Comparative Analysis of Average Characteristics of π^-– mesons and Protons Produsedin Noncentral and Semicentral CTa-Collisions at 4.2 AGeV/c

L. T. Akhobadze, V. R. Garsevanishvili, Yu. V. Tevzadze
Institute of High Energy Physics Tbilisi State University, Universitetskaya st. 9, 0186, Tbilisi, Georgia

Abstract:

Comparative analisis of 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.

Introduction

After the beams of monoenergetic relativistic nuclei on the accelerators have been obtained the possibility arose to compare nucleon - nucleon, nucleon- nucleus and nucleus – nucleus interactions. It is possible to study multinucleon, collective processes. The study of central and semicentral interactions and its 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 are 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 exprosed by beams of p, D, He, C, F, Mg nuclei from the synchrophasotron with momentum of 4.2 AGeV/c. Methodological problems of the experiment are described in Refs [1, 2, 3]. Central nucleus – nucleus interactions at various energies are studied in a number of papers (see, e. g. [4, 5, 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 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 Nπ^- =5967. π^-– mesons with P_{LAB}<0.08GeV/c do not contribute to the statistics, because the minimum value of momentum when π^-– mesons are well identified is 0.08GeV/c.

Average number of protons and π^-– mesons in one CTa – collisions 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

The number of semicentral collisions is N(s)=628

Semicentral events are assumed not to have stripping particle (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 where the number 15 is 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 are compared with each other.

Table 1.

The number of events: N(t)-total number. N(n)-noncentral number and N(s) is semicentral .Np is average number of protons and n_{π^-} is 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

If the division of events on noncentral and semicentral is reliable, then average values of momenta p, emission angles ϑ, average number of charge secondaries in one CTa-collisions, average temperatures T, anisotropy and asymmetry coefficients, average values of Feynman variable x_F and rapidity - y_L, should significantly differ in noncentral and semicentral collisions. And really it is so (see Table 2). There exists on opinion that criterium of selection according to stripping particles is weak. We will sow that is not so (see Table 1 and 2. Fig. 1 and Fig. 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 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 $dN/d\cos\vartheta$ of protons in the NN centre of mass system in noncentral and semicentral collisions significantly differ. In semicentral interactions the influence of heavy targets nucleus Ta is significant (the main part of protons is emited backward). In noncentral collisions there is approximate forward - backward asymmetry. This is confirmed by the asymmetry coefficients calculated by formula (1) and (2) (see Table 3. Fig. 3 and Fig. 4).

$$\alpha_{f\,b} = N_f / N_b \qquad (1)$$

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

N_f – number of forward moving protons

N_b – number of backward moving protons

Table2

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 interact-tions	$<p_L>$ GeV/c*	$<p_\perp>$ GeV/c	$<\vartheta_L>$degrees	$<y_L>$	$<\cos\vartheta>_{cms}$
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	

