SOVIET PHYSICS

JETP

A translation of the Zhurnal Éksperimental'noĭ i Teoreticheskoĭ Fiziki.

Vol. 14, No. 4, pp 705-950 (Russ. orig. Vol. 41. No. 4, pp 993-1336, October, 1961) April, 1962

STUDY OF THREE-PRONG STARS PRODUCED IN NUCLEAR EMULSION BY INELASTIC pn INTERACTIONS AT 9 Bev

V. A. BOTVIN, Zh. S. TAKIBAEV, I. Ya. CHASNIKOV, N. P. PAVLOVA, and É. G. BOOS

Institute of Nuclear Physics, Academy of Sciences, Kazakh S.S.R.

Submitted to JETP editor January 20, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 993-1002 (October, 1961)

Three-prong stars produced in nuclear emulsion in pn interactions involving 9-Bev primary protons are analyzed. The c.m.s. proton and pion angular distributions, energy spectra, and transverse momentum distributions are studied. The magnitude of the asymmetry in the angular distributions is considered in detail. Each type of reaction is analyzed separately, and the fraction of energy carried off by a proton and pion is found to be independent of the type of reaction. The distribution of the true inelasticity coefficients K is given for the reaction $p + n \rightarrow p + p + \pi^- +$ neutral particles. A tendency for the formation of two peaks is observed in the K distribution and this may indicate the existence of two different mechanisms of multiple production.

INTRODUCTION

INTERACTIONS of 9-Bev protons with free and quasi-free emulsion nucleons have been studied in a number of experiments.[1-7] The results obtained, however, differ in a number of respects. In [2,4,5] the total angular distribution of the secondary particles in pp and pn interactions was considered as a function of the multiplicity under the assumption that the velocity of the secondary particles in the center-of-mass system (c.m.s.) is equal to the velocity of the c.m.s. relative to the laboratory system (l.s.) ($\beta_i' = \beta_c$). It was noted that a marked asymmetry resulting from the preferential emission of secondary particles in the forward direction is observed in the angular distribution of pn interactions of low multiplicity, and it was concluded that this asymmetry was due to protons.

Subsequently, individual cases of three-prong stars in which it was possible to determine the nature and energy of all secondary particles were analyzed in [6]. It was shown that the secondary particles from the interactions selected for analysis in [6] were emitted preferentially in the forward direction and that this asymmetry was not due to protons, but to pions.

Meanwhile, it was noted[7] that the c.m.s. angular distribution of protons emitted in pn interactions is almost symmetric. Although there was a certain tendency to the forward emission of protons, the large errors make it impossible to establish the existence of an asymmetry for the protons.

Taking these facts into account, we have studied in detail the characteristics of the secondary particles in three-prong stars from pn interactions.

1. EXPERIMENTAL ARRANGEMENT

A stack consisting of 250 NIKFI-R 10×10 cm emulsion pellicles was exposed to the internal beam of the proton synchrotron of the Joint Institute of Nuclear Research. The pellicles were scanned along the proton tracks by the fast scanning method.[8] From all the recorded cases of primary proton interactions in the emulsion we selected for analysis proton-nucleon interactions which satisfied the appropriate selection criteria.[1,3,5]

In the present experiment we were interested only in inelastic pn interactions in which the stars have three prongs. The number of such cases was 110.

For these interactions we measured the angles in the plane of the emulsion λ_i and the dip angles φ_i of the secondary charged particles. From these measurements we determined the angle of emission of the secondary particles θ_i: $\cos\theta_i = \cos\lambda_i \cos\varphi_i \cos\varphi_0 + \sin\varphi_i \sin\varphi_0$, where φ_0 is the angle of the primary particle with respect to the plane of the emulsion. When the angles λ_i were very small, we measured them by the coordinate method; for large angles, the measurements were made with an eyepiece goniometer with scale divisions of 6′.

In order to identify the secondary charged particles we made multiple scattering and ionization measurements. We selected for measurement all tracks making an angle φ_i with the plane of the emulsion less than a cutoff angle $\varphi^0 = 8°$.

