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ALMA-ATA-GATCHINA-MOSCOW-TASHKENT-COLLABORATION

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ABSTRACT

Pseudorapidity and azimuthal two-particle correlations have been investigated in pion-nucleus interactions at 200 Gev/c. The considerable attention has been devoted to the exclusion of kinematical and pseudo.- correlations. The qualitative comparison of experimental results with some theoretical models has been performed.

The aim of the present paper is in the study of two-particle correlations between relativistic secondaries produced in incoherent pion-nucleus collisions at p_0 = 200 Gev/c and their dependence on multiplicity of different types of secondary particles. Experimental data on correlations in hadron-nucleus interactions at high energies are rather poor [1-6], although they could be very useful in discrimination of different models of multiple production (see, e.g. [7]). The preliminary results of this investigation based on a part of the total statistics and the comparison of correlations in pion-nucleus and proton-nucleus collisions at 200 Gev/c have been reported earlier [6] .

1. The experimental material analysed in this paper consists of 4853 inelastic interactions of 200 Gev/c π^--mesons with nuclei (π^-A events) and 1333 events satisfying to the criteria of pion-nucleon (π^-N) collisions, which were recorded and measured in nuclear emulsions exposed at the FNAL (Batavia). The scanning of emulsion plates has been carried out by the fast "along the track" method excluding any discrimination of the small multiplicity events. The selection of events for measurements has been done systematically without any omissions (π^-A and π^-N samples belong to the different lengths of scanned track). The abovementioned numbers of π^-A and π^-N events correspond to the ensembles purified from coherent reactions on nuclei [8] and from interactions on the free hydrogen of emulsion (the latters were excluded statistically only

from πN events). Thus, π^-A interactions analyzed in our paper correspond to the CNO (~26 %) and AgBr (~74%) nuclei of emulsion.

II. To analysis of two-particle correlations among shower particles along the longitudinal axis we have used the well known correlation functions

$$C_2(\eta_1,\eta_2) = \frac{1}{\sigma_{in}} \cdot \frac{d^2\sigma}{d\eta_1 d\eta_2} - \frac{1}{\sigma_{in}^2} \cdot \frac{d\sigma}{d\eta_1} \cdot \frac{d\sigma}{d\eta_2} \qquad (1)$$

$$R_2(\eta_1,\eta_2) = \sigma_{in} \cdot \frac{d^2\sigma}{d\eta_1 d\eta_2} \Big/ \frac{d\sigma}{d\eta_1} \cdot \frac{d\sigma}{d\eta_2} - 1 \qquad (2)$$

where as arguments we take the "quasirapidity" in the centre of mass frame of πN collisions (or π^-- intranuclear nuclon in the case of π^-A interactions):

$$\eta = -\ln(\tan\theta/2) - \mathrm{Arch}\,\gamma_c \qquad (3)$$

(θ is the polar angle and γ_c is the Lorentz factor of the center of mass frame in the laboratory system).

The main difficulty in the study of correlations by means of correlation functions is in the quantitative account of strong pseudocorrelations arising from the broad multiplicity distribution of shower particles (n_s) and dependence of one-particle distributions ($d\sigma/d\eta$) on n_s as well as from the trivial correlations due to the kinematical constraints in individual events (the energy-momentum conservation and so on) [1] . In view of this we have calculated correlation functions in events simulated by the Monte-Carlo method for all experimental groups (π^-N, π^-A, π^-A at the fixed n_s (see below) and so on) in accordance with the simple independent emission model (IEM).

In this model:

a) the emission angles of secondary particles are statistically independent,

b) one-particle distribution $d\sigma/d\eta$ in the each event reproduces the empirical semiinclusive distribution $(d\sigma/d\eta)$ in collisions with the appropriate n_s for the ensemble under consideration,

c) n_s - distribution in the each ensemble of simulated events reproduces the empirical n_s-distribution of the real ensemble.

In the following we denote the correlation functions calculated in the IEM ensembles by C_2^o, R_2^o and differences C_2^{exp}- C_2^o, R_2^{exp}- R_2^o by C_2' and R_2', respectively.

Let us discuss now to what extent one can treate the non-zeroth values of C_2' and R_2' as manifestation of dynamical correlations.

In the papers [4, 5] the comparison of correlation functions calculated in the inclusive ensembles of random stars generated according to the cilindrical phase-space model (CPS) and IEM has been done in the energy range 20 - 200 Gev. Multiplicity distributions and dependences of $(d\sigma/d\eta)$ on n_s in those ensemnles were the same, the only difference was taken into account of conservation laws in the CPS events. Multiplicity distributions exactly and $(d\sigma/d\eta)_{n_s}$ approximately (the noticeable deviations were observed only at small n_s) reproduced the observed ones in the real hadron-nucleon collisions at the considered energies. The analysis showed that conservation laws in the form inherent to the statistical theory of multiple production diminish weakly C_2 and R_2 in comparison with $C_2^{\bullet}$ and $R_2^{\bullet}$ at $\Delta\eta \equiv |\eta_1-\eta_2| \leq 2$ (the "short-range" correlations) and increase theirs at large $\Delta\eta$. This result qualitatevely is comprehensible: the action of conservation laws leads to the supression of fluctuations such as accumulation of particles (the nearer this accumulation to the end of the rapidity interval, the stronger the supression) permitted by the independent emission. For the following it is important that the omission of conservation laws in the IEM *) increases only the "dynamical significanc " of the enhancements $C_2' > 0$, $R_2' > 0$ at small $\Delta\eta$.