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

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

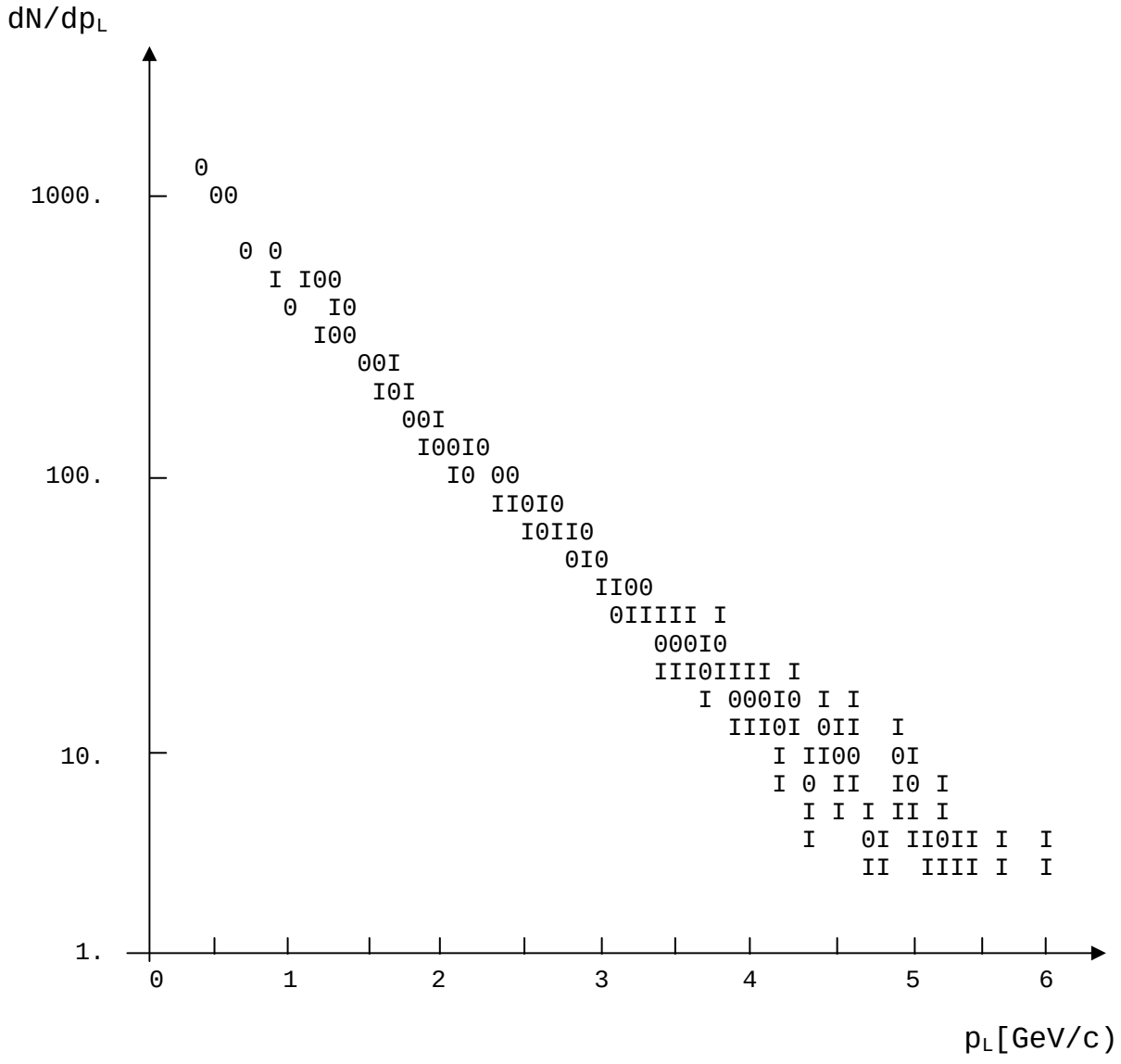

Fig. 1. dN/dp – momentum distributions (in Lab s) of protons, from s – semicentral interactions;

