DISCUSSION

YODH : Was the 290 MeV experiment reported last year at Kiev, or is there new data on it?

MUKHIN : These experiments at 290 MeV were reported in Kiev at the previous conference, but better statistics have been obtained and it is on the basis of these better statistics that I have reported the results.

YODH : Do you have any information as to the other channel : $\pi^0+\pi^-+p$ and any numbers on the ratio of the two channels?

MUKHIN : At the moment we have no such information in our laboratory.

INELASTIC (π^-, N)-INTERACTIONS AT THE ENERGY OF 7 BeV

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Recently the inelastic interactions of π^--mesons with nucleons have been investigated in a number of experimental [1-8] and theoretical [10-13] papers because of a great interest in the understanding of the nucleon structure [9]. In my lecture I shall restrict myself to referring to the new results obtained in (π^-, N) interactions at the energy of 7 BeV in the High Energy Laboratory of the Joint Institute for Nuclear Research by the photoemulsion method (PEM) [7] and by the propane bubble chamber (BChM) [8].

In the photoemulsion block, consisting of 240 emulsions NIKFI-R, there have been found 535 cases of interactions of π^--mesons with nucleons, using the well known selection rules [2, 14]. With a propane bubble chamber of 24 liters in a magnetic field of 13700 gauss, 357 such cases were observed along with 74 electron pairs produced by γ rays.

Distribution of (π^-, N) interactions as a function of charged particles is given in Table I.

I. EXPERIMENTAL RESULTS

1. Mean number of charged and neutral particles

The mean number of charged particles obtained in (π^-, p) interactions by PEM was equal to $\bar{n}_{z,p} = 3.0 \pm 0.1$, and by BChM was equal to $\bar{n}_{z,p} = 3.2 \pm 0.2$.

The mean numbers for (π^-, n) interactions by PEM was equal to $\bar{n}_{z,n} = 3.0 \pm 0.1$ and by BChM was equal to $\bar{n}_{z,n} = 3.3 \pm 0.4$. These numbers are consistent.

In order to identify protons and $\pi^\pm$-mesons measurements of ionization and multiple scattering were made with the PEM. This method, however, cannot distinguish between π-mesons and protons (for $p\beta$ in the region of 1.5 to 2.7 BeV/c. By applying a supplementary analysis it is possible to show that the majority of particles in the doubtful region are π-mesons and that the total number of protons is equal to 238 ± 21, i.e. the mean number of protons in (π^-, N) interactions is equal to $\bar{n}_p = 0.5 \pm 0.05$ accord to PEM.

From this it follows that the mean of charged $\pi^\pm$-mesons is equal to 2.5 ± 0.1.

On the basis of results obtained by PEM and upon the supposition that for each multiplicity the mean energy of charged and neutral particles is the same, the mean number of neutral π^0-mesons (using the conservation of energy) was calculated and the value $\bar{n}_{\pi^0,p} = 1.3 \pm 0.2$ was obtained for all (π^-, p)-interactions. The mean value of π^0-mesons, obtained in BChM using the electron pairs produced by γ rays, is equal to 0.9 ± 0.1, while in (π^-, p)-interactions $\bar{n}_{\pi^0 p} = 1.0 \pm 0.1$ and in (π^-, n)-interactions $\bar{n}_{\pi^0 n} = 0.7 \pm 0.2$. From these values it follows that the mean number

Table I. Distribution of stars as a function of multiplicity

Number of protons	Number of events		%		% theory	Number of protons	Number of events		%		% theory
	PEM	BChM	PEM	BChM			PEM	BChM	PEM	BChM	
0	13	7	4.4±1.2	2.7±1.0		1	56	16	23.1±3.2	17.2±4.6	17.0
2	142	119	48.5±5.0	45.1±4.9	46.0	3	143	53	59.1±5.9	57.0±9.8	57.5
4	122	115	41.6±4.6	43.5±4.9	44.0	5	36	21	14.9±2.5	22.6±5.4	18.5
6	14	22	4.8±1.3	8.3±1.9	6.0	7	7	3	2.9±1.1	3.2±1.9	2
8	2	1	0.7±0.5	0.4±0.4	0.1						
sum	293	264					242	93			

of π^0-mesons is equal to about $^1/_3$ of all π-mesons. Thus the mean value of the number of particles produced in one interaction is 4.8.

2. Angular distribution of charged and neutral particles

The angular distribution of protons and $\pi^{\pm}$-mesons using the PEM, and π^0-mesons using the BChM in c.m.s. for stars with different multiplicity is shown on Fig. 1, 2, 3 and 4. From these figures, it is obvious, that the protons are flying backwards for all multiplicities i.e. are keeping their primary direction of flight. Their angles of emission are given on Fig. 1. These measurements can be considered as a result important for theoretical considerations.