The other commant concerns the correlation functions structure itself depending on densities calculated in ensembles of events (inclusive, semiinclusive or exclusive). Unfortunately the majority of works on correlations ignore the important and long established fact: these correlation functions are sensitive not only to correlations of particles from individual events (just these are the most interesting), but also to the degree of heterogeneity of events constituting the considered sample. Even the exclusive ensemble consisting from two types of IEM events with different angular distributions ($d\sigma/d\eta$) demonstrates significant pseudocorrelations (with

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*) It should be noted that due to the practical impossibility of separating of secondaries in nuclear interactions to "produced" during the act of collision and emitted ones by the nucleus after the act (as well as due to impossibility of determination of the real target mass), the precise account of kinematical correlations cannot be done without the model (i.e.

"short-range" character). Although in hadron-nucleus interactions such heterogeneity provokes the physical interest (the different production mechanisms), in hadron-nucleus collisions this interest is problematic. In fact, since the ensembles with the fixed n_s , for instance, consist of events corresponding to the different number of intranuclear collisions (or to different length of tube of nuclear matter and so on - the model language is immaterial her), the heterogeneity of events constituting given semiinclusive ensembles should manifest itself, even at the single production mechanism.

Summarizing, we can conclude that the precise model-independent search for dynamical correlations in hadron-nucleus interactions by means of correlation functions seems to be impossible; the reliable conclusions on the consistence of some model approach with nuclear production data can be obtained only by the direct comparison of experimental data with the values of correlation functions calculated in the framework of that model, with the account of experimental conditions. The most attractive way is the realistic simulation of events according to the tested hypothesis; the best pattern of such concretization of physical model is given, to our opinion, by the multiperipheral cluster model, developed in papers [9] for hadron-nucleon interactions.

"speculative") assumptiens.

Nevertheless, the empirical information on correlation functions and their dependence on different characteristics in hadron-nucleus collisions can be useful for the comparison with the appropriate hN data. The other reason justifying the present paper is in the possibility of the qualitative comparison of experimental results with the expected ones from some models for hadron-nucleus interactions.

III. The number of slow heavily ionising particles (n_h) in nuclear interactions is the commonly using measure of the "thickness" of nuclear matter on the path of the incident hadron. Since characteristics of hadron-nucleus interactions depend the most strongly on the number of g-particles (gray particles consisting mainly from the recoil protons), just n_g will be used as such measure in our investigation. Table 1 presents the general characteristics of five groups of πA interactions; variation of n_h leads to the analogical results, and n_h for these groups are listed too.

Selected example of values of the "correlators" C_2, R_2, C_2' and R_2' for different groups of interactions are shown in Figs 1-5. Let us discuss those.

a) The values of correlation functions (especially) C_2) in nuclear interactions differ significantly from those in $\pi^- N$ collisions (Fig. 1,3); it is seen nevertheless that the considerable amount of this "effect" arises due to trivial pseudocorrelations coming from the difference in multiplicity and one-particle ($d\sigma/d\eta$) distributions. Correlator R_2 is less sensitive to these pseudocorrelations, and C_2' , R_2' represent, in the first approximation, the "dynamical surplus". The main difference between correlators in πN and πA interactions belongs to the target fragmentation region. This, of course, is not surprising, since, as well known, the significant difference between one-particle distributions and the abovementioned heterogeneity of πA interactions manifest themselves just in this region.

b) Correlator R_2 decreases when the thickness of intranuclear matter (or the number of intranuclear collisions) increases (Fig.3). The function C_2 demonstrates the reverce behaviour, but this circumstance is trivial. As regards the "dynamical" surpluses C_2' and R_2' , it should be remembered that the action of conservation laws weakens with the growth of n_g (due to correlations between n_s and n_g). Hence, the degree of understating of C_2' and R_2' caused by the using of the IEM (see discussion in the Section II) grows when n_g decreases. Therefore, functions C_2' and R_2' also demonstrate the decrease of correlations with the growth of nuclear matter thickness.

The decrease of correlator R_2 with the number of knock-out nucleons (protons) agrees well (although qualitatively) with the predictions of the parton model for hadron-nucleus interactions taking into accaunt the limited energies of particles participating in intranuclear collisions [7] .

c) The data presented in Figs 2,4,5 show the presence of positive short-range correlations in hadron-nucleus interactions, which cannot be explained by trivial and kinematical factors.

We have noted in the Section II that the surpluses $C'_2 > 0$ and $R'_2 > 0$ can be caused by the heterogeneity of hadron-nucleus interactions too. The direct indication to the significance of such heterogeneity can be seen, for instance, from the comparison of functions R'_2 for the full sample of $\pi^- A$ interactions (Fig.2) and for groups with different n_g (Fig.4,5): if the idea about the proportionality of n_g *) and the number of intranuclear collisions ν is correct, then the full sample of $\pi^- A$ events must be (especially in the target fragmentation region) more heterogeneous than the compatarively narrow groups of n_g, and correlations (in terms of R'_2 and C'_2) must be larger. Just this is observed in experimental data.

