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Множественность π^--мезонов во взаимодействиях α-частиц с импульсом 18 ГэВ/с с ядрами Li, C, Ne, Al, Cu и Pb

В статье представлены распределения по множественности π^--мезонов из взаимодействий α-частиц 18 ГэВ/с с ядрами ^{6}Li, C, Ne, Al, Cu и Pb полученные с использованием 2-метровой стримерной камеры /СКМ-200/. Проведено сравнение этих распределений с данными из взаимодействий элементарных частиц. А-зависимость средней множественности сравнивается с предсказаниями некоторых теоретических моделей.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Aksinenko V.D. et al. E1 - 12472

Multiplicity of π^--Mesons in the Interactions of 18 GeV/c α-Particles with Li, C, Ne, Al, Cu and Pb Nuclei

Multiplicity distributions of π^--mesons from the interactions of 18 GeV/c α-particles with ^{6}Li, C, Ne, Al, Cu, and Pb nuclei have been obtained with the use of a 2m streamer chamber (SKM-200). The distributions are compared with those from elementary particle interactions, and the A-dependence of the average multiplicity is discussed in terms of several theoretical models.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1979

1. INTRODUCTION

There are now several theoretical models which describe multiparticle production in the nucleus-nucleus interaction at relativistic energies (e.g., refs. [1-5]). Various experimental techniques have been used to obtain data on the multiplicity distribution and A-dependence of the average multiplicities of secondary particles (e.g., refs. [6-8]). In the present experiment multiplicities of π^- secondaries from several pure nuclear targets have been obtained in the same experimental conditions. The data come from an experiment with a streamer chamber (SKM-200) exposed to an ion beam extracted from the Dubna synchrophasotron, with targets mounted inside the chamber volume. Preliminary results were presented at the Budapest Conference [9] (see also refs. [10, 11]).

2. EXPERIMENTAL SETUP

The setup used in the experiment is described in ref. [12]. The 2m streamer chamber (60x100x200 cm ^{3}), used as a detector, was filled with pure neon at atmospheric pressure and placed in a magnetic field of about 0.8 T.

The targets made in the form of thin discs were mounted inside the fiducial volume of the chamber at a distance of 60 cm from its front wall. The target thicknesses were as follows: Li - 1.59 G/cm^2, C - 0.40 g/cm^2 , Al - 0.41 g/cm^2, Cu - 0.47 g/cm^2,Pb - 0.23 g/cm^2. The gas (neon) filling the chamber also served as a target. This arrangement made it possible to detect secondary particles in a 4π-geometry. The chamber was triggered whenever a primary particle had interacted with a target nucleus. The triggering system [13] consisted of two sets of scintillation counters mounted upstream and downstream the chamber. The counters upstream the chamber defined the beam particle, while those downstream as a veto-counter system (VC-system). The solid angle acceptance of the VC-system ranged from 0.18 to

0.55 msr for different exposures. Both counter systems measured the energy loss, dE/dx, thus selecting particles with charge $Z=2$. Most of the ^4He fragmentation products did not hit the VC-system due to their angular distribution and their deflection in the magnetic field. A small fraction of the projectile fragments could, however, hit the VC-system and thus simulate primaries which had not undergone an interaction. This "trigger bias" (discussed in more detail in section 3) was caused by the ^3He fragmentation products registered by the VC-system due to their charge $Z=2$, or, in the case of $^{1,2,3}H$ fragments, due to some fluctuation in their energy loss rate or to their interactions in a scintillator.

Three photographs in the Pb target experiment and two photographs in experiments with other targets were taken for every event with a stereophoto system placed above the chamber.

3. EXPERIMENTAL UNCERTAINTIES AND CORRECTIONS

The films were scanned twice and any ambiguities and discrepancies between the scanning results were subsequently solved by a third scan. Although all charged secondaries were registered in the scanning, a further analysis was confined to negative particles, most of which were π^- mesons. The sample of negative secondaries had the advantage of being free from a contamination with target and projectile fragments and, furthermore, was less contaminated with products of secondary interactions within the target. The multiplicity distributions for negative secondaries require, however, some corrections to be applied. We have analyzed the following possible sources of differences between "true" and "registered" multiplicity values:

1. The contamination of the sample of negative secondaries with an admixture of electrons from γ-quanta conversion and from Dalitz pairs ($\pi^0 \to 2\gamma$ or $\pi^0 \to \gamma + e^+ + e^-$ decays).

