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Plenary Sessions: Strong Interactions

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Plenary Sessions: Strong Interactions

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Meson Resonances

R. E. Diebold

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MESON RESONANCES*

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Abstract

1) Several narrow resonances have been suggested in the 950 MeV region, but need confirmation.

2) The ambiguity in the $I = 0$,S-wave $\pi\pi$ phase shift above the ρ has been resolved in favor of the down solution. The phase changes rapidly near $K\bar{K}$ threshold, and the data are well fit with a pole at 980-37i MeV.

3) Little variation with mass has been found in the phase of the A_1 amplitude, suggesting that it is just kinematic enhancement. There could also be a resonance in this region, but even if it should exist, the mass and width are very uncertain.

4) All high statistics A_2 experiments are well fit by a single Breit-Wigner and the old CERN MMS data have been reanalyzed and found to be less significant than originally believed. It seems very likely that the A_2 is an ordinary resonance.

5) A clean high statistics sample of $B(1235) \rightarrow \pi\omega$ has been obtained and yields the expected $J^{PC} = 1^{+-}$.

6) Several experiments have found a new resonance, $\rho' \rightarrow \rho^0\pi^+\pi^-$ with $M \sim 1.5$ and $\Gamma \sim 0.4$ GeV.

7) None of the narrow high-mass objects reported previously have been confirmed in spite of considerable effort.

8) Still no exotic mesons.

*Work performed under the auspices of the U. S. Atomic Energy Commission

Introduction

The minirapporteurs provided an interesting and informative program at the parallel sessions; many of their talks are included in the proceedings and should be consulted for details.

Let me remind you that the Review of Particle Properties by the Particle Data Group (1971, 1972) contains more than just The Tables which we carry constantly with us. The data card listings in the back have not only lists of individual measurements, but also references and concise, well written discussions of current problems.

Much useful information was exchanged at the 1972 Philadelphia Conference on Experimental Meson Spectroscopy, and I thank Prof. A. Rosenfeld for supplying an advance copy of the proceedings. I would also like to thank the Scientific Secretaries, A. B. Wicklund and C. E. W. Ward, for their help.

$\pi\pi$ Scattering

Considerable work on $\pi\pi$ scattering has been carried out since the Kiev Conference two years ago. In particular, the sudden onset of inelasticity at $K\bar{K}$ threshold has been used to resolve the $I = 0$, S-wave ambiguity in the region above the ρ meson.

Since pion targets are unavailable, one must rely on the separation of one pion exchange (OPE) diagrams (Fig. 1) from the many other possible diagrams leading to dipion production. For experiments with sufficient statistics, this separation is made with a Chew-Low extrapolation to the pion pole. As has been emphasized (e.g., Kane 1970), these extrapolations are not without pitfalls. For example, one should avoid extrapolation of density matrix elements which have singularities between the physical region and the pion pole (Williams 1970). Another possible source of error comes from constraining the differential cross section for reactions such as $\pi^- p \to \pi^- \pi^+ n$ to go through zero at $t = 0$ as expected for simple OPE; absorption effects can displace this zero.

High statistics spark chamber data (Baillon 1971, Grayer 1972a) agree well with the Poor Man's Absorption model (Williams 1970; Froggatt and Morgan 1972 consider a generalization of this approach). Having once determined that a particular model reproduces the production

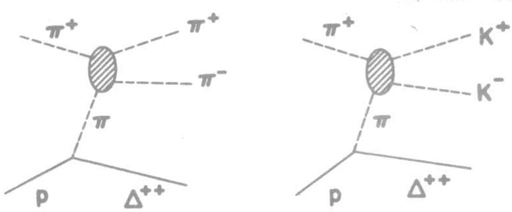

Fig. 1. Elastic and inelastic $\pi\pi$ scattering.

distributions, one can then use the model to investigate the validity of various extrapolation procedures. Williams (1972) finds that the higher order moments of the decay angular distribution do not extrapolate as simply as experimentalists have assumed. The situation is further complicated by the fact that other exchanges such as A_2 may be present, especially at larger t (Estabrooks and Martin 1972). In spite of all the complications, a reasonably consistent picture of $\pi\pi$ scattering has been obtained at various momenta from different reactions. See Peterson (1971) for a general review of the subject.

