объединенный
институт
ядерных
исследований
дубна

E1-84-354

L.A.Didenko, V.G.Grishin, M.Kowalski,
A.A.Kuznetsov, Z.V.Metreveli*

TEMPERATURE AND DENSITY OF NUCLEAR MATTER IN CENTRAL CC INTERACTIONS AT P=4.2 GeV/c PER NUCLEON

Submitted to the X International
Conference on Particles and Nuclei
(Heidelberg, 1984)

* IHEP, Tbilisi State University, USSR

1984

1. INTRODUCTION

Properties of nuclear matter at high temperatures and densities are one of the subjects of interest of theoretical physics [1-7]. The production of strongly compressed and highly excited hadronic matter is one of the most intriguing aspects of relativistic heavy ion physics. Possibilities of the phase transition of nuclear matter into pion condensation [1,2], abnormal nuclear matter [3,4] and quark-gluon plasma are widely discussed. Several papers devoted to an investigation of the temperature and density of nuclear matter in collisions of relativistic nuclei have been published so far [8,9].

In this paper we have tried to estimate these values for C + C interactions of P/A = 4.2 GeV/c.

Our sample consists of 1394 central events registered in the 2m propane bubble chamber, JINR. As "central" we took events with no more than two positive, singly-charged particles having momenta $P_{lab} \geq 3$ GeV/c and emitted at angles $\theta \leq 4°$ with respect to the beam direction [11,12]. In our analysis we used negative pions and protons to determine the temperature and protons to estimate the density of nuclear matter. Due to identification problems, our sample of protons emitted outside fragmentation regions of colliding nuclei ($P_{lab} \geq 300$ MeV/c or $P_{lab} \leq$ ≤ 3 GeV/c and $\theta \geq 4°$) may contain some misidentified positive pions and deuterons. Within a momentum interval of 700 MeV/c $\leq$ $\leq P_{lab} \leq 2.5$ GeV/c, the admixture of positive pions is about 20%. The contamination of the sample by misidentified deuterons was estimated using the internuclear cascade model (Dubna version) [10]. A possible influence of these admixtured on our results will be discussed in the next chapters.

2. TEMPERATURE

The temperature of nuclear matter has been determined from inclusive spectra $E\frac{d^3\sigma}{dP^3} = \frac{1}{P}\frac{d^2\sigma}{dTd\Omega}$ for negative pions and protons emitted at angles of ~90° in the nucleon-nucleon CM system. Here P is the momentum and T is the kinetic energy of particles. Taking particles emitted at angles of 90° one can neglect the influence of peripheral collisions. In this analysis we have studied distributions $f(T) = \frac{1}{P}\frac{dN}{dT}$ for protons and negative pions

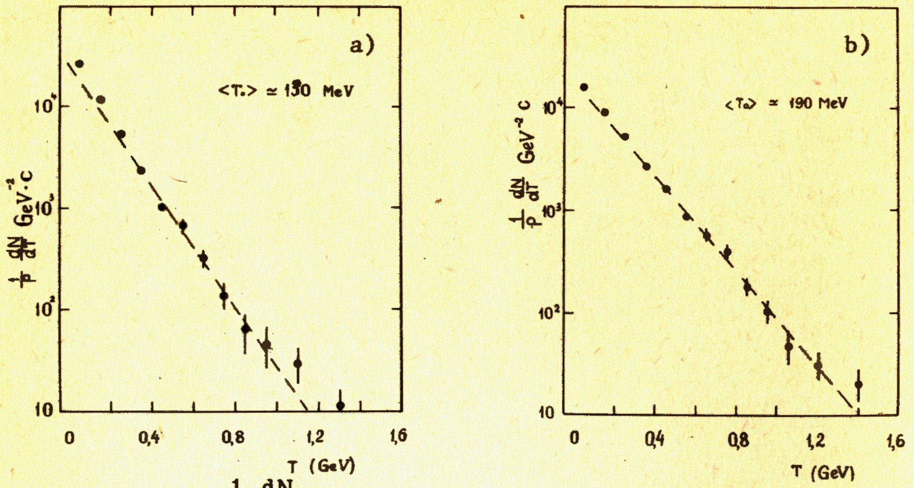

Fig.1. The $\frac{1}{P}\frac{dN}{dT}$ distributions of a) π^--mesons and b) protons emitted at an angle of $70^\circ \leq \theta \leq 110^\circ$ in the nucleon-nucleon c.m.s. The broken line is the result of approximation of the experimental data by the exponential dependence.

