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AN INTERPRETATION OF HIGH ENERGY INELASTIC INTERACTIONS OF PIONS WITH HEAVY EMULSION NUCLEI

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1. Introduction

One of the important domains of high energy physics is the study of inelastic interactions of particles with nuclei. Such investigations are interesting for the study of the mechanism of nuclear reactions and their various practical applications. In the present paper we analyse various distributions of secondary particles created in the interactions of pions with emulsion at the highest accelerator energy available. The analysis is based on cascade-evaporation model. According to this model, the nuclear reaction takes place in two stages independently. Firstly, the primary particle interacts with one of the internuclear nucleons and initiates nuclear cascade. At a relatively latter stage, the excited residual nucleus results in the evaporation of nucleons, deuterons and heavy fragments. At present stage, the cascade-evaporation model describes the experimental results up to several GeV satisfactorily. The applications of this model at still higher energies create interest especially in the investigations to be performed at Serpukhov and Batavia. In ref. /1/ calculations of cascade model in AgBr nuclei initiated by pions at 17 GeV were presented. The theoretical results agreed well with the experimental results available at that time. However, the new experimental data /2–4/ cannot be explained in the framework of this model. In these papers, it was pointed out that the calculations of cascade model require modifications based on the "trailing effect". As a consequence of this effect, the nuclear density decreases during the progress of the cascade. In this paper, we present results based on the calculations of cascade-evaporation model taking the above-said effect into consideration at 17.2 GeV pion-AgBr nucleus interactions. We also compare theoretical results with the recently published experimental results /5,6/ at 60 GeV. For the present investigation, we have selected heavy emulsion nuclei because in them there is a larger development of internuclear cascade.

2. Theoretical Approach

The method of calculation of internuclear cascade is the same as employed by the earlier works /1,7/ with the following main peculiarities:

a) The nuclear density is described by the Fermi formula

$$\rho = \frac{\rho_0}{1 + e^{(r-c)/a}}, \quad (1)$$

where parameters c and a are taken from the experiments concerning electron scatterings /8/.

In accordance with such distributions, before each calculation of cascade, the coordinate of all nucleons are fixed such that the distance between the centres of two nucleons is greater than twice the "kernel" radius (~ 0.8 fm). The location of nucleons during cascade development does not change.

b) At every stage of cascade, it is assumed that the faster particles undergo interactions first. The mean free path inside the nucleus is determined from the total cross section of particles with nucleons /7/. The nucleon and the created particles from the interaction with it become the usual cascade particles. In the former place occupied by the nucleon, a "hole" is created causing "trailing effect". Hence the particles moving after the faster particles meet less number of nucleons on their way inside the nucleus. The other features of our model (taking into account Pauli's principle, the absorption of pions in nuclei, etc.) were the same as in ref. /1/.

3. Modulation of π-N and N-N Interactions

For drawing a large number of internuclear cascades, it is very important to develop effective methods of establishing characteristics of elementary interactions at various energies. All such characteristics have been calculated in the c.m.s.

At energies $T > 10$ GeV, we have used polynomial approximation of experimental data proposed in ref. /9/. It is known that in inelastic π-N and N-N interactions there is a leading particle which takes away a large part of the primary energy /10,11/. The fraction of energy carried away by the leading particle depends on the coefficient of inelasticity - almost independent of primary energy. The distribution of coefficient of inelasticity is described by the following expression

$$K = \xi^{a} \left[\sum_{n=0}^{N} a_n \xi^n + \left(1 - \sum_{n=0}^{N} a_n\right) \xi^{N+1} \right], \qquad (2)$$

where ξ is a random number uniformly distributed in the segment (0-1) and the values of parameter a_i are given for the best agreement with experimental data in Table 1.

Further, we suppose that in inelastic π -N interactions in the c.m.s. there are two leading particles: the outgoing pion at $\theta \sim 0$ and nucleon at $\theta \sim \pi$.

The energy of the secondary particles without leading particle was calculated by the following formula:

$$\mathcal{T} = \mathcal{T}_{max} \xi^{1/2} \left[\sum_{n=0}^{N} b_n \xi^n + \left(1 - \sum_{n=0}^{N} b_n\right) \xi^{n+1} \right], \qquad (3)$$

$$b_n = \sum_{i=0}^{M} b_{ni} \, \ln (T + T_0)^i, \qquad (4)$$

$$\mathcal{T}_{max} = \sum_{i=0}^{M} c_i \ln (T + T_0)^i, \qquad (5)$$

where $T_0 = 10$ at $T < 40$ GeV and $T_0 = 20$ at $T \geq 40$ GeV and the values of parameter b_{ni} are given in Table 2 where $N = M = 3$.

