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Summary

Photoemulsions of two types, the first having ordinary composition of nuclei, the second enriched with light nuclei such that the heavy nuclei components Ag , Br are decreased by a factor of 2.5, were exposed to 60 GeV/c π -mesons and 70 GeV/c proton beams. This enabled the separation of the interactions with Ag , Br from those with light C , N , O .

Data concerning particle generation and nuclear disintegration were obtained from these two groups of emulsions. A comparison has been made with the models dealing with the interactions of fast hadrons with nuclei and also the question about hadron complexes (the following terms are adequate "the complex": fireball, excited states, nova) in inelastic interactions with nuclei has been discussed.

Introduction

Investigations of the interactions of fast hadrons with nuclei are of interest to the fields of elementary particles and nuclear physics. This interest has particulary increased after the last results concerning the question of the generation and cross section of hadron complexes inside nuclei.

In refs.[1,2,3] the interactions of 60 GeV/c π^- - mesons with photoemulsion nuclei and in refs.[4,5,6] those for 70 GeV/c protons have been investigated.

Papers [8,9] were devoted to the foundation of the question that collisions with nuclei were a real test for the generation mechanism of particles in the interactions of elementary particles with nucleons.

At present, wider information can be obtained using photoemulsion technique, that gives information first about particle generation during the collision of fast hadrons with nuclei, second about nuclear disintegration which is connected with first. Information obtained from the second type, will also lead to more information about the first kind and also their subsequent interactions inside the nuclei. Indeed, all these questions depend on the atomic weight of nuclei, but using emulsions with only ordinary type composition it is impossible to divide the interactions into those occuring with Ag, Br and those with C, N, O. That is why in this work we have utilized two kinds of emulsions, the ordinary kind and one enriched with light nuclei in which the heavy nuclear component (Ag, Br) has been decreased by a factor of ≥ 2.5 in volume units.

Experiment

BR-2 photoemulsions (denoted by I) and emulsions I enriched by ethylene glycol $(CH_2OH)_n$ (denoted by II for π^--mesons and by III for protons) were used in our experiments. The nuclear composition of these photoemulsions is given in Table I.

Photoemulsions I and II were exposed at the Serpukhov accelerator to 60 GeV/c π^--mesons, photoemulsions I and III - to 69 GeV/c protons.

The size of photoemulsions I was 10 x 20 cm^2, their thickness - 600 μc. The size of photoemulsions enriched by ethylene glycol was 10 x 10 cm^2, the initial thickness - 400 μc. After soaking the volume was increased by a factor of 2.68 (II) and 2.5 (III), the linear dimensions, the thickness of photoemulsions II and III - by a factor of 1.1, 2.21 and 2.1, respectively. After developing the thickness of photoemulsions II and III is the same as that of the developed photoemulsion I as a result of washing out the ethylene glycol in the course of development. Therefore the shrinkage coefficient of these emulsions is larger than the usual one by a factor of ≥ 2.1. Correspondingly the slope angles of secondary particles to the plane of the developed emulsions II, III are decreased in comparison with those in the developed emulsion I thus leading to increasing of star search efficiency.

The blob density in emulsion I was 33 per 100 μc, in emulsions II and III it was 21 and 17, respectively.

Events were searched for along the beam tracks. All

Table I

	Number of nuclei $cm^3 \times 10^{22}$		
	I	II	III
H	3.15	5.16	5.06
C	1.41	1.85	1.83
N	0.39	0.15	0.16
O	0.96	1.68	1.65
Br	1.03	0.39	0.42
Ag	1.04	0.39	0.42

1) the events including one-prong stars at an angle ≥ 6 mrad to the primary particle were detected.

These results are shown in Table II.

Due to additivity of the nuclear composition of emulsion I and CH_2OH, the interactions in emulsions II and III are considered as a sum of interactions with emulsion I nuclei and CH_2OH nuclei (H,C,O).

In order to determine the number of interactions with C,O nuclei of CH_2OH at first, 2) interactions with free protons (~ 4% of the total number in emulsion I and ~ 7% and ~ 10% in emulsions II and III as it follows from the hydrogen content in these emulsions) are subtracted from the stars. With that end in view the stars corresponding to pp events have been selected by application of the usual 3) criteria. Further we subtract the events of coherent generation on nuclei in emulsions I, II and III. The number of stars in emulsion I after subtracting pp and coherent events, found along a length L_I, is denoted by N_I; the numbers of stars in emulsions II and III, found along length L_{II} and L_{III} after a similar procedure of subtraction, are denoted by N_{II} and N_{III}. For example, $N_{III}(C,O)$, the number of stars on nuclei C, O in ethylene glycol for emulsion III, is equal to

$$N_{III}(C,O) = N_{III} - \frac{N_I}{V/V_0} \cdot \frac{L_{III}}{L_I} \quad (1)$$

Using the data of Table II and formula (1) we obtain that $N_{II}(C,O) = 147$; $N_{III}(C,O) = 139$. The values of $\langle N_s \rangle$ as a function of N_h for N_I and N_{II} for π^--mesons are given in fig.1. The N_s/N_h distributions for $N_{II}(C,O)$ are shown in fig. 2 and for $N_{III}(C,O)$ – in fig.3.