At low multiplicity the π-mesons fly forward so that an asymmetry arises in their angular distribution (the values of which are given on Fig. 2 and 3). The forward-backward asymmetry in the angular distribu-

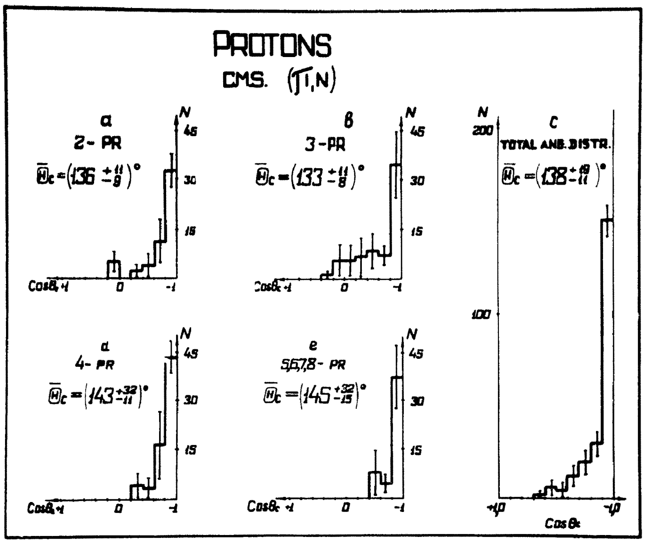

Fig. 1 Angular distribution of protons.

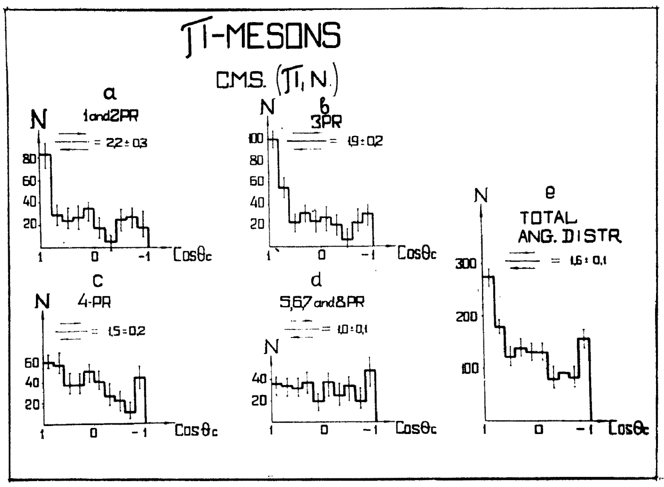

Fig. 2 Angular distribution of $\pi^{\pm}$-mesons.

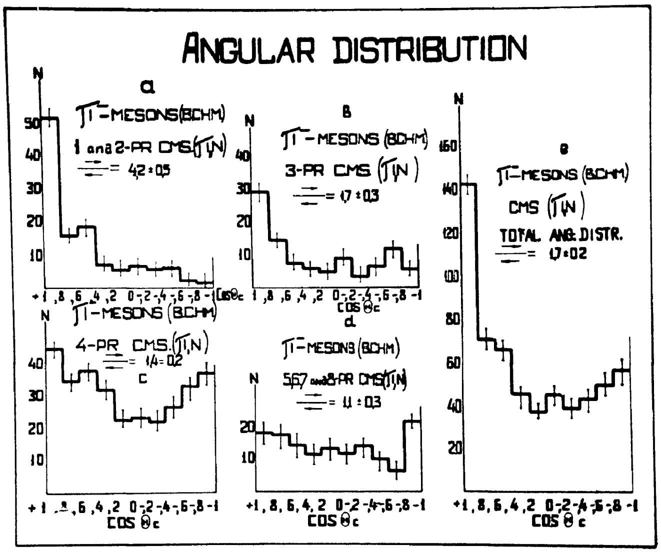

Fig. 3 Angular distribution of π^--mesons.

tion of all π-mesons is equal to 1.6 ± 0.1. The angular distribution of π-mesons for high multiplicity is close to the isotropic distribution.

The angular distribution of π^0-mesons likewise shows a forward-backward asymmetry equal to 1.4 ± 0.3 for their integral angular distributions. (The asymmetry is expressed as a ratio of the number of π-mesons flying into the forward hemisphere to the number of π-mesons flying into the the backward one.)

3. Momentum spectra of charged and neutral particles

The momentum spectra of protons and $\pi^{\pm}$-mesons using PEM and π^--mesons using BChM in the c.m.s. for stars with different multiplicity are shown in Fig. 5,6 and 7 respectively. In the PEM the momenta of particles were determined by measuring the multiple scattering along their tracks, and in the BChM from the curvature of their tracks in a magnetic field. The mean value of momenta of the protons is equal to $\bar{p}_p = (0.89 \pm 0.04)$ BeV/c, of the $\pi^{\pm}$-mesons to $\bar{p}_{\pi^{\pm}} = (0.46 \pm 0.06)$ BeV/c, of the π^--mesons to $\bar{p}_{\pi^-} = (0.53 \pm 0.03)$ BeV/c, and of the π^0-mesons to $\bar{p}_{\pi^0} = (0.48 \pm 0.03)$ BeV/c in c.m.s. (π^-, N) (See Table II).

Values of transverse momenta of $\pi^{\pm}$-mesons and protons are given in Table III using both PEM and BChM. The mean value of transverse momenta of π^0-mesons, obtained by BChM is equal to (0.35 ± 0.02) BeV/c. From the results given in Table III the mean value of transverse momenta of π-mesons as well as transverse momenta of protons does not depend upon the number of charged particles in the star.