Table 1

Average values of temperature T_0 (MeV)

θ \ Type of particle	Protons	π^--mesons*
$60^\circ \div 120^\circ$	195 ± 5	129 ± 3
$70^\circ \div 110^\circ$	190 ± 6	126 ± 3
$80^\circ \div 100^\circ$	186 ± 10	127 ± 5

*Approximation for pions was done without T cut.

from angular intervals:
1) 60°- 120°,
2) 70°- 110° and
3) 80° - 100°.

The admixture of coalescence deuterons in the proton sample for these intervals does not exceed 3.5%, however their presence can lead to increasing the temperature obtained from the proton spectra. In Figs.1a and 1b we present kinetic energy

distributions for negative pions and protons emitted within an interval of 70°- 110°. Fitted curves have been taken in the form:

$$f(T) = \frac{1}{P}\frac{dN}{dT} = A\exp(T/T_0). \qquad (1)$$

The value of T_0 is the average kinetic energy of considered particles, and it characterizes the temperature of nuclear matter at the moment of their emission. The parameter T_0 is commonly called an "apparent temperature". Values of T_0 obtained for π^- and p emitted within different angular intervals are presented in Table 1. The mean value of T_0 is presented in Fig.2. Approximation for protons has been done for $T \geq 300$ MeV. Our estimates have shown that the admixture of positive pions in the proton sample might decrease the value of temperature by ~5%. One can notice that the value of T_0 does not vary for different angular intervals both for protons and pions. The temperature obtained for protons is higher than that for pions which means that protons are emitted at the earlier stage of expansion of nuclear matter than pions.

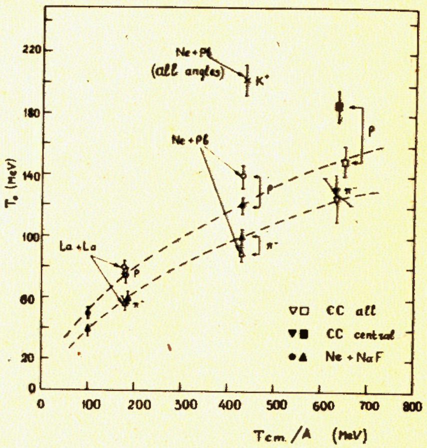

Fig.2. Average values of the temperature of π^--mesons and protons emitted at an angle of 90° in the c.m.s. for interactions of different nuclei versus collision kinetic energy.

We would like to call the readers' attention to the fact that studying noninvariant spectra, one can obtain smaller values of T_0: $T_0 = 163 \pm 8$ MeV for protons and $T_0 = 100 \pm 9$ MeV for pions.

3. DENSITY

The method for estimating the density of the excited nuclear matter in collisions of relativistic nuclei has been proposed by S.Nagamiya[13].It is based on results of searching for two-particle small-angle correlations. As is shown in refs /14-20/, such correlations can give information on the size of the particle emission volume. Independently, one can determine the number of interacting nucleons, studying multiplicity distributions of secondary particles. This allows one to estimate the density of the excited nuclear matter.

Here we have tried to apply the above method to central carbon-carbon interactions at P = 4.2 GeV/c per nucleon.

It should be noted that two-particle interferometry gives no information on the radius of the sphere on which particles become free of any interactions (decay of resonances, scatterings from other hadrons). In this connection it is convincing to determine the size of the emission region from correlations between particles which have a smaller mean free path as they should escape to excited volume at the earlier stage of its expansion. In our case such particles are protons. The sample under study consists of 14421 protons emitted outside fragmentation regions of colliding nuclei. As mentioned in the previous chapter, our sample may contain some misidentified positive pions and deuterons. A possible influence of these contaminations will be discussed below. The pp correlation function can be defined as a normalized ratio:

$$R_{pp}(q_T, q_0, V, r_0, \tau) = D(q_T, q_0, V, r_0, \tau) / D^{Backgr.}(q_T, q_0, V, r_0, \tau), \quad (2)$$

where $D(q_T, q_0, V, r_0, \tau)$ is the density of proton pairs in the phase space and $D^{Backgr.}(q_T, q_0, V, r_0, \tau)$ is the corresponding density obtained by mixing together particles from different events.