2. The secondary interactions in the target.

3. The target bias.

4. The ambiguities in the determination of the number of negative particles.

Let us consider the corrections in detail.

ad. 1. We estimate that about 65% of electrons have been identified in the course of the scanning, the identification being based on a rough estimate of the track curvature in the magnetic field versus its range and/or ionization. The remaining fraction of electrons was corrected for. The calculated correction factors, based on various assumptions about the correlations between π^0 and π^- multiplicity distributions (fulfilling the relation $\langle n_{\pi^-} \rangle = \langle n_{\pi^0} \rangle$ for average values), turned out to differ insignificantly. The correction factors are, of course, most important for targets with a large Z (Cu and Pb).

ad. 2. The corrections due to the secondary interactions within a solid target turned out to be significant only for the Li target which was much thicker than the other targets. The secondary interactions of relativistic ^4He fragmentation products in the target made a major contribution to these correction factors.

ad. 3. As mentioned above, the necessity of the correction, connected with the trigger, arises whenever ^4He fragments ^1H, ^2H, ^3H and ^3He hitting the VC-system, simulate non-interacting beam particles. In order to introduce corresponding corrections, one should know: a) the multiplicity distribution of π^- mesons in the ^4He interactions for different fragmentation channels and b) the probability of triggering the VC-system by the ^4He relativistic fragmentation products. The information on the π^- multiplicity distribution in the ^4He fragmentation channels was obtained from the momentum measurements which made it possible to distinguish among ^1H, ^2H, ^3H, ^3He. The probability of triggering the VC-system by the ^4He fragments was estimated from the counter geometrical parameters and fragment angular distributions determined by the measurements. An additional check was performed with the use of the result of the scanning and measurements of a sample of 500 interactions of the ^4He ions with a Li-target, registered in an exposure during which the VC-system was off but the triggering of the beam particles was on. The correction for one-prong events (e.g., $^3He + n$), practically undistinguishable in the scanning from noninteracting primaries, was also derived from measurements. According to a rough estimate based on our data and on the results of ref. /6/, the events with an almost unchanged momentum and direction of an incident ^4He did not exceed 2% of all ^4He inelastic interactions.

ad. 4. Another source of errors which had to be considered was the presence of flares and sparks accompanying, in some cases, steep tracks and the tracks of δ-electrons. Such cases were registered in the course of scanning, and their frequency allowed us to conclude that their influence on the multiplicity distributions was negligible.

As for the detection of low energy negative pions, our rough estimate showed that in the ^4He interactions, pions were registered with practically no bias when their momenta $p \gtrsim 60$ MeV/c (12 MeV kinetic energy) for the Li target and when $p \gtrsim 40$ MeV/c (5.6 MeV energy) for other targets. Pions with lower momenta were also registered, however, their detection efficiency depended on their path length in the target. The pions, produced in the interaction with the neon target, were observed if their momenta exceeded ~ 20 MeV/c (1.4 MeV energy). Thus, the loss of low energy negative pions in our experiment seems to be insignificant.

A quantitative analysis of the above corrections leads to a conclusion that, except for ^6Li, they are, as a rule, comparable to statistical errors in this experiment (see Table 1).

4. DATA NORMALIZATION

Whereas in the case of the elementary particle interaction the concept of an inelastic cross section has quite a definite sense, the following definitions of cross sections can be used to describe the nucleus-nucleus interaction: σ^{prod} which is the cross section for new particle production (mainly charged and neutral π-mesons); σ^{reac} which includes σ^{prod} and the cross section for the quasi-elastic breakup of at least one of the nuclei. With track detectors, the cross section measured is close to that defined above as σ^{reac}. In order to obtain the multiplicity distributions of π^--mesons it would be natural, in our opinion, to normalize them to σ^{prod}, treating this value as an analogue of the total inelastic cross section for elementary interactions. Since σ^{prod} cannot be determined experimentally, we have calculated the $\sigma^{prod}/\sigma^{reac}$ ratio theoretically. Using a simple "soft sphere" model /14/ which gives satisfactory predictions for absolute values of the cross sections in case of the nucleus-nucleus interactions /15/, we have obtained the following values of $\sigma^{prod}/\sigma^{reac}$ in αA-reactions for Li, C, Ne, Al, Cu and Pb nuclei, respectively: 0.83, 0.88, 0.88, 0.89, 0.93 and 0.95. This

