Backward asymmetry measurements in the elastic pion-proton scattering at resonance energies

I.G. Alekseev, N.A. Bazhanov, Yu.A. Beloglazov, P.E. Budkovsky, E.I. Bunyatova, E.A. Filimonov, V.P. Kanavets, A.I. Kovaliev, I.I. Koroleva, B.V. Morozov, V.M. Nesterov, D.V. Novinsky, V.V. Ryltsov, V.A. Shchedrov, A.I. Kovalev, L.I. Koroleva, B.V. Morozov, V.M. Nesterov, D.V. Novinsky, V.V. Ryltsov, V.A. Shchedrov, A.D. Sulimov, V.V. Sumachev, D.N. Svirida, V.Yu. T raumtman, and L.S. Zolin

1 Institute for Theoretical and Experimental Physics, Moscow, 117218, Russia
2 Joint Institute for Nuclear Research, Dubna, Moscow area, 141980, Russia
3 Petersburg Nuclear Physics Institute, Gatchina, Leningrad district, 188300, Russia

Received: date / Revised version: date

Abstract. The asymmetry parameter $P$ was measured for the elastic pion-proton scattering in the very backward angular region of $\theta_{\text{lab}} \approx 150 - 170^\circ$ at several pion beam energies in the invariant mass range containing most of the pion-proton resonances. The general goal of the experimental program was to provide new data for partial wave analyses in order to resolve their uncertainties in the baryon resonance region to allow the unambiguous baryon spectrum reconstructions. Until recently the parameter $P$ was not measured in the examined domain that might be explained by the extremely low cross section. At the same time the predictions of various partial wave analyses are far from agreement in some kinematic areas and specifically those areas were chosen for the measurements where the disagreement is most pronouncing. The experiment was performed at the ITEP U-10 proton synchrotron, Moscow, by the ITEP-PNPI collaboration in the latest 5 years.

PACS. 13.88.+e Polarization in interactions and scattering – 13.75.Gx Pion-Baryon interactions

1 Introduction

The history of the investigations of the pion-nucleon interaction is about 40 years old. The systematic set of data in the resonance region was obtained during this period. These days three partial wave analyses (PWA) are known which are the main source of the information on the baryon resonance parameters: the basic PWA of the Karlsruhe-Helsinki group KH80 \[1,2\] in the beam momentum range 0.020–10 GeV/c, analysis of the Carnegie-Mellon-Lawrence-Berkeley-Laboratory group CMB80 \[3\] up to 2.5 GeV/c and the series of solutions by George Washington University (GWU) group, formerly located at VPI, below 2.1 GeV/c \[4,5\]. The detailed presentation of all mentioned PWA results can be found at CNS DAC web page through the SAID program \[6\].

But even up to now there are some kinematic regions where the predictions of the different PWA are in evident contradiction with one another. In most cases this is due to the very low cross section values of the order of 0.1 mb/sr (fig. 1). Low quality or absence of experimental data in such regions leads to the continuous uncertainties in partial amplitudes as well as to the unresolved discrete ambiguities and consequent wrong choice of solution branches \[7\]. These minima in the differential cross section are caused by the specific behavior of the pion-nucleon amplitude or, rather, of the Barrelet zero trajectories, and that is why the measurements in such areas are particularly important for the correct reconstruction of the pion-nucleon amplitude. The main goal of this work is to provide new experimental information for the partial wave analyses specifically is such kinematic areas, where it may best help to resolve the existing PWA uncertainties and thus allow the reliable extraction of non-strange baryon resonance spectrum and properties.

This paper presents the latest results of the ITEP-PNPI collaboration on the measurements of the asymmetry $P$ both for $\pi^+p$ and $\pi^-p$ elastic scattering to the very backward angles in several energy points.

2 Experimental conditions

Polarization parameter $P$ in the elastic scattering is determined by the direct measurement of the azimuthal asymmetry of the reaction produced by incident pions on a proton target polarized normally to the scattering plane.

