SOME CHARACTERISTICS OF COMPOUND SHOWER AND GREY TRACKS MULTIPLICITY DISTRIBUTIONS PRODUCED IN PROTON EMULSION INTERACTIONS

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Data concerning "compound multiplicity" consisting of shower and grey tracks produced in proton-emulsion interactions are presented. Independence of energy for any target nucleus excitation is found for the normalized compound multiplicity distribution, starting from about 6 GeV of primary energy. Data can be understood in terms of consecutive collision models of the incident particle with target nucleons.

1. Introduction

In the paper we present some properties of the nucleon-nucleus interactions, independent of energy in a wide range (from 6 GeV to 200 GeV) which suggest that the production process of particles in nucleon-nucleus interactions is the same throughout the studied energy range.

We used experimental material (from our and other laboratories) in which multiplicity distribution of grey and black tracks in addition to the relativistic tracks were available: Proton-emulsion interactions at 6.2 GeV and 22.5 GeV (Winzeler [1]) and proton-emulsion interactions at 67 GeV and 200 GeV (Babecki et al. [2]).

The division of tracks into three groups corresponds to different physical processes in which they are produced. The relativistic tracks ($\beta \gtrsim 0.7$) include primary and secondary particles from high energy collisions mainly π-mesons of momentum $p \gtrsim 150$ MeV/c and proton recoils of $p \gtrsim 1.0$ GeV/c. The black tracks ($\beta \lesssim 0.25$) are attributed to evaporation from highly excited nuclei in thermodynamic equilibrium state. The evaporation takes place much later than the production of particles. The emission of the particles is

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isotropic and their energies do not exceed 30 MeV. Slow particles of energies greater than 30 MeV (grey tracks $0.25 \lesssim \beta \lesssim 0.7$) result from a process which has not been fully explained theoretically. It is believed that the particles are the low energy part of a possible inter-nuclear cascade which mainly consists of nucleon recoils, slow mesons (about 5%), and an admixture of deuterons and tritons. They leave the nucleus at the same time as the secondaries of the interaction. Contrary to the black tracks, the grey ones are collimated in the direction of motion of the primary particle.

In previous papers most attention was paid to the characteristics of the relativistic tracks. Their parameters were used for the comparison with predictions of different models. As the relativistic tracks do not involve slow mesons and recoil-nucleons, some model dependent corrections have to be made, which are based on the data on the number of slow mesons and recoils in the proton-proton interactions.

In this paper we analyse the properties of the minimum and grey tracks taken together, as being produced in the same time scale. The tracks include all the mesons produced and almost all recoil nucleons. (The occurrence of heavier nuclei among the grey tracks may be promoted by the Fermi motion of the nucleons within the nucleus. A nucleon may happen to move with small velocity relative to the recoil and emerge as a bound pair). In the following we shall call the number of minimum and grey trakcs per interaction the "compound multiplicity".

We present the dependence of the mean value and the dispersion of the compound multiplicity on energy and on the degree of the target nucleus exictation characterized by the number of black tracks. We find that the normalized compound multiplicity defined as $R^x = (n_s+N_G)/\langle n_{ch}\rangle$ (n_s, N_G — number of relativistic and grey tracks in nucleon-emulsion interaction, respectively; n_{ch} — number of charged particles in pp interactions) and the second moment of its distribution are independent of energy for any degree of excitation of the target nucleus. We compare the experimental results with several models of particle production.

The following notation is used throughout the paper:

N_B — number of black tracks,
n_{ch} — number of charged particles in $p-p$ interaction,
n_s — number of shower (relativistic) tracks in proton-nucleus interaction,
n_s+N_G — "compound multiplicity",
$R = n_s/\langle n_{ch}\rangle$ — normalized shower tracks multiplicity ($\langle\ \rangle$ — mean value),
$R^x = (n_s+N_G)/\langle n_{ch}\rangle$ — normalized compound multiplicity,
$D = (\langle n_s^2\rangle - \langle n_s\rangle^2)$ — dispersion of the shower tracks multiplicity distribution,
$D^x = \{\langle (n_s+N_G)^2\rangle - \langle (n_s+N_G)\rangle^2\}^{1/2}$ — dispersion of compound multiplicity distribution,
$D_N = D/\langle n_{ch}\rangle = \{\langle (n_s/\langle n_{ch}\rangle)^2\rangle - (\langle n_s\rangle/\langle n_{ch}\rangle)^2\}^{1/2} = \{\langle R^2\rangle - \langle R\rangle^2\}^{1/2}$ — normalized dispersion of shower track multiplicity, distribution,
$D_N^x = D^x/\langle n_{ch}\rangle = \left\{\left\langle\left(\frac{n_s+N_G}{\langle n_{ch}\rangle}\right)^2\right\rangle - \left(\frac{\langle n_s+N_G\rangle}{\langle n_{ch}\rangle}\right)^2\right\}^{1/2} = \{\langle (R^x)^2\rangle - \langle R^x\rangle^2\}^{1/2}$ – normalized dispersion of compound multiplicity distribution.

