TRANSVERSE ENERGY DISTRIBUTIONS IN 200A GeV O(S)+A COLLISIONS IN THE CENTRAL RAPIDITY REGION

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We present a simple scheme of p+p collision which reproduces with very good accuracy KNO scaling properties of charged particle multiplicities in the energy range from threshold energies to the top of the CERN ISR energies. This scheme is used in the independent scattering frame to the description of global characteristics like transverse energy production in proton + nucleus and nucleus + nucleus ultrarelativistic collisions.

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1. Introduction

The signals from the collective phenomena in ultrarelativistic heavy-ion collisions, like the quark-gluon plasma, QGP, creation will probably be found against the background of the conventional soft-momentum particle production, where plasma formation would not be expected. The simplest no-plasma model is the Independent Scattering Model, ISM, in which nucleus + nucleus collision is reduced to the sequence of inelastic nucleon + nucleon scatterings and, additionally, only collision geometry and nuclear density distribution are taken into account. We present here a simple scheme of the p + p scattering, which is then consistently extended to the description of the transverse energy distribution in ultrarelativistic $A + A$ collisions. Transverse energy is one of the global characteristics of heavy-ion collisions, similar to the multiplicity; both these measurements characterize the centrality, or the violence of the interaction.

2. The p + p collision scheme

The cms-energies of the colliding nucleons decrease after collision to the values:

$$E_i^* = \frac{(1-K_i)s^{1/2}}{2}\,, \tag{1}$$

where the "inelasticities" K_i are independently sampled from the uniform distribution (0.1, 0.9). The energy available for production then has triangular distribution. The produced fireball moves in the cm-system with Lorentz factor γ_F depending on the degree of asymmetry of the collision and decays anisotropically in its own rest frame with Gaussian rapidity shape and transverse momentum distribution in the Boltzmann form:

$$f(p_{\rm T}) = \frac{p_{\rm T}}{p_0^2}\exp\left(-p_{\rm T}/p_0\right), \tag{2}$$

with $p_0 = \langle p_{\rm T}\rangle / 2 = 0.175$ GeV/ c. As it is well known, the transverse momentum spectra can be described by this exponential form in the $p_{\rm T}$ range between roughly 0.3 and 1.5 GeV/c, nearly independent on beam energy in the AGS–SPS range and rapidity coverage, with slope constants between 0.17-0.19 GeV/c [1].

The rapidity shift, η, of the fireball in relation to the cm-system rapidity equals:

$$\eta = \ln\left[\gamma_F + (\gamma_F^2 - 1)^{1/2}\right]. \tag{3}$$

We choose the width of the rapidity distribution proportional to the maximum available rapidity $y_{\rm max}$: $y_{\rm max} = \ln(E_{\rm p}^*/m_\pi)$, where $E_{\rm p}^* = s^{1/2} - 2m_{\rm N}$ is the available cms-energy and m_π and $m_{\rm N}$ denote the pion and nucleon mass, respectively. Such energy dependence of the dispersion of the Gaussian rapidity (pseudorapidity) agrees with experimental results [1, 2]:

$$\sigma = \frac{\sigma_0 y_{\rm max}(s)}{y_{\rm max}(s_0)} = \sigma_0' \ln\left(\frac{E_{\rm p}^*}{m_\pi}\right), \tag{4}$$

where $\sigma_0' = \sigma_0/y_{\rm max}(s_0)$. The value of $\sigma_0 = 1.36$ reproduces satisfactorily the rapidity distribution of the negative particles at the energy $E_{\rm L}$ =200 GeV [3].

According to the presented scheme, the particles are emitted thermally, but the fireball expands mostly longitudinally, *i.e.* the longitudinal and transverse motion are approximately independent.

The cms-energy of the particle emitted with rapidity y equals:

$$E^* = m_{\rm T}\cosh y\,, \tag{5}$$

where $m_{\rm T} = (p_{\rm T}^2 + m^2)^{1/2}$ denotes the transverse mass (transverse energy).

