MULTIPLICITY DISTRIBUTION IN CENTRAL RAPIDITY REGION OF NUCLEAR COLLISIONS AND THE WOUNDED NUCLEON MODEL

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Wounded nucleon model is used to estimate the multiplicity distributions of charged particles produced in central rapidity region $|y| \leqslant 0.5$ of the collisions of 200 GeV ^{16}O nuclei with heavy targets. The results show marked differences with estimates from production of quark-gluon plasma.

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The construction of the ^{16}O 200 GeV beam at the CERN SPS opens a possibility of experimental investigation of nuclear collisions at high energies. The prime motivation for these experiments is the search for quark-gluon plasma. It is however widely recognized that there seems to be no clear signal of plasma formation and therefore very likely a success of such a search will critically depend on accurate calculations of the "background", i.e. the standard nuclear interactions. The information available till now (mostly from data on hadron-nucleus collisions) suggests that the bulk of nuclear collisions at high energies can be understood as a superposition of the elementary nucleon-nucleon collisions. The simplest model in which such a superposition is realized is the wounded nucleon model [1]. At the energies presently available, the wounded nuleon model is also a good approximation to dual parton model [2].

In the present paper we calculate the multiplicity distributions in the central region of rapidity following from this model and compare them with those estimated for plasma

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formation [3]. It turns out that they are sufficiently different to give a useful signal of the presence of quark-gluon plasma.

In the wounded nucleon model [1], the produced particles are emitted independently by each nucleon which participated in the collision, such a nucleon is called "wounded". The emission from a wounded nucleon in the central region of rapidity does not depend on the number of interactions of this wounded nucleon. Just one interaction is enough to make it fully active. An immediate consequence of these assumptions is that the number of wounded nucleons determines the average multiplicity of the collision. We have [1]

$$\bar{n}_{AB}/\bar{n} = (\bar{w}_A+\bar{w}_B)/2, \tag{1}$$

where $\bar{n}_{AB}$ is the average number of particles produced in collision of nuclei A and B, and $\bar{n}$ is that in nucleon-nucleon collision. $\bar{w}_A$ and $\bar{w}_B$ are the average numbers of wounded nucleons in A and B. Eq. (1) is consistent with data on hadron-nucleus [4, 5] and on $\alpha-\alpha$ collisions [6].

If one is interested in multiplicity distributions, it is necessary to know not only the average values $\bar{w}_A$ and $\bar{w}_B$ but the full probability distribution $P(w_A, w_B)$, of having w_A wounded nucleons in nucleus A and w_B wounded nucleons in nucleus B. Then the predicted multiplicity distribution in a given phase-space region is given by

$$P_{AB}(n) = \sum_{w_A,w_B} P(w_A, w_B) \sum_{n_1+\dots m_{w_B}=n} p(n_1) \dots p(m_{w_B}), \tag{2}$$

where $p(n)$ is the distribution of particles emitted by one wounded nucleon into the considered region. To determine $p(n)$, we apply Eq. (2) to the nucleon-nucleon collision. It was found recently [7–9] that the multiplicity distributions of particles produced in central rapidity region $|y| \lesssim 1.5$ of nucleon-nucleon interactions can be well approximated by negative binomial distribution

$$W(n) = \frac{(k+n-1)!}{(k-1)!n!}\left(\frac{\bar{n}}{\bar{n}+k}\right)^n\left(\frac{k}{\bar{n}+k}\right)^k, \tag{3}$$

with $k \simeq 2$, suggesting that it is a convolution of two distributions from independent sources. Observing that in nucleon-nucleon collisions there are exactly two wounded nucleons, we conclude that the contribution $p(n)$ from one of them is given by "geometric" distribution

$$p(n) = \left(\frac{\bar{n}/2}{1+\bar{n}/2}\right)^n \frac{1}{1+\bar{n}/2}. \tag{4}$$

In Eqs (3) and (4) $\bar{n} = \bar{n}(y_c)$ is the average number of particles produced in the considered interval $|y| \leqslant y_c$ for nucleon-nucleon collisions.

