AVERAGE MULTIPLICITY OF CHARGED SECONDARIES AS A FUNCTION OF THE NUMBER OF INTERACTING NUCLEONS IN THE COLLISIONS OF RELATIVISTIC NUCLEI IN THE ENERGY RANGE OF (0.250-200) AGEV

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Accepted for publication April, 2004

ABSTRACT. Average multiplicity of charged secondaries (produced in collisions of light and intermediate mass nuclei with intermediate and heavy mass nuclei, in the energy range of (0.250-200) AGeV) as a function of the number N_A of nucleons participating in the interactions, have been analysed.

It is shown that at low (≤0.400 AGeV) and at very high (200 AGeV) energies the deviation from the linear $< n (N_A) >$ -dependence is observed. An attempt is undertaken to explain the breakdown of linearity by the absorption (in heavy targets) and small cascade multiplication (at low energies); by the growth of the contribution of neutral particles to the total multiplicity and by the certain role of multiparticle (collective) proceses, which cause the neutralization of negative particles (at 200 AGeV).

INTRODUCTION

In references [1-7] the dependence of the average multiplicity <n> of charged secondaries produced in $A_i A_t$ -nucleus-nucleus interactions (A_i - atomic number of incoming nucleus, A_t - atomic number of the target) as functions of R, R_n b N_A (R, R_n and N_A are numbers of interacting protons, neutrons and nucleons) are studied. Quantities R, R_n and N_A are defined as follows [1,2,3].

$$R = (Z_i A_t^{2/3} + Z_t A_i^{2/3}) / (A_i^{1/3} + A_t^{1/3})^2 \quad (1)$$

Z_i (Z_t)- the charge of the incoming (target) nucleus.

$$R_n = (N_i A_t^{2/3} + N_t A_i^{2/3}) / (A_i^{1/3} + A_t^{1/3})^2 \quad (2)$$

N_i (N_t)- a number of neutrons in the incoming (target) nucleus

$$N_A = (A_i A_t^{2/3} + A_t A_i^{2/3}) / (A_i^{1/3} + A_t^{1/3})^2 \qquad (3)$$

Expression for R, R_n and N_A is derived assuming that the nucleons have sharp radii [1,3]. They are introduced in the framefork of the geometrical approach and can be interpreted as the maximal number of nucleons from both nuclei, which can participate in the collision, provided the total overlapping of colliding ions [6].

It is evident that in the reality a less than N_A nucleons are participating.

However one can assume that in central collisions the number of interacting nucleons is growing and approaches N_A. Note, that N_A does not depend on criteria of the event selection and in contrast to average number of NN - collisions is not connected with the uncertainity in choice of cross-section, i. e. it is exactly definite.

The analysis of data has shown, that at any energy and any A_i and A_t the dependence of average multiplicity on the number of protons <n(R)> is linear. The equality <n (R)> = R (according to refs [1, 2, 4, 7]) corresponds to the geometrical picture of the interaction, when the contribution to the multiplicity is given by protons only (one active proton gives one charged particle). Such a picture is realized in (p, He, Ne, Ar) (Ca, U) - collisions at the energy of 0.250 AGeV.

At the energy 0.400 AGeV a deviation from the geometrical picture is observed. At the energy 1.04 AGeV (and higher) a significant deviation from the geometrical picture is observed, but, the linearity of the <n (R)> - dependence is preserved (Fig.1a).

The question arises: whether or not the linearity is preserved in <n(R_n)> and <n(N_A)> dependences and what causes the breakdown of linearity.

