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Abstract

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INELASTIC pn INTERACTIONS AT AN ENERGY OF 9 BeV

In the present work we give experimental data obtained by us on inelastic *pn*-interactions at an energy of 9 BeV and their possible theoretical interpretation. The study of inelastic *pn*-interactions was carried out in an emulsion stack irradiated with protons in the internal beam of the synchrophasotron of the Joint Institute for Nuclear Research. Of all the recorded interaction events, only those satisfying the selection criteria ([1−3]) for proton-neutron interactions were chosen for analysis. The experimental method and the processing of the results obtained are analogous to those used previously ([4]). For the analysis, 236 events of inelastic *pn*-interaction were selected*.

The distribution according to the number of secondary charged particles is given in Table 1. For comparison, analogous data from work ([5]), renormalized in the appropriate way in order to exclude the influence of 1-prong events, are also given. Within the limits of error, fairly good agreement is observed.

One of the main results obtained in the present work is the value of the asymmetry of the angular distribution of protons after the collision. The point is that the angular distribution of secondary protons in the center-of-mass system (c.m.s.) is asymmetric: the majority of protons in the c.m.s. fly into the backward hemisphere, and this result does not depend on the number of secondary particles in the star. The magnitude of the asymmetry was determined by the ratio

$$\eta = \frac{N_+ - N_-}{N_+ + N_-}, \qquad N_+ + N_- = N, \tag{1}$$

where N_+ is the number of particles flying forward in the c.m.s., and N_- is the number of particles flying into the backward hemisphere.

The values of the proton asymmetry as a function of the number of secondary charged particles are given in Table 2. These values are close to one another. The reason for the discrepancy in the signs of the asymmetry for protons with the results of work–

Table 1

Number of interactions, %

Number of secondary charged particles:	3	5	7	9
results of the present work	74.1 ± 5.6	18.2 ± 2.8	6.4 ± 1.6	1.3 ± 0.7
data ([5])	65.6 ± 7.3	23.0 ± 4.3	10.6 ± 2.3	0.8 ± 0.8

Table 2

	Number of secondary charged particles	Number of secondary charged particles	Number of secondary charged particles	All *pn*-events without 1-prong events
	3	5	7–9	All *pn*-events without 1-prong events
η_p	-0.32 ± 0.12	-0.27 ± 0.16	-0.43 ± 0.23	-0.32 ± 0.10

* It should be noted that this number does not include 1-prong events, which we did not consider because of the impossibility of unambiguously separating them into elastic and inelastic collisions, as well as possible inaccuracies in the registration of such events during scanning.

···of the data in (5) lies in the large group of protons with $p\beta c \sim 0.8$–1.5 Bev, present in our experiment and absent in (5). The repeated measurements we carried out fully confirmed our initial data. The value of the asymmetry $\Delta_3 = +0.55 \pm 0.09$ (5), in the case where identification of the secondary particles was carried out, agrees within the errors with the value $\Delta_3 = +0.83 \pm 0.23$, obtained by an approximate recalculation from the laboratory system to the c.m. system under the assumption (2) that the velocity of the particles in the c.m. system is equal to the velocity of the c.m. system relative to the laboratory system ($\beta_i' = \beta_c$). This fact contradicts the observed energy spectrum of the protons (see (6)). The angular distribution of the produced π-mesons in the c.m. system for all inelastic pn events is close to symmetric. The magnitude of the π-meson asymmetry is $\eta_\pi = +0.17 \pm 0.08$. The requirement of isotopic invariance for all inelastic pn interactions indicates that the angular distribution of secondary charged π-mesons must be asymmetric in the c.m. system. The observed slight deviation is possibly connected with the exclusion from the analysis of one-prong

Fig. 1

Figure 1: Fig. 1

events or with an admixture of K mesons. The mean number of protons per interaction is $\bar{n}_p = 1.24 \pm 0.14$. The hypothesis of isotopic invariance predicts that $\bar{n}_p = 1.00$ for all inelastic pn events. The deviation of the experimental value from unity may also be due to the absence of one-prong events.

Fig. 1

The coefficient of inelasticity was determined for all inelastic pn interactions. In the c.m. system it was found to be $\bar{K}' = 0.66 \pm 0.02$. This value is in good agreement with the value found in (4) for three-prong pn interactions.

To interpret the results of the experiment we used the one-meson pole approximation (7). The principal requirement on the theory was to explain the observed asymmetry of the angular distribution of secondary protons in the c.m. system.

