PRELIMINARY RESULTS FROM COLLISIONS BETWEEN 3.2-TeV ^{16}O AND TARGET NUCLEI OF C,Cu and Au

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WA 80 COLLABORATION

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We present preliminary WA80 data from interactions of ^{16}O with C, Cu and Au at 200 GeV/nucleon. Charged-particle multiplicity distributions and transverse energy distributions as well as correlations of charged-particle multiplicity with the energy recorded in the zero-degree calorimeter are presented and thoroughly discussed.

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1. Introduction

The ultimate goal of the WA80 collaboration is to search for the transition from hadronic matter to deconfined quark matter. Such a transition may occur in the finite volume of hadronic matter that is formed with high energy density in very high-energy nucleus-nucleus collisions. At the CERN SPS energies of 200 GeV/nucleon, it is estimated that the required critical energy density may be reached in central collisions between sufficiently large nuclei, provided that the degree of nuclear stopping is high enough to concentrate a large fraction of the available c.m. energy at mid-rapidity. Thus, the immediate goal of the collaboration is to study the extent of stopping and the nature of the baryon-poor excited nuclear matter in the rapidity range intermediate between the projectile and the target rapidities. Comparisons between nucleon-nucleus and nucleus-nucleus collisions play a key role in such investigations. In addition to the above primary goal, WA80 aims to investigate the fragmentation region associated with the target remnants. As will be seen below, the WA80 experimental arrangement is uniquely suited to undertake such studies due to the use of the Plastic Ball detector.

WA80 is the CERN designation for the original "Plastic Ball" collaboration which, along with the "Streamer Chamber" collaboration, was one of the two original experiments[7] that were considered at the time of the 1982 agreement between CERN, GSI, and LBL, in which the foundations for the CERN heavy-ion program were laid. The fruition of this endeavor was reached last November when beams of ^{16}O nuclei at 200 and 60 GeV/nucleon were delivered to several experiments, including WA80. A 3.2-TeV ^{16}O test beam was made available briefly last September in the North Area of the SPS, but since WA80 is located in the West Area, results presented here were obtained less than four months ago. Consequently, their very preliminary nature must be stressed, and those who wish to quote the results given here should contact the WA80 collaboration in case further data processing results is significant quantitative changes.

2. Experimental set-up

The experimental arrangement of WA80 (Ref. 8) consists of the following detector systems: the Plastic Ball, several charged-particle multiplicity arrays, the Wall Calorimeter, SAPHIR (Single-Arm Photon Detector for Heavy-Ion Reactions), the time-of-flight wall, and the Zero-Degree Calorimeter. In addition, the setup includes several beam counters, a thin (500 microns) aluminum spherical reaction chamber located inside the Plastic Ball, and 5-cm-diameter carbon fiber/epoxy evacuated beam lines of 500-micron nominal thickness. Great care was taken to keep all extraneous material out of the reaction zone, resulting in negligible background levels during target-out operation. Thin targets were used to avoid significant contributions from secondary interactions. The target thickness were 185.7 mg cm^{-2} of C, 200 mg cm^{-2} of Cu, and 250 mg cm^{-2} of Au. The beam level was limited to less than 2 X 10^{6} particles/SPS spill. The projectile energy was 200 GeV/nucleon from November 19 to December 3, 1986, and 60 GeV/nucleon from December 3 until the end of the run on December 8. The detector systems of WA80 are described below.

3. Plastic Ball

The Plastic Ball[9] is the only detector of WA80 that was in existence when the collaboration was formed. It had been in operation for five years at the LBL Bevalac, until it was moved to CERN in early 1986. It consists of 655 ΔE-E particle-identifying detectors, where the ΔE counters are CaF_2 crystals and the E counters are plastic scintillators. The two types of counters are optically coupled and read out by one photomultiplier. The signals are separated by pulse shape discrimination. The near-4π coverage of the Plastic Ball was decreased somewhat to avoid the shadowing of downstream detectors. The resulting pseudorapidity coverage is $-1.7 \lesssim \eta \lesssim 1.3$, corresponding essentially to the rapidity region associated with target products. The device is operated in a mode in which it identifies and measured the energy of charged particles from protons through alphas, as well as positive pions.

