MEASUREMENT OF THE SPIN ROTATION PARAMETERS *A* AND *R* IN πp ELASTIC SCATTERING AT THE PION CHANNEL OF THE ITEP ACCELERATOR

PNPI participants of the PNPI-ITEP collaboration:
A.I. Kovalev, S.P. Kruglov, D.V. Novinsky, V.A. Shchedrov, V.V. Sumachev, V.Yu. Trautman

1. Introduction

This experiment is from the series of the spin rotation parameter measurements performed by the PNPI-ITEP collaboration during the last decade [1−5]. The main goal of this studies was to enrich the experimental data base of partial-wave analyses (PWA) with qualitatively new information on the spin rotation parameters, which have never been measured in the incident pion momentum interval under consideration.

2. Formalism

The importance of measurements of the *A* and *R* spin rotation parameters becomes clear from the expressions below, where the observed parameters are expressed in terms of the complex spin-nonflip amplitude *f* and spin-flip amplitude *g*:

$$F = f + ig\,(\boldsymbol{\sigma}\cdot\boldsymbol{n}),$$

where $\boldsymbol{\sigma}$ is the Pauli spin operator, $\boldsymbol{n}$ is a unit vector normal to the scattering plane. The relations connecting the observables with the amplitudes *f* and *g* have the following form:

$$d\sigma/d\Omega = |f|^2 + |g|^2,$$

$$P = \frac{1}{|f|^2+|g|^2}\, 2\,\mathrm{Im}(f g^*),$$

$$R = \frac{1}{|f|^2+|g|^2}\left[(|f|^2-|g|^2)\cdot\cos(\theta_p^{cm}-\theta_p^{\ell ab}) + 2\,\mathrm{Re}(fg^*)\cdot\sin(\theta_p^{cm}-\theta_p^{\ell ab})\right],$$

$$A = \frac{1}{|f|^2+|g|^2}\left[(|f|^2-|g|^2)\cdot\sin(\theta_p^{cm}-\theta_p^{\ell ab}) - 2\,\mathrm{Re}(fg^\bullet)\cdot\cos(\theta_p^{cm}-\theta_p^{\ell ab})\right],$$

where θ_p^{cm} and θ_p^{lab} are the angles of the recoil proton emission in the center-of-mass system and in the laboratory system, respectively. The parameters *A*, *R*, *P* are connected by the quadratic equation:

$$A^2 + R^2 + P^2 = 1.$$

3. Experimental layout

To determine the spin rotation parameters *A* and *R* in $\pi^{\pm}p$ elastic scattering, it is necessary to measure the polarization of the recoil protons produced by pions on a proton target polarized in the scattering plane. The polarization of the recoil protons is measured through the asymmetry of their secondary scattering on nuclei of a substance with known analyzing power (usually carbon).

The apparatus is shown in Fig. 1. Its basic elements are:

(i) polarized proton target (PT);
(ii) proton polarimeter including carbon filter (C), four sets of magnetostrictive chambers (MSC) to detect the recoil proton before and four sets of MSC to detect the recoil proton after *p*C-scattering;
(iii) six sets of MSC to detect the scattered pions;
(iv) six pion beam MSCs ;
(v) scintillation counters C1-C9 to provide the trigger and to identify pions in the beam by the time of flight.

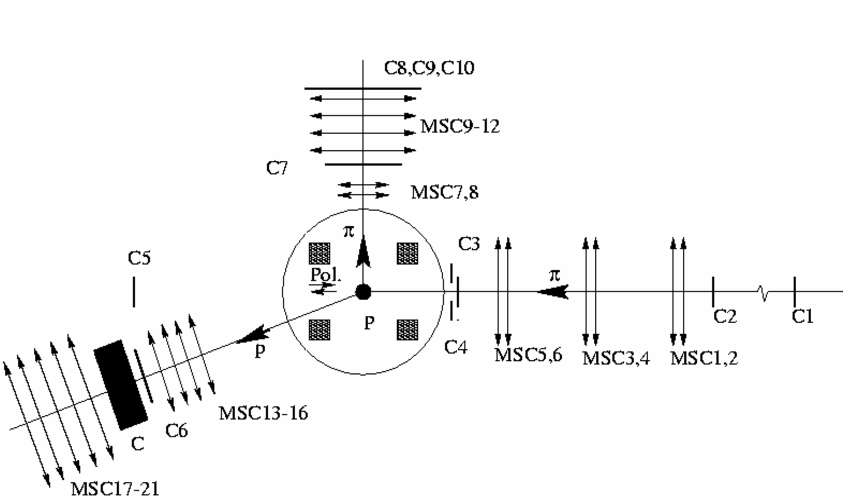

Fig. 1. Experimental setup for the spin rotation parameter *A* and *R* measurement

3.1. Polarized target

The polarized proton target with arbitrary spin orientation in the horizontal plane has been built at PNPI especially for the measurements of the spin rotation parameters in πp elastic scattering (Fig. 2.). A container filled with the target material (propanediole $C_3H_8O_2$ doped by Cr^V complexes) is placed into magnetic field of 2.5 T created by a Helmholtz pair of superconductive coils[1].