2. *Characteristics of compound multiplicity*

In Fig. 1a the mean compound multiplicity $\langle n_s+N_G\rangle$ in nucleon-nucleus interactions is plotted against the primary momentum in logarithmic scale. The upper curve corresponds to highly excited heavy nuclei of emulsions Ag, Br, characterized by $N_B \geqslant 9$, the lower

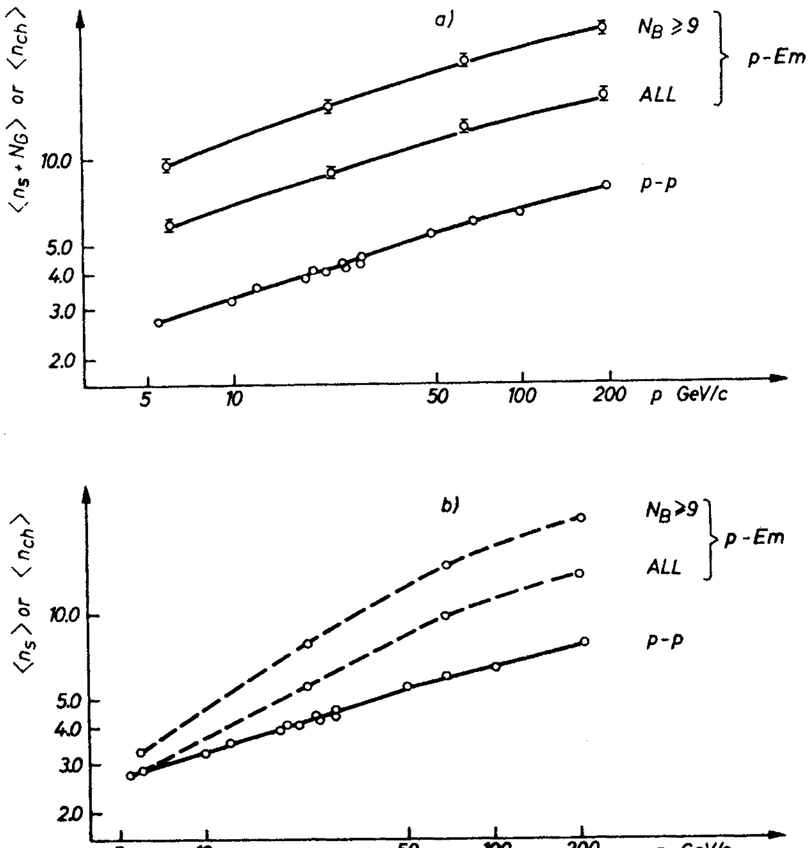

Fig. 1a). Mean compound multiplicity $\langle n_s+N_G\rangle$ in nucleon-nucleus interactions plotted as a function of the primary momentum p, with data concerning $\langle n_{ch}\rangle$ for p-p collisions. The upper curve corresponds to highly excited heavy nuclei Ag, Br, characterized by $N_B \geqslant 9$ (number of black tracks); the lower curve to interactions with all emulsion nuclei. b). The same for the relativistic tracks

one represents interactions with all emulsion nuclei. For comparison the number of mean charged particles $\langle n_{ch}\rangle$ in proton-proton interactions as a function of primary momentum is shown.

The dependence of compound multiplicity on primary momentum for nuclear interactions is similar to that for the elementary interactions. It can be expressed by the following equation:

$$\langle n_s+N_G\rangle = R^x(N_B)\cdot n_{ch}(p), \tag{1}$$

where $n_{ch}(p)$ is a function which describes the dependence of $\langle n_{ch} \rangle$ on momentum p for the elementary process, and R^x is a parameter dependent on the number of black tracks and independent of the primary momentum. Constancy of parameter $\langle R^x \rangle$ for interactions divided into three groups of different N_B ($N_B = 0-2, 3-8, \geqslant 9$) is illustrated in Fig. 2a. Horizontal lines represent the mean value of R^x taken over all energies for a given group of N_B.