The angular distribution of secondary particles is described by the following expression:

$$\cos\theta = 2\xi^{1/2} \left[\sum_{i=0}^{M} d_i \xi^i + \left(1 - \sum_{i=0}^{M} d_i\right) \xi^{M+1} \right] - 1, \qquad (6)$$

$$d_i = \sum_{k=0}^{M} d_{ik} (\ln T)^k . \qquad (7)$$

The value of parameter d_{ik} is shown in Table 3.

After the extraction of the leading particle, the energy and angles of other particles were determined. The energy of the last particle was determined on the basis of the law of energy conservation and the angles of the last two particles by the law of conservation of momentum. The number of created particles was determined by our method of calculation directly. Hence our method of calculation ensures the creation of random number of secondary particles from inelastic interactions.

Since the modulation of elementary inelastic interactions is important in the calculations of internuclear cascade model, we give a detailed comparison of results of modulation with the experimental results [10-15]. In figs. 1-4, various characteristics calculated on the basis of modulation have been compared with experimental data. It is seen that theory and experiments are in good agreement. The average statistical error of theoretical value is 2-3%.

The angles of the elastically scattered particles are given by:

$$d\sigma / dt = A(T) e^{-\beta(T)|t|} , \qquad (8)$$

where the parameter A(T) and $\beta(T)$ are taken from ref. [16]. The calculation of internuclear interactions for energies T < 10 GeV was the same as in ref. [17].

4. Results of Calculations and Comparison with the Experimental Data

In figures 5-10 and Table 4, the results based on the calculation of pion interactions with heavy emulsion nuclei along with experimental results have been presented. One can draw the following main conclusions:

a) The average theoretical characteristics of shower particles at 17.2 and 60 GeV are in good agreement with the experimental results. However, there is a small discrepancy in the value of average multiplicity at 60 GeV.

b) Taking into consideration the "trailing effect", the average values of N_g and N_b at higher energies decrease considerably. Remember that without such an effect, $\langle N_h \rangle$ has already been calculated at energies $T \geq 5$ [1,18,19] and the values obtained are anomalously large.

c) The situation about average number of N_g is more indefinite. At energy 60 GeV, the theory and experiment are in agreement. However, at 17.2 GeV, where the discrepancy is more probable, the theoretical $\langle N_g \rangle$ is 4.2 and the experimental value = 2.7 Recently, the value of $\langle N_g \rangle$ as determined in the interactions of 67 GeV protons with emulsion nuclei [20] is 2.5, which is in bad agreement with the value 4.1 obtained in ref. [6].

For the final conclusion about the applicability of this model for the cascade particles, more experimental data are required at high energy However, the given cascade model, which takes into account the "trailing effect", explains a large number of characteristics of secondary particles and is able to reflect the basic features of the mechanism of inelastic interactions of particles with nuclei at the present day energies available at Serpukhov.

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TABLE I

Values of Parameters in Formula (2)

Parameter / Energy	α	α_0	α_1	α_2	α_3
$10 < T < 30$	0.7	$7.852\ 10^{-1}$	$-1.950\ 10^{-1}$	$2.066\ 10^{-1}$	$9.576\ 10^{-3}$
$T > 30$	0.5	$7.884\ 10^{-1}$	$-1.963\ 10^{-1}$	$2.052\ 10^{-1}$	$9.589\ 10^{-3}$

T A B L E 2

Values of Parameters in Formulae (4) and (5)

θ is the angle in the c.m.s. of created particle.

	b_{oi}		b_{1i}		b_{2i}		b_{3i}		c_i	
i \ θ	$\theta > 73^\circ$	$\theta < 73^\circ$	$\theta > 73^\circ$	$\theta < 73^\circ$	$\theta > 73^\circ$	$\theta < 73^\circ$	$\theta > 73$	$\theta < 73^\circ$	$\theta > 73^\circ$	$\theta < 73^\circ$
0	-I.9734	-I.972I	I.I032	I.I032	-27.073I	-27.0765	65.7295	65.7304	I.2I40	3.2774
I.	I.2524	I.2522	-4.7670	-4.7662	II.4446	II.4503	-29.4326	-29.4342	-0.3480	-0.9396
2	-0.2I8I	-0.2I73	0.7282	0.7304	- I.7662	- I.770I	4.8095	4.8I03	0.0599	0.I6I7
3	0.0II7	0.II5	-0.0372	-0.0364	0.09I8	0.09I7	-0.2589	-0.2584		