I = 0, S-Wave $\pi\pi$ Phase Shift

While the P-wave $\pi\pi$ phase shifts corresponding to the ρ meson have been known fairly well for many years, there has been considerable ambiguity in the I = 0, S-wave amplitude. Part of this ambiguity was removed a few years ago by careful extrapolation of the $\pi\pi$ cross section below the ρ mass. The ambiguity above the ρ has recently been resolved using the cusp effect at $K\bar{K}$ threshold (Alston-Garnjost 1971) predicted from earlier $K\bar{K}$ studies (Hyams 1970, Beusch 1970).

$K\bar{K}$ Cusp Effect. Fig. 2 shows some of the data from a 7 GeV/c bubble chamber experiment (Protopopescu 1972) with results not only for elastic $\pi\pi$ scattering from $\pi^+p \to \pi^+\pi^-\Delta^{++}$, but also inelastic $\pi^+p \to K^+K^-\Delta^{++}$. The $\pi\pi$ cross section was found to decrease rapidly in the region near 980 MeV, as shown by the mass spectrum both in the physical region and extrapolated to the pole. Since only S and P waves are important in this region, it is clear that the amplitude for at least one of these two waves is falling rapidly.

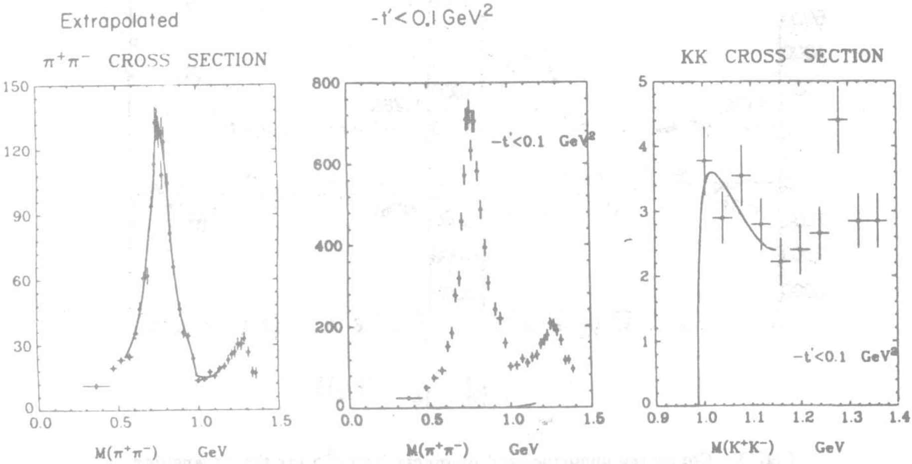

Fig 2. Cross sections at small t and extrapolated to the pion pole for $\pi^+p \to \pi^+\pi^-\Delta^{++}$ and $\pi^+p \to K^+K^-\Delta^{++}$ at 7 GeV/c (Protopopescu 1972). The curves show the result of the fit described in Table 1.