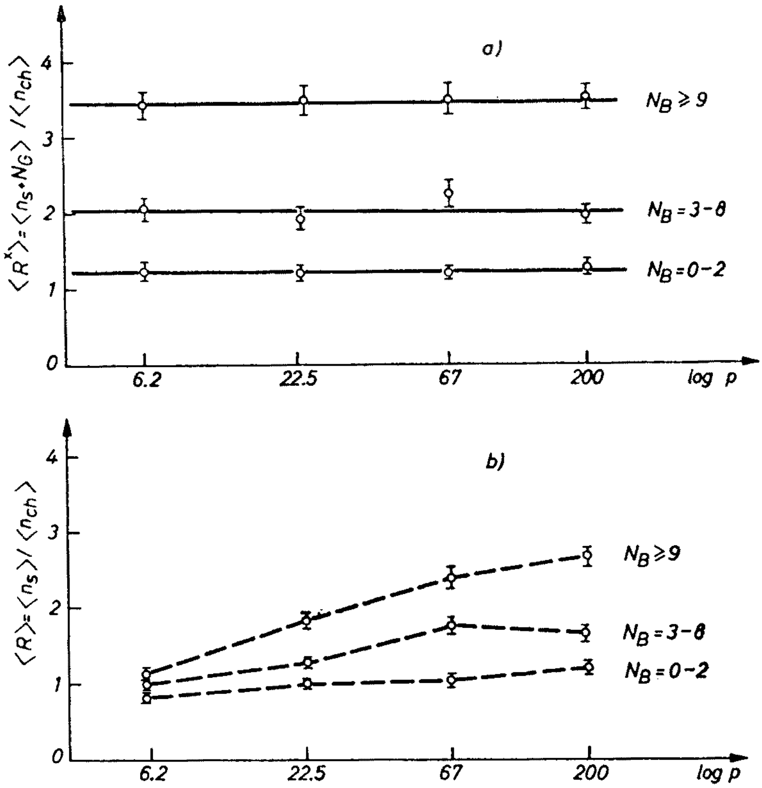

Fig. 2a). Normalized mean value of the compound multiplicity $\langle R^x \rangle$ vs primary momentum for three groups of interactions characterized by the number of N_B. b). The same for the relativistic tracks

The value of the parameter $\langle R^x \rangle$ as a function of the degree of excitation of the target nucleus revealed by the number of black tracks N_B are shown in Fig. 3a. The dependence can be approximated by the straight line

$$\langle R^x \rangle = 1.05(\pm 0.03) + 0.20(\pm 0.01) \langle N_B \rangle, \tag{2}$$

up to $N_B \leqslant 13$ for any value of energy. Values of $\langle R^x \rangle$ for $N_B \geqslant 14$ for all energies lie below the line.

Similar relations for relativistic tracks n_s are drawn in Figs 1b, 2b, and 3b. In the range of energy examined normalized multiplicity $\langle R \rangle = \langle n_s \rangle / \langle n_{ch} \rangle$ depends on energy

[Fig. 2b]. The dependence is stronger for higher degrees of target excitation. It follows that the relation of $\langle R\rangle$ vs $\langle N_B\rangle$ (Fig. 3b) for relativistic tracks is not the same for all energies as it is the case for the compound multiplicity.

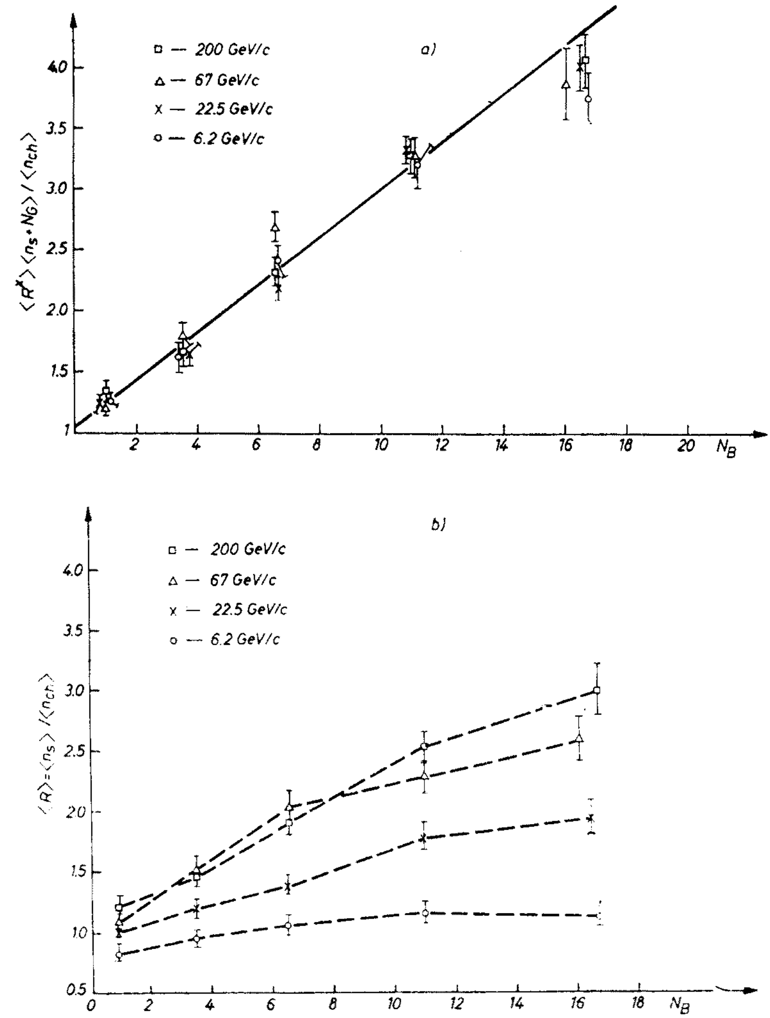

Fig. 3. a). $\langle R^x\rangle$ as a function of the mean number of black tracks N_B in a group of collisions. b). The same same for the normalized shower track multiplicity $\langle R\rangle = \langle n_s\rangle/\langle n_{ch}\rangle$

Further characteristics of the (n_s+N_G) tracks are given by the second moment of their multiplicity distribution D^x (see Table I).

