**CHARGED-PARTICLE MULTIPLICITY DISTRIBUTIONS IN OXYGEN-NUCLEUS
COLLISIONS AT 60 AND 200 GeV PER NUCLEON**

HELIOS Collaboration

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Abstract

Multiplicity distributions of charged particles produced in the pseudorapidity range $0.9 < \eta_{\text{lab}} < 5.5$ were measured in oxygen–nucleus collisions for Al, Ag, and W target nuclei at incident energies of 60 and 200 GeV per nucleon. The multiplicity differential cross-sections and the pseudorapidity distributions as a function of transverse energy are presented for the various target nuclei. The correlation between charged multiplicity and transverse energy is studied as a function of transverse energy. Data are compared with predictions of the IRIS and FRITIOF generators.

Large energy densities over extended volumes can be obtained in high-energy nucleus–nucleus collisions [1,2] and could possibly lead to transitions to new phases of matter [3]. Some insight into the dynamics of such collisions can be gained by the investigation of multiplicity and pseudorapidity*) density distributions of charged particles [4]. We report results on such a study for oxygen collisions with various nuclear targets at incident energies of 60 and 200 GeV per nucleon. According to the geometrical acceptance of our various detector components, we define the following pseudorapidity regions:

‘backward’	$\equiv 0.9 < \eta < 2.9$
‘forward’	$\equiv 2.9 < \eta < 5.5$
‘restricted forward’	$\equiv 2.9 < \eta < 4.9$
‘trigger’	$\equiv -0.1 < \eta < 2.9$.

The set-up of the HELIOS (High Energy Lepton and IOn Spectrometer) detector features muon spectrometry, particle identification and, relevant to this analysis, energy flow and multiplicity measurements. The energy flow is measured using calorimeters [5] with a full solid-angle coverage in the centre-of-mass frame, and with good granularity in the trigger region. The charged-particle multiplicity (N_{ch}) is measured in two highly segmented, 300 μm thick, silicon detectors. A silicon pad detector [6] (see fig. 1) consists of an array of 400 segments varying in size from $0.02 \times 0.167 \text{ cm}^2$ to $0.167 \times 0.66 \text{ cm}^2$. It covers the forward region and is centred on the beam axis 9.0 cm behind the target. A silicon ring detector [7] (see fig. 1) covers the backward region. It is placed 3.0 cm behind the target and is made of 384 segments forming 32 rings approximately equally spaced in pseudorapidity. For both detectors, the signals from the individual segments are sent to ADCs and discriminators, the latter entering a fast summing logic which provides a set of multiplicity triggers (silicon ring) and the interaction trigger (silicon pad). More details on the performances of the detectors can be found elsewhere [6,7].

Two small scintillator counters placed 23.0 cm and 21.5 cm upstream of the target define the arrival of a beam nucleus and provide a measurement of its charge by dE/dx information. The oxygen component in the beam was selected using this information together with the total energy measured in the calorimeter. A set of thin disk targets (of the order of 1% of an interaction length) were used: W (0.102 mm), Ag (0.205 mm), and Al (0.500 mm). The data samples presented here are those listed in ref. [1]. The trigger required $N_{\text{ch}} > 10$ and the transverse energy (E_T) in the trigger region to exceed one of five different thresholds. The pattern of the correlation between multiplicities

*) Throughout this paper we denote by η the pseudorapidity measured in the laboratory reference frame: $\eta = -\ln(\text{tg } \theta_{\text{lab}}/2)$.

in the silicon detectors and between multiplicities and E_T allowed an efficient rejection of non-target interactions. The remaining contamination, varying from about 75% at the lowest E_T to $\leq 1\%$ at $E_T > 50$ GeV, was subtracted using special runs taken without target. More details about the E_T trigger and the analysis of the energy flow can be found in refs. [1, 2, 8].

The mapping of the silicon detector segments into η - ϕ bins was performed using a geometrical Monte Carlo program with appropriate weights taking into account the measured beam offset (up to several hundred μm) and width (of the order of 1 mm r.m.s.). The acceptance and efficiency for each η bin were computed.

The raw multiplicity distributions are determined from the number of segments having a pulse-height value above threshold, and have to be corrected for instrumental inefficiencies due to dead or noisy segments (about 30% for this particular run), multiple hits in a single segment, threshold inefficiencies, charge sharing, and cross-talk. Furthermore, decays in flight, secondary interactions, and gamma conversions have to be subtracted.

The correction for multiple hits was done segment by segment by using the average occupancy and Poisson statistics. For average central collisions, the segment occupancy ranges from 0.2 hits per event to 0.45 in the silicon ring detector and from 0.12 to 0.6 in the silicon pad detector. We have checked the Poisson statistics assumption in the following way. Each of the segments is individually calibrated by fitting a modified Landau function [9, 10] to the pulse-height spectra in low multiplicity events. The spectra for events in a narrow E_T window are generally well reproduced by a sum of modified Landau distributions, each corresponding to the energy loss of one up to five particles (fig. 2), with relative weights calculated from the total hit probability assuming Poisson statistics. However, in the region $0.9 < \eta < 2$ we measure an excess of pulse heights greater than 4 minimum ionizing particles (MIP).

