THE TRANSVERSE-ENERGY DISTRIBUTIONS OF ^{32}S -NUCLEUS
COLLISIONS AT 200 GeV PER NUCLEON

HELIOS Collaboration

T. Åkesson³⁾, S. Almedhed⁶⁾, A.L.S. Angelis²⁰⁾, N. Armenise¹⁾, H. Atherton³⁾, P. Aubry⁸⁾,
H.W. Bartels⁴⁾, G. Beaudoin⁸⁾, J.M. Beaulieu⁸⁾, H. Beker³⁾, O. Benary¹⁸⁾, D. Bettoni^{3,8)}, V. Bisi¹⁹⁾,
I. Blevis²¹⁾, H. Bøggild^{3,b)}, W. Cleland¹²⁾, M. Clemen¹²⁾, B. Collick¹²⁾, F. Corriveau⁷⁾, S. Dagan¹⁸⁾,
K. Dederichs^{3,d)}, S. Dell'Uomo¹³⁾, P. Depommier⁸⁾, R.C.E. Devenish^{3,e)}, N. DiGiacomo⁵⁾,
S. Di Liberto¹³⁾, J.R. Dodd²⁰⁾, B. Dolgoshein¹⁰⁾, A. Drees⁴⁾, H. En'yo³⁾, B. Erlandsson¹⁷⁾,
M.J. Esten³⁾, C.W. Fabjan³⁾, P. Fischer⁴⁾, Z. Fraenkel²¹⁾, A. Gaidot¹⁵⁾, I. Gavrilenko⁹⁾,
F. Gibrat-Debu¹⁵⁾, P. Giubellino¹⁹⁾, P. Glässel⁴⁾, U. Goerlach⁴⁾, R. Haglund⁶⁾, L.A. Hamel⁷⁾,
H. van Hecke⁵⁾, V. Hedberg⁶⁾, R. Heifetz¹⁸⁾, A. Hölscher⁴⁾, B. Jacak⁵⁾, G. Jarlskog⁷⁾,
S. Johansson⁶⁾, A. Kalinovski¹⁰⁾, A. Kantserov¹⁰⁾, H. Kraner²⁾, V. Kroh⁴⁾, F. Lamarche⁷⁾,
C. Leroy⁷⁾, L. Lessard⁸⁾, D. Lissauer²⁾, G. London¹⁵⁾, B. Lörstad⁶⁾, A. Lounis⁸⁾,
A. Marzari-Chiesa¹⁹⁾, M. Maserà¹⁹⁾, S. Mayburov⁹⁾, M.A. Mazzoni³⁾, E. Mazzucato⁷⁾,
M.L. McCubbin²⁰⁾, N.A. McCubbin¹⁴⁾, P. McGaughey⁵⁾, F. Meddi¹³⁾, U. Mjörnmark⁶⁾,
M.T. Muciaccia¹⁾, S. Muraviev⁹⁾, M. Murray¹²⁾, M. Neubert⁴⁾, P. Nevski¹⁰⁾, S. Nilsson¹⁷⁾,
L. Olsen²⁾, Y. Oren¹⁸⁾, J.P. Pansart¹⁵⁾, Y.M. Park¹²⁾, A. Pfeiffer⁴⁾, F. Piuze³⁾, V. Polychronakos²⁾,
G. Poulard³⁾, M. Price³⁾, D. Rahm²⁾, L. Ramello¹⁹⁾, L. Riccati¹⁹⁾, G. Romano¹⁶⁾, G. Rosa¹³⁾,
J. Russ^{3,f)}, J. Schukraft³⁾, M. Sekimoto³⁾, B. Sellden¹⁷⁾, M. Seman^{3,c)}, A. Shmeleva⁹⁾, P. Shotton³⁾,
V. Sidorov¹¹⁾, S. Simone¹⁾, Y. Sirois⁷⁾, H. Sletten³⁾, S. Smirnov¹⁰⁾, W. Sondheim⁵⁾, H.J. Specht⁴⁾,
I. Stumer²⁾, A. Sumarokov¹⁰⁾, J. Sunier⁵⁾, V. Tcherniatin¹⁰⁾, H.H. Thodberg³⁾, J. Thompson¹²⁾,
V. Tikhomirov¹⁰⁾, I. Tserruya²¹⁾, G. Vasseur¹⁵⁾, R. Veenhof^{3,a)}, R. Wigmans³⁾ and W. Willis³⁾

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- 1) University of Bari and INFN, Bari, Italy.
- 2) Brookhaven National Lab., Upton, NY, USA.
- 3) CERN, Geneva, Switzerland.
- 4) Heidelberg University, Fed. Rep. Germany.
- 5) Los Alamos National Lab., N. Mex., USA.
- 6) University of Lund, Sweden.
- 7) McGill University, Montreal, Canada.
- 8) University of Montreal, Canada.
- 9) P.N. Lebedev Inst. of Physics, Moscow, USSR.
- 10) Inst. of Moscow Engineering Physics, Moscow, USSR.