To ensure good statistical reliability for the scattering and ionization measurements, we followed the secondary tracks into the neighboring pellicles, so that the length of the measured track was at least $5000\,\mu$ for measurements with 250-μ cells and at least 10000 for measurements with 500-μ cells. When it was necessary to use a bigger cell, we increased the track length correspondingly by following the tracks further, so that the error in determining the energy did not exceed 20 – 25%.

The scattering measurements were made with $250 - 4000\,\mu$ cells. The optimum cell length for a given track was chosen with the aid of the parameter $\rho\overline{D}'''/\overline{D}$ where $\overline{D}$ and $\overline{D}'''$ are the mean second and third differences.[9] For pure Coulomb scattering $\rho_C = \sqrt{3/2} = 1.225$; for spurious scattering $\rho_S = 1.75 + 0.07$. The cells were recalculated for larger cell lengths until ρ was less than 1.4 – 1.5. The value of $\overline{D}_C$ for pure Coulomb scattering was found from the formula

$$\overline{D}_C = [(\rho_s \overline{D}^2 - \overline{D}'''^2)/(\rho_s^2 - \rho_C^2)]^{1/2}.$$

At the same time, the value of $\overline{D}_C$ was estimated from the formula

$$\overline{D}_C = \sqrt{\overline{D}^2 - \overline{n}^2},$$

where $\bar{n}$ is the mean value of the spurious scattering. The numerical value of $\bar{n}$ was determined from scattering measurements along 9-Bev proton tracks and was based on a large volume of statistical material.[10] The values of $\overline{D}_C$ found from these two formulas, and also, in some cases, with smaller cells[9] were in agreement with one another.

The ionization was measured by blob counting along the secondary particle tracks and along several beam tracks in the vicinity of the secondary track. The correction for the dip angle was based on the method of Viryasov and Pisareva.[11] As a measure of the ionization we used the ratio $b^* = B/B_0$, where B and B_0 are the blob densities of the secondary and primary particle tracks, respectively. For the identification of the tracks we used the b^* versus $p\beta c$ curves. In the region $p\beta c \gtrsim 1$ Bev, the measurement error of b^* was no greater than 3%.

To check choice of the correct curves we identified the particles by means of the following curves which have been used by various investigators: a) the curves based on Barkas and Young's tables;[12] b) the curve given by Edwards et al.;[13] c) the curve given recently by Jongejans.[14] It should be noted that the curves of Barkas and Young practically coincide with those of Jongejans. Figure 1 shows the above-mentioned curves of b^* vs ($p\beta c$) and the experimental points. From the position of the experimental points it seems to us that the best agreement is obtained with curves lying between those of Barkas and Young and those of Edwards et al.

Following Wang et al[7] we assumed that most of the particles in the region $1.5 \le p\beta c \le 2.5$ Bev were pions.

All the b^* vs $p\beta c$ curves are of similar shape. The difference involves only the rate of rise of the ionization from the minimum to the plateau. To facilitate the use of these curves, the value of b^* on primary particle tracks is usually taken as unity. This leads to the renormalization of the curves and results in a certain relative displacement of the curves. As can be seen from Fig. 1, however, the choice of the b^* vs. $p\beta c$ curves will not actually affect the conclusions, since the number of points representing particles whose identification will be changed is small.

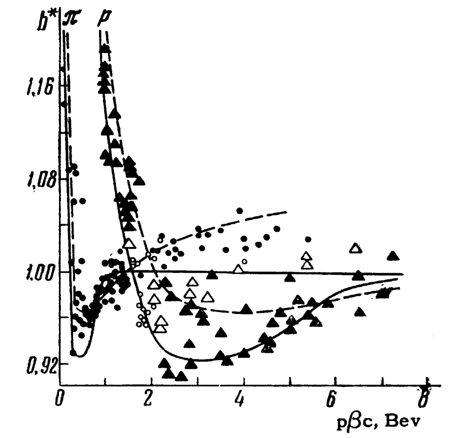

FIG. 1. Plot of b* vs. pβc for protons and pions; dotted curves – according to Barkas and Young, solid curves – according to Edwards et al.