We associate this excess with target evaporation fragments ('black tracks') and knock-on protons ('grey tracks') since from measurements performed with the same beams on emulsion targets [11] we know that a fraction of the observed multiplicity in the region $\eta < 2$ is due to heavily ionizing tracks with $\beta < 0.7$. These tracks are known to have an isotropic or only slightly asymmetric angular distribution, which is peaked around $\eta = 0$. In our sample, the excess hits with high pulse heights have an angular distribution and an absolute level compatible with those expected from grey and black tracks; about half of the grey and black track hits are above 4 MIP, and they are removed by estimating the multiplicity in that part of the spectra by integration of the tails of the modified Landau distributions. The remaining contribution to the spectra below 4 MIP is removed by Monte Carlo using the information on the number, angular distribution, and energy from the emulsion measurements. The total correction is of the order of 30% of the true multiplicity for $\eta < 2$, with a systematic error estimated at 10%.

The distortion in the observed multiplicity distributions due to particle decays (mostly K_S^0) and gamma conversions is evaluated using particle distributions provided by the IRIS generator [12], which is based on colour exchange, with the Dual Parton Model as the starting point, and Lund fragmentation. For average central collisions this correction results in a reduction of the observed multiplicity ranging from 6.4% at $\eta = 1$ to 2.5% at $\eta = 5$.

We studied the sensitivity of our analysis procedure to the various assumptions, for example by verifying the flatness of the reconstructed azimuthal distributions (owing to the beam offset and the geometry of the silicon pad detector, our set-up is not azimuthally symmetric), and we estimate the average systematic error on $dN_{\text{ch}}/d\eta$ to be $\pm 5\%$, increasing to $\pm 10\%$ for $\eta > 4.5$ and for $\eta < 2.0$. The agreement between the two detectors in the overlap region is better than 5%. We estimate an 8% systematic error on the absolute N_{ch} scale.

The differential charged multiplicity cross-section ($d\sigma/dN_{\text{ch}}$) is obtained from the raw segment multiplicity cross-section ($d\sigma/dN_{\text{ch}}^{\text{raw}}$) by applying all the above-mentioned corrections, averaged over

each data sample after factorization of the trivial dependence of the corrections on N_{ch}^{raw} . It is then deconvoluted for the multiplicity resolution $\sigma \approx 80-120\% \times \sqrt{N_{ch}}$ for $N_{ch} = 20-300$. In fig. 3 and tables 1 to 6 we show $d\sigma/dN_{ch}$ for ^{16}O at 60 and 200 GeV per nucleon incident on Al, Ag, and W targets. Owing to our trigger region, the cross-sections are presented separately for the backward region and for the restricted forward region. Since the events were taken using several E_T thresholds, we built $d\sigma/dN_{ch}$ using only those events for which N_{ch} is sufficiently far above the region influenced by the corresponding E_T thresholds.

The shape of the $d\sigma/dN_{ch}$ distributions is similar to that observed [1] in the transverse energy distributions $d\sigma/dE_T$: a rather flat region ('plateau') extending to a shoulder ('central') followed by a steep fall ('tail'). This shape can be understood [1] in terms of the impact parameter dependence and the geometry of collisions between extended nuclei.

The predictions of the IRIS 3.05 generator [12] are superimposed on the 200 GeV per nucleon data in fig. 3b. The model is in good agreement with the data. However, as the target mass increases, the model underestimates the cross-section in the backward region and overestimates it in the restricted forward region. This is also reflected in the pseudorapidity distributions, shown later.

The pseudorapidity densities $dN_{ch}/d\eta$ for ^{16}O incident on the various targets are shown in fig. 4a and 4b for the two beam energies and for three selected E_T intervals corresponding to the plateau, the average central collisions, and the tail of the respective $d\sigma/dN_{ch}$ distributions. The main features of the distributions are summarized in fig. 5, where the mean η , the standard deviation, and the maximum pseudorapidity density (obtained from a fit to a Gaussian distribution) are shown as a function of E_T .

The peak of the distributions $dN_{ch}/d\eta$ is clearly shifted towards smaller pseudorapidities with increasing E_T and increasing target mass. This possibly reflects the displacement of the effective centre-of-mass due to the increasing number of participating target nucleons. The backward displacement is accompanied by a slight reduction of the width of the pseudorapidity distributions, which is expected as the degree of stopping increases. We note that these widths are considerably larger than those expected from the isotropic decay of a fireball^{*)}. The maximum density is independent of beam energy and target mass, and is a function of E_T only.

