# *INELASTIC* $\pi^-p$ *INTERACTIONS AT 7 BeV*

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A total of 154 inelastic $\pi^-p$ interaction events involving the emission of secondary protons with momenta between 180 and 500 MeV/c were selected from stereoscopic photographs of a propane bubble chamber irradiated by a beam of 6.8 ± 0.6 BeV/c $\pi^-$ mesons. An analysis of the events indicates that they possess some features that are characteristic of peripheral interactions. These features are more pronounced in two-prong interactions than in four-prong interactions. A new selection criterion for interactions involving free protons is considered. It is connected with calculation of the so-called missing mass. With help of this criterion it is shown, in particular, that in four-prong stars the fraction of background interactions with carbon is much higher than in two-prong stars.

THE present work is a continuation of investigations of inelastic $\pi^-N$ interactions at 6.8 BeV, carried out at the Joint Institute for Nuclear Research with a 24-liter propane bubble chamber [1,2]. The results obtained are based on a study of $\pi^-p$ interactions accompanied by emission of slow protons. Events of this type may be suitable for the study of peripheral interactions.

The events were selected in accordance with the universally accepted criteria [1], but it was required in addition that one black or grey track be contained among the secondary positively charged particles. All cases were measured, the angles and momenta of all the particles were calculated, and only those inelastic interactions with a secondary proton of momentum $180 \leq p_p \leq 500$ MeV/c were finally selected.

The distribution of events by multiplicity of charged particles is listed in the table. For comparison, the same table lists the distribution by multiplicity of all inelastic $\pi^-p$ interactions obtained in the preceding work [1], in which there was no limitation with respect to the secondary-particle momentum. The change in the character of the distribution can be naturally related with the fact that the peripheral reactions pertain essentially to stars with few prongs. [3-5]

In this sense, the momentum distributions of the secondary protons in the laboratory frame, shown in Fig. 1, are also instructive. Had we actually dealt with peripheral interactions, then it would be natural to expect a maximum of momentum distribution in the low-momentum region [6]. As can be seen from Fig. 1, a clear-cut maximum is observed only for two-prong interactions.

Figure 2a shows the angular distribution in the c.m.s. for $\pi^-$-mesons from two-prong stars. The distribution is strongly peaked forward, i.e., the $\pi^-$ meson "strives" to maintain the initial direction of motion. Such an angular distribution is also in qualitative agreement with the peripheral-interaction scheme.

If we assume that we deal with a $\pi\pi$ interaction, it is useful to consider the angular distribution of the $\pi^-$ mesons in the rest system of the two pions ($\pi\pi$ system). The distribution for the two-prong stars is in this case peaked forward (Fig. 3a), i.e., the scattering of $\pi^-$ mesons by $\pi$ mesons is diffractive in character. This deduction was arrived at tentatively at our laboratory previously [1]; it agrees with the notions developed in the papers of Bozoki et al [7] and Morrison [8]. We note that for four-prong stars the c.m.s. angular distributions of the $\pi^-$ mesons are less anisotropic than for the

| Multiplicity | Present work | | [1] | |
|---|---|---|---|---|
| | number of interactions | % | number of interactions | % |
| 2 | 96 | 62.3±3.9 | 119 | 45.4±4.2 |
| 4 | 57 | 37.0±3.8 | 115 | 43.9±4.3 |
| 6 | 1 | 0.7±0.7 | 20 | 7.6±1.7 |