Using the N_h distributions of C,O nuclei from CH_2OH and assuming that the N_h distributions of nitrogen nuclei are similar to the first ones of $N_{II}(C,O)$ and $N_{III}(C,O)$ we obtain the distributions of $N_{I,II}(C,N,O)$ and $N_{I,III}(C,N,O)$ for the pions and protons from those of $N_{I,II}$ and $N_{I,III}$.

Table II

Particle	Emulsion	Coefficient V/V_0	Length m	Number of stars: tot	Number of stars: coh + elem	Number of interactions: C, N, O	Number of interactions: Ag, Br
π^- 60 GeV/c	I	I	109.8	210	12	44	154
	II	2.68	338	420	40	198	182
p 69 GeV/c	I	I	97.8	247	23	49	175
	III	2.50	184.5	341	34	176	131

To calculate the number of stars on nuclei C, N, O in emulsion I from the values of N_I, we used the nuclear composition of emulsion I and the cross sections of the interaction with nuclei. This gave ~ 23% of interactions on nuclei C, N, O.

The N_s/N_h distributions of $N_{I,II}$ (C,N,O) and $N_{I,III}$ (C,N,O) obtained by this method agree with the distributions of N_{II} (C,O) and N_{III} (C,O). Later on the results are summarized. Figures 4a and 4b show these total distributions: N_{II} (C,O) + $N_{I,II}$ (C,N,O) and N_{III} (C,O) + $N_{I,III}$ (C,N,O). In order to obtain the N_s/N_h distributions of Ag, Br nuclei, evidently one must take the difference of the distributions for pions and for protons N−N (C,N,O). The obtained distributions are shown in figs. 5a and 5b, respectively, They are free of all speculations done in attempts to obtain the distributions of Ag, Br nuclei (selection according to the number of prongs $N \geq 6$ or $N \geq 8$, path criterion, etc.)

As is seen from figs. 5a and 5b, the fraction of stars with $N_h \leq 6$ is 51% and 48% for π^--mesons and protons, correspondingly. Therefore a comparison with the results obtained by usual methods, where this fraction is equal to 0, has not been made.

Results

The experimental data on the interaction of π^--mesons and protons with nuclei are presented in this paper for elucidating the mechanism of interactions of fast hadrons with nuclei; data concerning nuclei disintegration are used as much as necessary for this purpose.

One should take into account that the difference in energy of primary π^--mesons and protons is not large enough. This difference is especially insignificant because, according to refs. [12,13], the values of $\langle n_s \rangle$ in collisions with free nucleons are practically equal. In accordance with this, some results in our tables and diagrams are presented simultaneously.

Figure 6a gives for π^--mesons and protons the values of $\langle N_s \rangle$ as a function of the number of particles (N_h) for nuclei C, N, O and Ag, Br.

Table III presents the dependence of the average values characterizing particle generation for some groups of nuclei and their decay.

For comparison Table III also presents the mean number of charged particles $\langle n_{ch} \rangle$ and angles $\theta_{s,1/2}$ averaged for interactions with protons and neutrons.

Figure 6b shows the dependence of the ratio $\langle N_s \rangle / \langle n_{ch} \rangle$ on N_h for the interactions of pions and protons with nuclei C, N, O or Ag, Br and presents the results of ref. [7] for the interactions of 200 GeV protons with all the nuclei of emulsions. As is seen from fig. 6b, one can observe a small difference in the data behaviour for 70 and 200 GeV.

Table III shows a weak dependence of $\langle N_s \rangle$ on the atomic weight. One can also see this well in fig. 7 in which the line $A^{0.26}$ is taken from ref. [9] and the line $A^{0.1}$ has been calculated using the values of $\langle n_{ch} \rangle$ for collisions with nucleons from Table III.

Figure 8 from ref. [7] presents the values of $\langle N_s \rangle$ as a function of primary proton momentum. In the same figure our point for the interaction with all the nuclei of photoemulsions is plotted. The figure also shows the calculations [15] for the intranuclear cascade in the model of multiparticle interactions. (In this model it is assumed that the collision of the fast hadron with one of the nucleons inside a nucleus takes place. The produced particles flying forward in a narrow cone have nearly equal velocities and interact with the same of subsequent nucleons. In ref. [16], while interpreting the interactions of 60 GeV/c π^--mesons with nuclei, it is supposed to decrease the density of nucleons in the nucleus for subsequent collisions of the cascade with the first interactions. However, Table.III

60 Gev/c

	$\langle A \rangle$	$\langle N_s \rangle$	$\langle N_g \rangle$	$\langle N_b \rangle$	$\langle N_h \rangle$	$\theta_{s,1/2}$
C,N,O	I4	7.42 ±0,24	0.72 ±0,08	I.84 ±0,I	2.56 ±0,I3	8.8° ±0,8°
Ag, Br	92	8.89 ±0,30	2.26 ±0,20	4.80 ±0,30	7.06 ±0,37	I6.4° ±0.6°
Nucleon	I	$n_s+n_g=n_{ch}$ 6.2 ± 0.2				6°

