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ANGULAR DISTRIBUTIONS IN PROTON-NUCLEUS COLLISIONS AT 67 AND 200 GeV

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Angular distributions of particles produced in collisions of protons with the nuclei of photographic emulsion are investigated in function of the excitation of the target nucleus. The data favour the models of elementary collisions in which particles are generated through an intermediate state.

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Following our previous letter about multiplicities in proton-nucleus collisions [1] we present in this note some empirical regularities found in the angular distributions of secondary particles produced in collisions of protons with the nuclei of photographic emulsion.

There is at present a widespread opinion [2,3,4] that the multiple production in hadron-nucleus collisions at high energies provides a sensitive test for the mechanism of multiple production in hadron-nucleon collision. E.g. the strong suppression of the multiplicity in nuclear collisions observed in cosmic ray experiments [5,6] and in the latest experiments in emulsions exposed in the largest accelerators [1,7] is in favour of the class of models in which the multiple production in elementary collisions occurs via an intermediate state. This idea was proposed some years ago on the basis of cosmic ray results [8,9], and is now extensively discussed not only for groups of pions produced coherently [10] but also for other types of production in hadron-nucleus collision [2,3,4]. These production models are usually set against those in which the secondary particles are directly produced. According to the assumed model of multiple production in hadron--nucleon collision, many authors make predictions as to how the final state of the hadron-nucleus interaction will look, and how it will depend on the energy of the projectile and the mass-number A of the target [2,3]. All this calls for experiments with numerous target nuclei performed at different energies.

It seems to us however, that the nuclear emulsion technique offers a unique possibility of selecting events according to the actually realized number of collisions inside the nucleus. This is due to the fact that in nuclear emulsion we know what happens with the hit target nucleus through the direct observation of the number of heavily ionizing particles N_h, which are the products of spallation or evaporation of the nucleus. The well-known independence of the number distribution of these particles on the primary energy [11,12,13], the linear relation between the average charged multiplicity $\bar{n}_s$ and N_h [11,12,14,15,16], and the correlation of some other parameters with N_h [16,17,7] all suggest a monotonic relation between N_h and the number of collisions inside the nucleus. Therefore in nuclear emulsion the sample of events with given N_h may be more uniform than one obtained from a uniform target /with given A/ but without the knowledge of its excitation /N_h/.

This is why we used the number N_h in the present investigation as a main parameter to systematize our experimental data.

Our experimental data consist of two samples of 675 and 999 events due to interactions of protons with energy 67 GeV and 200 GeV, respectively. The exposure conditions and scanning procedure were described in our previous paper [1]. The angles between the direction of the primary proton and each secondary particle giving a minimum ionizing track / $v/c > 0.7$ / were measured and denoted by θ_L. The number N_h of all strongly ionizing particles / $v/c < 0.7$ / was also counted in each event. We used the variable $\eta = \ln \tan \theta_L/2$ for presentation of the angular distributions. This variable is a reasonable approximation of the laboratory rapidity.

Fig.1 is a summary of our data. It shows the average numbers of minimum ionizing particles Δn_s which were emitted at a given η within an interval $\Delta\eta = 1$ in an event with a given N_h. It is presented as a contour map of the surface $\Delta n_s = f/\eta, N_h/$ which was fitted to our data. Full contours and the brocken ones belong to 200 GeV and 67 GeV data respectively. The numbers indicated at the contours denote the respective Δn_s-values.

The map presented in Fig.1 could be easily constracted owing to the fact that the numbers of particles produced at a given angle in events having different N_h obeyed a linear relation:

a/E

$$\Delta n_s/E, \eta, N_h/ = a/E, \eta/ + b/E, \eta/N_h \qquad /1/$$

This relation turned out to be valid over the whole range of η as seen from the confidence levels /Table 1/ of straight lines fitted to our data in 10 narrow intervals /$\Delta\eta = 1$/ [19].

Fig.2 shows the values of the coefficients a and b in function of η together with their statistical errors.

Full lines and broken lines correspond to 200 GeV and 67 GeV data, respectively.

