BONN–GATCHINA PARTIAL WAVE ANALYSIS: SEARCH FOR MISSING BARYON STATES*

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The number of experimentally known baryon states is noticeably smaller than those predicted by existing models. The situation became even more tense after latest analysis of the πN elastic reaction which did not confirm many "well known" states. In this paper the status of the Bonn–Gatchina partial wave analysis is reported. It is shown that data from inelastic pion-induced reactions provide a crucial information about P-wave baryon resonances, which were not observed in the latest analysis of the elastic data.

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1. Introduction

In the classical quark models, the interaction of the three constituent quarks provides a rich spectrum of baryons [1–4] which so far was not observed experimentally. This issue is referred to as the problem of missing resonances. A large part of the information about baryon spectrum was obtained from the analysis of πN elastic scattering where states with large πN branching are observed clearly. However, resonances with large inelasticity and small πN coupling contribute rather little to this cross-section and cannot be identified.

The set of facilities with photon beams like ELSA (Bonn), JLab (Newport News), MAMI (Mainz), and SPring-8 (Hyogo) provide us information from photoproduction experiments. It is complementary to data obtained with hadronic beams, giving us an access to additional properties like helicity amplitudes. The analysis of unpolarized and single-polarized data

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from these experiments revealed a set of new baryons: $P_{13}(1900)$, $P_{11}(1840)$, $D_{13}(1870)$, $D_{15}(2070)$. The first double-polarization data on the $\gamma p \to K\Sigma$ and $\gamma p \to K\Lambda$ reactions provided us a strong proof for the existence of $P_{13}(1900)$ [5] and the analysis of forthcoming double-polarization data for other final states should ultimately confirm (or disproof) the existence of other states.

On another side, the latest analysis of the πN elastic data [6] did not confirm the set of states which were considered as well-established from earlier analyses of a smaller set of elastic data (see Table I).

TABLE I

Comparison of average values from the PDG compilation [7] and the result from latest Bonn–Gatchina combined partial wave analysis for the states which were not observed in the recent analysis of the elastic data [6].

State	PDG (Pole position)(MeV)		Bonn–Gatchina (MeV)	
	Mass	Width	Mass	Width
$P_{11}(1710)^{***}$	1720 ± 50	230 ± 150	1725 ± 25	200 ± 20
$P_{33}(1600)^{***}$	1550 ± 100	300 ± 100	1540^{+40}_{-80}	230 ± 40
$P_{33}(1920)^{***}$	1900 ± 50	200^{+100}_{-50}	1910 ± 50	330 ± 50
$D_{13}(1720)^{***}$	1680 ± 50	100 ± 50	1730 ± 30	140 ± 35

In this paper, we study the consistency of the πN elastic amplitudes with amplitudes of πN transition into $\Lambda\ K^+$, $\Sigma^+ K^+$, $\Sigma^0 K^0$ and $n\eta$ final states as well as with large number of photoproduction amplitudes.

2. The data features and the result of partial wave analysis

The contributions of dominant waves to the reaction $\pi^- p \to K^+\Lambda$ are shown in Fig. 1. The dominant wave at the threshold is S_{11} which decreases fast with increasing of energy. The P_{11} wave is the second dominant wave below 1800 MeV. It shows a clear resonance behavior peaking at 1720 MeV. The P_{13} wave increases steadily from the threshold region reaching maximum at 1900 MeV.

The differential cross-section and recoil asymmetry for the reaction $\pi N \to K\Lambda$ is shown in Fig. 2. From the threshold region up to ≈ 1750 MeV, the angular distribution rises nearly linearly in $\cos\theta$ which is expected due to the interference of S_{11} and P_{11} waves. There is a small quadratic part, indicating contributions from the interference of S_{11} and P_{11} with the P_{13} wave which is clearly seen above 1700 MeV. Above 1850 MeV the angular distribution is close to the $1 + 3\cos^2\theta$ contribution signaling a large P_{13} wave.