TABLE 3

Values of Parameters Used in Formula (7)

k	α_{0k}	α_{1k}	α_{2k}	α_{3k}
	For all particles created in N - N interactions			
0	0.0936737	3.64487	- 7.48822	8.5205I
I	0.333I08	-0.0699797	0.096456I	-0.244000
2	0.34288.IO^{-2}	-0.I35987	0.483035	0.553090
3	0.I37573.IO^{-3}	0.708733.IO^{-4}	-0.IOI642.IO^{-2}	0.I69870.IO^{-2}
	For all particles created in π- N interactions			
0	0.287967	3.25745	-II.9234	I7.34I4
I	-0.I09827	-I.I9825	9.9588I	-I6.I774
2.	0.0I90864	0.26953I	-I.935I6	3.02I8I
3	-0.II0477I.IO^{-2}	-0.0I9I9I2	0.I24586	0.I8848I

T A B L E 4

Average Characteristics of Secondary Particles Produced in the Interactions of Pions with Heavy Emulsion Nuclei

The statistical errors of theoretical values are 2-3%.

Characteristics \ T	17.2 GeV		60 GeV	
	Theoretical	Experimental /13/	Theoretical	Experimental /6/
$N_s^{\pm}$	5.9	5.96 ± 0.30	I2.3	I0.2 ± 0.3
$N_{s\pi}$	8.I		I6.9	
N_{sn}	I.5		I.6	
$\theta^o_{1/2\pi}$	24	22.0 ± I.I	I4.8	I6.4 ± 0.6
$P_{\perp s}$, GeV/c	0.38	0.37 ± 0.03	0.39	
E_{tot}, GeV	I.74	I.60 ± 0.I0	2,0	
$Ng^{\pm}$	4.2	2.7 ± 0.2	5.I	4.I ± 0.3
Ng_{π}	I.0		I.3	
Ng_n	6.8		9	
$\theta^o_{1/2g}$	59	6I ± 4	55	
$P_{\perp g}$, GeV/c	0.3I		0.32	
E_{kg} GeV/c	0.I3		0.I4	
$N_h^{\pm}$	I2.8	9.8 ± 0.4	I4.2	I0.3 ± 0.3

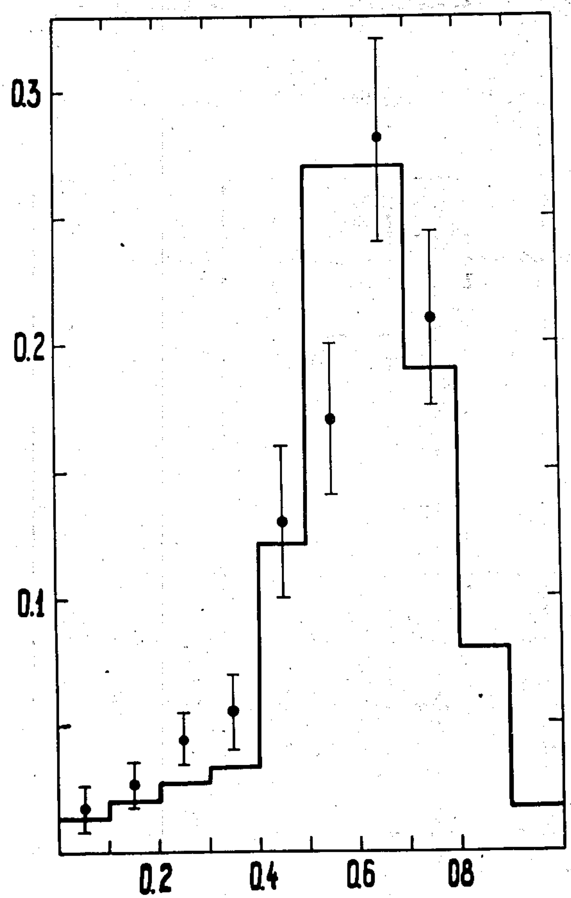


Fig.1.The distribution of coefficient of inelasticity in π -N interactions at 60 GeV. Experimental data /10/ are presented by points.

