PROTON-PROTON INTERACTION AT 9 Bev

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The c.m.s. angular distributions of protons and π mesons emitted in emulsions in proton-proton collisions were measured. The proton angular distribution is symmetric and possesses a pronounced anisotropy. The π-meson distribution is symmetric and more isotropic. The angular dependence of the total energy in the c.m.s. has been determined for protons. It is shown that, on the average, protons expend about 74% of their energy in the c.m.s. on meson production. Within the limits of experimental error, the mean values of the transverse momentum and the total energy in the c.m.s. are the same for various multiplicities.

A large number of experiments[1-3] have been carried out during the last two years to study the interaction of protons with nucleons at 9 Bev. In these experiments, the main features of pp collisions were revealed, and certain ideas on the nucleonic "dimensions" were also obtained. Unfortunately, the energy measurements and the identifications were carried out mainly for slow particles, and the results obtained by various authors are not always in agreement. Because of this, we have continued the study of pp interactions at 9 Bev energy.

An emulsion chamber consisting of layers of NIKFI-R emulsion was used. This chamber was irradiated by 9-Bev protons from the Joint Institude for Nuclear Research Synchrotron. The chamber was scanned along the tracks of primary protons using a magnification of 630 x. In all, 593 m of tracks were scanned, and 1609 nuclear interactions and scattering events at an angle $\theta \geq 5°$ were found, which gives a mean free path for the interaction equal to 36.9 ± 0.9 cm. This value, within the limits of experimental error, is in agreement with the results obtained earlier by other authors.[1,2]

The selection of inelastic pp interactions was based on the known criteria.[1,2,4,5] It should be mentioned that among the number of disintegrations studied there was not a single case accompanied by the emission of at least one slow proton with range $l \leq 4$ mm.

Out of all the disintegrations found, 123 were considered as inelastic pp colisions. Their distribution with respect to the number of secondary charged particles is as follows:

Number of events:	2	4	6
Number of interactions, %:	44.7 ± 6.1	48.0 ± 6.2	7.3 ± 2.4

The mean number of charged particles per pp interaction was 3.25 ± 0.16.

The secondary particles produced in inelastic pp collisions were identified by multiple Coulomb scattering and by the blob density along their tracks. The scattering and ionization measurements were carried out in an emulsion layer at least 20 μ below the surface, along tracks having an angle of dip $\varphi \leq 5°$. There were 147 such tracks.

In order to increase the measurement accuracy of both the multiple Coulomb scattering and the blob density, the tracks were followed in emulsion layers adjoining the ones used for the measurement.

Coulomb scattering was determined from the measurement of second differences of coordinates of three multiple cells.[6-8] This method, as is well known, makes it possible to exclude false scattering for each separate track.

On tracks for which the number of independent second coordinate differences on double and quadruple cells is small, the quantity $p\beta$ was determined with account of false scattering averaged over the given emulsion layer. The mean values of second coordinate differences for false scattering D_f are as follows:

Cell length, μ:	500	1000	2000
D_f, μ:	0.141	0.221	0.411

To increase the accuracy of the estimate of $p\beta$ in all events, we have taken the relation between the

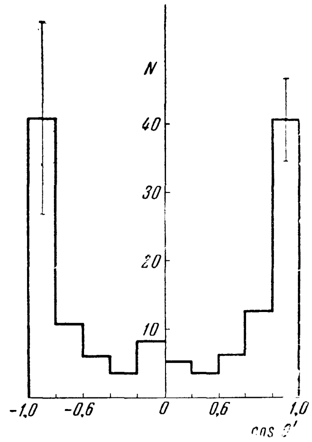

FIG. 1. Angular distribution of protons in the c.m.s.

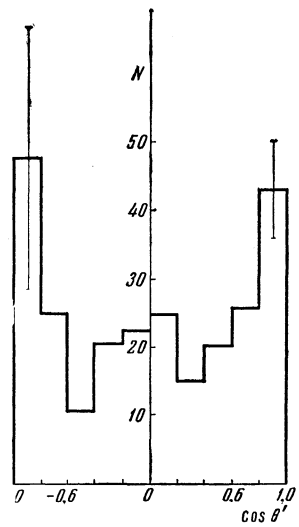

FIG. 2. Angular distribution of π mesons in the c.m.s.

second and third coordinate differences into account.