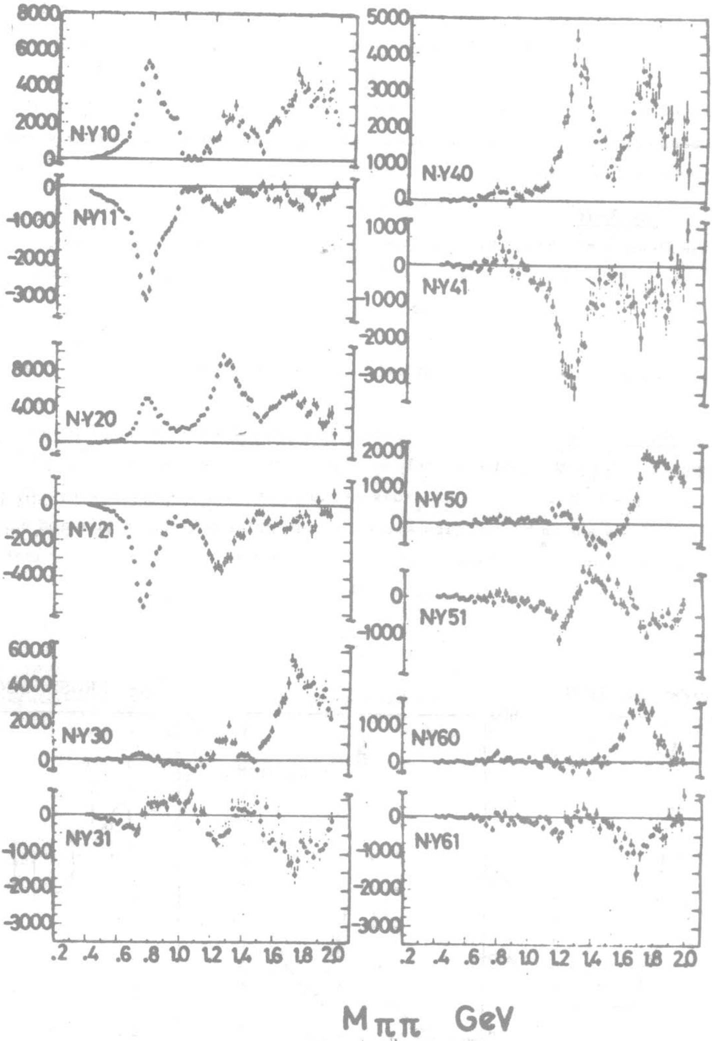

Fig. 3. Corrected unnormalized moments $N\langle Y_\ell^m\rangle$ for the $\pi\pi$ angular distribution from $\pi^- p \to \pi^-\pi^+ n$ at 17 GeV/c (Grayer 1972a).

This effect was also found at 17 GeV/c by the CERN-Munich Group with their wire-chamber spectrometer (Grayer 1972a). With more than 300,000 good events for the reaction $\pi^- p \to \pi^+ \pi^- n$, the statistical errors for the moments are indeed small, Fig. 3. The unnormalized moment $N\langle Y_2^0 \rangle$ is proportional to the P-wave contribution in the mass range of interest; near 980 MeV this distribution is rather smooth, so it must be a sudden loss of S-wave amplitude which causes the drop in cross section. This qualitative picture is consistent with the Y_1^0 moment which falls rapidly to zero in this mass region (Flatté 1972).

To get a quantitative fit, Protopopescu (1972) used the energy dependent parametrization outlined in Table 1. In particular, for the I = 0,S-wave a 2 x 2 M matrix was used to describe the coupled $\pi\pi$ and $K\bar{K}$ channels. With 24 free parameters, fits were made to 171 data points: the extrapolated cross sections and moments up to Y_6^0 over the $\pi\pi$ mass range 550 MeV to 1150 MeV, as well as the K^+K^- data of Fig. 2. The extrapolated $\pi^+\pi^-$ cross sections were obtained using Dürr-Pilkuhn form factors, while the moments were extrapolated linearly in t. Although this is a standard form of extrapolation, it is clear that the method is not perfect since ρ - ω interference effects remained in the extrapolated data. Quite reasonable fits to the data were obtained with χ^2 values in the region 150 to 160 for 147 degrees of freedom, the exact values depending on slight variations of the parametrization.

The results for δ_0^0 are shown in Fig. 4; below the ρ meson the fits give values similar to those obtained previously by Baton (1970) and Baillon (1972). From the ρ up to about 900 MeV, the fit follows the old down solution, but from 900 to 1000 MeV, the phase shift increases rapidly to the final value of about 200°. While this solution is in disagreement with the results of Baton, one of the Baillon points lies very closely to the curve in this region

Table I. Parametrization of partial waves.