2. PROTON AND PION C.M.S. ANGULAR DISTRIBUTION

To construct the c.m.s. angular distribution we used particles which could be identified under the conditions of the experiment. Since we could not determine the nature of all secondary particles in all interactions, but took, as a rule, a given sample of tracks ($\varphi_i \leq \varphi^0 = 8°$), it was necessary to introduce geometrical corrections which took into account particles with large dip angles. We arrived at these corrections in different ways.

A. If it is assumed that there is azimuthal symmetry in the l.s. (which is an entirely reasonable assumption), then each measured particle emitted at an angle θ in the l.s. should be assigned a statistical weight determined from the expression[15]

$$P = \frac{\pi}{2 \arcsin (\sin \varphi^0 / \sin \theta)}. \tag{1}$$

But we noted that the introduction of a statistical weight in this way increases somewhat the number of particles emitted at large angles (the sum of the statistical weights found from the measured particles is greater than the actual number of observed particles emitted at large angles).

B. Along with this approach, we determined the statistical weights in another way. The experimentally observed angular distribution of secondary particles in the l.s. was used to find the "experimental statistical weight" of each measured particle. We knew the number of measured particles and the total number of particles for any angular interval of the experimentally obtained histogram of the l.s. angular distribution. We could therefore determine the statistical weight for the given interval of angles θ as the ratio of the total number of secondary particles to the number of measured particles falling in the given angular interval. The experimental statistical weight determined in this way can be used in two cases: a) when particle tracks with $\varphi \leq \varphi^0$ are selected for identification, b) when all the particles are measured, even those with gray tracks in the emulsion. The experimental statistical weight determined for the second case will give the upper limit for the number of particles emitted in the backward hemisphere in the c.m.s.

We note that the introduction of the experimental statistical weights under assumption a) or using formula (1) and the taking into account of all gray tracks with a statistical weight of unity does not change the results.

In a previous experiment[16] we gave the experimental characteristics for different methods of introducing geometrical corrections. It was shown that the majority of the experimental data depend weakly on the choice of the statistical weights. However, more reliable results (in particular, for the $p_\perp$ distribution of protons) are obtained with the use of the experimental statistical weights under assumption b). We therefore present here the experimental results corresponding to the method of introducing the experimental statistical weights under assumption b).

The c.m.s. pion and proton angular distributions are shown in Figs. 2a and 2b. In these figures, as in those which follow, the dotted histograms correspond to the identification of particles with the curves of Barkas and Young and the solid histograms correspond to the curves of Edwards et al (unless indicated otherwise). It is seen from the pion c.m.s. angular distribution that the number of pions emitted forward is larger than the number of pions emitted backward. On the other hand, the opposite is observed for protons.

For a more careful check of this result, we assumed that all particles with $p\beta c \geq 2.5$ Bev in

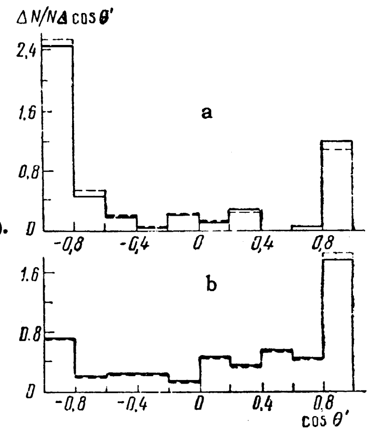

FIG. 2. C.m.s. angular distribution for protons (a) and pions (b).

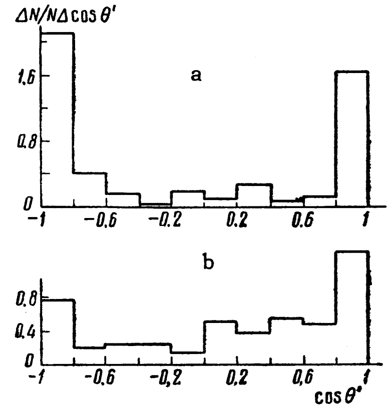

FIG. 3. Angular distributions of protons (a) and pions (b) under the assumption that all particles with $p\beta c \geq 2.5$ Bev (l.s.) are protons.