In fig. 4b we compare the pseudorapidity densities $dN_{ch}/d\eta$ of our 200 GeV per nucleon data with the absolute predictions of the IRIS 3.05 generator [12]. Collisions at the same cross-section have been chosen in both data and IRIS, as was done in ref. [1], using the fact that E_T in the trigger region of the data samples exceeds the corresponding E_T in the IRIS samples by $\sim 20\%$. The IRIS prediction does not fully reproduce the backward rapidity shift with increasing E_T . This is a possible indication of the importance of target fragmentation and intranuclear cascading, neither of which are included in the model, and/or an underestimation of stopping.

A detailed comparison is presented in fig. 6 for 200 GeV per nucleon ^{16}O -Ag collisions from the tail of the cross-section, between the $dN_{ch}/d\eta$ distribution measured with the silicon detectors ($103.2 < E_T < 114.7$ GeV) and that measured in 31 ^{16}O -emulsion interactions [13], where grey and black tracks have been excluded. The integrated numbers of charged particles in the backward plus forward regions are 253 for the silicon detector data and 237 for the emulsion data. In the backward region the numbers are $136 \pm 2(\text{stat.}) \pm 7(\text{syst.})$ for the silicon detector and $125 \pm 2(\text{stat.})$ for the emulsion. Taking into account the estimated systematic errors, the agreement between our silicon detector and emulsion data can be considered satisfactory. This is also true for the other E_T bins. For comparison we also show the IRIS 3.05 prediction (full line) and the prediction of the FRITIOF 1.6 model [14] (broken line).

*) In this case $dN/d\eta$ approaches the form $1/\cosh^2(\eta - \eta_0)$ which has a FWHM of 1.76.

The measurements of the transverse energy and charged multiplicity flow allow the study of the variation of the mean ratio E_T/N_{ch} , which is related to the mean transverse momentum (p_T). Such a measurement is of interest as it has been advocated that the dependence of the mean transverse momentum on multiplicity could indirectly signal the occurrence of a deconfinement phase transition in nucleus–nucleus collisions [15].

We show in fig. 7 the E_T dependence of the ratio E_T/N_{ch} measured in the backward region, for both 60 and 200 GeV per nucleon incident energies. Data below $E_T = 60$ GeV are omitted because of the increasing fraction of non-target interactions. The apparent rise with E_T is about twice our estimated non-linearity error, which is 6.4% (4% from the E_T scale and 5% from the N_{ch} scale).

The value of the E_T/N_{ch} ratio is related to a ‘global’ p_T , averaged over all particle species, via the charged- E_T over neutral- E_T ratio. Given the unknown particle composition, we can only extract a model-dependent value of ‘ $\langle p_T \rangle$ ’. Using the prediction of the Lund fragmentation scheme, which gives $E_T(\text{charged})/E_T \approx 0.59$, independent of E_T , we find ‘ $\langle p_T \rangle$ ’ = (382 ± 42) MeV/c for 200 GeV per nucleon. The error is determined by the overall scale uncertainty of 11% (7.1% from the E_T scale and 8% from the multiplicity scale). This is about the same value observed at central rapidities in pp collisions for similar nucleon–nucleon c.m. energies. We do not see the drastic variation of p_T with energy density observed in cosmic-ray events by the JACEE Collaboration [16] or in $p\bar{p}$ collisions [17]. It should be noted, however, that a variation in the particle composition with E_T , or a different p_T dependence for different particle species, could obscure a change of slope in our data. Furthermore, recent hydrodynamical calculations predict considerably softened changes of slopes [18].

We have presented multiplicity results for oxygen–nucleus interactions at 60 and 200 GeV per nucleon. The global features of the differential cross-section $d\sigma/dN_{ch}$ reflect the dominant role of the impact parameter dependence and the geometry of collisions between extended nuclei. The maximum of the pseudorapidity density distributions $dN_{ch}/d\eta$ is shifted backward towards small pseudorapidities with both increasing E_T and target mass, possibly a kinematical effect reflecting the displacement of the effective centre-of-mass for an increasing number of interacting participants from the target. The strong correlation between E_T and charged-particle multiplicity is emphasized by the almost linear relation found between average E_T and average N_{ch} . Using the ratio of charged E_T to total E_T as predicted by the LUND fragmentation scheme we find a ‘ $\langle p_T \rangle$ ’ characteristic of soft physics for nucleus–nucleus collisions.