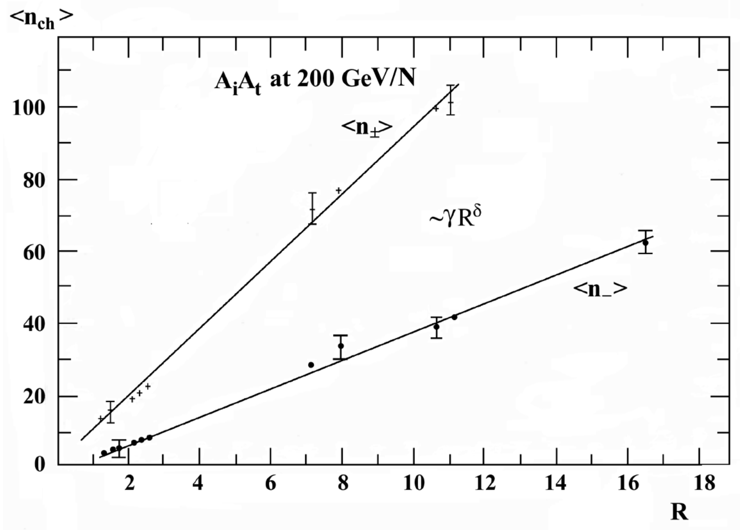

Fig.1a

Fig.1. $<n_{ch}>$ average hadrons multiplicity as a function of the number of interacting protons R, neutrons R_n and N_A – nucleons, for $A_i A_t$ -collisions at 200 AGeV.

„•" - negative hadrons for p(Mg,S,Ar,Ag,Xe,Au), O(Cu,Au), S(S,Cu,Pb) collisions.

„+"- total charged hadrons multiplicity for p(Mg,Ar,Ag,Xe,Au), O(Cu,Au), S(S,Cu)- collisions.

1a. $<n_{\pm}(R)>$ - dependence for all charged secondary hadrons, $<n\_(R)>$ - dependence for negatively charged secondary hadrons.

1b. The same as on Fig.1a, but only for R_n - the number of neutrons.

1c. The same as on Fig.1b, but only for N_A - the number of nuclons

ANALYSIS OF EXPERIMENTAL DATA ON $<N_I(R)>$,

$<N_I(R_N)>$ AND $<N_I(N_A)>$ - DEPENDENCES AT 200 AGEV

In the present article the $<n_i(R)>$, $<n_i(R_n)>$ and $<n_i(N_A)>$ - dependences in p(Mg, S, Ar, Ag, Xe, Au), O(Cu, Au), S(S, Cu, Pb) - interactions at 200 AGeV [8, 9, 10] are analysed. Data at other energies [1-7], are used for comparison. $<(n_i)>$ - is the average multiplicity of charged hadrons; „i" = **„**±" - all charged hadrons; „i" = **„-"** negatively charged hadrons.

$<n_i(R)>$, $<n_i(R_n)>$ b $< n_i(N_A)$ - dependences for $A_i A_t$- collisions are approximated by the formula

$$< n_i >= \gamma R^{\delta} \qquad (R = R, Rn , N_A). \qquad (4)$$

Results of the approximation are presented in Figs. 1a, 1b, 1c. <n (R)> - dependence for p(Mg, S, Ar, Ag, Xe, Au), O(Cu, Au) and S(S, Cu, Pb) - interactions is linear for both $<n_\pm>$ ($\delta = 0.98 \pm 0.01$; $\gamma = 9.59 \pm 0.01$) and $<n_->$ ($\delta = 1.02 \pm 0.01$; $\gamma = 3.18 \pm 0.08$). However, the dependence $<n_i(R_n)>$ is clearly nonlinear ($\delta = 0.80 \pm 0.01$; $\gamma = 12.10 \pm 0.21$ for $<n_\pm>$; and $\delta = 0.86 \pm 0.01$; $\gamma = 4.02 \pm 0.07$ for $<n_->$).

The $<n(N_A)>$ dependence is also nonlinear ($\delta = 0.89 \pm 0.02$; $\gamma = 5.83 \pm 0.18$ for $<n_\pm>$. $\delta = 0.93 \pm 0.01$; $\gamma = 1.91 \pm 0.07$ for $<n_->$).

Note, that for $<n(N_A)>$ - dependence the deviation from linearity is not so strongly pronounced. It is natural, because the deviation from linearity in $<n(N_A)>$ - is caused by R_n only.

At the energies of 1.04 AGeV and 2.1 AGeV the dependences $<n(N_A)>$ and $<n(R_n)>$ are linear. But at lower energies (namely at 0.400 AGeV) the $<n(N_A)>$ -dependence is nonlinear (Fig.2). This is caused by the nonlinearity of $<n(R_n)>$ -dependence. Note that deviation from linearity is observed, starting from $N_A > 20$.