Partial wave	Parametrization	Number of free parameters
I=0 s wave	2X2 M-matrix coupling $\pi\pi$ and $K\bar{K}$ channels	7
I=1 p wave	ρ resonance + background, both become inelastic at 900 MeV	7
I=0 d wave	f_0 resonance coupled to $\pi\pi$ and $K\bar{K}$ + background which becomes inelastic at 900 MeV	5
I=1 f wave	Elastic g resonance + background which becomes inelastic at 900 MeV	5
I=2 s wave	$\eta_2^0=1,\ \delta_2^0 = q \sum_{n=0}^{5} c_n q^{2n}$	0
I=2 d wave	$\eta_2^2=1,\ \delta_2^2 = aq^5$	0

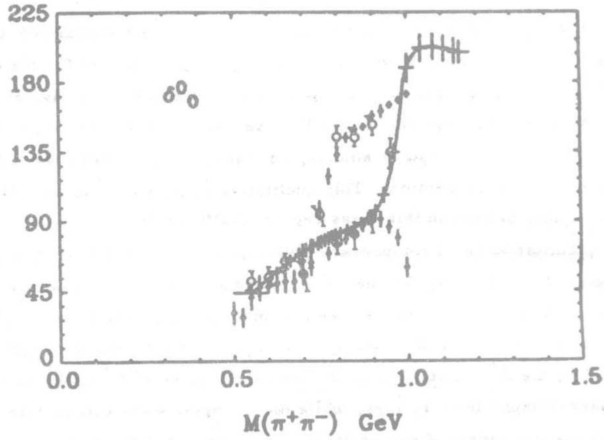

Fig. 4. Phase shifts for I = 0, S-wave $\pi\pi$ scattering: line and crosses Protopopescu (1972), solid dots Baton (1970), open circles Baillon (1972).

Fig. 5 compares the Protopopescu δ^0_0 results with various theoretical solutions collected by Schmid at the Amsterdam Conference (1971). The authors of these theoretical curves used dispersion relations, crossing, unitarity, and so on, to get self-consistent solutions for the highly interlocked $\pi\pi$ system. The Protopopescu results follow most closely the Morgan-Shaw (1970) solution BD1. For a recent discussion of theoretical constraints see Basdevant (1972).

Pole Description. The Protopopescu parametrization gives two poles on the second sheet of the complex energy plane, with parameters shown in Table 2. While a simple Breit-Wigner has a pole at $M_0 - i\Gamma/2$, the pole position for relativistic forms is somewhat displaced. Experience with the πN system indicates that the pole location may be better determined than M_0 and Γ. Fits to the πp mass distribution in the Δ region gave resonant masses from 1231 to 1234 MeV and widths from 112 to 120 MeV depending on the particular formula used (Particle Data Group 1971). The location of the S-matrix pole was found to be more stable: $M - i\Gamma/2 = 1211 - 50i$ MeV, with different fits agreeing to within 1/2 MeV (Ball 1972); a very detailed discussion of various fits is given in the most recent Review of Particle Properties (Particle Data Group 1972). One might suppose that the poles of the $\pi\pi$ amplitude will also be more stable than simple Breit-Wigner descriptions.

An alternative solution was recently obtained by Protopopescu (1972); it does not contain the ϵ pole and the existence of an ϵ resonance thus remains in doubt. The final interpretation of this effect must await further analysis and will probably require additional low mass data.