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REFERENCES

- [1] T. Åkesson et al., Z. Phys. **C38** (1988) 383.
- [2] T. Åkesson et al., Phys. Lett. **B214** (1988) 295.
- [3] K. Kajantie and L. McLerran, Ann. Rev. Nucl. Part. Sci. **37** (1987) 293, and references therein.
- [4] A. Bamberger et al., Phys. Lett. **B184** (1987) 271 and **B205** (1988) 583;
R. Albrecht et al., Phys. Lett. **B202** (1988) 596.
- [5] T. Åkesson et al., Nucl. Instrum. Methods **A262** (1987) 243.
- [6] R. Beuttenmuller et al., Nucl. Instrum. Methods **A252** (1986) 471.
- [7] P. Giubellino et al., Nucl. Instrum. Methods **A275** (1989) 89.
- [8] Y. Sirois, Ph.D. Thesis, McGill University, Montreal, March 1988.
- [9] S. Hancock et al., Nucl. Instrum. Methods **B1** (1983) 16.
- [10] J. Schukraft, Proc. Quark Matter, 87, Z. Phys. **C38** (1988) 59.
- [11] N. Ardito et al., Europhys. Lett. **6** (1988) 131.
- [12] J.P. Pansart, IRIS306, Saclay report DPhPE 89-04, March 1989, and references therein.
- [13] G. Romano, Summary of emulsion data on high-energy nucleus-nucleus interactions, preprint CERN-EP/89-30, to appear in Proc. Quark Matter '88, Lenox, Mass., USA, 1988.
- [14] B. Nilsson-Almqvist and E. Stenlund, Comp. Phys. Commun. **43** (1987) 387;
B. Andersson et al., Nucl. Phys. **B281** (1987) 289;
B. Andersson, G. Gustafson and T. Sjöstrand, Z. Phys. **C6** (1980) 235.
- [15] L. Van Hove, Phys. Lett. **B118** (1982) 138;
E.V. Shuryak and O.V. Zhirov, Phys. Lett. **B89** (1980) 253 and **B171** (1986) 99.
- [16] Y. Takahashi, Proc. Int. Conf. on Quark Matter, Asilomar, 1986, Nucl. Phys. **A461** (1987) 263c;
T.H. Burnett et al., Nucl. Phys. **A447** (1985) 189.
- [17] T. Alexopoulos et al., Phys. Rev. Lett. **60** (1988) 1622.
- [18] M. Kataja et al., Phys. Rev. **D34** (1986) 2755;
H. von Gersdorff, Proc. Int. Conf. on Quark Matter, Asilomar, 1986, Nucl. Phys. **A461** (1987) 251c;
J.-P. Blaizot and J.-Y. Ollitrault, Nucl. Phys. **A458** (1986) 745;
X.-N. Wang and R.C. Hwa, Phys. Rev. **D35** (1987) 3409.

Table 1

The charged multiplicity differential cross-section $d\sigma/dN_{\text{ch}}$
for 60 GeV per nucleon ^{16}O -Al collisions

N_{ch}	bin half-width	$d\sigma/dN_{\text{ch}}$ (mb)	error (mb)
Backward region ($0.9 < \eta < 2.9$)			
18.7	4.3	$1.32 \times 10^{+1}$	$3.6 \times 10^{+0}$
27.3	4.4	$1.52 \times 10^{+1}$	$1.1 \times 10^{+0}$
36.2	4.5	$9.55 \times 10^{+0}$	7.4×10^{-1}
45.2	4.6	$5.66 \times 10^{+0}$	5.6×10^{-1}
54.5	4.7	$2.98 \times 10^{+0}$	2.6×10^{-1}
64.0	4.8	8.17×10^{-1}	5.5×10^{-2}
73.8	5.0	1.92×10^{-1}	2.4×10^{-2}
85.6	6.8	1.87×10^{-2}	5.2×10^{-3}
Restricted forward region ($2.9 < \eta < 4.9$)			
20.4	3.3	$2.88 \times 10^{+1}$	$6.3 \times 10^{+0}$
27.0	3.3	$2.00 \times 10^{+1}$	$1.4 \times 10^{+0}$
33.7	3.4	$1.10 \times 10^{+1}$	$1.0 \times 10^{+0}$
40.6	3.5	$4.54 \times 10^{+0}$	6.8×10^{-1}
47.7	3.6	$1.21 \times 10^{+0}$	3.2×10^{-1}
54.9	3.6	2.36×10^{-1}	1.5×10^{-1}
62.2	3.7	1.85×10^{-2}	5.9×10^{-2}
69.8	3.8	6.80×10^{-3}	4.1×10^{-3}
77.6	3.9	6.92×10^{-4}	3.1×10^{-4}
85.6	4.0	6.40×10^{-5}	3.6×10^{-5}

Table 2

The charged multiplicity differential cross-section $d\sigma/dN_{ch}$
for 60 GeV per nucleon ^{16}O -Ag collisions