4. Effective cross section of interactions of π^--mesons with protons

From the 357 interactions observed by BChM, 264 were (π^-, p) interactions with free and almost free protons, the other 93 were interactions with

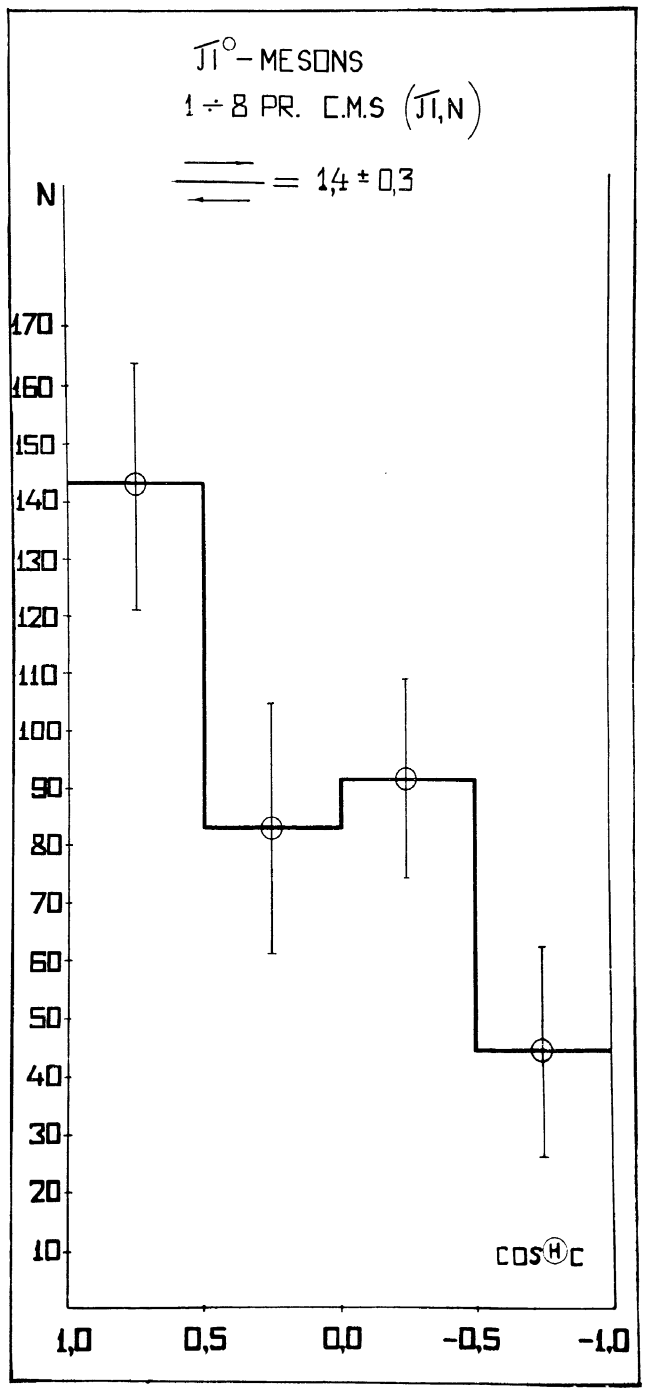

Fig. 4 Angular distribution of π^0-mesons.

Table II. Results about π^0-mesons obtained by BChM

Multiplicity	p_{π^0} lab.s.	$p_{\pi^0\perp}$	p_{π^0} c.m.s.	Number of π^0 in one interaction
2	1.32±0.25	0.40±0.07	0.56±0.09	1.03±0.19
4	0.86±0.08	0.40±0.08	0.48±0.11	0.80±0.18
1, 3, 5	1.20±0.22	0.28±0.08	0.44±0.08	0.66±0.16
0, 2, 4, 6, 8	1.00±0.13	0.37±0.04	0.49±0.06	1.04±0.14
0, 1, 2, 3, 4, 5, 6, 8	1.03±0.11	0.35±0.04	0.48±0.06	0.94±0.11

almost free neutrons. The difference of these numbers gives the number of inelastic interactions with free protons in propane. The corresponding effective cross section is equal to:

$$(23\pm3)\ \text{mb}.$$

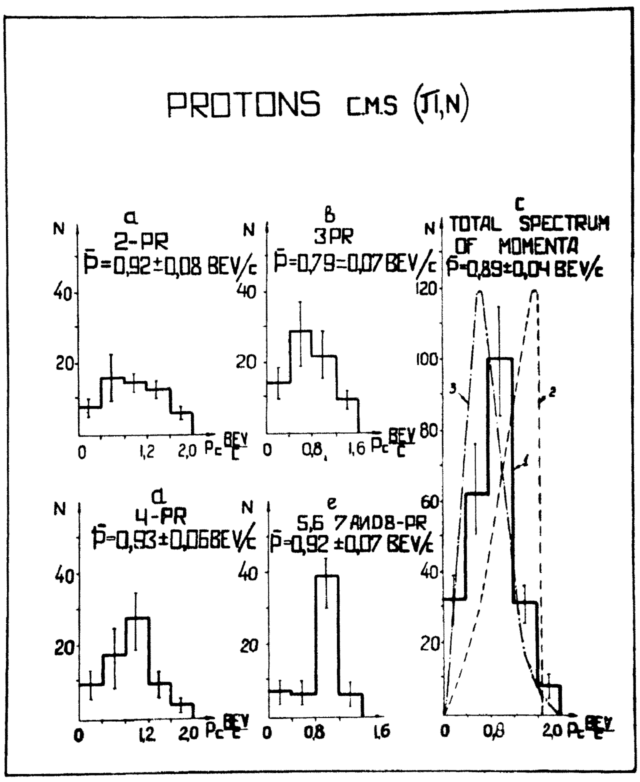

Fig. 5 Spectrum of momenta of protons.