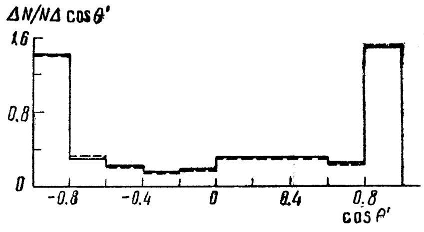

FIG. 4. Combined c.m.s. angular distribution of protons and pions.

the l.s. are protons, which is clearly not in accordance with the experimental data. The proton and pion angular distributions constructed under this assumption are given in Figs. 3a and 3b. It is quite evident that even under such an extreme assumption we did not observe a redistribution of the protons in the forward hemisphere, and we can say only that the protons are emitted symmetrically forward and backward in the c.m.s.

The combined angular distribution of the protons and pions is shown in Fig. 4. It is readily seen that the distribution is symmetric.

Since the question of the asymmetry of the angular distribution is very important, we analyzed all the assumptions involved in the introduction of the geometrical corrections. We shall consider qualitatively the question of the asymmetry of the particles. We define the asymmetry in terms of the quantity

$$\eta = (N_+ - N_-)/(N_+ + N_-), \qquad N_+ + N_- = N, \tag{2}$$

where N_+ is the total number of particles of a given kind emitted in the forward hemisphere, N_- is the corresponding number of particles for the backward hemisphere. The values of η for protons and pions and also for the combined distribution are shown in Table I for geometrical corrections introduced in various ways. The errors shown in the table were calculated with the aid of the binomial distribution of the values of N_+/N, where to determine the errors in the quantities N_+ and N we used different numbers of measured particles without taking into account their statistical weight. It is seen from the table that there is a significant tendency for the preferential emission of protons in the backward hemisphere and of pions in the forward hemisphere (in the c.m.s.); the value of the asymmetry determined by (2) lies outside the limits of error.

Hence we can conclude that the symmetry of the particles in the angular distribution for three-prong stars in the pn interactions found in[4,5] is the result of the unjustified assumption that the c.m.s. velocity of the secondary particles is equal to the velocity of the c.m.s. relative to the l.s. ($\beta_1' = \beta_c$). In fact, the combined proton and pion

Table I. Value of asymmetry in pion and proton distributions and combined angular distribution for different methods of introducing geometrical corrections and different assumptions on the relation between the ionization and the momentum of the particles

	Statistical weight from Eq. (1)		Experimental statistical weight			
			for case a		for case b	
	Barkas and Young	Edwards et al.	Barkas and Young	Edwards et al.	Barkas and Young	Edwards et al.
η_p	−0.36±0.15	−0.43±0.12	−0.32±0.11	−0.41±0.12	−0.35±0.10	−0.42±0.10
	−0.17±0.10*		−0.16±0.10		−0.16±0.09	
η_π	+0.14±0.07	+0.16±0.06	+0.31±0.07	+0.32±0.06	+0.40±0.07	+0.41±0.07
	+0.07±0.08		+0.22±0.08		+0.31±0.08	
$\eta_{p+\pi}$	+0.04±0.07	+0.04±0.07	+0.06±0.07	+0.05±0.07	+0.09±0.06	+0.08±0.06
	−0.03±0.07		+0.05±0.07		+0.08±0.06	

*The values in these curves correspond to the assumption that all particles with $p\beta c \geq 2.5$ Bev are protons.