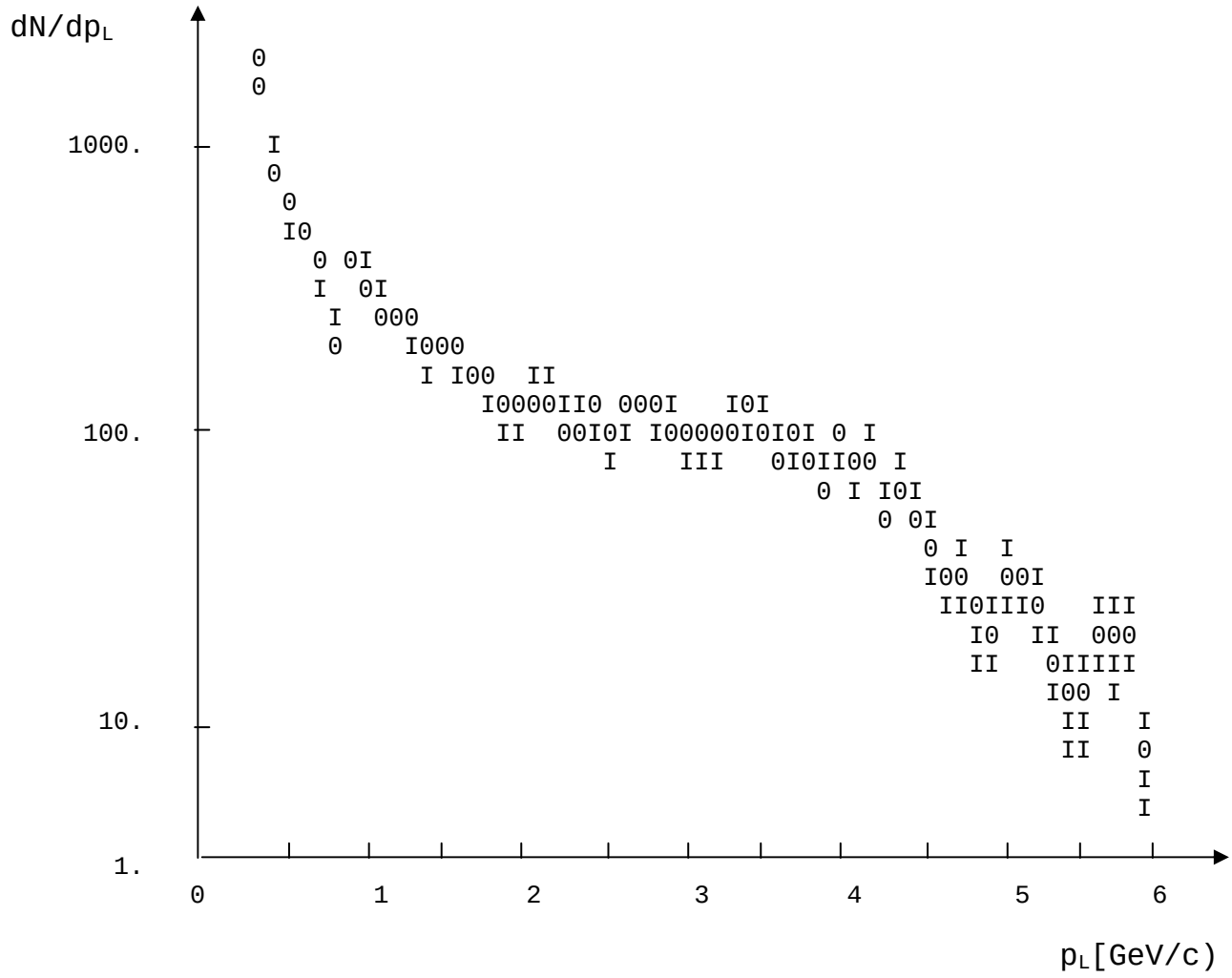

Fig. 2. dN/dp – momentum distributions (in Lab s) of protons, from n –noncentral interactions;

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

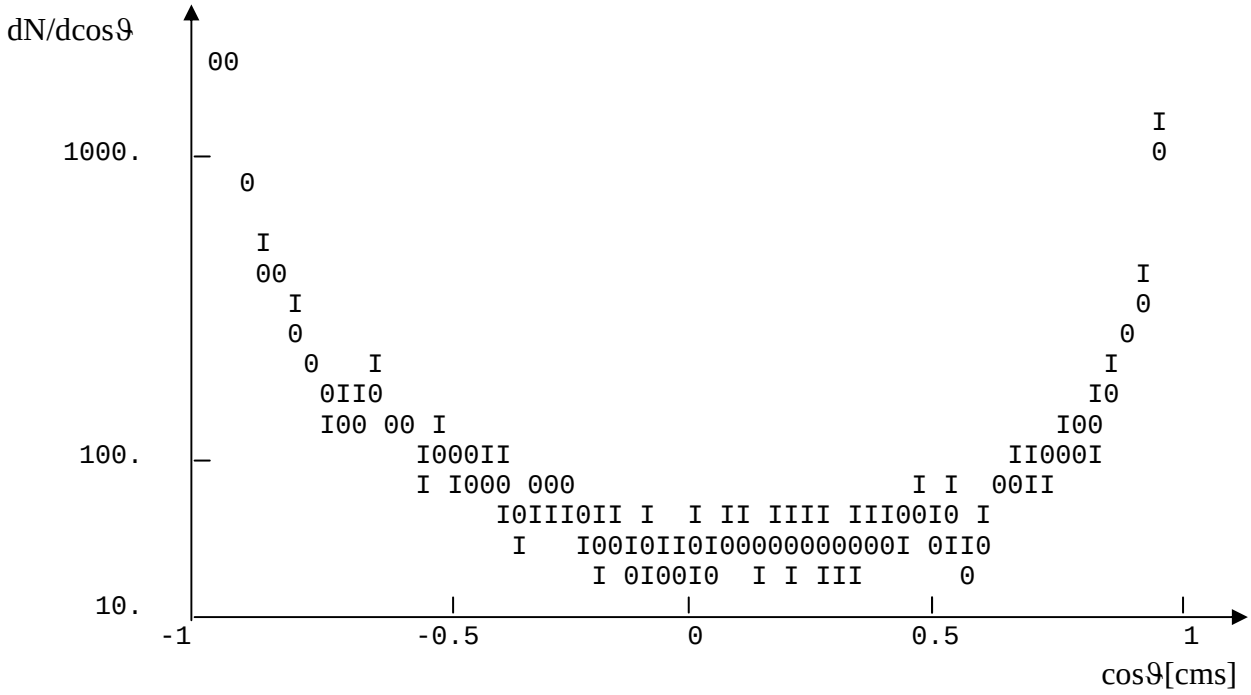

Fig. 3. cosϑ distributions (in cms) of protons from n-noncentral interactions;

