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EVIDENCE FROM πp PHASE SHIFT ANALYSIS FOR NINE
MORE POSSIBLE NUCLEON RESONANCES

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ABSTRACT

From πp phase shift analyses at 59 energies, linked with partial wave dispersion relation fits, we suggest the probable existence of nine new nucleon resonances in the mass range 1680-2190 MeV, all with very small branching ratios to the elastic channel.

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It is now well established ¹⁾ that πp scattering contains several resonances not visible in total cross-sections but only through detailed phase shift analysis. However, because of improved experiments, even these are no longer sufficient to give phase solutions which vary smoothly with energy. Thus either there are serious and widespread systematic errors in the data, or else still more resonances are needed. This much has been concluded independently in a new analysis by Bareyre et al. ²⁾. However we go further, and suggest an actual list of new resonances.

By using partial wave dispersion relations, we can smooth the phase shifts and eliminate structures which violate causality ³⁾ such as clockwise circles in the complex plane. The genuine resonances in the experimental phase shifts then show up much more clearly. To evaluate the dispersion relations we represent every partial wave by a series of complex functions ⁴⁾, each possessing the right-hand cut and correct threshold behaviour, and each multiplied by an adjustable real parameter. To them is added the nearby left-hand cut contribution known from earlier analyses ⁵⁾ and several poles with adjustable residues to represent the distant left-hand cut. The sum is then fitted to our experimental phases and elasticities for that partial wave. The number of right-hand terms needed is found from statistical tests. Here is the main difficulty, since if there are too few genuine structure may be lost, while if there are much too many the fits become unstable. This situation arises in any smoothing process, e.g., in polynomial fits to differential cross-sections, the only difference being that we are smoothing for analyticity as well as continuity. We got over it by folding the dispersion relation fits to all waves, with very big errors, back into the phase shift analysis at each energy. These then become overdetermined, so the experiments are able to reject those dispersion relation predictions they do not like, and still be smoothed by the acceptable ones. The whole procedure is then iterated. Since the phases are now smoother and have smaller errors, more terms can be included in the dispersion relation fits without instability. Eventually the experimental phase shift analyses (solid squares) and the theoretical dispersion relation fits (solid lines) move very close to each other, as can be seen from our graphs. The open circles are the new Saclay phase shifts ²⁾ whose comparative bumpiness is obvious.

D_{33} is a good example of what happens. Our earlier dispersion relation fits ⁶⁾ gave a smooth $T = \frac{3}{2}$ solution in good agreement with the experiments at that time and with nothing remarkable in D_{33} . However this was upset mainly by the new Berkeley polarizations ⁷⁾. At first we did not know which partial wave to suspect, but the above procedure of overconstrained fits showed that the D_{33} predictions gave trouble at a whole series of energies. It eventually became clear that a new highly absorptive resonance was needed (Fig. 1c). The new Saclay ²⁾ and Berkeley ⁸⁾ solutions both have the sharp drop in $\delta(D_{33})$ which is characteristic of a highly absorptive resonance, but they do not have the inelastic peak in $\eta(D_{33})$ which is required to be associated with it by causality. This indicates that the resonant behaviour in $\delta(D_{33})$ is experimental. The corresponding behaviour of $\eta(D_{33})$ is not directly experimental, but seems required even by qualitative dispersion theoretic considerations given the experimental behaviour of $\delta(D_{33})$. It is furthermore consistent with the experiments.

The Table shows the resonant-like effects contained in our solution. There are nine new ones, all with small branching ratios to the elastic channel, which explains why they were not seen before. The masses were determined from Argand diagrams, assuming a multiplicative background. This usually gives the point of maximum absorption as the mass. Figure 1 (a-i) shows the partial waves containing new resonances. Graphs of all waves and a detailed comparison with the new Saclay ²⁾ and Berkeley ⁸⁾ solutions will appear elsewhere ⁹⁾. It appears that several of our new resonances can be traced in the current Berkeley solution also. Tables of our phase shifts are available on demand ¹⁰⁾.

We cannot exclude the possibility that someone will find an equally satisfactory solution with, say, 14 new resonances all in different places from ours, and we therefore do not claim to have established our set conclusively. However, unless the experiments are seriously wrong, it will be impossible to find any reasonably continuous solution without several new resonances.