The areas under the curves "a" and "b" in Fig.2 can be denoted as:

$$\int a/E,\eta/d\eta = A/E/ \qquad \int b/E,\eta/d\eta = B/E/ \qquad /2/$$

and consequently the well-known and tested integral relation between $\bar{N}_s$ and N_h [11,12,14,15] can be written as:

$$\bar{N}_s/E,N_h/ = A/E/ + B/E/N_h \ . \qquad /3/$$

n sub s

Dividing by the average charged multiplicity in proton-proton collisions $/\bar{N}_{pp}/E/\ /$, we obtain for the ratio r of multiplicities in nuclear and elementary collisions:

$$r/E,N_h/ = \frac{\bar{N}_s/E,N_h/}{\bar{N}_{pp}/E/} = \alpha/E/ + \beta/E/N_h \ . \qquad /4/$$

Using our data at 67 GeV and 200 GeV and those at lower energies [11,12] as well as cosmic ray data at about 1000 GeV [5], we present in Fig.3 the coefficients α and β in function of the primary proton momentum. One can say that within the energy interval 67 and 200 GeV these coefficients change very little if at all. At still higher energies there are indications from the cosmic ray data [5,16] that r is a function of N_h only and practically the same as for 200 GeV. However, at lower energies $/E < 67$ GeV/ the coefficient β is no longer energy independent. It falls rapidly with energy. The coefficient α reveals the same tendency. This behaviour is, at least partially, due to the fact that at lower energies the percentage of slow particles / $v/c < 0.7$ / produced increases, and therefore the number n_s of fast particles /$v/c > 0.7$ / is no longer a good approximation to the number of charged particles produced.

From the above analysis it follows that the linear dependence between $\bar{n}_s$ and N_h observed by many authors is a consequence of more detailed linear relations between $\Delta n_s/\eta/$ and N_h which are valid in the narrow intervals of η over the whole range of η /see Table 1/. Consequently the angular distributions of produced particles can be separated into two components:

I. a component /given by curve "a"/ which does not depend on N_h and which represents /in first approximation/ the angular distribution of particles produced in proton-nucleon collision,

II. a component /given by curve "b" multiplied by N_h/ which gives the angular distribution of particles produced owing to the target nucleus.

These components behave very differently /see Fig.2/ :

1. The main part of the curve "b" covers large angles only. At small angles it is small and negative.

2. The curve "a" covers approximately the same interval of η as do the particles produced in proton-nucleon collision.

With changing proton energy from 67 GeV to 200 GeV:

3.

3. the curve "b" probably does not change its absolute maximum value and the position of this maximum. It only widens, remaining small and negative for small angles.
4. the absolute value of the maximum of the curve "a" increases with the increasing energy and its position moves toward small angles in accordance with kinematics.
5. the ratio $\frac{{}^{B}N_h}{A}$ of the total number of particles belonging to the different components does not change. It is equal $/7.8 \pm 0.9/ \times 10^{-2} N_h$ and $/7.6 \pm 0.8/ \times 10^{-2} N_h$ for 67 GeV and 200 GeV primary protons respectively.
6. the ratio of the total number of particles belonging to the same component equals the ratio of the average charged multiplicity in proton-proton collisions.
7. At large angles the two components separately coincide /or scale/.

The above-listed phenomena observed in proton-nucleus collisions favour the class of models of elementary collisions in which particles are generated through the intermediate states of peculiar properties. Here we refer to the models proposed by Dar and Vary [2], Fishbane and Trefil [3], and the phenomenological model described by Friedländer [20]. Common for those models is the creation of a fast cluster in hadron-nucleon collision which on its way trough the nucleus interacts with nucleons and produces slow clusters, itself remaining practically unchanged. The predictions of the Energy Flux Cascade Model proposed by Gottfried [4] are similar to those above described. The behaviour of our components of the angular distribution is in agreement with such models. It is astonishing that the components created through the systematization of the data based on N_h, possess such properties. Of course, this strongly suggests that there must be a relation between N_h and the number of collisions ν. If we knew this relation we would be able to present the total number and the angular distribution of particles produced per one collision inside the nucleus. At present we know only that it is given by the curve "b" within the accuracy of the normalization factor.

It is interesting to assume a linear relation between N_h and ν and to make predictions concerning the angular distribution of produced particles which follows from equation /1/. Analysis of similar type based on Gottfried's model [4/] has been performed in paper [21/].

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Captions for Figures

Fig.1 Angular distribution of produced charged particles in an average proton-nucleus collision in function of N_h shown as a contour map. The numbers indicated at the contours denote the number of particles produced within a unit interval of $\ln \tan \Theta_L/2$ at an angle Θ_L. Continuous and broken lines correspond to 200 GeV and 67 GeV data, respectively. The error bars reflect typical statistical errors. Dotted lines are the average $\ln \tan \Theta_L/2$-values.

