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P. N. LEBEDEV PHYSICAL INSTITUTE

HIGH ENERGY PHYSICS AND COSMIC RAYS

PREPRINT N 77

AN ANALYSIS OF ANGULAR DISTRIBUTION OF RELATIVISTIC PARTICLES IN INELASTIC PION - NUCLEUS COLLISIONS AT 200 GEV/C

ALMA-ATA-GATCHINA-MOSCOW-TASHKENT COLLABORATION

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Alma-Ata-Gatchina-Moscow-Tashkent Collaboration

Z.V.Anzon, A.Sh.Gaitinov, L.E.Eremenco, E.G.Kanygina,
Zh.S.Takibaev, I.Ya.Chasnikov and Ts.I.Shakhova

Institute of High Energy Physics, Academy of Sci of The
Kazakh SSR, Alma-Ata

F.G.Lepekhin and B.B.Simonov
B.P.Konstantinov Institute of Nuclear Physics, Academy of Sci.
of the USSR, Gatchina

M.I.Adamovich, V.G.Larionova, G.I.Orlova, M.I.Tretyakova,
S.P.Kharlamov, M.M.Chernyavsky and F.R.Yagudina
P.N.Lebedev Physical Institute, Academy of Sci. of the USSR,
Moscow

Sh.Abduzhamilov, S.A.Azimov, M.Dzhuraev and S.I.Gadzhieva
S.V.Starodubtsev Physical Technical Institute, Academy of Sci.
of the Uzbek SSR, Tashkent

R.A.Bondarenko, K.G.Gulamov, U.G.Gulyamov,Kh.D.Kabulniyazov,
V.Sh.Navothny, V.I.Petrov, and G.M.Chernov
Institute of Nuclear Physics, Academy of Sci. of the Uzbek SSR,
Tashkent

ABSTRACT

General parameters characterizing single particle inclusive distributions of shower particles and their dependence on the multiplicity are discussed in πA interactions at 200 Gev. The qualitative comparison of data presented with predictions of several popular models for hadron-nucleus collisions are performed.

Angular spectra of charged secondaries are one of the basic sources of information on the single particle distributions in hadron-nucleus interactions provoking the considerable interest last years in connection with the hope to clarify the mechanism of multiple production at high energies.

The present paper devoted to the study of angular distributions of shower particles in inelastic π^--nucleus (πA) interactions at $p_0 = 200$ Gev/c and their dependence of various parameters characterizing incoherent events. Multiplicity distributions and two particle correlations in these collisions were discussed in other papers; some preliminary results on angular characteristics based on a part of the total statistics were published in the papers [1, 2].

The experimental material analyzed in this report consists of 4853 inelastic πA events and (for comparison purposes) 1333 events classified as interactions on the free and quasifree nucleons ($\pi^- N$ events). These events were systematically selected for measurements without any omissions after the "along the track" scanning of emulsion plates exposed to 200 Gev/c π^-- mesons at the FNAL accelerator (Batavia). The data for πA and $\pi^- N$ collisions belong to the different lengths of scanned track. The abovementioned numbers of πA and πN events do not include coherent reactions on emulsion nuclei (those are analyzed in details in the paper [3]); additionally we have statistically excluded interactions on the free emulsion hydrogen from πA events. So, the considered sample of πA

events consists of incoherent interactions with C,N,O (~26%) and Ag, Br (~74%) nuclei. More detailed information is given in the refererces [1, 4].

As angular variable we are using the quantity $\eta = -\ln\tan\theta/2$, where θ is the polar angle in the laboratory system. This is the so called pseudorapidity giving for secondary pions a good approximation of longitudinal rapidity $y = (1/2)\ln\left[(E+p^{\shortparallel})/(E-p^{\shortparallel})\right]$. In cosmic ray physics the quantity $\lambda = \lg\tan\theta$ is used usually and it is easy to connect η and λ using the relations for the mean values and standards

$$\begin{aligned} \langle\lambda\rangle &\simeq -0.43\,(\langle\eta\rangle-0.7), \\ \sigma(\lambda) &\simeq 0.43\,\sigma(\eta). \end{aligned} \qquad (1)$$

The accuracy of these formulae at considered p_0 is not worse than a few % for all analyzed groups of events; the first formula is true, with the same accuracy, also for the separate tracks at $\eta \gtrsim 1$.