N_{ch}	bin half-width	$d\sigma/dN_{ch}$ (mb)	error (mb)
Backward region ($0.9 < \eta < 2.9$)			
26.7	4.3	$2.22 \times 10^{+1}$	$2.9 \times 10^{+0}$
35.3	4.4	$1.46 \times 10^{+1}$	$2.0 \times 10^{+0}$
44.1	4.5	$1.33 \times 10^{+1}$	$1.7 \times 10^{+0}$
53.2	4.6	$1.37 \times 10^{+1}$	$1.2 \times 10^{+0}$
62.5	4.7	$1.22 \times 10^{+1}$	5.0×10^{-1}
72.1	4.8	$1.13 \times 10^{+1}$	4.8×10^{-1}
81.9	5.0	$9.03 \times 10^{+0}$	4.2×10^{-1}
92.0	5.1	$7.07 \times 10^{+0}$	2.6×10^{-1}
102.4	5.3	$4.09 \times 10^{+0}$	1.1×10^{-1}
113.1	5.4	$1.91 \times 10^{+0}$	7.2×10^{-2}
124.2	5.6	6.71×10^{-1}	3.9×10^{-2}
135.6	5.8	1.81×10^{-1}	1.8×10^{-2}
147.3	6.0	3.22×10^{-2}	6.7×10^{-3}
159.5	6.2	5.88×10^{-3}	2.3×10^{-3}
172.2	6.4	1.13×10^{-3}	7.3×10^{-4}
Restricted forward region ($2.9 < \eta < 4.9$)			
19.6	3.1	$5.92 \times 10^{+1}$	$1.8 \times 10^{+1}$
25.9	3.2	$4.03 \times 10^{+1}$	$4.0 \times 10^{+0}$
32.3	3.3	$3.25 \times 10^{+1}$	$3.2 \times 10^{+0}$
38.9	3.3	$2.70 \times 10^{+1}$	$2.7 \times 10^{+0}$
45.7	3.4	$2.06 \times 10^{+1}$	$1.4 \times 10^{+0}$
52.6	3.5	$9.74 \times 10^{+0}$	9.4×10^{-1}
59.6	3.6	$1.74 \times 10^{+0}$	5.1×10^{-1}
66.9	3.7	3.79×10^{-1}	2.9×10^{-2}
74.3	3.8	4.62×10^{-2}	7.2×10^{-3}
82.0	3.9	5.85×10^{-3}	1.6×10^{-3}
89.8	4.0	1.06×10^{-3}	3.8×10^{-4}
97.9	4.1	5.90×10^{-5}	3.9×10^{-5}

Table 3

The charged multiplicity differential cross-section $d\sigma/dN_{\text{ch}}$
for 60 GeV per nucleon ^{16}O -W collisions

N_{ch}	bin half-width	$d\sigma/dN_{\text{ch}}$ (mb)	error (mb)
Backward region ($0.9 < \eta < 2.9$)			
26.1	4.2	$3.23 \times 10^{+1}$	$5.8 \times 10^{+0}$
34.6	4.3	$2.24 \times 10^{+1}$	$2.8 \times 10^{+0}$
43.2	4.4	$1.59 \times 10^{+1}$	$2.2 \times 10^{+0}$
52.1	4.5	$1.84 \times 10^{+1}$	$1.0 \times 10^{+0}$
61.2	4.6	$1.53 \times 10^{+1}$	9.4×10^{-1}
70.6	4.7	$1.41 \times 10^{+1}$	8.9×10^{-1}
80.2	4.9	$1.37 \times 10^{+1}$	5.7×10^{-1}
90.1	5.0	$1.30 \times 10^{+1}$	3.4×10^{-1}
100.3	5.2	$1.14 \times 10^{+1}$	2.7×10^{-1}
110.8	5.3	$9.01 \times 10^{+0}$	1.5×10^{-1}
121.6	5.5	$6.10 \times 10^{+0}$	1.2×10^{-1}
130.9	3.8	$3.84 \times 10^{+0}$	1.1×10^{-1}
138.5	3.8	$2.11 \times 10^{+0}$	7.6×10^{-2}
146.3	3.9	$1.16 \times 10^{+0}$	5.3×10^{-2}
154.2	4.0	5.09×10^{-1}	1.6×10^{-2}
162.4	4.1	2.01×10^{-1}	9.4×10^{-3}
170.7	4.2	8.96×10^{-2}	5.6×10^{-3}
179.2	4.3	2.98×10^{-2}	2.9×10^{-3}
190.2	6.7	6.47×10^{-3}	9.0×10^{-4}
203.9	7.0	1.36×10^{-3}	3.4×10^{-4}
218.1	7.3	2.49×10^{-4}	9.8×10^{-5}
235.5	10.2	2.30×10^{-5}	1.7×10^{-5}
Restricted forward region ($2.9 < \eta < 4.9$)			
19.2	3.1	$1.54 \times 10^{+2}$	$2.9 \times 10^{+1}$
25.4	3.1	$7.26 \times 10^{+1}$	$7.1 \times 10^{+0}$
31.7	3.2	$5.08 \times 10^{+1}$	$4.4 \times 10^{+0}$
38.2	3.3	$3.97 \times 10^{+1}$	$3.5 \times 10^{+0}$
44.8	3.3	$3.59 \times 10^{+1}$	$2.5 \times 10^{+0}$
51.6	3.4	$2.21 \times 10^{+1}$	$1.6 \times 10^{+0}$
58.5	3.5	$7.59 \times 10^{+0}$	$1.1 \times 10^{+0}$
65.6	3.6	$2.05 \times 10^{+0}$	1.3×10^{-1}
72.9	3.7	3.97×10^{-1}	4.1×10^{-2}
80.4	3.8	8.45×10^{-2}	1.1×10^{-2}
88.1	3.9	2.96×10^{-2}	5.0×10^{-3}
96.0	4.0	7.22×10^{-3}	1.9×10^{-3}
104.2	4.1	1.50×10^{-3}	6.1×10^{-4}
112.6	4.3	6.83×10^{-4}	2.5×10^{-4}
121.2	4.4	1.86×10^{-4}	1.2×10^{-4}

