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# THE STUDY OF CHARACTERISTICS OF CHARGED SECONDARY HADRONS IN CTA, HETA AND DTA-COLLISIONS IN HARD AND SOFT INTERACTIONS AT 4.2GEV/C

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***Abstract***
*Experimental data are obtained on the two meter propane bubble chamber (PBC-500) of the Laboratory of High Energies of JINR(Dubna). The chamber was exposed to P,d,He, C,F and Mg beams in the momentum range (2-10)AGeV/c. Three Ta-tantalum thin plates were placed in the chamber [1÷4]. Methodic problems of the experiment are considered in Refs [5-8].*

## Analisis of Experimental Data

Our statistics consists of 2469 CTa, 1149 HeTa and 1475 dTa-interactions registered in the propane bubble chamber PBC-500. Thus, total number of collisions are: $N^t_{ev}$(CTa)=2469, $N^t_{ev}$(HeTa)= 1149, $N^t_{ev}$(dTa)=1475. The total number of protons: $N^t_p$(CTa)=22447, $N^t_p$(HeTa)=3320 and $N^t_p$(dTa)=4231. Statistics at $\pi^-$ -mesons is as follows: $N^t_{\pi^-}$(CTa)= 5967, $N^t_{\pi^-}$(HeTa)=1132, $N^t_{\pi^-}$ (dTa)=889. The statistics does not include so called evaporated (spectators of target nucleus) and stripping protons and $\pi^-$ -mesons where momenta are poorly identified [8].

The separation of hard and soft processes can be performed by means at the so called cumulative number variable

$$n_k = (E - p_{\|}) / m_N \qquad (1)$$

E and $p_{\|}$ are energy and longitudinal momentum of the particles in the laboratory frame, $m_N$ is the nucleon mass. So defined $n_k$ finds its origin in the parton model and light front dynamics [9]. $n_k$ can be interpreted as a minimal mass of the target, which is necessary for the creation of the given particle,. If $n_k \geq 1$, the particle is called cumulative. In general $n_k$ is called the order of cumulativity,. Particles with $n_k \geq 1$ give information on the hard processes and on the role of nuclear medium in the formation of particle characteristics. Therefore the average characteristics of particles with $n_k \geq 1$ and $n_k < 1$ should considerably differ from each other.

## The Dependence of Characteristics of Protons on the Comulative Number

The average value of cumulative number of created protons in CTa-collisions is $\bar{n}_k(p) = (0.72 \pm 0.01)$ fig.1

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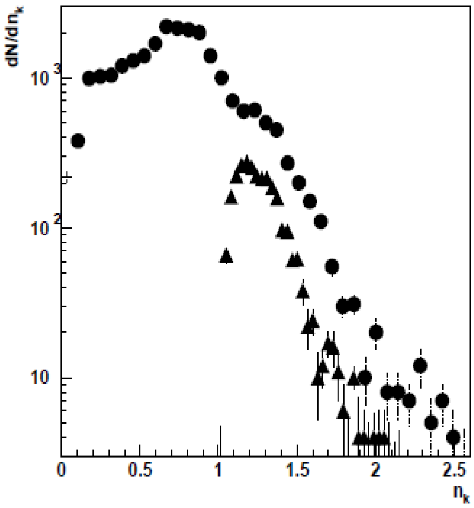


fig.1 Distribution of secondary protons in CTa –collisions as a function of the cumulative number: •-$n_p(t)$ for total statistics and ▲-$n_p(b)$ for protons moving in backward direction in the laboratory frame

Protons with $n_k \geq 1$ are called cumulative. Such protons are 18% of total statistics. There average momentum $\overline{P}_L$ is significantly smaller than average momentum of protons with $n_k<1$, but the emission anile is considerably bigger than the emission angle of protons with $n_k<1$ $(\overline{\theta}^0_L(n_k \geq 1) >> \overline{\theta}^0_L(n_k < 1))$.

The role at the heavy target in the production at the cumulative proton is much more pronounced than for noncumulative ones (Table 1,2,3)

Table 1.