Thus, in $A_i A_t$ - collisions the $<n(N_A)>$ - dependence is nonlinear at 0.400 AGeV and 200 AGeV.

For the analysis of the situation at 0.400 AGeV and 200 AGeV consider first the $<n(N_A)>$ dependence for $A_i C$ and $A_i Ta$ collisions at 2.48 AGeV and 4.30 AGeV (Fig.3). As is shown the slope of $<n(N_A)>$ - dependence is increased with energy and at fixed energy (at 2.3 AGeV) the slope of curve is increased more in $A_i C \equiv$ (p, d, He, C)

C -collisions than in A_iTa ≡ (p, d, He, C)Ta -collisions. So, for light target the avarage multiplicity <n> is growing faster than for heavy target [7].

In Refs. [2,7] such a picture is realized for <n(R)> dependence. The difference in slopes is explained by the absorption in heavy target (especially at low energy) which plays more significant role in heavy

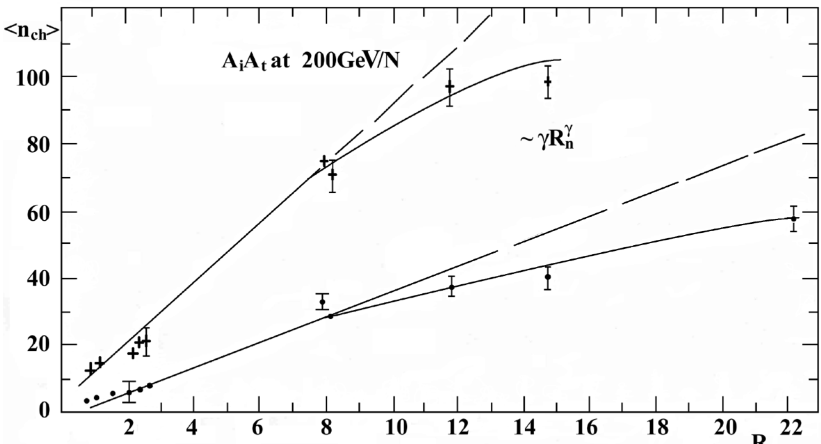

Fig.1b

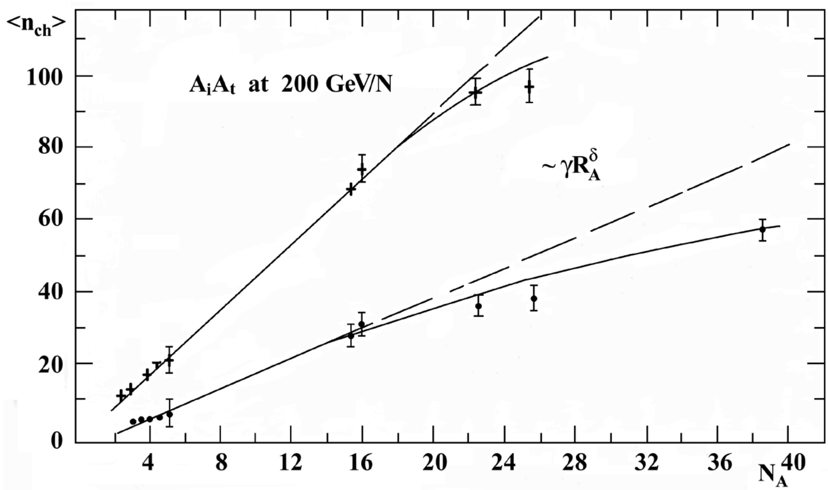

Fig.1c

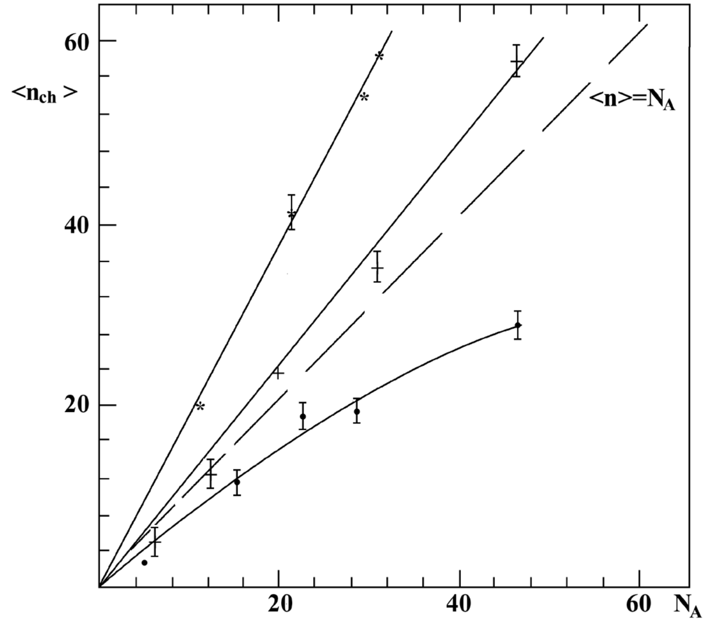

Fig.2. $<n_{\pm}(N_A)>$ - dependence for $A_i A_t$ - collisions at 0.400; 1.040 and 2.100 AGeV

„•" - (He, Ne)Al, Ne(Ag, Au), ArU at 0.400 AGeV

„+" -(p, He, Ne, Ar)U, ArCa - at 1.040 AGeV

„*" - Ne(Al,Ag, Au,U) - at 2.100 AGeV

