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WA80 Collaboration

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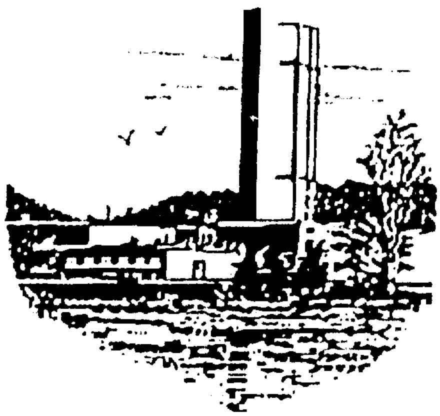

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1. INTRODUCTION

Two years ago we presented very preliminary results at this meeting, less than two months after the ^{16}O run at CERN was completed. Since that time a great deal of effort has been devoted to detailed data analysis and to a second run, which took place with ^{32}S ions in the fall of 1987. Following the 1987 Bormio meeting we presented our results at several other conferences, including two Quark Matter meetings,[1-7] and also published several papers in the open literature.[8-10]

The main goal of the CERN heavy-ion experiments is the search for an indication that the predicted state of deconfined quarks and gluons, the quark-gluon plasma (QGP), has been produced. The most promising indication that this may, in fact, be the case comes from the NA38 dimuon measurements, which are focused on the question of J/ψ suppression. This effect was predicted to be one of the signatures of QGP formation before any measurements were made, and it is the subject of the two other talks at this conference that deal with nucleus-nucleus reactions at ultrarelativistic energies. In this presentation we consider the general (global) features of heavy-ion reactions at CERN energies, and we examine the degree to which they differ from mere superpositions of nucleon-nucleon collisions. We discuss the present status of our data analysis and our main conclusions from the first round of CERN experiments with emphasis on transverse energy measurements, on attained energy densities, and on the spectra of produced neutral pions. Because of time limitations we will not discuss our measurements of distributions of charged particles and the analysis of these distributions in terms of fluctuations nor the results that we have obtained with the Plastic Ball on the behavior of target spectator matter.

2. EXPERIMENTAL ARRANGEMENT

A simplified version of the WA80 experimental arrangement is shown in Fig. 1. For the purpose of clarity most of the detectors used to measure the multiplicities of charged

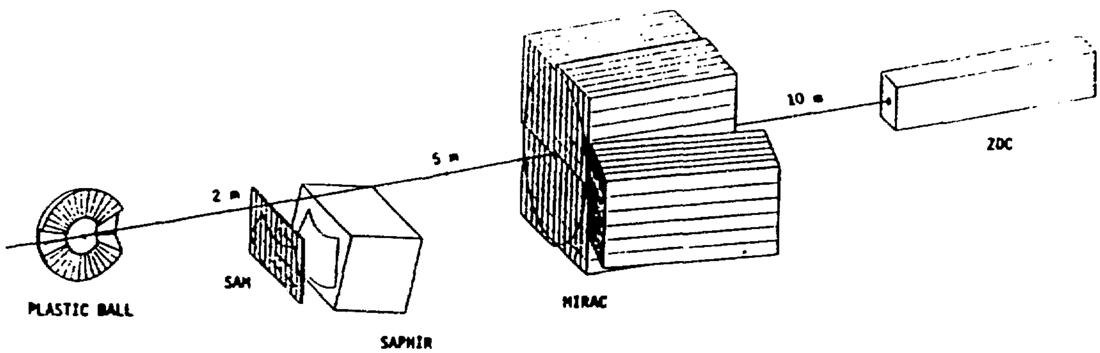

Fig. 1. *Simplified version of the WA80 experimental setup.* **The target is located at the center of the Plastic Ball. SAPHIR is the single-arm photon detector. SAM is an associated charged-particle detector. MIRAC is the Midrapidity Calorimeter, and ZDC is the Zero-Degree Calorimeter. Most of the arrays used to measure the multiplicities of charged particles are not shown.**

particles are not shown. The transverse energy distributions presented here were obtained with the midrapidity calorimeter MIRAC. It covers a pseudorapidity, η, region from 2.4 to 5.5 and has full azimuthal coverage in this η range. The spectra of neutral pions were deduced by reconstruction from photon measurements performed with the single-arm photon spectrometer, SAPHIR. This detector covers about one-sixth of the solid angle in the range $1.5 < \eta < 2.1$ and is capable of measuring photons that have energies greater than 200 MeV. The Zero-Degree Calorimeter (ZDC) is used to measure projectile spectators and, thus, provides us with an indication of collision centrality for each event. The WA80 setup and its individual detectors have been described in detail elsewhere.[11–14]