Table 1

n	LITHIUM observed	LITHIUM corrected	CARBON observed	CARBON corrected	NEON observed	NEON corrected
0	1669	2009 ±171	383	438 ±36	333	338 ±22
1	1541	1676 ±105	410	432 ±30	343	343 ±19
2	601	613 ± 39	203	210 ±16	204	204 ±14
3	166	151 ±18	79	80 ±10	64	64 ± 8
4	41	32 ± 7	19	18.5±5	33	33± 6
5	6	$1.9^{+2.9}_{-1.9}$	5	4.9±2.2	9	9± 3
6	2	$1.3^{+1.4}_{-1.3}$			2	2±1.4
Total number of interactions	4026		1099		988	

n	ALUMINIUM observed	ALUMINIUM corrected	COPPER observed	COPPER corrected	LEAD observed	LEAD corrected
0	361	412 ± 37	189	219 ± 25	220	242 ± 20
1	426	450 ± 30	234	250 ± 20	261	265 ± 17
2	243	252 ± 18	178	185 ± 14	236	238 ±15
3	126	127 ± 12	119	120 ±11	184	184 ±14
4	61	60 ± 8	55	52 ± 9	80	74 ±11
5	17	15.6± 5	22	19.6± 5	47	46 ± 7
6	3	2.5± 1.8	3	2.4±1.9	15	12.1± 4.8
7	1	1 ± 1	4	3.3±2.2	5	4.3±2.3
8	1	1 ± 1				
Total number of interactions	1239		804		1048	

enables us to normalize our data, although not in a model-independent way, to σ^{prod} .

For model-independent comparison of the obtained multiplicity distributions of negative particles with those from elementary particle interactions, we have used the normalization to the cross section for the production of at least one negative particle (σ^{neg}).

Of course, the probability of inelastic interactions without the production of negative particles is not used in this comparison.

5. MULTIPLICITY DISTRIBUTIONS

Table 1 presents the values of the multiplicities of the negative particles obtained directly from the scanning as well as those after corrections for the effects discussed in section 3.

It is interesting to compare the multiplicity distributions in the nucleus-nucleus interactions with those in the "elementary" hadron-hadron interactions. Figure 1 shows the integral multiplicity distributions of the negative particles in the pp -interactions and our data normalized to σ^{prod}. The pp data obtained at incident proton momenta of 6.6 - 405 GeV/c [16] have been recalculated according to the charge conservation law $P_{n_-} = P_{n_{ch}}$, where $n_- \equiv n = \frac{n_{ch} - 2}{2}$. The multiplicity distributions of the negative particles (P_n) in the nucleus-nucleus interactions seem to be similar to those from the pp interactions.

A model-independent comparison (normalization to σ^{neg}) of our distributions with those from "elementary" interactions is shown in Fig. 2a,b. These figures also show the multiplicity distributions in the π^+p, K^+p , pNe , and π^+Ne interactions [16] normalized to σ^{neg} in the interval of average multiplicities from 1.2 to 2.6.

For comparison of the data for the "elementary" interaction with our results, only the distributions for interactions of positive primaries have been used, as in this case the distributions of secondary negative particles cannot contain primaries.

Figure 3 shows a similarity of the distributions in terms of the dispersion dependence on the average value (with both normalizations, namely based on σ^{prod} and σ^{neg}).