The existing theoretical approaches to hadron-nucleus interactions can be separated conventionally into two large groups: models with the repeated independent collisions, where hadron-nucleus interactions can be considered as some superposition of intranuclear collisions with the separate nucleons; the second class consists of models, where the effective target at high energies should be considered as structureless medium. In correspondence with the axiomatics of these models the parameter, coniotioning structure of the "average" event is, in the first class, the effective number of intranuclear collisions (ν), and, in the second class, the thickness of nuclear matter interacting with a projectile nucleon. Both these quantities, stricly speaking, are not measurable experimentally, however it is widely assumed that their's measure (in average) is given by the number of slow (heavily ionizing or h-) particles emitted by the target nucleus. It has been pointed out in the number of papers (see, for instance [4]) that multiplicity and other characteristics of produced particles under go the most rapid variation with the change in the number of so called g-particles (consisting mainly from recoil protons). So, we can conclude, if the abovementioned circumstance is true, the best quantity characterizing $\langle\nu\rangle$ or the mean mass of effective target is n_g . We are using n_g as the basic parameter characterizing hA interactions in this sense; due to proportionality (Fig.1) of n_g and n_h (h-particles include all the heavily ionizing secondaries having the velocity $\beta \leq 0.7$) all the conclusions about n_g-dependence of considered characteristics are true also for n_h-dependencies (we have tested this directly too).

Fig.2 shows inclusive η-distributions of shower particles in A and N interactions at 200 Gev/c as well as in π^-A interactions with the different n_g. In Fig.3 we have plotted the difference $d=(1/\sigma_{in}^{\pi A})(d\sigma^{\pi A}/d\eta)-(1/\sigma_{in}^{\pi N})(d\sigma^{\pi N}/d\eta)$, and the ratios $r=\frac{\sigma_{in}^{\pi N}}{\sigma_{in}^{\pi A}}(d\sigma^{\pi A}/d\eta)/(d\sigma^{\pi N}/d\eta)$ for the quoted groups of π^-A interactions. One can see, that:

1. η - distributions in $\pi^- A$ interactions differ significantly from those in $\pi^- N$: in $\pi^- A$ collisions they are enriched by particles with small η and simultaneously they have less number of the most fast (leading) particles. These qualitative features of η-spectra are well known for different projectiles in the wide energy interval. "Deformations" of angular distributions are the stronger, the larger n_g (and/or n_h); this means obviously that the number of slow particles is, in some extent, the measure of the influence of target-nucleus to the production of particles.

2. The shapes of η -spectra in $\pi^- A$ and $\pi^- N$ interactions are different too, they undergo very specific deformation with the growth of n_g (Fig.2). Distributions in the majority of $\pi^- A$ groups are characterized by the bimodal structure and contribution of the "second" maximum, which is small at small n_g , becomes dominant at large n_g. It is important to notice here that bimodal structure in η-spectra can arise even at the absence of any structure in distributions of longitudinal rapidities due to merely kinematical effects [5] , but, on the other hand, the bimodality does not display itself in proton-nucleus interactions at the same p_o = 200 Gev/c [2] although the influence of secondary protons at accelerator energies should be negligible. This indicates that bimodality is the property inherent to pion-nucleus interactions at high energies.

The noted here changes of η-spectra in πA interactions comparatively with πN collisions, dependence of η-spectra on n_g and the difference between spectra in pA and πA interactions at the same p_0, seem to be hardly explained by the simple versions of "tube" model [6,7], where production in hA interactions is identical entirely to that in hN collisions at some higher energies in the centre of mass system. It should be noted, that the composite nature of emulsion having two groups of nuclei (C,N,O and Ag,Br) cannot be responsible to the observed deformation of η-spectra, since: 1) groups of hA interactions with $n_g \geq 3$ consist of Ag,Br events solely, 2) pA interactions in emulsion do not show bimodality, and 3) the direct separation of πA interactions into collisions with C,N,O and Ag,Br nuclei performed in accordance with method described in [4] gives the same results (Fig.5).

