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Physics

Comparative Analysis of Average Characteristics of π^-- Mesons and Protons Produced in Noncentral and Semicentral CTa-Collisions at 4.2 AGeV/c

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ABSTRACT. Comparative analysis of the average characteristics of π^--mesons and protons produced in noncentral and semicentral CTa-collisions at the momentum of 4.2 AGeV/c is performed. The angular dependence of the temperature of nuclear matter T is studied. One centre- and two-centre production mechanisms are considered. The results obtained are compared with the Dubna version of the cascading model (DCM) and with the results of other works.

Key words: *nucleon, collision, asymmetry, temperature, nucleus.*

Introduction

The production of beams of monoenergetic relativistic nuclei on accelerators has allowed to compare nucleon-nucleon, nucleon-nucleus and nucleus-nucleus interactions, study of multinucleon collective processes. The study of central and semicentral interactions and their comparison with noncentral interactions is of special interest. More precisely: in this paper average characteristics of π^--mesons and protons from noncentral and semicentral interactions are compared with each other and with the results of other papers.

Experimental data were obtained using the two metre propane bubble chamber - PBC-500 (Laboratory of High Energies, JINR, Dubna) placed in the magnetic field of 1.5T and exposed to beams of p, D, He, C, F, Mg nuclei from the synchrophasotron with the momentum of 4.2 AGeV/c. Methodological problems of the experiment are described in [1-3]. Central nucleus-nucleus interactions at various energies are studied in a number of papers (see, e. g. [4-6] and references therein).

Analysis of Experimental Data

Our statistics consists of 2469 events registered in the detector. The number of participating protons is N_p=23093. Participating protons are assumed to be those with p_{LAB}>0.3GeV/c, since among protons with p_{LAB}<0.3GeV/c the majority are spectator of target nuclei Ta, the so-called evaporating protons. The number of π^--mesons N_π =5967. π^--mesons with P_{LAB}<0.08GeV/c do not contribute to the statistics, because the minimum value of the momentum when π^--mesons are well identified is 0.08GeV/c.

Average numbers of protons and π^--mesons in one CTa-collision in noncentral (n) and semicentral (s) collisions are: $n_p(n) = 5.66 \pm 0.14$; $n_p(s) = 20.18 \pm 0.18$; $n_{\pi^-}(s) = 5.27 \pm 0.14$; $n_{\pi^-}(n) = 1.44 \pm 0.04$.

The number of noncentral collisions is N(n)=1841 and that of semicentral collisions is N(s)=628.

Semicentral events are assumed not to have stripping particles (i. e. particles with p_L/z>3GeV/c and $\theta_{LAB}<4^0$) [7] and with number of charged secondaries $n_\pm$>15. From

Table 1

The number of events: N(t)-total number. N(n)-noncentral number and N(s) in semicentral number. n_p is the average number of protons and $\bar{n}_{\pi^-}$ is the average number of π^- -mesons, in noncentral and semicentral interactions

N(t)	N(s)	N(n)	n_p(s)	n_p(n)	n_{π^-} (s)	n_{π^-} (n)
2469	628	1841	20.18±0.80	5.66±0.14	5.27±0.14	1.44±0.04

where is the number 15 taken? It is known that at 4.2 AGeV/c in CTa-collisions in average 6 nucleons from the incoming carbon participate in the interaction. In one nucleon-nucleon interaction in average 2.5 charged particles are produced.

The number of such events is 628 (see Table 1). Approximately the same division is obtained of multiplicity distributions P_n of charged secondaries.

If the division of events into noncentral and semicentral collisions is reliable, then the average values of momenta p, emission angles ϑ, average number of charge secondaries in one CTa-collision, average temperature T, anisotropy and asymmetry coefficients, average values of Feynman variable x_F and rapidity - y, should significantly differ in noncentral and semicentral collisions. And this is really the case (see Table 2). There exists an opinion that the criterion of selection according to stripping particles is weak. We will show that this is not so (see Tables 1 and 2; Figs. 1 and 2).

When comparing the characteristics of particles produced in nocentral and semicentral collisions it has to be taken into account that for NN-collisions at 4.2 GeV/c the maximal value of transverse momentum for proton is $p_{\perp max} \approx 1.22$ GeV/c, i. e. $p^2_{\perp max} \approx 1.5$ (GeV/c)^2.