P 69 GeV/c

	$\langle A \rangle$	$\langle N_s \rangle$	$\langle N_g \rangle$	$\langle N_b \rangle$	$\langle N_h \rangle$	$\theta_{s,1/2}$	$\theta_{g,1/2}$
C,N,O	I4	7.53 ±0,27	0.90 ±0,05	2.57 ±0,I3	3.47 ±0,I5	9.6° ±I°	60° ± 3°
Ag,Br	92	I0.53 ±0.48	2.98 ±0.I0	6.6 ±0.5	9.58 ±0,6	I4.0° ±0.5	66,4 ±I°
Nucleon	I	$n_s+n_g=n_{ch}$ 6.0 + 0.2				6,5°	

The average effective atomic weight $\langle A \rangle$ has been calculated taking into account the composition of emulsions I, II, III and the cross sections of inelastic interactions with nuclei according to ref. [14].

in this case the time factor of this process is not considered. Both the models [15,16] lead to decreasing the values of $\langle N_s \rangle$, $\langle N_g \rangle$ and, according to V.S.Barashenkov, it is necessary to consider them simultaneously taking into account the development of the process in time).

In ref. [9] on the basis of the simplified model of the usual intranuclear cascade the value of $\langle N_s \rangle / \langle n_{ch} \rangle$ as a function of primary proton energy and nucleus atomic weight has been calculated. These results and the data of this paper for protons and pions are shown in fig. 9. The present data agree with the computated curve for protons at 70 GeV.

Let us consider the angular distributions of secondary particles. Figure 10 shows the dependence of the number of particles N_s on their emission angle in the lab. system for the collisions of protons with light nuclei and Ag, Br.

Figure 11 gives the same dependence of the number of particles N_g for the interactions of protons with light nuclei and Ag, Br. The figures show a weak dependence on the atomic weight.

Figure 12 presents the dependence $\log \mathrm{tg}\,\theta$ (at these energies this value is nearly equal to rapidity) for the interactions of pions with protons, light nuclei and Ag, Br. Figure 13 shows similar dependences for the collisions with protons.

Let us summarize the obtained results and compare them with theoretical models.

1. One can observe a weak dependence of $\langle N_s \rangle$ on the atomic weight $\sim A^n$, where $0.1 < n < 0.26$. This is in agreement with [9,15].

The value of $\langle N_s \rangle$ is less for the interactions of 60 GeV π^--mesons than for 70 GeV protons although in the interactions with nucleons $\langle n_s \rangle$ is somewhat larger for π^--mesons.

2. The ratio $\langle N_s \rangle / \langle n_{ch} \rangle$ as a function of N_h (fig. 6b) at 70 GeV is close to that for 200 GeV protons [7].

3. The values of $\langle N_g \rangle$ and $\langle N_h \rangle$ for protons are less than the calculated ones in ref.[15].

4. The angular distributions of s-particles for protons are similar to those for π^--mesons.

The bulk of these data cannot be explained by the usual cascade model (similar to that as shown in a series of papers). The model of multiparticle interactions [15] agrees with the values of $\langle N_s \rangle$ but gives larger values of $\langle N_g \rangle$, $\langle N_h \rangle$.

The last values strongly depend on the multiplicity of the collisions of primary hadrons and secondary particles with nucleons. If according to ref. [17] the cross section of the interaction of the hadron complex in the nucleus is similar to the cross sections of the interaction of hadrons with nucleons then the models (for example, diffraction generation [9] with the production of the hadron complex) should lead to the results close to those of the multiparticle model. In fact, in both cases a complex of particles will interact with the nucleon inside the nucleus and the cross section in the multiparticle model coincides with that of hadron collisions. However, a comparison with ref. [9] can be made only by one parameter $\langle N_s \rangle$ because we have no calculations for g-particles and emission angles of s- and g-particles.

The most important of our results is that the values of $\langle N_s \rangle$, $\langle N_g \rangle$ and $\langle N_h \rangle$ for light nuclei and Ag, Br are larger for protons than for π^--mesons. On the one hand, (in particular for N_h) this can be related to that the summary charge of the proton plus the nucleus is two units larger than for π^--mesons. On the other hand, it is possible and very important that this difference is due to a larger value of the cross section of the interaction in the nucleus of the proton complex in comparison with the meson one similar to that the proton-nucleon cross section is ~1.7 times larger than the π-N cross section.

Note that in ref. [18] it has been concluded that for agreement of the diffraction generation model [9] with experiment it is necessary to assume that the cross section for excited nucleons is less than that for nucleon-nucleons.

In conclusion it should be noted that investigations of the collisions of fast hadrons with nuclei give us new possibilities to consider a complicated and interesting question - how do particles interact and generate in time and space?

