Eur. Phys. J. A **12**, 117–120 (2001)

**THE EUROPEAN PHYSICAL JOURNAL A**



# Measurements of the spin rotation parameter A in the elastic pion-proton scattering in the D13(1700) resonance region

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Received: 17 August 2001 / Revised version: 10 September 2001
Communicated by V.V. Anisovich

**Abstract.** The spin rotation parameters $A$ and $R$ were measured for the elastic pion-proton scattering by the PNPI-ITEP collaboration in the $D_{13}(1700)$ resonance region. The main goal of the experimental program is to resolve the current partial-wave analyses (PWA) uncertainties. Simultaneously with $A$ and $R$ the polarization parameter $P$ was measured with the purpose to improve the experimental database and estimate systematic errors. The constraint which demands a smooth energy dependence of all $\pi^- p$ transverse amplitude zeros in the complex plane together with the new experimental data on $A$ parameter can lead to the conclusion that the Barrelet branch of "zero trajectories" is chosen improperly in PWA of the Carnegie-Mellon-Lawrence-Berkely-Laboratory groups at the range of the pion beam momentum near 1.0 GeV/$c$. The setup included a longitudinally polarized proton target with superconductive magnet, multiwire spark chambers and carbon polarimeter with thick filter. The experiment was performed at the ITEP proton synchrotron, Moscow.

**PACS.** 13.75.Gx Pion-baryon interactions – 13.85.Dz Elastic scattering – 13.88.+e Polarization in interactions and scattering – 14.20.Gk Baryon resonances with $S = 0$

## 1 Introduction

The history of the pion-nucleon nonstrange resonance spectrum investigations is about 30 years old. These days three partial-wave analyses (PWA) are known which are the main source of information on resonance parameters: the basic PWA of the Karlsruhe-Helsinki groups KH80 [1,2] in the beam momentum range 0.020–10 GeV/$c$, PWA of the Carnegie-Mellon-Lawrence-Berkely-Laboratory groups CMB80 [3] up to 2.5 GeV and the set of analyses of the Virginia Polytechnic Institute group (VPI) [4] below 2.1 GeV/$c$. The details of all PWAs can be seen in SAID program [5].

Each PWA was based on many thousands of experimental data points. The latest PWA of the VPI groups (SM99) includes new experimental data for $\pi N$ elastic scattering.

It is a surprise that such a resonance as $D_{13}(1700)$ was not found in the solutions by the VPI group though it has high (3-star) status in the *Review of Particle Physics* [6]. This 3-star resonance was observed in many inelastic channels [6].

The PNPI-ITEP collaboration started measurements of the spin rotation parameters $A$ and $R$ in the second pion-nucleon resonance region ($P\pi$ = 0.9–1.9 GeV/$c$) in 1994 aiming to resolve the nonstrange baryon resonance spectrum uncertainties. In the region of the $D_{13}(1700)$ resonance chosen for this measurement there is a maximum discrepancy in the predictions by the KH and VPI groups, on the one hand, and CMB group, on the other hand, for the $A$ parameter in $\pi^- p$ scattering.

For the first time, the $D_{13}(1700)$ resonance was included in the *Review of Particle Properties* in the 1970 [7] as a poor resonance. It used to have the highest rating (****) in 1980-1982, but in 1984 its status was reduced back to (***) and is kept at this level till now.

From the classification standpoint the $D_{13}(1700)$ resonance is included in the unitary multiplet $(\{8\},^4 P_{1/2,3/2,5/2})$ of the $N = 1(70, 1-)$ supermultiplets of the basic $SU(6)$ representation together with the $S_{11}(1650)$ (****) and $D_{15}(1675)$ (****) resonances.