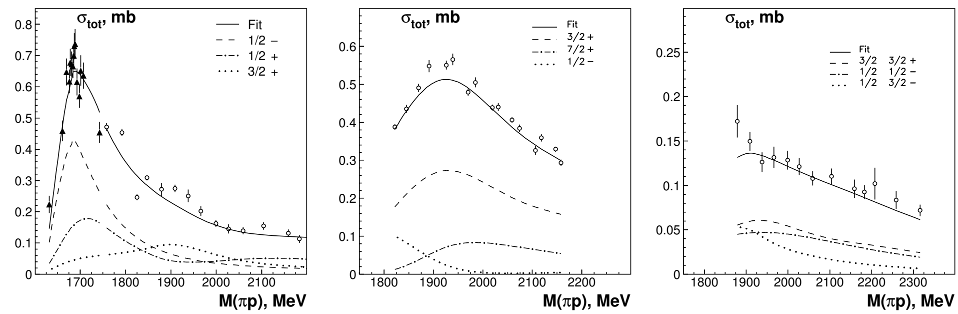

Fig. 1. Total cross-sections for $\pi^- p \rightarrow K\lambda$ (left), $\pi^+ p \rightarrow K^+ \Sigma^+$ (middle) and $\pi^- p \rightarrow K^0 \Sigma^0$ (right) and contributions from leading partial waves.

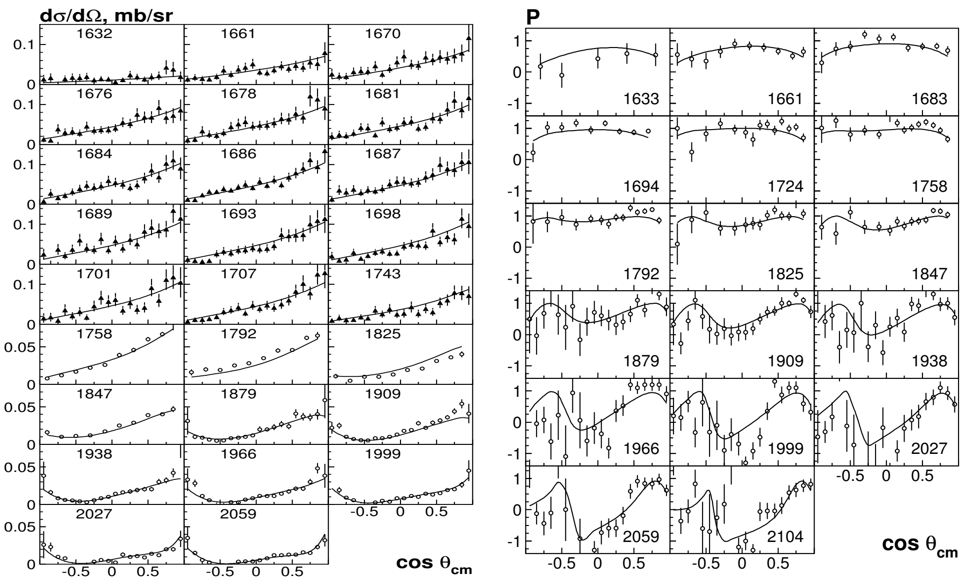

Fig. 2. Differential cross-section and recoil asymmetry for the reaction $\pi^- p \rightarrow \Lambda\, K^+$.

Two largest contributions to the reaction $\pi^+ p \rightarrow K^+ \Sigma^+$ stem from the P_{33} and F_{37} partial waves (see Fig. 1). The best evidence for the existence of $\Delta(1920)P_{33}$ is derived from this reaction where only Δ resonances contribute. If the P_{33} wave is assumed to be non-resonant in this mass region neither angular or recoil distributions can be reproduced well. Both Δ and nucleon partial waves may contribute to the $\pi^- p \rightarrow K^0 \Sigma^0$ reaction (see Fig. 1). The contribution from Δ-states can be fixed from the fit of the $\pi^+ p \rightarrow K^+ \Sigma^+$ reaction. At the region 1850–1950 MeV one of the largest contributions is due to the D_{13} wave, which indicate a presence of a resonance with mass just below the fitted energy region.

The differential cross-section and recoil asymmetry for the reaction $\pi^+p\to K^+\Sigma^+$ is shown in Fig. 3. The dominance of the P_{33} wave below 2000 MeV is seen from the angular distribution which follows roughly the $(3z^2+1)$ dependence. The dominance of one partial wave explains a small recoil asymmetry below 1900 MeV.