We assume that the average charged multiplicity in p + p collision can be presented in the form:

$$\langle n_{\rm ch}\rangle_{\rm pp} = 2.0 + \tfrac{2}{3}\langle n\rangle\,, \tag{6}$$

where $\langle n\rangle$ denotes the average multiplicity of newly produced particles. If the incident particles transfer to the cluster on the average $\langle K\rangle$ of the available cms-energy, then the average multiplicity of produced particles is:

$$\langle n\rangle \cong \frac{\langle K\rangle\,(s^{1/2} - 2m_{\rm p})}{\langle E^*\rangle}\,, \tag{7}$$

where $\langle E^*\rangle$ denotes the average center of mass energy:

$$\langle E^*\rangle = \langle m_{\rm T}\rangle \int \cosh(y) f(y) dy\,.$$

For Gaussian rapidity distribution the integration can be performed analytically with the result [4]:

$$\langle \cosh y\rangle = \cosh\langle y\rangle \exp(\sigma^2/2)\,.$$

In the case of absence $p_{\rm T}-p_{\rm L}$ correlation, we have from (5) in the cm-system, *i.e.* for $\langle y\rangle = 0$:

$$\langle E^*\rangle = \langle m_{\rm T}\rangle \langle \cosh y\rangle = \langle m_{\rm T}\rangle \exp(\sigma^2/2)\,, \tag{8}$$

where $\sigma \equiv \langle y^2\rangle^{1/2}$ depends on the energy like $y_{\rm max}$, and, finally, the average multiplicity of charged particles has the form:

$$\langle n_{\rm ch}\rangle_{\rm pp} = 2.0 + \tfrac{2}{3}\langle K\rangle \frac{E^*_{\rm p}}{\langle m_{\rm T}\rangle} \exp\left[- 0.5\sigma_0'^2 \ln^2(E^*_{\rm p}/m_\pi)\right]. \tag{9}$$

For $\langle K\rangle = 0.5$ and the relative yields of pions, kaons and baryons 0.88, 0.08 and 0.04, respectively, we have $\langle m_{\rm T}\rangle = 0.42$ GeV and the relation (9) reproduces well the average charged multiplicity in wide energy range 4.5–2000 GeV, as compared with numerical fits for both the power [5] and the squared logarithm type [6]. A standard test for the p + p scattering scheme is its comparison with the KNO predictions. The KNO scaling hypothesis [7] for the multiplicity distribution is that a single universal function $\Psi(z)$ describes topological cross sections in the asymptotic region:

$$\langle n\rangle P_n \equiv \Psi(z,s) \underset{s\to\infty}{\Longrightarrow} \Psi(z)\,, \tag{10}$$

where $z = n/\langle n\rangle$ and $\sigma_n, \sigma_{\rm in}$ are the n-prong, and total inelastic cross sections, respectively.

As a result of the constancy of the algebraic moments C_q in (10)

$$C_q \equiv \langle z^q\rangle = \frac{\langle n^q\rangle}{\langle n\rangle^q}, \tag{11}$$

the second central moment D^2 is proportional to $\langle n\rangle^2$, *i.e.* dispersion D is proportional to $\langle n\rangle$:

$$D = (C_2 - 1)^{1/2}\langle n\rangle\,. \tag{12}$$

As it is well known, the last relation, and, consequently, also Eq. (10), cannot be satisfied at lower energies, at least in p + p collisions because the very well experimentally established Wróblewski's formula [8] gives:

$$D = a\langle n\rangle - b = a(\langle n\rangle - 1)\,. \tag{13}$$

The best fit to the data in the energy range $s^{1/2}$ =4.9–62 GeV gives $a = 0.589 \pm 0.006$ [9]. After substitution of $\langle n\rangle$ by $\langle n-1\rangle$, *i.e.* for another scaling variable:

$$z' \equiv \frac{n-1}{\langle n\rangle - 1}, \tag{14}$$

the data for energies below 50 GeV lie also near the universal curve [8]. An analogous modification of the KNO scaling were proposed in [10], where the new variable $z' = (n-\alpha)/(\langle n-\alpha\rangle)$ with an energy independent parameter $\alpha = 0.9$ provides an extension of the KNO scaling to energies as low as 5.5 GeV.