In Fig. 4 we present the dispersion D^x for all interactions (independently of N_B) as a function of $\langle n_s+N_G\rangle$ at the four energies discussed (p$-$Em, ALL). Points can be approximated by a straight line

$$D = (0.71\pm0.02)\langle n_s+N_G\rangle-(0.44\pm0.16), \tag{3}$$

TABLE I

p(GeV/c)	6.2 (N = 1771)		22.5 (N = 894)		67 (N – 675)		200 (N – 999)	
N_B	$\langle n_s+N_G\rangle$	D^x	$\langle n_s+N_G\rangle$	D^x	$\langle n_s+N_G\rangle$	D^x	$\langle n_s+N_G\rangle$	D^x
0—2*	3.47±0 08	1.96±0.06	5.12±0.16	2.97±0.11	7.10±0.25	4.12±0.17	10.14±0.29	5.92±0.21
3—4	4.50±0.14	2.53±0.10	7.05±0.32	4.22±0.23	10.56±0.53	5.75±0.38	12.69±0.51	7.16±0.36
5—8	6.72±0.17	3.21±0.12	9.22±0.35	4.73±0.25	15.79±0.61	7.25±0.43	17.85±0.71	9.49±0.51
9—13	8.99±0.21	3.64±0.15	14.20±0.50	6.11±0.36	19.32±0.95	8.62±0.68	25.19±0.87	10.30±0.62
14	10.49±0.28	3.47±0.20	16.95±0.82	6.14±0.59	22.63±1.21	9.03±0.86	31.05±1.39	12.35±0.99
all	5.93±0.09	3.75±0.06	8.56±0.20	5.86±0.14	12.27±0.32	8.26±0.23	15.77±0.34	10.64±0.24

p (GeV/c)	6.2		22.5		67		200	
N_B	$\langle R^x\rangle$	D_N^x	$\langle R^x\rangle$	D_N^x	$\langle R^x\rangle$	D_N^x	$\langle R^x\rangle$	D_N^x
0—2*	1.24±0.07	0.70±0.04	1.20±0.07	0.70±0.05	1.20±0.06	0.70±0.04	1.32±0.06	0.77±0.04
3—4	1.61±0.11	0.90±0.07	1.66±0.12	0.99±0.07	1.79±0.12	0.98±0.08	1.65±0.09	0.93±0.06
5—8	2.40±0.15	1.15±0.08	2.17±0.13	1.11±0.09	2.68±0.15	1.23±0.09	2.32±0.12	1.23±0.09
9—13	3.21±0.19	1.30±0.10	3.34±0.20	1.44±0.12	3.28±0.22	1.46±0.13	3.28±0.15	1.34±0.10
14	3.75±0.24	1 24±0.11	3.99±0.28	1.44±0.17	3.84±0.27	1.53±0.18	4.04±0.27	1.61±0.15
all	2.12±0.11	1.34±0.07	2.01±0.10	1.38±0.06	2.08±0.0	1.40±0.06	2.05±0.06	1.39+0.05

models	$\langle R\rangle$	D_N	$\langle R\rangle$	D_N	$\langle R\rangle$	D_N	$\langle R\rangle$	D_N
ex. state model	1.79	1.20	1.82	1.22	1.85	1.25	1.88	1.27
fireball model	2.03	1.28	2.06	1.29	2.08	1.30	2.11	1.32
tube m.							1.23	0.76

* Group N_B = 0—2 includes coherent interactions.

similar as in the case of the relativistic tracks [12, 13, 14]. The line for the elementary process is given by $D_0 = 0.58(n_{ch}-1)$ [3] which is marked in Fig. 4 by a dashed line. In the same plot we present the dispersion of the compound multiplicity distribution in interactions belonging to different groups of N_B plotted against the mean value of (n_s+N_G).