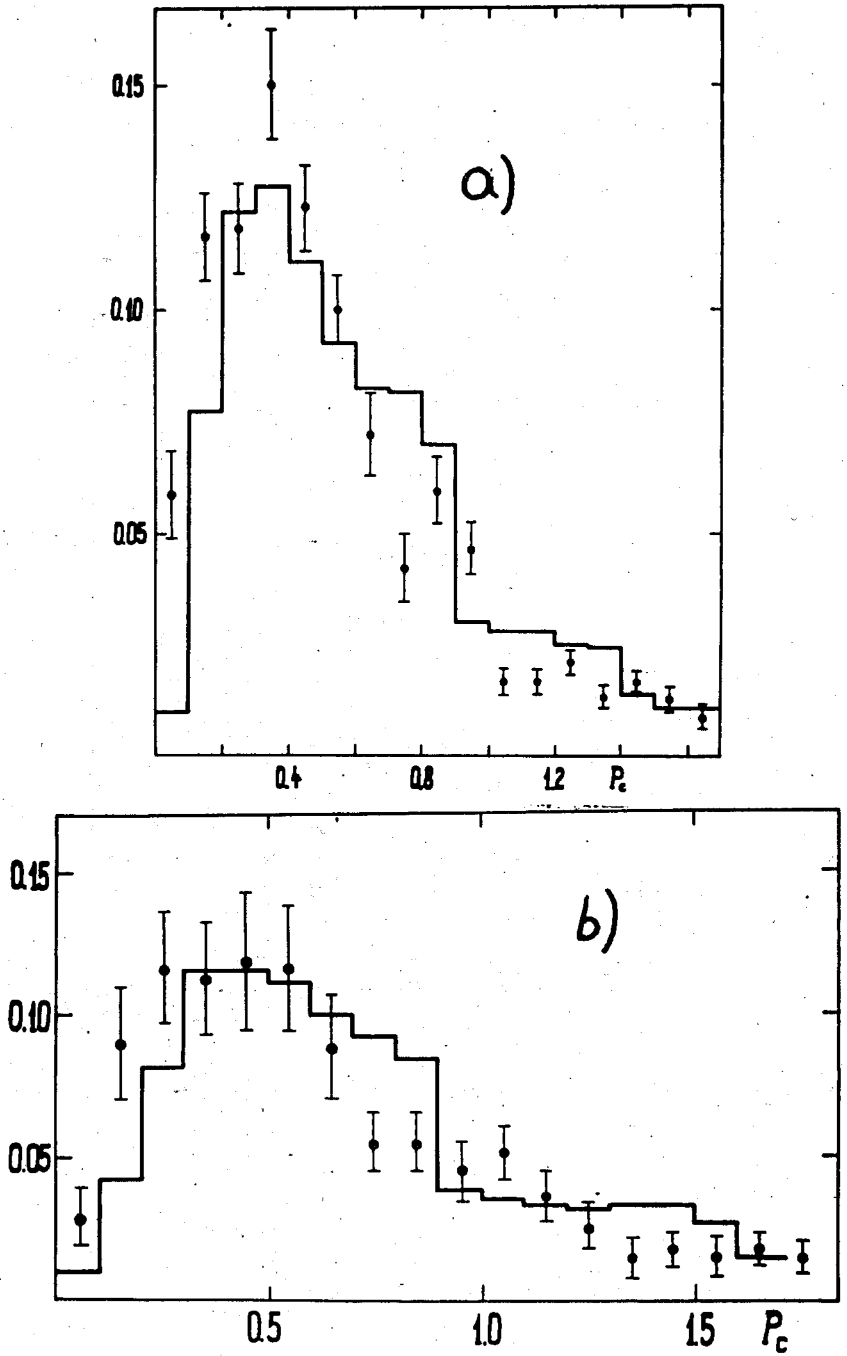
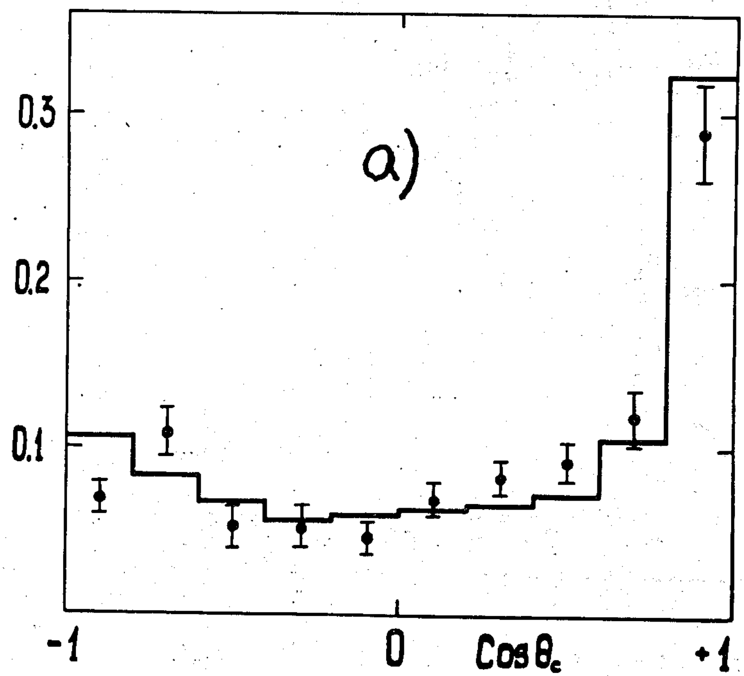


