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Physics

Momentum and Angular Characteristics of Protons and π^--Mesons from HeTa and dTa Interactions at 4.2 AGeV/c

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ABSTRACT. Angular dependence of the temperature of nuclear matter is observed in HeTa and dTa interactions at the incident momentum of 4.2GeV/c. Comparative analysis of angular and momentum spectra of protons and negative π^-- mesons produced in central and noncentral collisions is performed. *© 2010 Bull. Georg. Natl. Acad. Sci.*

Key words: *nucleon, anisotropy, interactions, asymmetry, nucleus.*

Introduction. Experimental data are obtained with the help of two metre propane bubble chamber (PBC-500) in the Laboratory of High Energies of the Joint Institute for Nuclear Research (JINR, Dubna). The chamber was bombarded by p, d, He, C, F, Mg nuclei in the momentum interval (2-10)AGeV/c. Three Ta - tantalum thin plates were located in the chamber. Details of the experiment can be found in [1-5]. Central A_iA_t-nucleus-nucleus interaction is studied in [6-11].

Analysis of Experimental Data. Our statistics contains 1149 HeTa and 1475 dTa-interactions which are detected in PBC-500, i.e. N^t_{ev}(HeTa)=1149 and N^t_{ev}(dTa)=1475. Total number of protons N_p(HeTa)=3320, N_p(dTa)=4230, total number of π^--mesons N_{π^-}(HeTa)=1132, N_{π^-}(dTa)=889. This statistics does not contain stripping protons with momentum bigger than 3GeV/c and emission angle less than 4^0[12, 13]. The statistics does not contain also protons with momenta less than 0.3GeV/c (spectators of target nucleus). π^--mesons with momenta less than 0.08GeV/c are excluded from consideration, because they are poorly identified.

We call central those HeTa-collisions where there is no charged stripping particle - n_s and total number of charged secondaries is bigger than 10 (n_s=0,$n_\pm$>10).

$P_{n\pm}$ multiplicity distribution of secondaries for events where there is at least one stripping charge particle ($n_s\neq0$) is given in Fig. 1. $P_{n\pm}$ multiplicity distribution of those events where there is no charge stripping particle (n_s=0) is also given in Fig. 1.

It is seen from Fig.1 that multiplicity distributions significantly differ. Strippingless events where $n_\pm$<4 belong to n-noncentral interactions. Then the contribution of n-noncentral events to the full statistics is 52%. $P_{n\pm}$-distributions for n-noncentral events and events with $n_\pm\geq4$ are given in Fig. 2. The shapes of distributions for central and noncentral events significantly differ from each other. The number of HeTa-collisions where there are no strippings and $n_\pm\geq4$(N_{ev}(n_s=0,$n_\pm$>4) is 48.0% of the full statistics. From here central events should be selected. Since He-helium contains 4 nucleons and if all 4 of them participate in the collision, then there should not be any strippings in the final state and number of charged secondaries should be bigger than 10 (since in NN-interactions on the average 2.5 particles are produced). The contribution of such events to full statistics is 11.6%.

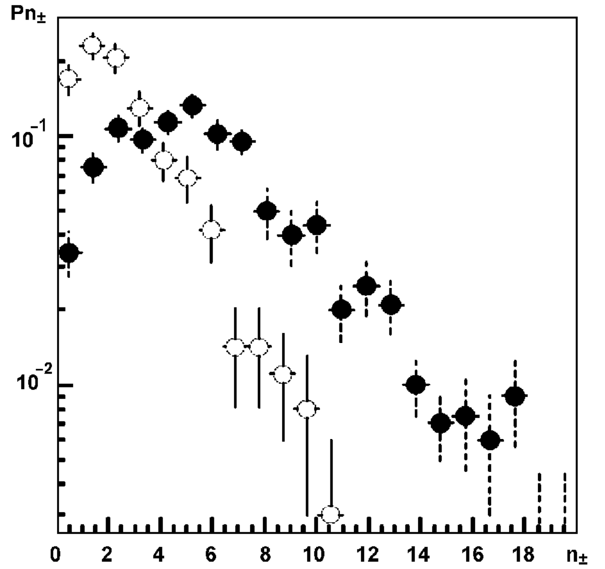

Fig. 1. Multiplicity distributions of charged secondaries in HeTa-interactions for noncentral events ($n_s \neq 0$, (○)) and for those events where there are no charged stripping particles ($n_s=0$, (●)).

