Vector analyzing power iT_{11} in the $\pi^+ d \to pp$ reaction in the energy region 350–450 MeV

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The vector analyzing iT_{11} has been measured in the reaction $\pi^+ d \to pp$ at energies of 350, 400, and 450 MeV and at c.m. angles $\theta > 40°$. A sharp increase in iT_{11} is found at 450 MeV ($\sqrt{S} = 2.4$ GeV). This increase may be associated with anomalies seen previously in the $pp \to d\pi^+$ reaction.

The reaction $\pi^+ d \to pp$ and its inverse $pp \to \pi^+ d$ are the basic processes by which pions are absorbed and produced at intermediate energies. A detailed understanding of these processes and a knowledge of the reaction amplitudes would make it possible to test various models for nucleon–nucleon and pion–nucleon interactions and also to obtain information about effects associated with threshold phenomena or dibaryon resonances in elementary interactions. As is well known, reconstructing the amplitude for a πd interaction process, within a common phase, requires measuring 11 independent quantities, including the cross sections and asymmetries in the $pp \to \pi^+ d$ reaction and the vector (iT_{11}) and tensor components of the analyzing power of the deuteron. Measurements in the first of these groups (measurements of the cross sections and asymmetries in the $pp \to p^+ d$ process) have been carried out in a significant number of experiments at energies up to $\sqrt{S} = 3.0$ GeV ($T_\pi = 1.5$ GeV, $T_p = 3.0$ GeV).[13] Characteristics of the polarization properties of the deuteron have been measured only at far lower energies ($\sqrt{S} = 2.3$ GeV, $T_\pi = 325$ MeV).[4] The reason lies in the incomparably greater difficulty of such measurements, which are usually [[??carried out?? (Russian page unreadable here)]] in the $\pi^+ d \to pp$ channel with the help of π-meson beams, whose energies and intensities are limited. Even for the particular property in this group which has been studied most thoroughly—the vector analyzing power iT_{11}—the measurements have been limited to energies[4] $T_\pi = 325$ MeV. There is an urgent need for measurements of this type, not only in order to directly reconstruct the amplitude for the $\pi^+ d \to pp$ decay (as mentioned above) but even to carry out a reasonably reliable partial-wave analysis of this reaction. An analysis of this sort has been carried out at the Leningrad Institute of Nuclear Physics.[5–7] It included predictions of the behavior of the polarization properties and of the processes under discussion here at energies up to $\sqrt{S} = 2.4$ GeV. However, data[3] obtained later on the asymmetry in the reaction $pp \to \pi^+ d$ at $\sqrt{S} = 2.4$ and 2.7 GeV revealed discrepancies with this analysis and features not predicted by it.

The standard method for finding information on the analysis power is to carry out relative measurements of the differential cross sections for the reaction $\pi^+ d \to pp$ at a polarized deuteron target, for different signs of the target polarization. In this case, the data of interest here can be found from the well-known equation which relates the differential cross sections for the reaction $\pi^+ d \to pp$ to the magnitude and sign of the target polarization (the "sign" here means the direction with respect to the normal to the reaction plane):

$$\sigma^{\pm} = \sigma^0 [1 \pm \sqrt{3}(iT_{11}) P_z^{\pm} + \frac{3}{2} P_{zz} (T_{22} + \frac{T_{20}}{\sqrt{6}})]. \quad (1)$$

If $P_z^+ = P_z^-$, then

$$iT_{11} = \frac{1}{2\sqrt{3} P_z} \frac{\sigma^+ - \sigma^-}{\sigma^0}, \quad (2)$$

where σ^+, σ^-, and σ^0 are the cross sections for the reaction in the cases of polarized and unpolarized targets; P_z and P_{zz} are the vector and tensor polarizations of the target deuteron; and iT_{11}, T_{22}, and T_{20} are the vector analyzing power and two components of the tensor analyzing power.

Components of the tensor analyzing power can be found from (1) and (2) in a corresponding way, although measurements of the latter components require a much larger statistical base, since the tensor polarization (P_{zz}) of the target is small.

An experiment was carried out to measure the vector analyzing power iT_{11} in the reaction $\pi^+ d \to pp$ at energies $T_\pi = 350$–450 MeV at the synchrocyclotron of the Leningrad Institute of Nuclear Physics. The measurement apparatus included a polarized deuteron target based on deuterated propanediol. A system of scintillation counters detected the reaction products. The apparatus used in the present study was installed in the π-meson channel of the accelerator, where it was possible to produce pion beams with energies of 350–500 MeV and intensities of $(2\text{–}3) \times 10^5\ s^{-1}$.

Protons from the reaction $\pi^+ d \to pp$ were detected in coincidence at kinematically conjugate angles by hodoscopes of scintillation counters. These hodoscopes made it possible to measure the transit time of the particles over a 2-m baseline and to measure the energy loss dE/dx in scintillators 1 cm thick. The combination of these criteria made it possible to select particles from the reaction of interest against the background of particles from quasielastic scattering of π mesons by target nuclei and parts of the cryostat for the polarized target. In the course of the experiment, measurements were carried out at positive and negative target polarizations and also with an unpolarized working target, with a background target containing no deuterium, and at parts of the apparatus. The operation was monitored with some scintillation counters installed in front of the target in the π-meson channel and by a secondary monitor behind the target. The composition of the beam of incident particles was analyzed simultaneously, in order to discriminate against the admixture of protons in the beam ($\simeq 2\%$).

