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NA35 COLLABORATION

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STUDY OF THE ENERGY FLOW IN ^{16}O - NUCLEUS COLLISIONS AT 60 AND 200 GEV/NUCLEON

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Abstract: We report a systematic study of midrapidity E_T production and forward energy flow in the interaction of ^{16}O projectiles on Al, Cu, Ag and Au at 60 and 200 GeV/nucleon. First results on E_T production with ^{32}S projectiles are presented.

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1. INTRODUCTION

Forward energy flow and transverse energy production in ultrarelativistic nucleus - nucleus interactions depend on the centrality of the collision and on the degree of stopping that takes place in each collision. It appears that sufficient stopping occurs, making it possible to reach energy densities in central collisions high enough for matter to undergo a phase transition into an unconfined, chirally restored state as has been predicted by lattice QCD calculations [1].

A systematic study of the interactions induced by 60 and 200 GeV/nucleon ^{16}O projectiles with Al, Cu, Ag, and Au nuclei has been performed by the NA35 collaboration at the CERN SPS. Here we present the results on the forward energy flow, on the transverse energy production, and on the pseudorapidity distribution of transverse energy from peripheral up to the most central collisions. Preliminary results have been published in [2]. For the same reactions the cross sections and charged multiplicities have been reported in [3], rapidity and transverse momentum distributions for charged particles in [4], two pion interferometry and the space-time distribution of the pion emitting source in [5] and the strange particle production in [6]. We also present here first results for the interaction of 200 GeV/nucleon ^{32}S with Au.

2. EXPERIMENTAL SETUP

The experiment was designed with the aim of doing a survey study of ^{16}O and ^{32}S induced reactions on a variety of targets. It consists of a Streamer Chamber in a superconducting Vertex Magnet followed by a set of calorimeters which covers the pseudorapidities forward of 2.0 [7]. A perspective view of the calorimeters in the experimental setup, without the Vertex Magnet and the Streamer Chamber, is shown in Fig. 1. The beam particles are selected by a 5 mm quartz Cherenkov counter 25 m upstream of the target. This counter has single charge resolution up to ^{32}S . A series of scintillator veto counters downstream of it, the innermost one having a hole of 1 cm diameter, rejects events with halo particles or interactions in the quartz. The beam is then selected again with a 300 μm thin scintillator counter which is in coincidence with the quartz Cherenkov counter. The targets are placed at the entrance of the Streamer Chamber. A thickness of 1 % of an interaction length for ^{16}O has been used for Au, Ag, Cu and Al. Behind the Streamer Chamber, 4 m downstream of the target, a 3 cm diameter, 1 mm thick scintillator counter (S4) is used to provide an interaction trigger by selecting events which produce a pulse height that is less than that of the projectile. The forward angles are covered by a set of four calorimeters to measure the energy flux of the emitted reaction products. The angular domain $\theta < 0.3^\circ$, which corresponds to the projectile fragmentation region, is covered by a 4-segment "Veto" calorimeter. The subsequent interval, from $0.3^\circ - 2.2^\circ$, is seen by a single cell electromagnetic and hadronic Intermediate Calorimeter, with an outer diameter of 53 cm. The larger angle domain is covered by the Photon Position Detector (PPD), an electromagnetic calorimeter of high granularity, consisting of alternating layers of lead and planes of proportional tubes read out by 3072 ADC channels. The PPD is 3 m x 3 m in size with an inner square hole of 50 cm x 50 cm and has a thickness of 9.8 radiation lengths and 0.5 interaction lengths. This calorimeter is backed up by the Ring Calorimeter which has a barrel shape and is 3 m in diameter with an inner hole of 56 cm diameter. It is subdivided into 240 cells, 24 in azimuth and 10 radially with the ring size chosen so as to cover equal units in pseudorapidity. The PPD and Ring Calorimeter can be moved together and were positioned at each energy so as to best cover midrapidity. The resulting acceptances for the PPD and Ring Calorimeter are shown in Fig. 2 and are summarized in Table 1.

Three different types of triggers were used in the experiment: the interaction trigger with the S4 scintillator, a trigger on the Veto Calorimeter signal which selects events that have a leading energy less than a certain threshold, and a trigger on the E_T seen by the PPD (66 % of its signal is of electromagnetic origin). During the experiment all these triggers have been run with the field of the Vertex Magnet switched off, to preserve the axial symmetry important for the calorimetric study, and with a 1.5 T field which allows for charged particle momentum measurements in the Streamer Chamber. In the present report all of the data were taken in the field off configuration except where it is explicitly noted.

All NA35 calorimeters except the Intermediate Calorimeter have been used in previous experiments (NA5, NA24). Their behavior and calibration has been studied in detail and is published in [8], [9]. It is known that the response to electrons is linear down to energies below 1 GeV. For hadrons the response has been studied down to 10 GeV only, which is the lowest hadron energy that the H2 beamline of the CERN SPS can deliver. No calibration was possible at another beamline since our calorimeters do not have a modular structure, which would have enabled us to transport at least part of it; nevertheless, in tests of a prototype of the Ring Calorimeter a linear response to hadrons was seen down to 2 GeV. For the present analysis the response has been assumed to be linear. This introduces a systematic uncertainty of about 10 – 15% in the determination of the transverse energy, E_T , because of the large abundance of hadrons with $E < 2$ GeV in the PPD/Ring Calorimeter acceptance in the field – off configuration. The e/π ratio was found to be 1.6 for the PPD and the energy resolution σ/E for electromagnetic and hadronic showers in the calorimeter system was found to be 30%/ $\sqrt{E}$ and 100%/ $\sqrt{E}$ respectively. The calibration has been repeated for selected positions before the ^{16}O run with electrons and hadrons of several energies.

3. DATA ANALYSIS

With the Streamer Chamber situated directly behind the target, material of several percent of an interaction length is unavoidable in the path of the beam. For a minimum bias trigger, this leads to a high trigger rate for events whose interaction was not in the target. In order to have a reasonable fraction of target interactions in the recorded data, a target thickness of 1 % of an interaction length was used, which is a compromise between the fraction of good events and the need to reduce the probability of secondary interactions and e^+e^- pair production in the target. To test whether the E_T distributions could be affected by secondary interactions in the Streamer Chamber body, which is thicker than the target, two target positions were used for the 60 GeV/nucleon ^{16}O run, one with the target at the entrance of the Streamer Chamber, the second with the target downstream of the chamber but maintaining the same distance from the target to the calorimeters. We found that after target – out subtraction, there was no difference between the spectra. Therefore, for the calorimeter data in the observables reported here secondary interactions can be neglected. For the minimum bias and the medium hard triggers it was essential to collect approximately the same number of events for target in and target out. For low E_T the statistical errors are relatively large due to the large background subtraction. In constructing the final distributions, up to four different trigger thresholds have been used besides the interaction trigger, the harder ones being essentially background free.

The transverse energy, E_T , is calculated for each event by summing up the appropriately weighted energies found in each individual PPD and Ring Calorimeter channel. The weights are calculated as $\sin \theta_i$, with θ_i determined by the PPD wire distance from the beam or the distance from the center of the Ring Calorimeter cell to the beam and the distance from the target to the respective calorimeter, taking into account the average shower development in depth. The cartesian PPD readout is corrected for by an overall factor of $\pi/4$. For dead or noisy PPD channels a correction that replaced their signals by the average of their neighbours has been applied. For the 200 GeV/nucleon configuration eight cells in the upper and lower part of the outermost ring of the Ring Calorimeter are shadowed by the Vertex Magnet. In the 60 GeV/nucleon case, with the target upstream of the Streamer Chamber their number increased to 20. These cells were given a zero weight, the unshadowed ones being weighted up to compensate for the missing azimuth. The central quadratic hole of the PPD leaves several Ring cells uncovered. For the two inner rings only cells with the PPD in front are used, weighted up to compensate for the loss of coverage.

On the average 98 % of the electromagnetic energy incident on the midrapidity calorimeters is contained in the PPD. Depending on the wire position, a varying fraction of between 20 % and 50 % of the PPD signal is of hadronic origin. This fraction was estimated from the response of the PPD wires in events with the magnetic field on and off in the region where the field sweeps out all of the charged particles. In the calculation of the total E_T this fraction, multiplied by the e/π ratio of 1.6, has been added to the hadronic energy. The remaining electromagnetic energy has a large systematic uncertainty, of about 20 %, due to this correction.