Table 4

The charged multiplicity differential cross-section $d\sigma/dN_{\text{ch}}$
for 200 GeV per nucleon ^{16}O -Al collisions

N_{ch}	bin half-width	$d\sigma/dN_{\text{ch}}$ (mb)	error (mb)
Backward region ($0.9 < \eta < 2.9$)			
20.2	4.6	$1.26 \times 10^{+1}$	$2.2 \times 10^{+0}$
29.5	4.7	$1.35 \times 10^{+1}$	$1.9 \times 10^{+0}$
39.1	4.8	$1.26 \times 10^{+1}$	$1.6 \times 10^{+0}$
48.8	5.0	$8.97 \times 10^{+0}$	$1.3 \times 10^{+0}$
58.9	5.1	$6.64 \times 10^{+0}$	$1.2 \times 10^{+0}$
69.2	5.2	7.14×10^{-1}	2.6×10^{-1}
79.7	5.4	2.49×10^{-4}	1.4×10^{-4}
Restricted forward region ($2.9 < \eta < 4.9$)			
15.6	3.6	$1.24 \times 10^{+1}$	$3.3 \times 10^{+0}$
22.8	3.6	$1.36 \times 10^{+1}$	$2.7 \times 10^{+0}$
30.2	3.7	$1.24 \times 10^{+1}$	$2.3 \times 10^{+0}$
37.7	3.8	$1.23 \times 10^{+1}$	$2.0 \times 10^{+0}$
45.4	3.9	$1.13 \times 10^{+1}$	$1.6 \times 10^{+0}$
53.3	4.0	$8.59 \times 10^{+0}$	$1.5 \times 10^{+0}$
61.3	4.1	$7.51 \times 10^{+0}$	$1.2 \times 10^{+0}$
69.6	4.2	$5.08 \times 10^{+0}$	9.7×10^{-1}
78.0	4.3	$2.40 \times 10^{+0}$	6.4×10^{-1}
86.7	4.4	$2.56 \times 10^{+0}$	6.2×10^{-1}
95.6	4.5	3.44×10^{-1}	2.0×10^{-1}
104.8	4.6	2.13×10^{-1}	1.2×10^{-1}

Table 5

The charged multiplicity differential cross-section $d\sigma/dN_{ch}$
for 200 GeV per nucleon ^{16}O -Ag collisions