Using Eqs (2) and (4) we are now able to calculate the multiplicity distribution in A+B collision. The result is the superposition of negative binomial distributions of the form ($w = w_A + w_B$):

$$P_{AB}(n) = \sum_{w_A, w_B} P(w_A, w_B) \frac{1}{\left(1+\frac{\bar{n}}{2}\right)^w} \left(\frac{\bar{n}/2}{1+\bar{n}/2}\right)^n \frac{(n+w-1)!}{(w-1)!n!}. \tag{5}$$

This equation expresses the multiplicity distribution in A+B collision by the average multiplicity in nucleon-nucleon collision and the distribution of wounded nucleons in interacting nuclei. It should be valid in small rapidity intervals around $y = 0$, where phase--space corrections are not important [10]. At 200 GeV it is probably safe to take $|y| \lesssim 0.5$.

The main technical problem in evaluating $P_{AB}(n)$ is the determination of $P(w_A, w_B)$ which involves, in general, complicated multidimensional integrals in the impact parameter space [1, 11, 12]. For $\alpha-\alpha$ collisions $P(w_A, w_B)$ was evaluated explicitly [13]. The resulting multiplicity distribution reproduces data from ISR [6]. For large A and B however, the only feasible way of calculating $P(w_A, w_B)$ seems to be Monte-Carlo simulation. We have performed such simulation for collisions of ^{16}O with targets of atomic weigths $B = 50$, 120, 180 and 230[1].

The results for impact parameter $b = 0$ are shown in Fig. 1. One sees that the distributions are close to gaussians. In Fig. 2 and 3 the multiplicity distributions calculated from Eq. (5) in central region of rapidity $|y| \leqslant 0.5$ for variety of heavy targets are shown. The value $\bar{n} = 1.94$ was used as input [14]. The distributions obey an approximate KNO scaling

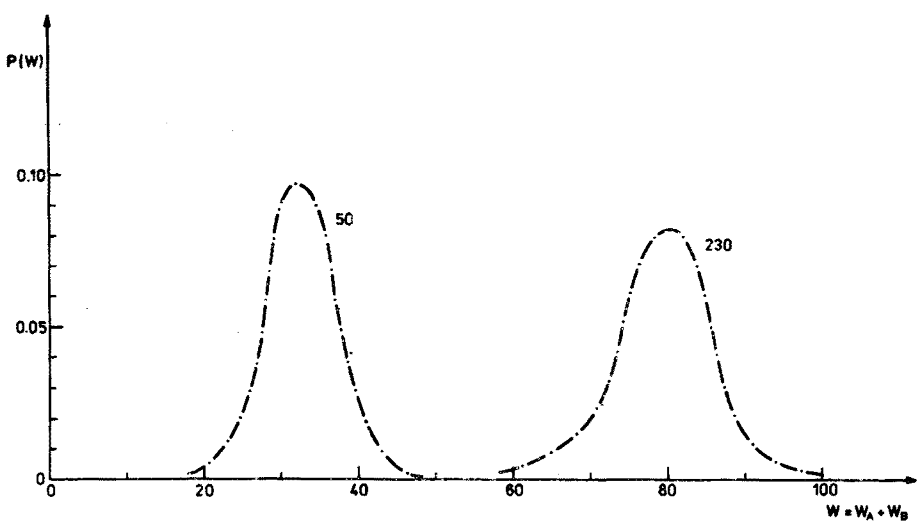

Fig. 1. The distribution of wounded nucleons $w_A + w_B = w$ for ^{16}O collisions with $B = 50$ and $B = 230$ targets

[1] In the simulation the standard Saxon-Woods nuclear density with $R = 1.1 \cdot A^{1/3}$ and $a = 0.545$ was used. For ^{16}O R was taken 2.57 f. The parameters of the nucleon nucleon cross-section were taken from Ref. [13].