The presented scheme reproduces well Wróblewski's curve (the calculated $D/(\langle n\rangle - 1)$ ratio changes from 0.592 at the energy 4.5 GeV to 0.568 at 2060 GeV), and experimental energy dependence of the relative dispersion $D/\langle N_{ch}\rangle$, [11, 12], and also the higher moments $C_q (q = 2, \ldots, 5)$ agree well in the energy range 4.5–200 GeV with the values calculated on the basis of the modified KNO-α scaling function [10]:

$$\Psi(z') = 2.30(z' + 0.142)\exp(-0.0586z' - 0.659z'^2)\,. \tag{15}$$

3. The p+A and A+A collision scheme

The independent scattering model for high-energy p+A and $A + A$ collisions (p+A collision is in the ISM in some sense a very asymmetric $A + A$ collision [13]) is the result of geometrical overlapping of the compound objects with Woods–Saxon distributed interacting elements: nucleons inside the nuclei. According to this model a nucleus + nucleus collision is a sequence of collisions between the nucleon + nucleon pairs from two groups of participant nucleons, *i.e.* projectile and target nucleons in the interaction zone; their Fermi motions being negligible. The energy losses of the incoming nucleon(s) are directly correlated with the number of intranuclear collisions in accordance with experimental observations in 100 GeV/c p+A collisions [14].

The nuclear density distributions are well known and should not be treated as free parameters; the new parameters in $A+A$ scheme comparing to the p + p one are the interaction length $\lambda_{\text{in}} = 2.16$ fm and inelasticity coefficient in the i-th intranuclear collision $\langle K_i \rangle = 0.25$ for $i > 1$ [15].

The presented scheme reproduces very well the average multiplicities of negatives in 200 GeV p + A collisions: 4.76 (4.9 ± 0.4), 6.23 (6.2 ± 0.2), 7.06 (7.0 ± 0.4) for A = Mg, Ag, and Au, respectively (the numbers in parentheses are experimental results from Ref. [16]), and also charged particles distribution in 200A GeV O + W collisions [17], as it was shown in [18]. In this paper we present calculated transverse energy distributions in 200A GeV O(S)+A (C, Al, Cu, Ag and Au) collisions.

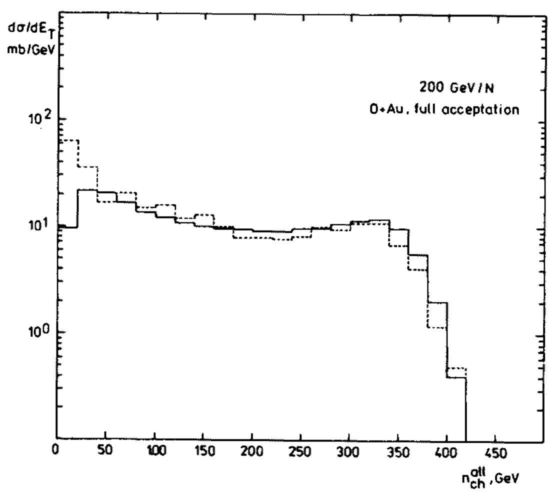

Fig. 1. Transverse energy distribution in ^{16}O+^{197}Au 200A GeV collisions with complete acceptation (full line). The dashed line histogram represents FRITIOF model predictions [19]. The dip at the lowest energies is a consequence of insufficiency of a "minimum bias" trigger in our calculations.

In Fig. 1 we compare the predictions of the presented scheme with the results of FRITIOF model [19] based on the LUND model, "the best available N+N collision model" [20] — both these distributions are very similar, just as the multiplicity and rapidity distributions (not shown here). The