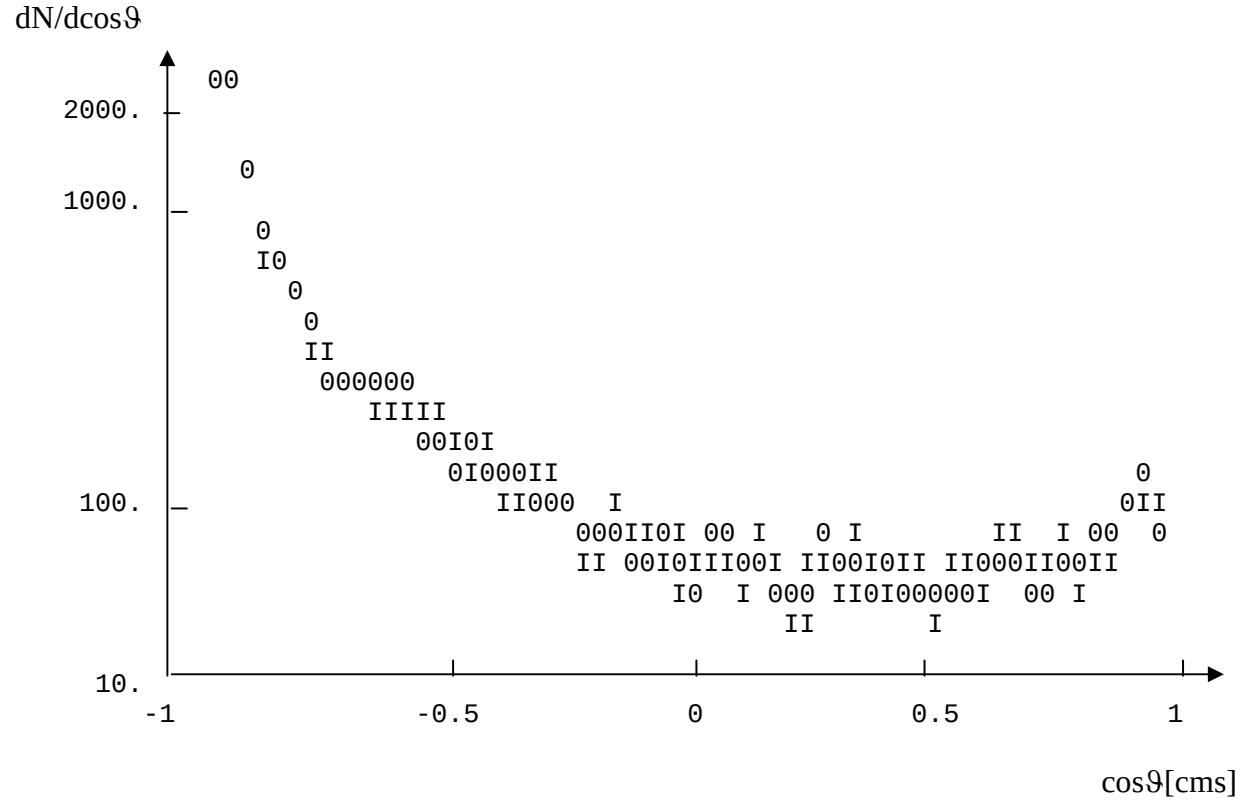

Fig4. cosϑ distributions (in cms) of protons from s-semicentral interactions;

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). Among them main part (2372 protons) belongs to semicentral interactions. Out of the kinematic limit ($p_{\perp max}$=1.22GeV/c) of NN- interaction there are aproxmately 2.6% (614) protons. Among them aproximately 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

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

Extracting parameter a one can calculate the anisotropy coefficient

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

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 anisotropicaly, but in noncentral collisions approximately 34%. (see Fig. 5 and Fig. 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 ≈1.17±0.07 and R≈0.28±0.03). In central ArKCl – collisions at 1.8 AGeV/c [6] R≈ 0.17. This is also in agreement with our result.