- 11) Institute of Nuclear Physics, Novosibirsk, USSR.
- 12) University of Pittsburgh, Pittsburgh, Pa., USA.
- 13) University of Rome and INFN, Rome, Italy.
- 14) Rutherford Appleton Laboratory, Didcot, UK.
- 15) DPhPE, CEN-Saclay, Gif-sur-Yvette, France.
- 16) University of Salerno and INFN, Salerno, Italy.
- 17) University of Stockholm, Sweden.
- 18) Tel Aviv University, Israel.
- 19) University of Turin and INFN, Turin, Italy.
- 20) University College London, UK.
- 21) Weizmann Institute of Science, Rehovot, Israel.

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- f) Carnegie-Mellon University, Pittsburgh, Pa., USA.
- g) University of Syracuse, Syracuse, NY, USA.

ABSTRACT

Transverse-energy distributions have been measured for the collisions of the ^{32}S nucleus with Al, Ag, W, Pt, Pb, and U target nuclei, at an incident energy of 200 GeV per nucleon. The shapes of these distributions reflect the geometry of the collisions, including the deformation effects. For central collisions, the transverse-energy production in the region $-0.1 < \eta_{\text{lab}} < 2.9$ increases approximately as $A^{0.5}$, where A is the atomic mass number of the target. This increase is accompanied by a relative depletion in the forward region $\eta_{\text{lab}} > 2.9$. These results are compared with those obtained under similar conditions with incident ^{16}O nuclei. A comparison is also made with the predictions of a Monte Carlo generator based on the Dual Parton Model. Finally, we give estimates of the energy density reached and its dependence on the atomic mass number of the projectile.

At high energies, the collisions of two heavy nuclei produce a system of very dense hadronic matter, which may consist of deconfined quarks and gluons [1]. In 1986, the CERN Super Proton Synchrotron (SPS) provided beams of oxygen nuclei at an energy of 3.2 TeV, thus allowing a first measurement of observables that are relevant for the study of hadronic matter at high density. This Letter presents the results of measurements carried out in 1987 with sulfur beams at the same energy per nucleon, allowing a direct comparison of the energy deposition as a function of projectile mass. Data taken with a number of targets, including targets of similar mass but different deformation, lead to a much improved understanding of the shape of the transverse-energy spectrum.

The HELIOS (High-Energy Lepton and IOn Spectrometer) detector, currently in operation in the H8 beam line at the SPS, includes calorimeters with a full solid-angle coverage in the centre-of-mass frame to measure the transverse-energy flow [2, 3]. The transverse energy E_T can be correlated with the charged-particle multiplicity measured with highly segmented silicon detectors [4].

A small liquid-scintillator cell, 140 cm upstream from the target, is used to tag the well-collimated ^{32}S component of the beam. A scintillator veto counter, 10 cm upstream of the target, allows rejection of most of the interactions occurring in the beam counter or in the air between the beam counter and the target. Three silicon hodoscopes, located 1 cm (RING 1), 6 cm (RING 2), and 26 cm (RING 3) downstream from the target, are each composed of 384 segments arranged in 32 rings covering approximately equal pseudorapidity intervals. They provide charged-particle multiplicity measurements in the pseudorapidity ranges of $0.3 < \eta_{\text{lab}} < 1.8$ (RING 1), $1.4 < \eta_{\text{lab}} < 3.5$ (RING 2), and $2.8 < \eta_{\text{lab}} < 5.0$ (RING 3). The most forward detector also provides the interaction trigger requiring a minimum charged-particle multiplicity of 5 in $2.8 < \eta_{\text{lab}} < 5.0$. These detectors allow effective separation of the target interactions from the background, which is produced in the beam-pipe window, in the air, and in the detectors themselves.

Using sulfur beams with intensities of about $2 \times 10^5/\text{s}$, the total numbers of collisions recorded were: 19,000 with Al; 22,000 with Ag; 264,000 with W; 24,000 with Pt; 15,000 with Pb; and 23,000 with U. These totals include both interaction triggered events and events with several (E_T) thresholds.

A selection on the calorimetric measurement of the total energy removes all events with two simultaneous beam particles which have not been rejected at the trigger level. Interactions occurring downstream from the target give a large multiplicity in RING 3, with zero multiplicity in RING 1, and hence are effectively eliminated by a comparison of relative multiplicities. Similarly, most of the upstream interactions are eliminated through a study of the correlation of hits in RING 1 and RING 2. Above an E_T of 30 GeV, the target interactions can be recognized independently by the relation between their E_T and their multiplicity. In this region, the non-target background is eliminated with an efficiency close to 100%. Between 6 and 15 GeV (E_T), these cuts bring the non-target contribution from (typically) 90% to 20%, whilst the efficiency for the good events is $\geq 95\%$. The remaining contamination of non-target interactions is removed by subtracting the spectra obtained with no target, under the same experimental conditions.