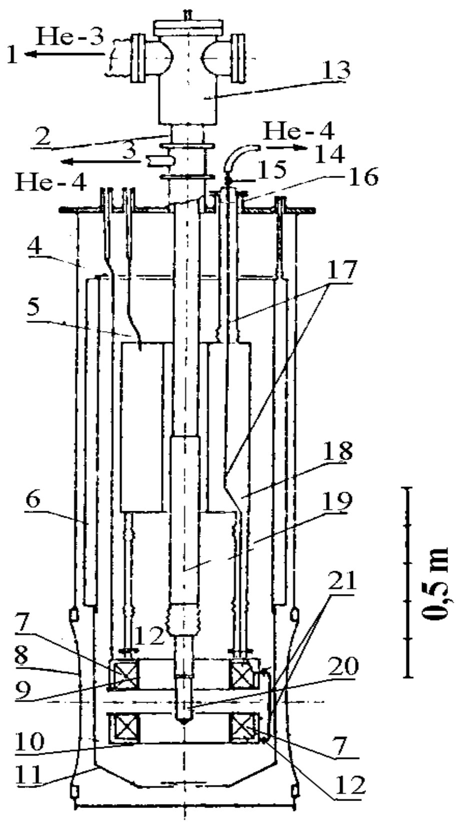

Fig. 2. Target in the vertical sectional view

3 – helium-4 pump-out
4, 11 – nitrogen screens
5, 21 – helium inputs
6 – nitrogen tank
7 – magnet
8 – window
9 – magnet frame
10 – housing
12 – indium compaction
13 – rotating tee-joint
14 – helium-4 output through current-input
15 – connection to current source
16 – current-input compaction and helium-4 output
17 – current input
18 – helium tank (at 4.2 K)
19 – refrigerator
20 – appendix with target matter ($C_3H_8O_2$)

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[1] E.I. Bunyatova *et al.*, Preprint LNPI-1191, Leningrad, 1986.

The container has a cylindrical form with vertical size and diameter of 30 mm × 30 mm. Cooling of the target down to 0.5K is provided by an evaporation-type ^{3}He-cryostat.The polarization is pumped by the dynamic nuclear orientation method up to the absolute value of 70–80% with an uncertainty of 1.5%. The method of nuclear magnetic resonance (NMR) is used for measuring the polarization value. These measurements are based on the calculations of area under the NMR curve. The equipment (Fig. 3) is calibrated on the equilibrium target polarization at temperature of 0.8 K. To measure the area under the NMR curve the system containing *Q*-meter with sequential contour, analogous integral-synchronize detector and digital device made in CAMAC standard was used.

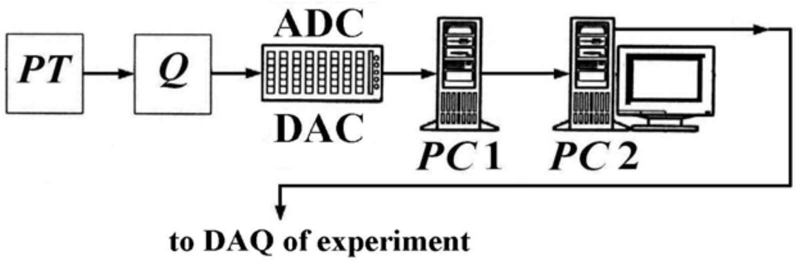

Fig. 3. Electronics for measuring the polarization value

3.2. Recoil proton polarimeter

The recoil proton polarimeter consists of two sets of MS chambers (four chambers in each set) and a carbon block in between. The accuracy of determination of the secondary scattering angle is near 1°.

For realization of present experiment, it is necessary to have a possibility to measure the normal components of recoil proton polarization in the proton energy range from 100 to 1600 MeV and to know the *p*C analyzing power in this energy region. The PNPI-ITEP collaboration performed the associated investigations. At the first step the existing world experimental data were collected and *p*C analyzing power has been systematized[2] as a function of proton scattering angle θ_{pC}, proton kinetic energy T_p and energy losses in the process of *p*C-scattering in the investigated energy range. At the next step the *p*C analyzing power for polarized protons has been experimentally measured[3] by the PNPI-ITEP collaboration for proton beam momenta of 1.36, 1.60, 1.78 and 2.02 GeV/c and for carbon scatterer thicknesses of 4.9, 19.4 and 36.5 g/cm^2. These data have been compared with previous results and used to fit analyzing power obtained for various proton energies and scattering angles. For measurements of the spin rotation parameters *A* and *R* the thickness of carbon blocks should be optimized in accordance with the recoil proton energy and range.