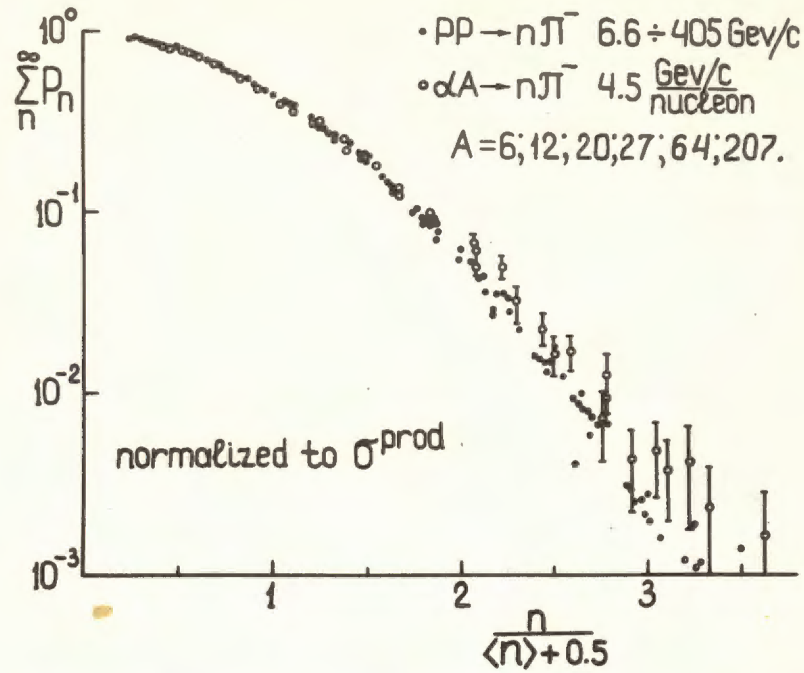
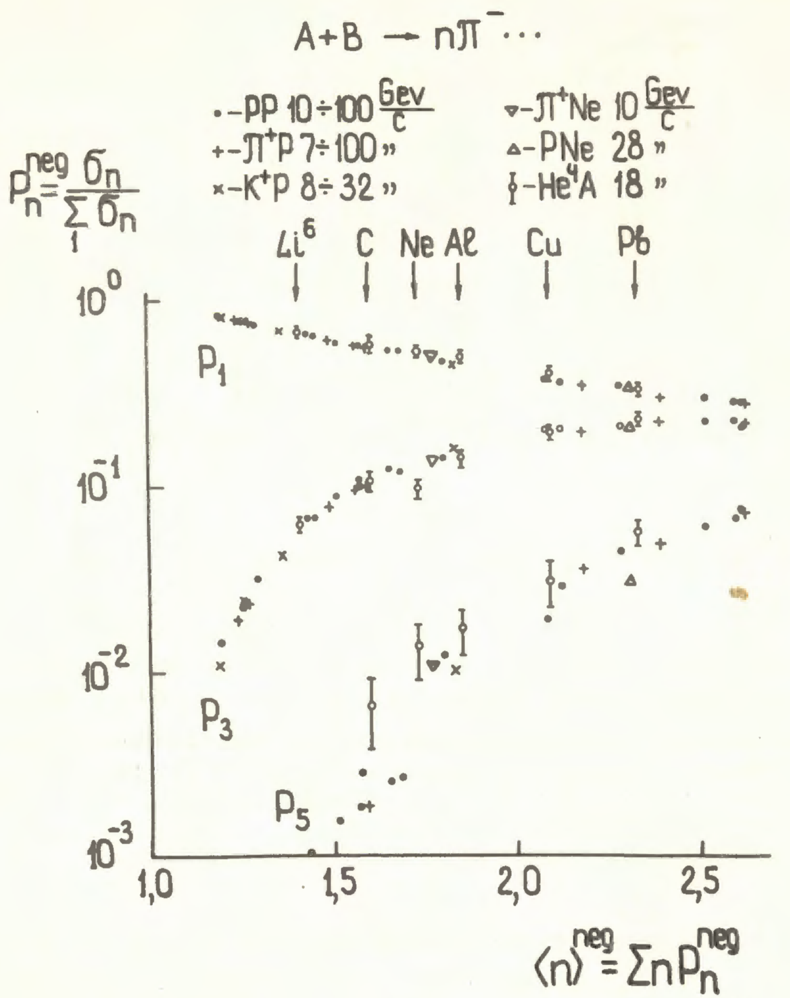


Fig. 1. The integral probability $\sum_{k=n}^{\infty} P_k$ versus $n/(\langle n\rangle + 0.5)$ for the multiplicity distributions of negative particles in the αA interactions at 18 GeV/c and in the pp interactions at 6.6 - 405 GeV/c. In the denominator, 0.5 has been added to $\langle n\rangle$ for convenience only.