The thicknesses (in millimetres) of the disk targets used were: 1.0 (Al); 0.3 (Ag); 0.2 (W); 0.25 (Pt); 0.2 (Pb); 0.32 (U). As in ref. [2], systematic studies were made with respect to possible secondary interactions, showing that the above disk targets were thin enough for the contamination from multiple interactions to be less than the statistical errors.

The E_T differential cross-sections in the pseudorapidity range $-0.1 < \eta < 2.9$ are presented in fig. 1 and in tables 1 to 6 as a function of E_T for the various target nuclei. These distributions have been corrected for calorimeter response to different particles (e/π), for leakage (affecting the scale), and for the resolution (affecting the shape), using the procedures of ref. [2]. The systematic uncertainty on the E_T scale is estimated to be 7.1%. The maximum E_T reached increases with the atomic mass of the target from $E_T \approx 100$ GeV for ^{32}S -Al to $E_T \approx 330$ GeV for ^{32}S -U. For all targets

the E_T distributions present a shape already observed in the case of an incident oxygen beam [2]: a plateau (less well defined for the Al target) followed by a steeply falling tail.

In order to compare the different cross-sections, we have repeated (see ref. [2]) the study of $\langle E_T^{\text{central}} \rangle$, the average transverse energy produced by central collisions. The results are presented in table 7. Fits to the form A^α have been performed for ^{32}S and compared with the ^{16}O data. The values $\alpha = 0.48 \pm 0.02$, 0.53 ± 0.04 , and 0.53 ± 0.05 have been obtained for ^{16}O at 60 and 200 GeV per nucleon and for ^{32}S at 200 GeV per nucleon, respectively. The value of α varies with the η range covered by the experiment [5, 6]. The question of this dependence will be discussed further when we report on our full η coverage measurements in a forthcoming publication. The fact that $\langle E_T^{\text{central}} \rangle$ rises as a function of A indicates that we are in an energy regime where the projectile energy is not fully dissipated after traversing the target nucleus ('partial stopping' regime). In case of full stopping, $\langle E_T^{\text{central}} \rangle$ would cease to rise beyond a certain size of target. It may be noted that for both ^{16}O and ^{32}S collisions, the increase of $\langle E_T^{\text{central}} \rangle$ in our pseudorapidity interval is stronger than the $\sim A^{1/3}$ expected from naïve scaling with the target nucleus thickness.

In fig. 2 we compare the E_T distribution in $-0.1 < \eta_{\text{lab}} < 2.9$ for 200 GeV per nucleon ^{32}S and ^{16}O beams on W targets with the predictions of the IRIS [7] event generator, which combines the Dual Parton Model (DPM) [8] for non-diffractive inelastic scattering and the Lund Fragmentation Model [9]. The DPM is based on colour exchange with a long formation time. The hadronization is determined using the Lund Model, and the IRIS parameters have been adjusted to describe ISR pp data and PETRA e^+e^- data. The extension to p-nucleus and nucleus-nucleus collisions involves no further new parameters, except in the description of the geometry of the nucleus for which a Woods-Saxon radial density distribution is assumed. From fig. 2 we see that IRIS reproduces the plateau in a satisfactory way but may underestimate the high- E_T tail. This could indicate that cascading in the nucleus, not implemented in IRIS, contributes to the measured E_T . In the tail ($d\sigma/dE_T \approx 10^{-1}$ mb/GeV), the ratio of the E_T obtained in IRIS to the E_T observed experimentally is 17% larger for a ^{32}S projectile than for a ^{16}O projectile. An error of up to 7% on the calorimeter energy scale is possible, but this would affect the ratio for oxygen and the ratio for sulfur in the same way. Thus the difference between the ratios is indeed significant. A possible explanation might be a relatively smaller amount of cascading in ^{32}S collisions than in ^{16}O collisions.

The measured E_T distributions reflect the geometry of the collisions between two nuclei. For any impact parameter an 'overlap integral', defined as the product of the overlapping nuclear densities, can be evaluated. The shape of this overlap integral bears a striking resemblance to the E_T spectrum. This integral is converted to an effective number N of collisions by multiplying it by the nucleon-nucleon inelastic cross-section ($\sigma_{NN} = 32$ mb at 200 GeV). In ref. [2] the ^{16}O transverse energy cross-sections have been found to be well described by a two-parameter fit, assuming that the total E_T is Gaussian-distributed with mean $N\epsilon_0$ and variance $\omega N\epsilon_0^2$ (where ϵ_0 and ω are free parameters). The application of the same procedure to the ^{32}S data leads to an excellent description of the E_T cross-sections. The fitted values of the parameters are given in table 8. The parameter ω measures fluctuations of the produced E_T . For non-spherical target nuclei, their random orientation is a source of fluctuations. To a good approximation, the effect of the deformation of the nuclei on the E_T distribution can be treated as an increase in the parameter ω . In the limit where the projectile nucleus is much smaller than the target nucleus, the overlap integral for central collisions on a deformed nucleus differs from the overlap integral for central collisions on a spherical nucleus of the same atomic number by a factor of $1 - (\delta/3) + \delta \cos^2 \mu$, where δ is the deformation parameter and μ is the angle between the major axis of the target nucleus and the axis of the collision. This increases ω by $\omega_d = 4/45 N_{\text{coll}} \delta^2$ (where N_{coll} is the number of collisions given by the overlap integral in the central case). The measured fluctuations ω are thus the sum of fluctuations ω_{true} due to the properties