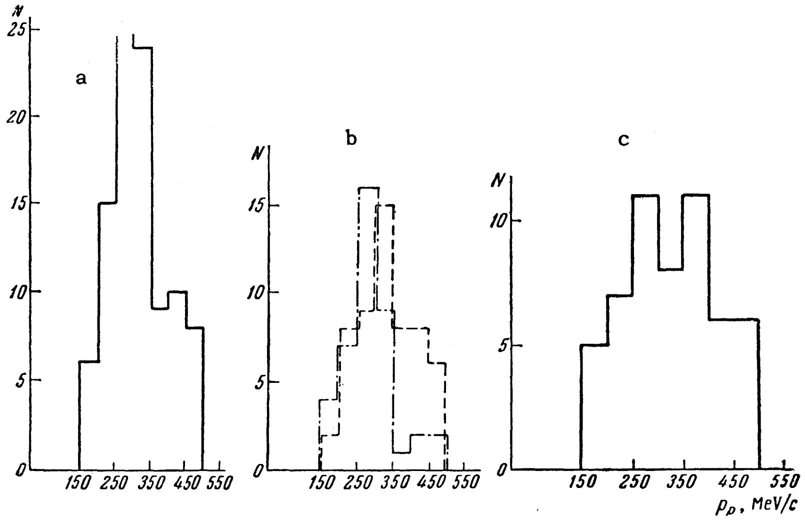


FIG. 1. Momentum distributions of secondary protons in the l.s.: a – for all two-prong interactions; b – for two prong stars with $M_x^2 > 0$ (dashed) and $M_x^2 < 0$ (dash-dot); c – for four-prong interactions.

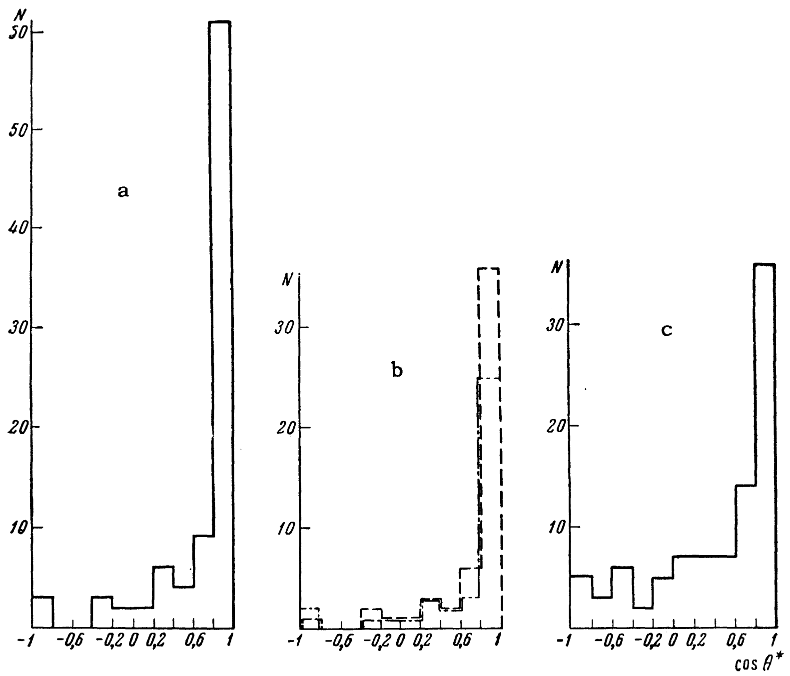


FIG. 2. Angular distributions of $\pi^-$ mesons in the c.m.s.: a – for all two-prong stars; b – for two-prong stars with $M_x^2 > 0$ (dashed) and $M_x^2 < 0$ (dash-dot); c – for four-prong interactions.

two-prong stars (Fig. 2c), and in the $\pi\pi$ system these $\pi^-$ mesons are emitted not forward but more likely backward (Fig. 3b).

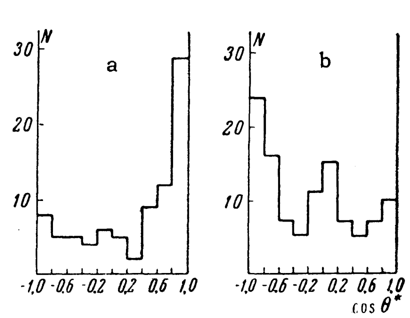


FIG. 3. Angular distributions of $\pi^-$ mesons in the $\pi\pi$ system: a – for two-prong interactions; b – for four-prong interactions.