Table 2. Poles in the Complex Energy Plane for the I = 0, S-Wave $\pi\pi$ Scattering Amplitude of Protopopescu (1972)

ϵ	600	-	250i
	±100		±70
S^*	980	-	37i
	±7		±8

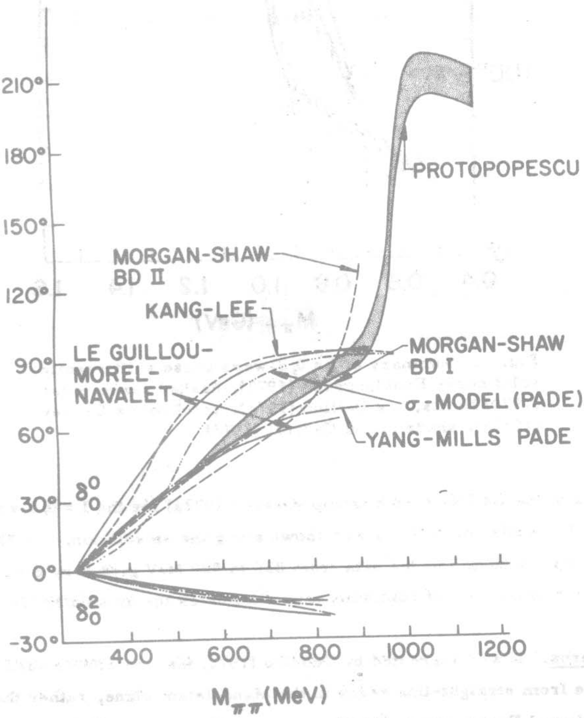

Fig. 5. Comparison of the Protopopescu phase shift with theoretical work compiled by Schmid (1971).

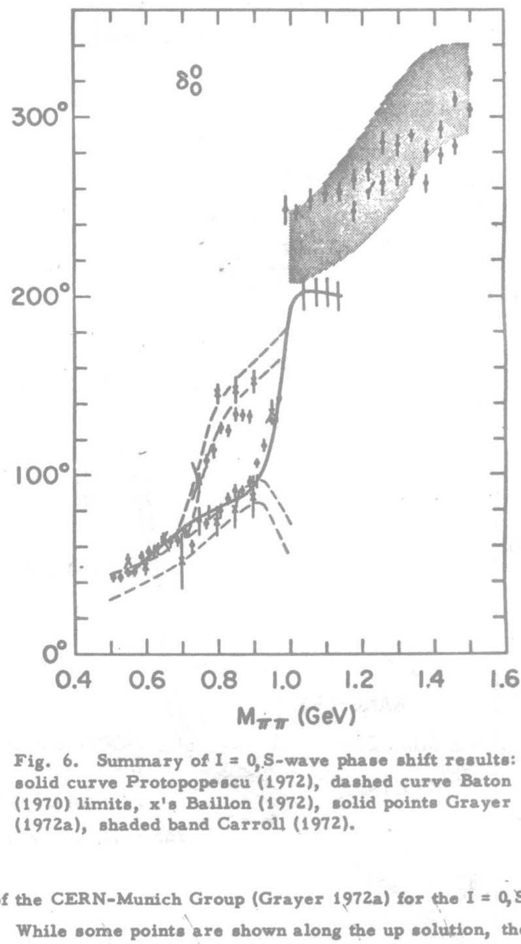

Fig. 6. Summary of I = 0, S-wave phase shift results: solid curve Protopopescu (1972), dashed curve Baton (1970) limits, x's Baillon (1972), solid points Grayer (1972a), shaded band Carroll (1972).

The results of the CERN-Munich Group (Grayer 1972a) for the I = 0, S-wave phase shift are shown in Fig. 6. While some points are shown along the up solution, the 900 to 940 MeV region contains no up solution, and the data from 820 to 900 MeV give very poor fits to the up solution. A simple requirement of continuity thus eliminates the up solution from this analysis as well.

Odorico Zeros. It was suggested by Odorico (1972) that the effects seen in $\pi\pi$ scattering near 980 MeV come from straight-line zeros in the Mandelstam plane, rather than $K\bar{K}$ threshold effects. Pennington and Protopopescu (1972) have used the phase shift results to find the zeros shown in Fig. 7. These zeros do not turn out to be straight lines, and as discussed by Fujii (1972), it is difficult to see how the Odorico zeros could give such sharp structure as a function of $\pi\pi$ mass.