Angular distributions dN/dcosϑ of protons in the NN centre of mass system in noncentral and semicentral collisions significantly differ. In semicentral interactions the influence of heavy target nucleus Ta is significant (the main part of protons is emitted backward). In noncentral collisions there is approximate forward - backward asymmetry. This is confirmed by the asymmetry coefficients calculated by formulae (1) and (2) (see Table 3; Figs. 3 and 4).

$$\alpha_{fb} = N_f / N_b, \quad (1)$$

$$\alpha = (N_f - N_b) / N_t, \quad (2)$$

where N_f is number of forward moving protons, N_b – number of backward moving protons.

Rapidity y_L-distribution of participating protons is sharply asymmetric around zero (especially noncentral events). Only 2% (≈470) of protons are out of the kinematic limit (y_L^{max}=2.21) of NN-interaction and practically all from noncentral interactions. Approximately 16% (3788) of protons have large transverse momenta ($p_\perp$>0.7GeV/c). Most of them (2372 protons) belong to semicentral interactions. Out of the kinematic limit ($p_{\perp max}$=1.22GeV/c) of NN-interaction there are approxi-

Table 2

Average characteristics of protons and π^--mesons produced in CTa-interactions at 4.2 AGeV/c.
t – total, n – noncentral and s – semicentral interactions.

p – protons

Type of interactions	$\langle p_L \rangle$GeV/c*	$\langle p_\perp \rangle$ GeV/c	$\langle \vartheta_L \rangle$degrees	$\langle y_L \rangle$	$\langle Cos\vartheta \rangle_{cms}$
s	0.973±0.012	0.487±0.007	49.83±0.44	0.511±0.007	- 0.628±0.008
n	1.419±0.016	0.420±0.007	39.82±0.40	0.783±0.011	- 0.343±0.006
t	1.144±0.010	0.457±0.05	46.32±0.30	0.624±0.007	- 0.500±0.007
t(DCM)	1.127	0.462	47.6	0.610	- 0.504

π^- -mesons

s	0.403±0.010	0.208±0.004	53.90±0.94	0.708±0.019	- 0.312±0.011
n	0.513±0.012	0.216±0.006	44.73±0.87	0.958±0.026	- 0.114±0.007
t	0.458±0.010	0.212±0.006	50.80±0.65	0.809±0.01	- 0.224 ±0.007
t(DCM)	0.470±0.01	0.225±0.004	51.59±0.6	0.79±0.02	

*$p_{LAB} \equiv p_L$
$\vartheta_{LAB} \equiv \vartheta_L$
$y_{-LAB} \equiv y_L$

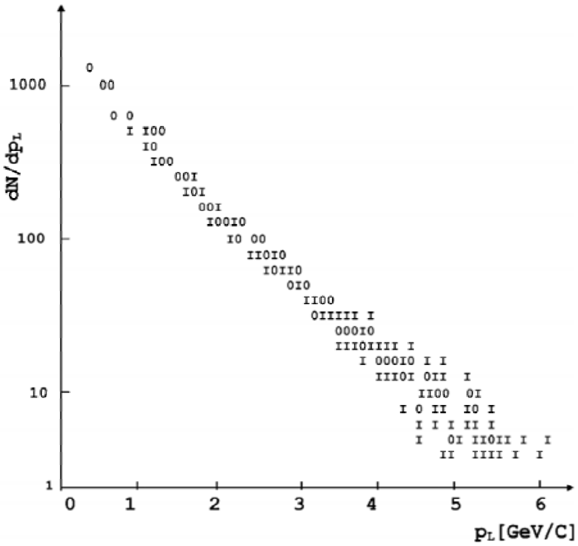

Fig. 1. Momentum distribution of protons produced in semicentral interactions.

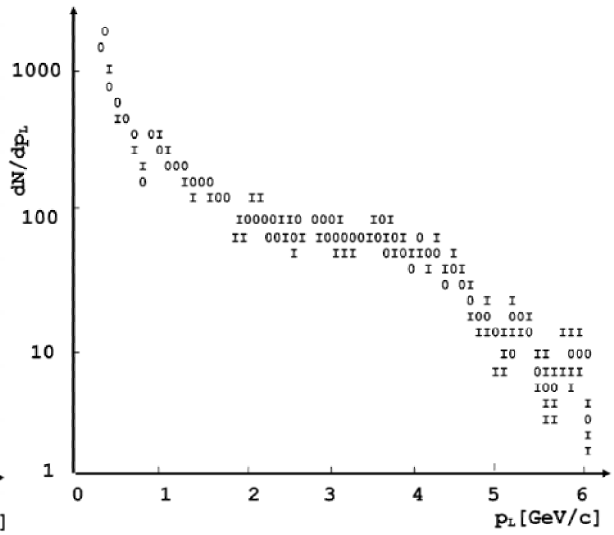

Fig. 2. Momentum distribution of protons produced in *n* noncentral interactions.

mately 2.6% (614) protons. Among them approximately 430 protons are from semicentral interactions.