No attempt was made to reconstruct individual showers in the calorimeters. Instead, the effect of the shower spread in the response of the different cells was obtained from a Monte Carlo study using Fritiof generated events [10] together with a parametrization of the lateral shower spread. The shower profiles in the Ring Calorimeter for the hadron calibration data were fitted with a sum of two exponentials as a function of the radius. The combination of the shower spread with the radial energy gradient results in an effective energy transport from the inner to the outer rings. The largest effects were a 20 % higher response in the inner ring due to leakage from the Intermediate Calorimeter, and a 10 % loss in the outer ring due to leakage out of the calorimeter. These corrections were applied when calculating the total E_T and the E_T in each ring.

In order to calculate the pseudorapidity distributions $dE_T/d\eta$ the information from the Ring Calorimeter (with $\Delta\eta = 0.166$ in each ring) and from the PPD with its cartesian readout had to be combined. The PPD response was unfolded in an iterative way to obtain a radial distribution. Starting with the assumption of a flat pseudorapidity distribution the results of the first unfolding were used as input for the second iteration. The procedure converged after the second iteration.

The systematic error in the total E_T scale is estimated to be 15 %, while the scale in the electromagnetic $E_{T\text{em}}$ spectra is uncertain by 20 %.

4. RESULTS

The Veto Calorimeter energy spectra (E_{veto}) are shown in Fig. 3. The $^{16}\text{O} + \text{Au}$ spectra for 60 and 200 GeV/nucleon are compared on a relative energy scale normalized to the beam energy. Obviously, the probability for having almost no energy going forward is higher for 60 GeV/nucleon than for 200 GeV/nucleon. The opening in the Intermediate Calorimeter that served as an aperture for the Veto Calorimeter was $60 \times 65 \text{ mm}^2$ (at an effective distance from the target of 8.0 m (6.6 m) for 200 (60) GeV/nucleon). The E_{veto} spectra for different targets (Cu, Ag, Au) at 60 GeV/nucleon are shown in Fig. 3b. The difference in collision geometry for different target sizes results in different probability distributions for the projectile nucleons to remain spectators during the interaction [11]. This fact is reflected by the E_{veto} spectra because projectile spectators give the main contribution to the E_{veto} signal. For Au a central collision peak is seen at low E_{veto} values. All E_{veto} spectra shown here were taken with the minimum bias S4 trigger. The position of the S4 counter and the trigger threshold were kept constant for all targets and for both energies. The change of the kinematics with the bombarding energy make a difference in its acceptance for projectile fragments which resulted in different values for the integrated cross section for 60 and 200 GeV/nucleon. Most of the time the NA35 experiment had to be transparent to the beam so that NA36, situated downstream in the same beamline, could run simultaneously. As a consequence our forward energy flow studies could not be as comprehensive as the results on E_T spectra.

Controlled by the impact geometry of a collision, E_{veto} and E_T are anticorrelated as can be seen in Fig. 4 for a minimum bias trigger for $^{16}\text{O} + \text{Au}$ at 200 GeV/nucleon. Central collisions lead to low E_{veto} and high E_T , a fact that was used to select such events by triggering on E_{veto} or E_T PPD for Streamer Chamber data taking. It is in the actual shape of this correlation that one can make the most stringent tests of model predictions regarding calorimeter observables. Lacking the Veto Calorimeter information for most of the systems and since two – dimensional distributions are hard to show quantitatively the target mass and bombarding energy systematics will be presented as projected E_T distributions.

Differential transverse energy distributions for ^{16}O at 200 GeV/nucleon on Al, Cu, Ag and Au targets are shown in Fig. 5 and Fig. 6. The total transverse energy in the calorimeter acceptance E_T and the electromagnetic component only, $E_{T\text{em}}$, show similar distributions characterized by a rapidly varying cross section for peripheral collisions, followed by a long plateau which ends in a steep fall off. At 60 GeV/nucleon the same is true as can be seen in Fig. 7 and Fig. 8 for Cu, Ag and Au targets. The spectral shapes are basically determined by the geometry of the colliding nuclei. This was con-

cluded from a variety of models [12] that take the impact parameter dependent geometry into consideration to describe our published data and simultaneously spectra for p - p , p -nucleus, and nucleus-nucleus interactions measured by other experiments. The integrated cross sections of the spectra shown here are different from the reaction cross sections reported in [3] in which the Streamer Chamber pictures were scanned with an interaction criterion and corrections for trigger bias and electromagnetic dissociation were applied. For $^{16}\text{O} + \text{Au}$ at 200 GeV/nucleon E_{T}^{em} is roughly one fifth of the total E_{T} with spectral shapes being slightly different. A ratio of 1:3 between electromagnetic and total E_{T} is expected for the produced pions. The small fraction of the total E_{T} that we find to be electromagnetic could be explained if more than 40 % of the transverse energy in the calorimeter acceptance are non-pionic in origin. Fritiof generated events [10] show a 1 : 3.2 ratio for the same acceptance with 19 % of the E_{T} being non-pionic.

In our first published results on E_{T} spectra [2] it was demonstrated that the central collision peak of an $^{16}\text{O} + \text{Pb}$ E_{T} spectrum at 200 GeV/nucleon can be understood in position and shape as a 16-fold convolution of a $p + \text{Au}$ spectrum for nonperipheral collisions. Not all of the corrections in the extraction of E_{T} described here had been included in [2] and in particular, the innermost ring of the Ring Calorimeter was excluded from the acceptance. These changes, including the larger acceptance employed in the present study, have led to higher observed E_{T} values but they leave the conclusion employed in the present study, as it relied on the relative p -nucleus and ^{16}O -nucleus data only.

The PPD and Ring Calorimeter do not have identical acceptance in pseudorapidity as seen in Fig. 2. Because the center of mass rapidity in the laboratory frame (calculated for the system consisting of the target and the projectile participant nucleons in central collisions) lies close to the acceptance limit (see Fig. 2) the effect of this small difference is magnified when we compare spectra for 200 GeV/nucleon with those for 60 GeV/nucleon. The calorimeters were moved closer to the target by 1.5 m for the 60 GeV runs. By this, the acceptance coverage at the two energies was such that it included the transverse energy produced close to the participant cm for all the targets used. Therefore if the shape of the transverse energy distribution is given by the impact parameter geometry, then for a given target it should scale with bombarding energy where the scaling factor is given by the relative stopping power and the calorimeter acceptance. That this is the case is shown in Fig. 9, where for $^{16}\text{O} + \text{Au}$ the 60 GeV/nucleon $d\sigma/dE_{\text{T}}$ is compared to the 200 GeV/nucleon spectra with E_{T} scaled down by a factor of 0.58. The same excellent agreement is seen for all targets both in $d\sigma/dE_{\text{T}}$ and $d\sigma/dE_{\text{T}}^{\text{em}}$. The scaling factors are listed in Table 2. They are different for different targets and not the same for E_{T} and E_{T}^{em} , as one expects for not having identical relative acceptance coverage in pseudorapidity (the scaling factors are higher for lighter targets because at 60 GeV/nucleon the center of mass rapidity of the participant nucleons is positioned more symmetrically within the calorimeter acceptance, see Fig. 2). The average scaling factor, of about 0.65, between the E_{T} generated at 60 GeV/nucleon and at 200 GeV/nucleon indicates a slightly higher stopping power to prevail at the lower energy since the total center of mass energy ratio is only 0.55. In previously reported results of the WA80 collaboration [11] the E_{T} spectra are found to be drastically different in shape for the two energies. This occurred because the acceptance was not changed to correspond to the beam energy; their maximum observed E_{T} thus saturated already for intermediate mass targets for 60 GeV/nucleon because for heavier targets more of the produced E_{T} lay outside the detector acceptance [11]. We conclude that for any comparison of the energy and target dependence of E_{T} spectra found by different experiments (WA80, NA34, NA35) acceptance differences have carefully to be taken into consideration.

Using a naive uniform sphere model the number of target participants has been calculated for central collisions on different targets and is given in Table 3 together with $E_{\text{T}}^{\text{max}}$, the maximum transverse energy that could be observed in a hypothetical 4π calorimeter if all the energy of the projectile plus target participants were to be emitted isotropically in their center of mass frame, for instance by a perfectly thermalized fireball produced by the interaction of the participants. The kinematic limits are calculated for the head-on collision of a projectile with B nucleons on a target with A nucleons. For $B < A$ the number of participants is $n_{\text{part}}(\text{total}) = n_{\text{part}}(\text{projectile}) + n_{\text{part}}(\text{target})$ where the number of projectile participants $n_{\text{part}}(\text{projectile}) = B$ in a central collision and the number of target participants is given by

$$n_{\text{part}}(\text{target}) = A - B \left[(\Lambda/B)^{2/3} - 1 \right]^{3/2}. \quad (1)$$

The energy that can be seen by calorimetry is $\sqrt{s}$ minus the rest mass of the participants, and for a completely thermalized system the maximum transverse energy is $E_{\text{T}}^{\text{max}} = (\pi/4) (\sqrt{s} - m_{\text{part}})$. Fig. 10 shows the A dependence of the number of target participants, the total number of participants and of $E_{\text{T}}^{\text{max}}$. The $E_{\text{T}}^{\text{max}}$ dependence for the ^{16}O projectile is very close to $A^{0.2}$, and $E_{\text{T}}^{\text{max}}(60 \text{ GeV/nucleon}) = 0.5 E_{\text{T}}^{\text{max}}(200 \text{ GeV/nucleon})$ for all targets.