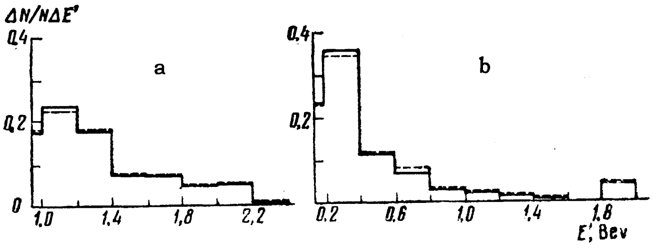

FIG. 5. Energy spectra of protons (a) and pions (b) in the c.m.s.; E′ – total energy of protons and pions (ΔE′ – in units of $\mu_\pi c^2$).

angular distribution (Fig. 4) is symmetric. Despite the fact that no asymmetry is observed, in the combined angular distribution of all particles, even under the stronger assumption as regards the nature of the high-energy particles ($p\beta c \geq 2.5$ Bev), we are inclined to believe that the observed strong tendency for the emission of pions in the forward hemisphere and of protons in the backward hemisphere in the c.m.s. reflects the existence of a real physical phenomenon which has not been explained as yet.

3. ENERGY CHARACTERISTICS OF SECONDARY PARTICLES, DISTRIBUTION OF TRANSVERSE MOMENTA AND INELASTICITY COEFFICIENTS

The experimental proton and pion c.m.s. energy distributions are shown in Fig. 5. We cannot, at present, make a direct comparison with the various theories of meson multiple production, since we do not have the calculated energy spectrum for reactions involving only three charged particles among the secondary particles.

We give below the mean values of the proton and pion energies in the c.m.s. $\overline{E}'_{tot}$ and the corresponding values for particles emitted in the forward $\overline{E}_f$ and backward $\overline{E}_b$ hemispheres (in Bev):

	$\overline{E}'_{tot}$	$\overline{E}'_f$	$\overline{E}'_b$
Protons:	1.426 ± 0.044	1.365 ± 0.046	1.453 ± 0.045
Pions:	0.460 ± 0.024	0.449 ± 0.050	0.487 ± 0.052

It is seen that these values do not differ from one another, within the limits of experimental error, which, of course, indicates that the particle energies were measured correctly.

The transverse momentum distributions of the protons and pions are shown in Fig. 6. The mean values of $\overline{p}_\perp$ for protons and pions were (in Bev):

	$\overline{p}_\perp$	$\overline{p}_\perp$, forward	$\overline{p}_\perp$, back
Protons:	0.317 ± 0.025	0.359 ± 0.052	0.297 ± 0.028
Pions	0.212 ± 0.012	0.205 ± 0.012	0.229 ± 0.036

Also shown in the table are the corresponding mean values for the forward and back hemispheres in the c.m.s.

From the mean values of the energy carried away by pions and nucleons, we estimated the inelasticity coefficient and the fraction of c.m.s. energy expended on the production of neutral mesons. If the mean number of pions per three-prong star is 1.76 and their mean energy is 0.460 ± 0.024 Bev, then the fraction of energy expended on the production of charged mesons is (31 ± 5) %. The fraction of energy carried away by nucleons is (37 ± 3) % and, correspondingly, the inelasticity coefficient is (63 ± 4)%. Hence (32 ± 6)% of the primary energy remains for the production of neutral mesons.

If it is considered that the number of neutral mesons is one-half the number of charged mesons (this is confirmed at high energies in the cosmic ray region), then it should be assumed that the π^0-meson energy spectrum in three-prong stars is of lower energy than the charged-meson spectrum but this seems unlikely.

If it is assumed that the neutral and charged mesons have the same energy spectra, then we arrive at the conclusion that the mean number of neutral mesons per three-prong star should be approximately equal to the number of charged mesons.

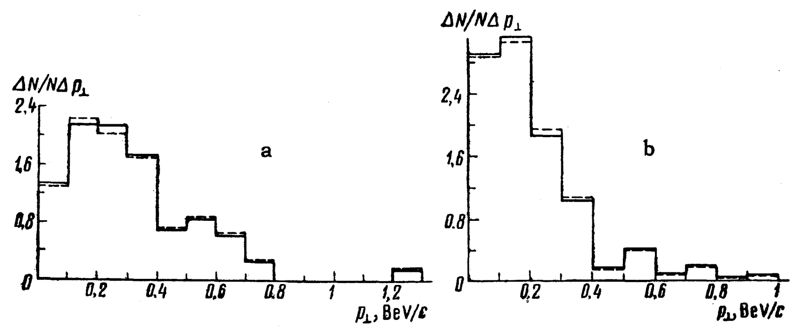

FIG. 6. Transverse momentum distributions of protons (a) and pions (b) ($p_\perp$ in units of Bev/c).