The degree of anisotropy in the emission of pions can be extracted from the angular distributions in the centre of mass frame of colliding nuclei.

Experimental spectra have been approximated by the formula

$$(dN/d\cos\vartheta)_{cms}=A(1+a\cos^2\vartheta_{cms}). \quad (3)$$

Extracting the parameter *a*, one can calculate the anisotropy coefficient

$$R=a/(a+3) \quad (4)$$

The results of the approximation and anisotropy coefficient are given in Table 4. It is seen that in semicentral interactions approximately 18% of pions are emitted anisotropically, but approximately 34% in noncentral collisions (Figs. 5 and 6).

Anisotropy coefficient in CTa-interactions obtained by us is in agreement with the result of Ref 6, for CPb-collisions at 4.5AGeV/c ($a \approx 1.17\pm0.07$ and $R\approx0.28\pm0.03$). In central ArKCl-collisions at 1.8 AGeV/c [6] $R\approx 0.17$. This is also in agreement with our result.

Temperatures for protons and π^--mesons

The temperature of the excited nuclear matter is one of the important parameters. We define temperature with the slope parameter in the kinetic energy E_k spectra of protons and pions . Experimental spectra have been approximated by the dependence

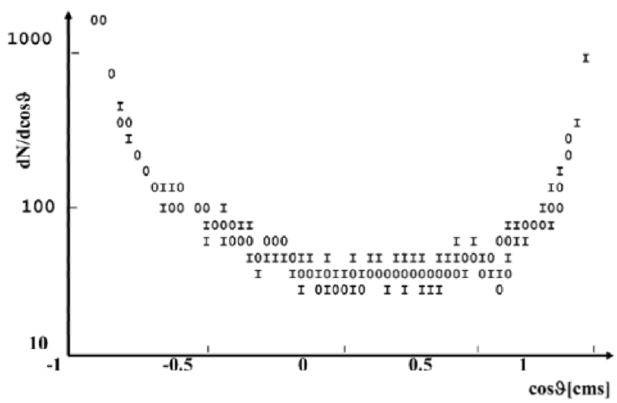

Fig. 3. cosϑ distribution (in cms) of protons in *n* noncentral interactions

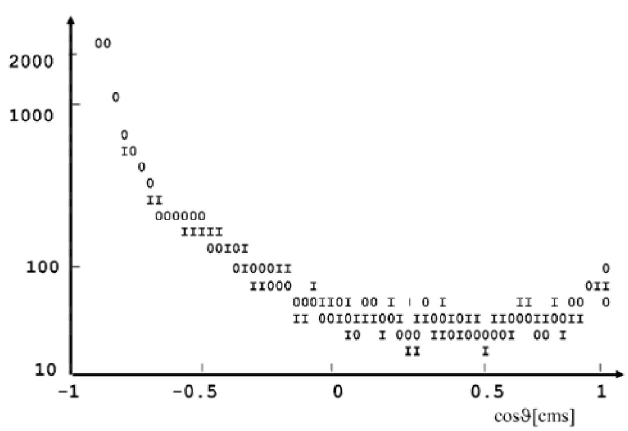

Fig. 4. cosϑ distribution (in cms) of protons in semicentral interactions

Table 3

The asymmetry coefficient of protons α_{fb} and α - the result of calculation of $\cos\vartheta_{cms}$ distributions, using formulae 1 and 2.

Type of interaction	α_{fb}	α
s - semicentral	0.154±0.04	- 0.73±0.01
n – noncentral	0.400±0.010	- 0.42±0.01

Table 4

Values of parameters *a* and R obtained from the distributions $(dN/d\cos\vartheta)_{cms}$ (with formulae (3) and (4)) $CTa \rightarrow \pi^-$ . . .