More detail comparison with predictions of coherent tube model is given below.

3. The differences d and ratios r of inclusive distributions on nuclear and nucleon targets shown in Figs.3,4 demonstrate the following characteristic property. The values of pseudorapidity η_0, at which $\frac{1}{\sigma_{in}^{\pi A}} \frac{d\sigma^{\pi A}}{d\eta} = \frac{1}{\sigma_{in}^{\pi N}} \cdot \frac{d\sigma^{\pi N}}{d\eta}$ does not depend within experimental errors on the number of slow particles ($\eta_0 \simeq 5$), being consistent with the Gottfried's EFC model [8], which predicts that the value of ($y_0^* = \eta_0 -$ Arch γ_c), should depend on p_0 only, being independent on A. In the multiperipheral model (MPM)[9] the value of y_0^* in contrast, should

depend on A, being independent on p_0 . The data presented in Fig.3,4 do not display any A dependence of η_0 , but we cannot state the inconsistence with the MPM due to the qualitative character of prediction. On the other hand, there is the doubtless A dependence of shape of the "surpluses" d : distribution demonstrate some structure and their centers displace towards small η . This circumstance contradict the EFC model. Moreover, the width of distributions, presented in Fig.3 is larger considerably that in hN interactions at small energies (corresponding to amount of energy carried out by the slow Gottfried's hadrons); this contradiction of experimental data with the EFC model has been stated earlier in the paper [10] .

It should be noted, however, that for the certainty the analysis of data in the wide energy interval is needed.

4. n_g - dependence of ratios of inclusive distributions r is conditioned by the value of η . The most clearly this can be seen from Fig.6. At $\eta > \eta_0 \approx 5$ r decreases with growing n_g in such a way that the larger η , the less r (the diminishing in the number of leading particles); this contradicts the models including the "passivity" of primary hadrons after the first intranuclear collision.

At $n_g \leqslant 7$ the dependence $r(n_g)$ can be fitted satisfactorily by linear dependences, at larger n_g there is the effect of "saturation" r present (Fig.6). These properties of ratio r agree qualitatevely with expectations on the basis of parton picture for hA interaction [11] .

Let us consider some other general characteristics of angular spectra in $\pi^- A$ collisions. Figs.7,8 show n_s and n_g dependences of centers $\langle\eta\rangle$ and standard deviations $\sigma(\eta)$ of η -distributions (Figure 7 examplifies n_h dependences too). Fig.8 shows additionally the mean values $\langle\sigma(\eta)\rangle$ of standard deviations of η -spectra from individual $\pi^- A$ collisions. As seen from Fig.7, $\langle\eta\rangle$ decreases monotonically with increasing multiplicity of all types of particles (there is the characteristic "oscillations" between $\langle\eta\rangle$ for the odd and even multiplicity events ar small n_s, analogical to those observed in πN collisions and caused by charge conservation in peripheral interactions). Let us assume, for the estimate of dependence of on the number of intranuclear collisions ν , that $\langle\nu\rangle \sim n_g^{1/2}$ (or $n_h^{1/2}$). The justification of this assumption is given by the fact, that $\langle\nu\rangle \sim A^{1/3}$ and n_g (or n_h) $A^{2/3}$ (see, e. g. [4]). The data presented in Figs.7 c,e do not contradict the linear dependence of $\langle\eta\rangle$ on $\langle\nu\rangle$, i.e. on $A^{1/3}$. This is inconsistent with predictions of the "tube" type models [6, 7] (see [12]).

The another interesting property of η -spectra in hA interactions is the independence of their wigths $\sigma(\eta)$ on the number of slow particles (Fig.8). This is true also (except the region of very small n_g, n_h, where the larger part of cross section is governed by peripheral interactions with the one intranuclear nucleon) for the standards of individual collisions. The analogical property has been demonstrated earlier in proton-nucleus interactions in the range 20-200 Gev/c [12].