During the investigation of the same films from bubble chamber, 37 cases of π^- disappearances were found (37 so-called zero-prong stars, [17]). From them 11 cases were excluded in which inelastic π^0-mesons were produced. The cross section corresponding to the 26 remaining zero-prong cases were determined to be ~ 1.3 mb. If we subtract from this value the cross section for creation of Λ^0 and K^0 particles in zero-prong stars equal to ~ 0.3 mb. [18], we obtain for the upper limit to the inelastic charge exchange

Table III. Transverse momenta

PEM $\bar{p}_\perp$ BeV/c.			BChM $\bar{p}_\perp$ BeV/c.	
Multi-plicity	$\pi^\pm$-mesons	Protons	Multi-plicity	π^--mesons
1, 2	0.31±0.04	0.30±0.06	2	0.38±0.03
3	0.26±0.03	0.37±0.08	4	0.37±0.02
4	0.36±0.04	0.41±0.08	6	0.30±0.06
5, 6, 7, 8	0.31±0.05	0.40±0.10	2, 4, 6, 8	0.37±0.05
1, 2, 3, 4, 5, 6, 7, 8	0.31±0.02	0.37±0.04		

cross section the value 1.0 ± 0.3 mb (if we assume that 3 π^0-mesons are produced in each case [7), 8)]). It is necessary to mention that this value is little sensitive to the proposed supposition about the mean number of π^0-mesons in inelastic zero-prong stars. If we take for the mean number 2 or 4 π^0-mesons, we obtain for the cross section the value 0.8 mb or 1.2 mb respectively.

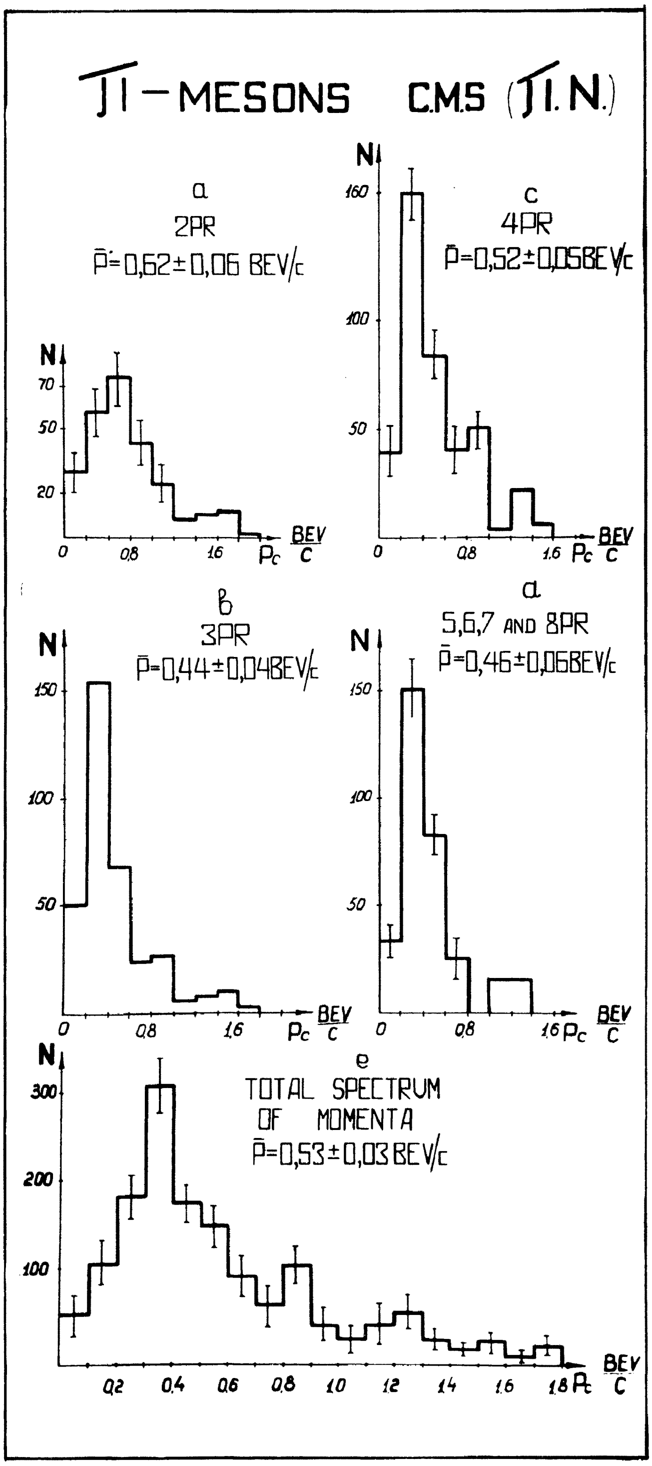

Fig. 6 Spectrum of momenta of $\pi^{\pm}$-mesons.