Temperatures for protons and π^--mesons

The temperature of the exited 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

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

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

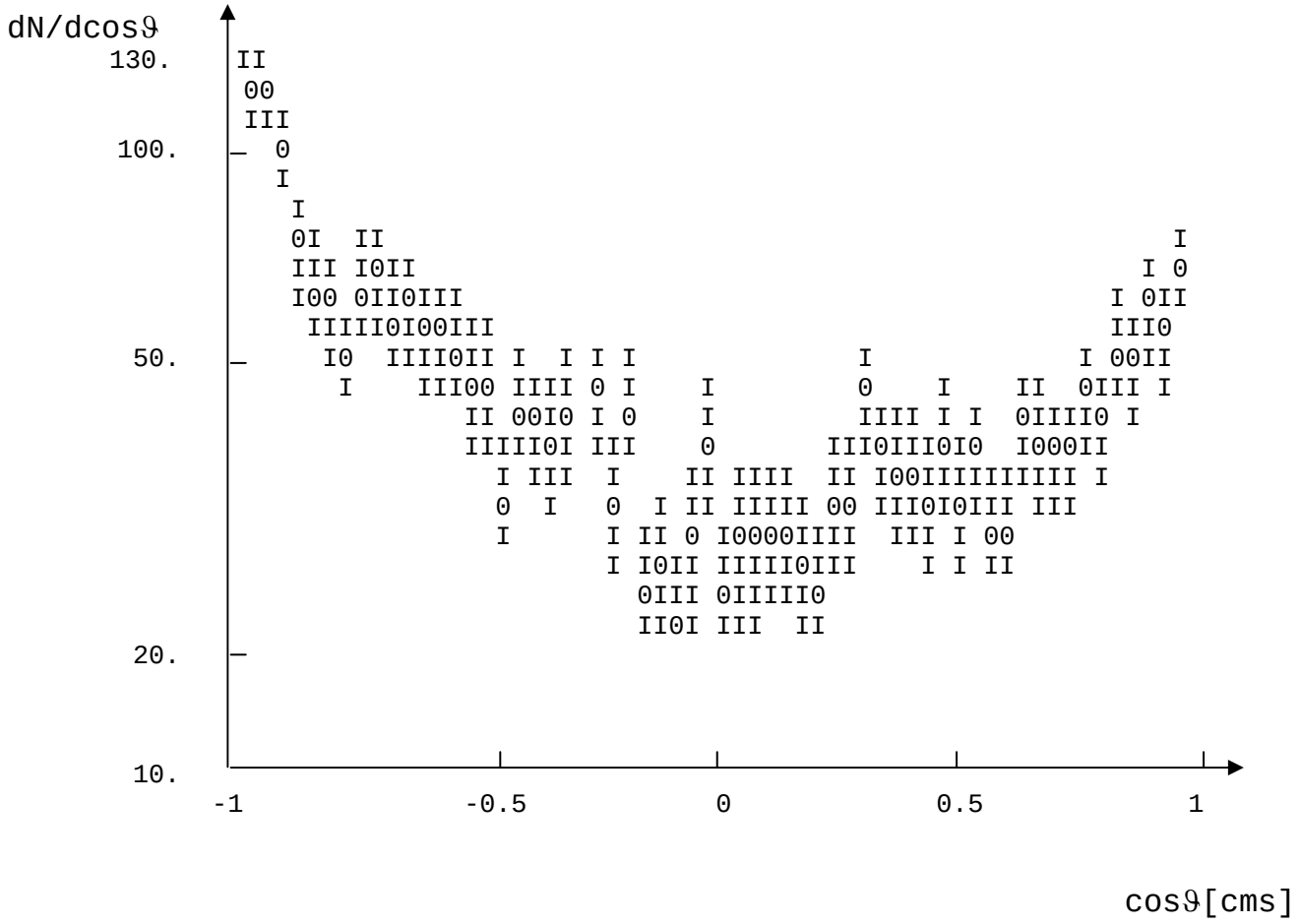

Fig. 5. cosϑ distributions (in cms) of π mesons from n-noncentral interactions;

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

$E_{\perp}=(m^2+ p_{\perp}^2)^{1/2}$ 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 Refs [8-12]).