We have stated, nevertheless, that correlations (R'_2 and R_2) at small $\Delta\eta$ have the tendency to decrease with the growth of n_g (except the region of very small η, where the effects of heterogeneity will be maximal). Since the heterogeneity of nuclear events, probably, does not decreases **) from one group to another (see our definition of groupe-Table 1), we can conclude from this tendency that there is the contribution of "geniune" dynamical correlations.

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*) The relation has, probably, the nonlinear form, since $\langle\nu\rangle \sim A^{1/3}$ and $\langle n_g\rangle \sim A^{2/3}$ [10].

**) This intuitive assumption is veryfied by the Monte Carlo calculations according to simple model of repeated collisions [10].

d) The short- range character of observed correlations does not means that there are not the long-range correlations. It should be remembered that the values of C_2' and R_2' at $\Delta\eta \geq 2$ (see Section II) are not correct.

e) Although the quantitative model calculations are absent for hadron-nucleus interactions, we can give some qualitative conclusions (see above for the example with the parton model [7]). The significant difference in the form of correlators for $\pi^- A$ and $\pi^- N$ collisions (it is true also for pA and pN and pN interactions in the wide energy range [4,5]) seems to be inconsistent with some "tube" models, where hA interactions are analogical entirely to hN collisions (although at higher energies) [11, 12] . The another model contradicting to the presented data is (in accordance with [7]) the eikonal model, where only the leading particle interacts with intranuclear nucleons: in this model correlator R_2 in hA collisions is smaller than in hN only in the projectile fragmentation region.

IY. We have studied also two-particle azimuthal correlations by means of asymmetry

$$A = \left(\int_{\pi/2}^{\pi} \frac{d\sigma}{d\varepsilon} d\varepsilon - \int_{0}^{\pi} \frac{d\sigma}{d\varepsilon} \cdot d\varepsilon\right) \Big/ \int_{0}^{\pi} \frac{d\sigma}{d\varepsilon} d\varepsilon \qquad (4)$$

coefficient, where

$$\varepsilon_{12} = \arccos\left(\vec{p}_{11}\,\vec{p}_{12} / p_{11}\, p_{12}\right) \qquad (5)$$

is the angle between transverse momenta of shower particles in $\pi^- N$ and $\pi^- A$ interactions.

Fig.6 shows A as functions of n_s for πA interactions in comparison with πN data and CPS model predictions (the solid curve). The CPS calculations were done under assumptions [4] :
1) Multiplicity distribution of neutral pions at the fixed n_s obeys the truncated binomial law with the mean values corresponding to experimental data from the FNAL bubble chambers.
2) The presence of "unobservable" (i.e. not incoming to n_s) recoil nucleons has been taken into account in the average under assumption that nuclear densities obey the Saxon-Woods distribution.

As one can see from Fig.6, the azimuthal correlations such as asymmetry in πA interactions, being weaker than in πN collisions can be satisfactorily described by the simple statistical approach. The same is true for coplanarity coefficient (not shown here). Thus no effects are observed, which can be associated, for example, with the large transverse momenta of clusters and/or by large angular momentum transfer. It has been established in our preliminary report [6] that azimuthal effects do not change noticeably with the nature of projectile particle.

Finally, Fig.7 examplifies the dependence of A on $\Delta\eta$ - the relative dostance along the "longitudinal" scale for two considered particles for some selected multiplicities in πA interactions. Data do not display any dependence of A on $\Delta\eta$, inparticular, the short range correlations expected, for instance, in the simple versions of multiperipheral model.

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Table 1

Some characteristics of groups of $\pi^- A$ interactions

Group	n_g	$\langle n_g \rangle$	$\langle n_h \rangle$	$\langle n_s \rangle$
1	0	0	1,2±0,1	8,9 ± 0, 1
2	1	1	3,9±0,1	10,5 ± 0,2
3	2-3	2,4±0,1	7,5±0,1	12,8 ± 0,2
4	4-6	4,8±0,1	13,3±0,2	16,2 ± 0,3
5	≥7	9,3±0,1	19,3±0,2	17,8 ± 0,3
all $\pi^- A$	-	2,4±0,1	6,9±0,1	12,2 ± 0,1

FIGURE CAPTIONS

Fig.1 - Example of inclusive correlation functions $C_2(\eta_1, \eta_2)$ and $R_2(\eta_1, \eta_2)$ in $\pi^- A$ (the full circles) and $\pi^- N$ (the open circles) interactions. The curves represent the IEM (see text) for $\pi^- A$ (the solid curves) and N (the dotted ones) events.

Fig.2 - Inclusive correlators $C_2'(\eta_1, \eta_2)$ and $R_2'(\eta_1, \eta_2)$ for the examples presented in Fig.1.

Fig.3 - Correlation functions $C_2(\eta_1, \eta_2)$ and $R_2(\eta_1, \eta_2)$ for different groups of $\pi^- A$ interactions (see also Table 1). The dotted curves reproduce $R_2(\eta_1, \eta_2)$ for $\pi^- N$ interactions.

Fig.4 - Correlators $C_2'(\eta_1, \eta_2 = \eta_1)$, $R_2'(\eta_1, \eta_2 = \eta_1)$ for different $\pi^- A$ events.

Fig.5 - Correlators $C_2'(0, \eta)$, $R_2'(0, \eta)$ for different groups of $\pi^- A$ interactions.