3. TRANSVERSE ENERGY DISTRIBUTIONS

Transverse energy distributions obtained from interactions of 200-GeV/nucleon ^{16}O and ^{32}S projectiles with various target nuclei are shown in Fig. 2. The data have been described in Refs. 1, 5, and 8. As was pointed out, it is primarily the geometry of the nuclear collision that determines the shape of these distributions. The rise at low values of the transverse energy is due to the relatively large cross section associated with large impact parameters. The bump observed at high E_T values in the case of the heaviest targets results from the fact that collisions with a relatively broad range of central impact parameters involve a nearly constant number of participants. A trigger cut is responsible for the apparent dip at the lowest E_T values while at the high end of the distribution the Gaussian

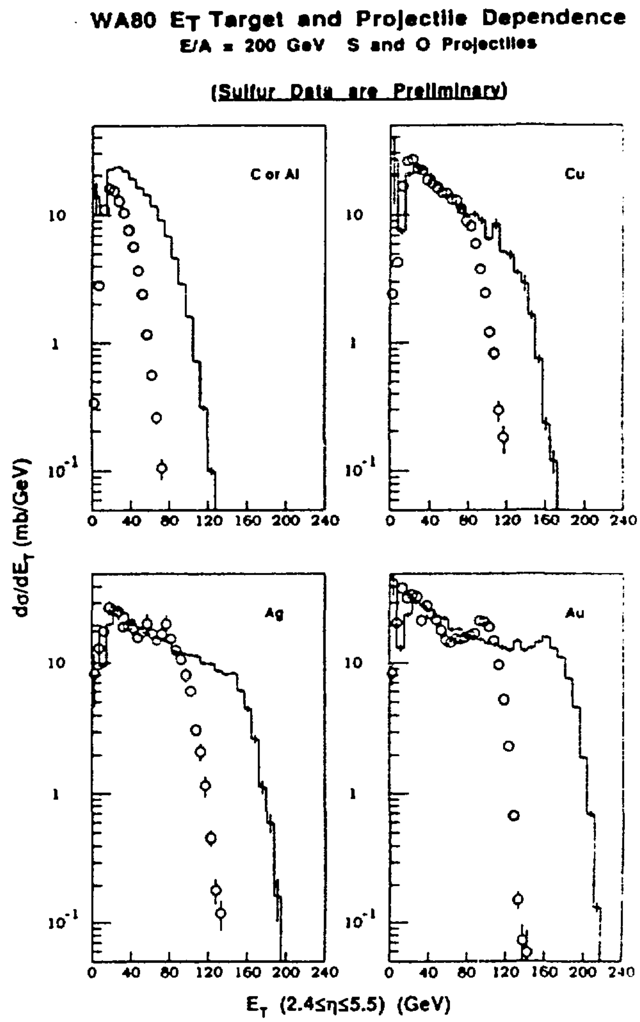

Fig. 2. Transverse energy distributions from 200-GeV/nucleon ^{16}O (circles) and ^{32}S (histograms) reactions with various target nuclei in the pseudorapidity range $2.4 < \eta < 5.5$. The sulfur data are preliminary.

tail is due to fluctuations in the violence of nearly head-on collisions. The two main trends observed are the increase in the transverse energy produced with increasing mass of the colliding system and the increase of transverse energy with increasing bombarding energy. The measured E_T is, as expected, anticorrelated with the energy measured in the ZDC.