N_{ch}	bin half-width	$d\sigma/dN_{ch}$ (mb)	error (mb)
Backward region ($0.9 < \eta < 2.9$)			
19.6	4.5	$1.26 \times 10^{+1}$	$5.9 \times 10^{+0}$
28.6	4.6	$1.00 \times 10^{+1}$	$4.8 \times 10^{+0}$
37.9	4.7	$1.45 \times 10^{+1}$	$4.0 \times 10^{+0}$
47.4	4.8	$9.40 \times 10^{+0}$	$3.2 \times 10^{+0}$
57.1	4.9	$9.44 \times 10^{+0}$	$2.7 \times 10^{+0}$
67.1	5.1	$6.43 \times 10^{+0}$	$2.2 \times 10^{+0}$
77.4	5.2	$8.92 \times 10^{+0}$	$2.3 \times 10^{+0}$
87.9	5.3	$7.87 \times 10^{+0}$	$1.8 \times 10^{+0}$
98.8	5.5	$6.62 \times 10^{+0}$	3.8×10^{-1}
109.9	5.7	$5.10 \times 10^{+0}$	3.3×10^{-1}
121.4	5.8	$3.46 \times 10^{+0}$	2.7×10^{-1}
133.3	6.0	$1.93 \times 10^{+0}$	2.0×10^{-1}
145.5	6.2	9.00×10^{-1}	9.5×10^{-2}
158.2	6.4	4.52×10^{-1}	3.6×10^{-2}
171.3	6.7	1.51×10^{-1}	2.0×10^{-2}
184.8	6.9	4.68×10^{-2}	1.1×10^{-2}
198.9	7.2	5.75×10^{-3}	3.6×10^{-3}
Restricted forward region ($2.9 < \eta < 4.9$)			
14.5	3.3	$1.99 \times 10^{+1}$	$1.0 \times 10^{+1}$
21.2	3.4	$2.77 \times 10^{+1}$	$8.4 \times 10^{+0}$
28.0	3.4	$8.37 \times 10^{+0}$	$6.1 \times 10^{+0}$
34.9	3.5	$1.50 \times 10^{+1}$	$5.5 \times 10^{+0}$
42.1	3.6	$1.59 \times 10^{+1}$	$4.4 \times 10^{+0}$
49.4	3.7	$6.76 \times 10^{+0}$	$3.4 \times 10^{+0}$
56.8	3.8	$1.02 \times 10^{+1}$	$3.1 \times 10^{+0}$
64.5	3.9	$1.48 \times 10^{+1}$	$3.5 \times 10^{+0}$
72.3	4.0	$4.82 \times 10^{+0}$	$1.6 \times 10^{+0}$
80.4	4.1	$6.42 \times 10^{+0}$	4.4×10^{-1}
88.6	4.2	$8.49 \times 10^{+0}$	5.1×10^{-1}
97.1	4.3	$7.48 \times 10^{+0}$	4.8×10^{-1}
104.3	2.9	$6.01 \times 10^{+0}$	5.3×10^{-1}
110.3	3.0	$4.13 \times 10^{+0}$	4.1×10^{-1}
116.3	3.0	$2.16 \times 10^{+0}$	2.6×10^{-1}
122.5	3.1	7.28×10^{-1}	1.1×10^{-1}
128.7	3.2	1.85×10^{-1}	1.9×10^{-2}
135.1	3.2	4.01×10^{-2}	6.1×10^{-3}
141.7	3.3	6.92×10^{-3}	1.6×10^{-3}
148.4	3.4	1.30×10^{-3}	3.4×10^{-4}
155.2	3.5	9.60×10^{-5}	4.3×10^{-5}
162.2	3.5	1.50×10^{-5}	5.0×10^{-6}

Table 6

The charged multiplicity differential cross-section $d\sigma/dN_{\text{ch}}$
for 200 GeV per nucleon ^{16}O -W collisions

N_{ch}	bin half-width	$d\sigma/dN_{\text{ch}}$ (mb)	error (mb)
Backward region ($0.9 < \eta < 2.9$)			
19.5	4.4	$2.04 \times 10^{+1}$	$5.6 \times 10^{+0}$
28.5	4.6	$2.20 \times 10^{+1}$	$4.4 \times 10^{+0}$
37.7	4.7	$2.44 \times 10^{+1}$	$3.0 \times 10^{+0}$
47.2	4.8	$1.66 \times 10^{+1}$	$2.5 \times 10^{+0}$
56.9	4.9	$1.49 \times 10^{+1}$	$1.7 \times 10^{+0}$
66.8	5.0	$1.26 \times 10^{+1}$	$1.4 \times 10^{+0}$
77.0	5.2	$1.28 \times 10^{+1}$	9.8×10^{-1}
87.5	5.3	$1.20 \times 10^{+1}$	7.9×10^{-1}
98.3	5.5	$1.12 \times 10^{+1}$	2.7×10^{-1}
109.5	5.6	$1.03 \times 10^{+1}$	2.6×10^{-1}
120.9	5.8	$9.16 \times 10^{+0}$	2.4×10^{-1}
132.7	6.0	$8.06 \times 10^{+0}$	2.2×10^{-1}
142.9	4.1	$6.54 \times 10^{+0}$	1.9×10^{-1}
151.2	4.2	$5.46 \times 10^{+0}$	9.4×10^{-2}
159.7	4.3	$4.42 \times 10^{+0}$	8.3×10^{-2}
168.3	4.4	$3.12 \times 10^{+0}$	6.8×10^{-2}
177.2	4.5	$2.06 \times 10^{+0}$	5.3×10^{-2}
186.3	4.6	1.21×10^{-1}	3.9×10^{-2}
195.7	4.7	6.85×10^{-1}	2.8×10^{-2}
205.2	4.8	3.62×10^{-1}	2.0×10^{-2}
215.0	5.0	1.64×10^{-2}	1.2×10^{-3}
225.1	5.1	7.43×10^{-2}	7.8×10^{-3}
235.4	5.2	2.68×10^{-2}	1.7×10^{-4}
246.1	5.4	1.06×10^{-3}	9.7×10^{-4}
257.0	5.6	4.56×10^{-3}	5.7×10^{-4}
268.3	5.7	1.81×10^{-4}	3.2×10^{-4}
279.9	5.9	7.86×10^{-4}	1.8×10^{-5}
294.9	9.2	2.22×10^{-5}	6.6×10^{-5}
313.8	9.7	9.30×10^{-5}	3.2×10^{-6}
333.7	10.2	1.60×10^{-5}	9.0×10^{-6}

(cont.)