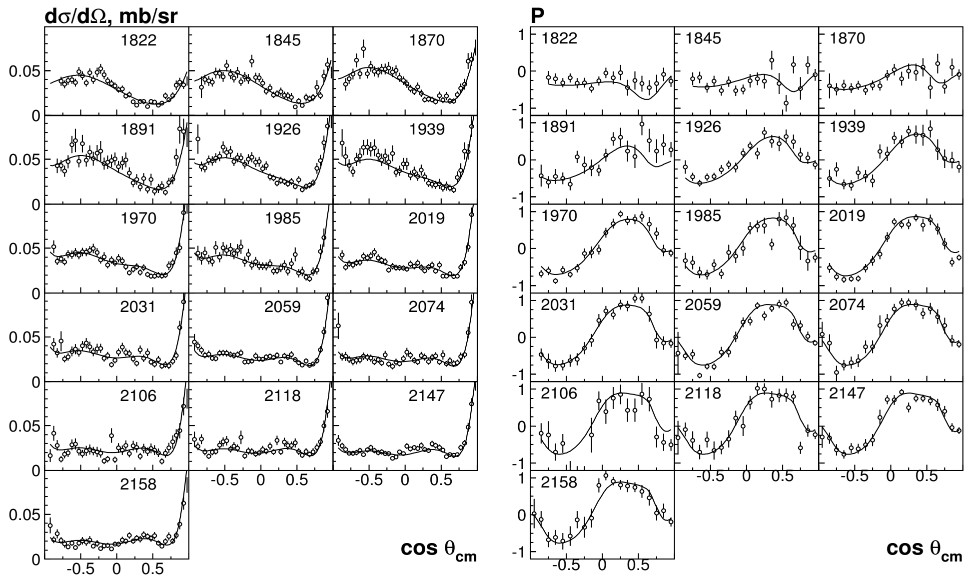

Fig. 3. Differential cross-section and recoil asymmetry P for the reaction $\pi^+p\to K^+\Sigma^+$.

The differential cross-section and recoil asymmetry for the reaction $\pi^-p\to K^0\Sigma^0$ is shown in Fig. 4. In the region 1879-1940 MeV the differential cross-section is very similar to that from the $\pi^+p\to K^+\Sigma^+$ reaction which indicates a dominance of the $3/2^+$ partial waves. Above 1940 MeV the structure of the differential cross-section is rather complicated due to the presence of high partial waves, in particular, F_{37}.

There is a set of measurements for the $\pi^-p\to\eta n$ differential cross-section which have large systematic discrepancies above 1.8 GeV. In the present article we fit rather precise data from the Crystal Ball Collaboration [8] and the data at higher region from [9]. These two sets of data are more or less compatible in the 1500–1550 MeV mass region and probably can be trusted up to 1800 MeV. The angular distribution is rather flat in the region below 1550 MeV due to the dominance of the S_{11} wave (see Fig. 5). In the region 1600–1800 MeV, the angular distribution is rather asymmetrical, which comes from the interference of the S_{11} with D_{13} and P_{11} waves. The P_{11} wave provides us the contribution which has maximum at 1720 MeV and is compatible with $P_{11}(1710)$.