Type of interactions	a	R
t-total	1.14±0.09	0.27±0.03
s-semicentral	0.65±0.10	0.18±0.04
n-noncentral	1.54±0.15	0.34±0.05

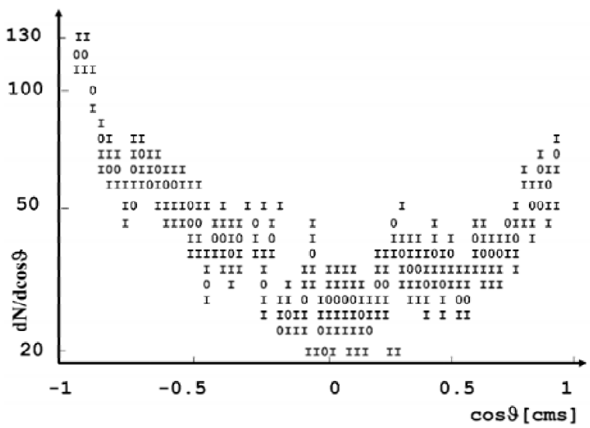

Fig. 5. cosθ distributions (in cms) of π^--mesons in noncentral interactions.

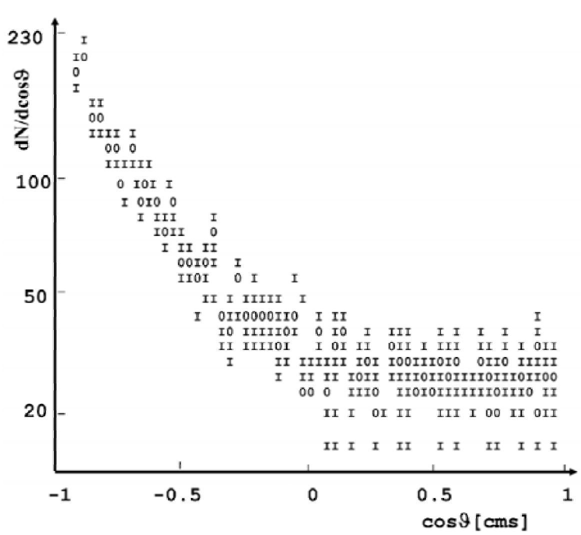

Fig. 6. cosθ distributions (in cms) of π^--mesons in semicentral interactions

$$F(E_k)=(1/pE)dN/dE_k=A\exp(-E_k/T), \qquad (5)$$

p is the momentum, E is total energy, E_k is kinetic energy in the cms. T is usually called average or inclusive temperature. The temperature can be extracted also from transverse momentum spectra. This has been proposed in the Hagedorn thermodynamical model

$$dN/dp_\perp=Ap_\perp(TE_\perp)^{1/2}\exp(-E_\perp/T), \qquad (6)$$

where $E_\perp=(m^2+p_\perp^2)^{1/2}$ is the transverse energy.

The temperature can be defined also by the formula

$$F(E_k)=(1/p)dN/d\,E_k=A\exp(-E_k/T). \qquad (7)$$

For our analysis we use mainly the formula (5). The formulae (6) and (7) are used for comparison (see [8-12]).

Since the temperatures of π^--mesons from noncentral and semicentral interactions are approximately the same (formula 5) we give only the temperature of π^--mesons from semicentral interactions. It is seen that the angular dependence of the temperature is observed (for protons and mesons). Also temperature for semicentral interactions is on the average higher than for the noncentral interactions (for protons). When moving from $\cos\vartheta=\pm1$ to $\cos\vartheta=\pm0.10$ noncentral and semicentral collisions tend to be closer to each other, but always T(s)>T(n) (Table 5 and Figs. 7 and 8)

Angular dependence of the temperature is mentioned also in [12]. Strong angular dependence of the temperature (especially for π^--mesons from semicentral interactions) allows one to think that the generation mechanism of particles at 90^0 (central region) significantly differs from the generation mechanism in the fragmentation region.

