase in the projectile radius. Therefore, about the same energy density is reached in ^{32}S induced reactions, but of course the volume, over which this density is obtained, is bigger. Other methods to estimate the energy density lead to similar conclusions [13].

4. MULTIPLICITY FLUCTUATIONS

There are many different methods to investigate multiplicity fluctuations. Hwa [3] asked whether a phase transition (e.g., from a quark-gluon plasma state back to a hadron gas) would exhibit a large correlation length, similar to the dynamical effects seen in critical phenomena, such as critical opalescence. If this occurred, the ratio of the dispersion to the mean of the multiplicity distribution should become large. However, in order to examine this, one must first remove the geometrical part of the fluctuations, e.g. from impact parameter variations. One can restrict the impact parameter by restricting the mean multiplicity. Hwa suggested varying the mean multiplicity instead by changing the η–window while keeping its center fixed. The ratio dispersion to mean could then be studied as a function of the η-window size. The fluctuations arising from geometry should be nearly independent of the window size, while those arising from dynamical effects should be enhanced for a small window size. The following definitions are made to apply the method proposed by Hwa:

$P(n)$ = probability to measure n charged particles

$< n >$ = mean on $P(n)$ distribution

$D = \sqrt{< n^2 > - < n >^2}$ is the dispersion

$C_2 = < n^2 > / < n >^2$ is the second central moment.

Hwa has shown that the quantity $S_2 = C_2 - 1/< n >$ is of special interest since it can be expressed as the sum of two terms, where one term reflects the geometry only and the second term contains the effects of dynamical correlations.

The results of the WA80 runs with 200 GeV per nucleon ^{16}O have been analyzed according to the above suggestions. A similar analysis has also been carried out for events generated by the VENUS event generator (version 1.06) [14]. The values of S_2 are presented in Table 1 for minimum bias events and for central events selected by requiring that the energy in the Zero-Degree Calorimeter be less than 20% of the projectile energy.

$\delta\eta$	Minimum Bias				Central			
	Data		VENUS		Data		VENUS	
	< n >	S_2	< n >	S_2	< n >	S_2	< n >	S_2
0.30	15.1	1.36	14.8	1.40	26.5	1.03	27.6	1.04
0.60	29.6	1.39	28.3	1.45	53.6	1.02	54.8	1.03
0.90	44.1	1.39	42.0	1.46	80.0	1.02	81.4	1.03
1.20	57.6	1.39	55.3	1.45	104.6	1.02	107.2	1.02
1.50	70.2	1.38	68.2	1.45	127.3	1.02	132.1	1.03
1.80	82.2	1.38	80.4	1.45	148.8	1.02	155.4	1.02
2.10	94.1	1.38	91.9	1.44	170.2	1.02	177.1	1.02
2.40	106.1	1.38	102.6	1.44	191.7	1.02	197.3	1.02

Table 1: Mean value < n > and S_2 for different η-windows for the reaction ^{16}O + Au at 200 GeV per nucleon. Results are presented both for WA80 data and for events generated using the VENUS code.

Given the similarity of the results from the data and the VENUS model events, there is no evidence for the existence of dynamical correlations in the data. We have also checked that the use of pseudo-rapidity instead of rapidity in the analysis does not alter the results by analyzing VENUS events in terms of rapidity.

The analysis method proposed by Bialas and Peschanski [4] is a more general version of the above analysis. The scaled factorial moments, F_i, of the multiplicity distribution are extracted and examined for the presence of large, non-statistical fluctuations. The authors pointed out that the variation of these moments with the window selected in rapidity would give an indication of the existence of a particular scale in rapidity for the creation of the final particles; such a scale might reflect the conditions at hadronization of a quark-gluon plasma. They also suggested that one might instead observe a pattern in these moments that is characteristic of what is known as "intermittency" in hydrodynamics. This is a pattern known from studies of turbulent fluid flow in which fluctuations appear on a range of different scales but are limited to small parts of phase space.