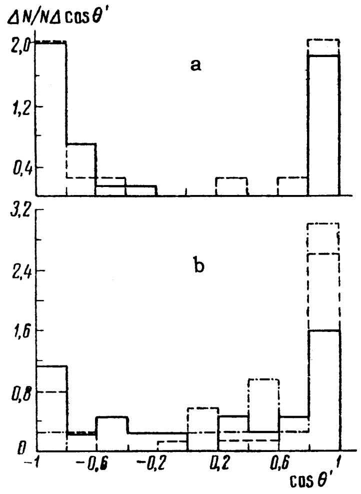

FIG. 7. Angular distribution of protons (a) and pions (b) for different types of reactions: solid line – reaction (I); dotted line – reaction (II); dash-dots – reaction (III).

4. ANALYSIS OF INTERACTIONS IN WHICH THE NATURE OF ALL SECONDARY CHARGED PARTICLES WERE IDENTIFIED

In the determination of the nature of the secondary charged particles, we were able to identify all three charged secondary particles in 41 cases. If we do not consider reactions in which strange particles and nucleon-antinucleon pairs are produced (the cross section of such interactions is quite small), then it is necessary to analyze only the following reactions:

$$p+n\rightarrow p+p+\pi^-+k\pi^0, \qquad \text{(I)}$$

$$p+n\rightarrow p+n+\pi^++\pi^-+k\pi^0, \qquad \text{(II)}$$

$$p+n\rightarrow n+n+\pi^++\pi^++\pi^-+k\pi^0, \qquad \text{(III)}$$

where $k = 1, 2, 3, \ldots$ is the number of π^0 mesons produced. For the cases in which all particles could be measured, the cross sections of reaction (I), (II), and (III) are in the ratio $\sigma_I:\sigma_{II}:\sigma_{III} = 1.71 : 3.14 : 1$. The angular distributions of pions and protons for these reactions are shown in Fig. 7.

In order to improve the statistics, we included in the proton angular distribution of reaction (I) protons in which as a result of the measurements two particles were identified as protons and the third particle (unidentified) was evidently a pion. The number of such cases was 10. All curves correspond to the number of measured particles without the introduction of geometrical corrections.

From the comparison it is seen that the pion angular distribution for reaction (I) is symmetric, but the protons tend to be emitted forward ($\eta_p^I = 0.18$), while in reaction (II) the pions are emitted forward ($\eta_\pi^{II} = 0.55 \pm 0.13$), but the proton angular distribution is symmetric. The pion angular distribution in reaction (III) is strongly asymmetric (which, perhaps, is due to the selection of events and the poor statistics for such reactions).

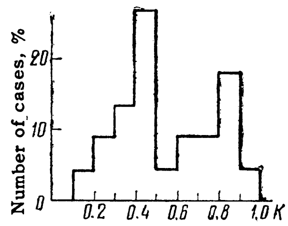

FIG. 8. Distribution of K for reaction (I) (l.s.).

Hence, in the angular distributions constructed for all reactions (Fig. 2), the asymmetry of backward protons is apparently due to reaction (I), while the forward asymmetry of the pions is due to reactions (II) and (III). The possibility of such an interpretation will be considered separately in another article.