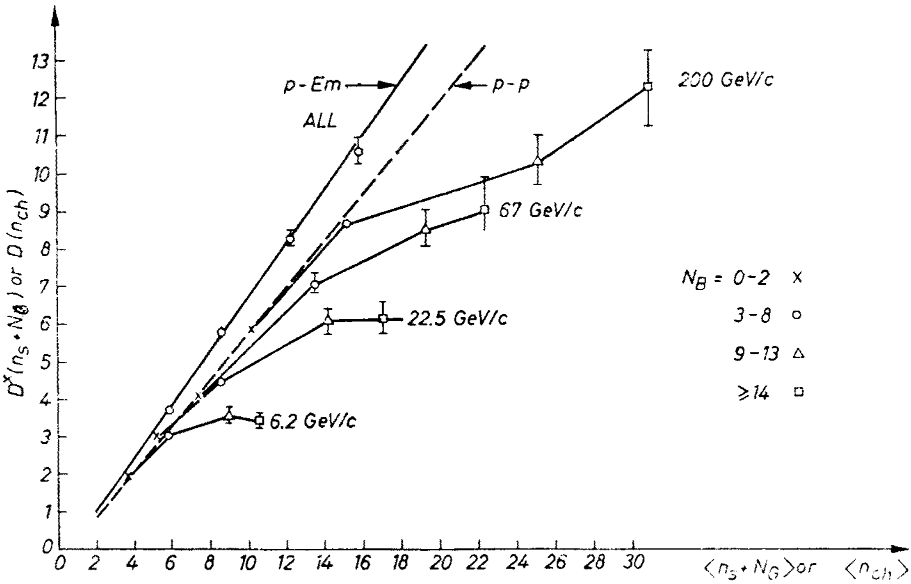

Fig. 4. 1) Dispersion of the compound multiplicity vs average compound multiplicity for all proton-emulsion interactions (independent of the number of black tracks) at energies: 6.2, 22.5, 67, 200 GeV. 2) Dispersion for interactions divided according to N_B. Points for the same energy are joined by a line. 3) Dashed line: D vs n_{ch} dependence for p-p interactions

Points for the same energy are joined with a line. From Fig. 4 we see that D^x vs $\langle n_s+N_G\rangle$ for interactions characterized by a low state of excitation of the target nucleus ($N_B < 3$) shows a dependence similar to D_0 vs $\langle n_{ch}\rangle$ for the elementary process which has been found to be a universal relation [13, 14] (independent of energy and target). For groups with higher values of N_B the same dependence is different from the universal one (it is energy dependent).

The energy dependence of D^x vs (n_s+N_G) disappears for the normalized compound multiplicity R^x and its dispersion D_N^x. In Fig. 5a D_N^x vs $\langle R^x\rangle$ is shown, calculated separately for five groups of N_B: 0–2, 3–4, 5–8, 9–13, ≥ 14. All points belonging to the same N_B group lie at one curve regardless of primary energy.

Since there is an energy independent relation between $\langle R^x\rangle$ and $\langle N_B\rangle$, the relation D_N^x vs $\langle N_B\rangle$ can also be approximated by one curve for all energies (Fig. 6a).

It should be stressed that in the case of the shower tracks the relations between normalized dispersion D_N and $\langle R\rangle$ or $\langle N_B\rangle$ depend on energy (Fig. 5b and 6b).