Fig.6 - Coefficient of azimythal asymmetry A as function of n_s in $\pi^- A$ and $\pi^- N$ collisions. The curve is the CPS predictions.

Fig.7 - Dependence of A on $\Delta\eta$ in $\pi^- A$ interactions for some selected n_s .

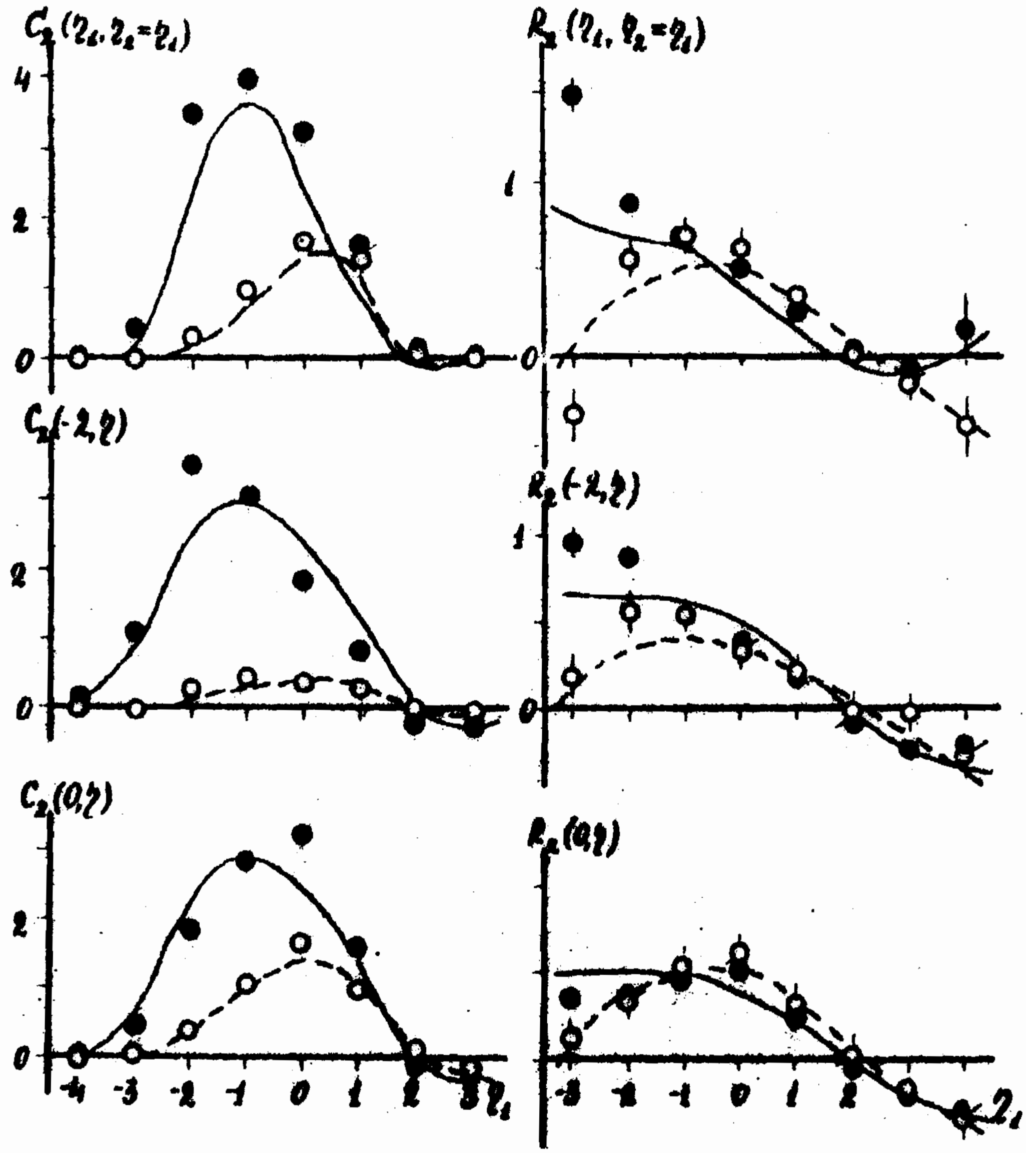


Fig.1.