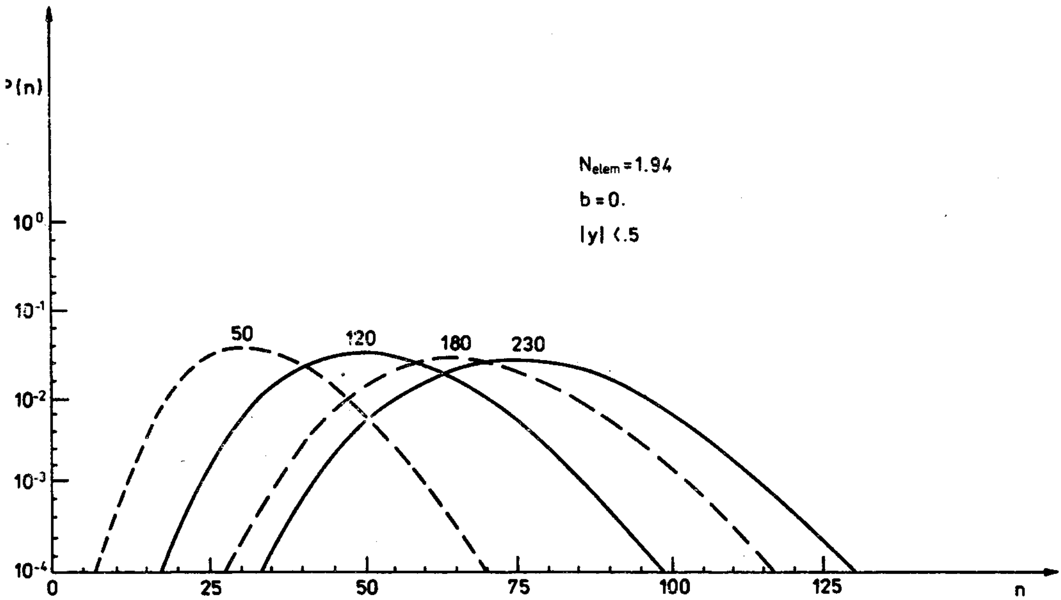

Fig. 2. Charged multiplicity distribution for $|y| \leqslant 0.5$ predicted by wounded nucleon model for central $b = 0$ collisions of ^{16}O with heavy targets

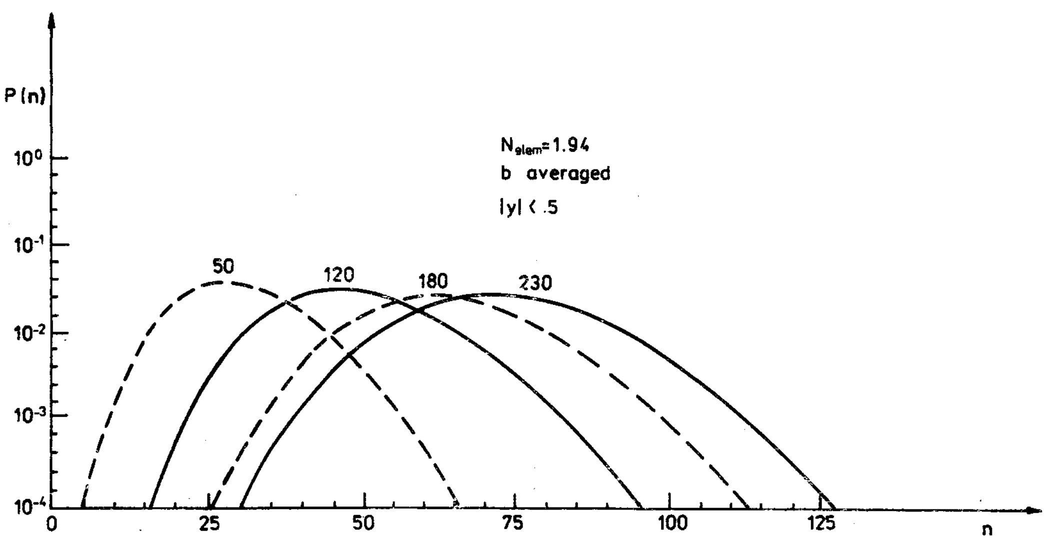

Fig. 3. The same distributions as in Fig. 2 but averaged over impact parameter within the interval (0–4) fm for $B = 120$, 180 and 230 and within (0–3) fm for $B = 50$

[15] as demonstrated in Fig. 4 where the relative moments

$$c_k = \langle n_{AB}^k \rangle / (\bar{n}_{AB})^k \tag{6}$$

for $B = 230$ target versus $\bar{n}$ are plotted. In Fig. 5 the average multiplicity $\bar{n}_{AB}$ against B is displayed.