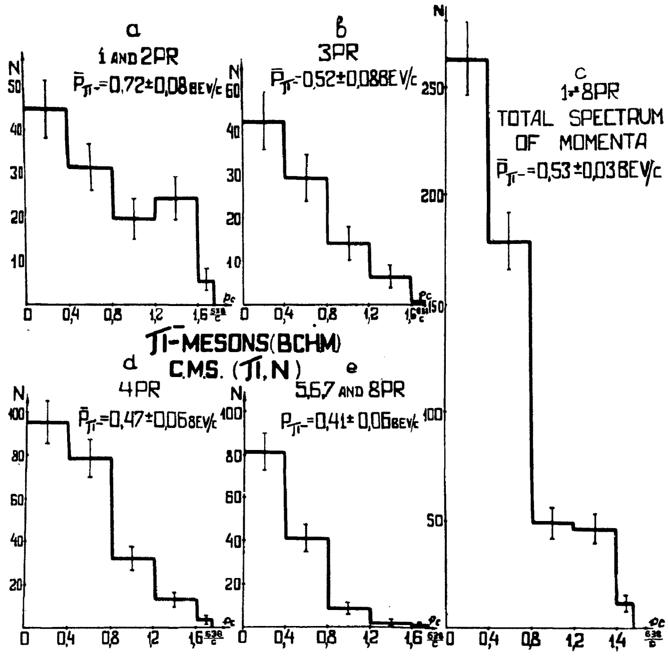

Fig. 7 Spectrum of momenta of π^--mesons.

II. ANALYSIS OF EXPERIMENTAL RESULTS

At present no theory exists which could give a complete interpretation of all experimental events concerning inelastic interactions of pions and nucleons. Such processes have been analysed by applying the statistical theory of Fermi and others and by using models in which the nucleon is considered as a core with its meson cloud.

1. Analysis of experimental results from the point of view of the statistical theory

In the experiments at lower energies as well as in our present work at 7 BeV there exist a number of general characteristics, which can be brought in agreement with the statistical theory.

For example, the mean value of charged particles in (π^-, p)-interactions $\bar{n}_{\pi, p} = 3.0 \pm 0.1$ coincides with the calculated value contained in papers by Barashenkov [11)]. The distribution of charged particles of various multiplicities calculated according to the statistical theory is given in Table I. They are in good agreement with experimental results.

As regards the production of π^0-mesons in (π^-, p) interactions, the comparison of experimental values with calculated ones is given in Fig. 8. The crosses

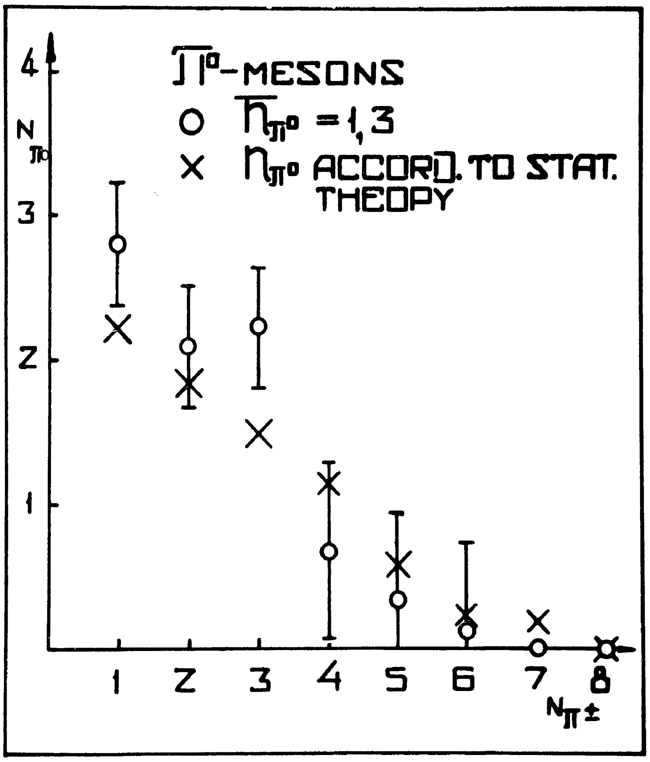

Fig. 8 Distribution of the number of π^0-mesons in the dependence on multiplicity.

represent the numbers of π^0-mesons, calculated according to papers [12, 15, 16], and the circles the numbers from the results on the basis of energy conservation. The decrease of the mean number of mesons observed in the experimental way with the increase of charged mesons is also in agreement with the mentioned calculations. The mean number of π^0-mesons produced in all (π^-, p) interactions is $\bar{n}_{\pi^0 p} = 1.0 \pm 0.1$ (obtained by BChM). This coincides within the limits of error with $\bar{n}_{\pi^0 p} = 1.3 \pm 0.2$ (obtained by PEM).

The curve of the total impulse spectrum of charged $\pi^{\pm}$-mesons calculated according to the statistical theory by Barashenkov coincides with the experimental histogram obtained by PEM. The calculated value of $\bar{p}_{\pi\pm} = 0.55$ BeV/c agrees with the experimental one $\bar{p}_{\pi\pm} = (0.53 \pm 0.03)$ BeV/c. The curve calculated for the total momentum spectrum of protons is given in the Fig. 5c (curve 3); the experimental spectrum (histogram 1, Fig. 5c) appears a little harder than the calculated one.

However, a number of other very specific characteristics cannot be brought into agreement with the calculations of the statistical theory, mainly the angular distribution of π-mesons and nucleons.