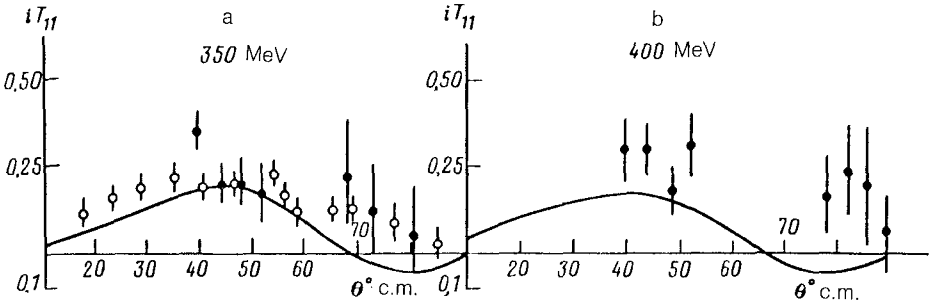

FIG. 1. a: Angular distribution of the vector analyzing power iT_{11} in the reaction $\pi^+ d \to pp$ at an energy of 350 MeV. ●—Present study; ○—measurements at an energy of 325 MeV (Ref. 4); line—predictions of the analysis of Ref. 7 at an energy of 363 MeV. b: The same, at an energy of 400 MeV. The line in this case is the prediction of Ref. 7 for an energy of 390 MeV.

Figures 1 and 2a show data obtained at three energies over the region 350–450 MeV. Figure 2b shows the energy dependence of iT_{11} for the angle $\theta = 50°$ (c.m.), which corresponds to the expected peak on the angular distribution $iT_{11}(\theta)$. Also shown in Fig. 1a are the results of some previous measurements, carried out at the Swiss meson factory.[4] The agreement between our data at 350 MeV and the previous results[4] at roughly the same energy, 325 MeV, indicates that the measurements are free of any significant systematic errors. Further evidence that there are no significant systematic errors comes from the agreement between (on the one hand) the value $iT_{11}(80°) = 0.067 \pm 0.15$ at $T_\pi = 350$ MeV and the value $iT_{11}(90°) = 0.074 \pm 0.131$ at $T_\pi = 400$ MeV and (on the other) the value $iT_{11}(90°) \equiv 0$, which is determined by

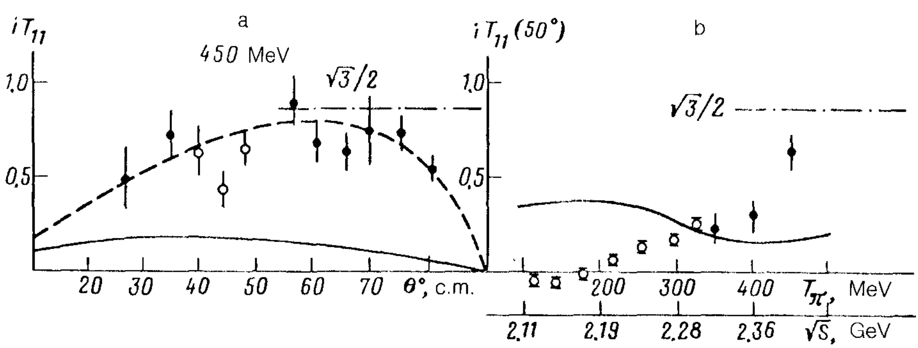

FIG. 2. a: Angular distribution of the vector analyzing power iT_{11} at 450 MeV. ●, ○—Results of two series of measurements; solid line—predictions of the analysis of Ref. 7; dashed line—an eyeball fit of the points. b: Energy dependence of the vector analyzing power at an angle $\theta = 50°$ (c.m.). Solid line—Predictions of the analysis of Ref. 7; open circles—results of Ref. 4.

symmetry considerations for the final state of the reaction. The data obtained at 450 MeV reveal a sharp increase in the vector analyzing power. This increase might be associated to some extent with the anomalies at the same energy ($\sqrt{S} = 2.4$ MeV) in the differential cross sections[3,8] in the $\pi^+ d \to pp$ channel and the asymmetry in the reaction $pp \to \pi^+ d$. At the moment, the explanation of these anomalies is not completely clear, although attempts[3,8,9] have been made to explain them in terms of a contribution to the πN amplitude from a D_{13} state, which has a resonance pole near the energy $(1440\text{–}60i)$ MeV, and also from a $^1G_4$ dibaryon resonance in NN scattering. The data which have been found also fail to support the predictions of the amplitude analysis of Ref. 7. They indicate the need for further analysis, incorporating the entire set of results which have been acquired in recent years.

[1]M. Akemoto *et al.*, Phys. Lett. B **149**, 321 (1984); H. L. Anderson *et al.*, Phys. Rev. D **9**, 580 (1974).
[2]D. Dekkers *et al.*, Phys. Lett. **11**, 161 (1964); J. Hoftiezer *et al.*, Nucl. Phys. A **402**, 429 (1983); M. Ya. Borkowsky *et al.*, J. Phys. G **11**, 69 (1985).
[3]R. Bertini *et al.*, Phys. Lett. B **162**, 77 (1985); Phys. Lett. B **203**, 18 (1988).
[4]G. R. Smith *et al.*, Phys. Rev. C **30**, 980 (1984).
[5]A. B. Laptev and I. I. Strakovsky, *A Collection of Exerimental Data for the $\pi^+ d \to pp$ Process*, Vol. 1, 2, LNPI, Leningrad, 1985.
[6]A. V. Kravtsov *et al.*, J. Phys. G **9**, L187 (1983).
[7]A. V. Kravtsov *et al.*, LNPI Preprint-963, 1984.
[8]B. G. L. Bakker *et al.*, Nucl. Phys. A **505**, 551 (1989).
[9]J. Arvieux *et al.*, Adv. Nucl. Phys. **18**, 107 (1987).

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