The approximation of $F(E_k)$ for π^--mesons by two exponentials (with T_1 and T_2) shows that T_1 and T_2 significantly differ. This is an indication of the existence of two production centers of π^--mesons. When moving to the centre ($\vartheta\approx90^0$) T_1 decreases rapidly - from (45±1) MeV ($\cos\vartheta=\pm1$) to (10±2) MeV ($\cos\vartheta=\pm0.10$). T_2 -temperature

Table 5

Temperature T of protons and π^--mesons - result of approximation by formula (5), in different angular intervals - emission angle ϑ and $\cos\vartheta$ - in the NN –nucleon-nucleon cms

ϑ intervals	$\cos\vartheta$ intervals	T_p [MeV]	T_{π^-} [MeV]	Type of interaction
$0^0 \div 180^0$	±1		84±1	s - semicentral
				n – noncentral
			78±1	t – total
$41^0 \div 139^0$	±0.75	200±2	66±1	s
		172±2		n
		188±2	70±1	t
$60^0 \div 120^0$	±0.5	177±2	63±1	s
		154±2		n
		168±2	66±1	t
$70^0 \div 110^0$	±0.34	169±2	59±1	s
		147±2		n
		161±2	63±1	t
$75^0 \div 105^0$	±0.25	162±4	58±1	s
		142±4		n
		154±3	62±1	t
$80^0 \div 100^0$	±0.17	163±5	57±1	s
		139±5		n
		154±4	65±1	t
$84^0 \div 96^0$	±0.10	155±6	46±1	s
		132±6		n
		145±4	63±1	t

decreases also, but not so rapidly: from (109±2) MeV ($\cos\vartheta$=±1) to (81±3) MeV. Thus in the central region one centre model works.

In order to compare our results with those of [6] $p_\perp$-distribution was approximated by the formula (6) in the rapidity interval ($0.3<y_L<1.7$). The results are in agreement with each other: $T_p(s)$=(141±2) MeV (our result) and $T_p(s)$=(147±2) MeV for CPb – collisions at 4.5 GeV/c [6].

Analysis of F(E_k-distribution with formula (7) gives qualitatively the same result, but T by the formula (7) are always larger than T by the formula (5)

Analysis of $p_\perp^2$-distributions

$p_\perp^2$- distribution for π^--mesons is described fairly well by two exponentials,

$$dN/dp_\perp^2 = A\exp(-ap_\perp^2) + B\exp(-bp_\perp^2). \quad (8)$$

For all three types of events in the interval ($0< p_\perp^2 <1$) (GeV/c)^2. The values of the slope parameters <u>a</u> and <u>b</u> are approximately the same for all three types of events. That is why we give only the results for the total distribution a=(38.50±1.40) (GeV/c)$^{-2}$, b=(7.41±0.30) (GeV/c)$^{-2}$. (Table 6). This is in agreement with the results of other

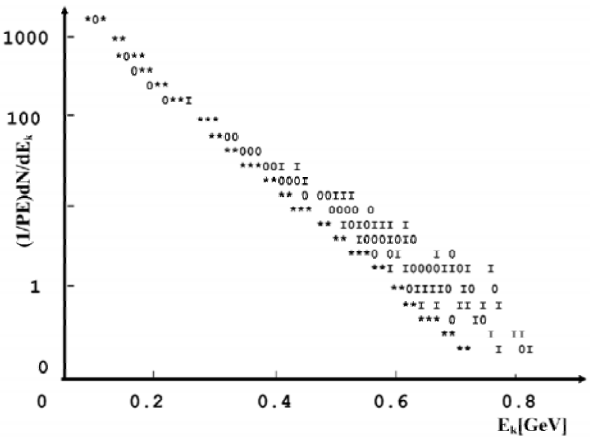

Fig. 7. Noninvariant kinetic energy spectra of π^--meson (semicentral interactions)
Experimental data points - 0
Result of fitting by (5) (one exponent) - *

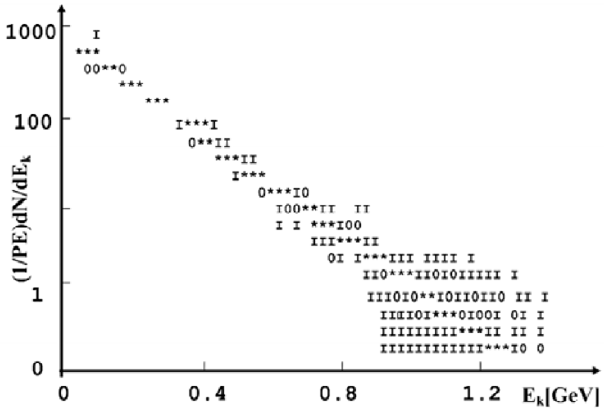

Fig. 8. Noninvariant kinetic energy spectra (E_k) of protons (t - total number of interactions) approximation using formula (5)
* - result of fitting
0 - experimental data points

Table 6

Values of slope parameters of the exponentials for π^--mesons $p_\perp^2$ - distributions in CTa – interactions (total number of π^--mesons). Formula (8).