Table 6 (cont.)

N_{ch}	bin half-width	$d\sigma/dN_{ch}$ (mb)	error (mb)
Restricted forward region ($2.9 < \eta < 4.9$)			
14.1	3.2	$4.99 \times 10^{+1}$	$1.1 \times 10^{+1}$
20.5	3.3	$3.30 \times 10^{+1}$	$7.6 \times 10^{+0}$
27.1	3.3	$3.13 \times 10^{+1}$	$6.2 \times 10^{+0}$
33.9	3.4	$2.67 \times 10^{+1}$	$4.8 \times 10^{+0}$
40.8	3.5	$2.54 \times 10^{+1}$	$3.1 \times 10^{+0}$
47.8	3.6	$1.80 \times 10^{+1}$	$2.9 \times 10^{+0}$
55.1	3.7	$2.21 \times 10^{+1}$	$2.0 \times 10^{+0}$
62.5	3.8	$1.72 \times 10^{+1}$	$1.5 \times 10^{+0}$
70.1	3.8	$1.73 \times 10^{+1}$	$1.1 \times 10^{+0}$
77.9	3.9	$1.61 \times 10^{+1}$	3.8×10^{-1}
85.9	4.1	$1.72 \times 10^{+1}$	4.0×10^{-1}
94.1	4.2	$1.70 \times 10^{+1}$	3.9×10^{-1}
101.2	2.8	$1.61 \times 10^{+1}$	4.7×10^{-1}
106.9	2.9	$1.28 \times 10^{+1}$	4.1×10^{-1}
112.7	3.0	$8.99 \times 10^{+0}$	1.4×10^{-1}
118.7	3.0	$6.06 \times 10^{+0}$	1.1×10^{-1}
124.8	3.1	$3.51 \times 10^{+0}$	7.9×10^{-2}
131.0	3.1	$1.76 \times 10^{+0}$	5.1×10^{-2}
137.4	3.2	7.10×10^{-1}	2.8×10^{-2}
143.8	3.3	1.66×10^{-1}	4.6×10^{-3}
150.5	3.3	5.52×10^{-2}	2.1×10^{-3}
157.2	3.4	1.86×10^{-2}	9.6×10^{-4}
164.2	3.5	4.34×10^{-3}	3.4×10^{-4}
171.2	3.6	1.15×10^{-3}	1.2×10^{-4}
178.5	3.7	2.26×10^{-4}	3.3×10^{-5}
185.9	3.8	5.50×10^{-5}	1.0×10^{-5}
193.6	3.9	6.00×10^{-6}	2.0×10^{-6}

Figure captions

- Fig. 1 The target region and the calorimetric part of the experimental set-up. The inset shows the segmentation of the two silicon detectors. The target is surrounded by a box consisting of a calorimetrized dipole magnet, U/scintillator, and U/Cu/scintillator modules.
- Fig. 2 Pulse-height spectrum for a segment ($\eta \approx 2.0$) of the silicon ring detector, with the modified Landau distributions for one up to four particles (dotted curves) and their sum (solid curve), for $114.6 < E_T < 126.1$ GeV. (The distribution for five particles is negligible in this case.)
- Fig. 3 Charged-particle differential cross-section $d\sigma/dN_{ch}$ in the backward and restricted forward regions: a) at 60 GeV per nucleon; b) at 200 GeV per nucleon. The error bars are statistical only; the global systematic error on the multiplicity scale is 8%. The lines indicate IRIS predictions.
- Fig. 4 Distribution of pseudorapidity density for three selected windows in E_T within the trigger region: a) at 60 GeV per nucleon; b) at 200 GeV per nucleon. The errors shown are statistical only. The lines indicate IRIS predictions.
- Fig. 5 Evolution of mean η , standard deviation, and maximum pseudorapidity density with E_T for Ag targets (squares) and W targets (circles), at 60 GeV (open symbols) and 200 GeV (closed symbols) per nucleon.
- Fig. 6 Distribution of $dN_{ch}/d\eta$ for 200 GeV per nucleon ^{16}O -Ag collisions in the tail of the cross-section: from silicon detectors ($103.2 < E_T < 114.7$ GeV, solid circles), emulsions (histogram), IRIS prediction (full line) and FRITIOF prediction (broken line). For the silicon detectors $dN_{ch}/d\eta$, statistical errors and combined statistical and systematic errors are shown.
- Fig. 7 Average E_T divided by the number of charged particles, integrated over the backward region, versus E_T in the trigger region for 60 GeV per nucleon and 200 GeV per nucleon ^{16}O -W collisions. The dashed lines indicate the point-to-point systematic errors.

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