If we assume that the interaction of the $\pi^-$ meson with the proton results in two diverging systems, one of which is connected with the nucleon, then the nucleon mass can be calculated from the approximate formula[9]:

$$M_1 = E_0^*/(\gamma_N^* + \sqrt{\gamma_N^{*2} - 1}). \qquad (1)$$

Here $E_0^*$ is the total energy of all the particles in the c.m.s. and $\gamma_N$ is the Lorentz factor of the secondary nucleon in the c.m.s. The distribution of the values of $M_1$, calculated for two-prong stars, is shown in Fig. 4a. A clear-cut maximum is observed in the distribution in the mass region 1.0–1.1 BeV/c$^2$. This apparently denotes that the pattern described above is actually obtained in the case of two-prong stars. If there is any maximum in the distribution of the values of $M_1$ for four-

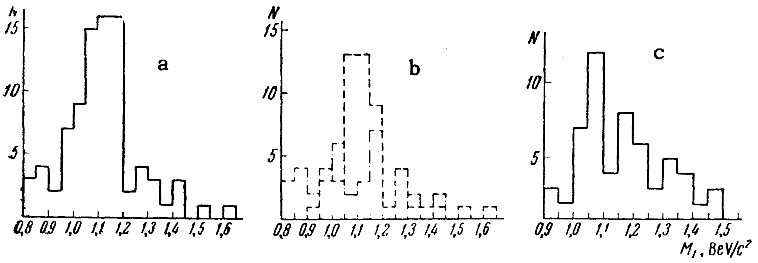

FIG. 4. Distributions of the values of $M_x$: a — for all two-prong interactions; b — for two-prong stars with $M_x^2 > 0$ (dashed) and $M_x^2 < 0$ (dash-dot); c — for four-prong interactions.

prong stars, it is much less pronounced (Fig. 4c).

Thus, two-prong stars have many peculiarities characteristic of peripheral interactions; these peculiarities manifest themselves much less pronouncedly in four-prong stars, taken as a whole. It is not excluded that this difference is connected to some degree with the fact that the events selected by us pertain partially to interactions on carbon. It will be shown below, in particular, that in the case of four-prong stars the share of the interaction on carbon is considerably larger than for two-prong stars.

To separate the events on hydrogen from the events on carbon, we attempted to use a new criterion, connected with the calculation of the so-called missing mass $M_X$ carried away by the neutral particles formed in the interactions. The calculations were made with the formula

$$M_x^2 = \left(E_0 - \sum E_i\right)^2 - \left(\mathbf{p}_0 - \sum \mathbf{p}_i\right)^2. \quad (2)$$

Here $E_0$ and $\mathbf{p}_0$ —total energy and momentum of the particles prior to interaction, $E_i$ and $\mathbf{p}_i$ —total energies and momenta of the charged secondary particles. In the interaction with a free proton, the quantity $M_X^2$ is always positive. For interactions with a nucleus (in our case, carbon) the formal calculations of $M_X$ frequently lead to imaginary quantities with rather large moduli. Therefore an imaginary value of $M_X$ indicates that the interaction has taken place on carbon (the converse is generally speaking not true).

By way of an example let us consider a "quasi-elastic" interaction on a bound proton, in accordance with the scheme

$$\pi^- + A \to \pi^- + p + O,$$

where A —initial nucleus and O —recoil nucleus. If the momentum of O is small, then there is no visible track and such an interaction will be taken to occur in accordance with the scheme

$$\pi^- + p \to \pi^- + p + X^0,$$

where $X^0$ are hypothetical neutral particles. Simple calculations lead to the expression

$$M_{X^0} \approx \sqrt{-p_O^2},$$

where $p_O$ is the momentum of the recoil nucleus. An examination of more complicated reactions, particularly those with neutral-pion production, leads to analogous results.