It was recently recognized [14, 16–19] that multiplicity distributions for charged particles in all high energy processes follow the negative binomial distribution (3) with k fitted as a free parameter.

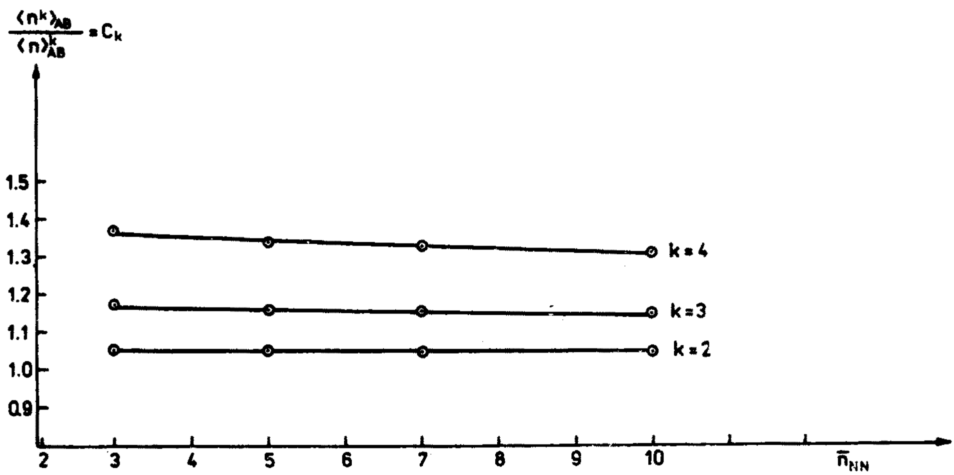

Fig. 4. Normalized moments of the distributions of charged particles, $|y| \leq 0.5$, for $B = 230$