$<n_{\pm}(N_A)> = N_A$ geometrical picture of interaction

target, than in the light one. Obviously, the similar explanation is valid for $<n(N_A)>$ - dependences, which are considered here.

Return now to the Fig.2. The decrease of the slope of $<n(N_A)>$ - dependence at 1.04 AGeV as compared to 2.1 AGeV is obviously caused by the decrease of intranuclear cascading and by the growth of the absorption effect. It is evident that at 0.400 AGeV cascading process is decreased (especially for heavy target). This leads to the fact, that the slope of the $<n(N_A)>$ -dependence at 0.400 AGeV is even smaller than at 1.04 AGeV and 2.10 AGeV. For large N_A ($N_A >$ 20) the linear dependence is broken.

Consider now A_iA_t -collisions at 200 AGeV. Introduce the quantity

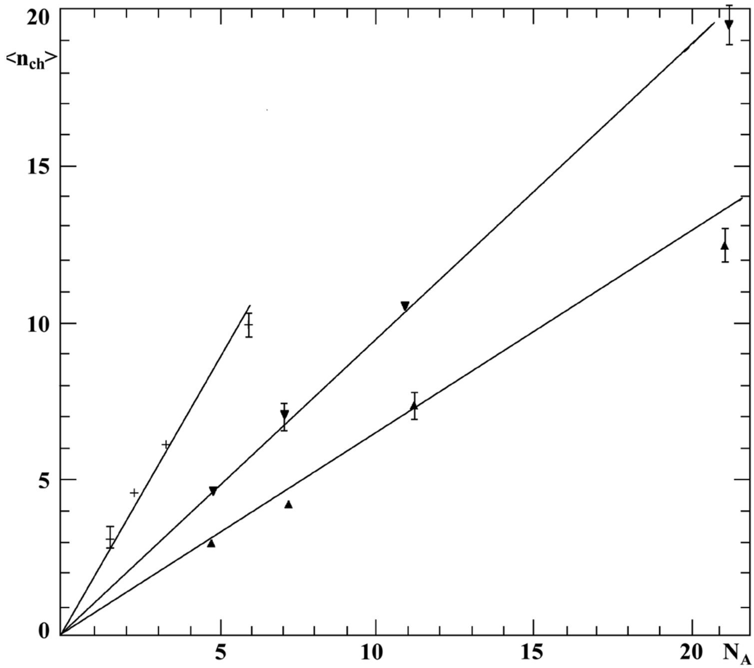

Fig.3. $\langle n_{\pm}(N_A) \rangle$ - dependence for **A_iC A_iTa** -collisions at 2.48 AGeV
(A_iC – "+", A_iTa -„▲"); and for A_iTa - collisions at 4.30 AGeV „▼"

$$L A_i A_t) = L^i(A_i A_t) = \langle n_i \rangle_{A_i A_t} / N_A , \qquad (5)$$

where $L(A_i , A_t)$ - is the average number of the charged secondaries, corresponding to one (active) nucleon.