The kinematical quantities used in formula (2) are defined as:

$$\vec{q}_T = \vec{q} - \vec{n}(\vec{q}\cdot\vec{n}), \quad \vec{n} = \frac{\vec{P}_1 + \vec{P}_2}{|\vec{P}_1 + \vec{P}_2|}, \quad \vec{q} = \vec{P}_1 - \vec{P}_2,$$

$$q_0 = |E_1 - E_2|, \quad V = \frac{|\vec{P}_1 + \vec{P}_2|}{E_1 + E_2}.$$

The parameters r_0 and τ characterizing the space-time size of the radiation region were introduced assuming that the sources of particle emission are distributed according to the Gaussian-type distribution

$$\rho(\vec{r}, t) \sim \exp\left(-\frac{r^2}{2r_0^2} - \frac{t^2}{2\tau_0^2}\right). \quad (3)$$

All the values are defined in the nucleon-nucleon CM system.

Because of limited statistics, we have been able to study only one-dimensional distributions (integrated over q_0 and V).

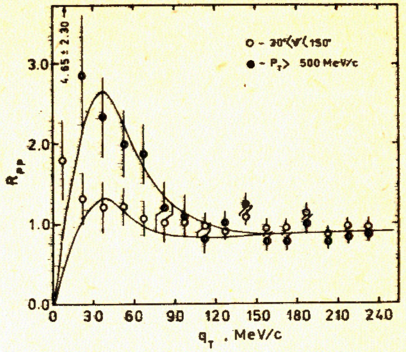

Fig.3. The q_T distributions for proton pairs emitted at angles of $30° \leq \theta \leq 150°$ and for proton pairs at $P_\perp^p \geq 500$ MeV/c.

The theoretical pp correlation function has been calculated according to formula given in ref. /20/ assuming q_0 = 10 MeV, V = 0.6 and τ = 1 fm. As shown in this paper, the values of r_0 weakly depend on the choice of other parameters. In Fig.3 we present the q_T distributions for pairs of protons together with the fitted curves. One can notice that for $q_T < 15$ MeV/c the behaviour of the pp correlation function is different from that predicted by theory which is probably caused by the contamination of the sample by misidentified positive pions. This, however, should not change our conclusions because this part of the pp correlation function is mainly determined by Coulomb repulsion which does not depend on the size of the radiation region. In order to avoid the influence of this admixture on the results of the fit, we have neglected the first point of the distribution in our fitting procedure.

A contamination of the proton sample by misidentified deuterons should not seriously affect the height of the maximum of the pp correlation function (according to our estimates by ~14% for a 30% admixture), but it should lead to an appreciable shift of the position of this maximum towards higher values of q_T. As this is not observed, we infer that the contamination of our sample by misidentified deuterons should be negligible.

The results of the fit for different kinematical selections are presented in Table 2.

The decrease of values of r_0 with increasing $P_\perp$ could be explained by the thermodynamical concept.

A higher value of $P_\perp$ corresponds to a higher temperature, so, taking such particles into account, we can observe the excited volume at the earlier stage of its expansion.

The value of $\rho(0)$ in Table 2 defined as

$$\rho(0) = \frac{\langle \nu \rangle}{(2\pi r_0^2)^{3/2}} \quad (4)$$

is the maximum of the density distribution of nuclear matter.

Table 2

	r_0, fm	r.m.s. radius R, fm	$\rho(0)$, fm^{-3}	$\rho(0)/\rho^{norm.}(0)$
$30° \leq \theta \leq 150°$	2.5±0.2	4.1±0.3	0.08±0.02	0.5±0.1
$60° \leq \theta \leq 120°$	2.2±0.1	3.9±0.2	0.10±0.03	0.6±0.2
$P_\perp \geq$ 300 MeV/c	1.7±0.1	2.9±0.2	0.23±0.07	1.4±0.4
$P_\perp \geq$ 500 MeV/c	1.5±0.2	2.6±0.4	0.31±0.08	1.8±0.5

The value of $<\nu>$ is the average number of nucleons taking part in the collision, and it can be determined from the multiplicity distributions of secondary particles:

$$<\nu> = 2(<n_{ch}> - 2<n_->) \quad (5)$$

In our case $<\nu>$ = 17.29±0.5.