6. A-DEPENDENCE OF THE AVERAGE MULTIPLICITY

Our data are not consistent with the often used formula $\langle n\rangle = cA^{\alpha}$. However, if our extreme points (^{6}Li and Pb targets) were to be used to estimate the slope parameter, then α is 0.24 if normalized to σ^{reac} and 0.20 if normalized to σ^{prod} This value is still larger than those commonly obtained in the pA and πA interactions: $\alpha = 0.15 \div 0.19$ [17].

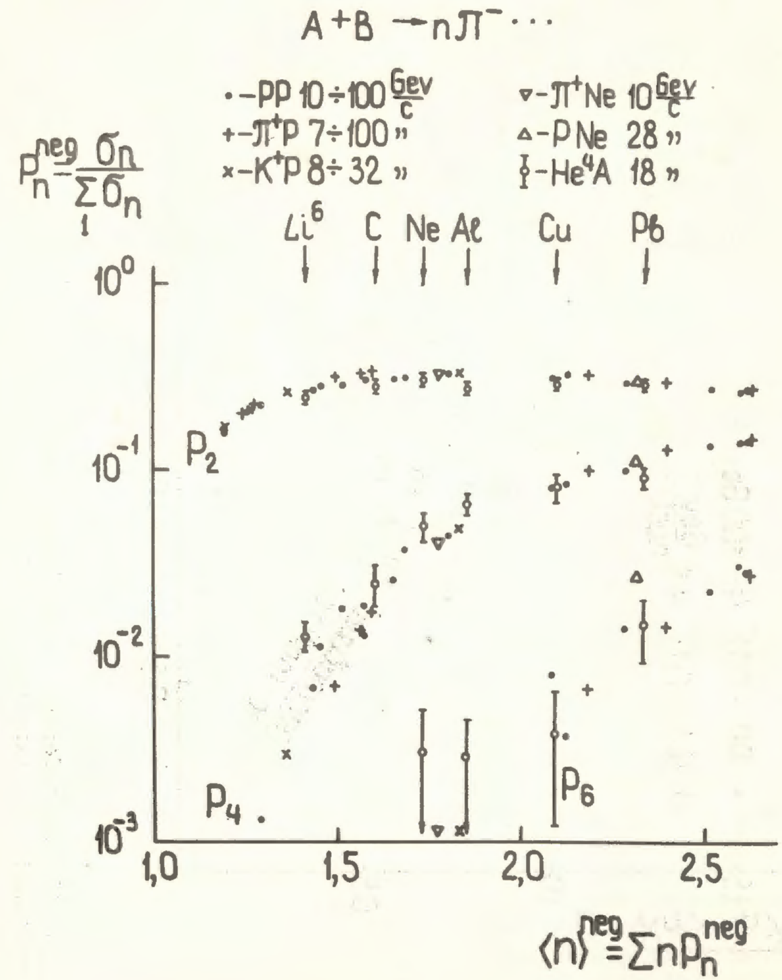
Figure 4 presents our data on the average multiplicity of negative particles normalized to σ^{prod} together with rough estimates based on some models. The curves based on the predictions of hydrodynamical model [1], "wounded nuc-



a/

Fig.2 . The plot of the partial probabilities P_n^{neg} normalized to σ^{neg} versus $\langle n^{neg}\rangle = \sum_{n=1} n\times P^{neg}$. Our results as well as the multiplicity distributions obtained in several other experiments [17] are presented.

leon" model [2] and collective statistical model [3] have been calculated with the formulae of references [1,2,3] and the experimental data on the average π^--multiplicities in the np -interactions [18] at energies close to ours.



