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A PARTIAL WAVE ANALYSIS OF $\pi N \rightarrow \pi\pi N$ AT CENTER-OF-MASS ENERGIES BELOW 2000 MeV *

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ABSTRACT

We present the results of a partial wave analysis of $\pi N \rightarrow \pi\pi N$ in the energy region 1300-2000 MeV. Two continuous solutions have been found, in which all the major resonances are observed in the inelastic channels. The existence of $P_{13}(1700)$ and $P_{11}(1700)$ states are confirmed, and evidence for a new resonance, $D_{13}(1700)$, is presented. Further, our best solution ("B"), indicates the presence of resonant structure in the 1700-1900 MeV region for the P_{33} wave.

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We have performed an energy independent partial wave analysis[1] of the reaction $\pi N \rightarrow \pi\pi N$ using a generalized isobar model.[2] Details of the model, our fitting procedure, and the extensive tests and checks performed are described in the above references and in Refs. 3 and 4. Two continuous solutions ("A" and "B") have been found which are very similar in regions where data exists, but differ in the continuation of the amplitudes through a gap of 100 MeV between our low (1300-1540 MeV), and high (1640-2000 MeV), energy data.

In 1972 a 24-wave Solution A was presented at the Batavia Conference;[1] the Argand plots are shown in Fig. 1. This solution has some "undesirable" theoretical properties in that the relative coupling signs of the DD13(1520) and DD15(1660)[5] conflicted with the predictions of broken $SU(6)_W$ and current-to-constituent quark transformations.[6] Therefore, we studied the stability of Solution A, adding several new amplitudes suggested by theory. A second 28-wave solution, Solution B, was obtained. The new solution is a better fit to the data, and differs from Solution A only in the continuation across the gap and in the presence of four new waves — $\pi\Delta$ (SD11, SD33, FF15) and ρN (PP11). The Argand plots for this new solution are shown in Fig. 2, where the four new waves are marked "new".

Both Solutions A and B show strong energy-dependent structure associated with the existence of resonant states already established from elastic phase shifts analyses ("EPSA"). Much information on the inelastic couplings of these states to ϵN, $\pi\Delta$, ρN is provided by our analysis. It is interesting to note that almost all of the inelasticity predicted by the EPSA is accounted for by these amplitudes.[7] Both solutions have demonstrated the existence of a new resonance $D_{13}(1700)$ and confirmed both the $P_{13}(1700)$ and the $P_{11}(1700)$. Solution B has evidence for another new resonance — a broad P_{33} with mass near 1700 MeV. Furthermore, the phases of the resonant amplitudes in Solution B[7] are now consistent with theory.[8] In separate publications,[7,9] resonance parameters have been extracted in several different ways. These results are compared with each other and with the predictions from the quark model, Vector Dominance, and SU(3) and SU(6).

As emphasized above, Solutions A and B are little different in regions where data exist. To test between them requires analysis of new data in the 1540-1650 MeV gap. We have now analyzed 6227 new events from an Imperial and Westfield College experiment on the reaction

$$\pi^+ p \rightarrow \pi^+ p \pi^o$$

at 1610 MeV. Details of the experiment and event selection are reported elsewhere.[10] A single-energy partial wave analysis was performed on the data, within the framework of the isobar model, and a unique 8-wave fit was obtained (using the same set of amplitudes required at that energy – see Fig. 2). However, only 4 of these Argand amplitudes can be quantitatively compared with both our solutions A and B.[11] This comparison is illustrated in Fig. 3. The four amplitudes at 1610 MeV are shown in the unitary circle at the left of the figure. They are labelled 1, 2, 3, 4, for $\Delta\pi$ (SD_{31}), ρN (SS_{31}), $\pi\Delta$ (DS33), ρN (DS33). Their overall phase is unknown, so the whole 1610-MeV solution can be rotated as a rigid body.

The top row of four Argand plots represents our solution A; the letters J through Z are single-energy fits, the smooth curves are energy-dependent K-matrix fits to these single-energy amplitudes,[7] and the predicted value of each amplitude at 1610 MeV is indicated with an arrow. We have rotated the 1610 MeV solution so that the largest amplitude ($\Delta\pi$ (SD_{31})) has the phase of the

K-matrix prediction; then we find that 2 of the remaining 3 partial waves agree badly with the Solution A predictions.

The lower row displays the four corresponding Argand plots for Solution B. Again we rotate the 1610 MeV solution so that the phase of $\Delta\pi$ (SD_{31}) agrees with Solution B, but now all the other phases agree as well.