Consider the $L(A_iA_t)$ - dependence on N_A at 200 AGeV (Fig.4, Table 1). It is seen that $L(A_i A_t)$ decreases with increasing N_A.

This decrease is more pronounced for negative hadrons (in pA_t -collisions).

If we consider the same dependences for (p, d, He, C)Ta and (p, d, He, C, F, Mg)C -collisions at 2.48 AGeV and 4.30 AGeV a different picture arises (Fig.5).

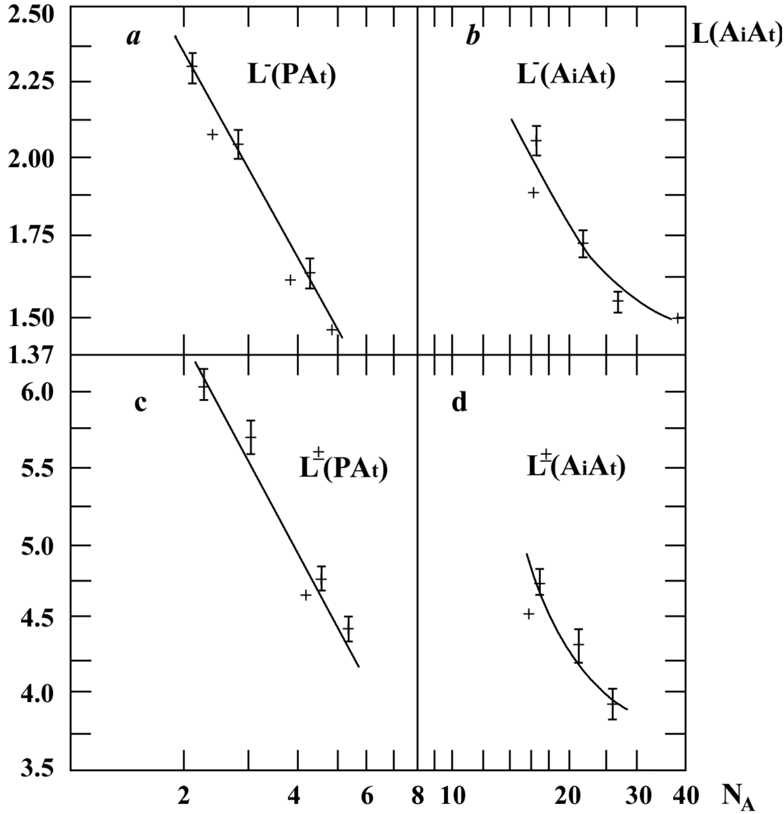

Fig.4. L $(A_i A_t) = f(N_A)$ **-** dependence for at 200 AGeV.
L $(A_i A_t) = \langle n \rangle_{Ai\,At} / N_A$ average number of particles corresponding to one active nucleon

4a. $L^-(P, A_t) = f(N_A)$ for negatively charged hadrons from p(Mg, S, Ar, Ag, Xe, Au) -collisions

4b. $L^-(A_i, A_t) = f(N_A)$ for negatively charged hadrons from S(S, Cu, Pb), O(Cu, Au) -collisions

4c. $L^{\pm}(P, A_t) = f(N_A)$ for all charged hadrons from p(Mg, Ar, Ag, Xe, Au) -collisions

4d. $L^{\pm}(A_i, A_t) = f(N_A)$ for all charged hadrons from S(S, Cu), O(Cu, Au) - collisions.

Table 1.