Because temperatures of π^--mesons from noncentral and semicentral interactions are approximately the same (formula 5) we give only 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 in average higher than for the noncentral interactions (for protons). When moving from

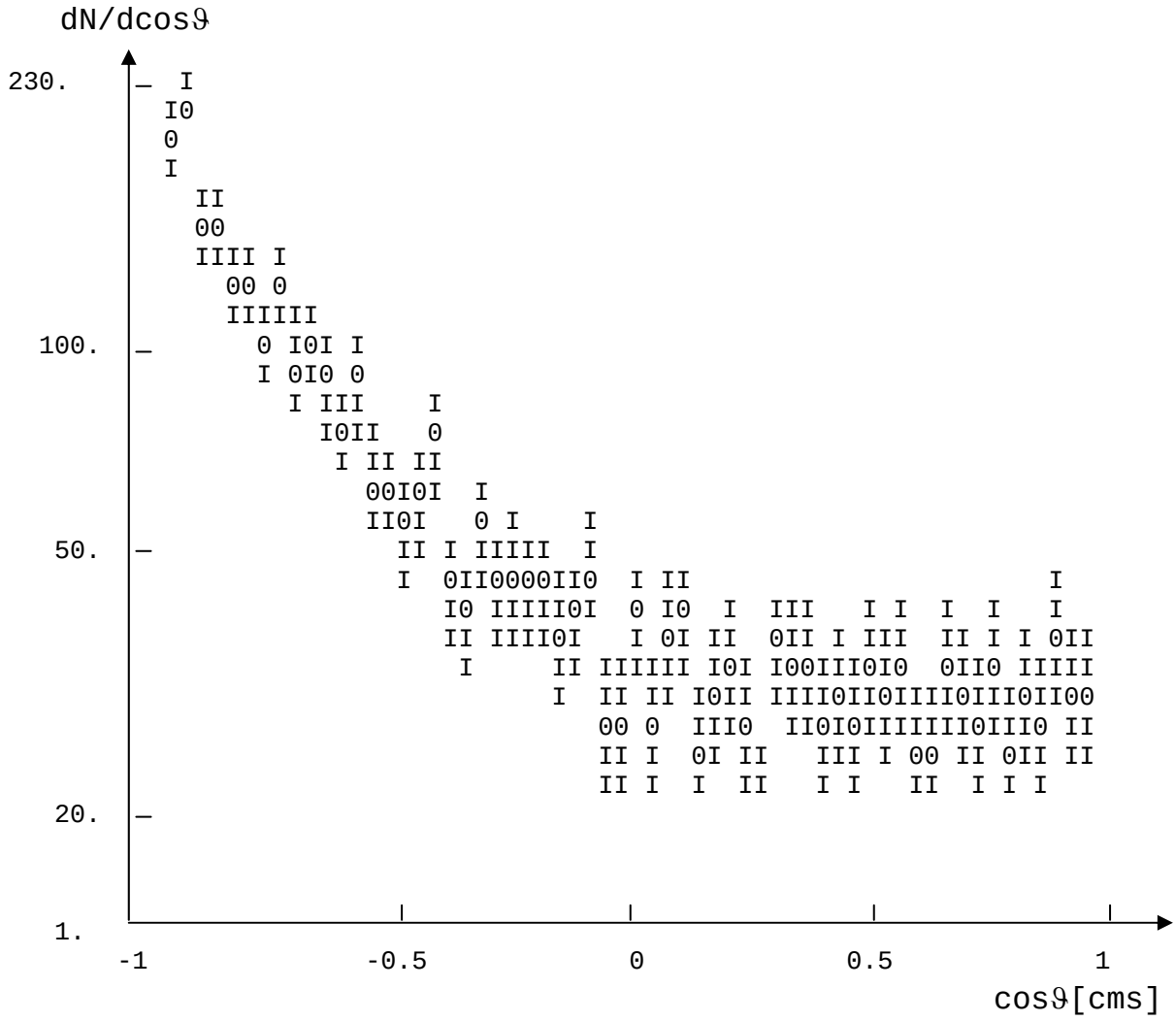

Fig. 6. cosϑ distributions (in cms) of π mesons from s-semicentral interactions;

cosϑ=±1 to cosϑ=±0.10 noncentral and semicentral collision have tendency to be closer to each other, but always T(s)>T(n). (Table 5 and Fig. 7 and Fig.8)

Table 5

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

ϑ intervals	cosϑ 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

Angular dependence of the temperature is mentioned also in Ref [13]. Strong angular dependence of the temperature (especially for π^- mesons from semisentral 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.