In Ref. 1 it was shown that for oxygen-induced reactions at a given bombarding energy, the transverse energy produced depends on the number of participating nucleons and that the transverse energy/participant is nearly independent of target mass and of collision centrality. In a simple geometrical picture the doubling of the mass of the projectile should increase the number of participants approximately by a factor of $2^{2/3}$, and consequently, an increase in E_T of about a factor of 1.59 was anticipated for the ^{32}S + Au reaction relative to the ^{16}O + Au reaction. In Fig. 3 the transverse energy spectra from the above two reactions are compared. The ^{16}O E_T values have been multiplied by 1.6, which results

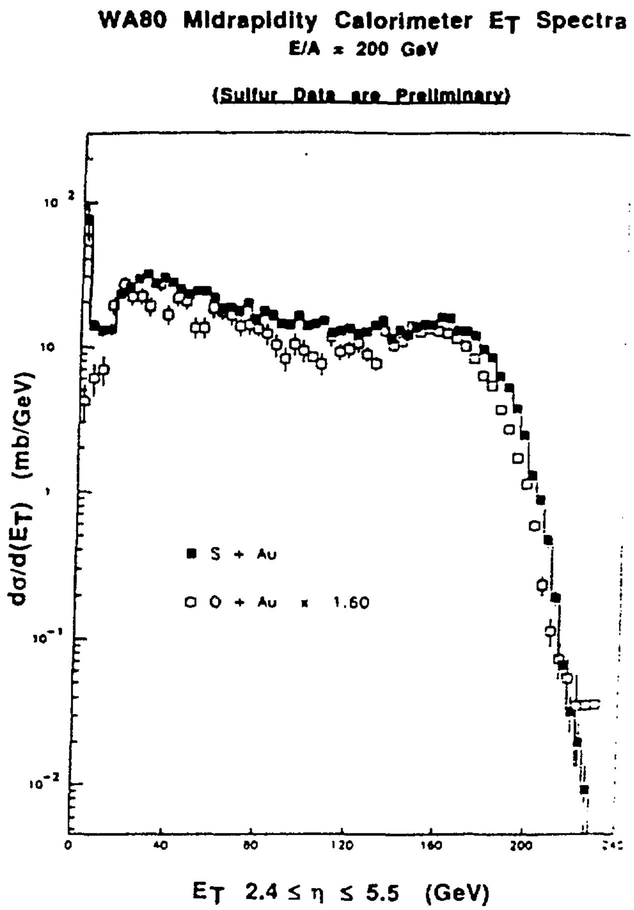

Fig. 3. Comparison of transverse energy distributions from ^{16}O- and ^{32}S-induced reactions of Au. The energy scale of the ^{16}O + Au data has been multiplied by 1.6 (see text). The sulfur data are preliminary.

in an alignment of the tails of the two distributions and indicates that the relationship between the number of participants and the produced transverse energy also holds in the case of sulfur-induced reactions. This point is confirmed in Fig. 4 where E_T/participant values are plotted as a function of the energy measured by the ZDC for both oxygen- and sulfur-induced reactions at 200 GeV/nucleon. A nearly constant E_T/participant value of

2 GeV is obtained in all cases. In Fig. 4, as in Ref. 1, the relationship between the number of participating baryons and the observed ZDC energy was obtained via the Monte Carlo simulation code FRITIOF.[15]