If one accepts $E_{\text{T}}^{\text{max}}$ for each target and energy as a natural scale in which the observed E_{T} should be measured, one can replot the results for all targets at each energy as shown in Fig. 11. We see that the average central collision, as defined by the shoulder at the end of the plateau for heavy targets, scales with $x = E_{\text{T}}/E_{\text{T}}^{\text{max}}$ and produces at 200 GeV/nucleon 27 % of the maximum transverse energy in our acceptance (32 % at 60 GeV/nucleon). The probability to have an average central collision is increasing with the target mass by a factor of 7.5 from Al to Au. The fluctuations to higher E_{T} from this average are large and up to 60 % at the cross section level of 1 mb. It is surprising to see that all the distributions converge for large x , that is they scale with $E_{\text{T}}^{\text{max}}$. For these events the transverse energy per participant nucleon in our calorimeters decreases from 2.9 GeV for Al to 2.4 GeV for Au targets at 200 GeV/nucleon.

Our result that E_{T} scales approximately with $E_{\text{T}}^{\text{max}}$ and therefore with $A^{0.2}$ has to be compared with the results reported by the NA34 collaboration [13] that in the adjacent backward pseudorapidity region $-0.1 < \eta < 2.9$ the A dependence is much stronger since it scales with A^α , with $\alpha = 0.48 \pm 0.02$ and 0.53 ± 0.04 for 60 and 200 GeV/nucleon. The A dependence has been extracted in [13] in a slightly different way, which changes the exponent α insignificantly. The different apparent A dependence of E_{T} in various parts of longitudinal phase space, may be qualitatively understood from the central collision geometry of a mass B projectile on a mass A target where $B < A$. In a central $^{16}\text{O} + \text{Au}$ collision, for example, 16 projectile participants interact with a cylinder in the target containing about 53 nucleons (from eq. (1)). Viewed in the center of mass frame, this leads to an asymmetry in the stopping-down of the energy initially contained in the target (projectile) participants: about three target nucleons fall into the projected path of a projectile nucleon whereas the target participants each interact only about once. In the first generation of binary nucleon collisions the 16 projectile nucleons interact with the first 16 target nucleons. The 'wounded' projectile nucleons (their leading partons) then cause the subsequent interactions with the remaining about 37 target nucleons. No detailed QCD model exists to treat such parton-nucleon interactions. However, as net result of the overall interaction one expects to find the energy (parton) content of the projectile shifted downwards in rapidity in proportion to the length of the target cylinder (proportional to $A^{1/3}$), whereas the target participants are shifted upwards only proportional to $B^{1/3}$. The generated E_{T} from projectile stopping thus should gather at about $2.5 < \eta < 4.5$ whereas the target fraction of E_{T} gathers at about $0.5 < \eta < 2.5$. The latter fraction is proportional to the number of target participants. Inspecting Fig. 10b, and eq. (1), we observe that this quantity (which naively should be proportional to $A^{1/3} B^{2/3}$) in fact can be parametrized to increase like $A^{0.42}$ thus explaining the NA34 result for $-0.1 < \eta < 2.9$. The acceptance of our calorimeters, on the other hand, contains the E_{T} mostly from the projectile degradation. This should scale as $A^{1/3}$ for independent subsequent nucleon-nucleon collisions. However, since the collisions following the first generation are of parton-nucleon nature, the dependence may well reduce to the observed $A^{0.2}$. This coincides with the dependence of the kinematical E_{T} limit (see Fig. 10a) in $^{16}\text{O} + \text{nucleus}$ central collisions, thus also suggesting an explanation to the apparent scaling with $E_{\text{T}}^{\text{max}}$ obvious from Fig. 11.

For 60 GeV/nucleon we see in our acceptance more than 50 % of the transverse energy observed at 200 GeV/nucleon (see Table 2). One would expect a ratio of 1 : 2 for equal relative coverage of the transverse energy pseudorapidity distribution if the same relative stopping occurred at both energies. Our knowledge about pseudorapidity distributions (especially for events in the tails of the E_{T} spectra) is very limited so that it is difficult to give an estimate on what fraction of the totally produced E_{T} we see in our detectors. The acceptance coverage looks less favorable for 60 GeV/nucleon (see Fig. 2). Nevertheless, we infer from Fig. 11 that the relative stopping is 20–25 % higher for 60 GeV/nucleon. Assuming a gaussian shape for the pseudorapidity distribution to extrapolate into acceptance regions not covered by their detectors, the WA80 collaboration also infers a higher relative stopping for the lower beam energy [11]. For the $^{16}\text{O} + \text{Au}$ spectra we find for the central collision peak in Fig. 11

the position $x = 0.25$ (0.30) for 200 (60) GeV/nucleon. If we assume that we accept roughly 50 % of the totally produced E_T we come to 50 (60) % relative stopping for average central collisions. Fig. 11 indicates the possibility that considerably higher stopping occurs for the events in the tails of the E_T distribution.

The data from the 1987 200 GeV/nucleon ^{32}S run at the CERN SPS allow for a study of the dependence of the transverse energy production on the projectile mass. In Fig. 12 the comparison of $^{16}\text{O} + \text{Au}$ and $^{32}\text{S} + \text{Au}$ is shown. The transverse electromagnetic energy $E_{T\text{em}}$ seen by the PPD shows an increase of about 70 % for central collisions as the projectile mass is increased. This is in good agreement with the upward shift of the kinematic E_T limit, $E_{T\text{max}} = 692$ GeV for $^{32}\text{S} + \text{Au}$ being a factor 1.77 higher than for the oxygen projectile. This factor is smaller than the intuitively expected factor two because of the different ratio of target and projectile participants (for $^{32}\text{S} + \text{Au}$, central collisions we have 81 target participants compared to 53 for $^{16}\text{O} + \text{Au}$). Also the impact geometry has changed (more projectile nucleons hit the target with large impact parameter even if the sulfur hits centrally), and the probability increased that a projectile nucleon interacts with target material that has already been boosted by an interaction with a first incoming nucleon. We see that the simple argument that explained the central $^{16}\text{O} + \text{Au}$ collision peak as a 16-fold convolution of a p-nucleus spectrum [2] breaks down for the sulfur projectile.

Pseudorapidity distributions $dE_T/d\eta$ for 200 GeV/nucleon $^{16}\text{O} + \text{Au}$ for two different E_T -PPD triggers and for a hard Veto trigger, are presented in Fig. 13. The effect of the triggers is shown in a) and b) which show the corresponding $E_{T\text{PPD}}$ and total E_T distributions together with the unbiased distributions. Characteristics of triggers I-III are compiled in Table 4. The $dE_T/d\eta$ distribution is shifted backwards towards the lower η region for the harder E_T trigger (I) compared to the hard Veto (III) and the not so hard E_T (II) trigger distributions. This is shown more explicitly in Fig. 13d where the distributions are normalized in each η bin to the Veto trigger. The pseudorapidity distribution for events with the highest E_T is markedly different from that for the more average central event selected by the Veto trigger.

Events corresponding to the hard E_T -PPD trigger (trigger I) reach a maximum value of $dE_T/d\eta$ of 91 GeV at the low η edge of the calorimeter acceptance. The energy density of these events can be estimated using the Bjorken formula [14] $\epsilon = (dE_T/d\eta)_{\text{max}} / (\tau R^2)$. Taking $R = 3$ fm and $\tau = 1$ fm one obtains an energy density of $\epsilon = 3.2$ GeV/fm³. WA80 and NA34 report similar results for the energy densities they extracted by the same method [11], [13]. The question whether thermalisation can take place within the short formation time $\tau = 1$ fm commonly used in the Bjorken formula has no answer up to now, but the energy densities that can be achieved in $^{16}\text{O} + \text{nucleus}$ collisions seem to be sufficiently high to open up the possibility of quark matter production. For $^{32}\text{S} + \text{Au}$ we found 70 % higher transverse energies (see above). The geometrical cross section of ^{32}S is a factor 1.59 higher so that we can expect only slightly higher energy densities for the sulfur reactions, however in a more extended interaction volume.