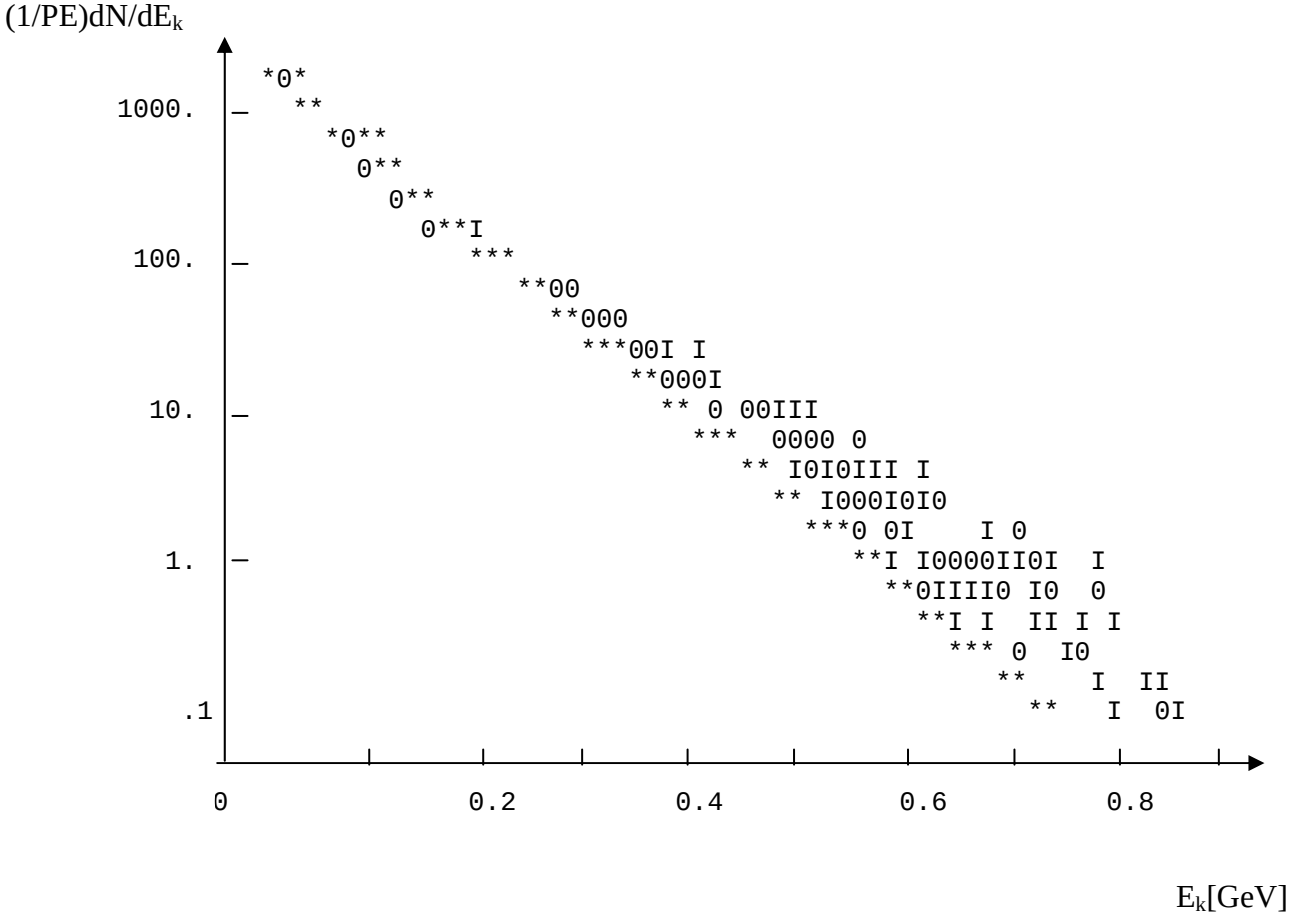

Fig. 7 Noninwariant kinetic energy spectra of π^- mesons (s-semicentral interactions)
Experimental data points – 0.
Result of fitting by (5) one exponent-*.

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 to the existence of two production centers of π^--mesons. When moving to the centre ($\vartheta \approx 90^0$) T_1 decreares from (45±1)MeV ($\cos\vartheta=\pm1$) to (10±2)MeV ($\cos\vartheta=\pm0.10$). T_2 – temperature decreases also, but not so rapidity: from (109±2)MeV ($\cos\vartheta=\pm1$) to (81±3)MeV. Thus in the central region one centre model works.

For the comparision of our results with the results of Ref[6] $p_\perp$-distribution have been approximated by the formula (6) in the rapidity interval ($0.3<y_L<1.7$). The results are in agriment with each other: $T_p(s)=(141\pm2)$ MeV (our result) and $T_p(s)=(147\pm2)$ MeV for CPb – collisions at 4.5 GeV/c [6].