The differential cross section in this case has the following form:

$$d\sigma/d\Omega = (d\sigma/d\Omega)_0 [1 + P \cdot (P_T \cdot n)]$$

where $(d\sigma/d\Omega)_0$ is the differential cross section of $\pi p$ elastic scattering on the unpolarized target, $P$ is polarization parameter, and $P_T$ is the polarization vector of the target.
The polarization vector in Fig. 2. The polarized target with vertical orientation of the recoil proton polarization vector with the accuracy better than 4 mm. Beam dimensions in the target plane are 32 mm x 27 mm (FWHM). The momentum spread of the beam is about ±2%.

To achieve the acceptance coverage of the very backward pion angles about 170° at beam momentum 0.8 GeV/c two configurations of the setup were used with opposite direction of the target magnetic field and correspondingly different positions of the proton arm.

The CAMAC based readout system allows to record up to 40 events per one accelerator cycle. Data storage as well as its on-line processing and the setup monitoring is provided by a single PC.

3 Data processing

The processing of the data was performed in the following steps. The straight trajectories of the beam pion, scattered pion and recoil proton were reconstructed in the corresponding chamber blocks outside the magnetic field of the target by the least square method. Obtained tracks for each event were then extrapolated to the target region through the magnetic field and the interaction vertex was found. Polar and azimuthal angles were separately determined for both scattered particles and their values were used for the event selection.

The procedure of the elastic event selection is illustrated by fig. 3. For each event the deviation from the elastic kinematics was calculated in terms of two variables: Δθ - the difference in c.m. scattering angle for the pion and the proton and Δφ - sum of their azimuthal deviations from the scattering plane, and two-dimensional distributions in these variables were filled. For the best background estimate the distributions were fit with a 2-dim 12-parameter polynomial excluding the area of the elastic peak and the error matrix was calculated for the obtained fit parameters. The number of the elastic events was determined as the distribution excess over the background, interpolated to the area under the peak. To account for the different statistics with opposite target polarization signes

\[
\frac{d\sigma}{d\Omega} \propto \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle \cdot \langle C \rangle
\]

Firing of the incident pions CH1-CH6, recoil protons CH7-CH10 and scattered pions CH11-CH14. In some configurations of the setup another block was added adjacent to CH11-CH14 to achieve a wider pion acceptance.

- Scintillation counters C1-C12 for the trigger logic. The readout of the chamber data was initiated on the following condition: (C1 ∙ C2 ∙ C3 ∙ C4 ∙ C5 ∙ (C6 ∙ C7) ∙ (C8 ∙ (C9 + C10))

- In case of positive beam TOF technique was used to separate pions from protons at low beam energies, while at beam momenta above 1.8 GeV/c the aerogel Cherenkov counter AGCC was additionally introduced into the beam for the pion tagging.

The secondary pion beam is formed by the universal magneto-optical channel based on the two-stage achromatic scheme and provides the intensity of up to 2 ∙ 10^5 pions per accelerator spill (t ≈ 0.6 s every 4 s). The 46.5 m long beam line is equipped with two vertical correctors allowing to change the beam position on the polarized target with the accuracy better than 4 mm. Beam dimensions in the target plane are 32 mm x 27 mm (FWHM). The momentum spread of the beam is about ±2%.

The CAMAC based readout system allows to record up to 40 events per one accelerator cycle. Data storage as well as its on-line processing and the setup monitoring is provided by a single PC.

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![Graph](image_url)
the intensity normalization was done based on the quasi-elastic event counts which are believed to be unpolarized and represent the main content of the background. Comparison of the results with various cuts around the elastic peak allowed to make additional systematic error tests. Statistical error accounts for the elastic event number, the background error matrix and the intensity normalization uncertainty.

The selected events were divided into several angular intervals in $\theta_{cm}$ and average angle was calculated for each interval according to the individual values from each event.