The purity of the carbon (graphite GMZ) in current use is 99.9%.

3.3. Scattered pion registration

Scattered pions are registered by the set of six two-coordinate MS chambers. Two chambers are placed immediately near the polarized target and four chambers out of the magnetic field of the target solenoid. The sensitive area of each module is 400 × 600 mm^2. The expected coordinate accuracy is near 0.5 mm.

3.3. Beam MS chambers

The pion beam of ITEP synchrotron has intensity up to 10^6 π/sec. On this account six MS chambers are used for the determination of beam pion direction.

3.4. Scintillation counters and trigger

The scintillation counters use the photomultiplier tubes FEU-97. The polystyrene is used as scintillation material. The sizes of the counter scintillators are defined by the pion beam sizes and by the acceptance

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[2] N.G. Kozlenko *et al.*, Preprint PNPI-2145, St.-Petersburg, 1997.
[3] I.G. Alekseev *et al*., Nucl. Instr. Meth. A **434**, 254 (1999).

angles for the scattered pions and recoil protons. Scintillation counters are C1–C9 (see Fig. 1). Beam is defined by counters C1, C2, C3 and C4. A veto counter C5 excludes non-scattered beam particles. The recoil protons in the polarimeter and the scattered pions are specified by counters C6 and C7, C8, C9, respectively.

The trigger pulse that initiates readout from MS chambers is generated by coincidence of counter signals: C1×C2×C3×C6×C7×(C8+C9) and anticoincidence of counters C4 and C5 signals.

3.5. Electronics

The electronics of this experiment includes:
– trigger signal from the scintillation counters;
– data from the Personal Computer handling the polarized target;
– electronics and its power supply for the MSC signal digitization.

The trigger production makes a start of the experimental setup. Each event includes the next information:
– beam particle coordinates;
– coordinates of the particles which passed through the polarimeter;
– scattered pion coordinates;
– information about the target polarization.

The event information is analyzed to make a preliminary data selection and to estimate at real-time the setup efficiency.

4. Data processing

The processing of the data is performed at three steps:
(i) The second scattering events in the polarimeter are analyzed and their (second) vertex and other parameters are determined. The events with recoil proton-carbon scattering angle 6°–20° are selected for further processing. From them only those events are taken for which all the azimuthal angles are allowed by the MS chambers geometry. The proton energy T_2 at the second vertex is calculated for each event and the analyzing power P_C is obtained from the empirical expression $P_C = f(T_2,\theta)$ which has been fitted to all available data on proton-carbon scattering between 100 and 1600 MeV.
(ii) The first scattering is reconstructed and the elastic events on free protons of the target are selected. Since trajectories of both particles are bent by the magnetic field of the polarized target and their momenta (and, hence, the curvatures of the trajectories) are not known beforehand, an iteration method is used for the reconstruction of the first vertex. The kinematical criteria of coplanarity and of correlation between polar angles of the scattered pions and the recoil protons are used for the selection. The background of quasi-elastic events on bound protons of target nuclei is known to be (from our previous measurements) not more than 20–30%, and it is taken into account in the data processing.
(iii) The selected events are divided into several angular bins corresponding approximately to $\Delta\cos\theta^{cm} = 0.1$ and in each bin the values of the polarization parameters A, P, R are calculated. The method of the maximum likelihood is used in this calculation. The experimental errors are defined according to the method described J. Bystricky *et al.* – see footnote [4].

At this processing one of two spin rotation parameters (A or R) and, respectively, the absolute value ($|R|$ or $|A|$) of another parameter are defined. Simultaneously the polarization parameter P value is obtained to compare with the existing data to estimate roughly systematical errors.

5. Results and systematic errors

Results of measurement of the parameters A and P for $\pi^- p$ elastic scattering at 1.43 MeV/c [5] are presented in Table and in Fig. 4.

The most important sources of the A parameter systematic errors are the uncertainties in the polarimeter analyzing power (~ 4%) and in the measurement of the target polarization (~2%). The contribution of the

[4] J. Bystricky *et al.*, Nuovo Cim. A **1**, 601 (1971).

background polarization is negligible. This fact was checked by varying the value of the background polarization from 0 to the normal polarization in πp elastic scattering. The final value of the ratio of the background polarization to the normal polarization in πp elastic scattering was taken equal to 0.7, similar to the ratio of polarizations in the elastic and quasi-elastic *pp* scattering (see footnote [3]).