Figure 5a shows the distribution over the values of $M_X$ for 90 inelastic two-prong $\pi^-p$ interactions. It must be emphasized that each of these events satisfied all the accepted criteria for separating $\pi^-p$ interactions. As can be seen from the figure,

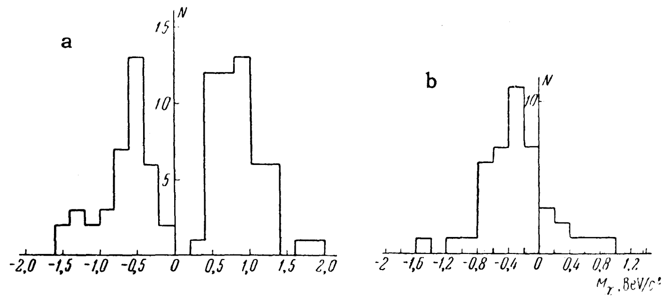

FIG. 5. Distribution of the values of $M_x$ for inelastic $\pi^-p$ interactions: a — two-prong; b — four-prong (negative $M_x$ denote imaginary quantities).

the distribution over $M_X$ has two clear cut maxima, separated by a dip near $M_X = 0$. The left-hand group[1], corresponding to interactions on carbon nuclei, contains 38 cases, while the right-hand one contains 52 cases. If we assume that these 52 cases are connected with the free hydrogen, then the cross section amounts to ~ 1.2 mb, which practically coincides with the results obtained in a hydrogen chamber[2] at the same primary $\pi^-$-meson energy.

Figure 5b shows the distribution over $M_X$ for four-prong stars. It is seen that most of these events have an imaginary mass $M_X$, i.e., they are events on carbon. Thus, the criterion under consideration turns out to be quite effective.

For an additional check on the reliability of the criterion we have considered 33 cases of elastic scattering of a primary negative pion on a free

[1]As far as we know, cases with imaginary values of missing mass were observed also by B. Shakhbazyan and Nguyen Dinh Ty.

[2]Private communication from Ya. M. Selektor, to whom the authors are grateful for a discussion of this question.

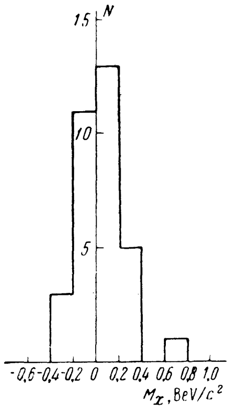


FIG. 6. Distribution of values of $M_x$ for elastic interactions.

proton. Separation of these cases was on the basis of the angle characteristics (coplanarity, ratio between emission angles). The distribution over $M_X$ plotted for these cases had, as expected, a clearly pronounced maximum at $M_X = 0$ (Fig. 6).

We note that for qualitative investigations the total separation of interactions with free protons is far from necessary in all cases. By way of an illustration we can cite the angular distributions of $\pi^-$ mesons in the c.m.s. and the momentum distribution of the recoil protons in the l.s., plotted for the two aforementioned groups of inelastic two-prong $\pi^-$p interactions (see Figs. 2 and 1, respectively). Qualitatively, the distributions in both groups pertain to the same type. On the other hand, distributions over the so-called "target mass" (Fig. 7) turn out to be noticeably different. The distributions with respect to $M_X$ also differ strongly from one another (Fig. 3).

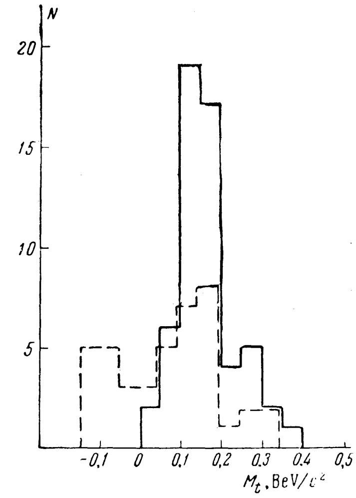


FIG. 7. Distribution of two-prong stars by "target mass": dashed – for cases with $M_x^2 > 0$, dash-dot – for cases with $M_x^2 < 0$.