References

1. N.Dalkhazhav, K.D.Tolstov, G.S.Shabratova, JINR, P1-5326, Dubna, 1970.
2. N.Dalkhazhav, G.S.Shabratova, K.D.Tolstov. Nucl. Phys., B40, 190 (1972).
3. Z.V.Anzon, T.S.Takibaev, I.Ya.Chasnikov. Letters to JETP, 14, 405 (1971).
4. G.S.Deka, K.Patkhak, Kh.K.Sarma. Yadernaya Fizika, 17, 660 (1973).
5. K.D.Tolstov, P.A.Khoshmukhamedov, JINR, P1-6897, Dubna, 1973.
6. Kh.M.Abdo, N.Dalkhazhav et al. JINR, P1-7217, Dubna, 1973.
7. P.Guer et al. Study of Nuclear Inter. of 200 GeV Protons in Emulsion, Intern. Conf. on Elem. Particles, Aix-en-Provence, France, 1973; Phys.Rev., D3, 238 (1971).
8. P.M.Fishbane, J.S.Trefil. Nucl.Phys., B58, 261 (1973); Preprint University of Virginia ITP-SB-73-36 (1973).
9. A.Dar, J.Vary. Phys.Rev., D6, 2412 (1972).
10. P.Hoskin et al. Nucl.Phys., 40, 260 (1969).
11. E.Lohrmann, M.W.Tencher. Nucl.Phys., 25, 957(1962).
12. N.Dalkhazhav et al. JINR, E1-6599, Dubna, 1972.
13. V.V.Ammosov et al. Phys.Rev.Lett., 42B, 519 (1972).

14. V.S.Barashenkov, V.D.Toneev. Interactions of High Energy Particles and Atomic Nuclei with Nuclei, Atomizdat (1972).
15. J.Z.Artykov, V.S.Barashenkov, S.M.Eliseev. Nucl. Phys., B6, 11 (1968).
16. V.S.Barashenkov, S.M.Eliseev. Yadernaya Fizika, 18, 196 (1973).
17. E.L.Feinberg. "Проблемы теоретической физики. Памяти И.Е.Тамма". "Наука", 1972. Препринт ОИЯИ Р2-6867, Дубна, 1972.
18. A.Subramanion, S.Lol, P.Vyos. Contributed papers, V Intern. Conf. on High Energy Phys. and Nucl. Structure, p. 44, Uppsala, 1973.

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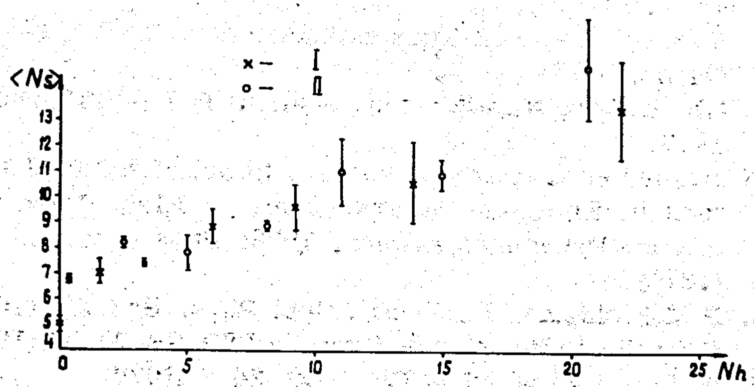

Fig. 1. $\langle N_s \rangle$ as a function of N_h in the interactions of 60 GeV/c π^--mesons with emulsion (I,II) nuclei.

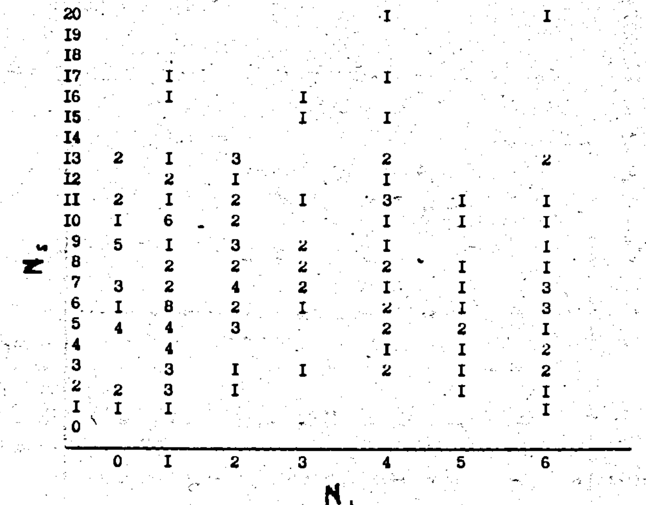

Fig. 2. N_s/N_h distribution of 60 GeV/c π^--mesons on nuclei C,O $-N_{II}$ (C,O).

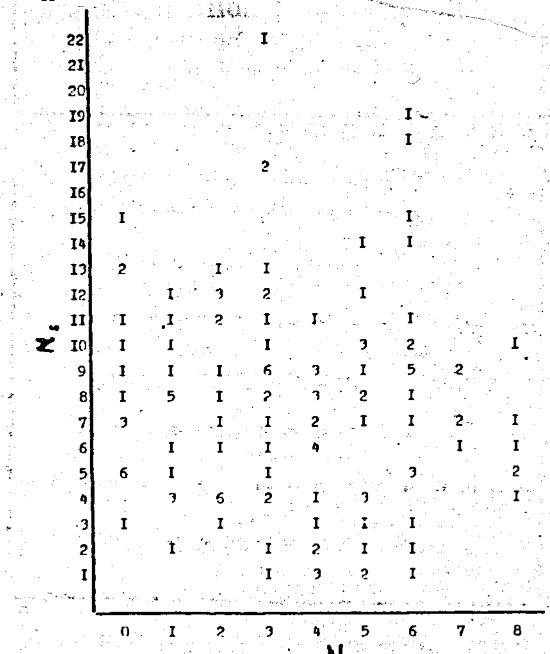

Fig. 3. N_s/N_h distribution of 70 GeV/c protons on nuclei C,O $-N_{III}$ (C,O).