Fig.2. Momentum distribution of pions from inelastic π -N interactions at 17.2 GeV (a) and 60 GeV (b). The experimental data /10,14/ are presented by points.


0.3
0.2
0.1
a)
-1
0
Cos θc
+1

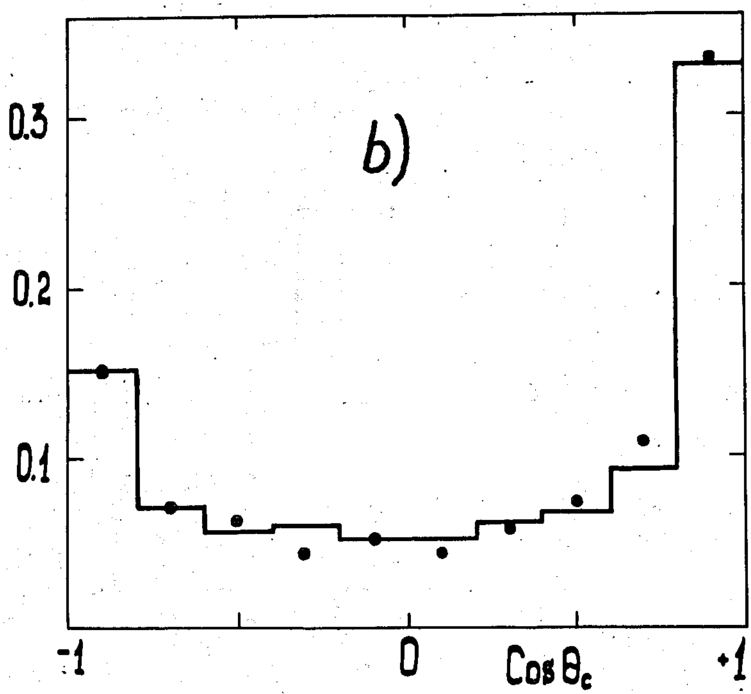
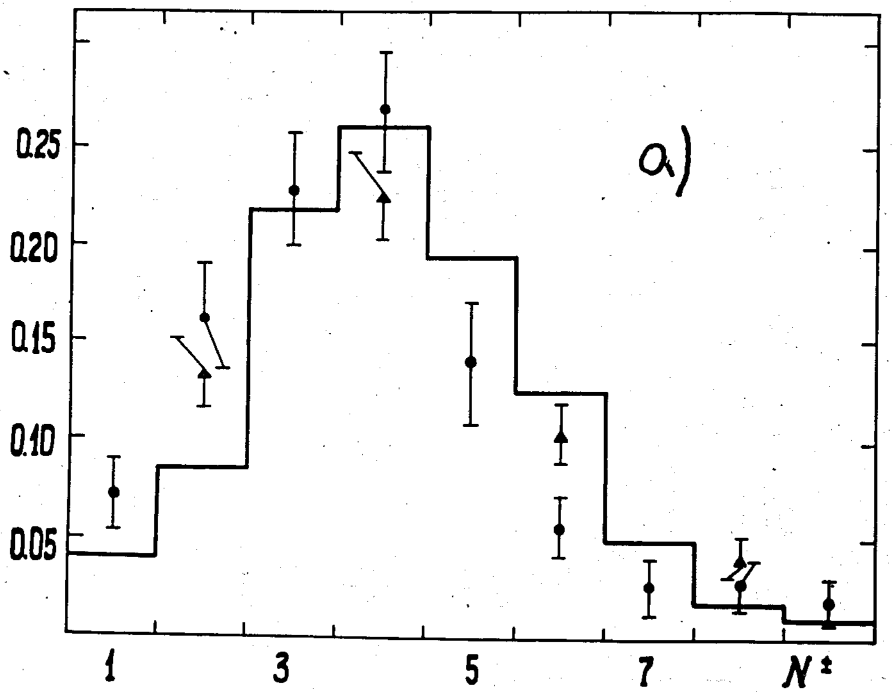