Since our solution is so much smoother than that of Ref. 2), it might be supposed that the fit to the experiments is worse. However, this does not appear to be so. At 310, 370, 410 and 1566 MeV we have included and fitted new data ¹¹⁾, some of which is in bad disagreement with the predictions of their phases. Even excluding these, comparing their phases with our data set at the 19 other energies used by them, gave $\chi^2 = 2313$ for 1918 data points, while our phases gave $\chi^2 = 1825$. Though this comparison might be claimed unfair, we do not seem to have paid much for our additional smoothness. We should mention, however, that in view of the considerable disagreements between the two main series of charge exchange experiments ¹²⁾, we were sceptical about the quoted errors on them, and this has helped our χ^2 . Our total χ^2 for all 59 energies is 4421 for 4102 data points. This includes several cases where two experiments are in obvious disagreement, notably 1935 MeV. The number of dispersion relation constraints is equal to the number of free parameters, so we regard 4102 as the expected value.

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TABLE - Resonance parameters (in MeV). * means new resonance.

wave	mass	Γ_{tot}	$\Gamma_{\text{el}}/\Gamma_{\text{tot}}$
P_{33}	1235.8	125.1	1.
P_{11}	1466	211	0.658
D_{13}	1541	149	0.509
S_{11}	1591	~268	0.696
S_{31}	1635	177	0.284
D_{15}	1678	173	0.391
F_{15}	1687	177	0.560
* P_{33}	1688	281	0.098
* D_{33}	1691	269	0.137
* P_{11}	~1751	327	0.320
* P_{13}	~1863	~296	~0.207
* F_{35}	1913	350	0.163
* P_{31}	1934	339	0.299
F_{37}	1946	221	0.386
* D_{35}	~1954	~311	~0.154
* F_{17}	1983	225	0.128
* D_{13}	2057	293	0.260
G_{17}	2265	298	0.349

REFERENCES

- 1) See, for example, A.H. Rosenfeld, A. Barbaro-Galtieri, W.J. Podolsky, L.R. Price, P. Soding, C.G. Wohl, M. Roos and W.J. Willis, Revs.Modern Phys. 39, 1 (1967).
- 2) P. Bareyre, C. Bricman and G. Villet, "Phase shift analysis of pion-nucleon elastic scattering below 1.6 GeV", Saclay preprint (1967).
- 3) See, for example, R.H. Dalitz, Ann.Rev.Nucl.Sci. 13, 339 (1963).
- 4) Formulae for these functions may be found in :
A. Donnachie, "Pion-nucleon phase shift analysis", Appendix 2, CERN preprint TH.690 (1966), to be published in "Particle Interactions at High Energies", Ed. T.W. Priest and L.L.J. Vick (Oliver and Boyd, Edinburgh, 1967).
- 5) A. Donnachie, J. Hamilton and A.T. Lea, Phys.Rev. 135, B515 (1964);
A. Donnachie and J. Hamilton, Phys.Rev. 138, B678 (1965);
G.C. Oades, private communication.
- 6) A. Donnachie, A.T. Lea and C. Lovelace, Phys.Letters 19, 146 (1965).
- 7) O. Chamberlain, M.J. Hansroul, C.H. Johnson, P.D. Grannis, L.E. Holloway, L. Valentin, P.R. Robrish and H.M. Steiner, Phys.Rev.Letters 17, 975 (1966).
- 8) C.H. Johnson, P.D. Grannis, M.J. Hansroul, O. Chamberland, G. Shapiro and H.M. Steiner, private communication from H.M. Steiner.
- 9) C. Lovelace, "Nucleon resonances and low energy scattering", CERN preprint TH.837, to be published in Proceedings of the 1967 Heidelberg Conference, North Holland.
- 10) A. Donnachie, R.G. Kirsopp and C. Lovelace, "CERN PiP phases", CERN preprint TH.838 Addendum (available on demand).
- 11) W. Gorn, C.C. Morehouse, T. Powell, P.R. Robrish, S. Rock, S. Shannon, H.M. Steiner and H. Weisberg, Bull.Am.Phys.Soc. 12, 469 (1967);
University College, Westfield College London Collaboration, " $\pi^{\pm}p$ elastic scattering between 1.72 and 2.80 GeV/c" paper presented at the 1967 Heidelberg Conference.

8.

- 12) L. Guerriero, Proc.Roy.Soc. (London) A289, 471 (1966):
C.B. Chiu, R.D. Eandi, A.C. Helmholtz, R.W. Kenney, B.J. Moyer,
J.A. Poirier, W.B. Richards, R.J. Cence, V.J. Peterson,
N.K. Sehgal and V.J. Stenger, Phys.Rev. 156, 1415 (1967).
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FIGURE CAPTION

Figure 1 (a-i) Partial waves containing new resonant-like effects.
The solid squares are our phases and elasticities,
the solid lines are our dispersion relation fits,
the open circles are the results of Ref. 2).

FIG.
1a.

FIG.
1b.

FIG.

1C.

FIG.
1d.

FIG.
1e.

FIG.

15.

FIG
19.

FIG
1h.

FIG.
14.