From visual inspection, it is clear that the new amplitudes fit Solution B much better than Solution A. More quantitatively, two χ^2 have been calculated and are shown below each Argand plot in Fig. 3; a χ^2_K which measures how well all data other than the new 1610 amplitudes fit to the K-matrix curve, and a χ^2 calculated just for the new amplitudes, based on the Imperial College/Westfield College events. It is already clear from the general fit to the previous data (χ^2_K) that solution B is strongly preferred, but the analysis of this new experiment in the "gap" region gives a strong discrimination between the two solutions A and B.

Thus we conclude that Solution B, which contains evidence for a new $D_{13}(1700)$ and a new $P_{33}(1700)$, confirms the existence of a $P_{13}(1700)$ and a $P_{11}(1700)$, and possesses signs of resonance amplitudes in good agreement with theory,[6,8] is the best description of inelastic πN scattering in this energy range.

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5. The notation used to describe our partial wave amplitudes is described fully in Ref. 1. The four character description gives the incident relative angular momentum, the outgoing relative angular momentum, 2 × the I-spin of the channel and 2 × the total spin (L_{in}, L_{out}, 2I, 2J). In addition there is an indication of the subparticle state being considered $\pi\Delta$, ρN, ϵN: since the spins of the ρ-meson and the nucleus may be combined to form total spin 1/2 or 3/2 there are two amplitudes denoted $\rho_1 N$ or $P_3 N$ respectively.

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11. Solution A is old, and we never made a K-matrix fit to the P_{31} or the P_{33} wave, nor was $\Delta\pi(DD_{33})$ tried in Solution A; hence, only four K-matrix fits are available. We have, of course, compared the new 1610 amplitudes with eyeball fits to the remaining amplitudes of Solutions A and B and find no disagreement with the conclusions of this paper.

FIGURE CAPTIONS

1 and 2: Arrows on the Argand plots are spaced every 20 MeV, with wide arrows every hundred MeV; base of wide arrows mark integral hundreds of MeV. To show the 100 MeV gap in our data, the straight line joining the five gap arrows has been deleted. The + or - signs at the upper left of each circle show how to transform from our "internal" sign convention to the "Baryon-first" convention. Lower-ℓ curves are plotted starting at $\sqrt{s}$ = 1400 MeV; higher-ℓ waves only where first needed in the fits. Last arrowhead is always at 1940 MeV. (Signs of ϵN and ρN amplitudes corrected, July 1974.)

3. Comparison of 4 amplitudes from a fit to the I. C./Westfield Coll. events at 1610 MeV (the four numbered points in the left circle) with our 1972 Soln. A (top row) and our 1973 Soln. B (bottom row). The letters represent the results of our single-energy fits (D-L 1310-1540 MeV, at approximately 30 MeV intervals, and M-Y 1650-1920 MeV, at approximately 40 MeV intervals), and the curves are K-matrix fits to these single-energy points.