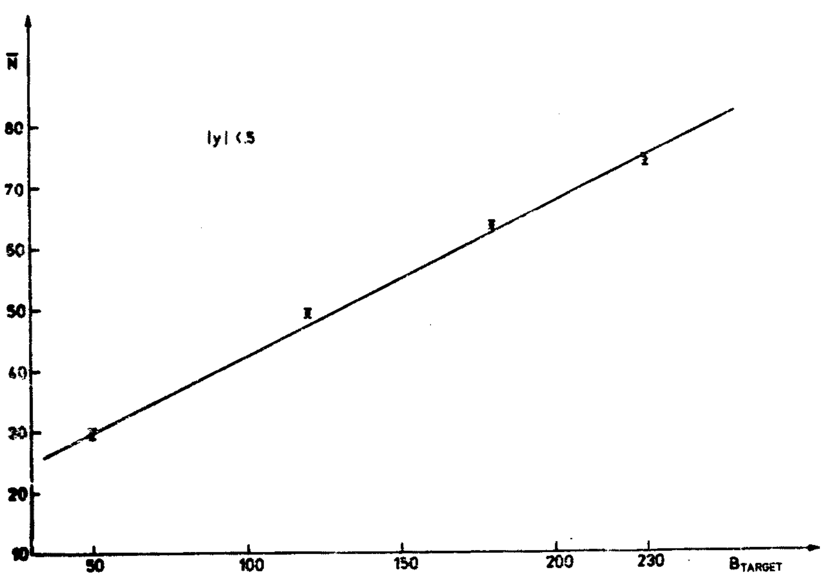

Fig. 5. Rapidity density of charged particles predicted by wounded nucleon model

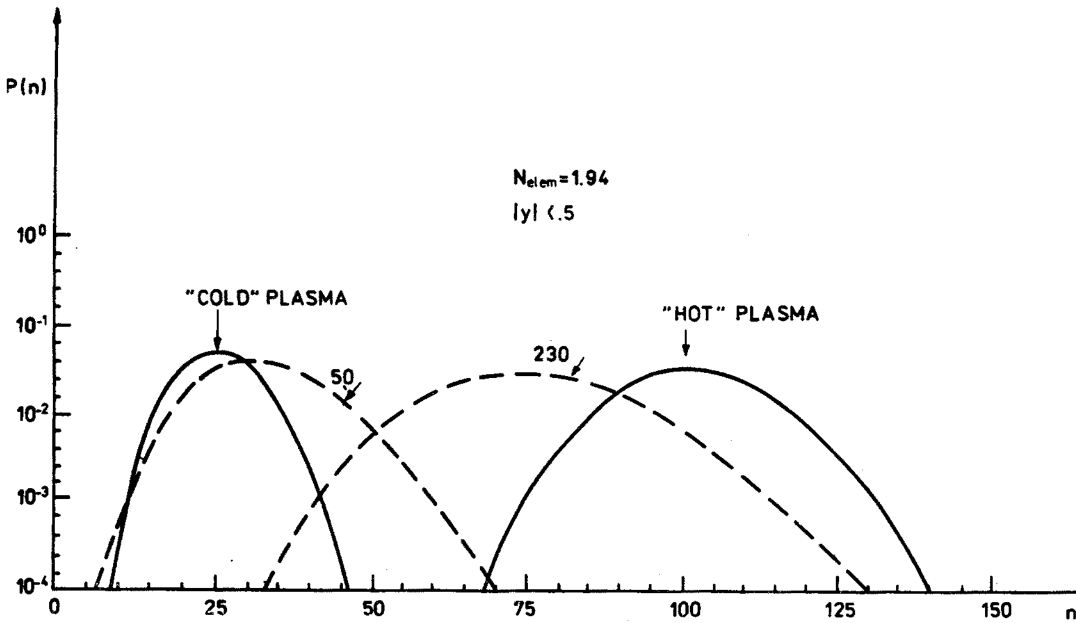

Fig. 6. Charged multiplicity distributions in central region of rapidity, $|y| \leqslant 0.5$, predicted for events with plasma formation, compared with distributions predicted by wounded nucleon model

TABLE I

B	k	$\bar{n}_{AB}$	χ^2/deg
50	15.3+0.6	29.9+2.6	1.4
120	26.8+0.8	50.5+1.9	1.3
180	35.9+0.6	63 +1.7	0.9
230	39.7+1.1	74.3+2.9	1.8

We have also performed such a fit to multiplicity distributions of charged particles shown in Fig. 2. The quality of the fit turned out to be very good and obtained curves reproduce well our Monte-Carlo results. The parameters of the fit are given in Table I.

The results presented above may serve for an estimate if a distinct signal of plasma formation can be expected from measurements of multiplicity distribution. Unfortunately, due to large uncertainties in models of quark-gluon plasma such estimates can only be very crude [3]. In Fig. 6 the multiplicities in the central rapidity region expected in events with plasma formation are plotted for two different sets of plasma parameters (they are functions of the proper hadron energy density and of critical quark-gluon plasma energy density, both estimated with some uncertainties [3]). The obtained multiplicities in plasma--dominated events are compared with multiplicities obtained before for $B = 50$ and $B = 230$. One sees that if temperature of plasma does not depend on nuclear number of colliding nuclei, the measurement of the multiplicity distribution can be used as a signal indicating plasma formation. Indeed, the "cold" plasma should be clearly seen in collisions with a heavy target as an enhancement at the lower end of the multiplicity spectrum, whereas the "hot" plasma is expected to show up as an enhancement at the upper end of the multiplicity distribution obtained in collisions with relatively light nuclei.

We conclude that the measurements of the target dependence of the multiplicity distributions may be useful in searching for quark-gluon plasma. We have calculated the multiplicity distributions in the central region of rapidities expected from a standard model of the nucleon-nucleon collisions for ^{16}O scattering on a range of targets. They show a specific, different from that expected in plasma formation dependence on the size of the target.

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