Cases of interaction in which two protons are among the identified particles are of interest, since they permit an estimate of the true value of the inelasticity coefficient K, i.e., the fraction of the primary particle energy expended on the production of charged and neutral particles. In the l.s., the value of K for each interaction was determined from the relation

$$K=\left(E_0+M-\sum E_p\right)/T_0,$$

where E_0 is the total energy of the primary proton, ΣE_p is the sum of the total energy for the two secondary protons, $T_0 = 9$ Bev is the kinetic energy of the primary proton. The value of the inelasticity coefficient K′ in the c.m.s. is

$$K'=\left(2M\gamma_c-\sum E'_p\right)/2M(\gamma_c-1),$$

where M is the proton mass.

Figure 8 shows the distribution of K (in the l.s.) for 22 cases. The corresponding K′ distribution (for the c.m.s.) is shown in Fig. 9.

It should be noted that the inelasticity coefficient distribution for reaction (I) does not have a clearly visible maximum, on the contrary the distribution is very broad and a tendency is observed for the formation of two maxima in the intervals 0.4 – 0.5 and 0.8 – 0.9 in both the l.s. and c.m.s. This suggests the existence of two mechanisms of inelastic interaction. But in order to establish this, it is necessary to increase the statistical material.

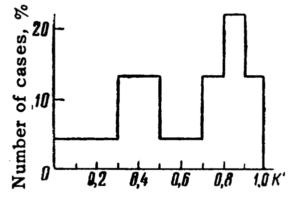

FIG. 9. Distribution of K′ for reaction (I) (c.m.s.).

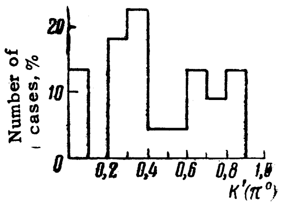

FIG. 10. Distribution of K′(π^0) for reaction (I) (c.m.s.).

Knowing the energy of the two protons and the pion, we can also find the value of K′(π^0), which is the fraction of energy expended in the production of neutral particles only. The corresponding distribution for reaction (I) is shown in Fig. 10. This distribution is also very broad.

Table II*

Type of reaction	Mean fraction of energy per proton, %	Mean fraction of energy per proton, %	Mean fraction of energy for all π^0 mesons, %
(I)	18.6 ± 0.8	16.4 ± 0.9	46.4 ± 2.5
(II)	15 ± 0.8	18 ± 0.8	34 ± 2.4
(III)	0	19.7 ± 1.1	4 ± 3.3
Mean values with allowance for the experimental statistical weights (case b)	18.7 ± 0.8	17.6 ± 0.9	–

*All data refer to the c.m.s.

One can still estimate the mean fraction of energy carried away by a single proton and a single charged pion for the various reactions. These values are shown in Table II. It is readily seen that the mean value of the energy carried away by a single proton and a single charged pion is practically independent of the form of the reaction. If it is assumed that the mean fraction of the energy carried away by the neutron in reaction (II) is equal to the mean fraction of energy carried away by protons in the same reaction and the mean fraction of energy for reaction (III) is the same as the corresponding value for reaction (I), then we can estimate the fraction of energy expended on the production of π^0 mesons. This value is also given in Table II (column 3). If it is assumed that the mean fraction of energy expended in the production of one π^0 is the same as the mean fraction of energy expended on the production of one charged pion, then it should be expected that, on the average, there are two to three π^0 mesons in reaction (I) and one to two π^0 mesons in reaction (II). In reaction (III) ~ 4% of the energy goes into neutral mesons, which is within the limits of experimental error.

The fraction of energy expended on the production of both charged and neutral mesons in reaction I is ~ 63%, while 59% of all the energy in reaction III is expended on the production of charged mesons only. These values are close to one another, which, indicates the absence of π^0 mesons in reaction (III), or, at most, the presence of only one π^0 meson.

On the basis of the foregoing discussion, it can be assumed that, with an increase in the multiplicity of the charged pions, the number of π^0 mesons decreases. Qualitatively, this also follows from other data. If it is considered that the mean energy of the pions does not depend on the multiplicity,[7] then, for $n_s = 7 - 8$, a negligible fraction of the energy should go into neutral particles. An analysis carried out in another experiment[17] indicates this, too.