This peculiarity of angular distributions can be crucial for several models of hA interactions. So, for instance, it contradicts the coherent tube model [7], which predicts that angular spectra in hA interactions are identical to those in hN collisions (with the displacement in the rapidity scale (1/6) lnA at larger by$\sqrt{\nu}$ energy in the center of mass system. According to this model, the standard of spectrum $\sigma(\eta)$ must increase with increasing ν (i.e. n_g, n_h), since

$$\left.\frac{[\sigma(y)]hA}{[\sigma(y)]hN}\right|_{p_0=\mathrm{const}} = \frac{\ln(\nu s)}{\ln s} = 1+\mathrm{const}\cdot\ln\nu \quad (2)$$

It should be noted, that application of η (instead of y), the consideration of spectra for all shower particles (instead of produced pions) cannot affect the last conclusion since the logarithmic growth of dispersions of η - distributions for charged particles in hN interactions is the well established experimental fact. So, one can conclude, the independence of $\sigma(\eta)$ on n_g (or n_h) - is the result contradicting the basic assumption of the coherent tube model.

The general properties of angular spectra of relativistic particles in nuclear interactions considered here seem to give the sensitive test for theoretical approaches to the problem. We would like to stress once more that the absence of quantitative calculations according to concrete models makes it difficult to give more certain conclusions about the applicability of nuclear production models.

We thank the managements of the FNAL and Division of Nuclear Physics of the Academy of Sci. of the USSR for organization of experiment, The work carried out by the technical staffs of our laboratories is acknowledged gratefully.

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FIGURE CAPTIONS

Fig.1 - n_h and n_g as functions of n_g in π^-A interactions at 200 Gev/c.

Fig.2 - Inclusive η -distributions for: (a) π^-A and π^-N ; (b) for π^-A interactions with different n_g.

Fig.3 - d as function of η for different n_g groups of π^-A events.

Fig.4 - r as function of η for different n_g groups of π^-A events.

Fig.5 - Inclusive η -distributions in $\pi^-N(1)$, $\pi^-CNO(2)$ and $\pi^-AgBr(3)$ collisions at 200 Gev/c.

Fig.6 - n_g dependence of the ratio $r(\eta)$: 1 + 9 - the data for $\eta < 0$, $0 < \eta < 1, \ldots,$ $6 < \eta < 7$ and $\eta \geq 7$, respectively. The straight lines are fits at $n_g \leq 7$.

Fig.7 - Dependence of $\langle\eta\rangle$ on n_s (a), n_g (b), $\sqrt{n_g}$ (c), n_h(d) and $\sqrt{n_h}$ (e) in π^-A interactions at 200Gev/c.

Fig.8 - Dependence of $\sigma(\eta)$ (the open data circles) and $\langle\sigma(\eta)\rangle$ (the black points) on n_s and n_g . The solid and dotted curves reproduce values of $\sigma(\eta)$ and $\langle\sigma(\eta)\rangle$ respectively, for π^-A interactions with $n_s \geq 2$. The triangles shows the data from π^-N interactions.