The Plastic Ball serves the function of both a calorimeter and a multiplicity detector. It will provide results that can be viewed as extensions of the Plastic Ball Bevalac program. These include the study of matter flow from global analysis, determination of the extent of spectator drag from the measurement of the average value of $p_{\parallel}$ in the target rapidity region, estimates of entropy from measured d/p ratios, and the extraction of source sizes and timescales from particle-particle correlations. The Plastic Ball provides a unique capability to identify charged baryons in the rapidity region of $-1.7 < \eta < 1.5$.

4. Multiplicity Detectors

A unique feature of WA80 is the essentially complete 4π coverage for the measurement of the multiplicity of charged particles (pseudorapidity range $-1.7 < \eta < 4.4$). Beyond the range of the Plastic Ball, this coverage is provided by a set of four charged-particle multiplicity detectors, which are based on the Iarocci streamer tube technology. The tubes are made of carbon-coated plastic, and filled with a mixture of isobutane and argon at atmospheric pressure. The central inner wire is kept at a potential of 4.8 kV. An impinging charged particle produces a local discharge (streamer) which is detected via capacitive coupling by means of a pad readout. The pads vary in size from 1 x 2.5 cm to 4 x 5 cm depending on their location. They are attached directly onto one side of a printed circuit board which also carries the readout electronics in the form of surface-mounted integrated circuits. The multiplicity arrays are (i) Large-Angle Multiplicity Detector (LAM), located at 2.4 m from the target, covering the region between 30° and 10° and consisting of 5664 pads; (ii) Mid-Rapidity Multiplicity Detector (MIRAM), located at 6 m, covering the region from 13° to 0.9 and consisting of a double layer of 8192 pads each; and (iii) Saphir Multiplicity Detector (SAM), located at 2.5 m, with $\Delta\theta = 10°$ and $\Delta\phi = 80°$ and consisting of 7200 pads. The two layers of MIRAM are located in front of the Wall Calorimeter, and SAM is located in front of SAPHIR.

Aside from generating charged-particle multiplicity data, the 29, 248-pad multiplicity arrays constitute an important component of the prompt trigger system by flagging events in which (a) at least N_{min} pads have fired (minimum bias) and (b) more than N_{high} pads have fired (high multiplicity events). In addition, MIRAM data are expected to enhance the information deduced from the Wall Calorimeter, and SAM measurements are needed to help identify charged-particle-induced hadronic showers in SAPHIR.

Preliminary total charged-particle multiplicity distributions obtained from 3.2-TeV ^{16}O reactions with C,Cu and Au target nuclei are shown in Fig. 1. The data shown account for only a few percent of the total available data, and their preliminary nature is again stressed. The distributions were obtained from a tape scan that took place during a scheduled interruption of the experiment. While the statistical errors in each bin are only of the order of a few percent, the results shown may be subject to significant systematic errors. For example, efficiency corrections are expected to increase the multiplicities of Fig. 1, while corrections for observed secondary events are expected to decrease them. These corrections are anticipated to be of the order of 15%, and the multiplicity scale of

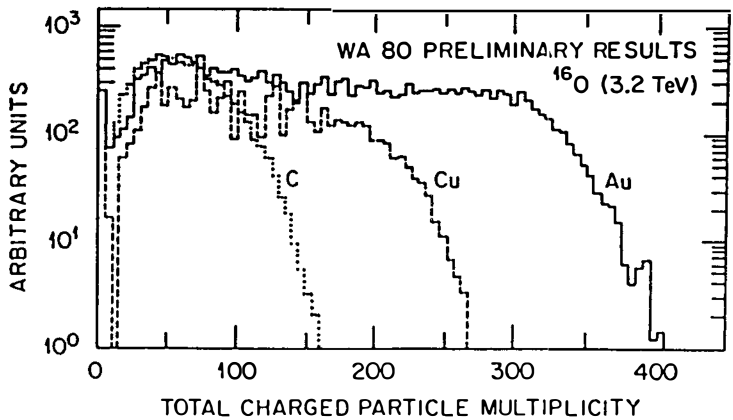

Fig. 1. Preliminary total charged-particle multiplicity distributions from interactions between 3.2-TeV ^{16}O nuclei with C, Cu and Au target nuclei.