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**Table 1.** Polarization parameters in $\pi^{\pm}p$ scattering at 1.00 GeV/$c$.

| | Angle range $\Theta_{\rm cm}$, degrees | Average angle $\Theta_{\rm cm}$, degrees | $P$ | $A$ | $\lvert R\rvert$ |
|---|---|---|---|---|---|
| $\pi^+p$ | 156.0–161.0 | 158.7 | $0.81 \pm 0.13$ | $0.37 \pm 0.22$ | $0.45 \pm 0.30$ |
| 1.00 GeV/$c$ | 161.0–164.7 | 162.8 | $0.59 \pm 0.14$ | $0.49 \pm 0.22$ | $0.64 \pm 0.21$ |
| | 164.7–170.0 | 167.0 | $0.66 \pm 0.13$ | $0.30 \pm 0.21$ | $0.69 \pm 0.16$ |
| $\pi^-p$ | 156.0–160.1 | 158.4 | $-0.46 \pm 0.11$ | $0.07 \pm 0.18$ | $0.89 \pm 0.06$ |
| 1.00 GeV/$c$ | 160.1–163.4 | 161.8 | $-0.63 \pm 0.12$ | $-0.22 \pm 0.18$ | $0.75 \pm 0.11$ |
| | 163.4–170.0 | 165.8 | $-0.61 \pm 0.12$ | $-0.37 \pm 0.18$ | $0.70 \pm 0.14$ |

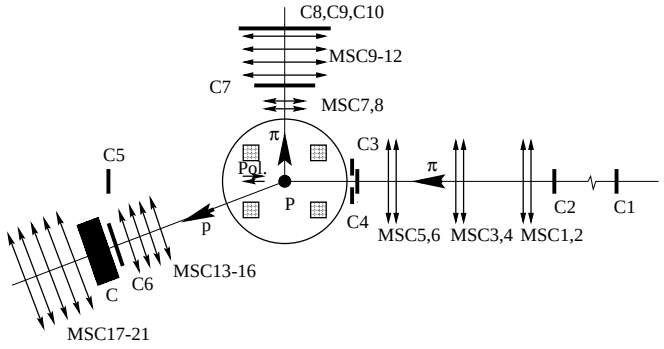


**Fig. 1.** The experimental layout (not to scale).

In addition, the $D_{13}(1700)$ resonance is included in Hoehler's baryon cluster $N^*$ around the pole (Re $=$ $(1665 \pm 25)$; Im $= -(55 \pm 15)$) MeV [8] together with the $S_{11}(1650)$, $P_{11}(1720)$, $P_{13}(1720)$, $D_{15}(1675)$ and $F_{15}(1680)$ resonances. But it is not seen in any of solutions by the VPI group.

## 2 Experimental conditions

Spin rotation parameters in elastic scattering are determined by the measurement of the polarization of recoiled protons produced by pions on a proton target polarized in the scattering plane. Polarization of the recoiled protons is measured through the asymmetry of their secondary scattering on the carbon.

The apparatus is shown in fig. 1. The basic elements of the apparatus are: i) a polarized target (PT) [9], ii) a carbon polarimeter (CP), iii) four sets of multiwire chambers (MSC1-16) for the detection of the incident and scattered pions as well as recoiled proton before and after the second scattering on carbon and iv) the system of scintillating counters for triggering and identification of the incident $\pi^+$ by the time-of-flight technique (C1-11). The container with polarized target material (propanediol $C_3H_8O_2$ doped by $Cr^V$ complexes) is placed into the magnetic field of 2.5 T created by a Helmholtz pair of superconductive coils. It has a cylindrical form with both vertical size and diameter of 30 mm. Cooling of the target material to 0.5 K is provided by an evaporation-type $^3$He cryostat. The protons of the target are polarized by the dynamic nuclear orientation method. The polarization is 70–80% with measurement uncertainty 1.5%.

