CHARGED PARTICLE DENSITIES IN CENTRAL S + S AND Pb + Pb COLLISIONS AT GSI AND RHIC ENERGIES

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Charged particle densities achievable at the future accelerators in extremely central S + S and Pb + Pb collisions are calculated on the basis of the independent scattering scheme.

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1. Introduction

The study of the particle density in heavy–ion collisions is a very interesting problem mainly because it is related to the achievable energy density and hence to a question of a quark–gluon plasma (QGP) formation. The search for the QGP is one of the main goals of present accelerators and will continue with new possibilities in GSI and RHIC energy region, *i.e.* $2 \times 20 \div 25$ GeV and 200 GeV per nucleon pair, respectively. First results from these two facilities are expected in the mid–1990's. Relativistic heavy–ion collisions could then rise the energy density ε to a level such that a QGP could be formed. For relatively flat rapidity distribution (it is rather good approximation at RHIC energy [1]), a well known linear relation proposed by Bjørken with a hydrodynamical model [2], between energy released per rapidity unit, dE/dy and energy density, ε, can be used. In the central region, where the longitudinal momenta are small, the energy is replaced in this formula by the transverse energy $E_{\mathrm{T}} = \left(p_{\mathrm{T}}^2 + m^2\right)^{1/2}$ (which is identified for mesons with the transverse mass m_{T}). Since there is a very strong correlation between the amount of transverse energy measured, E_{T}, and the number of charged secondaries, n_{ch}, (the experimentally measured mean transverse energy per charged particle, $\langle E_{\mathrm{T}} \rangle$, is almost independent of the total transverse energy [3]), the above mentioned formula can be slightly modified:

$$\varepsilon = \frac{3}{2}\,\frac{dn_{\rm ch}}{dy}\,\frac{\langle E_{\rm T}\rangle}{\tau_0 \pi R_A^2}\,, \qquad (1)$$

where τ_0 denotes the hadronization time and πR_A^2 is the transverse area of the interaction zone in $A+A$ collision (further we use a simple parametrization: $R_A = r_0 A^{1/3}$).

2. The $A + A$ collision scheme

The nucleus with mass number A and radius $\sim A^{1/3}$ is contracted to the thickness smaller than $\tau_0 c$ ($\tau_0 = 1$ fm/c) at Lorentz factor $\gamma_{\rm CM}$ greater than $\gamma_0 = 2R_A/\tau_0 c \sim A^{1/3}$, *i.e.* greater than ~ 3 and ~ 6 for S + S and Pb + Pb collisions, respectively. The secondaries with rapidities not too close to the projectile (target) one are then formed outside the nuclei if the cms–energy $s^{1/2}$ exceeds about 11 GeV even for heaviest beams and the cascading can be simply neglected from relatively low energies. No secondary collisions of the products with each other and with other nucleons inside the nuclei are taken into account also for RHIC energies, when the density of products is sufficiently higher.

In order to calculate the particle density in the central region in $A + A$ collisions, we have performed a Monte–Carlo calculations based on a simple independent scattering scheme described in [4]:
— non-invariant cross section $d^2\sigma/dp_{\rm T}^2 \sim \exp(-p_{\rm T}/p_0)$ with $p_0 = \langle p_{\rm T}\rangle/2 = 0.175$ GeV/c;
— uniform distribution of the inelasticity coefficient $K = 1 - x_{\rm L}$, where $x_{\rm L}$ is the Feynman x of the leading baryon, with $\langle x_{\rm L}\rangle = 0.5$;
— constant yields of pions, kaons and baryons: 0.88 : 0.8 : 0.04;
— gaussian rapidity distribution of produced particles at the SPS energies and a flat distribution with gaussian "wings" at the Sp$\bar{\rm p}$S ones.

The collided nuclei are considered as two geometrically overlapped clusters of Woods–Saxon–distributed nucleons and the $A + A$ collision is eventually reduced to the sequence of independent N + N collisions. The mean free path for an inelastic collision:

$$\lambda = \frac{1}{\rho\sigma_{\rm in}}\,, \qquad (2)$$

where ρ and $\sigma_{\rm in}$ are the average nuclear matter density and inelastic cross section, respectively, rises as $\ln^2 s$ with energy, from 2.16 fm at the CERN--SPS to 1.65 fm at RHIC energy. Each projectile nucleon in the collision zone ("projectile participant") can multiply interact inside the target nucleus (and *vice versa*). The average inelasticity in the first collision of the "fresh" nucleon is twice so large as in the case of "broken" nucleon collision [5]:

$$\langle K_1 \rangle = 0.5 = 2\langle K_i \rangle\,, \qquad i = 2, 3, \ldots \tag{3}$$

(Both inelasticity coefficients are uniformly distributed.)