Fig. 1 will propably turn out to be within 10-15% of the final scale, after all of the appropriate corrections have been made.

5. Wall Calorimeter

The ability to measure the transverse energy flux, $dE_T/d\eta$, in the mid-rapidity region is provided by the modular Wall Calorimeter. The design of the calorimeter is based on the uranium/plastic scintillator calorimeter of Akesson et al.[10] It consists of 30 stacks, and each stack contains six 20 cm by 20 cm towers, optically separated from each other by cuts in the plastic sampling material. Each tower consists of a lead-plastic electromagnetic section of 15 radiation lengths, providing an estimated containment of 97% for 1-GeV photons (91% for 30-GeV photons), and a steel-plastic hadronic section of

6.2 absorption lengths with an estimated longitudinal containment of 98% for 50-GeV protons. Each section is read out by dual wavelength-shifter plates located on the sides of the towers.

Extensive performance tests and calibrations of the Wall Calorimeter units have been carried out, at both the PS and the SPS accelerators. The resolution, linearity, containment, position response, and e/h response were evaluated. All of these quantities were found to be consistent with design expectations. At 10 GeV/c the e/π ratio was found to be 1.3, and the measured $\sigma/\sqrt{E}$ resolutions were 46% for charged pions and 17% for electrons. The final calibration of all calorimeter towers was made in the X1 beam line of the SPS with 10-GeV/c electrons, muons, and pions. The photomultiplier response to a laser pulser, from which light is injected into the front of each wavelength-shifter plate, was also determined at that time. This procedure made it possible to recover the calibration after the calorimeters were installed in their final location in the H3 beam line.

Twenty-four of the Wall Calorimeter stacks are deployed symmetrically around the beam line at 6.5 m, covering a pseudorapidity range $2.4 \lesssim \eta \lesssim 4.4$. Taking into account the Plastic Ball, WA80 lacks the detectors necessary for the measurement of the transverse energy flux only in a region that is slightly larger than one unit of pseudorapidity, i.e. from $\eta \approx 1.3$ to $\eta \approx 2.4$. The remaining six stacks of the Wall Calorimeter, however, are located in this rapidity gap adjacent to the bulk of the calorimeter, and, together with LAM and with the original time-of-flight wall of the GSI-LBL Plastic Ball collaboration, they constitute a unique single-arm detector that is capable of sampling the baryon (p,d,t, through Li) distribution in this region, and is also expected to yield information on the distribution of neutrons and of antiprotons.

The Wall Calorimeter towers covering the forward mid-rapidity region are used to generate a prompt trigger signal, flagging events with high-E_T values. This is accomplished by means of weighted linear summing of dynode signals.

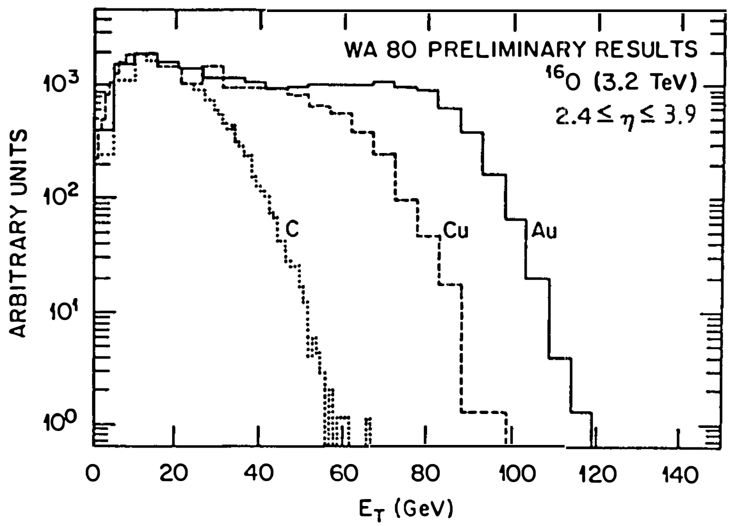

Fig. 2. Preliminary distributions of transverse energy measured in the pseudorapidity range of $2.4 < \eta < 3.9$ from interactions of 3.2-TeV ^{16}O nuclei with C, Cu and Au.