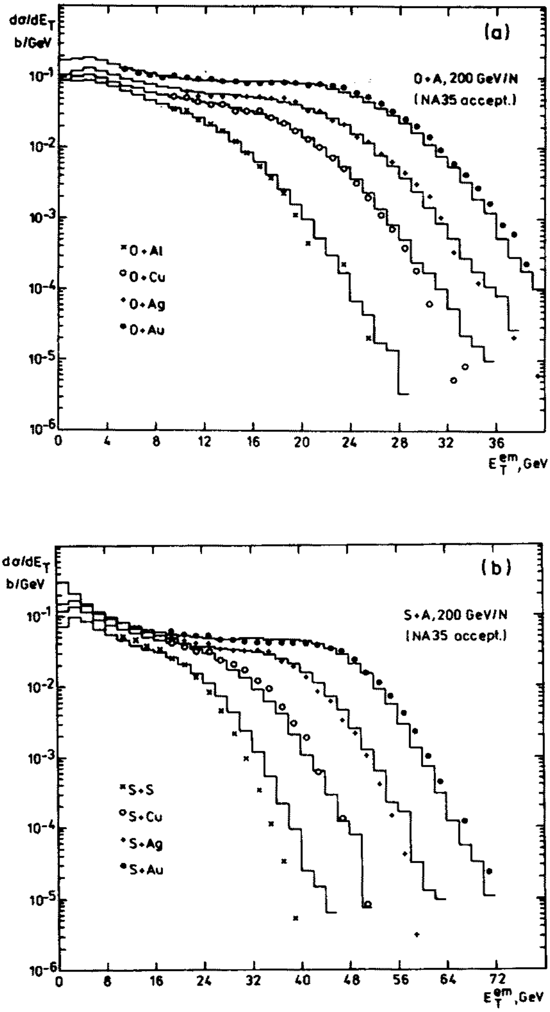

Fig. 2. Differential cross section for E_T^{em} (electromagnetic component of the transverse energy in: (a) 200A GeV O+A; (b) 200A GeV S+A collisions, where E_T^{em} is seen in NA35 PPD acceptance (histograms). The experimental points [21] are shown without statistical uncertainties; the systematic errors in the spectra are estimated to be 10%.

discrepancy between the results of the model presented and FRITIOF, appreciable at the lowest transverse energies is a result of the impact parameter cut-off in our calculations.

The transverse energy distribution in O(S) + A collisions was measured in the midrapidity region by the NA35 collaboration and in the central and forward region by the WA80 collaboration.

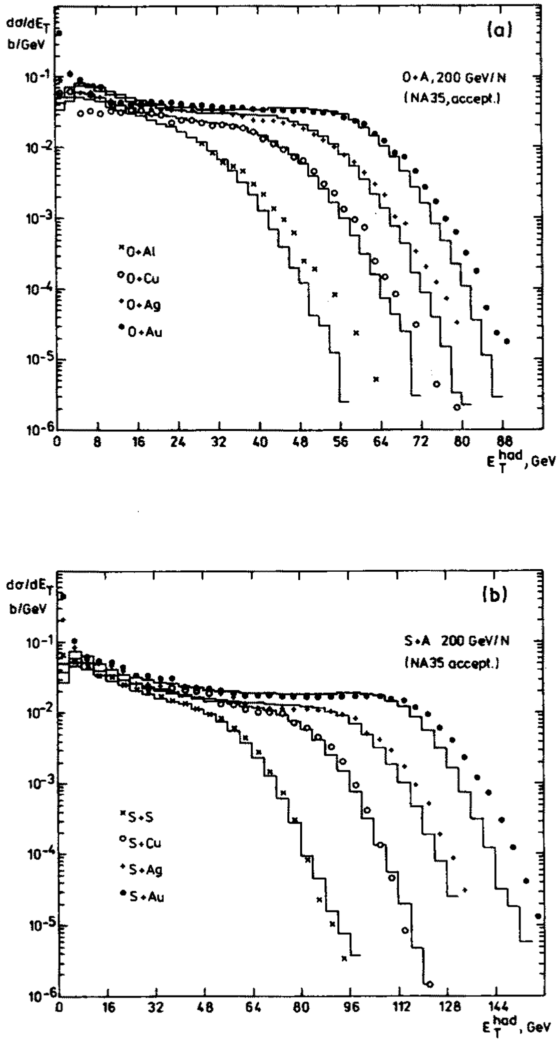

Fig. 3. Differential cross section for E_T^{had} (hadronic component of the transverse energy in: (a) 200A GeV O+A; (b) 200A GeV S+A collisions, where E_T^{had} is seen in NA35 Ring Calorimeter acceptance (histograms). The experimental points [21] are shown without statistical uncertainties; the systematic errors in the spectra are estimated to be 10%.

The calculated transverse energy spectra in 200A GeV O(S) + A collisions are compared with NA35 results [21], separately for the electromagnetic and hadron component (Figs. 2,3) and with the WA80 results [22] for the total E_T (Fig. 4).