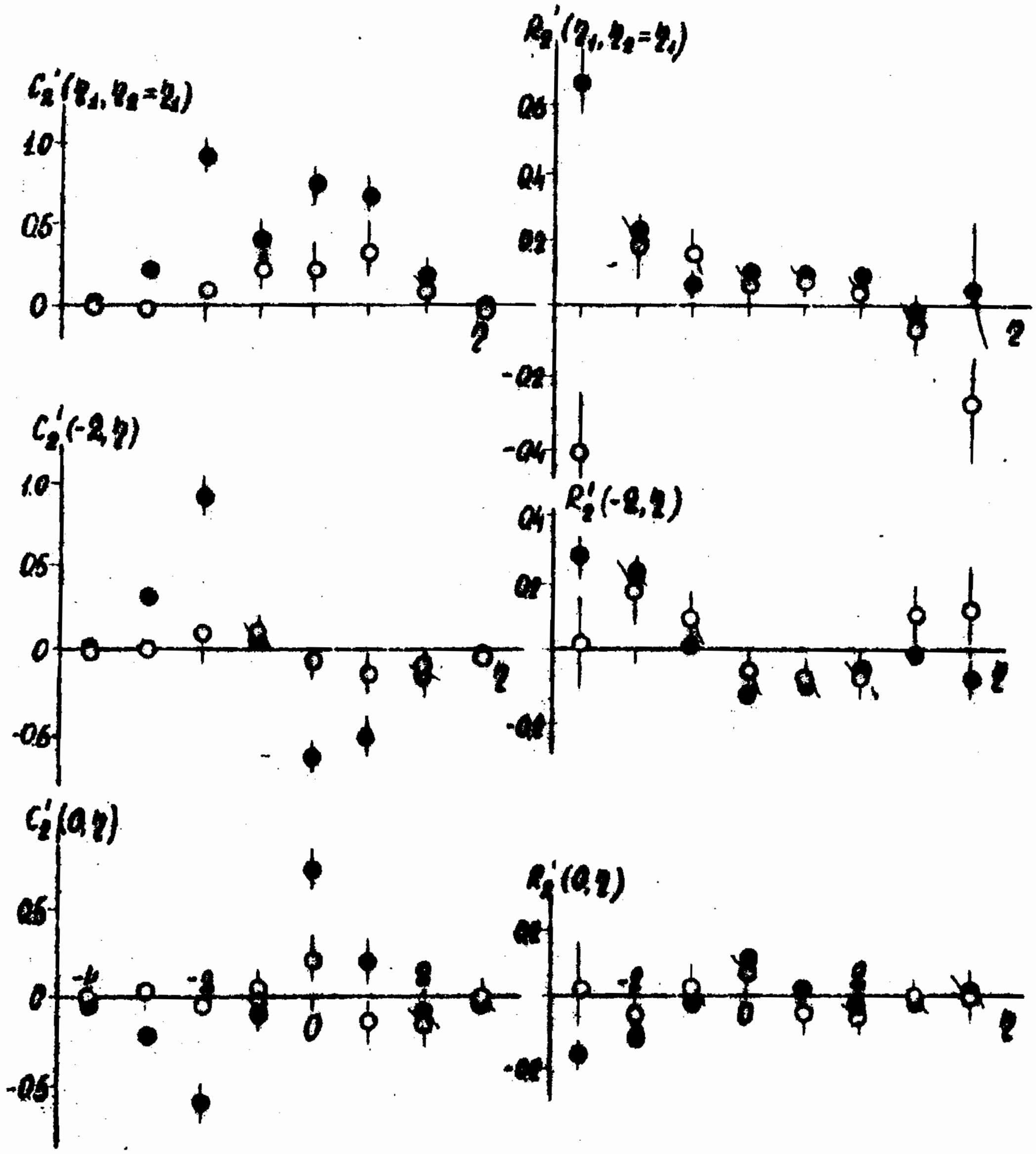

$C_2'(\eta_1, \eta_2=\eta_1)$
$R_2'(\eta_1, \eta_2=\eta_1)$
$C_2'(-2,\eta)$
$R_2'(-2,\eta)$
$C_2'(0,\eta)$
$R_2'(0,\eta)$

Fig.2.