Dependence of the average characteristics of protons on the $n_k$ cumulative number (CTa-interactions)

| | $\overline{p_L}(GeV/C)$ | $\overline{p_\perp}(GeV/C)$ | $\overline{\theta^0_L}$ grad | $\overline{\cos\theta^*_{NN}}$ | $\overline{Y_L}$ |
|---|---|---|---|---|---|
| $n_k<0.3$<br>$n_k \geq 0.3$ | 2.990±0.065<br>0.818±0.009 | 0.437±0.015<br>0.468±0.007 | 8.570±0.210<br>51.99±0.40 | 0.808±0.050<br>-0.734±0.007 | 1.710±0.020<br>0.429±0.005 |
| $n_k<0.6$<br>$n_k \geq 0.6$ | 1.942±0.026<br>0.618±0.008 | 0.486±0.009<br>0.457±0.007 | 17.99±0.40<br>62.84±0.51 | 0.076±0.003<br>-0.883±0.011 | 1.217±0.018<br>0.244±0.002 |
| $n_k<0.8$<br>$n_k \geq 0.8$ | 1.399±0.015<br>0.578±0.010 | 0.452±0.007<br>0.495±0.010 | 24.98±0.21<br>81.98±1.20 | -0.32±0.005<br>-0.911±0.016 | 0.891±0.011<br>0.094±0.003 |
| $n_k<1$<br>$n_k \geq 1$ | 1.202±0.012<br>0.588±0.015 | 0.460±0.006<br>0.505±0.009 | 33.1±0.25<br>105.1±1.5 | -0.456±0.007<br>-0.934±0.021 | 0.736±0.008<br>-0.072±0.013 |

Table 2.

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Dependence of the average characteristics of protons on the $n_k$ cumulative number (HeTa-interactions)

| | $\overline{p_L}(GeV/C)$ | $\overline{p_\perp}(GeV/C)$ | $\overline{\theta_L^0}$ grad | $\overline{\cos\theta_{NN}^*}$ | $\overline{Y_L}$ |
|---|---|---|---|---|---|
| $n_k<0.3$ | 2.261±0.043 | 0.349±0.037 | 8.81±0.600 | 0.755±0.060 | 1.52±0.100 |
| $n_k\geq0.3$ | 0.960±0.020 | 0.510±0.016 | 42.63±0.71 | -0.642±0.018 | 0.572±0.017 |
| $n_k<0.6$ | 1.463±0.043 | 0.434±0.025 | 18.56±0.490 | -0.153±0.010 | 1.375±0.025 |
| $n_k\geq0.6$ | 0.739±0.027 | 0.550±0.021 | 58.52±1.400 | -0.834±0.031 | 0.318±0.015 |
| $n_k<0.8$ | 1.234±0.0330 | 0.456±0.015 | 25.100±0.560 | -0.368±0.030 | 1.325±0.0.025 |
| $n_k\geq0.8$ | 0.693±0.0.035 | 0.597±0.032 | 77.280±2.500 | -0.877±0.051 | 0.149±0.013 |
| $n_k<1$ | 1.134±0.025 | 0.475±0.015 | 31.090±0.580 | -0.453±0.014 | 0.758±0.021 |
| $n_k\geq1$ | 0.716±0.042 | 0.637±0.051 | 98.100±1.500 | -0.902±0.072 | -0.019±0.007 |

Table 3.

Dependence of the average characteristics of protons on the $n_k$ cumulative number (dTa-interactions)

| | $\overline{p_L}(GeV/C)$ | $\overline{p_\perp}(GeV/C)$ | $\overline{\theta_L^0}$ grad | $\overline{\cos\theta_{NN}^*}$ | $\overline{Y_L}$ |
|---|---|---|---|---|---|
| $n_k<0.3$ | 2.258±0.112 | 0.331±0.043 | 8.41±0.56 | 0.846±0.021 | 1.522±0.124 |
| $n_k\geq0.3$ | 0.698±0.017 | 0.400±0.012 | 51.35±0.81 | -0.798±0.041 | 0.388±0.012 |
| $n_k<0.6$ | 1.400±0.052 | 0.397±0.021 | 17.91±0.120 | -0.201±0.013 | 1.014±0.045 |
| $n_k\geq0.6$ | 0.550±0.020 | 0.396±0.013 | 60.891±1.10 | -0.906±0.023 | 0.235±0.019 |
| $n_k<0.8$ | 0.971±0.027 | 0.371±0.017 | 26.61±0.56 | -0.561±0.010 | 0.704±0.021 |
| $n_k\geq0.8$ | 0.513±0.021 | 0.434±0.020 | 81.85±1.97 | -0.927±0.032 | 0.081±0.007 |
| $n_k<1$ | 0.846±0.021 | 0.388±0.012 | 36.09±0.63 | -0.658±0.008 | 0.572±0.016 |
| $n_k\geq1$ | 0.510±0.321 | 0.434±0.025 | 108±2.5 | -0.950±0.049 | -0.105±0.013 |

It is seen that at $n_k\geq0.6$ the form of the momentum distribution changes considerably(fig.2). The production mechanisms also changes. The following growth of $n_k$ don't leads to the essentially change of average momentum - $\overline{P}_L$, but average emission angle $\overline{\theta}_L$ is considerable change (Table 1,2,3).