In the case of NA35 results there is a systematic underestimation of the

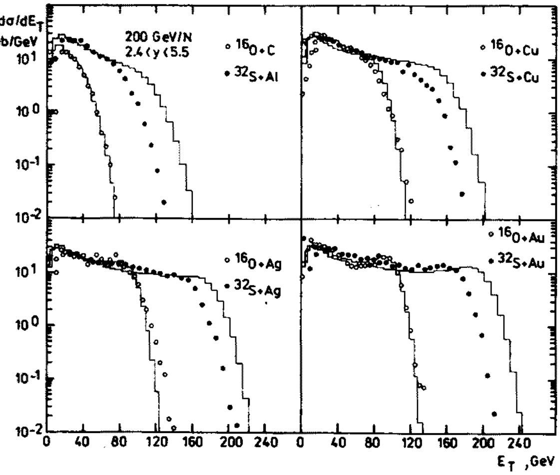

Fig. 4. Calculated transverse energy distributions in 200A GeV O+A and S+A collisions in the WA80 acceptation range (histograms). Experimental points are from Ref. [22].

high-E_{T} tail for the heaviest (S + Au) nuclei, especially for the hadronic component. This suggests that the participants fall into the acceptation region more often than in our calculations.

Transverse energy registered in the hadronic part of the NA35 calorimeter is corrected for leaking electromagnetic shower energy from the electromagnetic shower energy detector [21] and therefore the total E_{T} is shifted down by about 20% in comparison to previous NA35 report [23]. As is seen from Figs. 2,3 not only the shapes of the E_{T}-spectra in the midrapidity region but also the systematic trends for different targets and projectiles are satisfactorily reproduced by a simple superposition of independent N + N collisions. The calculated spectra also agree with the WA80 results in the pseudorapidity coverage 2.4-5.5 for 200A GeV O + A collisions and overestimate the transverse energy by about 10% in the S + A collisions at the same beam energy. This discrepancy is a direct consequence of the difference in the "scaling ratios" for very central (*i.e.* for the impact parameter $b \cong 0$), S + A and O + A collisions — $E_{\mathrm{T}}(\mathrm{S}+A;\ b=0)/E_{\mathrm{T}}(\mathrm{O}+A;\ b=0)$ — the acceptance corrected ratios are 1.89 and 1.52 for NA35 and WA80 experiments, respectively [1]. The successful description of the O + A collisions in the 2.4–5.5 rapidity interval shows that the inconsistency for the S + A case cannot be explained by the contamination of the projectile fragmentation products (which rises with the projectile mass-number) in the forward rapidity region, partly covered by the WA80 calorimeter. The registered transverse energies are clearly smaller than the calculated ones for different target nuclei (Al, Cu, Ag and Au). The drop of the average transverse energy per projectile participant of about 25% between O and S projectile observed in WA80 experiment does not agree with Monte Carlo results based on the independent scattering scheme and also with the NA35 results. These later ones may be treated approximately (in case of heavy targets) as a 16(32)-fold convolutions of the E_T spectra obtained in p + A collisions. As regards the WA80 200A GeV S + A results, they are, in our opinion, incompatible with the independent scattering scheme.

4. Results and conclusions

We use a geometric multiple collision model to describe the dynamics of nucleus + nucleus collisions. This scheme fixes an inelasticity distribution in a basic nucleon + nucleon collision for "fresh" and "broken" participants and the transverse momentum and rapidity distribution of produced particles. The first N + N collision in p + A and $A + A$ reactions can be treated as an ordinary hadronic collision in free space; it differs from the consecutive ones only on an average inelasticity. The hadronic interaction is so short-range that the presence of neighboring nucleons can be neglected. The secondaries in p + A and $A + A$ collisions are formed outside the nucleus due to the time dilation effect, at least if their rapidities are not close to the target rapidity.

We show that the global characteristics of nucleus + nucleus collisions: multiplicity and transverse energy distributions in the midrapidity region, may be reconstructed quite satisfactorily within the framework of an ISM based on a successful description of nucleon + nucleon collisions. From this agreement we conclude that if there exist collective effects like quark–gluon plasma formation, they are not sensitive to the transverse energy distributions in 200A GeV O(S) + A collisions.

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