of the collision mechanism, and fluctuations ω_d due to variations of the angle assumed by the target nuclei. The estimated values of ω_d and the resulting values of ω_{true} are shown in table 8. The ω_{true} values are less dispersed than the ω values, and approach the ω value of the spherical nucleus Pb. From these considerations, it can be understood that events in the extreme tail of the E_T distributions are events in which the target nucleus is aligned with the beam. We estimate that the U nuclei are 75% aligned in the tail of the ^{32}S -W transverse energy distribution (see fig. 1). Since the E_T achieved is proportional to the thickness of the target nucleus, a U nucleus with its long axis longitudinally aligned produces an E_T corresponding to a spherical nucleus of atomic number 400.

Table 8 shows the consistent tendency of ω to increase with the atomic mass number of both the target and the projectile, suggesting that the production of E_T in our acceptance is not simply a sum of the production from all baryon-baryon collisions. The parameter ϵ_0 clearly decreases with the increasing atomic mass number of the projectile, which could be due to the decrease of the fraction of E_T present in the pseudorapidity acceptance when the rapidity of the centre of mass increases.

The average E_T produced in a central collision is $N_{\text{coll}}\epsilon_0$. It reproduces the experimental values discussed before, in connection with table 7. The fraction R of additional E_T in the pseudorapidity range $2.9 < \eta < 5.5$ compared with the E_T in the range $-0.1 < \eta < 2.9$ for central collisions is also given; this number, needed to estimate the total E_T , has a large (10%) systematic uncertainty.

The distributions of E_T as a function of pseudorapidity, $dE_T/d\eta$, for ^{32}S -W collisions at 200 GeV per nucleon incident energy are shown in fig. 3. Three regions of E_T , corresponding to the plateau of $d\sigma/dE_T$, the E_T central values, and the highest E_T measured, have been selected. The shape of the η -distribution changes very little with increasing transverse energy.

An estimate of the energy density can be obtained using the Bjorken-scaling hydrodynamical model [10]. Selecting the ^{32}S -W central collisions, we find from figs. 1 and 3 $(dE_T/d\eta)_{\text{max}} \approx 96$ GeV. Using a transverse area of $F(^{32}\text{S}) = 41$ fm² and a formation time $\tau \approx 1$ fm/c [11], this leads to an estimate of the energy density of $\epsilon = [1/F(^{32}\text{S})c\cdot\tau](dE_T/d\eta)_{\text{max}} \approx 2.3$ GeV/fm³ compared to the value $\epsilon \approx 2.1$ GeV/fm³ obtained for ^{16}O -W central collisions where $(dE_T/d\eta)_{\text{max}} \approx 53$ GeV [2]. We also find $(dE_T/d\eta)_{\text{max}} \approx 150$ GeV in the tail of the E_T distribution for the W target and $\epsilon \approx 3.7$ GeV/fm³, close to the value found in the case of oxygen (≈ 3.6 GeV/fm³). It is clear that the increase of the transverse area largely compensates the gain in $dE_T/d\eta$ in this transverse energy region.

An estimate of the energy density can also be obtained in a situation of full stopping. However, as already noted, the dependence of $\langle E_T^{\text{central}} \rangle$ on A suggests that the energy of the projectile is only partially stopped. A value for ϵ similar to the one derived above in the high- E_T tail, is obtained from an estimate assuming a linear scaling of the energy density with partial stopping, and neglecting the large uncertainties in the definition of the interaction volume and the ambiguities in the calculation of the Lorentz kinematics of the collision [2].

These estimates, based either on hydrodynamical models or on the extrapolation from the partial stopping, are in the region of the critical value of ~ 2.5 GeV/fm³ obtained from lattice QCD calculations for the deconfinement transition.

The data presented here complete a survey of the global E_T properties in the pseudorapidity range -0.1 to 2.9 for ultra-relativistic heavy-ion collisions. For all projectiles considered, in this pseudorapidity acceptance and for target nuclei larger than the projectile nuclei, the E_T appears to be proportional to the number of collisions given by the overlap integral, as can be expected if there is a large hadronization time [12]. The values of the mean E_T and the fluctuations of the E_T have been obtained taking the deformation of the nuclei into account. It was seen how one can take advantage of the deformation of the nucleus to probe very large nuclei effectively. The IRIS model, with parameters fixed from known physics, reproduces the plateau of the E_T distributions, but does not

give the precise position of the tail. This situation might improve if cascading is included. The energy density reached increases by a small amount with an increased projectile atomic mass number over a volume whose linear dimensions are a factor of 1.25 larger. This suggests that the use of larger projectiles would not only provide larger interaction volumes but also a somewhat larger energy density.