2. Analysis of experimental results from the point of view of the nucleon model

The asymmetry in the angular distribution of secondary π-mesons can be qualitatively explained by applying the idea of peripheral collisions. The calculations of ref. [11] based on the supposition, that the major part of cases are peripheral collisions of the primary π^--meson with the meson cloud in the nucleon, have shown that the forward-backward asymmetry in the experimental angular distribution of all π-mesons can be satisfactorily understood. The statistical theory is, however, applied to (π, π) interactions as well as to central collisions. Without this division into two types of collisions, the statistical concept of (π^-, N) interactions cannot possibly explain the very important characteristic feature of high-energy collisions, i.e. the sharp asymmetry of recoil protons in (π, N)-c.m.s. This effect finds its natural explanation by applying the above-mentioned model of the nucleon. During a collision of a high energy π-meson with a nucleon, its meson cloud is " shaken off " and the nucleon core continues its flight almost in the same direction as before the collision.

It is necessary to emphasize that the primary π^--meson during the collision with the meson cloud gives a big part of its impulse to the target meson cloud. Consequently, π^--mesons produced at small multiplicities will fly forward and will cause the asymmetry of the angular distribution of π-mesons. At high multiplicities the secondary π-mesons are distributed more isotropically.

To demonstrate the presence of the interaction of the primary π^--meson with the meson cloud of a nucleon, the dependence of the energy E_L of the $\pi^{\pm}$-mesons on their angle of emission θ_L in the lab. syst. is given in Fig. 9 for the (π^-, p) interaction and for the (π, π) one. All energy values for the " slow " $\pi^{\pm}$-mesons ($E_L < 0{,}5$ BeV) (crosses in Fig. 9) and for the " swift " ones ($E_L > 0.5$ BeV) (points in Fig. 9) lie inside the region of (π, π) collision. This fact shows clearly that for (π^-, N) interactions there exists a possibility of (π, π) collision.

If we try to estimate the effective target mass M_t [19], with which the primary π^--meson interacts[14, 8, 4] then for two prong stars a maximum lying in the region of the π-meson mass is indicated. For cases with higher multiplicity such a maximum does not appear. In Table IV [20], the mean values of the

Table IV. Mean values of the quantity M_t (BChM)

Multi-plicity	Number of events	$\Sigma\Delta\pi^{\pm}$		$\Delta\pi^0$	$\overline{M}_t$		$\bar{\varepsilon}$	
		Min.	Max.		Min.	Max.	Min.	Max.
2	111	136	176	125	260	300	0.28	0.32
4	112	345	410	177	520	590	0.56	0.63
6	22	470	520	135	605	655	0.65	0.70
Sum	245	260	315	150	410	460	0.44	0.49

target mass M_t are given, which for two prong stars is approximately equal to the mass of m_π and for higher multiplicities grows to $\sim 5m_\pi$.

Considering the π-mesons with $M_t < 300$, their angular distribution in the (π^-, N) system and in the (π, π) one was constructed (Fig. 10). It is possible to see that the distribution in the (π, π) system is very nearly symmetric. This fact can be explained as existence of the interaction of the primary π-meson with a meson of the cloud of a nucleon.

On the basis of the experimental results one can make an estimate of the radius of a core. From the fact that the fraction of protons emitted forward is lower than 10%, it seems that not more than 10% of all interactions can be related with central collisions. From this fact, one estimates for the upper limit of the radius of the core the value $\leq 4\times10^{-14}$ cm. Using the measurements of the dispersions of the transversal momentum Δp_r it has been possible to determine a lower limit $\Delta r \geq 4\times10^{-14}$ cm. for the region in a nucleon which is responsible for the main part of inelastic interactions.

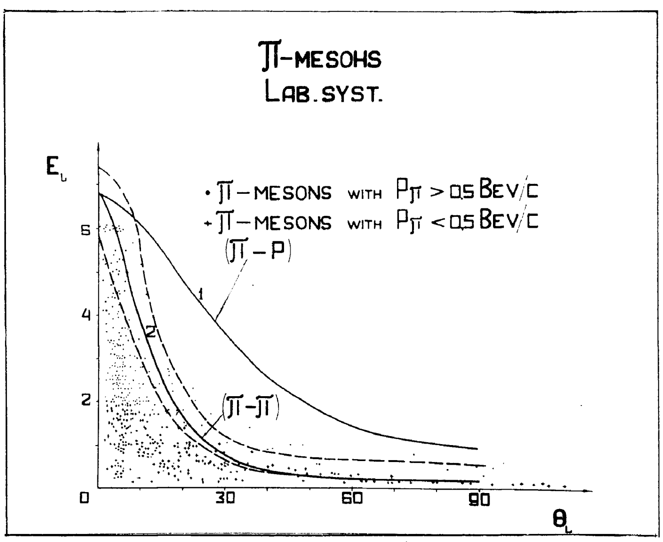

Fig. 9 Angular distribution of π-mesons in the lab. syst. according to PEM.

