# PION-NUCLEON PHASE SHIFTS AND RESONANCES ***

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Up to 310 Mev, conventional phase-shift analysis has been extensively performed. Above 310 MeV it cannot be done, because the presence of inelastic scattering doubles the number of parameters.

Recently Donnachie et al [1] calculated $P$, $D$ and $F$ waves from partial wave dispersion relations, and obtained excellent agreement with experiment up to 310 MeV. This suggests that their calculations may be at least partly valid at higher energies. Also a qualitative analysis by Auvil and Lovelace [2] of the experiments from 300 to 1300 MeV showed clearly which partial waves were large and which small. These were in agreement with what one would expect from DHL. In the present work therefore, we used the DHL calculations of the smaller partial waves as «theortical data» to supplement the experiments. Errors were put on these calculated values, and if the $\chi^2$ test showed that any of them was in conflict with the experiments, it was thrown out. The large partial waves, in which resonances and Ball-Frazer effects can be expected, were fitted without restriction. At the energies with most data we searched quite extensively for solutions. At other energies, we only looked for solutions which were reasonable interpolations between these pivotal energies. The total $\chi^2$ for the whole analysis was 583.91, the expected value being 558. The $\chi^2$ test gives this a probability of over 20%. Figure 1 shows the fits where we improved most on Roper [3]. Our solution is shown by the circles in Figures 2,3. Below 600 MeV, we also found another solution, which differs appreciably only in $S_{11}$, $P_{11}$, and $D_{13}$, and is shown by the triangles in Figures 2, 3. The ridge between the two solutions is not very high. However, we could not find any satisfactory continuation of solution II above 600 MeV, and we think it can probably be excluded. In this second solution $P_{11}$ only rises to 60°.

In our preferred solution, $P_{11}$ rises to around 90° at 600 MeV (mass 1512 MeV), and then falls back again, thus partly confirming Roper's resonance. The width is 400 MeV (260 MeV in terms of mass). At the maximum it is almost purely absorptive. This is why the errors on the phase are so large there. We tried very hard to find a solution at 698 MeV in which $P_{11}$ continued past 90° instead of falling back, but were unable to do so. Roper's solution, which has this behaviour, is a very bad fit to the charge exchange (Fig. 1d.) The inelastic decay mode of this resonance is puzzling [4] — if the $\sigma$ resonance of Shirkov and Brown and Singer [5] exists, then it could well be $N + \sigma$.

The $D_{13}$ resonance is at 620 MeV (mass 1525 MeV), but is only 90 MeV wide (56 MeV in terms of mass). (The DHL rescattering has been reduced to allow for this and is now in agreement up to 410 MeV). We think the shifting of the $D_{13}$ resonance to 676 MeV in Roper's solution was probably due to the constraint he put on the width. It is strongly absorptive, in fact the resonance appears also as a peak in the inelastic cross-section (Fig. 2c). Its inelastic decay mode may be $N^* + \pi$ [4].

$S_{11}$ shows a notable inelastic cusp at the threshold for $\eta$-production (558 MeV). Its height agrees with direct evidence on the $\eta$-production cross section. Since the $\eta$ is stable in strong interactions, a cusp at its threshold is very plausible. Coinciding with this cusp in the inelasticity, the phase rises sharply to 60° and then falls back. This is obviously due to the Ball-Frazer mechanism [6]. On the other hand, the behaviour of $S_{11}$ in Roper's solution, with the inelasticity rising strongly and the phase practically flat, is plainly in contradiction with partial wave dispersion relations.