The preliminary transverse energy distributions are shown for 3.2-TeV ^{16}O reactions with various target nuclei in Fig. 2. The data were obtained by the same means as those of Fig. 1, and the same disclaimer regarding their preliminary nature to them. The results shown were obtained from the 24 Wall Calorimeter stacks, excluding the four inner towers and covering the pseudorapidity range of $2.4 \lesssim \eta \lesssim 3.9$. As in the case of the multiplicity results, the systematic errors in the E_T values extracted from the Wall Calorimeter are estimated to be less than 15%. The data of Fig. 2 are consistent, within the quoted errors, with the results of the NA35 collaboration.[11] While quantitative arguments are not given here, it is reasonable to conclude from both sets of data that the degree of nuclear stopping is high.

6. SAPHIR

The SAPHIR detector has been designed to investigate one of the promising signatures of the formation of QGP, the production of direct photons. Several production mechanisms have been considered. These include quark-antiquark annihilation, quark-gluon Compton scattering, and the quark matter equivalent of bremsstrahlung. It is believed that the direct photon spectrum is related to the temperature of the QGP. In order to be able to determine the spectrum of direct photons, the detector has to be capable of identifying the large background of photons from the decay of neutral pions and eta mesons. This can only be achieved by the reconstruction of the decaying-meson events, and the high-granularity SAPHIR is, therefore, also an excellent detector for the measurement of neutral pion spectra. It consists of 1278 active lead-glass modules, each of dimensions 3.5 x 3.5 x 46 cm, arranged to cover an area of 98.0 x 171.5 cm^2. The center of the front surface of the detector is located at 3.12 cm from the target and at 20° with respect to the beam direction, covering an approximate pseudorapidity range of $1.5 \lesssim \eta \lesssim 2.1$. The choice of module size is based primarily on the results of the GAMS collaboration,[12] and the 18 radiation lengths of SF5 lead-glass gurantee a 98% shower containment for 30-GeV photons.

Prototype detector tests have been carried out at DESY with electrons of 0.6 to 6 GeV, and extensive further tests and calibrations have been carried out at the CERN PS and SPS accelerators. The results were found to be either consistent with, or somewhat superior to, design expectations. The energy resolution σ/E was found to be $(6.0\%/\sqrt{E} + 0.4\%)$, corresponding to a π^0 (η^0) mass resolution of a few percent dependent on the π^0 (η^0) energy. The position resolution is better than 4 mm, and adjacent shower separation is possible for distances greater than 2.4 cm at the surface of the detector. The π^0 reconstruction efficiency rises from 20-30% at low (0.2-0.3 GeV/c) values of the pion transverse momentum, $p_\perp$, to about

80% at 2 GeV/c and about 90% at 6 GeV/c. At still larger values of $p_\perp$, the π^0 efficiency decreases. A sharp π^0 peak was obtained in the invariant mass spectrum, reconstructed on-line, for events with $E_{\gamma\gamma}$ energies greater than 2.5 GeV, and distinct π^0 peaks were also obtained at lower $E_{\gamma\gamma}$ energies. SAPHIR is another component of the prompt trigger system, flagging events with a minimum number of high-energy photons. As in the case of the Plastic Ball and the Wall Calorimeter, its calibration and stability are determined by means of a laser pulser.