The combined estimate for the systematic error of the *A* parameter is ~8%.

As it was stressed above, there are no ways to eliminate the false asymmetry in the direction of the *P* parameter measurement ($\varphi_2 = 0, \pi$ plane) using our experimental data. Consequently, the systematic error of *P* cannot be reliably evaluated. Thus the results on this parameter can be used only for qualitative comparison with the main features of PWA solutions, for example: strong angular dependence, angular position of the polarization minimum and the value at the minimum close to –1.

Table

Polarization parameter *A* and *P* in the $\pi^- p$ elastic scattering at 1.43 GeV/c

$\Delta\theta$, degrees	θ_{mean}	A	ΔA	P	ΔP	N_{events}
155.0–162.2	160.4	–0.152	0.251	–1.150	0.166	2355
162.2–165.6	163.9	–0.360	0.260	–1.039	0.170	2259
165.6–172.0	167.4	–0.131	0.264	–0.501	0.175	2163
155.0–172.0		–0.219	0.149	–0.91	0.10	6787

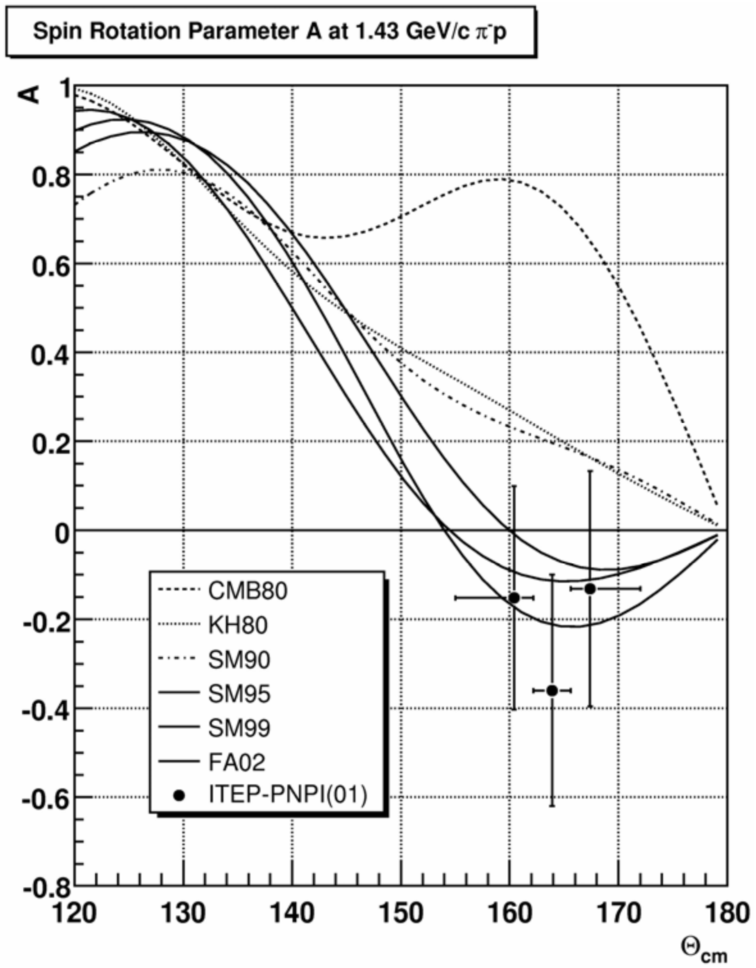

Fig. 4. Comparison of results for the *A* parameter with PWA predictions

6. Conclusion

Measurements of the polarization parameters were performed in the region of backward scattering where the predictions of various PWA have maximum discrepancy. The data on *A* parameter agree well with SM95 and FA02 PWA solutions of the GWU-VPI group[5]. They contradict to the predictions of the CMB80 analysis[6] while the deviation from KH80[7] is three standard errors. The data on *P* parameter are consistent with the main features of the latest analyses of the GWU group. The results of this experiment along with our previous measurements of the spin rotation parameters indicate that CMB80 and KH80 analyses do not reconstruct properly the relative phase of the transverse amplitudes for scattering to the backward hemisphere. This conclusion together with the fact that the latest analysis of the GWU group confirms only 4-stars resonances (and only one 3-stars resonance D_{35}(1930)) impose serious doubts about the present-day spectrum given in the Review of Particle Physics and properties of the light baryon resonance. The development of a new energy independent partial-wave analysis.

Acknowledgments

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