This is mentioned also in Ref [10].

When the value of the cumulative number decreases the average momentum of the produced proton increases and the average emission angle decreases. When the value of the cumulative number increases the average momentum of the produced proton decreases and $\overline{\theta}_L^0$ increases (Table 1,2,3).

The same tendency is observed for protons produced in HeTa and dTa-collisions (Table 2 and 3).

**It can be said that the** value $n_k\approx0.6$ is the threshold, where the regime of production changes and consequently the characteristics of produced particles considerably change. It can be explained

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as follows: at ≥0.6 the incoming nucleons interact with many nucleons (clusters, fluctons, multi quark states) on the target nucleus(fig.2)

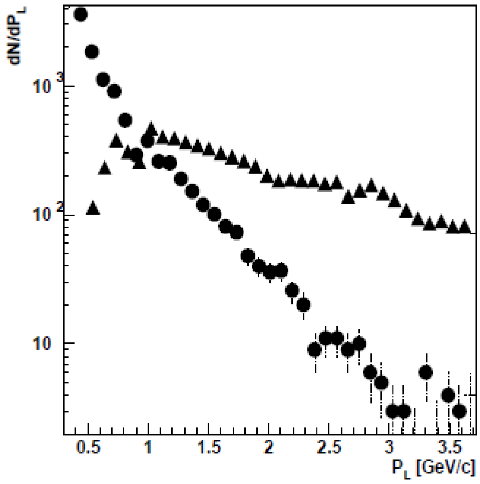


fig 2. Momentum distributions of protons produced in CTa-interactions; $n_k$≥0.6 (•) and $n_k$≤0.6 (▲)

It is know from experimental data that the growth of the number of produced particles the average value of the momentum $\overline{P}_L$ decreases and the emission angle increases. This effect is not observed in CTa-interactions for cumulative protons ($n_k$≥1). The growth of the number of cumulative protons from one to six does not cause the decrease of $\overline{P}_L$ and increase of $\overline{\theta}_L$. the weak increase of $\overline{P}_L$ and weak decrease of $\overline{\theta}_L$ take place. The statistics does not allow more strong conclusion. The average momentum changes from (0.524 ± 0.041)GeV/c (when the number of cumulative protons in the event $N_p(n_k \geq 1)=1$) to (0.621 ± 0.040)GeV/c (When $N_p(n_k \geq 1)=6$). This means that kinematical characteristics weakly depend on the number of cumulative protons $N_p$.

For the study of production mechanism in nucleus- nucleus interactions we compare characteristics of particles produced in $A_iA_t$ and NN-interactions. We also study the properties of backward moving particles ($\theta_L > 90^0$) in the laboratory frame and perform the model analysis.

It turned out that only 12% of the total number of protons moves backward in the laboratory frame. The average value of cumulative number is 1.32±0.03 and all protons are cumulative ($n_k$≥1). The average momentum of these protons is significantly smaller than the same average number for total statistics $\overline{P}_L(t)$.

The average value of the emission angle $\overline{\theta}_L$ is ~ 2.5 times bigger than the same number for total statistics. (Table 4.)

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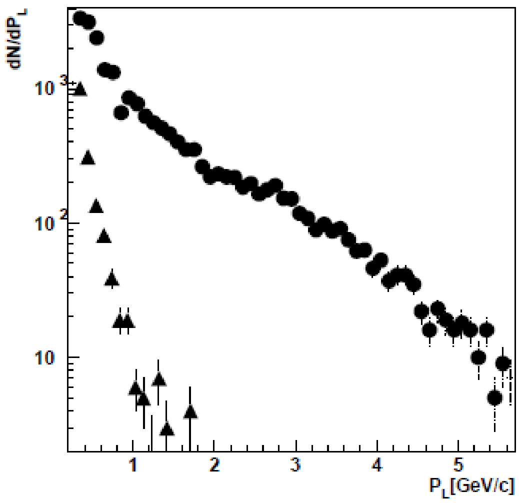


Fig. 3. The momentum distributions of produced protons in CTa-collisions. (•-p(t), ▲-p(b)).