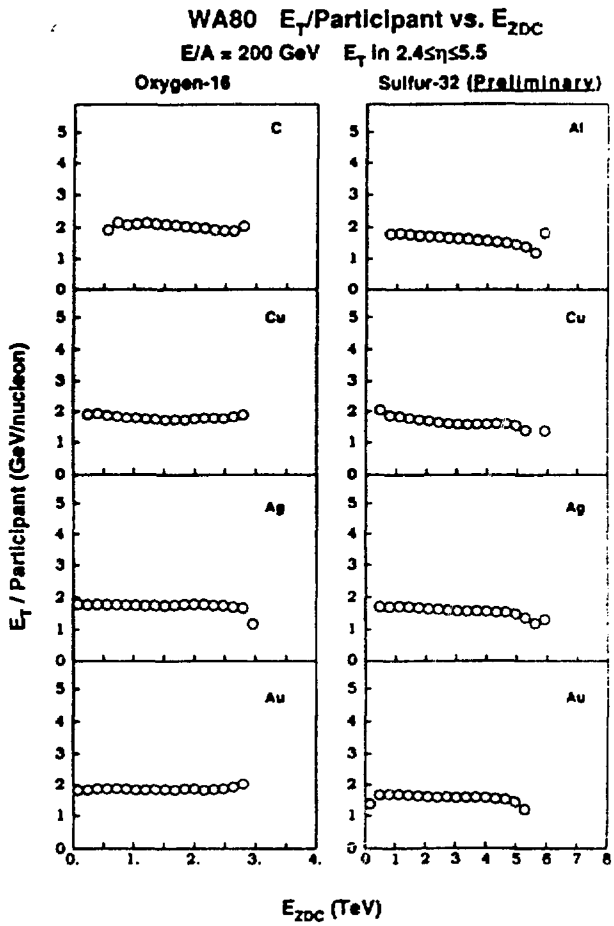

Fig. 4. Transverse energy per participant as a function of the energy, E_{ZDC}, measured by the Zero-Degree Calorimeter for several target–projectile combinations.

4. ENERGY DENSITIES

One of the crucial questions addressed during the first round of CERN experiments is: "Has the attained energy density been high enough to produce deconfinement?" There are two problems associated with attempts to answer this question. First, theoretical estimates for the required energy density vary considerably, although the currently accepted region seems to be in the vicinity of 3 GeV/fm^3. Second, no generally accepted method of extracting the attained energy density from the data is available. The most frequently-used approach is due to Bjorken.[16] However, this method is valid only in the extreme relativistic case, when the dE_T/dy distribution as a function of rapidity y is expected to exhibit a plateau. From our data, it is clear that this approximation is not valid in the CERN energy regime, and this led us to explore alternative approaches such as the application of the fireball model combined with the geometry considerations, which was described in the previous section.[17] The important conclusions from the application of the Bjorken method, as well as from alternative treatments, are that the attained energy density increases significantly with increasing bombarding energy and that it increases only very slowly with increasing mass of the target-projectile combination. Thus, for example, in the Bjorken formulation the maximum attained energy density from our E_T measurements is 2.3 GeV/fm^3 for the O + Au case and 2.4 GeV/fm^3 for the S + Au system compared to the 2.5 GeV/fm^3 which we estimate on the basis of the expected number of participants for the Pb + Pb system. Apparently, if the attainment of high energy densities is the most important consideration, efforts should be devoted to increasing the bombarding energy rather than the mass of the projectile.

The above discussion dealt with volume-averaged energy densities. It is likely, however, that in collisions between two massive nuclei, the energy density produced is not uniform in the radial direction. Thus for example, in a collision with zero impact parameter, the energy density is highest in a central core region. Estimates of this central energy density were first made by Sorensen *et al.*[1] In this picture, the energy density attained in the core region of a head-on 200-GeV/nucleon collision is estimated to increase from 2.9 GeV/fm^3 for O + Au to 4.1 GeV/fm^3 for Pb + Pb. The conclusion is that reactions with very heavy nuclei are likely to produce both larger volumes of deconfined matter and substantially higher energy densities in the central region than reactions with smaller nuclei at the same bombarding energy.

5. TRANSVERSE MOMENTUM DISTRIBUTIONS OF NEUTRAL PIONS

The primary purpose of the single-arm photon spectrometer SAPHIR is to measure the spectra of direct photons which may be emitted from the QGP. Photons and other electromagnetic probes, because of their noninteracting nature, are believed to be the best tools with which early reaction stages can be explored. The direct photon spectra can be extracted from the data only after the very large number of photons produced by decaying neutral pions and η mesons have been accounted for. This procedure is very complicated, and the final result is very sensitive to a number of factors such as acceptance, shower identification, and neutral pion reconstruction. The direct photon spectra that we have obtained to date are too preliminary to be included here, and are in the process of being reevaluated.