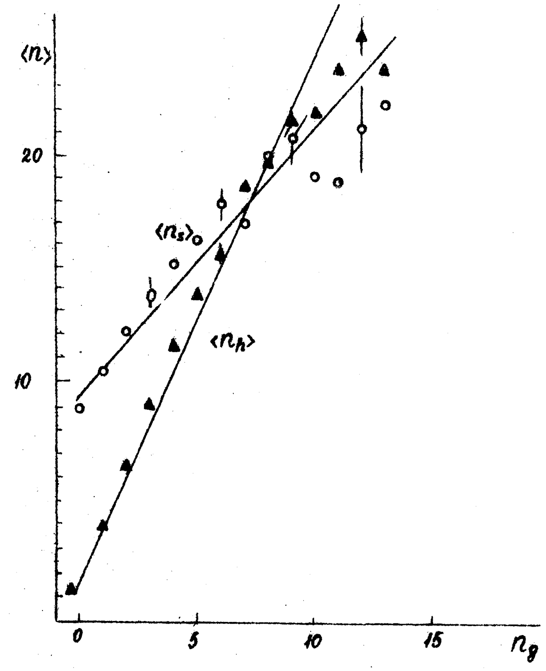
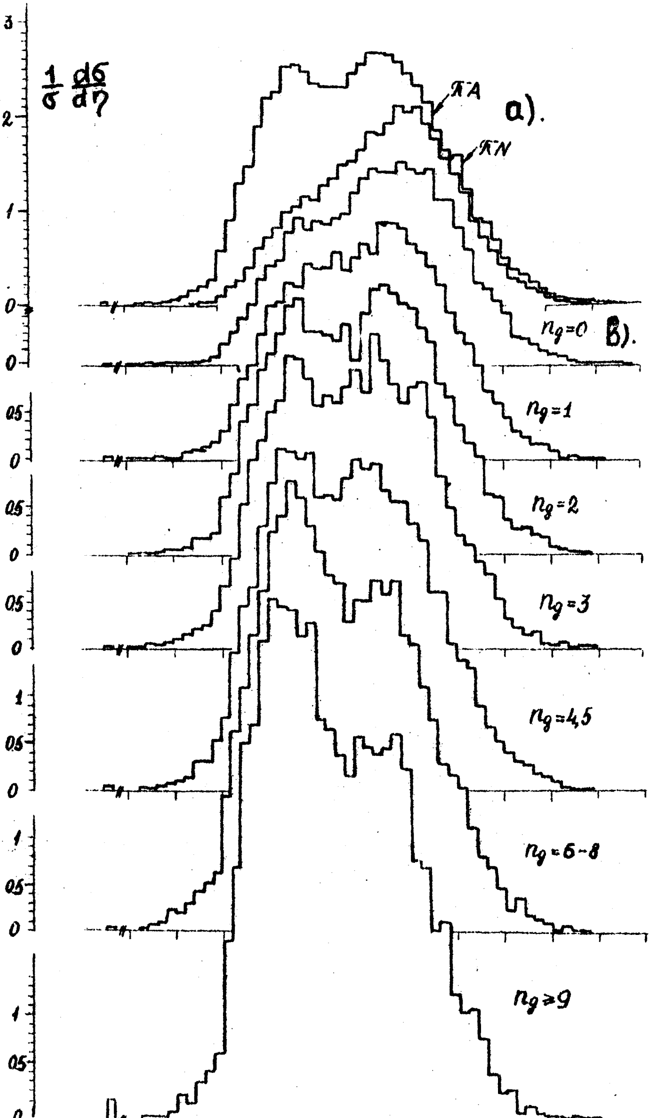


Fig.1.



$\frac{1}{\sigma}\frac{d\sigma}{d\eta}$
a).
πA
πN
b).
$n_g=0$
$n_g=1$
$n_g=2$
$n_g=3$
$n_g=4,5$
$n_g=6-8$
$n_g\geq9$
3
2
1
0
0.5
-2
-1
0
1
2
3
4
5
6
7
8
η

Fig.2.