The maximum of the density of nuclear matter in normal nucleus, $\rho^{norm.}(0)$, was assumed to be equal to 0.168 fm^{-3}. Angle θ was taken with respect to the beam direction. As already mentioned, this method does not allow one to study the very early moment of the collision (as far as we determine the reaction size from correlations of hadrons) and the obtained values of the ratio $\rho(0)/\rho^{norm.}(0)$ should be considered as a lower bound of the compression of nuclear matter. Despite of this, the fact that it reaches a value of about 2 at a rather late stage of expansion might provide some interesting information.

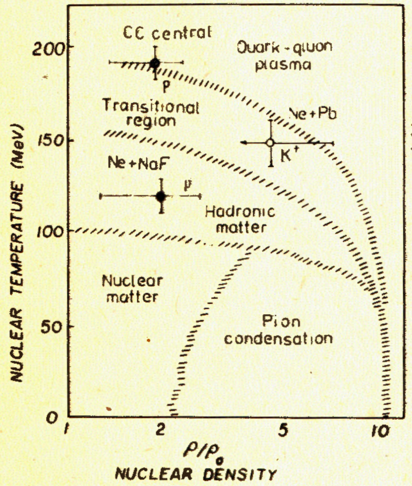

Fig.4. Diagram of phase transitions.

4.CONCLUSIONS

The temperature and density of nuclear matter have been estimated in central carbon-carbon collisions at P/A = 4.2 GeV/c(Fig.4). Our results show that at energies of about 4 GeV per nucleon it is possible to reach the transitional region between hadronic matter and quark-gluon plasma. The results could be however more convincing if one uses heavier ions than carbon. In conclusion the authors express their gratitude to the Collaboration for experimental data processing.

REFERENCES

1. Migdal A.B. Rev.Mod.Phys., 1978, 50, p.107.
2. Weise W., Brown G.E. Phys.Rep., 1976, 27C, p.1.
3. Lee T.D., Wick G.C. Phys.Rev., 1974, D9, p.2291.
4. Lee T.D. Rev.Mod.Phys., 1976, 47, p.267.
5. Jacob M., Tran Thanh Van J. Phys.Rep., 1982, 88C, p.321.
6. Stöcker H. et al. Phys.Lett., 1979, 81B, p.303.
7. Ruck V., Gyulassy M., Greiner W. Z.Phys., 1979, A277, p.391.
8. Nagamiya S., Gyulassy M. LBL-14035, February, 1982.
9. Nagamiya S. Int.Conf. on Nucl.Phys., Florence, Aug.29-Sept.3, 1983.
10. Gudima K.K., Toneev V.D. Yad.Fiz., 1978, 27, p.658.
11. Angelov N. et al. JINR, 1-12427, Dubna, 1979.
12. Akhababian N. et al. JINR, D1-82-536, Dubna, 1982.
13. Nagamiya S. Preprint University of Tokyo, UTPN-204, 1983.
14. Kopylov G.I., Podgorentsky M.I. Yad.Fiz., 1972, 15, p.392.
15. Kopylov G.I. Phys.Lett., 1974, 50B, p.412.
16. Cocconi G. Phys.Lett., 1974, 49B, p.459.
17. Yano F.B., Koonin S.E. Phys.Lett., 1978, 78B, p.556.
18. Gyulassy M., Kauffmann S.K., Wilson L.W. Phys.Rev., 1979, C20, p.2267.
19. Koonin S.E. Phys.Lett., 1977, 70B, p.43.
20. Lednicky R., Lyuboshitz V.L. Yad.Fiz., 1981, 35, p.1316.

Received by Publishing Department
on May 23, 1984.

Диденко Л.А. и др. Е1-84-354

Температура и плотность ядерной материи в центральных СС-взаимодействиях при P = 4,2 ГэВ/с на нуклон

Получены оценки температуры и плотности ядерной материи, образующейся в СС-центральных взаимодействиях при импульсе P/A = 4,2 ГэВ/с.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1984

Didenko L.A. et al. E1-84-354

Temperature and Density of Nuclear Matter in Central CC-Interactions at P = 4.2 GeV/c per Nucleon

An estimation of the temperature and density of nuclear matter in central carbon-carbon interactions at P/A = 4.2 GeV/c is presented.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1984