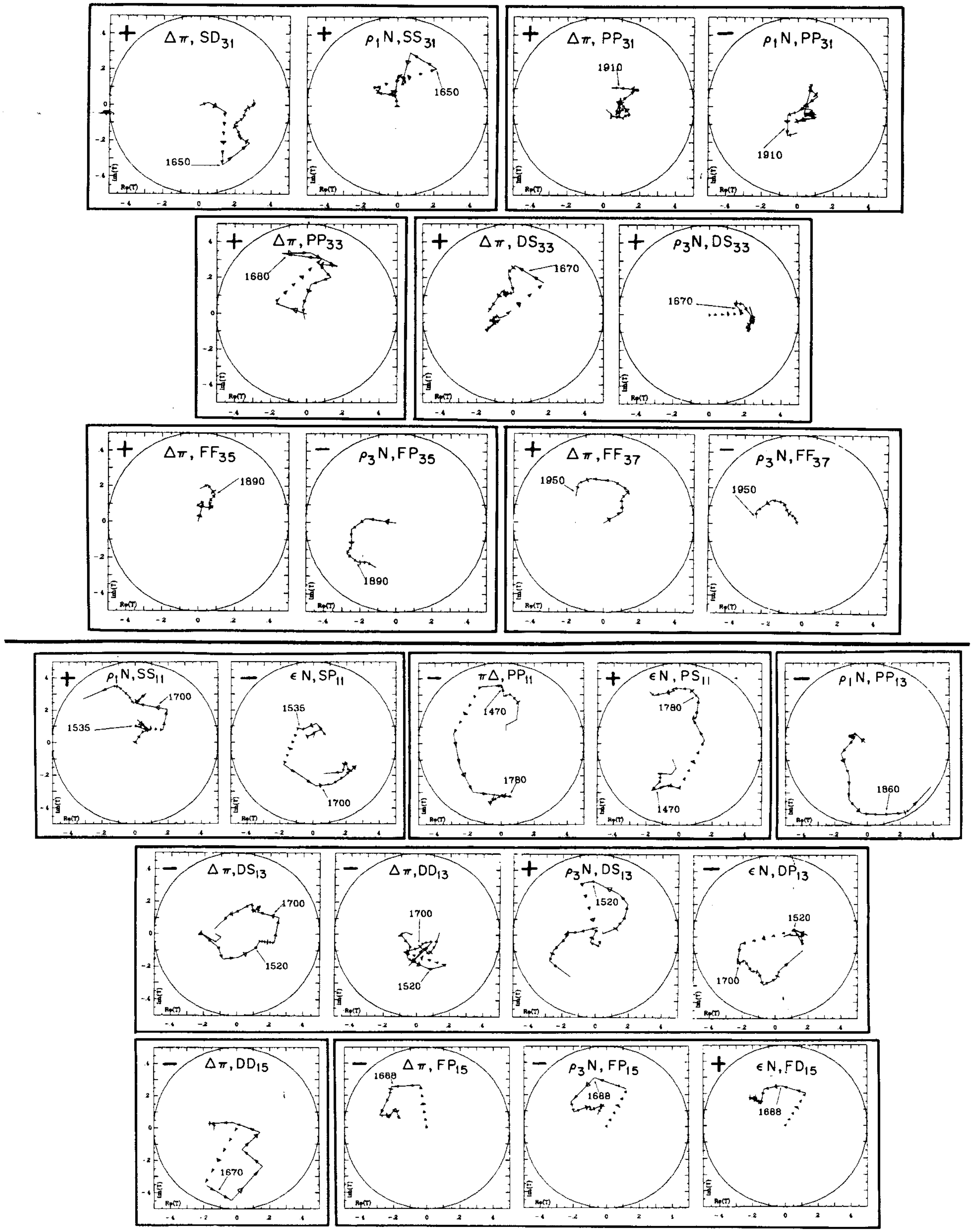

Fig. 1. Argand plots for Solutuion A (1972). The nominal energies come from the CERN 1972 partial wave analysis. For more details, see combined caption for both figures, at the end of the text.

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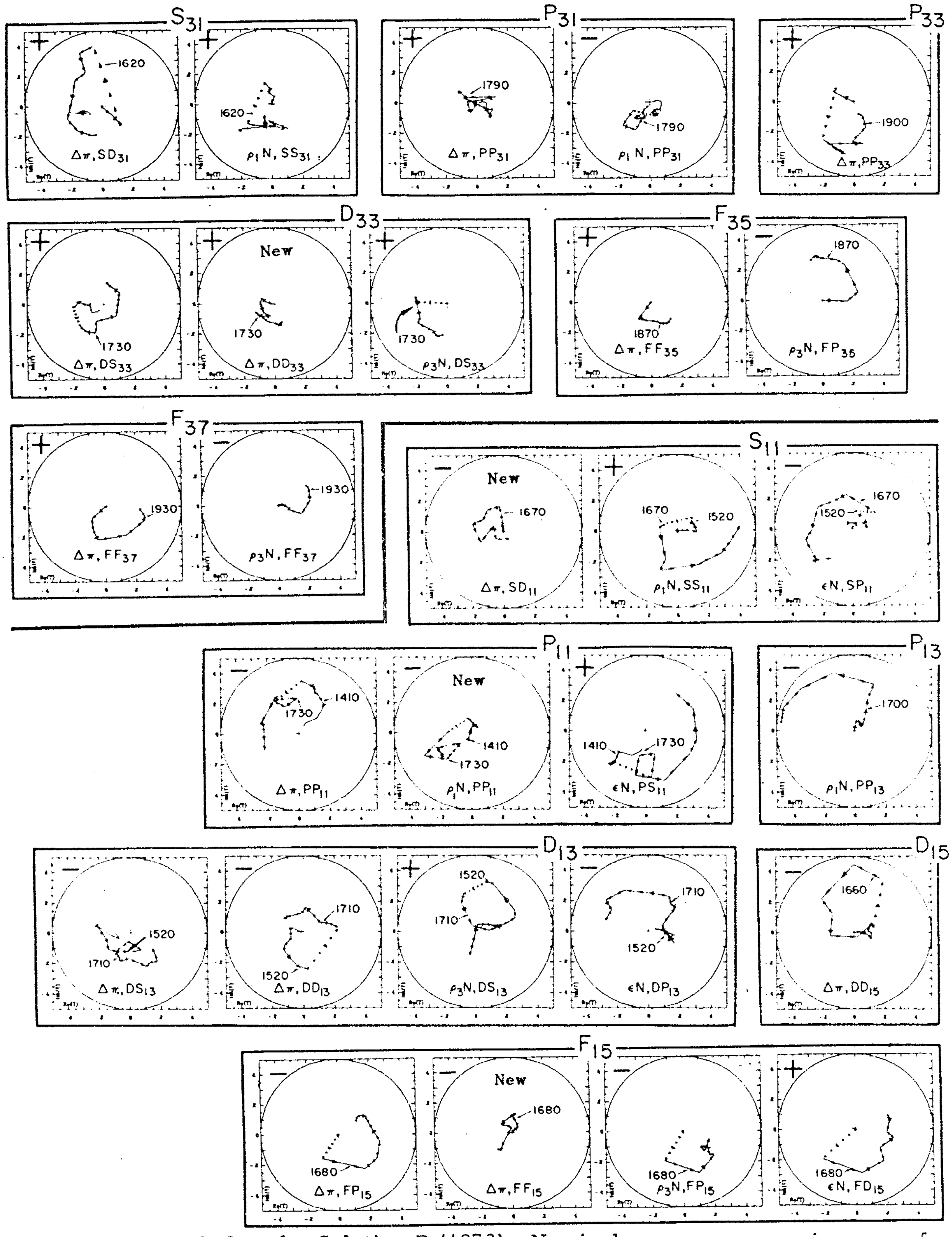