### 4 Results

The asymmetry $P$ was measured in the $\pi p$ elastic scattering in the very backward angular region of $\approx (150 - 170)^\circ$ in the c.m. frame at several beam momenta. The values of the momentum were intentionally chosen so that the disagreement in the PWA predictions is most pronouncing in the backward hemisphere at these momenta. It is worth mentioning that the differential cross section in the regions of the experiment is very different though very small in all of them. Thus the experimental conditions in terms of the event rate and signal to background ratio are also significantly different. Table 1 summarizes the statistical material obtained for all data regions. The third column together with fig. 1 presents the cross section values in the angular domain under study, giving the explanation to the number of elastic events obtained in approximately equal running periods (column 4) and background levels (column 5).

The tables 2-6 together with figs. 4,5 present the results of the measurements as a function of the c.m. scattering angle. The errors are only statistical while the systematic scale uncertainty due to the target polarization measurement is below 3% (typically 1.5%). The lines in the figures show the PWA predictions for comparison: ”classic” analyses CMB80 [3] (dotted) and KH80 [1] (dashed), the latest solution of GWU group SP06 [5] (solid) and their earlier solution SM95 [4] (dash-dotted). Older experimental data at smaller angles and in the overlapping regions are also shown with open markers.

The points at 1.78 GeV/c in $\pi^- p$ (fig. 4a) were taken to check the setup. Partial wave analyses do not show large variations from each other. The data show best agreement with CMB80, while the deviation of KH80 from the data points is obviously statistically significant. The point at 153.6$^\circ$ coincides with earlier data from [13] and supports even deeper and saturated minimum than any of the analyses show. Such minima indicates that a branching point of a PWA solution may be present close to this kinematic

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**Table 1. Summary of the obtained statistics and experimental conditions**

| $p_{BEAM}$, GeV/c | $d\sigma/d\Omega$, mb/sr | $N_{EL}$ | $N_{BG}/N_{EL}$ |
|-------------------|--------------------------|---------|-----------------|
| $\pi^- p$ 1.78    | 0.02-0.10                | 3252    | 0.45            |
| $\pi^- p$ 2.07    | 0.03-0.05                | 2047    | 0.43            |
| $\pi^+ p$ 0.80    | 0.03-0.17                | 3128    | 0.19            |
| $\pi^+ p$ 1.94    | 0.05-0.07                | 1066    | 1.01            |
| $\pi^+ p$ 2.07    | 0.02-0.03                | 701     | 1.56            |
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| CMB80 | KH80 | SM95 | SP06 | ITEP-PNPI | ITEP(91) | ALBROW(72) @ 1.73 | YUKOSAWA(74) @ 1.7 |
|-------|------|------|------|-----------|----------|-------------------|---------------------|
| 120   | -1.2 | -1   | -0.8 | -0.6      | -0.4     | -0.2              | 0                   |
| 130   | -1   | -0.8 | -0.6 | -0.4      | -0.2     | -0.2              | 0                   |
| 140   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0.2               | 0                   |
| 150   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0.2               | 0                   |
| 160   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0.2               | 0                   |
| 170   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0.2               | 0                   |
| 180   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0.2               | 0                   |

| CMB80 | KH80 | SM95 | SP06 | ITEP-PNPI | ITEP(91) | ALBROW(70) | MARTIN(75) @ 0.803 |
|-------|------|------|------|-----------|----------|------------|---------------------|
| 120   | -1   | -0.8 | -0.6 | -0.4      | -0.2     | 0          | 0.2                 |
| 130   | -1   | -0.8 | -0.6 | -0.4      | -0.2     | 0          | 0.2                 |
| 140   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0.2                 |
| 150   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0.2                 |
| 160   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0.2                 |
| 170   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0.2                 |
| 180   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0.2                 |

| CMB80 | KH80 | SM95 | SP06 | ITEP-PNPI | ITEP(91) | ALBROW(70) | MARTIN(75) |
|-------|------|------|------|-----------|----------|------------|------------|
| 120   | -1   | -0.8 | -0.6 | -0.4      | -0.2     | 0          | 0          |
| 130   | -1   | -0.8 | -0.6 | -0.4      | -0.2     | 0          | 0          |
| 140   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0          |
| 150   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0          |
| 160   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0          |
| 170   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0          |
| 180   | -0.8 | -0.6 | -0.4 | -0.2      | 0        | 0          | 0          |