The rapidity of the particles produced in the individual N + N collision above $s^{1/2} \sim 20$ GeV is parametrized as the flat central part with gaussian "wings". It is found that this shape of the rapidity distribution, where the ratio of the width of the plateau, d, to the standard deviation, σ, of the gaussian part is 1.2, agrees well with data in the Sp$\bar{\text{p}}$S energy range [1]. Both these parameters, d and σ, are rising logarithmically with the available energy $E_{\text{av}} = s^{1/2} - 2m_{\text{N}}$. This simple scheme describes satisfactorily the multiplicity distributions in p+p collisions from threshold energy to the SPS energies [6] and also gives an excellent fit to the moments $C_2 \ldots C_5$ in $s^{1/2} =$ 200 GeV p + $\bar{\text{p}}$ collisions [7] (see Table I). Parameters σ and d are fitted in the energy range 19.7 GeV $< s^{1/2} <$ 200 GeV with $\sigma = 0.916 + 0.154 \ln E_{\text{av}}$ and $d = -2.49 + 0.863 \ln E_{\text{av}}$. Also directly compared multiplicities of newly produced particles in full phase space: calculated negative multiplicity in 200 GeV/N central S + S collisions (2% of total inelastic cross section), $\langle n- \rangle = 108$, and the recently published experimental value, corrected for 4π acceptance: $\langle n- \rangle = 103 \pm 5$ [8] agree fairly well.

TABLE I

Calculated predictions for the moments μ, D, $C_2 \ldots C_5$ for the energy $s^{1/2} =$ 200 GeV compared with their experimental values [7] (bottom row of the Table). $D = (\langle n^2 \rangle - \langle n \rangle^2)^{1/2}$ and $C_q = \langle n^q \rangle / \langle n \rangle^q$. The set of parameters giving the best fit to the data is: $\sigma = 1.73$, $d = 2.08$.

$\langle n_{\text{ch}} \rangle$	D	C_2	C_3	C_4	C_5
21.4	11.7	1.30	2.00	3.47	6.63
21.4 ± 0.8	10.9 ± 0.4	1.26 ± 0.03	1.91 ± 0.12	3.3 ± 0.3	6.6 ± 0.9

The data given in Table II depend rather weakly on the assumptions about the rapidity shape in N + N collisions; dn_{ch}/dE growth connected with the drop of the d/σ ratio from 1.2 to 1.0 is less than 2%. The particle rapidity density calculated in the frame of independent scattering model (ISM) in the collisions with nearly-zero impact parameter is gaussian as an issue of the Central Limit Theorem. Also the experimentally investigated high-E_{T} tails in $A + A$ collisions are gaussian [9].

Only the collective models allow an estimate of the energy density ε (1). From this point of view, any estimate of ε is inconsistent in the frame

TABLE II

The multiplicities of charged particles and their dispersions (in the brackets) in the central rapidity intervals $|y_{cm}| < 0.5$. Calculations were performed for extremely central S + S and Pb + Pb collisions.

Facility	SPS	GSI	SppS
E_L [GeV]	160	$850 \div 1330$	21230
y_{CM}	2.92	$3.33 \div 3.98$	5.36
$\langle n_{ch} \rangle^{S+S}$	72(12)	$104 \div 111(18)$	166(27)
$\langle n_{ch} \rangle^{Pb+Pb}$	691(35)	$1084 \div 1103(52)$	1711(75)
ε^{Pb+Pb} [GeV/fm^3]	4.0	$6.2 \div 6.3$	9.8

of the ISM. But, on the other hand, the particle density as estimated from the ISM and the energy density from the hydrodynamical model are often coupled in the "hybrid" analysis of some experiments [10]. Just for the illustration's sake we evaluated the energy density deposited in the central region in Pb + Pb collisions (see bottom row of the Table II). The value of the hadronization time is rather poorly known and also the critical energy density which is enough to produce the QGP is predicted with large uncertainty. From this reason we show the estimated values of ε which scale with $1/\tau_0 r_0^2$ (see Table II). The value of ε at $E_L = 160$ GeV/N calculated for $E_T = 0.42$ GeV, $\tau_0 = 1$ fm/c, $r_0 = 1$ fm *i.e.* $\varepsilon = 4.04$ GeV/fm^3, agrees reasonably well with the result $\varepsilon = 4.23$ GeV/fm^3 obtained in [11], with the fluctuation in the transverse energy deposition taking into account.

3. Results and conclusions

In this note we compared the densities of produced charged particles and energy densities predicted for central $A + A$ collisions in the future accelerators with the present ones, on the common basis of independent scattering scheme. We note that our results for $dn_{ch}/dy|_{y=0}$ at $s^{1/2} = 200$ GeV are in reasonable agreement with the predictions obtained in the Dual Parton model (DPM) [12] (including multiple inelastic scattering within each N + N collision): 166 and 2030 for S + S and Pb + Pb collisions, respectively. This comparison suggests that the naive independent scattering scheme retains its predictive power also for RHIC energies. We note additionally that in full considered energy interval (about two decades of the cms–energy) transverse momentum distribution, kaons and baryons yields and inelasticity distribution in our calculations remain unchanged.

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