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Fig. 1

Figure 1: Fig. 1

Abstract

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INELASTIC INTERACTIONS OF PROTONS WITH NUCLEONS AT AN ENERGY OF 9 BeV

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In an emulsion chamber irradiated with protons of energy 9 BeV, by the method of scanning along the track, 760 cases were found which may be assigned to events of the type of inelastic interactions of protons with nucleons: 492 (p—p) events and 268 (p—n) events.

The distribution of the cases found according to the number of secondary charged particles n (multiplicity) is given in Table 1. The mean multiplicity for (p—p) events is 3.34 ± 0.06. For (p—n) events the upper limit of the mean multiplicity is 2.76 ± 0.09, and the lower limit is 2.44 ± 0.07.

Table 1

n	2	4	6	8	1	3	5	7	9
Number of events	213	230	47	2	82*	144	35	6	1

* The number of one-prong events with an emission angle of the secondary charged particle not less than 5° is given. At smaller angles there is a large background of quasi-elastic (p—n) and (p-nucleus) events.

For the identification of nonstopping secondary charged particles, measurements of multiple scattering and ionization density were carried out on all tracks with a dip angle up to 5°. Only secondary particles having $P\beta \leqslant 1.4$ BeV/c were identified. This means that practically all charged π-mesons emitted in the center-of-mass system (c.m.s.) into the backward hemisphere are identified, as well as all protons whose angle and momentum in the c.m.s., θ^* and P^*, satisfy the inequalities: $\cos\theta^* < -0.7$; $P^* > 0.4$ BeV/c.

Fig. 1

Figure 2

Figure 2: Figure 2

The mean number of charged π-mesons per interaction in (p—p) events is 2.36 ± 0.14. In (p—n) events, using the hypothesis of charge symmetry, one may estimate the upper limit for the number of charged π-mesons: 1.76 ± 0.09. It is natural to assume that the cross sections of the reactions $p + p \to N + N + m\pi$-mesons and $p + n \to N + N + m\pi$-mesons, where $m = 1, 2, ...$, at an energy of 9 BeV are approximately the same. Then it follows from charge independence that the mean number of π-mesons in a (p—N) interaction, if the presence of K-mesons is neglected, does not exceed 3.09 ± 0.12 per interaction.

The angular distributions of charged π-mesons in the c.m.s. (Fig. 1) are anisotropic, but the degree of anisotropy is small. The mean emission angles of the mesons $\bar{\theta}^*_{\pi\pm}$ are $47 \pm 3°$ and $50 \pm 4°$, respectively, in (p—p) and (p—n) events. In work ([1]), with smaller statistics, for the half-opening angle of charged π-mesons in (p—p) events a value of $38 \pm 10°$ was obtained, in agreement within errors with the mean angle found in the present work. If the charged π-mesons slow in the c.m.s., with $P^* < 0.2$ BeV/c, are selected, their angular distribution proves to be isotropic: $\bar{\theta}^*_{\pi\pm} = 56 \pm 2°$ and $54 \pm 4°$ for (p—p) and (p—n) events. Secondary protons both in (p—p) and in (p—n) events are distributed sharply anisotropically (Fig. 2). The mean emission angles

of protons, $\overline{\theta}^*_p$, in $(p{-}p)$-events are $15 \pm 2°$, $15 \pm 2°$, and $17 \pm 4°$ for two-, four-, and many-prong events. In all $(p-p)$-events $\overline{\theta}^*_p = 15.4 \pm 1.5°$, and in $(p-n)$-events $19.2 \pm 1.9°$. As for π-mesons, the anisotropy of protons apparently decreases with decreasing momentum. In $(p-p)$-events protons with $P^* > 1.2$ BeV/c have $\overline{\theta}^*_p = 14 \pm 2°$, while protons with momentum $0.4 < P^* < 1.2$ BeV/c have $\overline{\theta}^*_p = 18 \pm 2°$.

Fig. 2

If in $(p-p)$-events the angular distributions of secondary particles should be symmetric in the c.m.s., then for $(p-n)$-events this is not obligatory. The degree of asymmetry may be characterized by the quantity

$$\Delta = \frac{N_{\text{f}} - N_{\text{b}}}{N},$$

where N is the number of events, and N_{f} and N_{b} are the numbers of secondary charged particles emitted in these events, respectively, forward and backward in the c.m.s. Assuming the validity of the charge-symmetry hypothesis, one can estimate the asymmetry of charged π-mesons in $(p-n)$-events with number of prongs $n \geqslant 3$; it does not exceed 0.08 ± 0.02. The ratio of the number of charged π-mesons from the backward hemisphere of the c.m.s. to the total number of particles is 0.32 ± 0.03 for $n = 3$ and 0.41 ± 0.06 for $n \geqslant 5$. These figures show

Figure 3

Figure 3: Figure 3

that the angular distributions in the c.m.s. of charged π-mesons in these events are apparently close to symmetric.