3. Analysis of experimental results from the point of view of other theoretical concepts

Attempts to clear up the characteristic properties of the angular distribution of nucleons and π-mesons are made in the recent work of D. I. Blokhintsev and Van Gun [10]. Their calculations, according to the authors' opinion, are also in good agreement with our results, concerning the transverse momenta of π-mesons and nucleons. The distribution of the total momentum spectrum of protons calculated in in the paper by Blokhintsev [10] is shown by curve 2 on Fig. 5c. The experimental histogram lies between the curves 2 and 3. The maximum of the curve 2, however, shifts to the left, if we are considering besides the two prong interactions the interactions with higher multiplicity. For the transverse momentum of protons there was obtained in the paper by Blokhintsev [10] the optimal value of 335 to 350 MeV/c, if the momentum of the primary π-meson has the values from 6.8 to 1000 BeV/c, which is in satisfactory agreement with experimental results in Table III. The distribution of the transverse momentum of protons, using the experimental results of the paper by Beljakov et al [7] are given in Fig. 11 by the histogram 1 which shows up to $p_{p\perp} = 0.7$ BeV/c the same course as the curve calculated in the paper by Blokhintsev [10], having real application for momentum transfer <1 BeV/c.

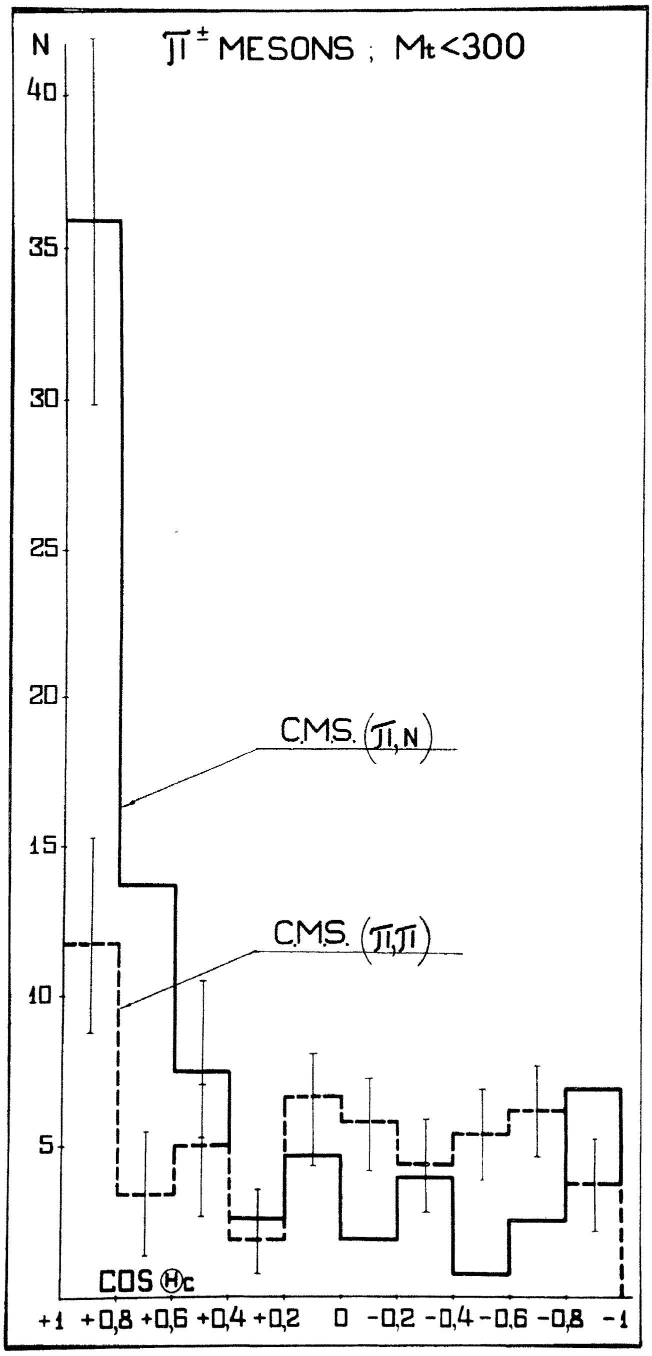

Fig. 10 Angular distribution of π-mesons for $M_t<300$.

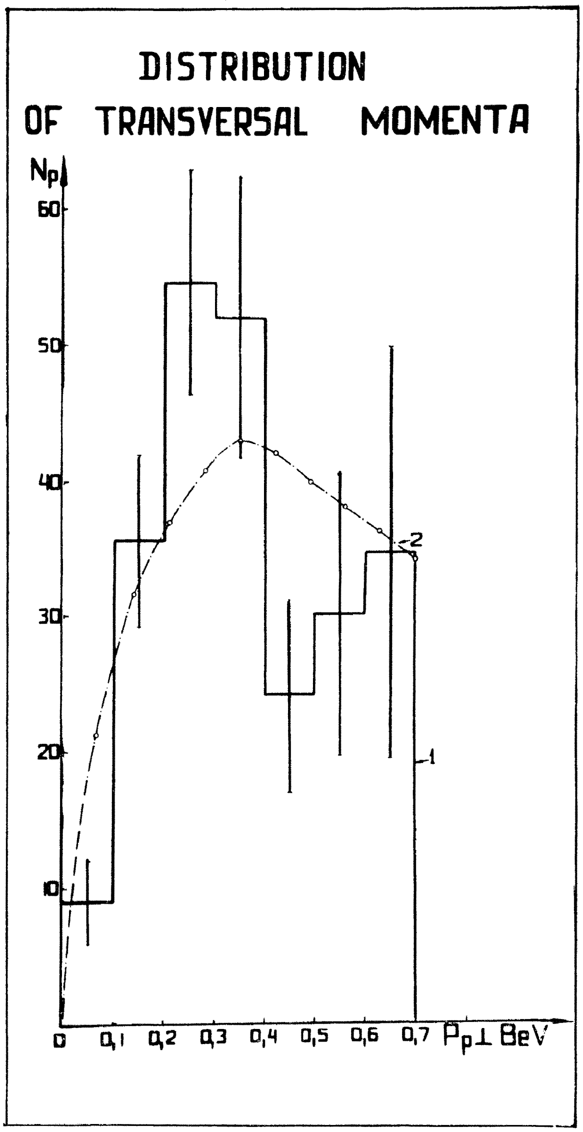

Fig. 11 Distribution of transverse momenta.