The factorial moments are defined as

$$F_i = \frac{1}{M} \sum_{m=1}^{M} \frac{M^i}{<N>^i} k_m (k_m - 1) \ldots\ldots (k_m - i + 1),$$

where M is the total number of equally-sized bins into which a given rapidity interval is subdivided, N is the total multiplicity in the rapidity interval and k_m is the number of particles in the m^{th} bin. These moments can be computed from the data. Bialas and Peschanski showed that if the F_i are averaged over many events, the resulting moments are equal to the moments of the true probability distribution of particles in phase space.

The presence of non-statistical fluctuations will influence the absolute values of the F_i and will also influence the variation of the F_i with the size of the rapidity bins, $\delta\eta$, into which the overall rapidity interval is subdivided. For example, if there exists a set of fluctuations on a fixed rapidity scale, then F_i will increase with decreasing $\delta\eta$ until that rapidity is reached, after which point the F_i will become constant. If, on the other hand, an "intermittent" pattern exists, in which the F_i depend on $\delta\eta$ via a power law relation, then F_i will be observed to increase with decreasing $\delta\eta$ down to the resolution limits of the data.

A plot of the logarithms of the 2^{nd}, 3^{rd}, 4^{th} and 5^{th} moments, $\ln(F_i)$, versus the negative logarithm of the width of the pseudo-rapidity bin, $-\ln(\delta\eta)$, is shown in Figure 3. Results are presented for peripheral and central collisions of E/A=200 GeV ^{16}O with Au. The peripheral events are given as filled triangles and correspond to observed energies in the ZDC of 1.0 - 1.8 TeV (31% - 56% of the projectile energy). The central events (filled squares) correspond to energies of less than 0.4 TeV in the ZDC (12% of the projectile energy). For both classes of events the logarithm of the moments rises linearly with the negative logarithm of the pseudo-rapidity