$\pi^0\pi^0$ Results. Two experiments on the reaction $\pi^- p \to \pi^0\pi^0 n$ were presented to this conference. Skuja (1972) at Berkeley studied the reaction from 1.6 to 2.4 GeV/c. At these low

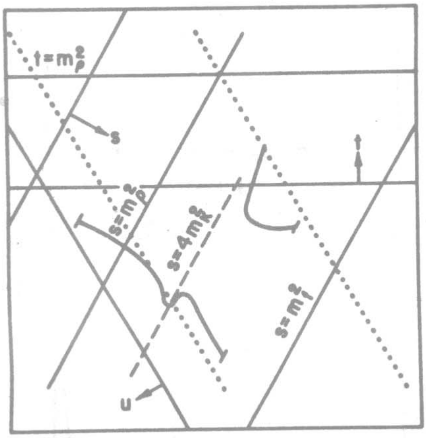

Fig. 7. Mandelstam plane for $\pi^+\pi^-$. The zeros determined from the phase shift analysis (Pennington and Protopopescu 1972), heavy curved lines, are compared with the Odorico (1972) zeros, dotted straight lines.

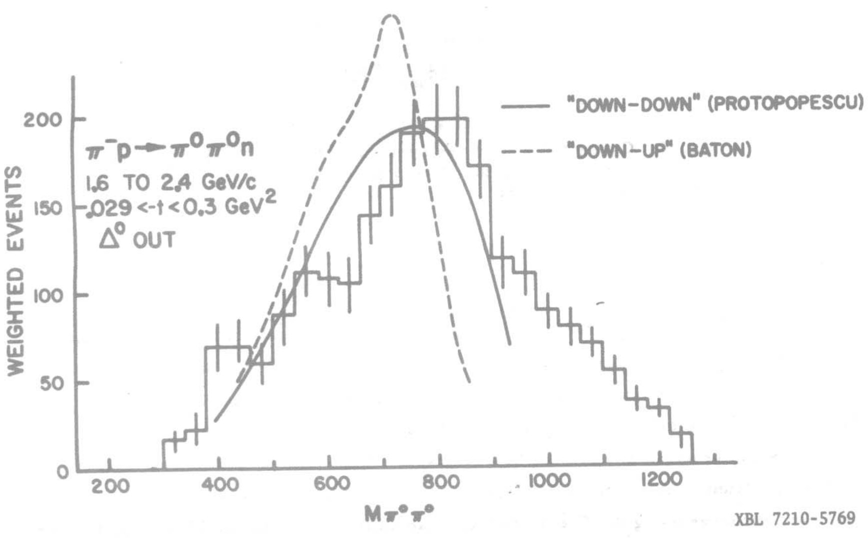

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Fig. 8. Comparison of $\pi^0\pi^0$ mass spectrum with that expected from S-wave phase shift solutions; the curves are normalized to the events between 400 and 940 MeV (Skuja 1972).

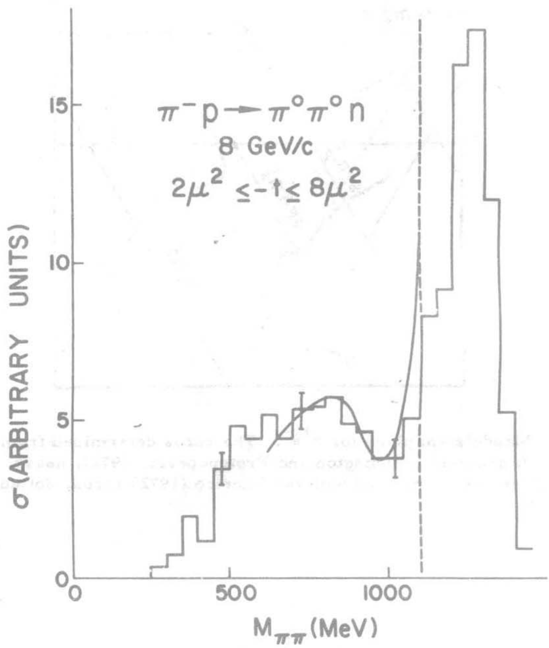

Fig. 9. Corrected $\pi^o\pi^o$ mass spectrum of Apel (1972) compared with that expected from the Protopopescu (1972) phase shift (the full t range is not accepted above 1100 MeV).