The particles were identified from the well-known dependence of ionization on particle velocity.[9] The corresponding curve was verified in the region of velocities greater than 0.94 of the velocity of light by measurements of the blob density along 9-Bev proton tracks and along tracks of electron-positron pair particles with sufficiently high energy, produced by high-energy γ rays.

The identification of particles with $p\beta$ between 1.5 and 2.5 Bev is very difficult and not always unambiguous. In the present experiment, the particles belonging to this range were identified by the method proposed by Kalbach et al.[4] As a result, 32% of the particles with $p\beta$ between 1.5 and 2.5 Bev were identified as protons, and the remainder as π mesons.

Using such an approach to the particle identification, the emission half-angles in the laboratory system (l.s.) for protons and π mesons in the doubtful energy range were found to be, on the average, equal to $\theta_p = (6 \pm 1)°$ and $\theta_\pi = (18 \pm {}^3_9)°$. Momentum and angular distributions in the l.s. for well-identified protons and π mesons have gaps in the range corresponding to $1.5 \leq p\beta \leq 2.5$ Bev which disappear if we include protons and π mesons from the doubtful range in the distribution.

The identification showed that, out of all 147 measured tracks, 70 belong to protons, 74 to π mesons, and 3 to K mesons. Taking into account the geometrical correction introduced by a method similar to that of Bogachev et al,[10] the number of protons was found equal to 141, that of π mesons 255, and that of K mesons 26. The mean number of protons per interaction is $\bar{n}_p = 1.2 \pm 0.2$, and the mean number of charged π mesons is $\bar{n}_\pi = 1.9 \pm 0.2$.

The angular distribution of secondary protons in the c.m.s. is shown in Fig. 1. It is characterized by symmetry with respect to the angle $\theta' = 90°$, and by sharp anisotropy. The emission half-angle for protons emitted forwards equals $(33 \pm 7)°$. The angular distribution of π mesons in the c.m.s. (Fig. 2) is also symmetrical with respect to the plane dividing the forward and backward hemispheres, but is characterized by a markedly smaller anisotropy. The emission half-angle obtained by the same method as for protons equals $(51 \pm {}^7_{11})°$.

The other main characteristics of secondary protons and mesons are shown in the table, where the values of the total energy E′ refer to the c.m.s. It can be seen from the table that the mean proton energy emitted forwards in the c.m.s. is identical with the mean proton energy emitted backwards in the c.m.s. The same is also observed for the π meson energies. However, the energy values obtained by us both for mesons and protons differ from the results of[3]. We have obtained somewhat higher π meson energies, while the proton energy is lower than that of[3].

	$\bar{n}$	$\bar{p}_\perp$, Mev/c	$\bar{E}'$, Mev		
			Particles emitted forward	Particles emitted backwards	All particles
Protons	1.20±0.14	437±52	1 311±53	1 257±77	1 280±42
π mesons	1.90±0.20	314±37	509±59	527±132	518±61
K mesons	0.17±0.10	—	—	920±240	920±240

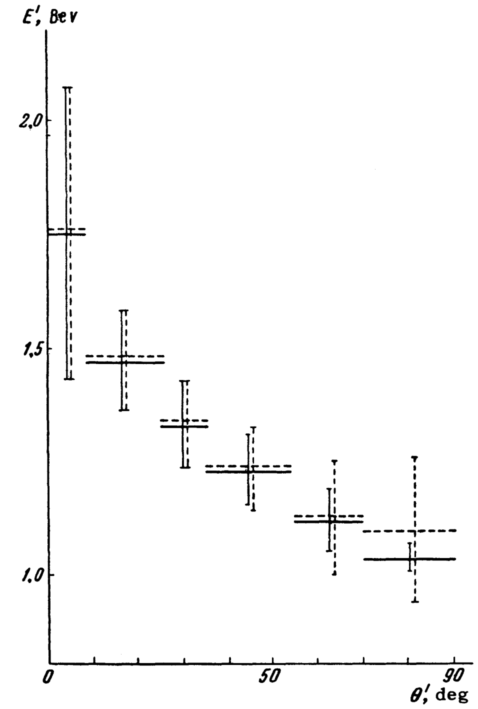

FIG. 3. Variation of the total proton energy with the angle of emission in the c.m.s.