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REFERENCES

- [1] Proc. Int. Conf. on Ultra-Relativistic Nucleus-Nucleus collisions:
 3rd: Quark Matter '83, Brookhaven, eds. T.W. Ludlam and H.E. Wegner [Nucl. Phys. **A418** (1984)].
 4th: Quark Matter '84, Helsinki, ed. K. Kajantie [Lecture Notes in Physics **221** (1984), Springer, Berlin-Heidelberg].
 5th: Quark Matter '86, Asilomar, eds. L.S. Schroeder and M. Gyulassy [Nucl. Phys. **A461** (1987)].
- [2] T. Åkesson et al., HELIOS Collaboration, Z. Phys. **C38** (1988) 383.
- [3] T. Åkesson et al., Nucl. Instrum. Methods **A262** (1987) 243.
- [4] P. Giubellino et al., preprint CERN-EP/88-89 (1988), submitted to Nucl. Instrum. Methods.
- [5] A. Bamberger et al., Z. Phys. **C38** (1988) 19.
- [6] R. Albrecht et al., Phys. Lett. **B202** (1988) 596.
- [7] J.P. Pansart, report DPhPE 86-06 (1986); also *in* Quark Matter '86, in Ref. [1], p. 521c.
- [8] A. Capella and J. Tran Thanh Van, Phys. Lett. **93B** (1980) 146.
- [9] B. Andersson, G. Gustafson and T. Sjöstrand, Z. Phys. **C6** (1980) 235.
- [10] J.D. Bjorken, Phys. Rev. **D27** (1983) 140.
 E.V. Shuryak, Phys. Rep. **61** (1979) 71.
- [11] D. Kisiielewska, Acta Phys. Pol. **B15** (1984) 1111.
- [12] A. Białas and M. Gyulassy, Phys. Lett. **B291** (1987) 793.
 A. Białas, Acta Phys. Pol. **B15** (1982) 647.
 A. Capella and A. Krzywicki, Phys. Lett. **B67** (1977) 84 and Phys. Rev. **D18** (1978) 3357.
 K.S. Kölbig and B. Margolis, Nucl. Phys. **B6** (1968) 85.

Table 1

The transverse energy differential cross-section $d\sigma/dE_T$ in $-0.1 < \eta_{lab} < 2.9$
for 200 GeV per nucleon ^{32}S -Al collisions

E_T [GeV]	Bin half-width [GeV]	$d\sigma/dE_T$ [mb/GeV]	Error [mb/GeV]
11.5	2.3	$3.14 \times 10^{+1}$	$4.22 \times 10^{+0}$
16.1	2.3	$3.90 \times 10^{+1}$	$4.47 \times 10^{+0}$
20.6	2.3	$2.65 \times 10^{+1}$	$4.64 \times 10^{+0}$
25.2	2.3	$2.85 \times 10^{+1}$	$4.32 \times 10^{+0}$
29.8	2.3	$2.58 \times 10^{+1}$	$4.14 \times 10^{+0}$
34.4	2.3	$2.56 \times 10^{+1}$	$3.53 \times 10^{+0}$
39.0	2.3	$2.32 \times 10^{+1}$	$3.09 \times 10^{+0}$
43.6	2.3	$1.43 \times 10^{+1}$	$2.53 \times 10^{+0}$
48.2	2.3	$1.45 \times 10^{+1}$	$2.14 \times 10^{+0}$
52.8	2.3	$1.13 \times 10^{+1}$	$2.12 \times 10^{+0}$
57.4	2.3	$9.06 \times 10^{+0}$	$1.76 \times 10^{+0}$
61.9	2.3	$7.77 \times 10^{+0}$	$1.41 \times 10^{+0}$
66.5	2.3	$7.94 \times 10^{+0}$	$1.66 \times 10^{+0}$
71.1	2.3	$3.81 \times 10^{+0}$	$1.06 \times 10^{+0}$
75.7	2.3	$1.89 \times 10^{+0}$	6.78×10^{-1}
80.3	2.3	6.26×10^{-1}	2.27×10^{-1}
84.9	2.3	2.34×10^{-1}	2.00×10^{-1}
89.5	2.3	4.77×10^{-2}	2.77×10^{-2}
94.1	2.3	2.74×10^{-2}	2.19×10^{-2}

Table 2

The transverse energy differential cross-section $d\sigma/dE_T$ in $-0.1 < \eta_{\text{lab}} < 2.9$
for 200 GeV per nucleon ^{32}S -Ag collisions