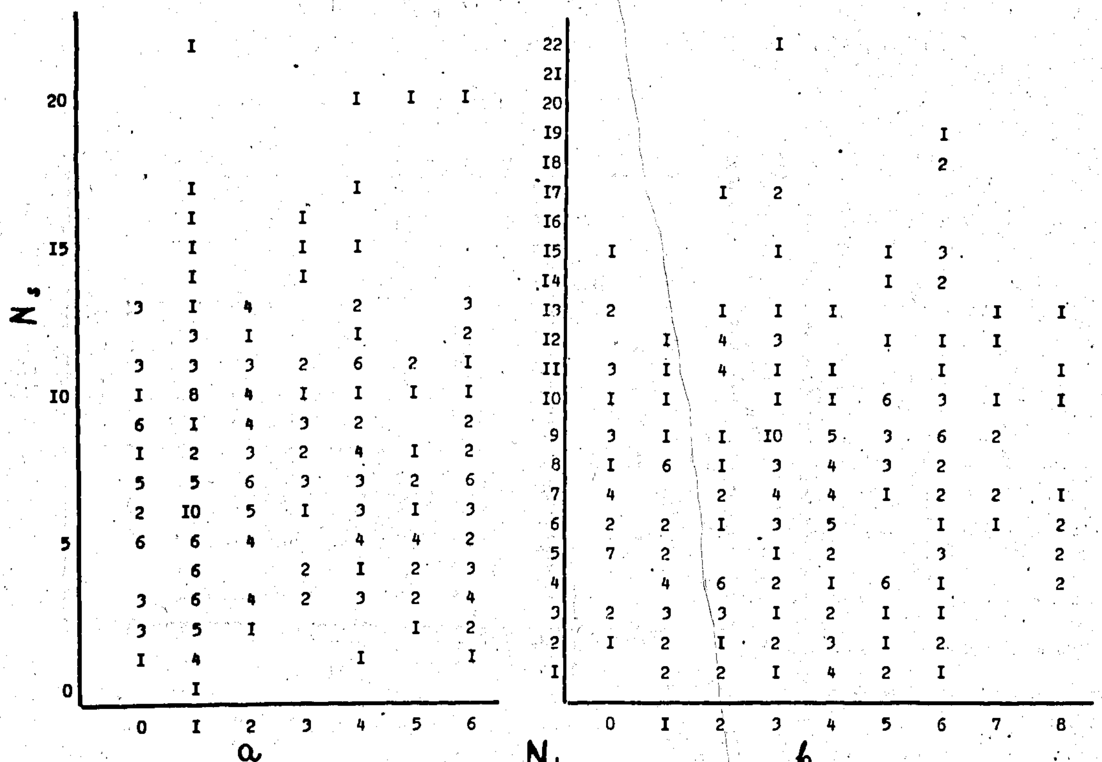

Fig. 4. N_s/N_h distribution of light nuclei: a) for 60 GeV/c π^--mesons N_{II} (C,O) + $N_{I,II}$ (C,N,O) ; b) for 70 GeV/c protons N_{III} (C,O) + $N_{I,III}$ (C,N,O).