We believe that one of the possible reasons for this discrepancy may lie in the different approach to particle identification in the doubtful region $1.5 \leq p\beta \leq 2.5$ Bev. As a rule, protons having $p\beta$ between 1.5 and 2.5 Bev in the l.s. are emitted in the c.m.s. with small energies and at large angles to the direction of motion of primary particles. It is therefore natural to expect that in the c.m.s. their mean energy will be lower, and the mean angle of emission greater, than for protons with values $p\beta < 1.5$ and $p\beta > 2.5$ Bev.

This is illustrated by Fig. 3, which represents the dependence of the mean total proton energy in the c.m.s. on the angle of emission in the c.m.s. The angle of emission for a particle going forwards in the c.m.s. is measured from the direction of motion of the primary proton, while, for particles propagating backwards in the c.m.s., it is measured from a line placed at 180° to the direction of

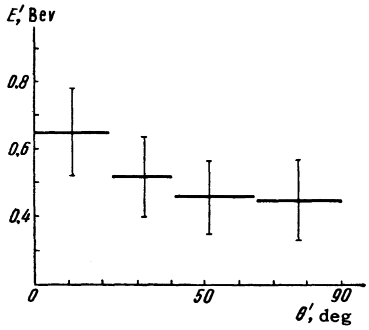

FIG. 4. Dependence of the total energy of π mesons on the angle of emission in the c.m.s.

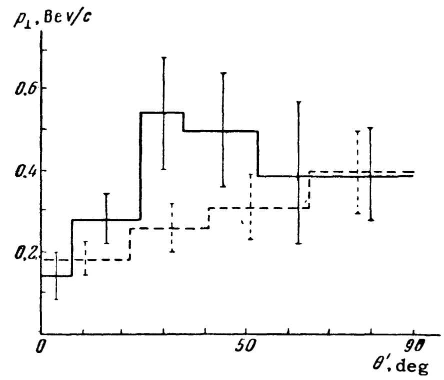

FIG. 5. Dependence of the transverse momentum of protons (solid line) and π mesons (dashed line) on the angle of emission in the c.m.s.

the incident particles. The solid lines correspond to the case where all protons, regardless of the value of $p\beta$ in the l.s., were included in the calculation, and the dotted lines to the case where protons with $p\beta$ between 1.5 and 2.5 Bev were excluded from the calculation. It can be seen from Fig. 3 that the mean proton energy decreases with increasing emission angle θ'.

An analogous dependence of the total energy of π mesons on the angle of emission in the c.m.s. is shown in Fig. 4. The c.m.s. angular distribution of transverse proton and π-meson momenta is shown in Fig. 5. The corresponding mean transverse momentum, both for protons and π mesons, depends weakly on the angle of emission of the particle in the c.m.s., with the exception of the range of small angles where the momentum conservation law begins to be felt.[11]

The calculation of the correlation coefficients between the total momentum and the angle of emission θ', and between the transverse momentum and the angle θ', has shown that, for protons, the total momentum varies more with the angle than the transverse momentum.

A similar calculation carried out for the π mesons has led to the conclusion that the dependence of the total and of the transverse momenta on the emission angle of the particle in the c.m.s. is of similar magnitude.

The inelasticity factors determined from nucleon and π meson energies in the c.m.s. are equal to 0.74 ± 0.09 and 0.68 ± 0.15 respectively. If we assume that the difference in the inelasticity factor obtained by different methods is due to the underestimate of the proton energy, then it follows from the proton energy balance in the c.m.s. that the mean proton energy is $\overline{E}' = 1.37 \pm 0.05$ Bev.

A calculation carried out under the assumption that the mean energy of neutral and charged mesons is the same shows that the mean number of neutral π mesons per interaction decreases from 2.7 (in stars with two charged particles) to zero (in events with $n_s = 6$). The total average number of π mesons per interaction is 3 or 4 for stars with different multiplicity, and the fraction of π^0 mesons on the average amounts to 0.4 ± 0.1 of the total number of mesons.

From the calculations carried out for events in which the momenta of all charged particles were measured, it follows that ~ 3.7 π mesons are produced on the average, in the reactions of the type $p + p \rightarrow p + p + n\pi^0$ and $p + p \rightarrow p + p + \pi^+ + \pi^- + n\pi^0$.

The result that, for protons and π mesons, the mean values of transverse momentum and of the total energy in the c.m.s. do not vary with multiplicity within the limits of experimental error is in agreement with the results obtained by other authors.[3, 11, 12]

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