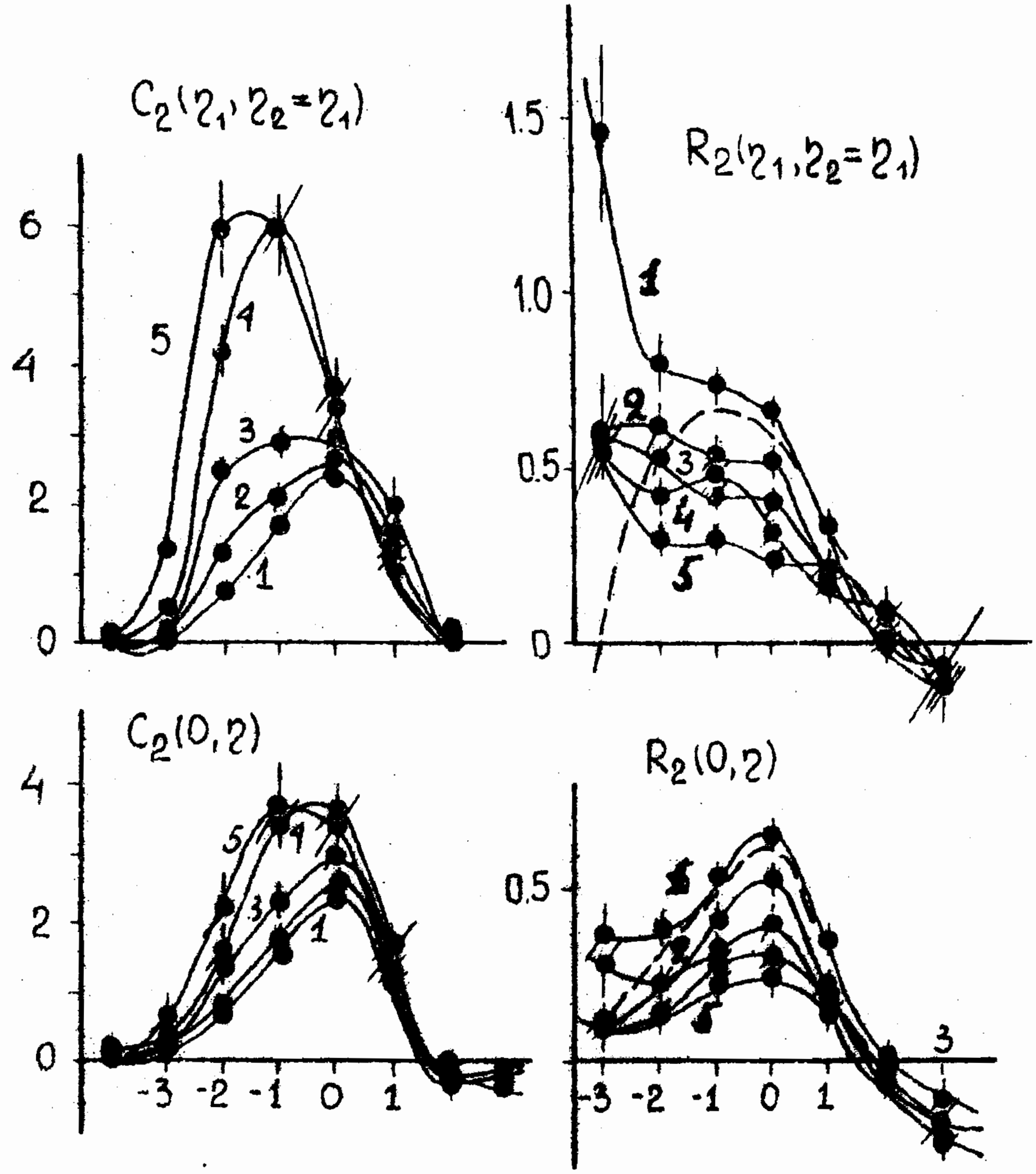
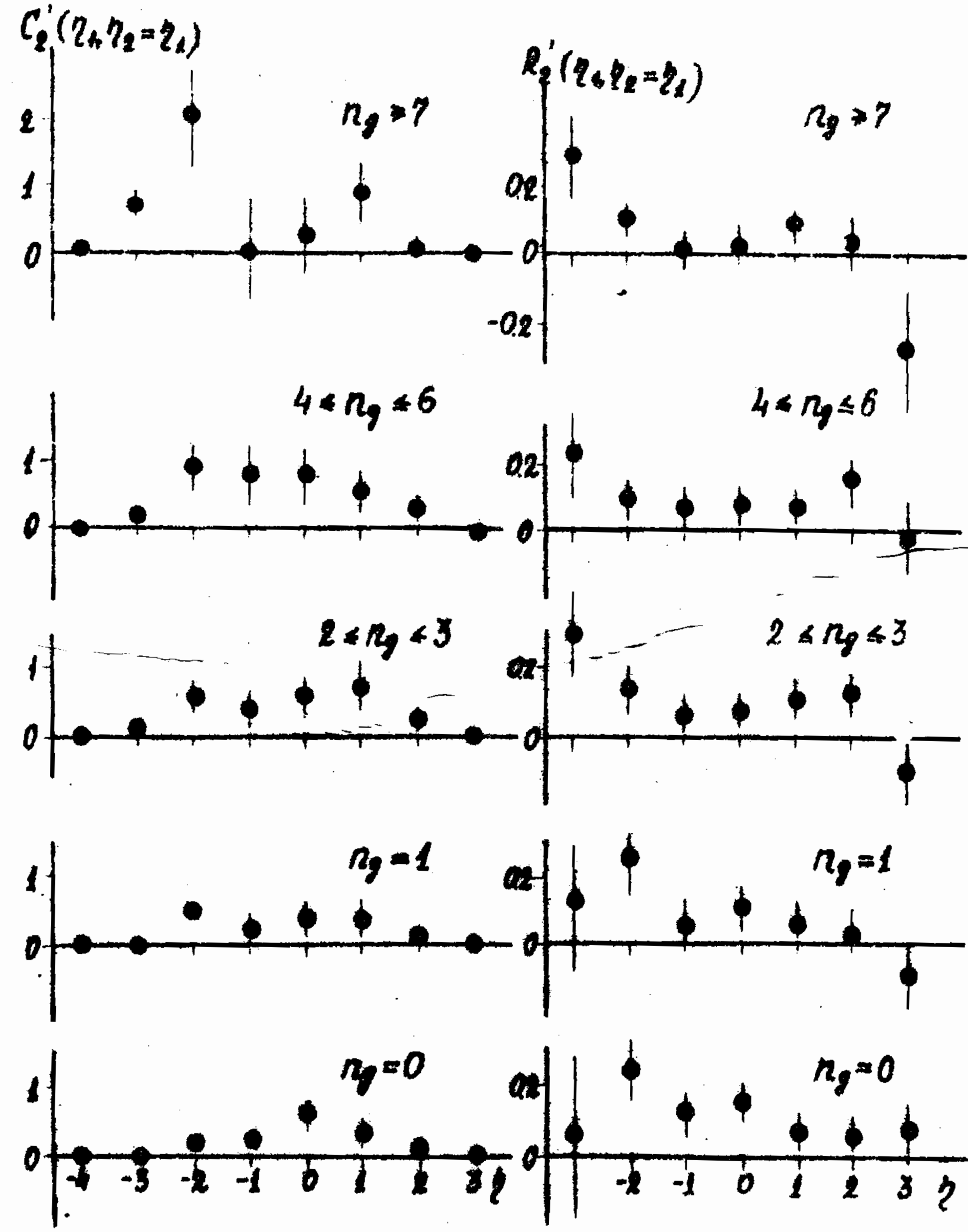


Fig.3.