5. MEASUREMENTS WITH MAGNETIC FIELD

The results discussed so far have been obtained from data taken during the relatively short periods of the ^{16}O run specially dedicated to calorimeter studies in which the magnetic field was switched off in order to preserve the azimuthal symmetry. Since the bulk of the data was taken with the Streamer Chamber magnet on, it is of interest to study the calorimeter response under this modified condition.

The dipole Vertex Magnet has an analyzing power of 4.32 Tm which effectively sweeps out of the calorimeter acceptance all low energy charged particles, and gives an extra 1 GeV p_T kick along the horizontal plane to the high momentum ones. In order to use the Veto Calorimeter as a trigger to select central collisions, its acceptance was increased asymmetrically in the horizontal direction so as to detect also the deflected projectile fragmentation protons. With this modification it was found to behave in the same way as with the field off in selecting events according to the violence of the collision.

The PPD sees essentially all the electromagnetic energy within its acceptance but also a fraction of the hadronic energy, that is redistributed by the magnetic field. In its use as a trigger device it was found to be rather insensitive to the field and performed as well as with field off. The correlation between Streamer Chamber variables and the Calorimeter information with field on is under study. Here we want to present an example of the additional information one can obtain for field on from the calorimeter observables by themselves.

In Fig. 14a one sees the E_T measured by the Ring Calorimeter cells in a hard $E_{T\text{PPD}}$ trigger run ($< E_{T\text{PPD}} > = 43.6$ GeV, $\sigma_{\text{int}} = 43$ mb). The charged particles are effectively swept out of the vertical axis region (valley) with only the neutral hadronic transverse energy remaining. To both sides of the vertical axis there is a large amount of E_T observed, with the net effect of an increase in the total transverse energy of the PPD and Ring Calorimeters of 25 %. Due to the positive charge excess one gets an horizontal left-right imbalance on the extra E_T produced by the field. As can be seen in Fig. 14b, this amounts to about 10 GeV for the limited NA35 mid-rapidity calorimeter acceptance, in agreement with the naive expectation that at least the charge of the eight projectile participant protons ends up in the calorimeters. Since the effect of the limited calorimeter acceptance is nontrivial a Monte Carlo study with a model predicting the flavor composition is needed to extract the information about the extra positive charge from the observed horizontal E_T imbalance. This will enable us to determine the rapidity distribution of the projectile valence quarks. Charge flow can thus be studied with the calorimeters in a kinematic region not accessible to the Streamer Chamber picture analysis.

6. CONCLUSIONS

Although calorimeters are not the instrument with which one can look event by event for the predicted striking signatures of quark matter formation, they are very useful to measure the energy flow in different regions of pseudorapidity and thereby classify the violence of the interaction. The systematic study of ^{16}O induced reactions on Au, Ag, Cu and Al at 60 and 200 GeV/nucleon has shown that the distribution of transverse energy produced in the region $2 < \eta < 4$ reflects very closely the geometry of the colliding nuclei. For the average central collision the transverse energy produced in the calorimeter acceptance is a constant fraction of the maximum E_T that would be produced by a completely thermalized participant system, independent of the target mass and corresponds to 27 % and 32 % at 200 and 60 GeV/nucleon. At the tail of the distributions much larger E_T s are produced reaching 50 % of $E_{T\text{max}}$ at 60 GeV/nucleon. For this class of events the observed E_T per participant nucleon is the highest for the more symmetric $^{16}\text{O} + \text{Al}$ system being 2.9 GeV/participant at 200 GeV/nucleon and decreasing for larger target mass. The maximum energy densities observed for 200 GeV/nucleon $^{16}\text{O} + \text{Au}$ are in the region where quark matter formation can be expected. Going to a larger projectile with ^{32}S collisions we achieve similar energy densities in a more extended interaction volume. Forward energy flow and transverse energy production are excellent observables to select central collisions for further investigation. Calorimeter measurements with magnetic field open up the possibility to study charge balance beyond midrapidity and neutral baryon production in the rapidity interval from 1.5 to 2.5.

7. ACKNOWLEDGMENTS

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Table 3: Number of participants and their kinematical variables for ^{16}O induced central collisions.

	200 GeV/nucleon				60 GeV/nucleon			
Target	Au	Ag	Cu	Al	Au	Ag	Cu	Al
$n_{\text{part}}(\text{target})$	52.7	42.0	33.9	22.7	52.7	42.0	33.9	22.7
$n_{\text{part}}(\text{total})$	68.7	58.0	49.9	38.7	68.7	58.0	49.9	38.7
$Y_{\text{part}}^{\text{cm}}$	2.44	2.55	2.66	2.86	1.84	1.96	2.06	2.26
$E_{\text{T}}^{\text{cm}}(\text{GeV})$	391.5	351.6	317.4	261.0	193.9	175.0	158.6	131.0
$E_{\text{T}}^{\text{cm}}/n_{\text{part}}$	5.69	6.06	6.36	6.74	2.82	3.02	3.18	3.38

Table 4: Mean E_{T} and σ for three central collision triggers of 200 GeV/nucleon ^{16}O + ^{16}O .

	$\langle E_{\text{T}}^{\text{PPD}} \rangle$ (GeV)	$\langle E_{\text{T}}^{\text{Veto}} \rangle$ (GeV)	σ_{trigger} (mbarn)
PPD – trigger I	39.5	126.1	70.3
$E_{\text{T}}^{\text{PPD}} - \text{trigger II}$	33.7	112.3	346.0
Veto – trigger III	32.8	114.8	80.0

10. FIGURE CAPTIONS

Figure 1: Schematic view of the calorimetric part of the NA35 (Streamers Chamber and Vertex Magnet are not shown). The distance from the target to the front of the PPD was 5.00 m (6.40 m) for 60 (200) GeV/nucleon.

Figure 2: Azimuthal acceptance of the midrapidity calorimeters for 60 and 200 GeV/nucleon. The quadratic shape of the front face of the PPD produces a gradual onset of its acceptance. Indicated by arrows are the rapidities of the participant center of mass for the different targets (see Tables 1 and 3).

Figure 3: Energy spectra in the Veto Calorimeter for an interaction trigger. In a) the Veto energy is scaled by the beam energy to compare 60 and 200 GeV/nucleon ^{16}O + Au collisions (open and full circles respectively). The effect of the trigger onset is seen for $x_{\text{T}} > 0.9$. In b) spectra for three different targets are compared at 60 GeV/nucleon. (See Tables A – D).

Figure 4: Correlation between the transverse energy, E_{T} , observed in the NA35 acceptance and the forward energy flux, E_{Veto} , in the projectile fragmentation cone for 200 GeV/nucleon ^{16}O + Au collisions for minimum bias trigger. Target out yield has been subtracted. The contour distances correspond to factors of 2.

Figure 5: Transverse energy spectra for ^{16}O on Au (●), Ag (■), Cu (▲), and Al (◆) at 200 GeV/nucleon as seen in the NA35 acceptance (see Tables E – H).

Figure 6: Differential cross section $d\sigma/dE_{\text{T}}^{\text{cm}}$ as function of the electromagnetic transverse energy E_{T}^{cm} seen in the PPD for ^{16}O on Au (●), Ag (■), Cu (▲), and Al (◆) at 200 GeV/nucleon (see Tables I – L).

Figure 7: Transverse energy spectra for ^{16}O on Au (●), Ag (■), and Cu (▲) at 60 GeV/nucleon as seen in the NA35 acceptance (see Tables M – O).

Figure 8: Differential cross section $d\sigma/dE_{\text{T}}^{\text{cm}}$ as function of the electromagnetic transverse energy E_{T}^{cm} seen in the PPD for ^{16}O on Au (●), Ag (■), and Cu (▲) at 60 GeV/nucleon (see Tables P – R).

Figure 9: Transverse energy spectrum for ^{16}O + Au for 60 GeV/nucleon (●) together with a fit (solid line) to the corresponding spectrum at 200 GeV/nucleon scaled down in E_{T} by a factor of 0.58 (see Table 3).

Figure 10: a) Maximum observable transverse energy, $E_{\text{T}}^{\text{max}}$, as a function of the target mass number A for 60 GeV/nucleon (open symbols) and 200 GeV/nucleon (filled symbols). b) Number of participants, n_{part} , and number of target participants, $n_{\text{part}}(\text{target})$ for central ^{16}O + nucleus collisions as a function of A (See Table 4).

Figure 11: a) Transverse energy spectra scaled with $E_{\text{T}}^{\text{max}}$ for each individual target (see Table 4) at 200 GeV/nucleon for ^{16}O + Au (●), Ag (■), Cu (▲), and Al (◆). b) Scaled E_{T} spectra at 60 GeV/nucleon for ^{16}O + Au (●), Ag (■), and Cu (▲).