Fig.3.Angular distribution of pions in π -N interactions at 17.2 GeV (a) and 60 GeV (b). Notations are the same as in Fig.2.



0.25
0.20
0.15
0.10
0.05
a)
1
3
5
7
N±

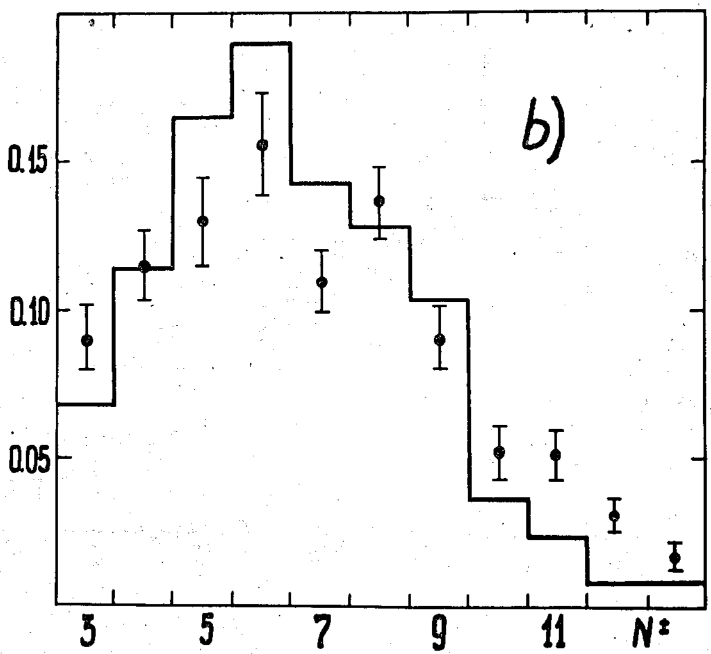


Fig.4. Multiplicity distribution of charged particles from inelastic π -N interactions at 17.2 GeV (a) and 60 GeV (b). In fig. (a), ● and ▲ represent the experimental data from /15/ and /13/ respectively, and in fig.(b), the experimental results are from /12/ .

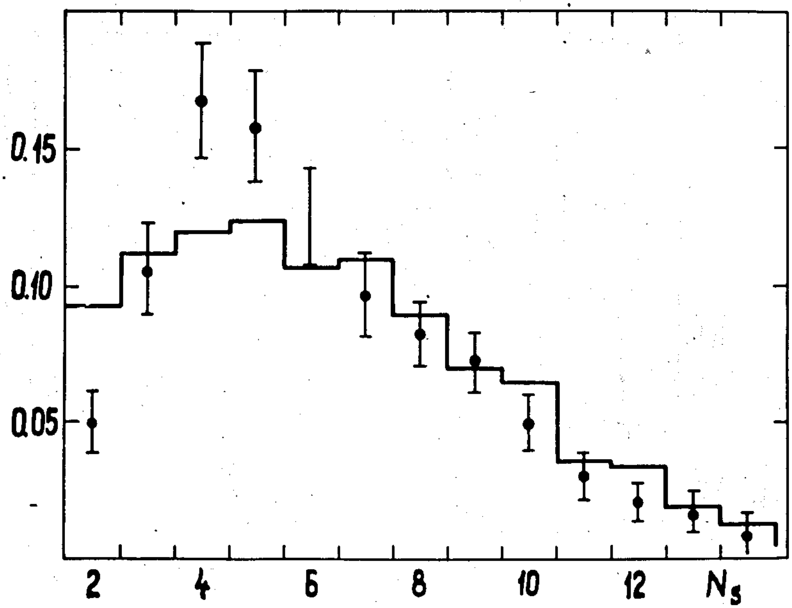


Fig.5. Multiplicity distribution of shower particles created in the interactions of pions with heavy emulsion nuclei at 17.2 GeV /13/ .