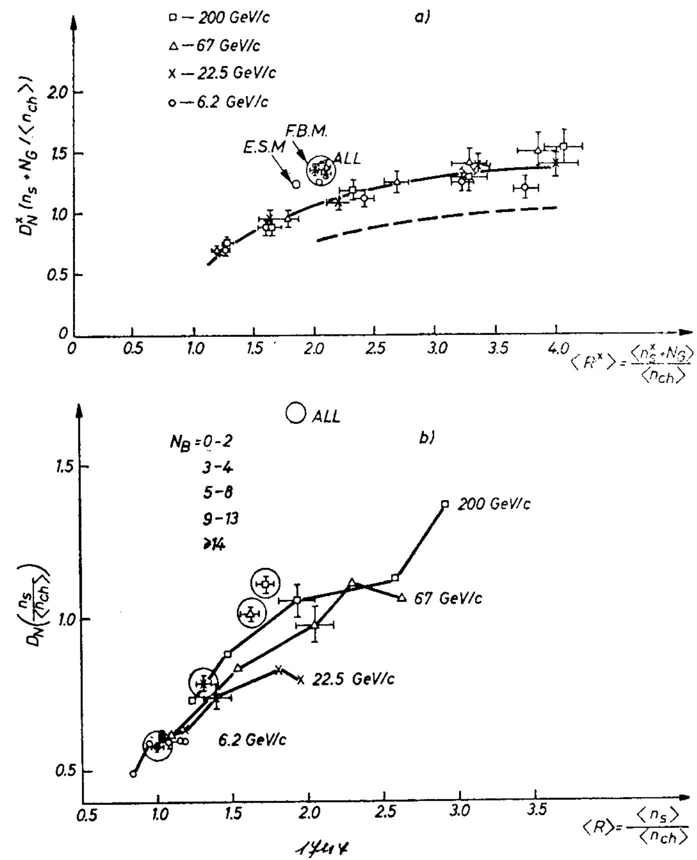

Fig. 5

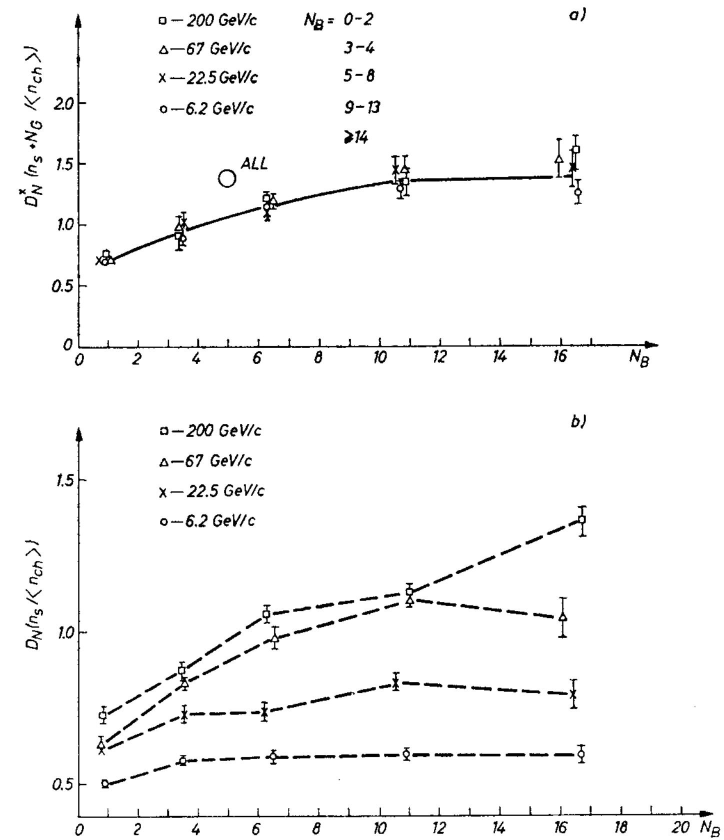

Fig. 6

Fig. 5. a) Dispersion of the normalized $(n_s + N_G)$ multiplicity distribution D_N^x calculated for each group of N_B separately ($N_B = 0-2, 3-4, 5-8, 9-13, \geqslant 14$) (dashed line — see text). b) The same for the relativistic tracks, in circles — data concerning all interactions at definite energy

Fig. 6.a) Dispersion of the normalized $(n_s + N_G)$ distribution D_N^x vs $\langle N_B \rangle$ calculated in groups of N_B. b) The same for relativistic tracks

3. *Discussion of results*

The independence from energy of the normalized compound multiplicity is a striking feature. If we assume that the grey tracks are closely connected with the particle production process, the energy independence of R^x and D_N^x imposes certain restrictions on the production models. The simple inter-nuclear cascade caused by secondary particles generated in the interaction of the primary with nucleons of the nuclei is eliminated (R and D_N in the cascade model grow with energy). Models with long creation times of secondaries in independent collisions with individual nucleons of the target nucleus are favoured. We can mention for example the long lived excitation state models [4, 5, 6]. In conglomerate models in which the nucleons on the path of the incident particle act cumulatively or coherently [7, 8] and the production process takes relatively long time, D_N^x is also independent of energy, provided R does not depend on energy. In the following we shall examine several models in some detail.

In the subsequent collision model, in which every nucleon taking part in the interaction contributes independently and equally to the observed multiplicity distribution (excited state model), the normalised multiplicity R, in fixed ν collisions is given by the formula

$$R = 0.5\,(1+\nu). \tag{5}$$

Assuming statistical independence of the consecutive collisions, the dispersion for a definite ν is given by [11]

$$D^2(\nu) = (1+\nu)D_0^2, \tag{6}$$

where D_0 is the dispersion of the multiplicity produced by the excited state. D_0 can be deduced from the proton-proton distribution using the same folding procedure

$$D_0^2 = 1/2 D_{pp}^2. \tag{7}$$

In interactions characterized by a given number of black tracks N_B a spread of the ν occurs. The dispersion $D(N_B)$ can be expressed in terms of $D(\nu)$ by the formula

$$D^2(N_B) = \sum_\nu p(\nu, N_B)D^2(\nu) + \sum_\nu p(\nu, N_B)\,\{n(\nu)-\langle n(\nu)\rangle\}^2, \tag{8}$$

where $p(\nu, N_B)$ are the probabilities of occurence of ν inelastic collisions in the interactions characterized by the given number of black tracks N_B.

The dispersion of the normalized multiplicity distribution D_N in the excited state model is

$$D_N^2(N_B) = 0.5\alpha^2[1+\langle\nu(N_B)\rangle]+0.25[\langle\nu^2(N_B)\rangle-\langle\nu(N_B)\rangle]^2. \tag{9}$$

Deriving equation (9) we took $D_{pp}/\langle n_{ch}\rangle = \alpha = 0.58$ omitting $0.58/\langle n_{ch}\rangle$ from Wróblewski's formula [3], that we believe to be approximately true for a target which is a mixture of protons and neutrons.