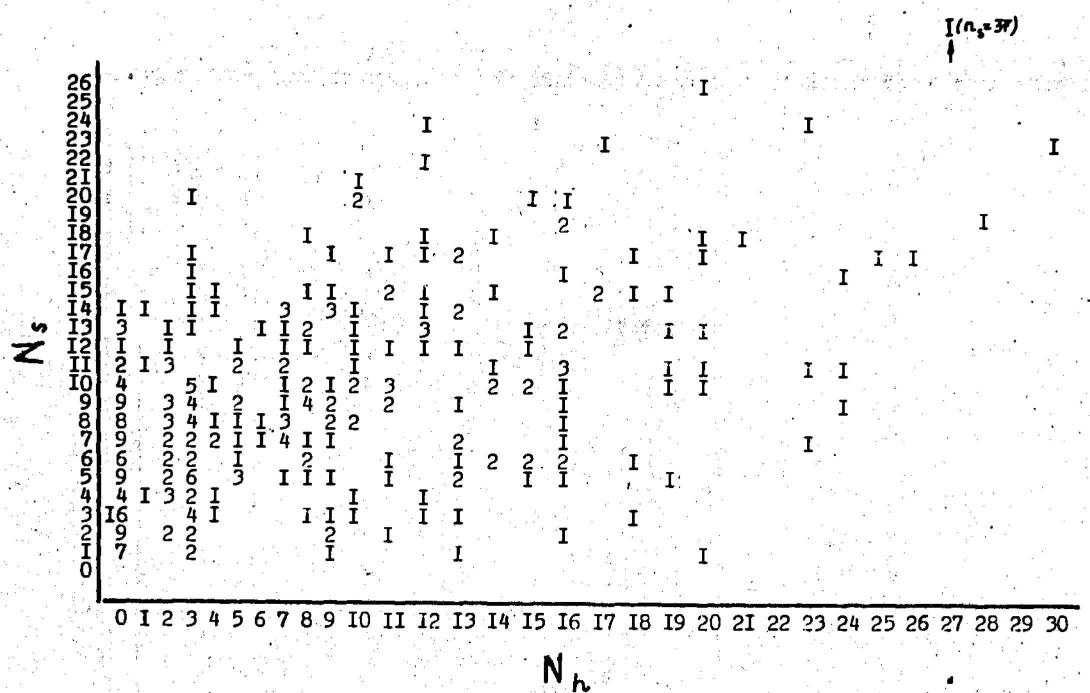

Fig. 5a. N_s/N_h distribution of 60 GeV/c π^--mesons on nuclei Ag, Br – N(Ag,Br);

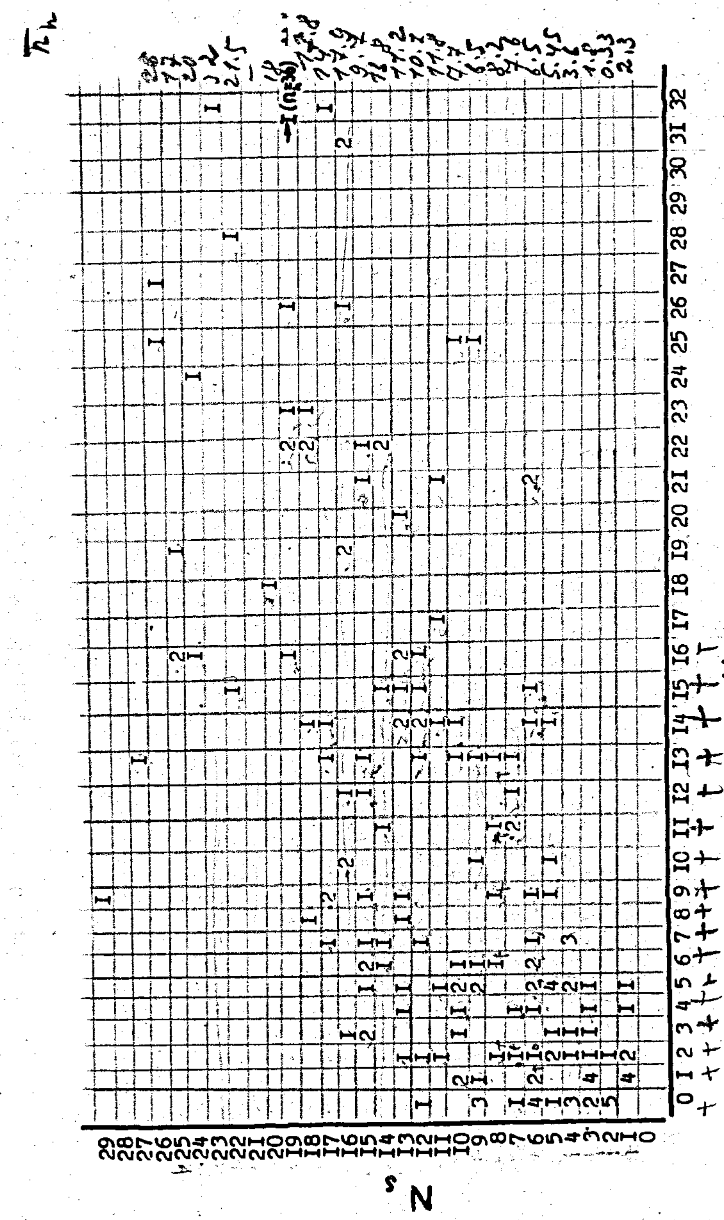

Fig. 5b. N_s/N_h distribution of 70 GeV/c protons on nuclei Ag, Br – N (Ag, Br).

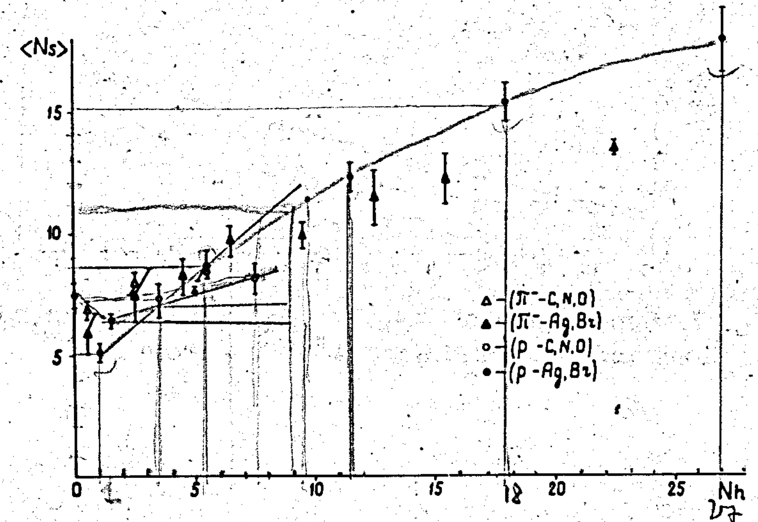

Fig. 6a. $\langle N_s \rangle$ as a function of N_h.