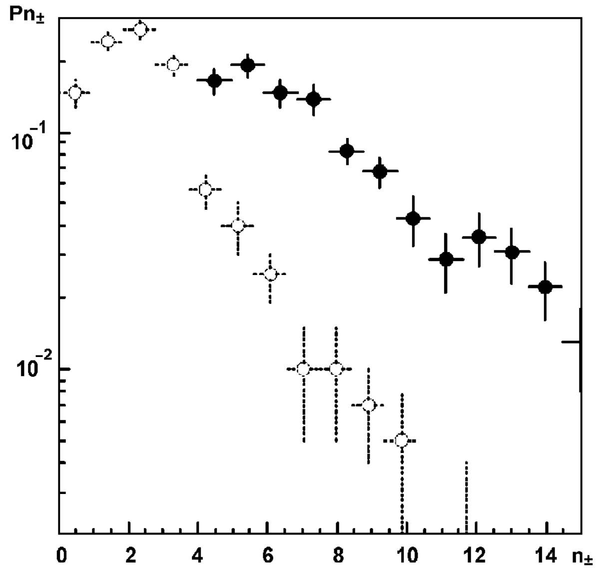

Fig. 2. Multiplicity distributions $P_{n_\pm}$ of charged secondaries in HeTa-collisions for n-noncentral events (○) and for those events where there are no stripping particles ($n_s=0$) and number of charged secondaries $n_\pm>4$ (●).

Some authors [13] use the double average method for the selection of central events: the event is assumed to be central, if $n_\pm > 2 < n_\pm >$, where $n_\pm$ is the multiplicity of charged secondaries, $< n_\pm >$ is the average multiplicity.

For the selection of central events from full statistics one can use the emitted total transverse energy $E_t^\pm$ [11,14,15]:

$$E_t^\pm = \sum_{i=1}^{n_\pm} [(M_i^2 + P_{i\perp}^2)^{1/2} - M_i \delta_i] \ , \qquad (1)$$

where M_i is particle mass, $P_{i\perp}$ is the transverse momentum, $\delta_i=0$ or 1 for pions and protons, respectively. For our case (HeTa-collisions) average value $<E_t^\pm>$ = (1.75±0.02) GeV.

We call central those collisions where $E_t^\pm > 2 < E_t^\pm >$. The contribution of such events is 12% of full statistics. In the central HeTa collisions the average value $< E_t^\pm >$ =(3.85±0.05)GeV.

For dTa-interactions total average value of emitted total transverse energy is $<E_t^\pm>$.=(1.09±0.04)GeV, i.e. central are those events where $E_t^\pm$>2.18GeV. In dTa-collisions 9% of total statistics are central events. Average characteristics of protons and π^- -mesons in HeTa and dTa interactions are given in Tables 2 and 3.

Average asymmetry in hadron-hadron, hadron-nucleus and nucleus-nucleus interactions means that there is a privileged direction in the c.m.s. which is connected either with projectile or with target nucleus. In HeTa and dTa-interactions angular distributions of protons in c-central and n-noncentral interactions considerably differ from each other. In c-central collisions 90% of produced particles are moving backward in the c.m.s. This is the influence of heavy target nucleus. This influence is more pronounced in dTa-collisions than in CTa-collisions. This is the effect of projectile. In n-noncentral collisions considerable forward-backward asymmetry is not observed (Fig. 3,4) and Tables (2,3).

The information on the anisotropy of secondaries can be extracted from the angular distribution, which is approximated by the relation [16]

$$\frac{dN}{d\cos\theta^*} = A(1 + a\cos^2\theta^*) \ , \qquad (2)$$

From the value of a-parameter the anisotropy parameter R can be obtained

$$R = \frac{a}{3+a} \ , \qquad (3)$$

In Tables 4 and 5 results of the approximation and anisotropy parameters R are given for protons and π^- -

Table 1.