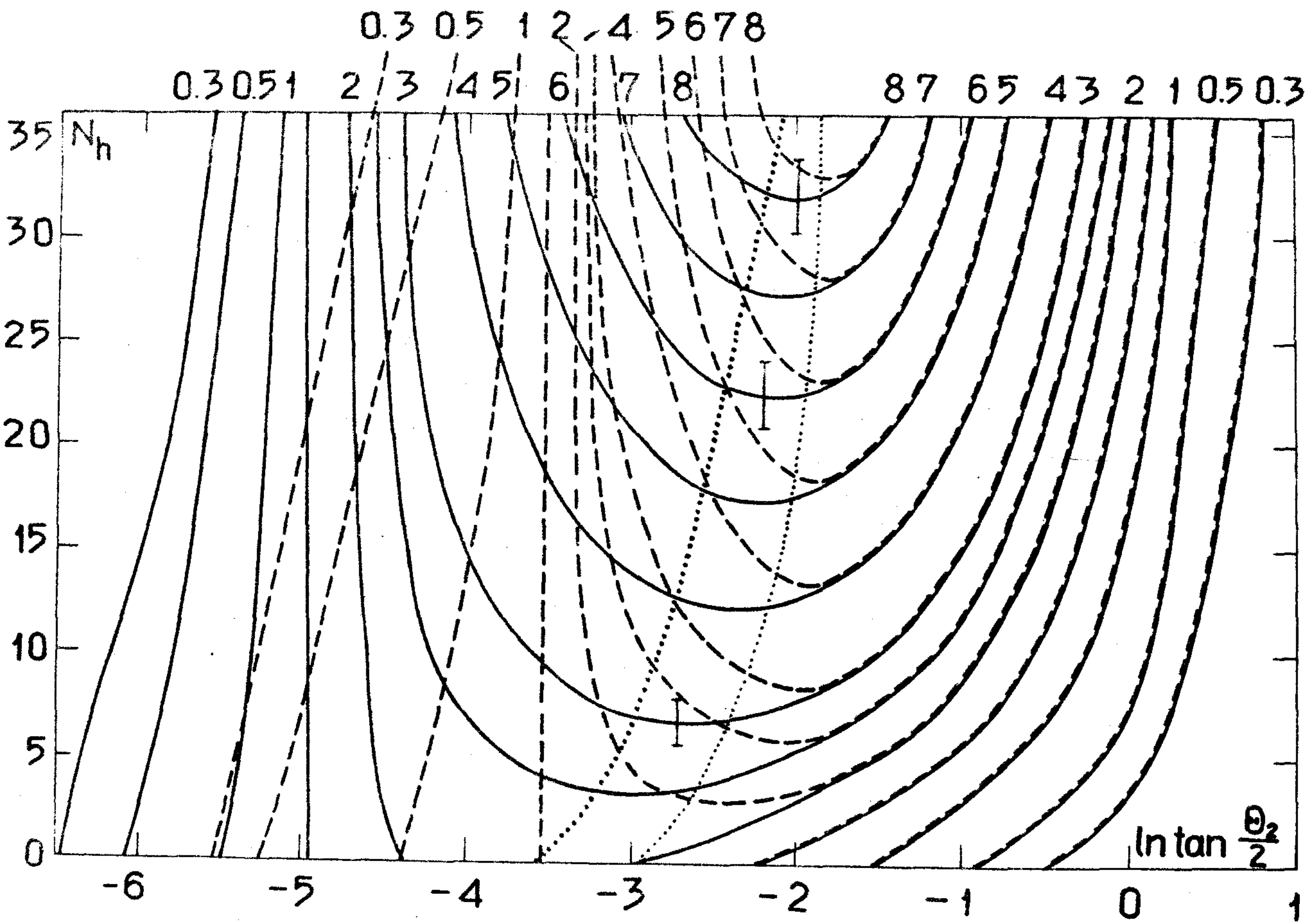
Fig.2 Coefficients a and b in eq./1/ in function of η $\circ$ - 200 GeV data, $\square$ - 67 GeV data. Continuous /200 GeV/ and broken /67 GeV/ lines are arbitrary interpolations used to construct the maps in Fig.1. Note that scales for a and b are different.

Fig.3 Coefficients α and β in eq./4/ in function of proton momentum. Note that scales for α and β are different.