Intervals of $p_\perp^2$ $(GeV/c)^2$					
CTa(t)		0.0 ÷ 1.0	χ^2/N	0.1 ÷ 1.0	χ^2/N
Parameters	$a(GeV/c)^{-2}$	38.50 ± 1.40	1.05	13.40 ± 1.90	0.67
	$b(GeV/c)^{-2}$	7.41 ± 0.30		3.61 ± 0.50	

papers .

If we exclude from the π^--mesons spectra the interval $p_\perp^2 < 0.1 (GeV/c)^2$, the values of the parameters obtained are lower, $(a=13.41\pm1.8)(GeV/c)^2$, $b=(3.61\pm0.50)(GeV/c)^{-2}$, (for total number of π^--mesons).

If we study $p_\perp^2$ - distributions separately for semicentral and noncentral events, in the interval $(0.1<p_\perp^2<1.0)$ $(GeV/c)^2$, the description is good with $a\approx10(GeV/c)^{-2}$. The value of the second parameter is approximately zero.

The inclusive spectrum $dN/dp_\perp^2$ of the participating protons is poorly described by the formula (8) (with one and two exponents as well) in the interval $(0\text{-}4)(GeV/c)^2$. If one excludes protons with $p_\perp^2 < 0.2$ $(GeV/c)^2$ the description is much better with $b=(4.2\pm0.18)$ $(GeV/c)^{-2}$.

Conclusions

1. Angular dependence of the temperature of protons and π^--mesons is observed in CTa-interactions.

2. When moving to the centre ($\vartheta \approx 90^0$) the temperature rapidly decreases .

3. The temperature for protons in semicentral interactions is always higher than in noncentral interactions.

4. The analysis of π^--mesons distributions according to kinetic energy shows that for the total spectrum the two-centre model works well (temperatures T_1 and T_2 do not differ significantly), but in the central region ($\vartheta = 90^0$) one centre model works (T_1 is much smaller than T_2).

One of the authors (V.R.G.) expreses his deep gratitude to Luis Alvarez-Gaume and Alvaro De Rujula for the warm hospitality at the CERN TH Division.

ფიზიკა

ნახშირბად-ტანტალის არაცენტრალურ და ნახევრადცენტრალურ დაჯახებებში დაბადებული პროტონების და π^--მეზონების მახასიათებლების შედარებითი ანალიზი, პირველადი იმპულსით 4,2 A გევ/c

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ი. ჯავახიშვილის თბილისის სახელმწიფო უნივერსიტეტის მაღალი ენერგიების ფიზიკისა და ინფორმატიზაციის ინსტიტუტი

(წარმოდგენილია აკადემიის წევრის ა. ხელაშვილის მიერ)

ნაშრომში განხილულია ნახშირბადის რელატიური იონების (იმპულსით 4,2 A გევ /c) ტანტალის მძიმე ბირთვებთან ურთიერთქმედების შედეგად დაბადებული პროტონების და π^--მეზონების მახასიათებლები. შედარებულია ერთმანეთთან იმ ნაწილაკების საშუალო მახასიათებლები (მრავლობითობები, იმპულსები, გამოფრენის კუთხეები, სისწრაფეები, ტემპერატურები), რომლებიც დაიბადნენ არაცენტრალურ და ნახევრად ცენტრალურ დაჯახებებში.

განხილულია ნაწილაკების დაბადების ერთ- და ორცენტრიანი მოდელები. მიღებული შედეგები შედარებულია სხვა ავტორების მიერ მიღებულ შედეგებთან და მოდელებთან.

დაკვირვებულია ბირთვული მატერიის ტემპერატურის დამოკიდებულება ნაწილაკის გამოფრენის კუთხეზე.

ნახევრად ცენტრალურ დაჯახებებში დაბადებული ნაწილაკების საშუალო იმპულსი გაცილებით მცირეა, ვიდრე არაცენტრალურში დაბადებულებისა, გამოფრენის საშუალო კუთხე კი ნახევრად ცენტრალურში მეტია, ვიდრე არაცენტრალურში.

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