Average number of charged secondaries in HeTa-interactions for c-central and n-noncentral events

$< n_\pm(n) >$	$< n_\pm(c) >$	$< n_p(n) >$	$< n_p(c) >$	$< n_{\pi^-}(n) >$	$< n_{\pi^-}(c) >$
2.21±0.10	13.25±1.10	1.19±0.07	8.80±0.04	0.56±0.04	2.22±0.20

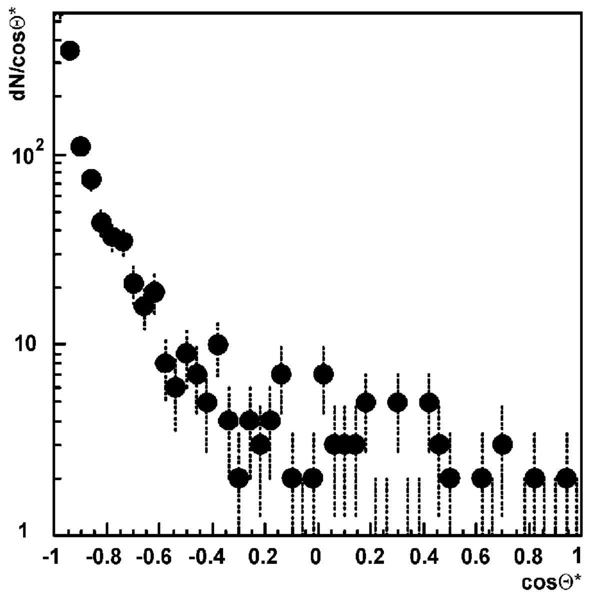

Fig. 3. Angular distribution of protons in the c.m.s. from dTa central collisions

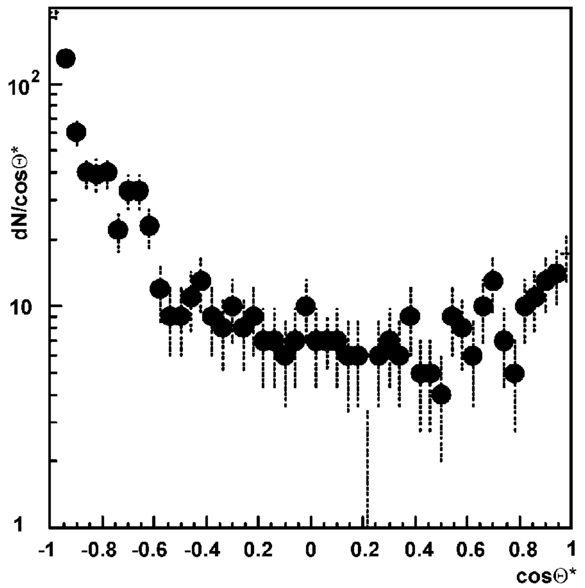

Fig. 4. Angular distribution of protons in the c.m.s. from dTa – noncentral collisions

Table 2

Average kinematical characteristics of protons and π^--mesons from HeTa-collisions for full statistics (t), central (c) and noncentral (n) events

HeTa→p

Type of collision	$<P_L>$GeV/c	$<P_\perp>$GeV/c	$<\theta_L^0>$	$<Y_L>$	$<Y^*>$	$<\cos\theta_L>$	$<\cos\theta^*>$
C	0.851±0.037	0.470±0.023	48.99±0.86	0.472±0.022	-0.631±0.026	0.587±0.031	-0.706±0.028
N	1.278±0.037	0.479±0.025	31.79±1.0	0.821±0.031	-0.275±0.022	0.784±0.041	-0.315±0.024
T	1.086±0.024	0.494	39.36±0.65	0.663±0.018	-0.439±0.014	0.702±0.022	-0.507±0.015
HeTa →π^-							
C	0.352±0.039	0.200±0.020	54.75±2.0	0.665±0.046	-0.431±0.044	0.504±0.041	-0.356±0.031
N	0.563±0.040	0.216±0.002	44.24±1.50	1.011±0.072	-0.085±0.031	0.621±0.072	-0.073±0.032
T	0.475±0.025	0.218±0.15	49.39±0.56	0.846±0.031	-0.256±0.017	0.564±0.03	-0.205±0.015