energies the reaction is dominated by Δ^o production, and one must cut hard to eliminate Δ effects; further, t_{min} is quite large. A marked enhancement is observed in the region above 700 MeV, Fig. 8. The solution of Protopopescu (1972) follows the data rather well in the region above the ρ, while the old down-up solution of Baton (1970) does not.

The same reaction was studied by a Karlsruhe-Pisa Collaboration (Apel 1972) at 8 GeV/c. The mass spectrum is shown in Fig. 9; it agrees reasonably well with the distribution calculated for one pion exchange using the Protopopescu phase shifts with Benecke-Dürr form factors.

High Mass Region. Above 1 GeV the I = 0, S-wave phase shift continues to increase, Fig. 6. As the mass increases, one must include more and more partial waves, each with uncertain inelasticity, and the results become less reliable. However, several groups (Beaupre 1971, Carroll 1972, Grayer 1972a, Gaidos 1972) are in general agreement that the S-wave amplitude is quite large, near 90° (270°), in the region of the f meson. The Protopopescu phase shift levels off near 210° above 1 GeV, disagreeing with this general consensus, perhaps due to

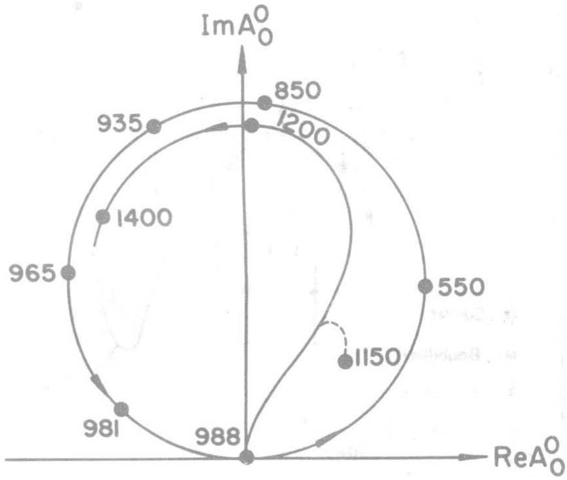

Fig. 10. Argand plot for I = 0, S-wave $\pi\pi$ scattering.

an inadequacy of the energy dependent parameterization. Lipkin (1972) has a quark model with two L = S = 1 states, J = 0 and 2, which interfere in a clever manner so as to reduce the J = 2 bump at $\cos\theta = 0$, as seen experimentally in the f region.

Argand Plot. Fig. 10 summarizes in a qualitative way the I = 0, S-wave $\pi\pi$ amplitude. Starting from the origin, the phase works its way up to 90° near 850 MeV. It then starts downward, moving faster and faster until it reaches $K\bar{K}$ threshold at which point it jumps off at 90° and becomes inelastic. The phase of 180° at $K\bar{K}$ threshold is taken from the fit of Protopopescu (1972). This phase depends on the particular energy-dependent parametrization used, however, and needs a careful analysis with high statistics and good mass resolution. Fits with other phases at threshold are shown by Flatté (1972). Above $K\bar{K}$ threshold, the amplitude wanders back up to about 90° in the region of the f. It becomes elastic, or nearly so, in this region and continues slowly around the plot.

The 0^{++} nonet expected in the quark model has been the subject of speculation for some time. At present the $\pi_N(975)$ and the strong S-wave $K\pi$ amplitude in the region 1100-1400 MeV are the best candidates for the I = 1 and 1/2 members. The Gell-Mann-Okubo mass formula then predicts that the octet I = 0 member has a mass in the 1200 to 1500 MeV region, in which case