## 3 Data processing

The processing of the data was performed in three steps:

- the first scattering was reconstructed, and the elastic events on the free protons of the target were selected. The kinematical criteria of complanarity and correlation between polar angles of the scattered pion and recoiled proton were used for the selection. The background of quasielastic events on the bound protons of the target nuclei was less than 8%, it was taken into account in the further processing;
- the second scattering was analysed, and its vertex and other parameters were determined. The events with a proton-carbon scattering angle 3–20° were selected for further processing;
- the selected events were divided into three angular ranges in $\Theta_{\rm cm}$ and in each range the values of $A$, $P$ were calculated by the maximum likelihood method similarly to [10]. The value of $|R|$ was taken from the equation $A^2 + P^2 + R^2 = 1$. The errors were defined according to the method described in [11].

## 4 Results

The spin rotation parameter $A$ was measured in the $\pi^{\pm}p$ elastic scattering in the baryon mass region $M \simeq 1.7$ GeV, where the PWA predictions have a maximal distinction in the back hemisphere [12]. The results of the experiments are summarized in the accompanying table 1.

Only statistical errors are presented in this table. All the systematic errors such as false setup asymmetry, uncertainties in the target polarization, analyzing power, amount and polarization of the background are negligible compared to the statistical errors. The results on the normal polarization $P$ measurements in the $\pi^{\pm}p$ elastic scattering do not contradict within the errors the results of the previous works [13,14] and predictions of PWAs KH80, CMB and VPI groups [5] (figs. 2, 3).

New results for the parameter $A^+$ are shown in fig. 4 and for the parameter $A^-$ are shown in fig. 5 together with PWAs of KH80, CMB and VPI groups [5] predictions.

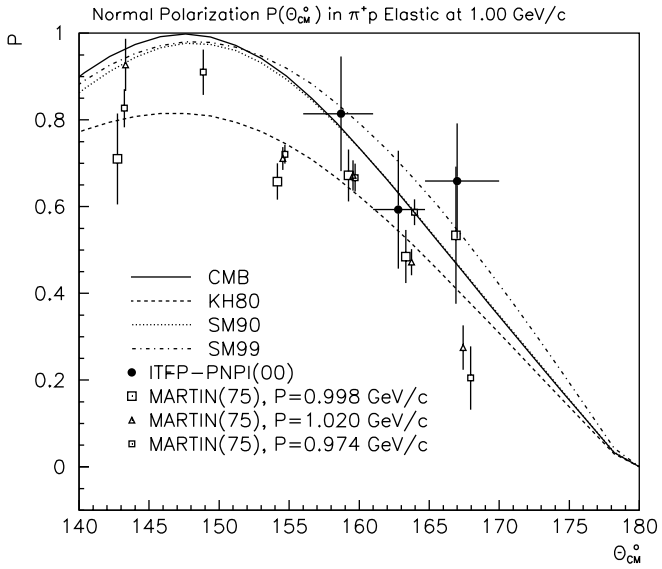


**Fig. 2.** Results of this work for the asymmetry **P** in the $\pi^+ p$ elastic scattering (full dots) compared with data from [13] and predictions of selected PWA [1,3–5].

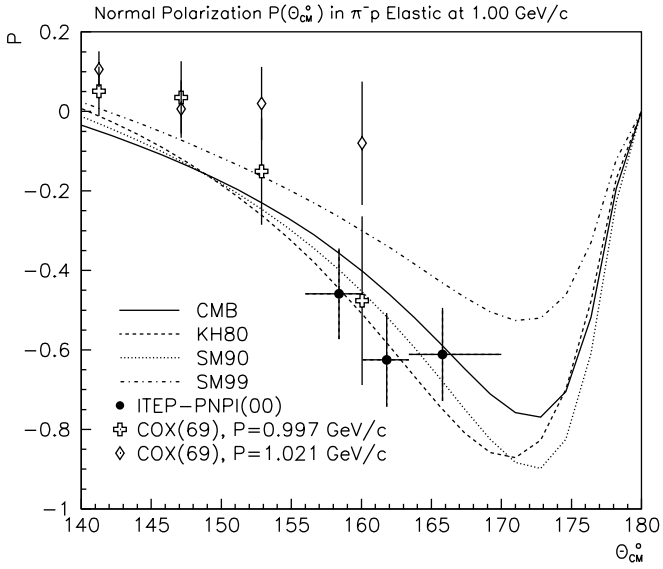


**Fig. 3.** Results of this work for the asymmetry **P** in the $\pi^- p$ elastic scattering (full dots) compared with data from [14] and predictions of selected PWA [1,3–5].