III. SUMMARY OF THE MAIN EXPERIMENTAL RESULTS IN (π^-, N) INTERACTIONS

The angular distribution of recoil proton does not seem to depend strongly from the multiplicity (Fig. 1); all protons according to results obtained by PEM and BChM fly backward in the (π^-, N)-c.m.s.

The distribution of total and transverse momenta of recoil protons does not depend upon the multiplicity (Fig. 5, Table III). The mean momentum of protons is equal to (0.89±0.04) BeV/c; the mean transversal momentum is equal to (0.37±0.04) BeV/c in the (π^-, N)-c.m.s.

The angular distribution of π-mesons does not show as sharp an asymmetry as it appears in the angular distribution of protons (Fig. 1, 2, 3, 4). The asymmetry expressed by the ratio of the number of π-mesons flying forward to the number of π-mesons flying backward (see Fig. 2, 3, 4) decreases with increasing multiplicity. Its mean value for all π-mesons is equal to (1.56 ± 0.10).

The mean momentum of π-mesons in the (π^-, N) c.m.s. varies slightly with the multplicity (Fig. 6, 7), the mean value of the momentum of all π-mesons is equal to (0.53 ± 0.03) BeV/c. The mean momentum $\bar{p}_L$ for π-mesons in the laboratory system decreases from (2.59 ± 0.19) BeV/c for the two prong stars to (0.91 ± 0.09) BeV/c for six prong stars.

The dependence on multiplicity seems to exist also for mean values of target mass $\overline{M}_t$ and the energy $\bar{\varepsilon}$, which the proton transfers to π-mesons (Table IV). For two prong stars there is $\overline{M}_t < 2m_\pi$ (Table IV), for cases with higher multiplicity

$$2m_\pi < \overline{M}_T < 5m_\pi.$$

The theoretical calculations done by D. I. Blokhintsev and Van Gun on one side and by Barashenkov on the other side and concerning the distribution of total and transverse momenta and the angular distribution of protons and π-mesons are in a satisfactory agreement with the experimental results.

At the end I wish to express my sincere thanks to D. I. Blokhintsev and to V. J. Veksler for the interesting discussion and for valuable suggestions during the elaboration of my report. With the same thanks I am obliged to all workers of the groups of the J. I. N. R., occupied with the investigations of the above problems.

APPENDIX

The work on pion-nucleon interactions is continuing at Berlin, Budapest, Pekin, and Prague. The best statistics up until the beginning of this conference were obtained by Dr. Lanius and his colleagues at the Institute of Nuclear Physics of the German Academy of Sciences, where 103 pion-nucleon collisions were analyzed. Of these, only one was an elastic collision; of the other 102 inelastic collisions, 61 were pion-proton and 41 were pion-neutron. The distribution function of the number of charged particles agrees with ours within the limits of the error except for the two-prong stars. The larger number of two-prong stars found at Berlin may be explained by the other scanning method. The same statement can be made about the Budapest results of Dr. Fennes and his colleagues. They have analyzed 18 pion-proton and 12 pion-neutron interactions. This work is well started at the four mentioned laboratories, and we can expect at the next conference much better results, particularly for the high multiplicities.

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19. The quantity M_t was evaluated on the basis of the relation [14]

$$M_t = \sum_i (E_{\pi, i} - p_{\pi, i} \cos \theta_{\pi, i}) \qquad (1)$$

(the sum was done over all π-mesons) or using the formula

$$M_t = M_N - (E_p - p_p \cos \theta_p) \qquad (2)$$

in cases in which a proton was emitted. $E_{\pi, i}$, E_p, $P_{\pi, i}$, P_p are the total energy and momentum of a π-meson and of a proton, respectively. $\theta_{\pi, i}$; θ_p are the angles of emission, and M_N is the mass of a nucleon.
20. The quantity M_t expressed in the mass of a nucleon is equal to the value of energy ε, which a proton gives to π-mesons, i.e. equal to the target mass, with which the π^--meson collides. The maximal and minimal values of M_t were obtained for limiting suppositions about the nature of identified swift positive particles (whether they are $\pi^\pm$-mesons or protons).

ELASTIC AND INELASTIC PROTON-NUCLEON INTERACTIONS AT HIGH ENERGIES

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(presented by V. I. Veksler)

PART I

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PROTON-PROTON ELASTIC SCATTERING AT THE ENERGY OF 8.5 AND 2.8 BeV

Preliminary data on proton-proton elastic scattering at 8.5 BeV were published earlier [1]. In this work the accumulation of statistics is continued. To increase the statistics in the region of small angles a photo-emulsion chamber, loaded with water [2] was exposed to 8.2 BeV protons. Because of the small difference in the energies these data were combined. 480 events of elastic scattering were detected on the whole.

Experimental results are given in Table I.

The total cross section of the elastic scattering is equal to 8.74+0.40 mb. The differential cross