In conclusion, the authors are glad to express their indebtedness to V. G. Grishin and G. I. Kopylov for useful discussions, and also to V. N. Strel'tsov and K. Igamberdiev for help with the work. The authors are grateful to the laboratory assistants who participated in the measurements and calculations.

[1] Birger, Wang, Wang, Ting, Katyshev, Kladnitskaya, Kopylova, Lyubimov, Nguyen Dinh Ty, Nikitin, Podgoretskiĭ, Smorodin, Solov'ev, and Trka, JETP **41**, 1461 (1961), Soviet Phys. JETP **14**, 1043 (1962).

[2] Lyubimov, Nikitin, and Trka, Preprint, Joint Inst. Nuc. Res. R-974, 1962.

[3] F. Salzman and G. Salzman, Phys. Rev. **120**, 499 (1960).

[4] Goldsack, Riddiford, Tallini, French, Neale, Norbury, Skillicorn, Davis, Derrick, Mulvey, and Radojicic, Nuovo cimento **23**, 941 (1962).

[5] Bozoki, Fenyves, Frenkel, Gombosi, and Suranyi, Nuovo cimento **24**, 29 (1962).

[6] G. F. Chew and F. E. Low, Phys. Rev. **113**, 1640 (1959). Gramenitskiĭ, Dremin, and Chernavskiĭ, JETP **41**, 856 (1961), Soviet Phys. JETP **14**, 613 (1962).

[7] Bozoki, Fenyves, Frenkel, and Gombosi, Preprint, 1962.

[8] D. R. O. Morrison, Proc. 1961 Intern. Conf. on Theoret. Aspects of Very High Energy Phenomena, Geneva, CERN, 61-22, p. 153. Proc. Intern. Conf. on Elementary Particles, Aix-en-Provence, 1, C.E.N., Saclay, 1961, p. 407. 1962 Intern. Conf. on High Energy Physics at CERN, Geneva, p. 606.

[9] Bohm, Petrzilka, and Suk, Preprint, 1962.

[10] N. G. Birger and Yu. A. Smorodin, JETP **37**, 1355 (1959), Soviet Phys. JETP **10**, 964 (1960).

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## ERRATA

Volume 16 (Russ. v. 43)

No. 1, p. 81 (Russ. p. 112), article by B. M. Smirnov.

The article contains an error. In the calculation of the matrix element $(\partial H/\partial t)_{km}$ contained in the formula of the adiabatic perturbation theory, an error was made in the sign of one of the terms, leading to a non-zero result, and the order of the expansion in the small parameter is lower than actual. A corrected paper will be published in "Optika i spekroskopiya."

Volume 17 (Russ. v. 44)

No. 2, p. 518 (Russ. p. 766), article by E. P. Shabalin

Right hand side of Eq. (3) should read

$$\frac{f_1 f_2 G^2 \sin(\varphi_0 - \varphi_1)}{2^8 \pi^4 7!! M} (Q^2 - 4m^2)(M - Q)^5 \left(1 + \frac{5Q}{M} + \frac{Q^2}{M^2}\right)$$

No. 5 p. 999 (Russ. p. 1485), article by D. K. Kopylova et al.

Caption to Fig. 7 should read:

Distribution of two-prong stars by "target mass": Continuous histogram - cases with $M_X^2 > 0$, dashed - with $M_X^2 < 0$.

Volume 18 (Russ. v. 45)

No. 4, p. 1100 (Russ. p. 1598), article by S. I. Syrovat-skiĭ et al.

Values of the fragmentation coefficient: in place of $a_{321} = -4.3618$ read $a_{321} = -3.3618$.