$C_2'(\eta_1,\eta_2=\eta_1)$
$R_2'(\eta_1,\eta_2=\eta_1)$
$n_g \geq 7$
$4 \leq n_g \leq 6$
$2 \leq n_g \leq 3$
$n_g = 1$
$n_g = 0$

Fig.4.

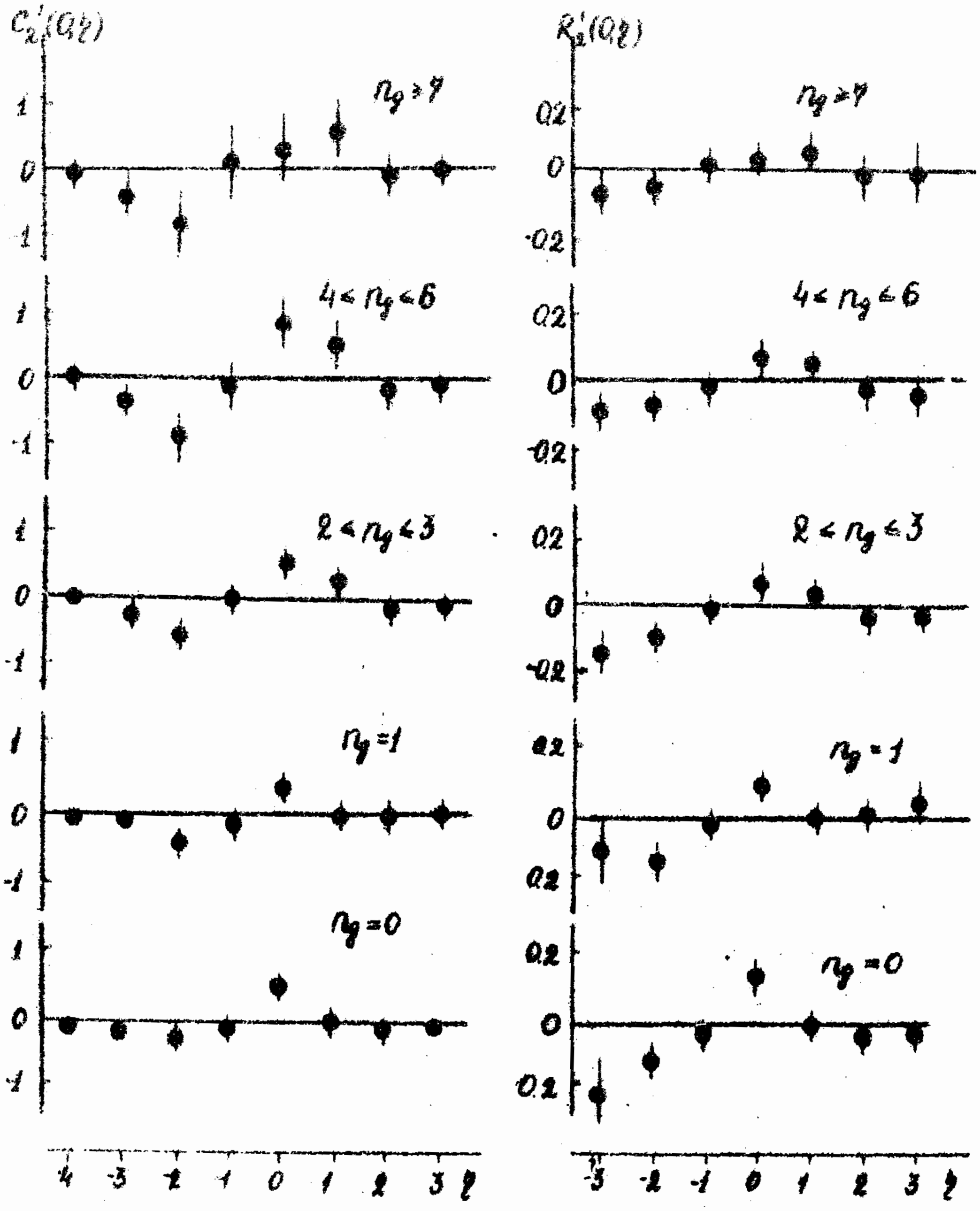


Fig.5.