The dependence of the ratio L (A_i, A_t) on N_A (see formula (5)). The dependence of the normalized average multiplicity of negative hadrons $r^-(i,t) = \langle n_- \rangle_{A_i A_t} / \langle n_- \rangle_{pN}$ on N_A (see formula (6))

N	$A_i A_t$	$\langle n_\pm \rangle$	$\langle n_- \rangle$	$L^\pm(A_i A_t)$	$L^-(A_i A_t)$	$r^-(i,t)$	N_A
1	PMg	13.1±0.9	4.9±0.4	6.12	2.29	1.61	2.14
2	PS		5.0±0.25	5.99	2.07	1.64	2.42
3	PAr	14.98±0.3	5.39±0.20	5.65	2.04	1.77	2.65
4	PAg	18.1±0.7	6.20±0.3	4.59	1.57	2.04	3.94
5	PXe	20.67±0.8	6.84±0.31	4.86	1.61	2.25	4.24
6	PAu	21.6±1.2	7.00±0.4	4.34	1.40	2.30	4.98
7	OCu	70±3	29.5±1.4	4.49	1.89	9.70	15.57
8	SS	75±5	33±1.9	4.69	2.06	10.85	16
9	SCu	97±5	38.6±2	4.32	1.72	12.70	22.45
10	OAu	98±6	39.4±1.4	3.80	1.53	12.96	25.78
11	SPb		57.01±1.8		1.46	18.75	38.84

$L^\pm$ (A_i, A_t) practically does not depend on N_A; $L^-(A_i, A_t)$ is slightly increasing with increasing N_A, especially for heavy target Ta.

The fact that L^- (A_i, A_t) at 4.30 AGeV is significantly larger than at 2.48 AGeV is explained by small cascading at 2.48 AGeV [5,6].

For the analysis a A_iTa and A_i C -collisions at 2.48 AGeV and 4.30 AGeV in ref. [5] the dependence of the normalized average multiplicity of the negative hadrons

$$r^-(i,t) = \langle n_- \rangle_{A_i A_t} / \langle n_- \rangle_{pN} \qquad (6)$$

on the average number of nucleon-nucleon collisions $< \nu_{it} >$ is considered. The quantity $r^{-}(i, t)$ can be called the multiplication coefficient of particles in the nucleus.

We consider here the dependence $r^{-}(i, t)$ on N_A, because $N_A \sim < \nu_{it} >$ [2].

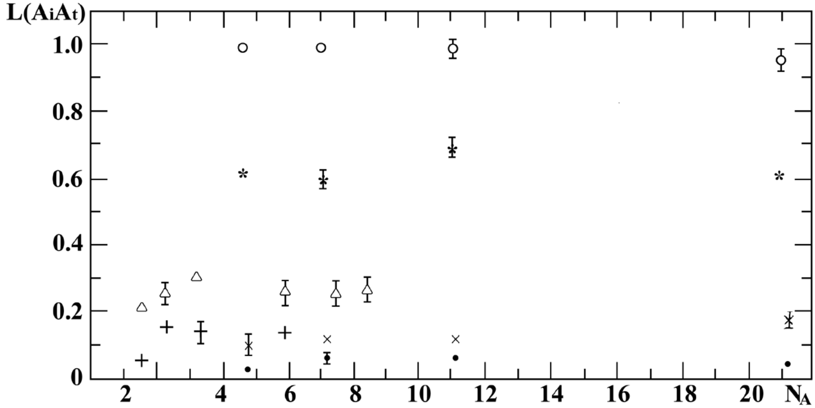

Fig.5. $L(A_i,A_t) = f(N_A)$ dependence at 2.48 and 4.30 AGeV
$L(A_i,A_t) = <n>_{Ai\,At} / N_A$
A_iTa („•”) and A_iC(„+”) - collisions at 2.48 AGeV
(for negatively charged particles)
A_iTa („X”) and A_iC **(„ ┌ ”) -** collisions at 4.30 AGeV
(for negatively charged hadrons)
A_iTa („*”) at 2.48 AGeV; A_iTa(„o”) at 4.30 AGeV
(for all secondary charged hadrons)

Consider in detail the dependence of $r^{-}(i, t)$ on N_A, at 200 AGeV, in the interval from pMg to SPb - collisions.

Let us devide this interval into two parts:

I - (pMg – OCu) and II - (OCu – SPb).