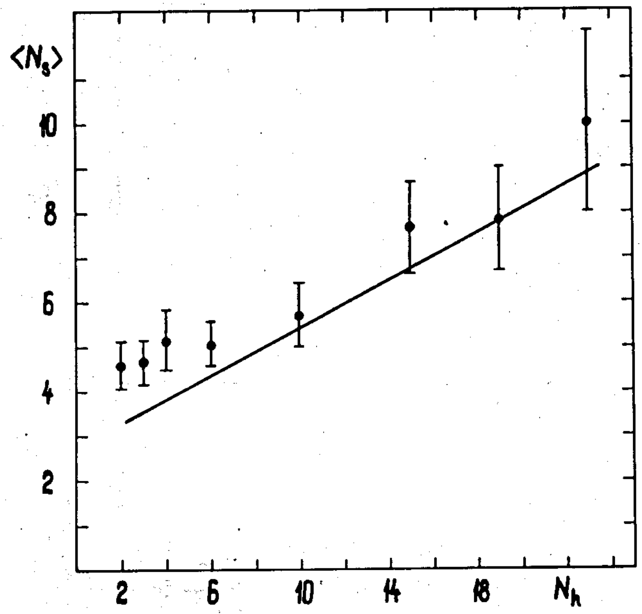


Fig.6.Dependence of $\langle N_s \rangle$ on N_h in the interactions of pions with heavy emulsion nuclei at 17.2 GeV /13/.

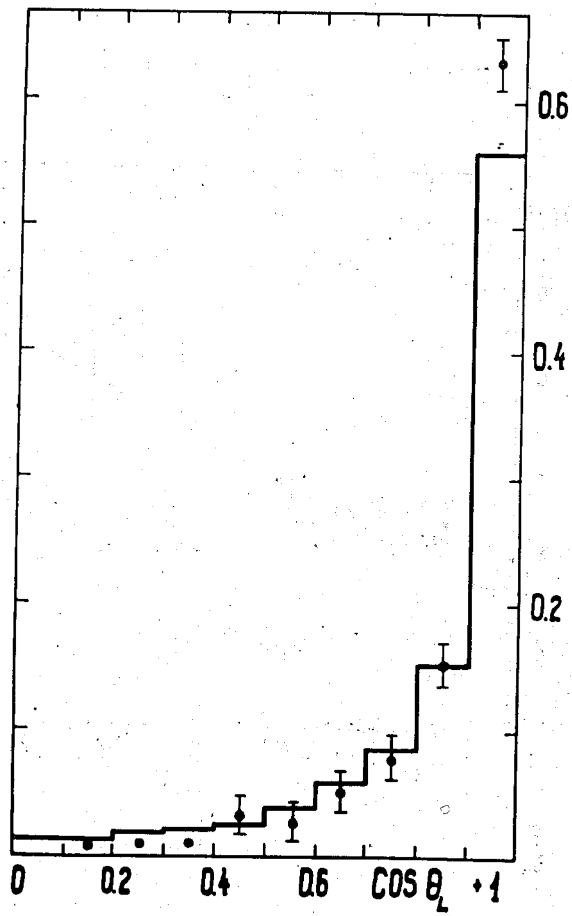


Fig.7.Angular distribution of shower particles in the lab. system at 17.2 GeV in the interactions of pions with heavy emulsion nuclei.

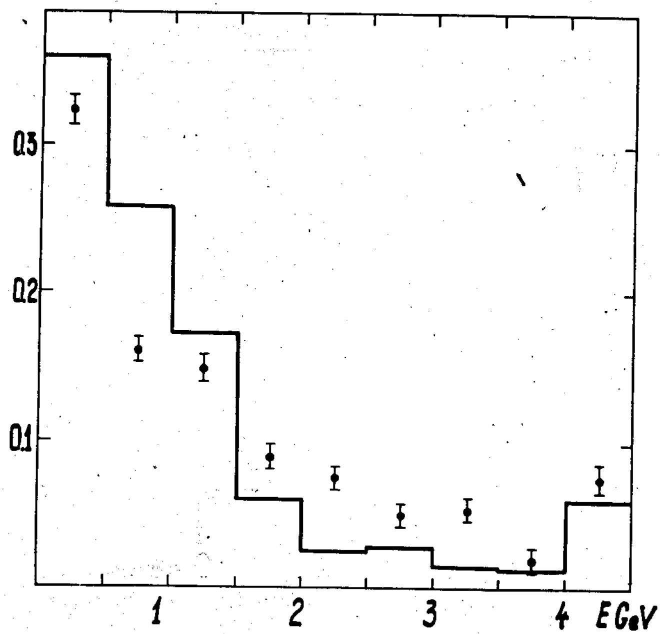


Fig.8.Energy distribution of shower particles in the lab. system at 17.2 GeV in the interactions of pions with heavy emulsion nuclei.

