Estimate of the cross sections of the reaction $\pi^- p \rightarrow \pi^+ \pi^- n$ near the threshold

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An experimental estimate is presented of the cross sections of the reaction $\pi^- p \rightarrow \pi^+ \pi^- n$ at energies 190 and 200 MeV.

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Knowledge of the cross sections of the reactions $\pi N \rightarrow \pi\pi N$ near threshold, besides being of importance in itself, is of interest from the point of view of comparison with the results that follow from current algebra[1] and with a phenomenological analysis of the reactions.[2] However, it is exceedingly difficult to obtain information on the cross sections in regions near the threshold, because of the smallness of the cross sections themselves. Thus, for the reaction $\pi^- p \rightarrow \pi^+ \pi^- n$ (the threshold is 172.4 MeV) the cross-section measurement closest to threshold was made at 215 MeV.[3] Near the threshold the cross section is usually measured by a track procedure (bubble chambers or emulsions), and the main difficulty is that it is impossible to pass a large flux of incident particles through track instruments.

The possibility of performing the experiment is based on the fact in emulsions the ionization losses of the beam of the incident pions and of the secondary pions produced in the interaction are substantially different. This difference increases

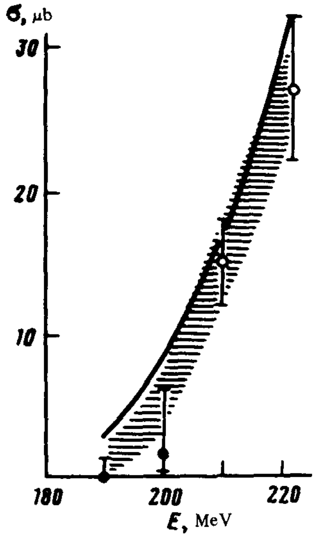

FIG. 1. Cross section of the reaction $\pi^- p \to \pi^+ \pi^- n$: ●—present results, —results of[3]; curve—calculation result,[8] shaded region—cross-section limits imposed by isotopic invariance

as the reaction threshold is approached, and the ratio of the ionization of the secondary pions for the central part of the spectrum to the ionization of the primary beam ions is 3.5 at a beam energy 190 MeV and 2.7 at 200 MeV. Consequently, if an emulsion is prepared or developed in such a way that it "does not feel" relativistic pions but registers effectively secondary pions with triple ionization, then it is possible to pass through the emulsion stack a beam of particles greatly exceeding the usually permissible value.

The experiment was performed with the synchrocyclotron of the Leningrad Institute of Nuclear Physics at two pion energies. The pion beams had the following parameters:

$$E_{\text{kin}} = 200 \pm 3 \text{ MeV} \quad \text{and} \quad 210 \pm 3 \text{ MeV},$$

$$\Delta p / p = 6\%, \quad \text{angle spread} \quad \pm 1^\circ.$$

The muon and electron contaminations of the pion beam were determined from the time of flight with accuracy 1%. Two emulsion stacks measuring 5×5×4 cm were irradiated in a direction parallel to the emulsion plane. The particle flux was measured with two scintillation counters connected for coincidence. The uniformity of the irradiation was monitored by proportional chambers. The emulsion stacks were made up of BR-2 layers 200 and 400 μ thick. To reduce the sensitivity, the emulsions were developed by a special method (which differs from the standard method in that the concentration of the hydrogen ions in the solutions is lower and the rate of the developant can be regulated smoothly). This made it possible to pass through the emulsion pion fluxes $\sim 1.5 \times 10^7$ cm^{-2}, which exceeded by almost two orders of magnitude the usual emulsion irradiation flux. The pion beam energies averaged over the investigated emulsion volume were 190 and 200 MeV. The efficiency of registration of the secondary pions was verified in a special experiment in which analogous stacks were exposed to pions of high energy, and amounted to 90% for pions with energy 14 MeV corresponding to the central part of the spectrum of the produced pions.

The search for the meson-production events was based on the characteristic $\pi^+ \to \mu^+$ decay. The angular distribution of the secondary pions in the laboratory frame is directed forward, assuming the statistical theory of their production, as is obviously the case near the threshold. Therefore to search for pion production events we used the emulsion volume corresponding to production of pions with maximum energy

Altogether we found approximately 2000 positive ions. The tracks of the π^+ mesons were traced to the parent stars, which we analyzed. The obtained π^+ mesons could be produced in interactions between π^- mesons and nucleons (the investigated process) or with the emulsion nuclei, or else be the consequence of double charge exchange of π^- mesons on nuclei. In the analysis of the parent stars it turned out that not a single case corresponds to the reaction $\pi^- p \to \pi^+ \pi^- n$ at 190 MeV and only one case at 200 MeV.

To determine the reaction cross section we took into account the efficiency of the search for π^+ mesons, the tracing efficiency, and the attenuation of the pion beam on passing through the emulsion. The correction for the contribution of the background events was assumed to be 20% in accordance with the data of[5]. The cross section of the reaction at 200 MeV was $1.6^{+4.7}_{-1.2}$ microbarn, and the upper bound of the cross section at 190 MeV is 1.3 μb at the 90% confidence level. The obtained cross sections are shown in the figure together with the results of[3].

The near-threshold cross sections of the reactions $\pi N \to \pi\pi N$ can be used in current algebra to verify different variants of the theory[1,6] and to determine the parameter ξ that breaks the chiral symmetry. Unfortunately, different approaches to current algebra—the method of the phenomenological Langrangian and the method of the current commutators—lead to different results.[6] If we use the formulas of[6] and the data shown in the figure, as well as the measured[5,7] cross sections in the reactions $\pi^- p \to \pi^+ \pi^- n$ and $\pi^- p \to \pi^0 \pi^0 n$ at somewhat higher energies (up to 280 MeV), then it turns out that in the phenomenological-Lagrangian method it is impossible to describe the experimental data at any value of ξ ($\chi^2/n = 8.2$, where n is the number of degrees of freedom). This indicates either an inappropriate form of the Lagrangian or the need for using data at lower energies. In the current-commutator method, using the same experimental data, we obtain $\xi = 2$ at $\chi^2/n = 2.1$. A more precise calculation by the current-commutator method was made by Chang[8] for the case $\xi = 0$, and his results are shown in the figure.

The near-threshold value of the cross sections can be obtained by using the isospin relations between the cross sections of the reactions $\pi N \to \pi\pi N$ and assuming a polynomial dependence of these cross sections on the energy.[2] It is possible to use the results of[2], where this problem was solved for the energy region 300—500 MeV, and continue the obtained solution to the meson-production threshold. In this case, using the experimental data in the energy interval 210—400 MeV, we obtain the region of permissible values of the reaction $\pi^- p \to \pi^+ \pi^- n$ indicated in the figure. It is seen that the cross sections obtained here do not contradict isotopic invariance.

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