CONCLUSIONS

1. The combined pion and proton c.m.s. angular distribution is symmetric.

2. The proton and pion angular distributions each show an asymmetry in the c.m.s., where the sign of the asymmetry is different; the protons are emitted preferentially in the backward hemisphere, while the pions are emitted preferentially in the forward hemisphere.

3. The estimate of the inelasticity coefficient based on the protons and pions indicates that half the energy going into the production of pions is carried away by π^0 mesons. If it is assumed that the energy spectra of the neutral and charged mesons are the same, then the number of π^0 mesons is equal to the number of $\pi^{\pm}$ mesons.

4. It has been shown that the mean energy carried away by one charged pion and one proton does not depend on the type of reaction.

5. The distribution of the true coefficient of inelasticity has no clearly discernible maximum; instead, we observe a tendency for the formation of two maxima. This conclusion, however, has to be confirmed with larger statistical material.

In conclusion, we consider it our pleasant duty to thank Academician V. I. Veksler for assistance in the exposure of the emulsion in the proton synchrotron of the Joint Institute for Nuclear Research and to M. I. Podgoretskii, K. D. Tolstov, and I. M. Gramenitskii and other staff members of the Joint Institute for Nuclear Research for discussions and a number of comments on this work.

1 Bogachev, Bunyatov, Merekov, and Sidorov, DAN SSSR **121**, 617 (1958), Soviet Phys.-Doklady **3**, 785 (1959).

[2] V. I. Veksler, Proceedings of the Second Intern. Conf. on the Peaceful Uses of Atomic Energy, Geneva, 1958.

[3] Barashenkov, Belyakov, Bubelev, Wang, Maltsev, Gyn, and Tolstov, Nucl. Phys. **9**, 74 (1958).

[4] V. I. Veksler, Proceedings of the Ninth Annual Intern. Conf. on High Energy Physics, Kiev, 1959.

[5] Bogachev, Bunyatov, Gramenitskii, Lyubimov, Merekov, Podgoretskii, Sidorov, and Tuvdendorzh, JETP **37**, 1225 (1959), Soviet Phys. JETP **10**, 872 (1960).

[6] Takibaev, Botvin, and Chasnikov, DAN SSSR **135**, 571 (1960), Soviet Phys.-Doklady **5**, 1249 (1961).

[7] Wang, Visky, Gramenitskii, Grishin, Dalkhazhav, Lebedev, Nomofilov, Podgoretskii, and Strel'tsov, JETP **39**, 957 (1960), Soviet Phys. JETP **12**, 663 (1961).

[8] Yu. P. Bannik and M. I. Podgoretskii, Pribory i tekhnika eksperimenta (Instruments and Experimental Techniques) No. 3, 36 (1960).

[9] I. Ya. Chasnikov, Trudy Instituta yadernoĭ fiziki AN Kaz SSSR (Trans. Nuclear Phys. Institute, Kazakh S.S.R.) **3**, 64 (1960).

[10] Chasnikov, Takibaev, Tursunov, and Sharapov, Pribory i tekhnika eksperimenta (Instruments and Experimental Techniques) No. 5, 15 (1960).

[11] N. M. Viryasov and L. P. Pisareva, ibid. No. 2, 17 (1960).

[12] W. H. Barkas and D. M. Young, UCRL-2579, 1954.

[13] Edwards, Losty, Perkins, Pinkau, and Reynolds, Phil. Mag. **3**, 237 (1960).

[14] B. Jongejans, Nuovo cimento **16**, 625 (1960).

[15] Bogachev, Bunyatov, Visky, Merekov, Sidorov, and Yarba, JETP **38**, 432 (1960), Soviet Phys. JETP **11**, 317 (1960).

[16] Botvin, Takibaev, Chasnikov, Boos, and Pavlova, Trudy Instituta yadernoĭ fiziki AN KazSSR (Trans. Nuclear Phys. Institute, Kazakh S.S.R.) **5** (in press).

[17] Boos, Botwin, Takibaev, Chasnikov, and Pavlova, JETP **42**, No. 1 (1962).

Translated by E. Marquit
173