On the other hand, the number of protons in the backward hemisphere of the c.m.s. with momentum $P^* > 0.4$ BeV/c is 0.43 ± 0.05 in $(p-p)$-events, while in $(p-n)$-events it is less than 0.29 ± 0.06 protons per event. At the same time, the total number of protons per event for $(p-p)$-events is 0.98 ± 0.14, while for $(p-n)$-events, from the charge-symmetry hypothesis, this quantity should be equal to unity. Apparently, secondary protons from the reaction $p+n \to p+n+\pi$-mesons are emitted into the forward hemisphere of the c.m.s. with greater probability than into the backward hemisphere.

Fig. 3

The momentum spectra in the c.m.s. of charged π-mesons (Fig. 3) are substantially softer than the momentum spectra of secondary protons (Fig. 4): the mean momenta $\overline{P}^*_{\pi^\pm}$ are 0.33 ± 0.03 BeV/c and 0.37 ± 0.03 BeV/c, while $\overline{P}^*_p = 1.25 \pm 0.04$ BeV/c and 1.16 ± 0.05 BeV/c for $(p-p)$- and $(p-n)$-events, respectively. At the same time, in the c.m.s. the average fraction of the kinetic energy of the colliding protons going into meson production is 0.51 ± 0.05 in $(p-p)$-events and 0.54 ± 0.07 in $(p-n)$-events. Division according to multiplicity shows that, with increasing number of secondary particles, the momentum spectra of both mesons and protons become somewhat softer. The mean momentum in the c.m.s. of charged π-mesons in two-prong events is 0.42 ± 0.05 BeV/c, and in four-prong events 0.29 ± 0.03 BeV/c. Similarly, the fraction of protons with momentum $P^* > 1.2$ BeV/c, relative to the number of protons with momentum $P^* > 0.4$ BeV/c, decreases from $79 \pm 6\%$ for two-prong events to $19 \pm 13\%$ for events with number of prongs,

greater than four. Since the anisotropy of the angular distributions of secondary particles in the c.m.s. decreases with decreasing momentum in the c.m.s., one should expect that, as the multiplicity increases, it will also decrease. However, it is not possible to observe this directly with the present event statistics.

The number of charged π-mesons with momentum $P^* > 0.6$ GeV/c per interaction is, in $(p—p)$ events, 0.18 ± 0.10. Thus, no large asymmetry is observed in the distribution of energy among π-mesons in a single $(p—p)$ interaction event.

The mean transverse momenta of secondary protons and π-mesons are close in magnitude and are, respectively, in $(p—p)$ events 0.32 ± 0.03 GeV/c and 0.21 ± 0.02 GeV/c. From this fact, and from the small value of the inelasticity coefficient, follows the difference, already mentioned above, between the angular distributions of protons and π-mesons.

Fig. 4

Figure 4: Fig. 4

Fig. 4

The experimental data obtained for secondary protons do not agree with the statistical theory of multiple production. Even for a large number of secondary particles, fast secondary protons in the c.m.s. exhibit considerable anisotropy. The asymmetry of the angular distribution in the c.m.s. of secondary protons from (p—n) events in principle contradicts the statistical theory. As already noted in Ref. ([1]), the momentum spectra of protons in the c.m.s. differ substantially from the statistical ones. In the experiment, more high-energy protons are observed than is predicted by the theory. π-mesons do not show such large deviations from the predictions of the statistical theory. It is possible that the anisotropy of their angular distribution in the c.m.s. will be consistent with the statistical theory if the latter takes into account conservation of angular momentum.

A collision picture close to that in the experiment is obtained in the peripheral-collision model. A calculation performed under the assumption of peripheral collisions of nucleons with exchange of one virtual meson gives, at an energy of 9 GeV, satisfactory agreement with experiment for the energy distribution of recoil protons in the l.s., the angular distribution in the c.m.s. of charged π-mesons, and the magnitude of the asymmetry of the angular distribution of secondary particles in (p—n) collisions ([2]). However, the one-meson-exchange variant also apparently does not describe the entire set of experimental data. Thus, in four-prong (p—p) events, for the number of cases with an asymmetric separation in the c.m.s. of secondary charged particles a value of 22% is predicted, whereas in the present work the minimum number of such cases proved to be $38 \pm 5\%$ of four-prong events. The one-meson-exchange model is probably quite good for describing interactions with a small number of produced particles (≤ 2), but at higher multiplicities a different theoretical approach is necessary.

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