The temperature of backward moving protons is significantly smaller than the inclusive temperature, $T_p^b(n_k \geq 1) = (73 \pm 1) Mev, \quad T_p(t) = (188 \pm 2) Mev.$ The temperature is extracted from the formula:

$$\frac{dN}{dp_\perp} = Ap_\perp (m_\perp T)^{1/2} \exp(-\frac{m_\perp}{T}) \qquad (2)$$

where, $p_\perp$ is the transverse momentum, $m_\perp = \sqrt{p_\perp^2 + m^2}$ , transverse mass, T-temperature.

Table 4.

Average characteristics of backward moving protons $p^b$ and inclusive protons p(t) in CTa-interactions

| $\overline{P_L^b}(GeV/C)$ | $\overline{P_\perp^b}(GeV/C)$ | $\overline{\theta_L^b} grad$ | $\overline{\cos\theta_{NN}^*}^b$ | $\overline{Y_L}^b$ |
|---|---|---|---|---|
| 0.440±0.015 | 0.366±0.013 | 119±2 | -0.975±0.026 | -0.192±0.008 |
| $\overline{P_L}(t) GeV/C)$ | $\overline{P_\perp}(t)(GeV/C)$ | $\overline{\theta_L^0}(t)$ | $\overline{\cos\theta_{NN}^*}(t)$ | $\overline{Y_L}(t)$ |
| 1.144±0.010 | 0.457±0.050 | 46.32±0.30 | -0.500±0.006 | 0.624±0.007 |

**<u>The dependence of characteristics of $\pi^-$ mesons on the cumulative number $n_k$</u>**

We have studied the dependence average characteristics of cumulative number $n_k$ of protons(Tables 1-3).

The same characteristics have been studied for $\pi^-$ -mesons. Their average momentum practically does not depend on $n_k$. The average emission angle $\overline{\theta}_L$ , and average rapidity $\overline{Y}_L$ -significantly depend on $n_k$. $\pi^-$ -mesons are mainly produced in target fragmentation region. DCM-Dubna cascade model satisfactory describes characteristics of $\pi^-$ -mesons for $n_k<0.3$; but deviate from the data on $\pi^-$ -mesons production on NN-interaction, for $n_k<0.3$.

Characteristics of $\pi^-$ -mesons produced in CTa-nucleus-nucleus interactions and characteristics of $\pi^-$ -mesons in NN-interactions considerably differ, for $n_k \geq 0.3$. This means that the role of nuclear medium in the formation of particle characteristics is significant (Table 5).

Table 5.

The dependence of average characteristics of $\pi^-$ -mesons on $n_k$ for $A_iA_t$ and NN-interactions and cascade model results for CTa-interactions

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| interactions | | $\overline{p_L}(GeV/C)$ | $\overline{p_\perp}(GeV/C)$ | $\overline{\theta_L^0}$ grad | $\overline{Y_L}$ | $\overline{\cos\theta_{NN}^*}$ |
|---|---|---|---|---|---|---|
| CTa | $n_c$<0.3 | 0.468±0.015 | 0.196±0.007 | 42±1.2 | 0.95±0.019 | -0.141±0.012 |
| | $n_c$≥0.3 | 0.434±0.010 | 0.344±0.025 | 104±2.5 | -0.172±0.016 | -0.802±0.010 |
| NN | $n_c$<0.3 | 0.610±0.010 | 0.223±0.002 | 32.49±0.57 | 1.25±0.01 | |
| | $n_c$≥0.3 | 0.370±0.010 | 0.310±0.010 | 93.48±1.75 | 0.99±0.02 | |
| DCM (CTa) | $n_c$<0.3 | 0.500 | 0.203 | 41.34 | 1.01 | |
| | $n_c$≥0.3 | 0.340 | 0.290 | 100.50 | -0.10 | |