Analysis of $F(E_k)$ – distribution with formula (7) gives qualitativly same results, but T by formula (7) are always large than T by formula (5)

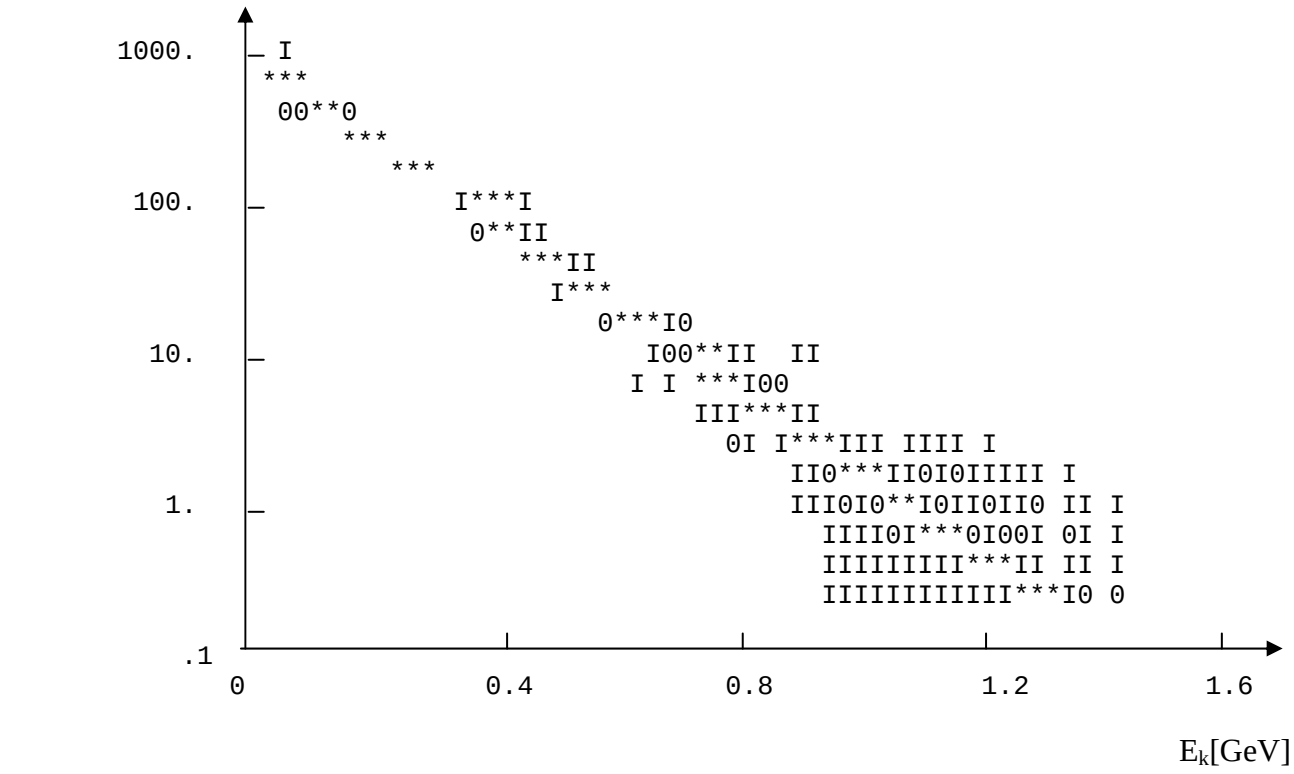

Fig.8. Noninvariant kinetic energy spectra of protons (t-total number of interactions)approximation using formula (5). * - result of fitting, o -experimental data points.

Analysis of $p_\perp^2$ –distributions

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

$$dN/dp^2_\perp = A\exp(-ap_\perp^2)+B\exp((-bp_\perp^2) \qquad (8)$$

For all three types of events in the interval ($0< p_\perp^2 <1$) $(GeV/c)^2$. The values of the slope parameters a and b are approximately the same for all three types of events. That is why we give only results for the total distribution $a=(38.50\pm1.40)$ $(GeV/c)^{-2}$, $b=(7.41\pm0.30)$ $(GeV/c)^{-2}$. (Table 6).This is in agreement with the results of other 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).

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)		$0.0 \div 1.0$	χ^2/N	$0.1 \div 1.0$	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	

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.

Inclusive spectrum $dN/dp_\perp^2$ of participating protons is badly described by 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 is rapidly decreased .
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 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).

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