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**Fig. 4.** Asymmetry in π⁻p elastic scattering at 1.78 GeV/c (a) and 2.07 GeV/c (b). Earlier data are from [11] (open circles), [12] (triangles) and [13] (squares).

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**Fig. 5.** Asymmetry in π⁺p elastic scattering at 0.80 GeV/c (a), 1.94 GeV/c (b) and 2.07 GeV/c (c). Earlier data are from [14] (squares and crosses), [15] (triangles) and [16, 17] (diamonds).

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point. Next point at 157.8° overlaps with the previous ITEP measurement [11] with different setup, proofing the good quality of the result.

The data at 2.07 GeV/c with negative pions (fig. 4b) are not exactly followed by any of the PWA solutions. Yet the closest two are SM95 and CMB80, while SP06 and KH80 do not even resemble the data behavior. Again good agreement with earlier ITEP data in the overlapping region should be stated. A narrow local minimum at 157° confirmed by two independent measurements draws additional attention and indicates the significant presence of partial wave with high orbital momentum of the order of $L = 8 - 9$. Similarly the sharp step at 167° in 1.78 GeV/c data may point out to the large value of the same partial amplitude.

In both cases with π⁻p scattering the latest solution SP06 of the GWU group is not in the closest to the new data. On the contrary, in the lower energy domain and the pure $I = 3/2$ isospin state the data are best described by this very solution (see fig. 5a for π⁺p at 0.80 GeV/c). CMB80 does not show the sharp and high peak at 175° implied by the data, while SM95 gives much smaller values.
of the asymmetry in the whole angular range of the measurement. It is worth mentioning that our data are in obvious contradiction to the 3 rightmost points from CMB80 at two adjacent energies. The authors claim very small errors for 4 out of these 6 points while the GWU group already excluded some of them from their analysis database.

π⁺p asymmetry at 1.94 GeV/c shows large negative values around 165° (fig. 5b). Neither of the solutions manifest so deep a minimum though all but CMB80 have qualitative behavior. The closest prediction in this region is from KH80. It is worth mentioning that our data are in obvious contradiction to the 3 rightmost points from CMB80 at two adjacent energies. The authors claim very small errors for 4 out of these 6 points while the GWU group already excluded some of them from their analysis database.

5 Conclusions

The obtained results show that in some kinematic areas one or both of the “classic” partial wave analyses CMB80 and KH80 are in disagreement with the new data. In some cases even the qualitative behavior of mentioned PWA does not correspond to that of the data, which may indicate the wrong choice of the solution branch by these analyses and, consequently, wrong extraction of baryon properties. The latest solution SP06 of GWU group seems to be consistent with the data in the lower energy domain, while in the region around 2 GeV/c beam momentum its behavior looks unstable.

The ITEP-PNPI experimental team believes that their new data on the backward asymmetry in the elastic pion-proton scattering notably improves the database for partial wave analyses and helps to make another step on the way of the elimination of PWA ambiguities of various kinds and thus obtain reliable light baryon spectrum.

6 Acknowledgments

Our thanks to I. Strakovsky for the interest in our experiment and fruitful discussion on the subject. We are grateful to the ITEP accelerator staff for providing us with the beam of excellent quality.

The work was partially supported by Russian Fund for Basic Research (grants 02-02-16121-a and 04-02-16335-a), Russian State Corporation on the Atomic Energy “Rosatom” and Russian State program “Fundamental Nuclear Physics”.

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