Table 6

Average characteristics of $\pi^-$ -mesons in $A_iA_t$ and NN-interactions for backward moving $\pi^-$ -mesons $\pi^-$ (b) in the laboratory frame

| $A_iA_t$- interactions | | $\overline{p_L}(GeV/C)$ | $\overline{p_\perp}(GeV/C)$ | $\overline{\theta_L^0}$ grad | $\overline{Y_L}$ |
|---|---|---|---|---|---|
| CTa | $\pi^-$(t) | 0.458±0.01 | 0.212±0.006 | 50.80±0.65 | 0.809±0.01 |
| | $\pi^-$(b) | 0.189±0.014 | 0.157±0.016 | 120±3 | - 0.386±0.024 |
| HeTa | $\pi^-$(t) | 0.475±0.025 | 0.218±0.015 | 49.59±0.50 | 0.846±0.031 |
| | $\pi^-$(b) | 0.197±0.020 | 0.151±0.019 | 123±4 | -0.419±0.06 |
| dTa | $\pi^-$(t) | 0.438±0.020 | 0.214±0.017 | 51.21±1.1 | 0.800±0.04 |
| | $\pi^-$(b) | 0.177±0.035 | 0.144±0.030 | 122±4 | -0.403±0.04 |
| DCM(CTa) | $\pi^-$(t) | 0.470±0.01 | 0.225±0.004 | 51.59±0.6 | 0.79±0.02 |
| NN | $\pi^-$(t) | 0.571±0.004 | 0.238±0.001 | 41.96±1.15 | 1.062±0.007 |

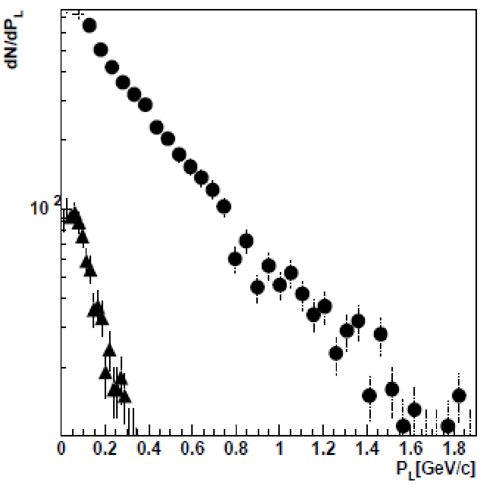


fig. 4. Momentum distributions of $\pi^-$ -mesons produced in CTa- interactions. (•-$\pi^-$ (t)-total statistics; ▲-$\pi^-$ (b)-backward mesons).

It is seen from the Table 6 that characteristics of $\pi^-$ -mesons in $A_iA_t$ and NN-interactions considerable differ, which is caused by the intranuclear rescatterings. The cascade model describes

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rather well experimental data. Backward moving $\pi^-$ -mesons in the laboratory frame have different characteristics as compared to ($\pi^-$ (t)- mesons. (Fig. 4).

The average value of the cumulative number for backward moving $\pi^-$ -mesons $\bar{n}_k(b) = 0.34 \pm 0.03$ is considerably different as compared to the same number for inclusive $\pi^-$ -mesons . $\bar{n}_k(t) = 0.16 \pm 0.02$. This means that in the production of $\pi^-$ (b)- mesons participate more nucleons than in the formation of $\pi^-$ (t)- mesons. Temperatures of $n^-$(b) and $\pi^-$ (t)- mesons also considerably differ: $T_n$(b)=(52±1)MeV, $T_n$(t)=(78±1)MeV.

# Conclusions

1. DCM- Dubna cascade model describes rather well average characteristics of $\pi^-$ (t)-mesons but deviates from the data for $\pi^-$ (b)-mesons. This is caused by the fact that $\pi^-$ (b)-mesons are produced in the target fragmentation region and the corresponding average cumulative numbers considerably differ: $\overline{n_k}(t) = 0.16 \pm 0.01, \quad \overline{n_k}(b) = 0.34 \pm 0.03$.
2. Kinematic characteristics of protons in the regions $n_k<0.3$ and $n_k \geq 0.3$ considerably differ, but when $n_k \geq 0.6$ momentum characteristics change very weak
3. The contribution real cumulative protons with $n_k(p) \geq 1$ to the total statistics approximately 18% and 60% of them are backward moving –jets in the laboratory frame.
4. There are practically no cumulative $\pi^-$ - mesons at our energy;
5. Backward moving protons and $\pi^-$ - mesons have average momenta smaller than inclusive protons and $\pi^-$ (t)- mesons and emission angles bigger than inclusive ones;
6. Average temperatures of $p^b$ and $\pi^b$ are considerably smaller than the inclusive temperatures:

$$\bar{T}(p^b) = 73 \pm 1)MeV, \qquad \bar{T}(\pi^b) = (52 \pm 1)MeV$$

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