Figure 12: Differential cross section $d\sigma/dE_{\text{T}}^{\text{cm}}$ as a function of the electromagnetic transverse energy, E_{T}^{cm} , seen in the PPD for ^{32}S + Au (●) with the corresponding spectrum for ^{16}O + Au (○) for comparison at 200 GeV/nucleon. The ^{32}S spectrum is preliminary.

8. REFERENCES

References

- [1] L. McLerran, Rev. Mod. Phys. 58(1986)1021 and references therein; Proc. Fifth Int. Conf. on Ultrarelativistic Nucleus - Nucleus Collisions, Asilomar, Calif., eds. L. S. Schroeder and M. Gyulassy, Nucl. Phys. A461(1986).
- [2] NA35 Collaboration A. Bamberger et al., Phys. Lett. B184 (1987)271.
- [3] NA35 Collaboration A. Bamberger et al., submitted to Phys. Lett. B.
- [4] NA35 Collaboration H. Ströbele et al. contribution to Quark Matter 87, Nordkirchen.
- [5] NA35 Collaboration T. Humanic et al. contribution to Quark Matter 87, Nordkirchen.
- [6] NA35 Collaboration G. Vesztegombi et al. contribution to Quark Matter 87, Nordkirchen.
- [7] NA35 Collaboration A. Sandoval et al., Nucl. Phys. A461 (1987)465.
- [8] C. De Marzo et al., Nucl. Instr. Meth. 217(1983)405;
- [9] C. De Marzo et al., Phys. Rev. D29(1983)405;
- [10] M. De Palma et al., Nucl. Instr. Meth. 216(1983)393.
- [11] C. De Marzo et al., Phys. Rev. D36(1987)8;
- [12] M. Wilker, PhD. Thesis, Univ. Freiburg 1987;
- [13] C. Loos, Dipl. Thesis, Univ. Freiburg 1987;
- [14] F. Zetsche, Dipl. Thesis, Univ. Freiburg 1987.
- [15] B. Nilsson - Almqvist and E. Stenlund, Com. Phys. Comm. 43(1987)387;
- [16] B. Andersson et al., Phys. Rep. 97(1983)31;
- [17] B. Andersson et al., Phys. Scr. 34(1986)451;
- [18] B. Andersson et al., Lund Univ. Report LU - TP 86 - 3 (1986).
- [19] WA80 Collaboration R. Albrecht et al., Phys. Lett. B199(1987)297.
- [20] J. Fiacnik et al., Phys. Lett. B188 (1987)279.
- [21] G. Baym, P. Braun - Munzinger, V. Ruuskanen, Phys. Lett. B190 (1987)29;
- [22] J. Rant, Phys. Lett. B188 (1987)379;
- [23] A.D. Jackson, H. Boggild, Nucl. Phys. A470 (1987)669;
- [24] Liu Lian - sou, Meng Ta - chung, Peng Hong - an FUB - HEP/87 - 5 preprint.
- [25] NA34 Collaboration T. Akeson et al., CERN - EP/87 - 176 preprint.
- [26] J.D. Bjorken, Phys. Rev. D27 (1983)140.

9. TABLES

Table 1:	Acceptances of the NA35 midrapidity calorimeters	
	200 GeV/nucleon	60 GeV/nucleon
η interval	Ring Calorimeter acceptance	
$\Delta\eta$	[2.28, 3.94]	[2.08, 3.72]
$< \eta >$	1.66	1.64
	3.11	2.90
η interval with full ϕ coverage	PPD acceptance	
η interval with partial ϕ coverage	[2.18, 3.61]	[1.95, 3.37]
$\Delta\eta_{eff}$	[1.85, 3.96]	[1.62, 3.72]
$< \eta >$	1.78	1.77
	2.96	2.73

Table 2:	E_T scaling factors between the 60 and 200 GeV/nucleon ^{18}O data.		
Target	Au	Ag	Cu
$E_{T\,cm}$	0.58	0.61	0.63
E_T	0.68	0.70	0.72

Table D: $ds/dE_{\text{veto}}^{16\text{O}} + \text{Cu } 60 \text{ GeV/nucleon}$.

E_{veto}	Bin Width	ds/dE_{veto}	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
30.0	60.0	0.127E-02	0.800E-04
90.0	60.0	0.175E-02	0.983E-04
150.0	60.0	0.176E-02	0.112E-03
210.0	60.0	0.148E-02	0.124E-03
270.0	60.0	0.130E-02	0.133E-03
330.0	60.0	0.155E-02	0.155E-03
390.0	60.0	0.130E-02	0.168E-03
450.0	60.0	0.116E-02	0.177E-03
510.0	60.0	0.143E-02	0.193E-03
570.0	60.0	0.167E-02	0.206E-03
630.0	60.0	0.162E-02	0.216E-03
690.0	60.0	0.153E-02	0.236E-03
750.0	60.0	0.167E-02	0.261E-03
810.0	60.0	0.185E-02	0.281E-03
870.0	60.0	0.180E-02	0.293E-03
930.0	60.0	0.174E-02	0.281E-03
990.0	60.0	0.848E-03	0.202E-03
1050.0	60.0	0.420E-03	0.922E-04
1110.0	60.0	0.326E-04	0.240E-04
1170.0	60.0	0.108E-05	0.597E-05

Table E: $ds/dE_T^{16\text{O}} + \text{Au } 200 \text{ GeV/nucleon}$.

E_T	Bin Width	ds/dE_T	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
4.0	8.0	0.147E+00	0.769E-02
12.0	8.0	0.496E-01	0.479E-02
20.0	8.0	0.338E-01	0.372E-02
28.0	8.0	0.249E-01	0.288E-02
36.0	8.0	0.235E-01	0.215E-02
44.0	8.0	0.207E-01	0.166E-02
52.0	8.0	0.201E-01	0.131E-02
60.0	8.0	0.184E-01	0.821E-03
68.0	4.0	0.174E-01	0.546E-03
76.0	4.0	0.173E-01	0.532E-03
84.0	4.0	0.179E-01	0.527E-03
92.0	4.0	0.165E-01	0.507E-03
100.0	4.0	0.176E-01	0.521E-03
108.0	4.0	0.174E-01	0.518E-03
116.0	4.0	0.182E-01	0.529E-03
124.0	4.0	0.174E-01	0.518E-03
132.0	4.0	0.172E-01	0.514E-03
140.0	4.0	0.169E-01	0.511E-03
148.0	4.0	0.159E-01	0.495E-03
156.0	4.0	0.138E-01	0.461E-03
164.0	4.0	0.118E-01	0.426E-03
172.0	4.0	0.923E-02	0.269E-03
180.0	4.0	0.659E-02	0.227E-03
188.0	4.0	0.496E-02	0.197E-03
196.0	4.0	0.340E-02	0.163E-03
204.0	4.0	0.246E-02	0.139E-03
212.0	4.0	0.130E-02	0.475E-04
220.0	4.0	0.757E-03	0.362E-04
228.0	4.0	0.441E-03	0.278E-04
236.0	4.0	0.242E-03	0.205E-04
244.0	4.0	0.119E-03	0.144E-04
252.0	4.0	0.567E-04	0.106E-04
260.0	4.0	0.206E-04	0.656E-05
268.0	4.0	0.120E-04	0.489E-05

Table F: $ds/dE_T^{16\text{O}} + \text{Ag } 200 \text{ GeV/nucleon}$.

E_T	Bin Width	ds/dE_T	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
4.0	8.0	0.580E-01	0.323E-02
12.0	8.0	0.355E-01	0.234E-02
20.0	8.0	0.279E-01	0.186E-02
28.0	8.0	0.204E-01	0.147E-02
36.0	8.0	0.196E-01	0.115E-02
44.0	4.0	0.170E-01	0.135E-02
52.0	4.0	0.156E-01	0.117E-02
60.0	4.0	0.157E-01	0.103E-02
68.0	4.0	0.153E-01	0.920E-03
76.0	4.0	0.146E-01	0.882E-03
84.0	4.0	0.143E-01	0.774E-03
92.0	4.0	0.139E-01	0.544E-03
100.0	4.0	0.132E-01	0.249E-03
108.0	4.0	0.128E-01	0.242E-03
116.0	4.0	0.125E-01	0.228E-03
124.0	4.0	0.121E-01	0.220E-03
132.0	4.0	0.111E-01	0.213E-03
140.0	4.0	0.101E-01	0.201E-03
148.0	4.0	0.881E-02	0.188E-03
156.0	4.0	0.765E-02	0.175E-03
164.0	4.0	0.570E-02	0.151E-03
172.0	4.0	0.439E-02	0.133E-03
180.0	4.0	0.332E-02	0.115E-03
188.0	4.0	0.211E-02	0.918E-04
196.0	4.0	0.135E-02	0.735E-04
204.0	4.0	0.845E-03	0.581E-04
212.0	4.0	0.364E-03	0.381E-04
220.0	4.0	0.248E-03	0.315E-04
228.0	4.0	0.129E-03	0.233E-04
236.0	4.0	0.507E-04	0.146E-04
244.0	4.0	0.322E-04	0.148E-04

Table G: $ds/dE_T^{16\text{O}} + \text{Cu } 200 \text{ GeV/nucleon}$.