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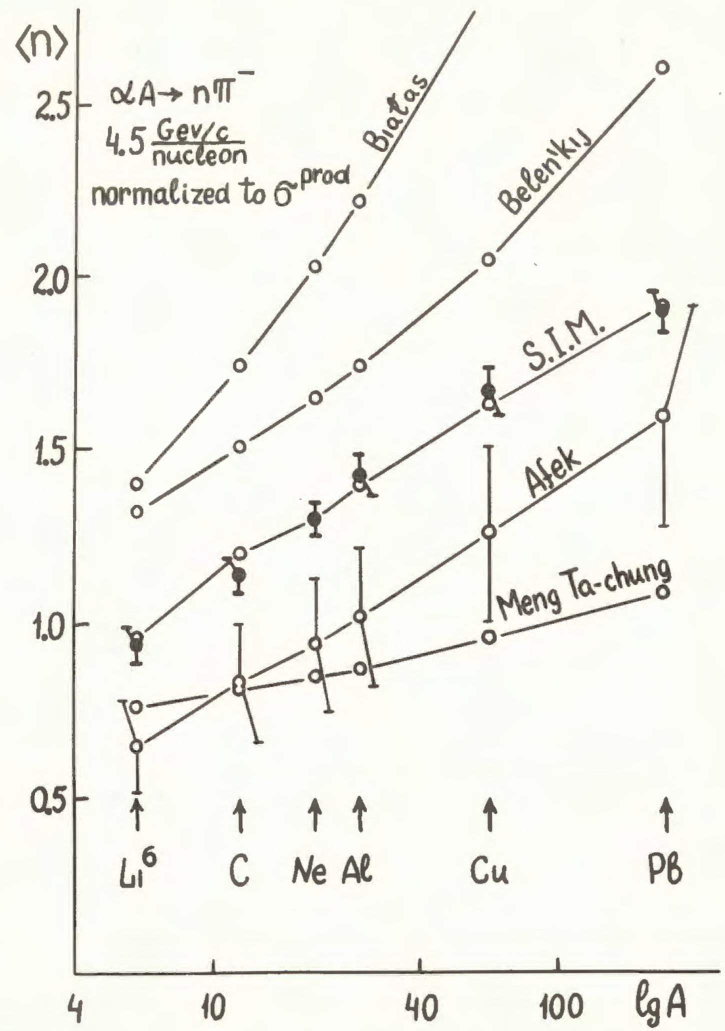

Fig. 4. The A-dependence of the average multiplicity of negative particles in the αA interactions and its comparison with the rough estimates based on some theoretical models.

assumptions, where $\langle n(np)\rangle$ is the average π^--production multiplicity in the np-interactions. The results of the calculation are presented in Fig. 4. They show a rather good agreement between the SIM predictions and the experimental data. It should also be noted that not only the average values but also the π^--multiplicity distributions, obtained within the framework of SIM, agree with the experiment.

The comparison of the experimental data with the rough estimates based on the above models shows that, whereas the characteristics of the A-dependence for several models (hydrodynamical model, CTM, SIM) are similar to those obtained experimentally, the absolute multiplicities in the CTM and hydrodynamical model differ from the experimental results. On the other hand, the consistency with our data of the predictions of a simple model of independent interactions suggests that perhaps such models, account for the interactions of α-particles with nuclei, at least at the energies about 5 GeV per nucleon.

7. CONCLUSIONS

The multiplicity distributions of negative particles in the interactions of 18 GeV/c α-particles with pure nuclear targets have been presented in Table 1.

In our energy range, these distributions, shown in Figs. 1-3, have a similar appearance as those observed in the hadron-hadron and hadron-nucleus interactions.

The dependence of the average multiplicity on the mass number, A, of a target nucleus obtained in this experiment is given in fig. 4, together with the predictions derived from several theoretical models.