Among the preliminary quantities of interest extracted from SAPHIR are the average values of the transverse momentum of neutral pions, $\langle p_\perp \rangle \pi^0$, and the slopes of the neutral transverse energy distributions, dN/dE_T. The $\langle p_\perp \rangle \pi^0$ values were correlated with maximum values of the charged-particle multiplicity, $(dN_c/d\eta)$ max. For 3.2-TeV ^{16}O + Au $\langle p_\perp \rangle \pi^0$ was found to be constant at about 500 MeV/c for $(dN_c/d\eta)$ max values between 30 and 80. For values of $(dN_c/d\eta)$ max greater than 100, somewhat higher values of $\langle p_\perp \rangle \pi^0$ (up to 550 MeV/c) were observed. At 960-MeV ^{16}O + Au, $\langle p_\perp \rangle \pi^0$ was found to be approximately 420 MeV/c. The inverse slopes of the neutral E_T distribution were found to be similar for the three targets (C, Cu and Au), ranging from about 200 MeV to about 250 MeV. These two findings are in qualitative agreement with hydrodynamical predictions[13] and with predictions of pion radiation from a hot plasma[14] but are inconsistent with both the LUND and HIJET models.

7. Zero-Degree Calorimeter

The final WA80 detector to be discussed is the Zero-Degree Calorimeter (ZDC). This 8-ton uranium-plastic sampling calorimeter is located behind the 7.5 cm by 7.5 cm beam line hole in the Wall Calorimeter, and is a key component of the trigger system. The three primary design considerations were near-total containment for protons of 225 GeV, excellent energy resolution, and fast count-rate capability. A design criterion, based on simulation calculations, was the ability of the ZDC to distinguish between the simultaneous incidence of either 15 or 16 nucleons of 50 GeV. The dimensions of the ZDC are

60 cm x 60 cm x 189 cm, with an electromagnetic section of 172 cm.

The main purpose of the ZDC is to characterize the degree of violence of each collision by measuring the remaining energy of the projectile spectators. In some collisions between ^{16}O projectiles and Au nuclei, no energy was observed in the ZDC, while in reactions between ^{16}O and C nuclei, some projectile fragmentation energy was always observed, as might be expected from the relative sizes of the colliding nuclei. This effect is seen in Fig. 3, which shows the charged-particle multiplicity as a function of the observed energy in the ZDC for reactions of 3.2-TeV ^{16}O with C, Cu and Au. At the high-energy end, the cutoff at 2.7 TeV is determined by the trigger adjustment. There is no low-energy experimental cutoff in the data of Fig. 3. The vertical dashed lines indicate widths (σ) of the multiplicity distributions.

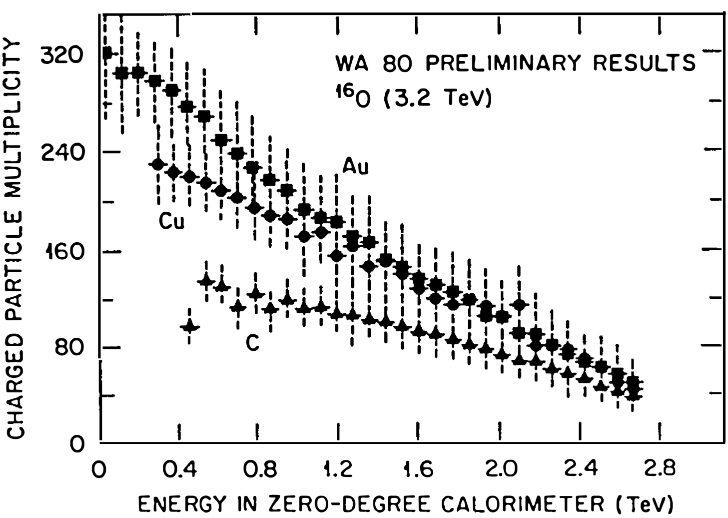

Fig. 3. Preliminary total charged-particle multiplicity as a function of the energy observed in the Zero-Degree Calorimeter from interactions of 3.2-TeV ^{16}O with C, Cu and Au. The vertical dashed lines are not error bars. They indicate the widths (σ) of the multiplicity distributions.