E_T	Bin Width	ds/dE_T	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
4.0	8.0	0.693E-01	0.362E-02
12.0	8.0	0.313E-01	0.258E-02
20.0	8.0	0.220E-01	0.203E-02
28.0	8.0	0.233E-01	0.166E-02
36.0	8.0	0.157E-01	0.114E-02
44.0	4.0	0.154E-01	0.711E-03
52.0	4.0	0.142E-01	0.623E-03
60.0	4.0	0.140E-01	0.564E-03
68.0	4.0	0.121E-01	0.494E-03
76.0	4.0	0.123E-01	0.460E-03
84.0	4.0	0.117E-01	0.421E-03
92.0	4.0	0.108E-01	0.391E-03
100.0	4.0	0.888E-02	0.149E-03
108.0	4.0	0.829E-02	0.139E-03
116.0	4.0	0.746E-02	0.120E-03
124.0	4.0	0.621E-02	0.103E-03
132.0	4.0	0.502E-02	0.947E-04
140.0	4.0	0.380E-02	0.793E-04
148.0	4.0	0.276E-02	0.663E-04
156.0	4.0	0.197E-02	0.560E-04
164.0	4.0	0.125E-02	0.446E-04
172.0	4.0	0.717E-03	0.338E-04
180.0	4.0	0.432E-03	0.263E-04
188.0	4.0	0.202E-03	0.180E-04
196.0	4.0	0.141E-03	0.150E-04
204.0	4.0	0.561E-04	0.995E-05
212.0	4.0	0.272E-04	0.685E-05
220.0	4.0	0.153E-04	0.747E-05
228.0	4.0	0.135E-04	0.746E-05

Table H: $ds/dE_T^{16\text{O}} + \text{Al } 200 \text{ GeV/nucleon}$.

E_T	Bin Width	ds/dE_T	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
50.0	4.0	0.836E-02	0.189E-03
54.0	4.0	0.668E-02	0.159E-03
58.0	4.0	0.571E-02	0.143E-03
62.0	4.0	0.406E-02	0.117E-03
66.0	4.0	0.315E-02	0.992E-04
70.0	4.0	0.211E-02	0.801E-04
74.0	4.0	0.157E-02	0.662E-04
78.0	4.0	0.921E-03	0.505E-04
82.0	4.0	0.486E-03	0.361E-04
86.0	4.0	0.273E-03	0.266E-04
90.0	4.0	0.193E-03	0.229E-04
94.0	4.0	0.763E-04	0.145E-04
100.0	8.0	0.176E-04	0.471E-05

Table I: $ds/dE_T^{em 16\text{O}} + \text{Au } 200 \text{ GeV/nucleon}$.

E_T^{em}	Bin Width	ds/dE_T^{em}	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
1.0	2.0	0.666E+00	0.335E-01
3.0	2.0	0.207E+00	0.194E-01
5.0	2.0	0.155E+00	0.134E-01
7.0	2.0	0.115E+00	0.912E-02
9.0	2.0	0.112E+00	0.661E-02
11.0	2.0	0.969E-01	0.501E-02
13.0	2.0	0.928E-01	0.350E-02
15.0	2.0	0.891E-01	0.167E-02
16.5	1.0	0.873E-01	0.232E-02
17.5	1.0	0.900E-01	0.235E-02
18.5	1.0	0.826E-01	0.226E-02
19.5	1.0	0.765E-01	0.217E-02
20.5	1.0	0.694E-01	0.148E-02
21.5	1.0	0.576E-01	0.134E-02
22.5	1.0	0.482E-01	0.123E-02
23.5	1.0	0.361E-01	0.106E-02
24.5	1.0	0.274E-01	0.926E-03
25.5	1.0	0.182E-01	0.755E-03
26.5	1.0	0.125E-01	0.294E-03
27.5	1.0	0.786E-02	0.234E-03
28.5	1.0	0.505E-02	0.187E-03
29.5	1.0	0.241E-02	0.129E-03
30.5	1.0	0.149E-02	0.102E-03
31.5	1.0	0.790E-03	0.747E-04
32.5	1.0	0.361E-03	0.505E-04
33.5	1.0	0.156E-03	0.332E-04
34.5	1.0	0.841E-04	0.256E-04
35.5	1.0	0.357E-04	0.178E-04

Figure 13: a) and b) show the event selection for different triggers electromagnetic and total transverse energy production for the NA35 acceptance. Triggers I and II are two differently hard E_T PPD – triggers while III corresponds to a hard Veto trigger (see Table 5). The effect on the differential pseudorapidity distribution $dE_T/d\eta$ in the interval $2.28 < \eta < 3.60$ is shown in part c). In d) one can see that while triggers II and III select essentially the same type of events, events in the tail of the E_T distribution (selected by trigger I) produce 16 % more E_T at $\eta = 2.3$.

Figure 14: Effect of the Streamer Chamber magnetic field on the E_T observed by the Ring Calorimeter cells for central collisions of $^{16}\text{O} + \text{Au}$ at 200 GeV/nucleon. The difference in size between the peaks for left – bent (+) and right – bent (–) particles is due to the surplus of positive charge and is quantified in b) which shows the distribution of the mean transverse energy imbalance per event projected along the horizontal and vertical axis (E_T^y and E_T^x). A net gain of 9.5 GeV is seen for the positive particles.

11. APPENDIX

Tables of cross sections do/dE_{veto} , do/dE_T and $do/dE_{T,\text{em}}$ for ^{16}O induced reactions at 200 and 60 GeV/nucleon on targets of Au, Ag, Cu and Al.

Table A: do/dE_{veto} $^{16}\text{O} + \text{Au}$ 200 GeV/nucleon

E_{veto} (GeV)	Bin Width (GeV)	do/dE_{veto} (barn/GeV)	Error (barn/GeV)
45.0	90.0	0.693E-03	0.574E-04
135.0	90.0	0.136E-02	0.807E-04
225.0	90.0	0.135E-02	0.800E-04
315.0	90.0	0.135E-02	0.808E-04
405.0	90.0	0.116E-02	0.751E-04
495.0	90.0	0.996E-03	0.692E-04
585.0	90.0	0.836E-03	0.646E-04
675.0	90.0	0.814E-03	0.668E-04
765.0	90.0	0.735E-03	0.684E-04
855.0	90.0	0.746E-03	0.683E-04
990.0	180.0	0.713E-03	0.537E-04
1170.0	180.0	0.704E-03	0.634E-04
1350.0	180.0	0.637E-03	0.681E-04
1530.0	180.0	0.713E-03	0.817E-04
1710.0	180.0	0.486E-03	0.880E-04
1890.0	180.0	0.630E-03	0.101E-03
2070.0	180.0	0.729E-03	0.112E-03
2250.0	180.0	0.905E-03	0.123E-03
2430.0	180.0	0.692E-03	0.136E-03
2610.0	180.0	0.124E-02	0.150E-03
2790.0	180.0	0.160E-02	0.173E-03
2970.0	180.0	0.133E-02	0.205E-03
3150.0	180.0	0.220E-02	0.212E-03
3330.0	180.0	0.208E-02	0.154E-03
3510.0	180.0	0.355E-03	0.623E-04
3690.0	180.0	0.492E-04	0.158E-04

Table B: do/dE_{veto} $^{16}\text{O} + \text{Au}$ 60 GeV/nucleon

E_{veto} (GeV)	Bin Width (GeV)	do/dE_{veto} (barn/GeV)	Error (barn/GeV)
15.0	30.0	0.117E-01	0.426E-03
45.0	30.0	0.660E-02	0.323E-03
75.0	30.0	0.562E-02	0.302E-03
105.0	30.0	0.425E-02	0.273E-03
135.0	30.0	0.319E-02	0.255E-03
165.0	30.0	0.296E-02	0.265E-03
195.0	30.0	0.242E-02	0.271E-03
225.0	30.0	0.260E-02	0.290E-03
255.0	30.0	0.221E-02	0.295E-03
285.0	30.0	0.237E-02	0.310E-03
330.0	60.0	0.225E-02	0.241E-03
390.0	60.0	0.210E-02	0.264E-03
450.0	60.0	0.255E-02	0.287E-03
510.0	60.0	0.239E-02	0.303E-03
570.0	60.0	0.180E-02	0.311E-03
630.0	60.0	0.240E-02	0.336E-03
690.0	60.0	0.218E-02	0.366E-03
750.0	60.0	0.216E-02	0.402E-03
810.0	60.0	0.247E-02	0.434E-03
870.0	60.0	0.256E-02	0.454E-03
930.0	60.0	0.197E-02	0.431E-03
990.0	60.0	0.169E-02	0.319E-03
1050.0	60.0	0.613E-03	0.143E-03
1110.0	60.0	0.824E-04	0.406E-04