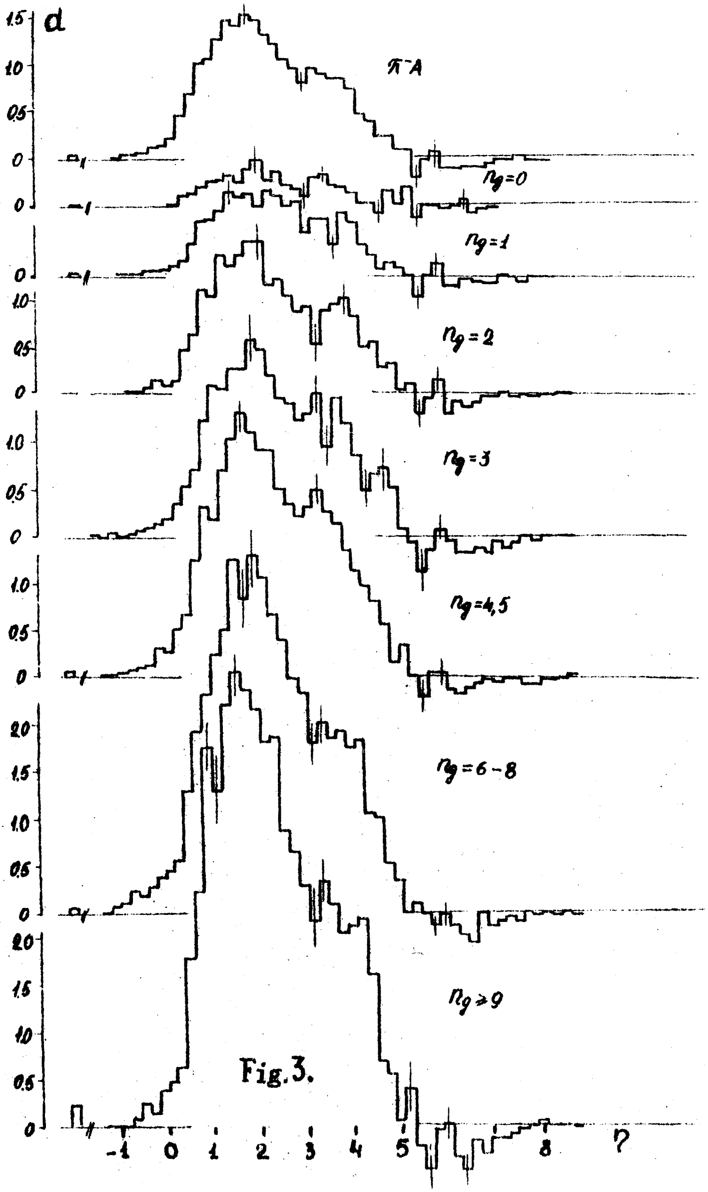


Fig.3.

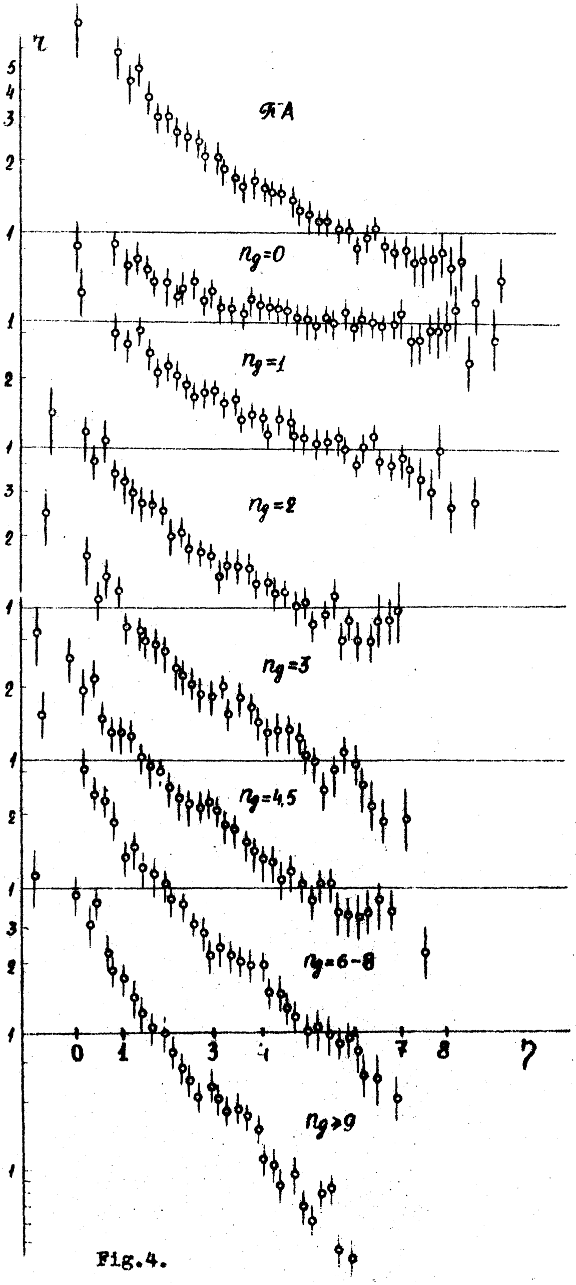

η
5
4
3
2
1
π⁻A
n_g=0
1
n_g=1
2
1
3
n_g=2
2
1
n_g=3
2
1
n_g=4,5
2
1
3
2
n_g=6-8
1
0
1
3
4
7
8
η
n_g>9
1

Fig.4.