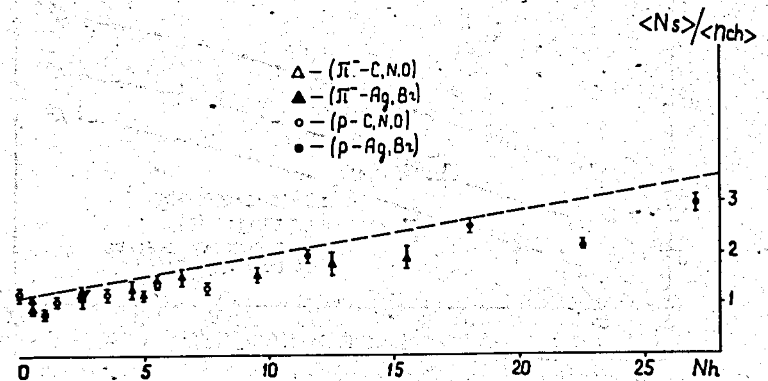

Fig. 6b. $\langle N_s \rangle / \langle n_{ch} \rangle$ as a function of N_h (dotted line ref. [7]).

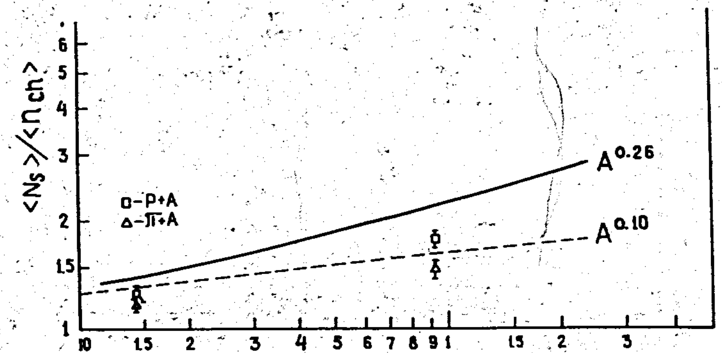

Fig. 7. Dependence of $\langle N_s\rangle/\langle n_{ch}\rangle$ on the atomic weight for pions and protons. Curve $A^{0.26}$ - from ref. [9].

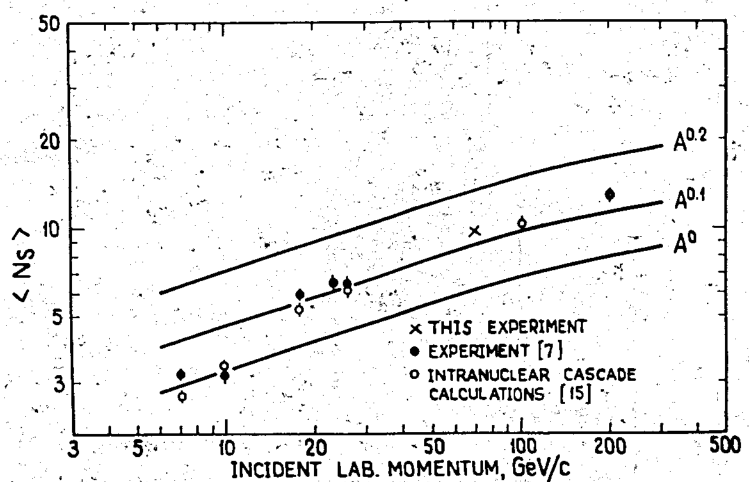

Fig. 8. $\langle N_s\rangle$ as a function of the proton momentum for all emulsion nuclei.

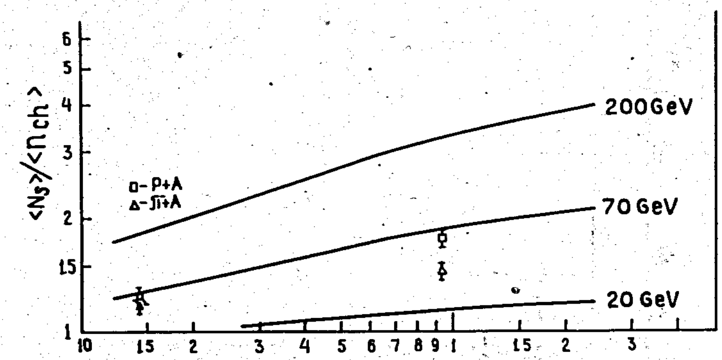

Fig. 9. $\langle N_s\rangle/\langle n_{ch}\rangle$ as a function of the proton energy and atomic weight.