E_T [GeV]	Bin half-width [GeV]	$d\sigma/dE_T$ [mb/GeV]	Error [mb/GeV]
91.8	4.6	$7.86 \times 10^{+0}$	5.39×10^{-1}
100.9	4.6	$7.29 \times 10^{+0}$	2.59×10^{-1}
110.1	4.6	$6.40 \times 10^{+0}$	3.72×10^{-1}
119.3	4.6	$5.56 \times 10^{+0}$	2.44×10^{-1}
128.5	4.6	$5.54 \times 10^{+0}$	2.28×10^{-1}
137.6	4.6	$4.52 \times 10^{+0}$	2.07×10^{-1}
146.8	4.6	$3.66 \times 10^{+0}$	1.83×10^{-1}
156.0	4.6	$3.12 \times 10^{+0}$	1.59×10^{-1}
165.2	4.6	$2.01 \times 10^{+0}$	9.22×10^{-2}
174.3	4.6	$1.07 \times 10^{+0}$	3.69×10^{-2}
183.5	4.6	5.48×10^{-1}	2.54×10^{-2}
192.7	4.6	2.44×10^{-1}	1.19×10^{-2}
201.9	4.6	7.41×10^{-2}	7.07×10^{-3}
211.0	4.6	2.72×10^{-2}	4.28×10^{-3}
220.2	4.6	3.34×10^{-3}	1.67×10^{-3}
227.1	2.3	2.29×10^{-3}	2.29×10^{-3}

Table 3

The transverse energy differential cross-section $d\sigma/dE_T$ in $-0.1 < \eta_{\text{lab}} < 2.9$
for 200 GeV per nucleon ^{32}S -W collisions

E_T [GeV]	Bin half-width [GeV]	$d\sigma/dE_T$ [mb/GeV]	Error [mb/GeV]
6.9	2.3	$4.06 \times 10^{+1}$	$8.05 \times 10^{+0}$
11.5	2.3	$2.57 \times 10^{+1}$	$2.99 \times 10^{+0}$
20.6	6.9	$2.34 \times 10^{+1}$	$1.75 \times 10^{+0}$
34.4	6.9	$1.95 \times 10^{+1}$	$1.49 \times 10^{+0}$
48.2	6.9	$1.23 \times 10^{+1}$	$1.16 \times 10^{+0}$
61.9	6.9	$1.11 \times 10^{+1}$	9.07×10^{-1}
75.7	6.9	$1.21 \times 10^{+1}$	7.44×10^{-1}
89.5	6.9	$1.10 \times 10^{+1}$	7.90×10^{-1}
103.2	6.9	$7.93 \times 10^{+0}$	2.74×10^{-1}
117.0	6.9	$7.64 \times 10^{+0}$	1.19×10^{-1}
130.8	6.9	$7.38 \times 10^{+0}$	8.58×10^{-2}
144.5	6.9	$6.94 \times 10^{+0}$	8.32×10^{-2}
158.3	6.9	$6.72 \times 10^{+0}$	8.23×10^{-2}
172.1	6.9	$6.15 \times 10^{+0}$	7.86×10^{-2}
185.8	6.9	$5.07 \times 10^{+0}$	3.46×10^{-2}
199.6	6.9	$3.80 \times 10^{+0}$	2.88×10^{-2}
213.3	6.9	$2.34 \times 10^{+0}$	1.34×10^{-1}
227.1	6.9	$1.33 \times 10^{+0}$	1.71×10^{-2}
240.9	6.9	6.08×10^{-1}	1.15×10^{-2}
254.6	6.9	2.22×10^{-1}	7.03×10^{-3}
268.4	6.9	6.75×10^{-2}	3.91×10^{-3}
282.2	6.9	1.76×10^{-2}	2.58×10^{-3}
297.5	6.9	3.15×10^{-3}	1.36×10^{-3}
309.7	2.3	6.41×10^{-4}	6.41×10^{-4}

Table 4

The transverse energy differential cross-section $d\sigma/dE_T$ in $-0.1 < \eta_{\text{lab}} < 2.9$
for 200 GeV per nucleon ^{32}S -Pt collisions