Table 3

Average kinematical characteristics of protons and π^--mesons from dTa-collisions for full statistics (t), central (c) and noncentral (n) events

dTa→p

Type of collision	$<P_L>$GeV/c	$<P_\perp>$GeV/c	$<\theta_L^0>$	$<Y_L>$	$<Y^*>$	$<\cos\theta_L>$	$<\cos\theta^*>$
dTa → p							
C	0.615±0.025	0.416±0.020	56.31±1.5	0.316±0.021	-0.821±0.04	0.485±0.021	-0.842±0.03
N	1.031±0.032	0.373±0.022	37.38±1.3	0.661±0.031	-0.441±0.06	0.710±0.031	-0.507±0.04
T	0.786±0.018	0.410±0.011	48.92±1.00	0.452±0.012	-0.650±0.016	0.577±0.015	-0.710±0.02
dTa → π^-							
C	0.338±0.030	0.200±0.021	55.35±1.6	0.656±0.05	-0.455±0.031	0.482±0.043	-0.35±0.033
N	0.521±0.015	0.230±0.023	44.71±1.20	0.981±0.071	-0.1285±0.042	0.622±0.051	-0.088±0.041
T	0.438±0.020	0.214±0.017	51.21±1.1	0.800±0.040	-0.303±0.020	0.537±0.031	-0.234±0.022

mesons from HeTa and dTa –interactions.

In nucleon-nucleon interactions anisotropy coefficient for π^- -mesons is 0.55 [10] which does not considerably differ from our R in noncentral collisions, where $R(n)\approx0.43$ (Table 4). This is indicative of the fact that in noncentral collisions there is no cascading scattering in heavy nucleus.

It is seen that anisotropy coefficients R in c-central collisions are considerably smaller than in noncentral collisions. For instance, in dTa-collisions 10% of π^- -

Table 4

Anisotropy parameters *a* and *R* obtained by Es. (2) and (3) in HeTa-collisions

Type of collisions	*a*	R
HeTa→π^-		
t	1.18±0.16	0.28±0.04
c	0.38 ±0.16	0.11±0.04
n	2.25±0.70	0.43±0.09
HeTa→p		
t	3.20±0.18	0.51±0.05
c	0.40±0.15	0.12±0.06
n	2.86±0.51	0.49±0.08

Table 5

Anisotropy parameters *a* and *R* by formulae 2 and 3 in dTa-collisions

Type of collision	*a*	R
dTa→π^-		
t	0.80±0.20	0.21±0.05
c	0.35 ±0.19	0.10±0.04
n	1.00±0.37	0.25±0.08
dTa→p		
t	2.01±0.28	0.40±0.06
c	0.78±0.29	0.21±0.06
n	5.02±1.04	0.62±0.10

Table 6

Temperature of π^--mesons and protons from HeTa-interactions as a function of emission angle (approximation by formula (4))

θ^* angular intervals	$\cos\theta^*$ intervals	T_p(MeV)	T_{π^-}(MeV)	Type of collisions
0^0 - 180^0	±1		89 ± 2	t
			79 ± 2	c
			94 ± 1	n
41^0 - 130^0	±0.75	153 ± 3	78 ±1	t
		190 ± 6	61 ± 2	c
		133 ± 5	83 ± 3	n
60^0 - 120^0	±0.50	138 ± 4	77 ± 3	t
		177 ± 7	68 ± 2	c
		126 ± 7	75 ± 4	n
70^0 - 110^0	±0.34	134 ± 5	81 ± 4	t
		188 ± 8	67 ± 3	c
		124 ± 8	77 ± 4	n
75^0 - 105^0	±0.25	133 ± 6	75 ± 8	t
		186 ± 9	70 ± 6	c
		111 ± 9	95 ± 5	n
80^0 - 100^0	±0.17	141 ± 8	76 ± 9	t
		184 ± 10	68 ± 3	c
		120 ± 10	96 ± 6	n
84^0 - 96^0	±0.10	131 ± 9	70 ± 10	t
				c
				n

mesons and 20% of protons are produced anisotropically, whereas in noncentral collisions 25% of π^--mesons and 62% of protons are produced anisotropically (Table 5).