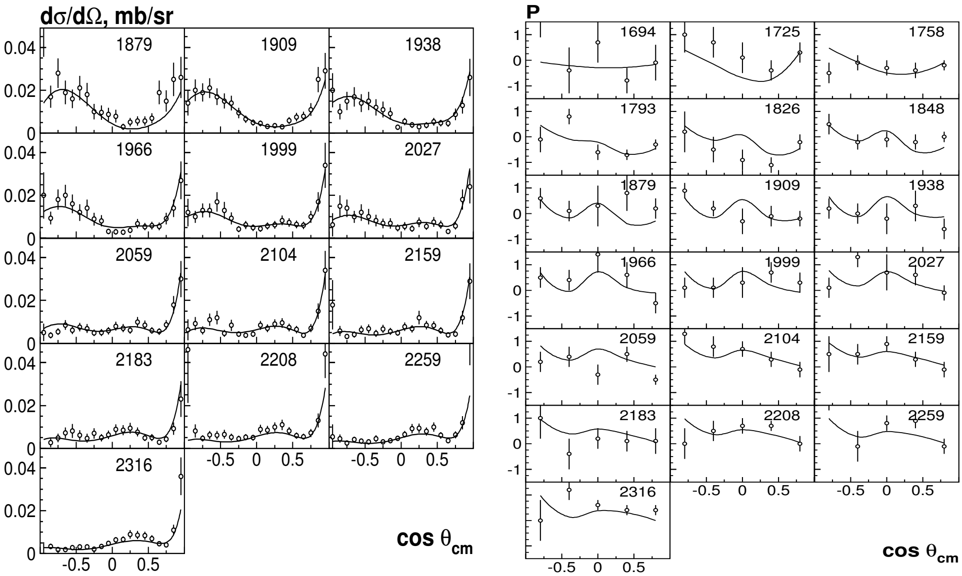

Fig. 4. Differential cross-section and recoil asymmetry for the reaction $\pi^- p \to K^0 \Sigma^0$.

Although any single reaction does not provide us a strong proof for the existence of $P_{33}(1600)$ state, it was impossible to obtain a combined description of the elastic and $\pi^+ p \to K^+ \Sigma^+$ data without contribution from this resonance. The pole position for this state is given in Table I.

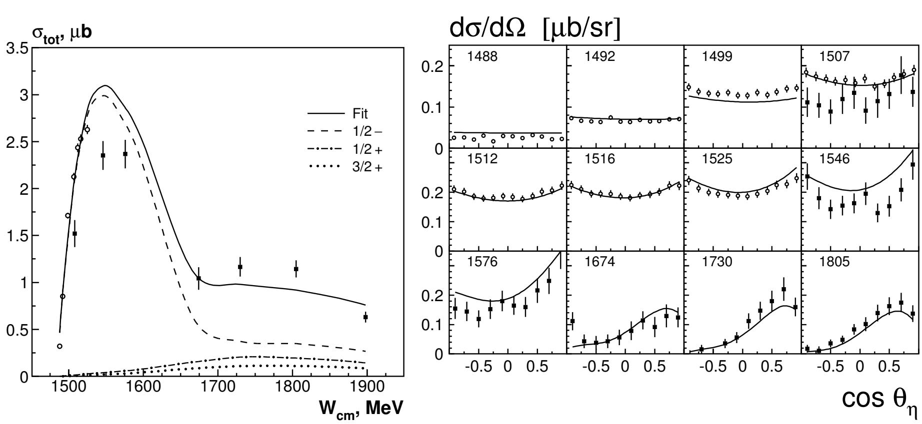

Fig. 5. Total and differential cross-sections for the reaction $\pi^- p \to \eta n$.

3. Conclusion

The analysis of pion-induced transition reactions provides us an ultimate proof for the existence of the resonances listed in Table I. This conclusion is by no means in conflict with the data on elastic scattering. Figure 6 shows the comparison of real and imaginary parts of our P_{11}, P_{33} and P_{13} elastic amplitudes with energy-fixed analysis from [6]. Our fit reproduces these data with a good χ^2 and in case of the P_{11} wave it demonstrates a clear structure at the region above Roper.

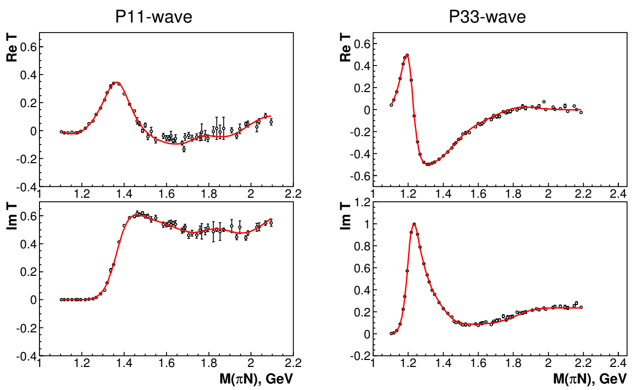

Fig. 6. Description of the P_{11}, P_{33} and P_{13} elastic amplitudes extracted by SAID from the energy-fixed partial wave analysis.

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