Fig. 2. Argand plots for Solution B (1973). Nominal resonance energies come from the 1973 Saclay elastic pwa. For details, see combined figure caption at end of text.

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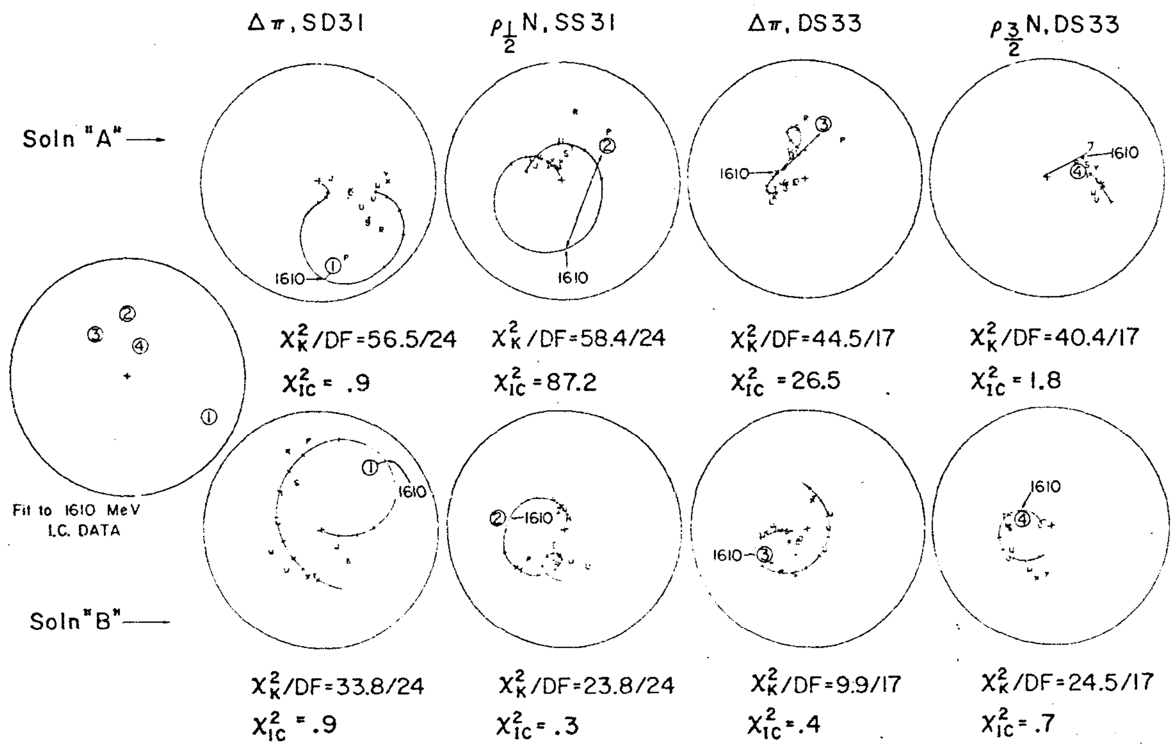

Fig. 3. Comparison of 4 amplitudes from a fit to the I.C./Westfield Coll. events at 1610 MeV (the four numbered points in the left circle) with our 1972 Soln. A (top row) and our 1973 Soln. B (bottom row). The letters represent the results of our single-energy fits (D-L 1310-1540 MeV, at approximately 30 MeV intervals, and M-Y 1650-1920 MeV, at approximately 40 MeV intervals), and the curves are K-matrix fits to these single-energy points. XBL 741-2326