Temperatures of protons and π^--mesons from HeTa and dTa-interactions. The temperature is extracted from the kinetic energy distributions. Approximation is performed by the formula:

$$(\frac{1}{pE})\frac{dN}{dE_k} = A\exp(-\frac{E_k}{T}), \quad (4)$$

where p is the momentum, E is total energy, E_k is kinetic energy in the c.m.s. T is called the inclusive temperature.

It is seen from Table 6 that temperature of protons from HeTa-collisions is not angular dependent in contrast to CTa-collisions [17]. The temperature of π^--mesons is also not angular-dependent when $|\cos\theta^*| \leq \pm 0.75$.

The temperature of protons is always bigger than the temperature of π^--mesons, since they are produced in the earlier stage of the expansion of nuclear matter [16]. In HeTa-collisions the temperature of protons is bigger in c-central collisions than in n-noncentral collisions. The same is true for dTa-collisions.

In c-central collisions the temperature of π^--mesons is in good agreement with [19], where the thermodynamical fireball model [20] is used.

Conclusions.

1. For HeTa-interactions 12% (280 mb) of collisions are central and for dTa-interactions 9% (175mb) of collisions are central;
2. Average kinematical characteristics of particles considerably differ for central and noncentral events;
3. For π^--mesons characteristics weakly depend on the atomic number of projectile. For protons this dependence is pronounced;
4. For HeTa-interactions the temperature of protons does not depend on the emission angle in the c.m.s. and for dTa-collisions this temperature does not depend on the emission angle if $|\cos q^*|<0.75$;
5. The temperature of protons is always bigger than the temperature of π^--mesons;
6. The temperature of protons from central events is always bigger than that for noncentral events.

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ფიზიკა

ჰელიუმ-ტანტალისა და დეიტონ-ტანტალის დაჯახებებში დაბადებული პროტონებისა და π^--მეზონების იმპულსური და კუთხური განაწილებები, პირველადი იმპულსით 4.2Aგევ/c

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** ი. ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტის მაღალი ენერგიების ფიზიკის ინსტიტუტი*
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ნაშრომში განხილულია ჰელიუმისა და დეიტონის რელატიური იონების (იმპულსით 4.2Aგევ/C) ტანტალის მძიმე ბირთვებთან დაჯახებების შედეგად დაბადებული პროტონებისა და π^--მეზონების კინემატიკური მახასიათებლები. ერთმანეთთან შედარებულია ცენტრალურ და არაცენტრალურ დაჯახებებში დაბადებული

ნაწილაკების მახასიათებლები (მრავლობითობები, იმპულსები, გამოფრენის კუთხეები, ტემპერატურები). ნაჩვენებია, რომ π^--მეზონების მახასიათებლები სუსტად არიან დამოკიდებული პირველადი (დამცემი) ბირთვის მასურ რიცხვზე, პროტონებისათვის კი ეს დამოკიდებულება არსებითია. ნაწილაკების ტემპერატურა გამოფრენის კუთხეზე არაა დამოკიდებული კუთხეებისათვის $|\cos\theta^*| \leq \pm 0.75$.

ცენტრალურ დაჯახებებში დაბადებული ნაწილაკების საშუალო იმპულსი გაცილებით ნაკლებია, ვიდრე არაცენტრალურში დაბადებულებისა. გამოფრენის კუთხე კი ცენტრალურში დაბადებულებისათვის მეტია, ვიდრე არაცენტრალურში დაბადებულებისათვის. მიღებული შედეგები შედარებულია სხვა ავტორების მიერ მიღებულ შედეგებთან და მოდელთან.

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