E_T [GeV]	Bin half-width [GeV]	$d\sigma/dE_T$ [mb/GeV]	Error [mb/GeV]
11.5	6.9	4.20×10^{-1}	5.53×10^{-0}
25.2	6.9	1.33×10^{-1}	3.05×10^{-0}
39.0	6.9	1.70×10^{-1}	2.95×10^{-0}
52.8	6.9	1.66×10^{-1}	2.62×10^{-0}
66.5	6.9	1.47×10^{-1}	2.35×10^{-0}
80.3	6.9	1.38×10^{-1}	2.17×10^{-0}
94.1	6.9	1.09×10^{-1}	1.97×10^{-0}
107.8	6.9	8.88×10^{-2}	9.94×10^{-1}
121.6	6.9	8.77×10^{-2}	3.46×10^{-1}
135.3	6.9	7.96×10^{-2}	3.24×10^{-1}
149.1	6.9	8.19×10^{-2}	3.29×10^{-1}
162.9	6.9	7.11×10^{-2}	3.06×10^{-1}
176.6	6.9	6.93×10^{-2}	3.03×10^{-1}
190.4	6.9	6.25×10^{-2}	2.49×10^{-1}
204.2	6.9	4.79×10^{-2}	1.52×10^{-1}
217.9	6.9	3.41×10^{-2}	9.50×10^{-2}
231.7	6.9	1.81×10^{-2}	6.90×10^{-2}
245.5	6.9	7.85×10^{-3}	4.22×10^{-2}
259.2	6.9	2.42×10^{-3}	1.26×10^{-2}
273.0	6.9	7.06×10^{-4}	6.92×10^{-3}
286.7	6.9	1.38×10^{-3}	2.88×10^{-3}
305.1	6.9	1.67×10^{-3}	9.62×10^{-4}

Table 5

The transverse energy differential cross-section $d\sigma/dE_T$ in $-0.1 < \eta_{lab} < 2.9$
for 200 GeV per nucleon ^{32}S -Pb collisions

E_T [GeV]	Bin half-width [GeV]	$d\sigma/dE_T$ [mb/GeV]	Error [mb/GeV]
26.1	11.0	$2.42 \times 10^{+1}$	$1.39 \times 10^{+0}$
43.8	6.9	$1.65 \times 10^{+1}$	$1.17 \times 10^{+0}$
57.5	6.9	$1.59 \times 10^{+1}$	$1.01 \times 10^{+0}$
71.6	6.9	$1.35 \times 10^{+1}$	8.98×10^{-1}
85.2	6.9	$1.11 \times 10^{+1}$	7.92×10^{-1}
98.9	6.9	$1.09 \times 10^{+1}$	7.86×10^{-1}
112.5	6.9	$9.70 \times 10^{+0}$	7.93×10^{-1}
126.6	6.9	$9.16 \times 10^{+0}$	2.59×10^{-1}
140.3	6.9	$8.58 \times 10^{+0}$	2.37×10^{-1}
153.9	6.9	$7.57 \times 10^{+0}$	2.19×10^{-1}
167.6	6.9	$7.69 \times 10^{+0}$	2.30×10^{-1}
181.5	6.9	$7.29 \times 10^{+0}$	2.30×10^{-1}
195.3	6.9	$6.41 \times 10^{+0}$	2.09×10^{-1}
209.0	6.9	$4.98 \times 10^{+0}$	1.77×10^{-1}
222.7	6.9	$3.46 \times 10^{+0}$	6.35×10^{-2}
236.5	6.9	$1.87 \times 10^{+0}$	4.61×10^{-2}
250.4	6.9	8.21×10^{-1}	2.95×10^{-2}
264.1	6.9	2.50×10^{-1}	1.63×10^{-2}
277.7	6.9	5.19×10^{-2}	7.19×10^{-3}
285.6	1.9	3.47×10^{-2}	1.13×10^{-2}

Table 6

The transverse energy differential cross-section $d\sigma/dE_T$ in $-0.1 < \eta_{lab} < 2.9$
for 200 GeV per nucleon ^{32}S -U collisions