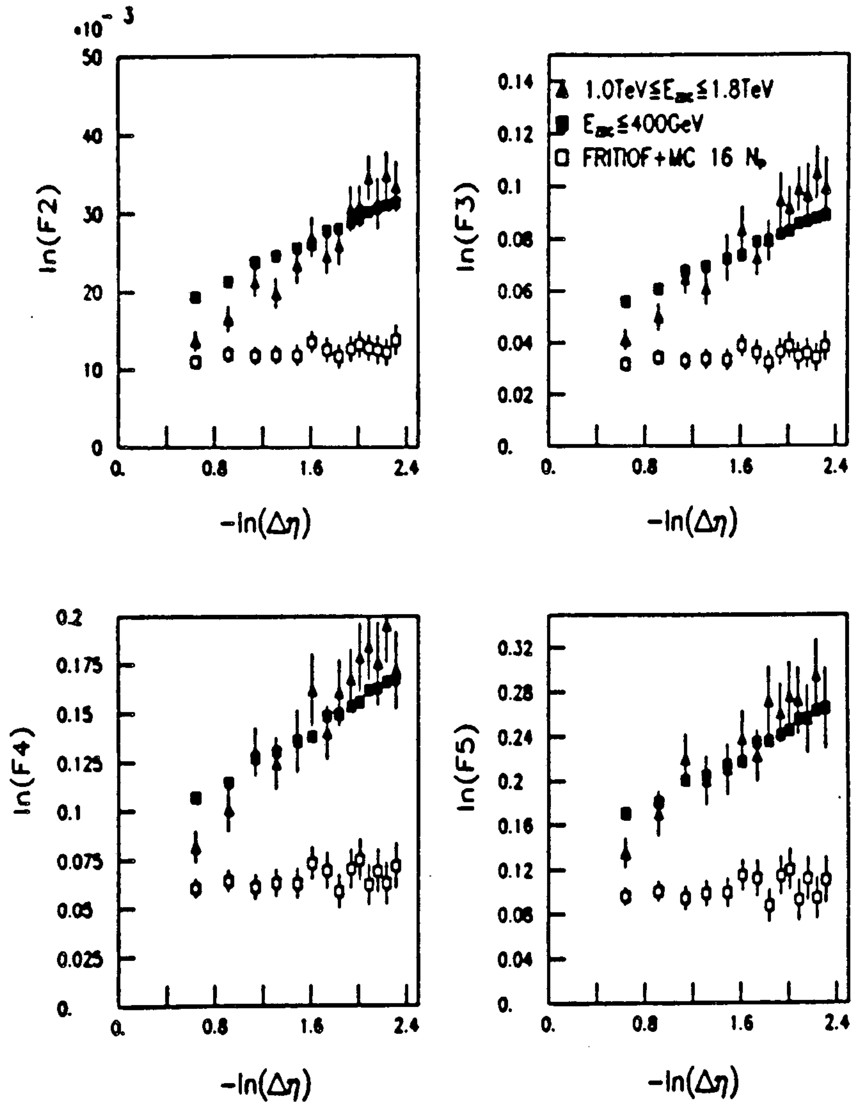

Figure 3: Scaled factorial moments for E/A = 200 GeV ^{16}O + Au

bin. The observed rise is not unlike that expected for an "intermittent" pattern. Also included on this figure are the results of the same analysis using events created by the string-model program FRITIOF [15]. These are shown as open squares and show little, if any, dependence of the factorial moments on the pseudo-rapidity window. Note that in all this analysis, the smallest pseudo-rapidity bin used was $\delta\eta = 0.1$.

The fact that the fluctuations are stronger for the more peripheral reactions and that even stronger effects have been observed for more elementary systems [16], suggests, that the observed correlations are a property of the basic interaction or of the hadronization process. Bose-Einstein correlations, arising from the symmetrization of the quantum state of like bosons, for example, could be the cause of the observed behavior [17]. It is possible as well, that the original suggestion of Bialas and Peschanski of a cascading model for the production of hadrons is needed to explain the data.

5. SUMMARY

From the measurement of the transverse energy in 200 A GeV ^{16}O induced reactions an initial energy density of the order of 1 to 3 GeV/fm^3 has been estimated. In the most central ^{32}S induced reactions the transverse energy increases by a factor of 1.6. This increase does not seem to lead to a higher energy density, but the volume over which this high energy density is obtained, increases with the projectile mass.

The two different methods to analyze multiplicity fluctuations do not show evidence for dynamical correlations on a fixed rapidity scale. However, down to the pseudo-rapidity range accessible with the WA80 experiment ($\eta = 0.1$), the behavior of the factorial moments resembles the pattern expected for an "intermittent" source.

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REFERENCES

1 H. Satz, H.J. Specht, R. Stock, eds, Z. Phys. C38 (1988).
2 L.S. Schroder and M. Gyulassy, eds, Nucl. Phys. A461 (1987).
3 R. Hwa, Z. Phys. C38, 277 (1988); R. Hwa, U. Oregon preprints OITS-385 and OITS-393.
4 A. Bialas and R. Peschanski, Nucl. Phys. B273, 703 (1986); R. Peschanski, these Proceedings.
5 T.C. Awes et al., to be published in Nucl. Instr. and Meth. A.
6 R. Albrecht et al., to be published in Nucl. Instr. and Meth. A.
7 P. Beckmann et al., to be published in Nucl. Instr. and Meth. A.
8 A. Baden et al., Nucl. Instr. and Meth. 203, 189 (1982).
9 S.P. Sorensen et al., Z. Phys. C38, 3 (1988).
10 J.D. Bjorken, Phys. Rev. D27, 140 (1983).
11 R. Albrecht et al., Phys. Lett. 199B, 297 (1987).
12 H.G. Ritter, Nucl. Phys. A488, 651c (1988).
13 M. Tincknell, these Proceedings.
14 K. Werner and M. Kutschera, Phys. Lett. 183B, 385 (1987); K. Werner, BNL Preprint 39726.
15 B. Nilsson-Almqvist and E. Stenlund, Comput. Phys. Commun. 43, 387 (1987); B. Anderson et al., Phys. Rep. 97, 31 (1983).
16 W. Kittel, Review talk at the XXIV Int. Conf. on High Energy Physics, Munich, Aug. 4-10, 1988, and references therein.
17 M. Gyulassy, to be published.