Table C: do/dE_{veto} $^{16}\text{O} + \text{Ag}$ 60 GeV/nucleon

E_{veto} (GeV)	Bin Width (GeV)	do/dE_{veto} (barn/GeV)	Error (barn/GeV)
15.0	30.0	0.446E-02	0.323E-03
45.0	30.0	0.302E-02	0.269E-03
75.0	30.0	0.309E-02	0.274E-03
105.0	30.0	0.230E-02	0.247E-03
135.0	30.0	0.263E-02	0.273E-03
165.0	30.0	0.267E-02	0.287E-03
195.0	30.0	0.186E-02	0.271E-03
225.0	30.0	0.221E-02	0.297E-03
255.0	30.0	0.210E-02	0.306E-03
285.0	30.0	0.201E-02	0.312E-03
330.0	60.0	0.207E-02	0.241E-03
390.0	60.0	0.186E-02	0.258E-03
450.0	60.0	0.206E-02	0.277E-03
510.0	60.0	0.186E-02	0.289E-03
570.0	60.0	0.179E-02	0.302E-03
630.0	60.0	0.192E-02	0.320E-03
690.0	60.0	0.220E-02	0.353E-03
750.0	60.0	0.155E-02	0.375E-03
810.0	60.0	0.183E-02	0.405E-03
870.0	60.0	0.280E-02	0.437E-03
930.0	60.0	0.163E-02	0.404E-03
990.0	60.0	0.538E-03	0.285E-03
1050.0	60.0	0.240E-03	0.127E-03
1110.0	60.0	0.495E-04	0.374E-04

Table J: $do/dE_T^{em} \text{ } ^{16}\text{O} + \text{Ag } 200 \text{ GeV/nucleon}$.

E_T^{em}	Bin Width	do/dE_T^{em}	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
1.0	2.0	0.280E+00	0.148E-01
3.0	2.0	0.173E+00	0.929E-02
5.0	2.0	0.113E+00	0.665E-02
7.0	2.0	0.108E+00	0.476E-02
9.0	2.0	0.828E-01	0.350E-02
11.0	2.0	0.774E-01	0.212E-02
11.5	1.0	0.711E-01	0.139E-02
12.5	1.0	0.682E-01	0.121E-02
13.5	1.0	0.670E-01	0.110E-02
14.5	1.0	0.618E-01	0.102E-02
15.5	1.0	0.567E-01	0.970E-03
16.5	1.0	0.516E-01	0.909E-03
17.5	1.0	0.443E-01	0.842E-03
18.5	1.0	0.381E-01	0.786E-03
19.5	1.0	0.297E-01	0.689E-03
20.5	1.0	0.218E-01	0.591E-03
21.5	1.0	0.151E-01	0.491E-03
22.5	1.0	0.927E-02	0.385E-03
23.5	1.0	0.655E-02	0.324E-03
24.5	1.0	0.378E-02	0.246E-03
25.5	1.0	0.216E-02	0.186E-03
26.5	1.0	0.103E-02	0.128E-03
27.5	1.0	0.423E-03	0.823E-04
28.5	1.0	0.242E-03	0.643E-04
29.5	1.0	0.100E-03	0.413E-04
31.0	2.0	0.551E-04	0.318E-04

Table K: $do/dE_T^{em} \text{ } ^{16}\text{O} + \text{Cu } 200 \text{ GeV/nucleon}$.

E_T^{em}	Bin Width	do/dE_T^{em}	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
1.0	2.0	0.314E+00	0.165E-01
3.0	2.0	0.160E+00	0.103E-01
5.0	2.0	0.111E+00	0.744E-02
6.5	1.0	0.947E-01	0.386E-02
7.5	1.0	0.826E-01	0.325E-02
8.5	1.0	0.743E-01	0.279E-02
9.5	1.0	0.669E-01	0.244E-02
10.5	1.0	0.643E-01	0.212E-02
11.5	1.0	0.527E-01	0.955E-03
12.5	1.0	0.497E-01	0.790E-03
13.5	1.0	0.437E-01	0.635E-03
14.5	1.0	0.356E-01	0.537E-03
15.5	1.0	0.290E-01	0.473E-03
16.5	1.0	0.225E-01	0.392E-03
17.5	1.0	0.166E-01	0.336E-03
18.5	1.0	0.109E-01	0.283E-03
19.5	1.0	0.689E-02	0.216E-03
20.5	1.0	0.410E-02	0.167E-03
21.5	1.0	0.231E-02	0.125E-03
22.5	1.0	0.125E-02	0.921E-04
23.5	1.0	0.592E-03	0.634E-04
24.5	1.0	0.292E-03	0.445E-04
25.5	1.0	0.125E-03	0.307E-04
27.0	2.0	0.538E-04	0.232E-04

Table L: $do/dE_T^{em} \text{ } ^{16}\text{O} + \text{Al } 200 \text{ GeV/nucleon}$.

E_T^{em}	Bin Width	do/dE_T^{em}	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
7.5	1.0	0.548E-01	0.108E-02
8.5	1.0	0.452E-01	0.924E-03
9.5	1.0	0.371E-01	0.785E-03
10.5	1.0	0.266E-01	0.639E-03
11.5	1.0	0.212E-01	0.528E-03
12.5	1.0	0.124E-01	0.406E-03
13.5	1.0	0.859E-02	0.318E-03
14.5	1.0	0.488E-02	0.239E-03
15.5	1.0	0.259E-02	0.170E-03
16.5	1.0	0.114E-02	0.114E-03
17.5	1.0	0.486E-03	0.722E-04
18.5	1.0	0.466E-03	0.708E-04
19.5	1.0	0.161E-03	0.403E-04
20.5	1.0	0.403E-04	0.201E-04
21.5	1.0	0.201E-04	0.142E-04

Table M: $do/dE_T \text{ } ^{16}\text{O} + \text{Au } 60 \text{ GeV/nucleon}$.

E_T	Bin Width	do/dE_T	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
2.0	4.0	0.115E+00	0.773E-02
6.0	4.0	0.742E-01	0.619E-02
10.0	4.0	0.515E-01	0.515E-02
13.0	2.0	0.540E-01	0.603E-02
15.0	2.0	0.473E-01	0.546E-02
17.0	2.0	0.448E-01	0.512E-02
19.0	2.0	0.437E-01	0.315E-02
21.0	2.0	0.406E-01	0.294E-02
23.0	2.0	0.411E-01	0.276E-02
25.0	2.0	0.351E-01	0.253E-02
27.0	2.0	0.361E-01	0.236E-02
29.0	2.0	0.322E-01	0.217E-02
31.0	2.0	0.324E-01	0.201E-02
33.0	2.0	0.326E-01	0.185E-02
35.0	2.0	0.297E-01	0.176E-02
37.0	2.0	0.321E-01	0.166E-02
39.0	2.0	0.318E-01	0.157E-02
41.0	2.0	0.293E-01	0.144E-02
43.0	2.0	0.293E-01	0.132E-02
45.0	2.0	0.319E-01	0.131E-02
47.0	2.0	0.302E-01	0.123E-02
49.0	2.0	0.316E-01	0.122E-02
51.0	2.0	0.321E-01	0.122E-02
53.0	2.0	0.325E-01	0.118E-02
55.0	2.0	0.323E-01	0.116E-02
57.0	2.0	0.319E-01	0.112E-02
59.0	2.0	0.321E-01	0.776E-03
61.0	2.0	0.288E-01	0.732E-03
63.0	2.0	0.258E-01	0.682E-03
65.0	2.0	0.236E-01	0.638E-03
67.0	2.0	0.199E-01	0.590E-03
69.0	2.0	0.155E-01	0.540E-03
71.0	2.0	0.122E-01	0.452E-03
73.0	2.0	0.917E-02	0.393E-03
75.0	2.0	0.640E-02	0.328E-03
77.0	2.0	0.427E-02	0.268E-03
79.0	2.0	0.233E-02	0.208E-03
81.0	2.0	0.166E-02	0.186E-03
83.0	2.0	0.764E-03	0.113E-03
85.0	2.0	0.608E-03	0.105E-03
87.0	2.0	0.289E-03	0.780E-04
90.0	4.0	0.222E-03	0.559E-04
94.0	4.0	0.862E-04	0.506E-04
98.0	4.0	0.254E-04	0.254E-04

Table N: $do/dE_T \text{ } ^{16}\text{O} + \text{Ag } 60 \text{ GeV/nucleon}$.