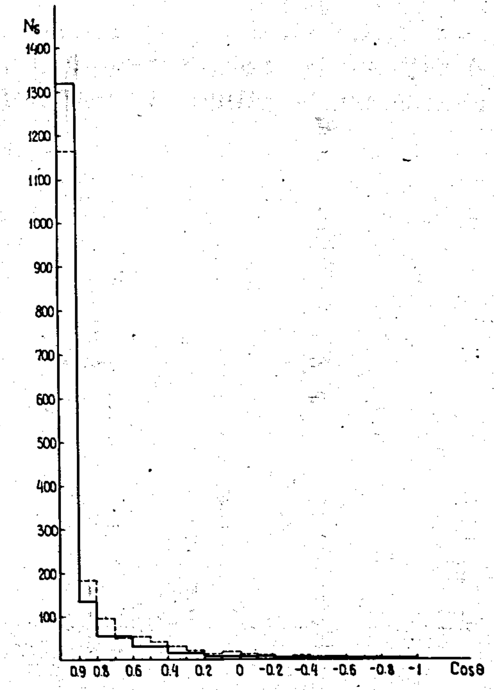

Fig. 10. Angular distribution of s -particles in the collision of protons with nuclei. Solid curve - with light nuclei C, N, O ; dotted curve - with heavy nuclei Ag , Br .

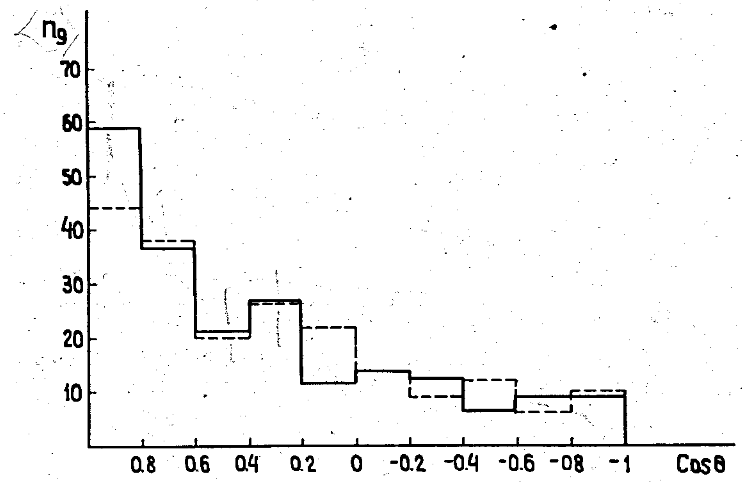

Fig. 11. Angular distribution of g -particles in the collision of proton with nuclei. Solid curve - with light nuclei C, N, O ; dotted curve - with heavy nuclei Ag, Br.

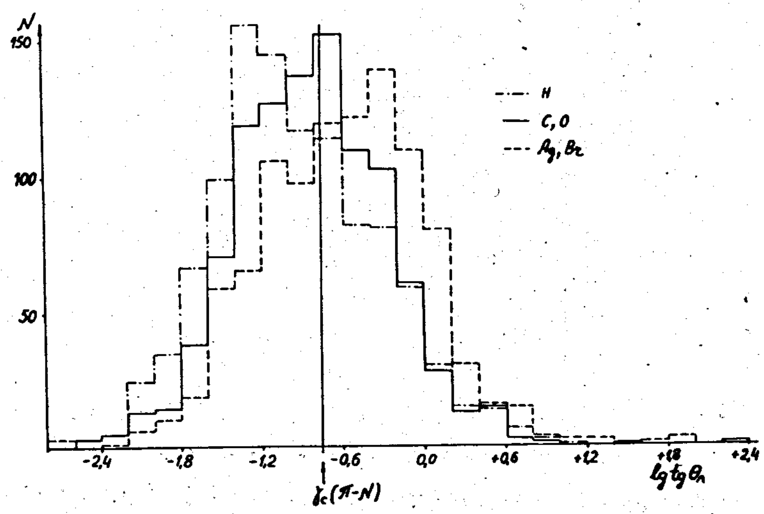

Fig. 12. $\log \mathrm{tg}\,\theta_s$ distribution in the interaction of 60 GeV/c π^--mesons with protons, nuclei C, N, O and Ag, Br.

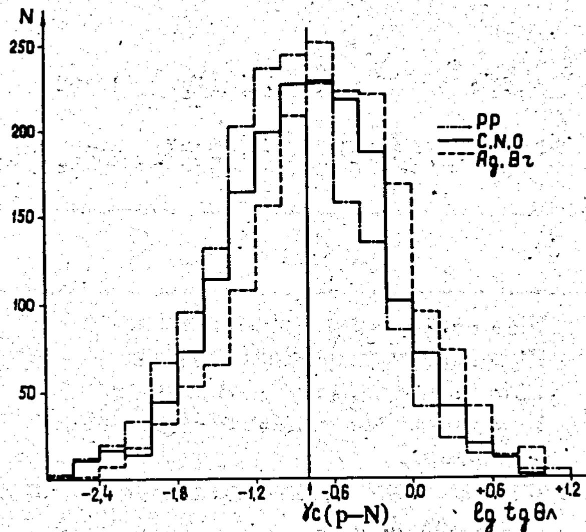

Fig. 13. $\log \mathrm{tg}\,\theta_s$ distribution in the interaction of 70 GeV/c protons with protons, nuclei C, N, O and Ag, Br.