8. Estimates of Energy Densities

An estimate of the range of energy densities, ε, produced in the central collisions is of crucial interest due to its relevance to the possible formation of the QGP. Unfortunately, no simple, reliable method exists to extract this quantity from the measured data. The following expression is often used in cosmic-ray studies and is due to Bjorken.[15]

$$\varepsilon = \frac{3}{2} \frac{\left(\frac{dN_c}{dy}\right)_{y=0} \langle M_\perp \rangle}{\pi R^2 \, ct_0} \quad (\mathrm{GeV/fm^3}),$$

where $M_\perp = \sqrt{p_\perp^2 + m_\pi^2}$, R = radius of reaction cylinder (~R projectile), and $t_0 \approx 1$ fm/c. The charged-particle multiplicity distribution dN_c/dy is approximated by $dN_c/d\eta$. Since we have measured charged-particle multiplicities (in MIRAM) correlated with energies (in the Wall Calorimeter), it is possible, using this prescription, to calculate, event by event, distributions of events in a $\langle p_\perp \rangle$ (average transverse momentum per particle) vs. energy density diagram. We have generated such distributions from our preliminary data for ^{16}O + Au at 60 and 200 GeV/nucleon. In both cases, the peak of the $\langle p_\perp \rangle$ distributions is estimated to be at about 350 MeV/c for central events. In the energy density dimension, the peaks are located at about 0.7 and 1.3 GeV/fm^3 for the 60 and 200 GeV/nucleon cases, respectively, with tails extending to about 1.1 and 2.0 GeV/fm^3. Due to both the ad hoc nature of the above prescription and due to the limited number of events used to generate the distributions, the crude, qualitative, nature of the above discussion is stressed, and the numbers are not to be quoted.

9. Concluding Remarks

In summary, we have presented preliminary WA80 data from interactions of ^{16}O with C, Cu and Au at 60 and 200 GeV/nucleon. These have included total charged-particle multiplicity distributions and transverse energy distributions. Ranges of transverse momentum per particle and of possible energy densities were discussed. Some of the unique features of WA80 were stressed. These are: (1) complete coverage of the target rapidity region, (2) complete coverage of charged-particle multiplicity measurement, and (3) measurement of intrinsic photons. WA80 was the only experiment with no magnetic analysis and the only large-scale experiment to obtain production data during the 1986 run which did not involve, primarily, the reconfiguration of an existing SPS experiment. From the point of view of the WA80 collaboration, the 1986 ^{16}O running period was very successful, and we wish to commend all members of the CERN, GSI, and LBL accelerator groups that have made the remarkable operation of the SPS with ^{16}O ions possible.

REFERENCES

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6. University of Tennessee, Knoxville, Tennessee 37996.
7. N. Angert et al., in Quark-Matter Formation and Heavy-Ion Collisions, M. Jacob and H. Satz, editors, World Scientific Publishers, Singapore, 1982, p. 557.
8. R. Albrecht et al., Report No. GSI-85-32, Gesellschaft für Schwerionenforschung, D-6100 Darmstadt, West Germany (August 1985).
9. A. Baden et al., Nucl. Instrum. Methods Phys. Res. 203,189 (1982).
10. T. Akesson et al., Nucl. Instrum. Methods Phys. Res. A241, 17(1985).
11. A. Bamberger et al., preprint CERN/EP 86-194 and paper presented at this conference.
12. F. Binon et al., Nucl. Instrum Methods 188,507(1981).
13. E.V. Shuryak, Phys. Rep. 61,71(1980); L. van Hove, Phys. Lett. 118B,138(1982); M. Kataja et al., Phys. Rev. D34, 2755(1986).
14. M. Danos and J. Rafelski, Phys. Rev. D27,671(1983) and reprint UFTP 94/1982.
15. J.D. Bjorken, Phys. Rev. D27,140(1983).

* Operated by Martin Marietta Energy Systems, Inc. under contract DE-AC05-84OR21400 with the U.S. Dep. of Energy.