E_T	Bin Width	do/dE_T	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
4.0	8.0	0.644E-01	0.391E-02
12.0	8.0	0.403E-01	0.273E-02
17.0	2.0	0.366E-01	0.450E-02
19.0	2.0	0.326E-01	0.229E-02
21.0	2.0	0.334E-01	0.219E-02
23.0	2.0	0.294E-01	0.202E-02
25.0	2.0	0.299E-01	0.191E-02
27.0	2.0	0.277E-01	0.176E-02
29.0	2.0	0.284E-01	0.168E-02
31.0	2.0	0.261E-01	0.153E-02
33.0	2.0	0.259E-01	0.141E-02
35.0	2.0	0.251E-01	0.137E-02
37.0	2.0	0.223E-01	0.120E-02
39.0	2.0	0.232E-01	0.119E-02
41.0	2.0	0.237E-01	0.113E-02
43.0	2.0	0.237E-01	0.109E-02
45.0	2.0	0.212E-01	0.102E-02
47.0	2.0	0.203E-01	0.980E-03
49.0	2.0	0.200E-01	0.960E-03
51.0	2.0	0.183E-01	0.921E-03
53.0	2.0	0.206E-01	0.945E-03
55.0	2.0	0.167E-01	0.851E-03
57.0	2.0	0.150E-01	0.806E-03
59.0	2.0	0.133E-01	0.438E-03
61.0	2.0	0.111E-01	0.401E-03
63.0	2.0	0.938E-02	0.370E-03
65.0	2.0	0.780E-02	0.335E-03
67.0	2.0	0.597E-02	0.292E-03
69.0	2.0	0.434E-02	0.249E-03
71.0	2.0	0.314E-02	0.212E-03
73.0	2.0	0.173E-02	0.158E-03
75.0	2.0	0.127E-02	0.135E-03
77.0	2.0	0.868E-03	0.116E-03
79.0	2.0	0.405E-03	0.760E-04
82.0	4.0	0.161E-03	0.393E-04
86.0	4.0	0.713E-04	0.242E-04

Table O: $do/dE_T \text{ } ^{16}\text{O} + \text{Cu } 60 \text{ GeV/nucleon}$.

E_T	Bin Width	do/dE_T	Error
(GeV)	(GeV)	(barn/GeV)	(barn/GeV)
4.0	8.0	0.415E-01	0.307E-02
12.0	8.0	0.424E-01	0.204E-02
17.0	2.0	0.345E-01	0.332E-02
19.0	2.0	0.310E-01	0.304E-02
21.0	2.0	0.260E-01	0.279E-02
23.0	2.0	0.237E-01	0.164E-02
25.0	2.0	0.238E-01	0.153E-02
27.0	2.0	0.208E-01	0.139E-02
29.0	2.0	0.215E-01	0.131E-02
31.0	2.0	0.209E-01	0.120E-02
33.0	2.0	0.200E-01	0.109E-02
35.0	2.0	0.184E-01	0.103E-02
37.0	2.0	0.190E-01	0.944E-03
39.0	2.0	0.172E-01	0.881E-03
41.0	2.0	0.167E-01	0.817E-03
43.0	2.0	0.168E-01	0.776E-03
45.0	2.0	0.156E-01	0.725E-03
47.0	2.0	0.143E-01	0.693E-03
49.0	2.0	0.114E-01	0.604E-03
51.0	2.0	0.110E-01	0.597E-03
53.0	2.0	0.934E-02	0.535E-03
55.0	2.0	0.756E-02	0.479E-03
57.0	2.0	0.635E-02	0.257E-03
59.0	2.0	0.547E-02	0.236E-03
61.0	2.0	0.378E-02	0.200E-03
63.0	2.0	0.263E-02	0.166E-03
65.0	2.0	0.180E-02	0.134E-03
67.0	2.0	0.115E-02	0.108E-03
69.0	2.0	0.938E-03	0.993E-04
71.0	2.0	0.650E-03	0.824E-04
74.0	4.0	0.198E-03	0.316E-04
78.0	4.0	0.105E-03	0.238E-04
84.0	8.0	0.272E-04	0.131E-04

Table P: $do/dE_T^{em} \text{ } ^{16}O + Au \text{ } 60 \text{ GeV/nucleon}$.

E_T^{em} (GeV)	Bin Width (GeV)	do/dE_T^{em} (barn/GeV)	Error (barn/GeV)
0.5	1.0	0.554E+00	0.363E-01
1.5	1.0	0.296E+00	0.235E-01
2.5	1.0	0.222E+00	0.180E-01
3.5	1.0	0.202E+00	0.148E-01
4.5	1.0	0.190E+00	0.838E-02
5.5	1.0	0.177E+00	0.704E-02
6.5	1.0	0.150E+00	0.583E-02
7.5	1.0	0.151E+00	0.511E-02
8.5	1.0	0.137E+00	0.451E-02
9.5	1.0	0.131E+00	0.410E-02
10.5	1.0	0.136E+00	0.400E-02
11.5	1.0	0.128E+00	0.341E-02
12.5	1.0	0.127E+00	0.228E-02
13.5	1.0	0.112E+00	0.208E-02
14.5	1.0	0.903E-01	0.183E-02
15.5	1.0	0.675E-01	0.156E-02
16.5	1.0	0.454E-01	0.126E-02
17.5	1.0	0.266E-01	0.952E-03
18.5	1.0	0.131E-01	0.662E-03
19.5	1.0	0.544E-02	0.428E-03
20.5	1.0	0.267E-02	0.315E-03
21.5	1.0	0.665E-03	0.150E-03
22.5	1.0	0.443E-03	0.127E-03
23.5	1.0	0.171E-03	0.914E-04

Table Q: $do/dE_T^{em} \text{ } ^{16}O + Ag \text{ } 60 \text{ GeV/nucleon}$.

E_T^{em} (GeV)	Bin Width (GeV)	do/dE_T^{em} (barn/GeV)	Error (barn/GeV)
0.5	1.0	0.332E+00	0.283E-01
1.5	1.0	0.231E+00	0.188E-01
2.5	1.0	0.178E+00	0.156E-01
3.5	1.0	0.190E+00	0.760E-02
4.5	1.0	0.150E+00	0.620E-02
5.5	1.0	0.135E+00	0.522E-02
6.5	1.0	0.129E+00	0.450E-02
7.5	1.0	0.111E+00	0.384E-02
8.5	1.0	0.961E-01	0.334E-02
9.5	1.0	0.979E-01	0.310E-02
10.5	1.0	0.831E-01	0.280E-02
11.5	1.0	0.731E-01	0.256E-02
12.5	1.0	0.618E-01	0.135E-02
13.5	1.0	0.431E-01	0.112E-02
14.5	1.0	0.298E-01	0.929E-03
15.5	1.0	0.170E-01	0.702E-03
16.5	1.0	0.922E-02	0.513E-03
17.5	1.0	0.398E-02	0.338E-03
18.5	1.0	0.182E-02	0.228E-03
19.5	1.0	0.302E-03	0.928E-04
20.5	1.0	0.177E-03	0.726E-04
21.5	1.0	0.443E-04	0.443E-04

Table R: $do/dE_T^{em} \text{ } ^{16}O + Cu \text{ } 60 \text{ GeV/nucleon}$.

E_T^{em} (GeV)	Bin Width (GeV)	do/dE_T^{em} (barn/GeV)	Error (barn/GeV)
0.5	1.0	0.242E+00	0.230E-01
1.5	1.0	0.214E+00	0.136E-01
2.5	1.0	0.166E+00	0.117E-01
3.5	1.0	0.160E+00	0.963E-02
4.5	1.0	0.113E+00	0.498E-02
5.5	1.0	0.107E+00	0.415E-02
6.5	1.0	0.920E-01	0.343E-02
7.5	1.0	0.826E-01	0.287E-02
8.5	1.0	0.741E-01	0.250E-02
9.5	1.0	0.652E-01	0.216E-02
10.5	1.0	0.474E-01	0.179E-02
11.5	1.0	0.378E-01	0.890E-03
12.5	1.0	0.239E-01	0.708E-03
13.5	1.0	0.141E-01	0.542E-03
14.5	1.0	0.780E-02	0.400E-03
15.5	1.0	0.370E-02	0.278E-03
16.5	1.0	0.188E-02	0.194E-03
17.5	1.0	0.469E-03	0.989E-04
18.5	1.0	0.182E-03	0.620E-04

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 11

FIG. 12

FIG. 13

FIG. 14b

FIG. 14a