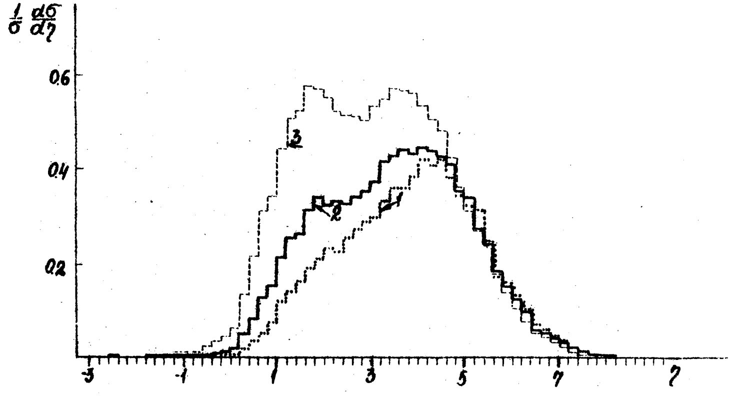
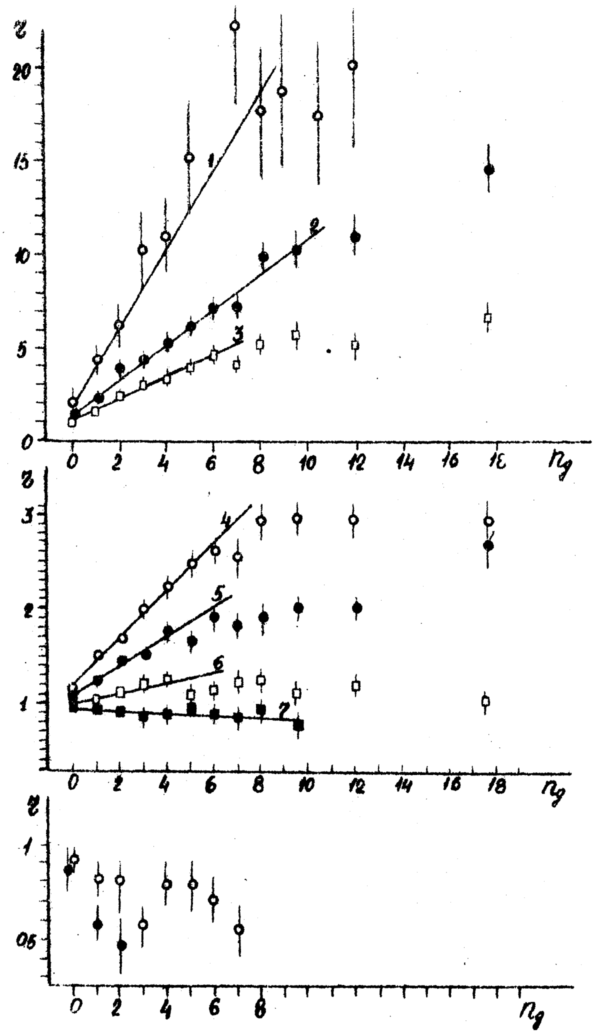


Fig.5.



z
20
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12
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18
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0
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z
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8
n_g

Fig.6.