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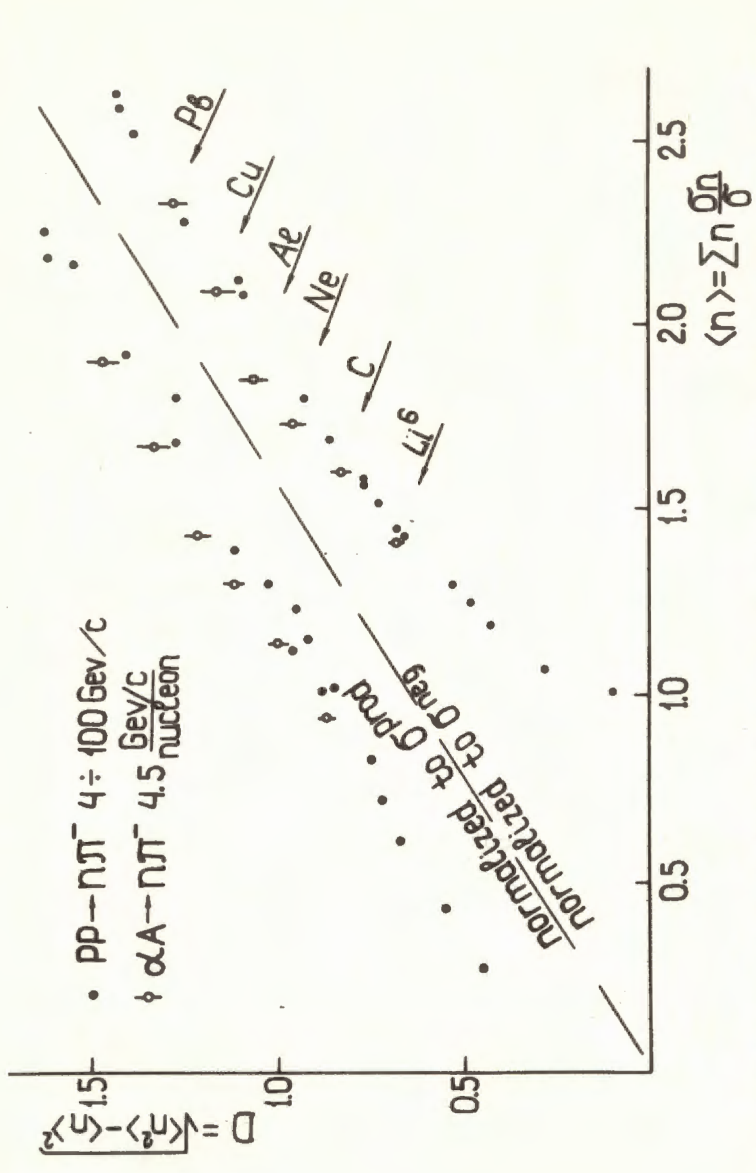

Fig. 3. The dependence of the dispersion $D=(\langle n^2\rangle-\langle n\rangle^2)^{1/2}$ on the average value of the multiplicity distributions of the negative particles in the αA and pp interactions. The points above the line correspond to the data normalization to σ^{prod}, while those below to σ^{neg}.

The estimation of the average multiplicity in the framework of the collective tube model (GTM) is taken from ref. /4/. The authors of this paper compare, in particular, the results of their calculation with our preliminary experimental data /11/. They come to the conclusion that their predictions are in a remarkable agreement with the experimental data but only after introducing some corrections to the low multiplicity channel.

In our opinion, however, the discrepancy between the CTM prediction calculated in /4/ and the experimental data is rather essential (see fig. 4). The agreement claimed in /4/ between calculations and experiment has been obtained on the assumption of a strong bias against the detection of the reaction channels with low multiplicity of π^--mesons (in particular, the channel with no negative pions). However, the suppression of these reaction channels in our experiment was rather weak and corresponding corrections were taken into account (see the description of the experimental setup and section 3). It cannot be excluded that the discrepancy between the CTM predictions and the experimental data is connected with the fact that the authors of ref. /4/ have used in their calculations the results on π^--production in the pp-interactions, whereas the number of negative pions produced in the pp-interactions at the same energy, $\sqrt{s}$, is much smaller than in the np and nn interactions.

Our estimates have shown that, if this circumstance is taken into consideration, the agreement between the CTM predictions and our experimental data is appreciably better.

There have been suggestions (see, e.g., ref. /5/) that the multiple π^- - production cannot be described within the framework of independent collision models. We have made an attempt to calculate the characteristics of multiple production using a simple single interaction model (SIM). The basic assumptions of SIM are as follows: (i) the nucleons of the projectile and target nucleus interact independently, (ii) each nucleon can undergo no more than one inelastic interaction (this assumption seems to be natural at a low energy).

Using a method similar to that described in ref. /14/, we have calculated the probabilities, P_k, of the interaction of $k (1 \le k \le 4)$ and only k nucleons of an incident α-particle with a nucleon of a target nucleus. Using the experimental data on the π^--production in the np-interactions /18/, one can obtain the average π^--production multiplicity $(\langle n(\alpha A)\rangle = \sum_1^4 k\times P_k \times\langle n(np)\rangle)$ within the framework of the above

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