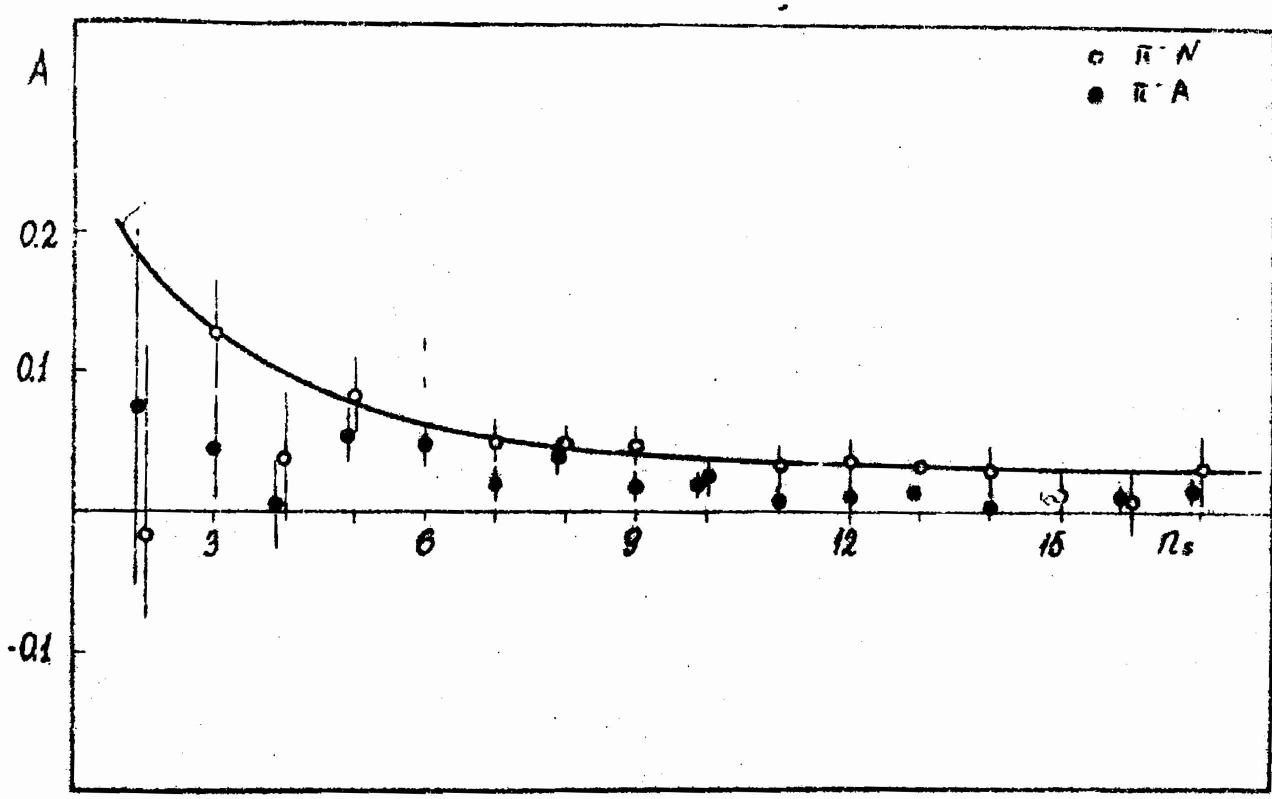


Fig.6.

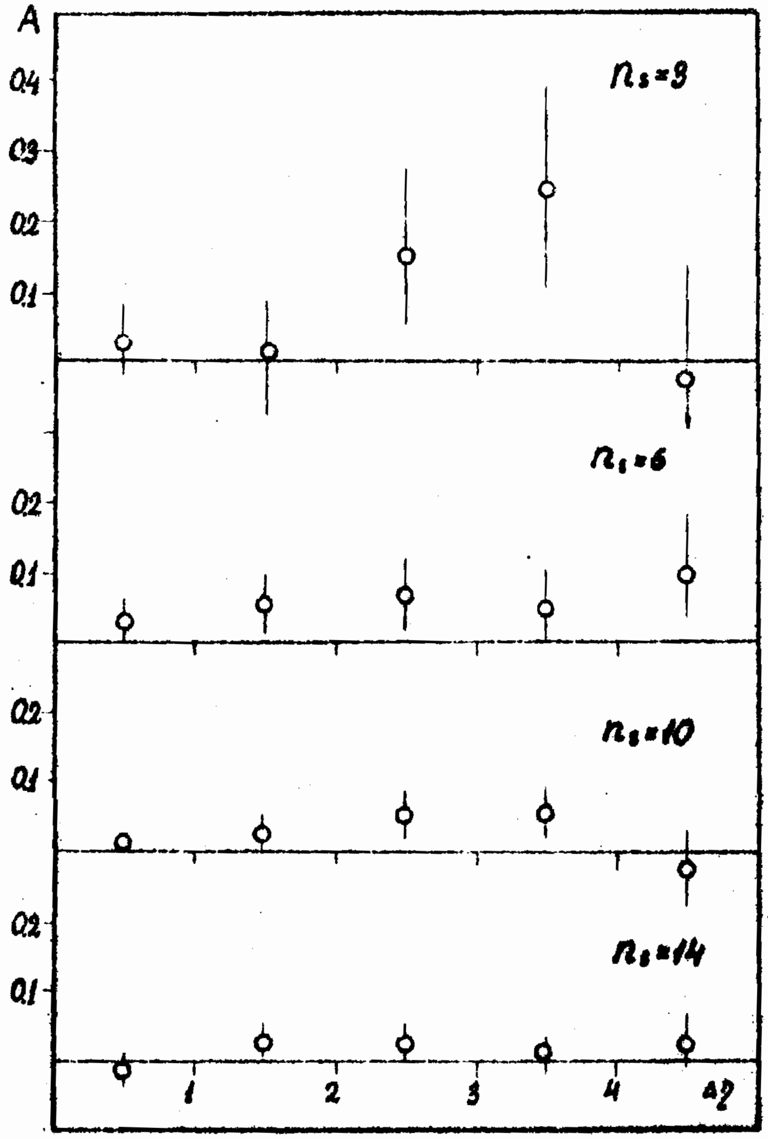


Fig.7.