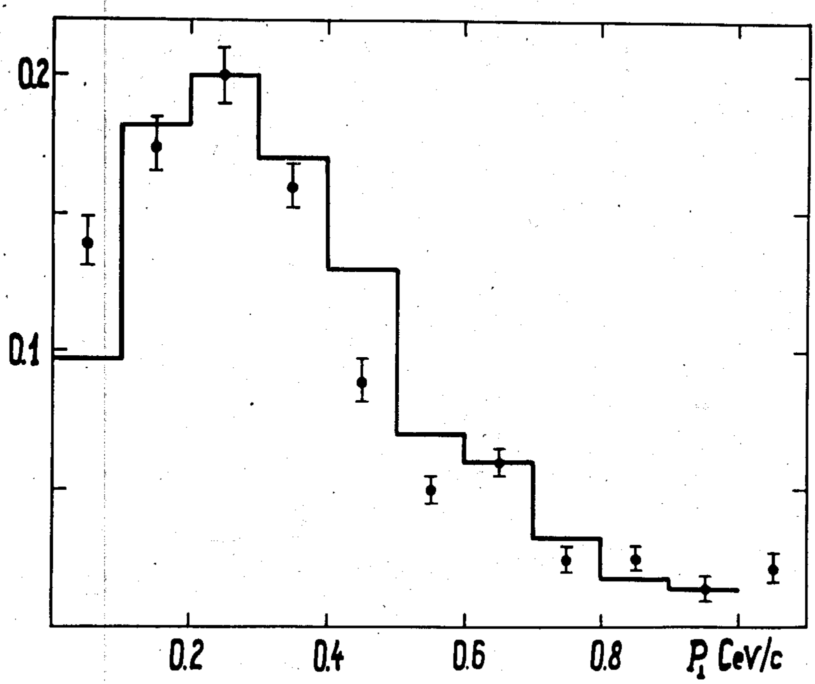


Fig.9.Transverse momentum distribution of pions created in the interactions of pions with heavy emulsion nuclei at 17.2 GeV.

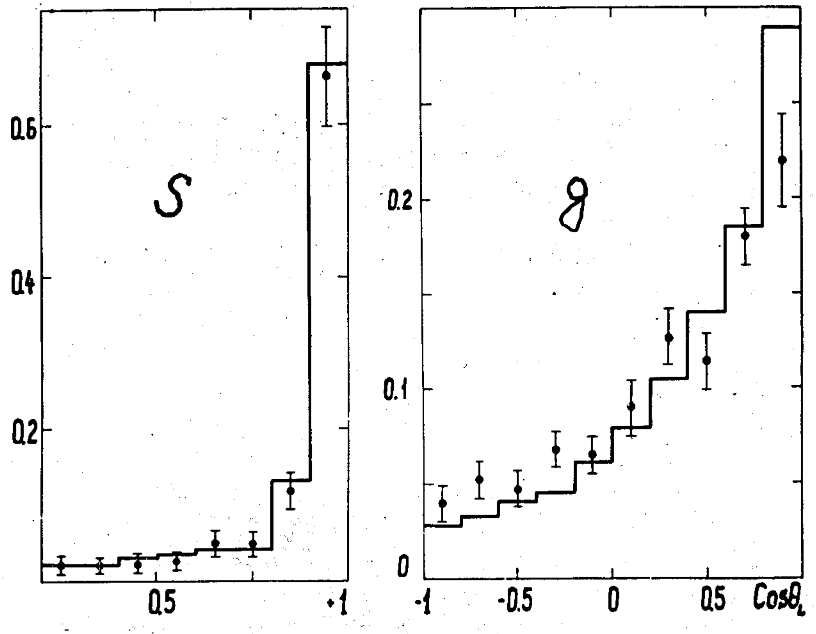


Fig.10.Angular distribution of g(a) and s(b) particles in the lab. system produced in the interactions of pions with AgBr nuclei at 60 GeV.