If we substitute in Eq. (9) the normalized multiplicity of interactions with a given number of black tracks

$$\langle R[\nu(N_B)]\rangle = 0.5(1+\langle\nu(N_B)\rangle), \tag{10}$$

we get following expression:

$$D_N^2(N_B) = \alpha^2\langle R[\nu(N_B)]\rangle + \sum_\nu p(\nu, N_B)\{R[\nu(N_B)] - \langle R[\nu(N_B)]\rangle\}^2. \tag{11}$$

Neglecting the weak energy dependence of $p(\nu, N_B)$ caused by differences in the inelastic cross-section we see from formula (10) and (9), that the excited state model gives energy independent $\langle R\rangle$ and D_N values for the normalized multiplicity distribution as was experimentally found for the compound multiplicity.

A comparison of the formula (9) or (11) with the experimental data is restricted. Neither can the distribution of ν for a given number of N_B be calculated, nor is the second term in Eq. (11) known from the experiment. We can only make a qualitative comparison of the experimental dependence D_N^x and $\langle R^x\rangle$ with the prediction of the model. In Fig. 5a the first term of equation (11) is drawn (dashed line). The shape of the line follows the shape of the experimental curve with a shift towards smaller D values, which can be attributed to the omission of the second term. The second term, which is equivalent to the second term in Eq. (9), can be estimated for all interactions in emulsion (without restrictions on N_B), since we can calculate the probability distribution of inelastic collisions in the nuclei of the emulsions by means of the Glauber like formalism using the Saxon Woods nuclear density distribution[1].

The values of D_N and $\langle R\rangle$ for overall interactions calculated for the excited state model are listed in Table I along with of the experimental data. (The values are calculated for given energies separately, taking into account the weak energy dependence of ν). They are also plotted in Fig. 5a.

The calculated points (D_N vs $\langle R\rangle$) are quite close to the experimental ones (in circles — Fig. 5a), suggesting that the number of inelastic collisions ν and their probability distribution seems to be the relevant quantity governing the (n_s+N_G) distribution. Furthermore, since the D_N^x value for all interactions characterized by $\langle N_B\rangle \simeq 4.7$ is higher than the corresponding value of $D_N^x(N_B)$ given by the experimental curve (Fig. 6a), we can conclude that the second term, which describes the dispersion of the collision number distribution is smaller in interactions selected according to N_B, than in the interactions without restriction on N_B tracks.

Fairly good agreement of the calculated D_N and R^x values with experiment is obtained in another version of the subsequent collision model. Treating the production of particles in interactions with nuclei as a superposition of elementary interactions caused by the primary particle only (the fast and slow particles are supposed to emerge from the nuclei without producing additional hadrons) and taking into account the

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[1] We are grateful to W. Czyż and M. Błeszyński for making available the results of their calculations concerning probability distribution of inelastic collisions.

energy degradation of the primary, (the noninteracting fireball model is a particular example [4]) we get

$$R \sim (\kappa^{\beta\nu}-1)/(\kappa^{\beta}-1), \quad (12)^{2}$$

$$D_N^2(N_B) = \frac{\alpha^2}{\kappa^{2\beta}-1}(\langle\kappa^{2\beta\nu(N_B)}\rangle - 1) + \frac{1}{(\kappa^{\beta}-1)^2}(\langle\kappa^{2\beta\nu(N_B)}\rangle - \langle\kappa^{\beta\nu(N_B)}\rangle^2), \quad (13)$$

where $\kappa = 1-K$ and K is inelasticity coefficient.

In calculating the above formulas we approximated the n_{ch} vs p (primary momentum) dependence for 5 GeV/c < p < 200 GeV/c by $n_{ch} = \gamma p^{\beta}$ with $\gamma = 1.671$ and $\beta = 0.294$ and assumed that n_{ch} in proton-neutron interactions is about the same as in proton-proton interactions.

The calculated values of $\langle R\rangle$ and D_N for $K = 0.5$ and $p = 200$ GeV/c are in agreement with the coresponding experimental values

$$\langle R\rangle = 2.11, \quad D_N = 1.32, \quad \langle R^x\rangle = 2.05 \pm 0.06, \quad D_N^x = 1.39 \pm 0.05.$$

In the models in which the primary particles act simultaneously with a group of ν nucleons [7, 8] the same formula can be applied to compute $D_N(N_B)$. Now $p(\nu, N_B)$ is the probability of an inelastic interaction of the primary particle with a group of ν nucleons [9]. It is calculated in the same way as in the case of subsequent collisions[3]. The interaction is assumed to be the same as that with one single nucleon, but an incident effective total CM energy squared $S_\nu = \nu S_1$. If $\langle n(S)\rangle \sim S^{1/4}$, $R = \nu^{1/4}$ and

$$D_N^2 = \langle \nu^{1/2}\sigma\rangle (\alpha^2+1) - \langle \nu^{1/4}\rangle^2. \quad (14)$$

Again we observe an independence of $\langle R\rangle$ and D_N of energy (apart from the weak energy dependence of ν) but the numerical values of $\langle R\rangle$ and D_N for the overall interactions are substantially smaller. $\langle R\rangle = 1.23$ and $D_N = 0.76$ coresponding experimental values 200 GeV/c are $\langle R^x\rangle = 2.05 \pm 0.06$ and $D^x = 1.39 \pm 0.05$.