In the first interval the growth ΔN_A of the quantity N_A is 13.48; but the growth of the quantity $r^{-}(i, t)$, $\Delta r^{-}(i, t) = 8.09$ (Table 1).

It can be said that the slope of the dependence $r^{-}(i, t) = f(N_A)$ in the first interval is characterized by the quantity

$$\alpha_1 = \Delta r^-(i, t) / \Delta N_A = 0.60 \qquad (7)$$

and in the second interval by the quantity

$$\alpha_{11} = 0.39. \qquad (8)$$

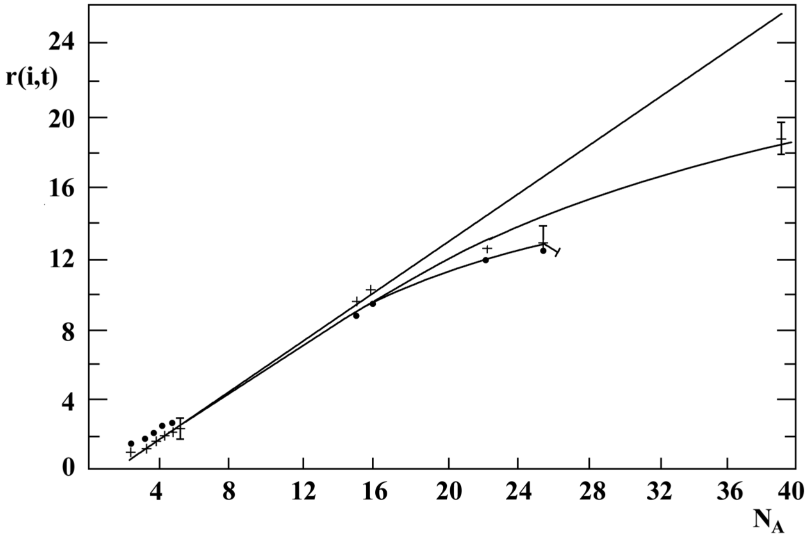

Fig.6. r (i , t) = f(N_A) – dependence. $r^-(i, t) = \langle n_-\rangle_{AiAt} / \langle n_-\rangle_{pN}$ „•" - for all secondary charged hadrons. „+" - for all negative charged hadrons for negative charged hadrons we have 11 points, at 200 AGeV p(Mg, S, Ar, Ag, Xe, Au), S(S, Cu, Pb), O(Cu, Au)) collisions. For $n_\pm$ we have 9 points) – there are does not exist data for SPb and PS collisions.

Comparing these two quantities, one can say that violation of the linear dependence $r^-(i, t) = f(N_A)$ (Fig. 6) takes place. In the same figure the dependence of $r^\pm(i, t)$ on N_A is presesnted. The deviation from the linearity takes place, but the effect is less pronounced, since the interval of variation of N_A is narrower (maximal value of $N_A \approx 26$ (OAu-collision).

Note, that the deviation from linearity (as, for $\langle n_i(N_A)\rangle$ dependence) starts at $N_A>20$ (Figs.1-c, 2).

The deviation from linearity in the r (i, t) = f(N_A) or in <n_i (N_A)> dependences in A_i,A_t - collisions at 200 AGeV, can be caused by the increase of the role of neutral particles to the total cross-section. Experiments show, that in pp-collisions the cross-section of the producton of the neutral particles increases with increase of energy and at 200 AGeV accounts 30% of the total inelastic cross-section. On the other hand the increase of the role of the neutral particles in the total cross-section leads to the decrease of the charged particles production and this can be the reason of the violation of the linearity in the <n_i(N_A)> - dependence.

At low energy (0.400 AGeV) the violation of linearity is explained by the absorption (especially in the heavy target) and small cascading. At 200 AGeV the deviation from linearity is caused may be by the increase of the role of neutral particles to the total charged multiplicity.

The certain role is played also by the collective effects. The reflect of this is that the deviation from linearity (at both energies) starts at $N_A \geq 20$.

The authors express their deep gratitude to D. Chokheli, D.Khubua and Z. Metreveli for helpfull discussions.

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