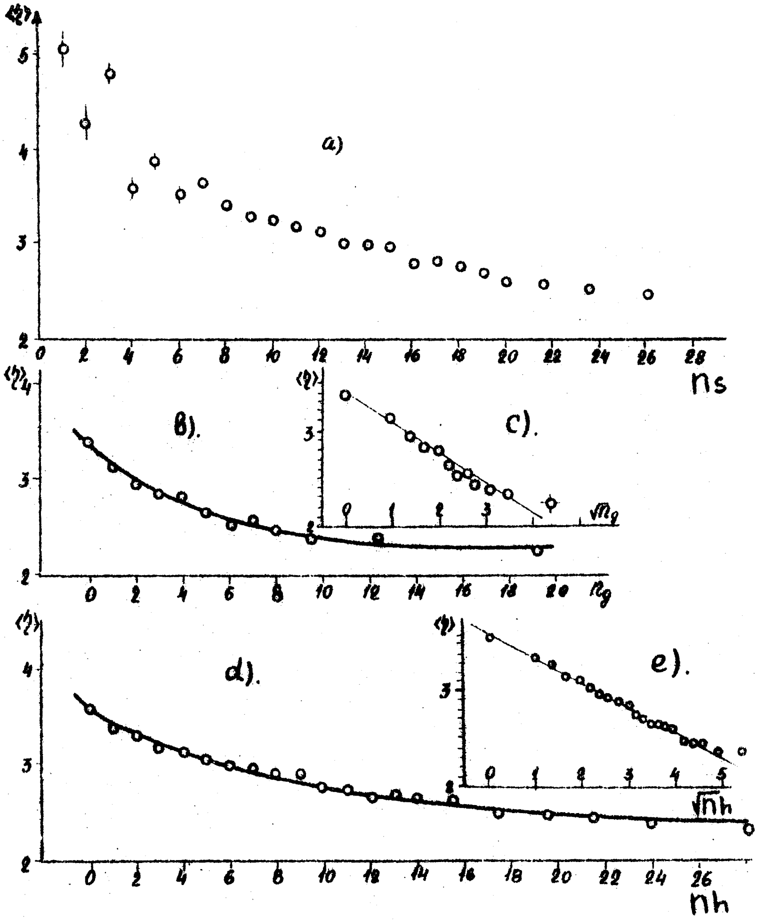

Fig.7.

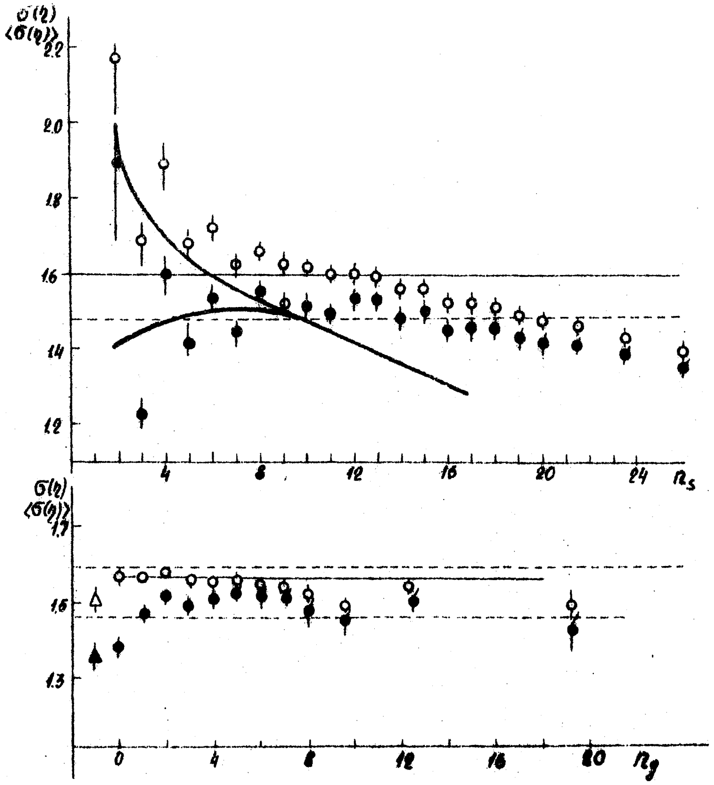

Fig.8.

Т - 09147

Подписано в печать 26 апреля 1977 года.

Заказ № 235.   Тираж 100 экз.

Отпечатано на ротапринте в ФИАН СССР

Москва, В-312, Ленинский проспект, 53