The Gottfried model [12] cannot be treated in the same way. Apart from the fact that it is formulated only for high energies, the second moment of the multiplicity distri bution of slow slices and its relation to D_{pp} is not known.

Comparing the characteristics of the $(n_s + N_G)$ distribution with the predictions of the models we assumed that the grey tracks were closely connected with the production process and that they were mainly recoil nucleons.

The calculated mean number of inelastic collisions is, for the average nucleus in emulsion, $\langle\nu\rangle = 2.75$. This gives about $1/2\langle\nu\rangle = 1.4$ charged recoils. The mean number of grey tracks in emulsion changes from (3.13 ± 0.02) to (2.55 ± 0.03) within the studied energy range. Correcting these values for slow mesons and taking into account the fact that part of the recoils form relativistic tracks[4], we are left with about one grey track/

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[2] Relation (12) is exactly true for created particles (without recoils). For charged particles the R value is slightly energy dependent and overestimated (at 200 GeV by about 6% taking the charge exchange into accoount).

[3] See footnote 1.

[4] The corrections have been made on the basis of the consecutive collisions model as in [10].

/interaction, which may be created in processes we neglected in our considerations, for example in elastic collisions or rescattering of the recoils. That number compared with the number of $\langle n_s+N_G\rangle$ is not large enough to influence appreciably the characteristics of the production process.

4. *Conclusions*

It is shown that the compound multiplicity (n_s+N_G) in proton-emulsion interactions depends on the primary energy in a way similar to the elementary process starting from low energy (about 6 GeV). The mean value and dispersion of the normalized compound multiplicity $(n_s+N_G)/\langle n_{ch}\rangle$ are independent of the primary momentum. These features suggest that the production process in nucleon-nucleon interactions is the same throughout the studied energy range.

Furthermore, the shape of D_N^x vs R^x or D_N^x vs. N_B dependence may be understood in terms of the consecutive collision models. In particular, two of the discussed models, the excited state model and the non-interacting fireball model, seem to be in fairly good agreement with the experimental data.

The relatively high value of D_N^x for all interactions (without restrictions on N_B), compared with the curve D_N^x vs N_B seems to indicate that the probability distribution of the inelastic collisions inside the nucleus is narrower for interactions characterized by a definite number of N_B than for all interactions. In other words, by collecting interactions according to N_B we have to do with a type of interactions that from the point of view of ν distribution is more uniform.

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REFERENCES

[1] H. Winzeler, *p-Nucleus Collisions in Multi-GeV Region*, Lectures in honour of 60-anniversary of F. G. Houtermans (1964).
[2] J. Babecki, Z. Czachowska, B. Furmańska, J. Gierula, R. Hołyński, A. Jurak, S. Krzywdziński, G. Nowak, B. Ślęzak, W. Wolter, *Phys. Lett.* **B47**, 268 (1973).
[3] A. Wróblewski, *Acta Phys. Pol.* **B4**, 857 (1973).
[4] M. Mięsowicz, *Progress in Elementary Particle and Cosmic Ray Physics* **10**, 128 (1971).
[5] P. N. Fishbane, I. S. Trefil, *Phys. Lett.* **51B**, 179 (1974).
[6] E. M. Friedländer, *Lett. Nuovo Cimento* **9**, 349 (1974).
[7] S. Z. Bilenkij, L. D. Landau, *Nuovo Cimento Suppl.* **3**, 15 (1956).
[8] G. Berlad, A. Dar, G. Eilam, *Phys. Rev.* **D13**, 161 (1976).
[9] A. Białas, W. Czyż, *Phys. Lett.* **58B**, 325 (1975).
[10] J. Babecki, Report INP No 911/PH, Cracow 1975.
[11] *Handbook of Probability and Statistics*, Burington and May, Handbook Publishers, Inc. Sundusky, Ohio 1953.
[12] K. Gottfried, Ref. TH 1735 — CERN (1973); *Phys. Rev. Lett.* **32**, 957 (1974).
[13] W. Busza et al., *Phys. Rev. Lett.* **34**, 836 (1975).
[14] A. Białas, W. Czyż, R. Hołyński, A. Jurak, W. Wolter, B. Wosiek, *Nucl. Phys.* **B100**, 103 (1975).