## 5 Conclusions

The results of this work are in agreement with last PWA VPI (SM99) predictions for both of $\pi^{\pm} p$ elastic scattering. The result for the $\pi^+ p$ elastic scattering substantiates our conclusion [15], that the Barrelet branch of associated "zero trajectories" is chosen realistically in PWA VPI [5] in pion beam momentum range 0.8–1.8 GeV/$c$. The visible distinctions between PWA predictions for the parameter $A^-$ in the beam momentum region $\simeq$1.0 GeV/$c$ are due to dissimilar choosing of the Barrelet branch of "zero trajectories" in PWAs KH80 and SM99 and PWA CMB. The results of this work are in evident conflict with PWA

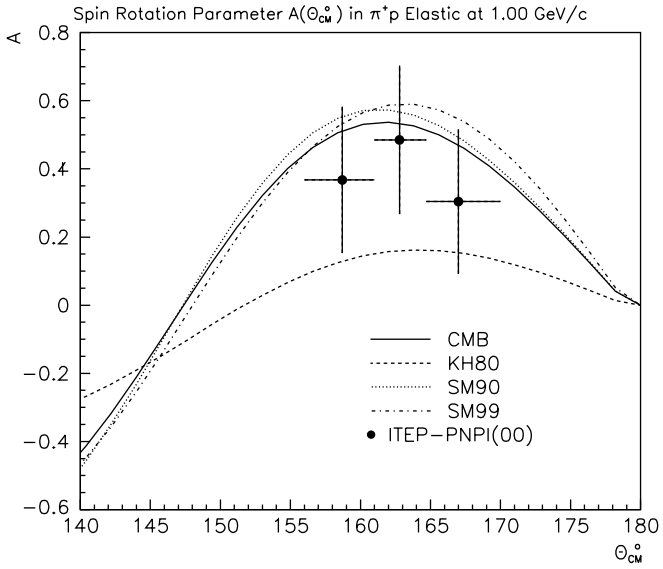


**Fig. 4.** Results of this work for the spin rotation parameter $A^+$ compared with PWA [1,3–5] predictions.

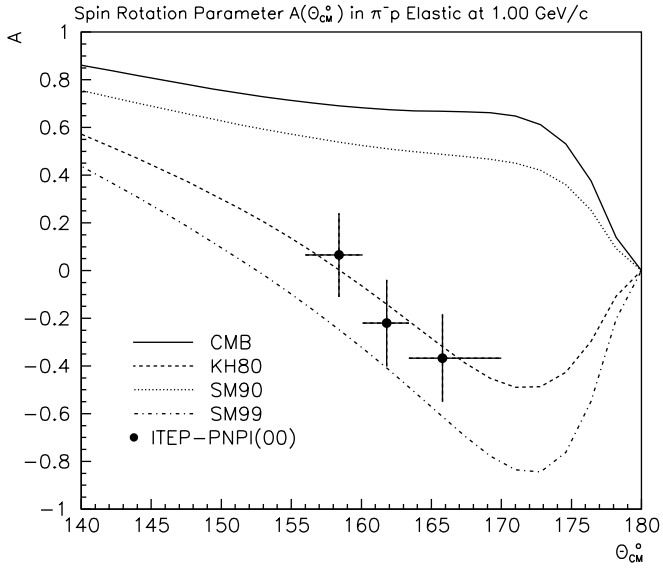


**Fig. 5.** Results of this work for the spin rotation parameter $A^-$ compared with PWA [1,3–5] predictions.

CMB predictions and allow us to conclude that the Barrelet branch of the associated "zero trajectories" is chosen incorrect in PWA CMB [3] in the essential pion beam momentum range near 1.0 GeV/$c$.

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