TABLE 1

χ^2 confidence levels for the linear fits $\Delta n_s/\eta/ = a/\eta/ + b/\eta/N_h$.

Interval of η from	to	Confidence level 200 GeV	67 GeV
-8	-7	0.90	0.90
-7	-6	0.40	0.25
-6	-5	0.70	0.005
-5	-4	0.10	0.03
-4	-3	0.75	0.01
-3	-2	0.60	0.05
-2	-1	0.60	0.30
-1	0	0.50	0.40
0	1	0.10	0.05
1	2	0.98	0.99



0.3 0.5 1 2 4 5 6 7 8
0.3 0.5 1 2 3 4 5 6 7 8
8 7 6 5 4 3 2 1 0.5 0.3
N_h
35
30
25
20
15
10
5
0
-6
-5
-4
-3
-2
-1
0
1
$\ln \tan \frac{\Theta_2}{2}$

Fig. 1

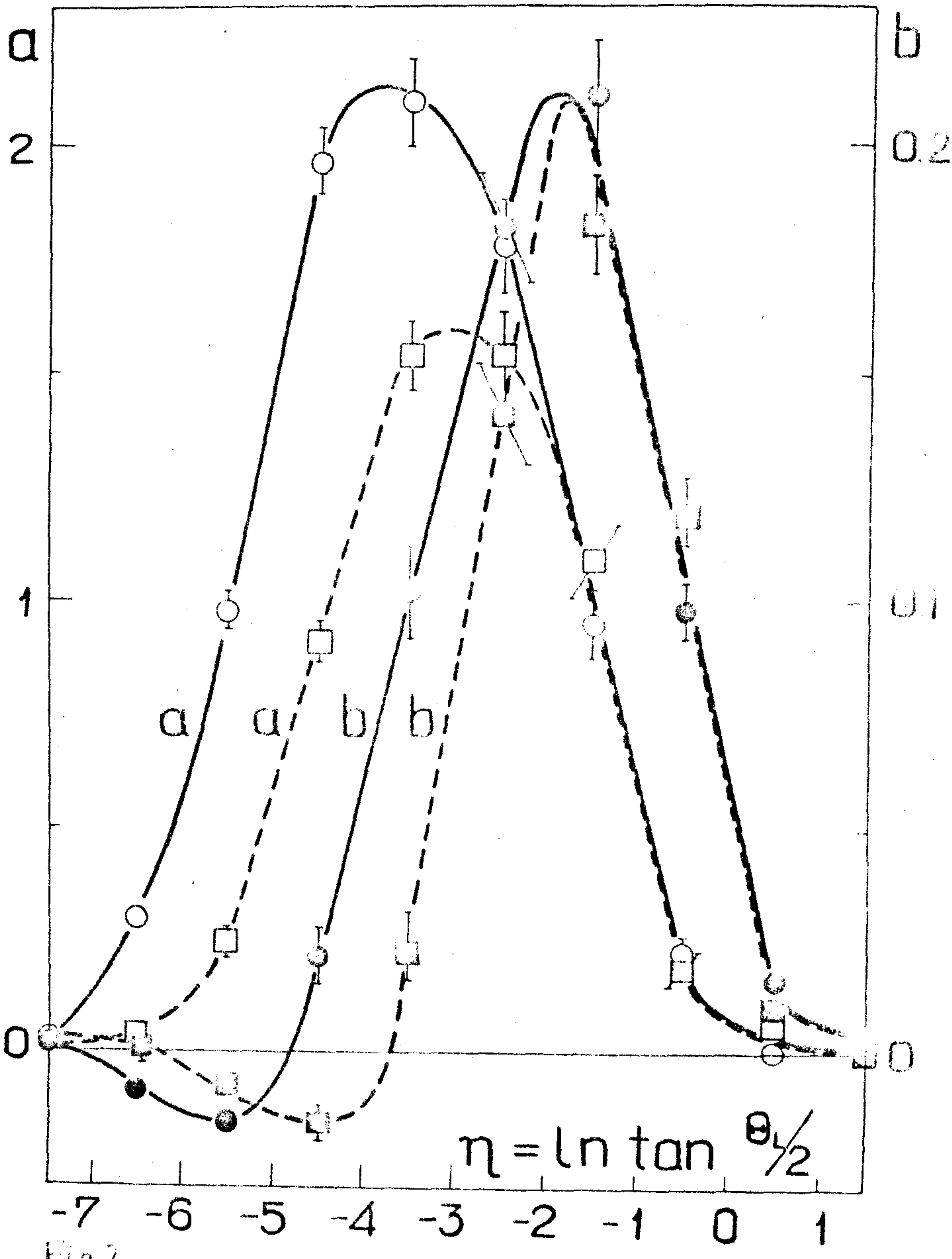


Fig.2

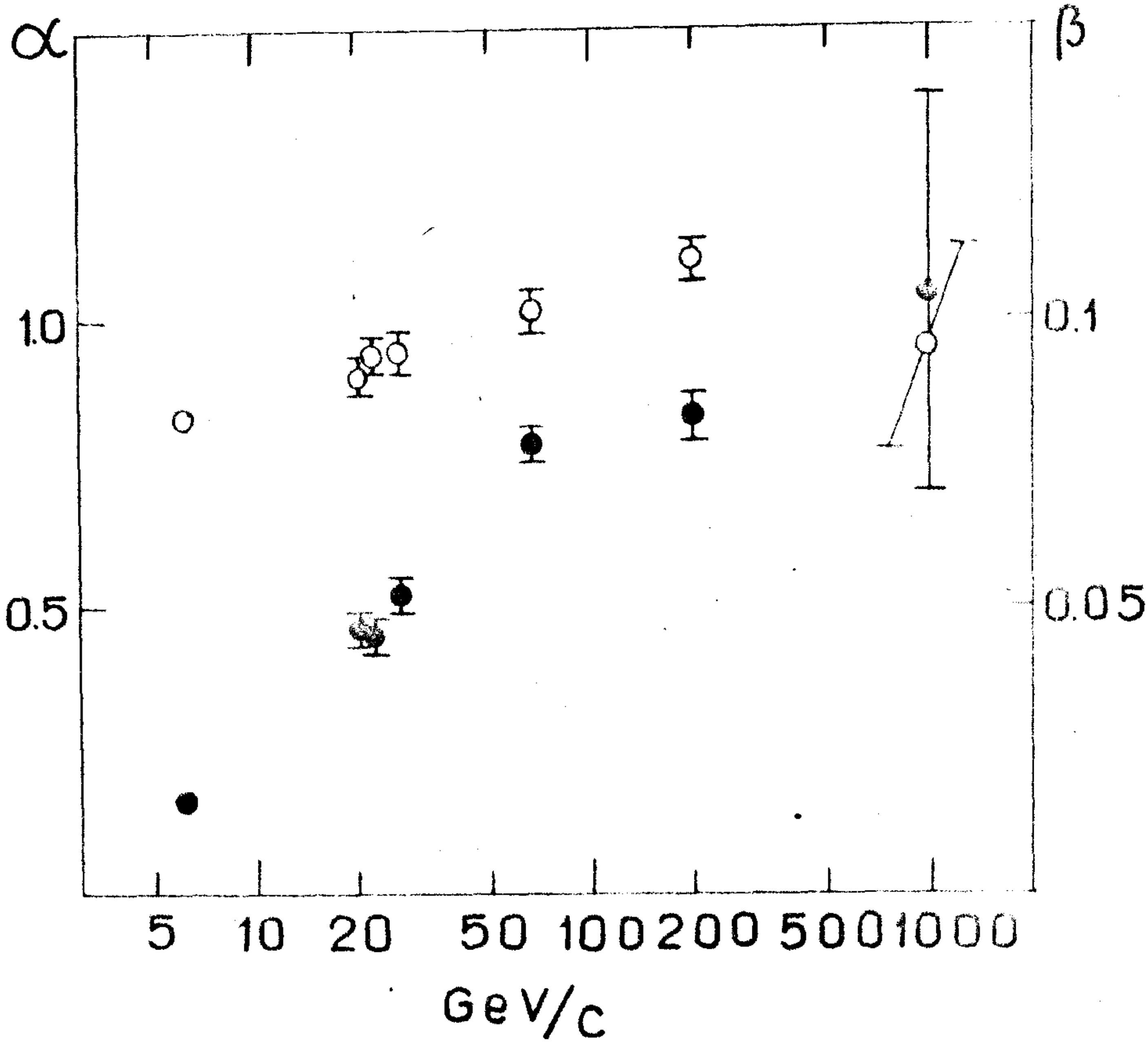


Fig. 3