Somewhat less sensitive to the factors mentioned above are the spectra of neutral pions which are obtained by invariant mass reconstruction. Results have been presented in Refs. 7 and 18. Neutral pion distributions obtained from the ^{16}O + Au reaction at 200 GeV/nucleon are shown in Fig. 5 as a function of transverse momentum, p_T, for two different ranges of collision centrality. Exponential fits in the transverse momentum range $0.8 < p_T < 2$ GeV/c are also shown. The slope parameters, T, are 189 ± 5 MeV/c for

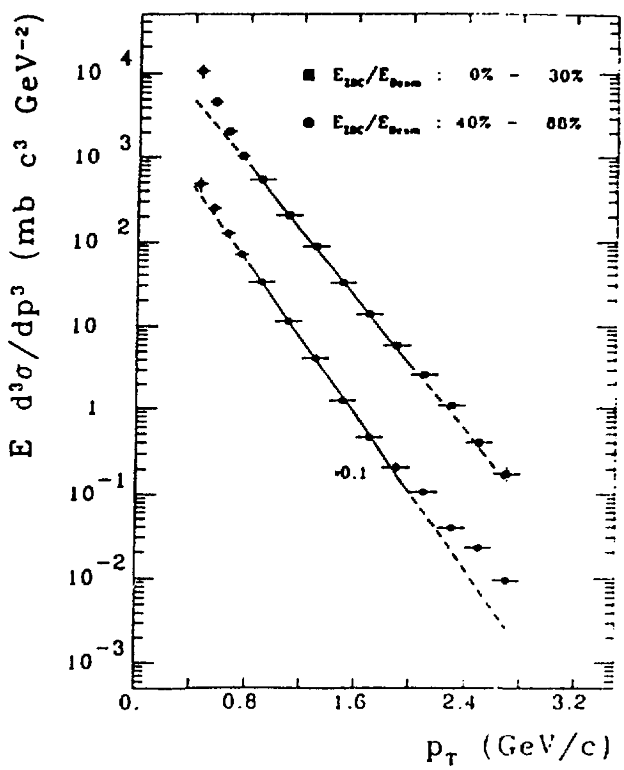

Fig. 5. Invariant π^0 cross sections from collisions of 200-GeV/nucleon ^{16}O projectiles with Au target nuclei measured in the pseudorapidity range $1.5 \leq \eta \leq 2.1$ for different ranges of the energy, E_{ZDC}, measured in the Zero-Degree Calorimeter. The squares correspond to central collisions and the circles to peripheral collisions. Exponential functions are fitted to the spectra in the range $0.8 \leq p_T \leq 2$ GeV/c and are extrapolated to the full p_T range as indicated by the dashed lines.

peripheral and 220 ± 5 MeV/c for central collisions, respectively. The slopes are extrapolated to higher and lower p_T regions. The following three main features of the data are to be noted: (1) Over most of the p_T range, the value of the slope parameter is significantly higher for central collisions than for peripheral collisions; (2) in the low p_T region lower values of the slope parameter are observed than in the central p_T region, but only in the case of central collisions; and (3) at high p_T values, no change is observed in the slope parameter for central collisions, while peripheral collisions exhibit a clear deviation from central p_T slope parameters to much higher values. This last behavior is similar to that observed in the data of $p + p$ collisions at similar energies. It is attributed to the onset of hard QCD scattering, which is, presumably, obscured by nuclear effects in central collisions. At lower values of p_T the changing of the slope parameter with centrality can be understood on the basis of a hydrodynamic model with isotropic expansion of a fireball.[19] The increased cross section at low p_T values in central collisions (see above and Fig. 5) is described in a thermodynamical picture as being a consequence of the rescattering of secondary pions.[20]

6. SUMMARY

The following main points have been made:

1. The broad features of measured transverse energy distributions are determined by the collision geometry.
2. The transverse energy per participating baryon produced in the pseudorapidity range from 2.4 to 5.5 has a value of about 2 GeV and does not vary significantly with projectile mass, target mass, or collision centrality.
3. Volume-averaged energy densities increase with increasing projectile energy but not significantly with increasing projectile size.
4. Energy densities attained in the central core do increase with projectile size.
5. Slope parameters of neutral pion transverse momentum spectra have higher values for central than for peripheral events.
6. Peripheral-collision neutral pion spectra display a marked change of slope at high values of transverse momenta in contrast to central-collision spectra.

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