E_T [GeV]	Bin half-width [GeV]	$d\sigma/dE_T$ [mb/GeV]	Error [mb/GeV]
9.2	4.6	$8.53 \times 10^{+1}$	$1.09 \times 10^{+1}$
18.4	4.6	$2.85 \times 10^{+1}$	$5.80 \times 10^{+0}$
27.5	4.6	$3.65 \times 10^{+1}$	$6.15 \times 10^{+0}$
36.7	4.6	$2.37 \times 10^{+1}$	$4.90 \times 10^{+0}$
45.9	4.6	$1.70 \times 10^{+1}$	$4.28 \times 10^{+0}$
55.1	4.6	$1.57 \times 10^{+1}$	$3.86 \times 10^{+0}$
64.2	4.6	$1.26 \times 10^{+1}$	$3.27 \times 10^{+0}$
73.4	4.6	$1.45 \times 10^{+1}$	$3.33 \times 10^{+0}$
82.6	4.6	$9.05 \times 10^{+0}$	$2.71 \times 10^{+0}$
91.8	4.6	$8.00 \times 10^{+0}$	$2.46 \times 10^{+0}$
100.9	4.6	$1.33 \times 10^{+1}$	$3.15 \times 10^{+0}$
110.1	4.6	$9.98 \times 10^{+0}$	6.40×10^{-1}
119.3	4.6	$1.01 \times 10^{+1}$	5.59×10^{-1}
128.5	4.6	$9.66 \times 10^{+0}$	5.36×10^{-1}
137.6	4.6	$8.59 \times 10^{+0}$	5.06×10^{-1}
146.8	4.6	$8.21 \times 10^{+0}$	4.95×10^{-1}
156.0	4.6	$7.97 \times 10^{+0}$	4.88×10^{-1}
165.2	4.6	$7.72 \times 10^{+0}$	4.80×10^{-1}
174.3	4.6	$7.61 \times 10^{+0}$	4.76×10^{-1}
183.5	4.6	$8.59 \times 10^{+0}$	5.06×10^{-1}
192.7	4.6	$7.04 \times 10^{+0}$	3.59×10^{-1}
201.9	4.6	$6.69 \times 10^{+0}$	2.00×10^{-1}
211.0	4.6	$5.87 \times 10^{+0}$	2.51×10^{-1}
220.2	4.6	$4.89 \times 10^{+0}$	1.71×10^{-1}
229.4	4.6	$3.87 \times 10^{+0}$	1.52×10^{-1}
238.6	4.6	$2.93 \times 10^{+0}$	1.32×10^{-1}
247.8	4.6	$2.19 \times 10^{+0}$	5.71×10^{-2}
256.9	4.6	$1.52 \times 10^{+0}$	4.73×10^{-2}
266.1	4.6	9.91×10^{-1}	3.81×10^{-2}
275.3	4.6	6.12×10^{-1}	2.99×10^{-2}
284.5	4.6	3.68×10^{-1}	2.32×10^{-2}
293.6	4.6	1.95×10^{-1}	1.67×10^{-2}
302.8	4.6	9.59×10^{-2}	1.18×10^{-2}
312.0	4.6	4.37×10^{-2}	7.85×10^{-3}
321.2	4.6	1.88×10^{-2}	5.94×10^{-3}
330.3	4.6	6.76×10^{-3}	3.08×10^{-3}
339.5	4.6	5.46×10^{-3}	2.73×10^{-3}

Table 7

The transverse energy of a central collision and
the corresponding ratio $R \equiv E_T(2.9 < \eta < 5.5)/E_T(-0.1 < \eta < 2.9)$
as a function of the atomic number of the target nucleus

200 GeV per nucleon sulfur projectile						
	Al	Ag	W	Pt	Pb	U
E_T^{central}	69.0 ± 6.0	$155. \pm 3.0$	$198. \pm 2.0$	$208. \pm 2.0$	$213. \pm 6.0$	$220. \pm 5.0$
R^{central}	1.19 ± 0.12	0.75 ± 0.07	0.64 ± 0.06	0.64 ± 0.06	0.64 ± 0.06	0.61 ± 0.06

Table 8

Best-fit values of the two free parameters for the geometrical parametrization of the ^{32}S
 E_T differential cross-sections. Are also given the deformation parameter (δ),
the fluctuations due to the nuclear deformation (ω_d), and the true value of the fluctuations (ω_{true}).
The ^{16}O values [$\epsilon_0(\text{O})$ and $\omega_{\text{true}}(\text{O})$] from ref. [2] are also given for comparison.

	Al	Ag	W	Pt	Pb	U
ϵ_0 [GeV]	0.89 ± 0.10	0.97 ± 0.02	1.01 ± 0.01	1.04 ± 0.01	1.04 ± 0.03	1.02 ± 0.02
ω	1.46 ± 0.7	2.98 ± 0.6	4.51 ± 0.4	3.31 ± 0.4	3.30 ± 0.6	5.75 ± 1.2
$\epsilon_0(\text{O})$	1.26	1.14	1.19			
$\omega_{\text{true}}(\text{O})$	1.05	2.64	2.53			
δ	—	0.13	0.22	0.13	0.00	0.31
ω_d	—	0.22	0.81	0.28	0.00	1.75
ω_{true}	1.46	2.76	3.70	3.03	3.30	4.00

Figure captions

- Fig. 1: Transverse energy differential cross-section $d\sigma/dE_T$ in $-0.1 < \eta < 2.9$ for 200 GeV per nucleon ^{32}S -Al, Ag, Pt, W, Pb, and U collisions; E_T is defined as $\sum E_i \sin \theta$, where $E_i = (p^2 + m^2)^{1/2}$, except for baryons where $E_i = (p^2 + m^2)^{1/2} - m$. The geometrical parametrization of the E_T differential cross-section for the ^{32}S -U collisions is shown as an example. A fit of the same quality is also obtained for the other targets.
- Fig. 2: The comparison of IRIS predictions with the data on $d\sigma/dE_T$ for ^{16}O and ^{32}S -W at 200 GeV per nucleon. The horizontal error bars indicate the systematic error of 7% on the E_T scale. Combined statistical and systematic errors give a global uncertainty of 15% on the IRIS predictions (see ref. [7]).
- Fig. 3: Distribution of E_T as a function of pseudorapidity for ^{32}S -W collisions, in three selected windows of E_T , for 200 GeV per nucleon incident energy normalized to the number of events n and E_T in the range $-0.1 \leq \eta \leq 2.9$.

Fig. 1

Fig. 2

Fig. 3