In (8) it was found that one-meson interactions represented by diagram a in Fig. 1 must be accompanied by preferential emission of protons forward in the c.m. system. On the other hand, as isotopic analysis shows, the observed proton asymmetry (predominant emission of them backward in the c.m. system) can be due only to one-meson interactions represented by diagram b and by the more general diagram v. Table 3 gives the values of η, calculated (under the usual assumption of statistical theory that the different isotopic reaction channels are equiprobable) for the processes described by diagram v. Comparison of the data of Table 3 with the experimental values of η for three-prong events, given in Table 2, leads to the conclusion that if the cross section of process v is sufficiently large, then the one-meson approximation is capable of explaining the nature of the backward proton asymmetry. The expression for the probability of process v can be written in the form

$$d\omega_{\mathrm{NN}} = (2\pi)^4 \sum_{n_1, n_2} \left| \frac{g(\bar{u}_2 \gamma_5 u_1)(\bar{u}_2' \Gamma u_1')}{\Delta^2 + \mu^2} - \frac{g(\bar{u}_2' \Gamma u_1)(\bar{u}_2 \gamma_5 u_1')}{\Delta'^2 + \mu^2} \right|^2 \times$$

$$\times \delta \left(p_0 + q_0 - p_1 - \sum_i^{n_2} q_i \right) \frac{d^3 p_1}{(2\pi)^3} \prod_i^{n_2} \frac{d^3 q_i}{(2\pi)^3}, \qquad (2)$$

Table 3

Complete number of secondary particles in the reaction

		3	4	5	6
1-prong events	η	$\sim +0.30$	-0.37	-0.23	-0.36
1-prong events	$\bar{n}_p$	0.40	0.44	0.48	0.52
3-prong events	η	0	-0.20	-0.30	-0.28
3-prong events	$\bar{n}_p$	2	1.3	0.95	0.79

where g is the renormalized coupling constant of the π meson with the nucleon; Γ is the operator for scattering of the π meson on the nucleon; p_0, q_0 are the momenta of the colliding nucleons; $\Delta = p_0 - p_1$; $\Delta' = p_0 - q_1$.

Owing to the strong anisotropy and to the restriction introduced below on the Δ^2 contribution of the interference term in (2), it may be neglected. The form of the operator Γ at high energies is unknown; therefore we replaced (see ([9])) the squares of the matrix elements containing Γ by the corresponding expressions including the total cross section for scattering of π mesons on nucleons. Then the cross section of the process under consideration has the form

$$\sigma_{NN}(E_0) = \frac{\tau_\alpha^2 f^2}{\mu^2 \pi^2 I_{NN}} \int \frac{d^4\Delta \cdot \Delta^2 \cdot \omega \sigma_{\pi N}(\omega)\, I_{\pi N}}{E_0 E_1 (\Delta^2 + \mu^2)^2}, \tag{3}$$

where E_0 and E_1 are, respectively, the energies of the primary and secondary nucleons in the c.m.s.; I_{NN} and $I_{\pi N}$ are fluxes; $f^2 = 0.08$ is the renormalized and rationalized coupling constant of the π meson with the nucleon; ω is the energy of the π meson.

Passing in (3) to nucleon variables and then expressing $|\vec{p}_1|$ through the variable mass of the πN system, m, we obtain the final expression for the cross section:

$$\sigma_{NN}(E_0) = \frac{\tau_\alpha^2 f^2}{4\pi^2 \mu^2} \int \frac{m\sqrt{(m^2 + 1 - \mu^2)^2 - 4m^2}\, p_1(m)\, \Delta^2(m)\, \sigma_{\pi N}(m)\, dm\, d(\cos\theta)}{E_0^2 \sqrt{E_0^2 - 1}\, [\Delta^2(m) + \mu^2]^2}, \tag{4}$$

where

$$\sigma_{\pi N}(m) = \frac{5}{9}\sigma_{1/2}(m) + \frac{4}{9}\sigma_{3/2}(m).$$

If, in integrating (4), no restrictions are imposed on Δ^2 other than those required by the conservation laws, the cross section of the process under consideration becomes very large and increases ($\sim \ln E_0$) with increasing E_0. However, if the calculations involve quantities $\Delta^2 > 1$, then, according to the uncertainty relation, they must correspond to central collisions of nucleons, whose consideration within the one-meson approximation is meaningless. It seems consistent to estimate $\Delta^2_{\max}$ on the basis of the static model with a cutoff ([10]), i.e., a model giving the value of the constant f^2. The value $f^2 = 0.08$ corresponds to a cutoff energy $\omega_{\max} = 6\mu$, which corresponds to $\Delta^2_{\max} = (5.5\mu) = 0.67$*.

Using (4) at $\Delta^2_{\max} = 0.67$ and the data on total cross sections for scattering of π mesons on nucleons ([11]), we found that for the energy $E_\Lambda = 9$ BeV ($E_0 = 2.4$) the cross section for inelastic interaction of a proton with a neutron is equal to 32 mbarn and at higher energies is equal to the constant value 30 mbarn. The contribution of process σ to process e at $\sigma_{\pi\pi} = 65$ mbarn is 7.3 mbarn for $E_0 = 2.4$. The calculated value of the mean inelasticity coefficient is 0.6. Thus, the experimental results presented (the predominant backward emission of protons in the c.m.s.,

* If, in estimating $\Delta^2_{\max}$, one proceeds instead from the size of the nucleon core $r_c \approx 1$, then application of the uncertainty relation $|\vec{\Delta}|_{\max} r_c \sim 1$ gives the result $\Delta^2_{\max} \approx (6\mu) = 0.83$.

average inelasticity, average number of protons per interaction, etc.) can be explained theoretically on the basis of a one-meson interaction process with the "excitation" of one of the interacting nucleons.

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Note: Figure translations are in progress. See original paper for figures.