The rapid rise in $F_{15}$ is evidence for this assignment for the 900 MeV resonance. $F_{15}$ is

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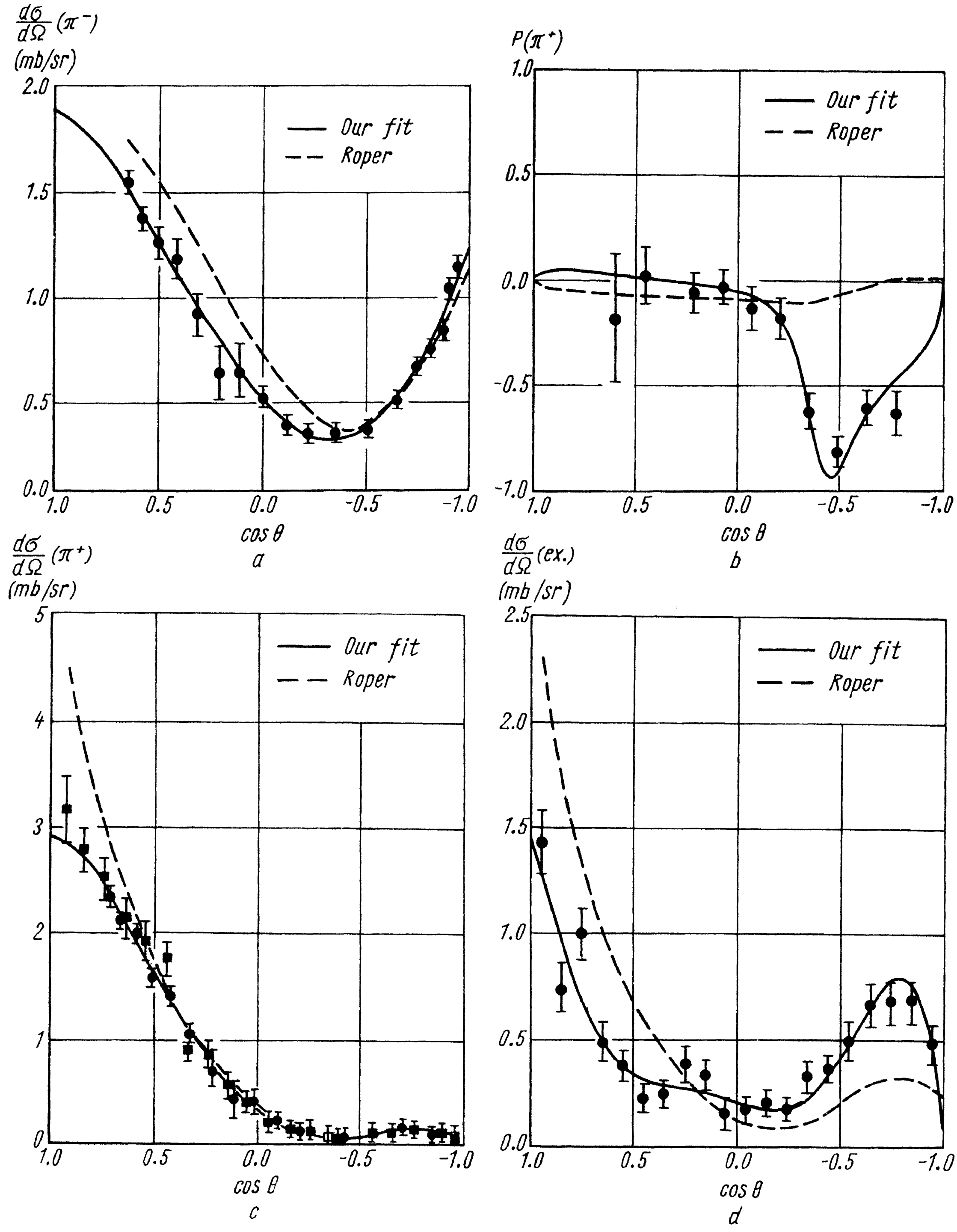


Fig. 1. Our predictions (———) and Roper's (— — —). (a) $\pi^-$ differential cross section at 410 MeV, (b) $\pi^+$ polarization at 490 MeV, preliminary Saclay data, (c) $\pi^+$ differential cross-section at 600 MeV. ● Ogden et al, ■ Newcomb, (d) charge exchange at 698 MeV, preliminary Berkeley data.

also appreciably inelastic at 700 MeV already, in agreement with our earlier conclusion [2] that the 900 MeV resonance is more inelastic than usually supposed.

A Breit-Wigner formula, based on the observed position and width of the 1350 MeV resonance, was used to calculate the rescattering for the theoretical values of $F_{37}$ [1]. The fact

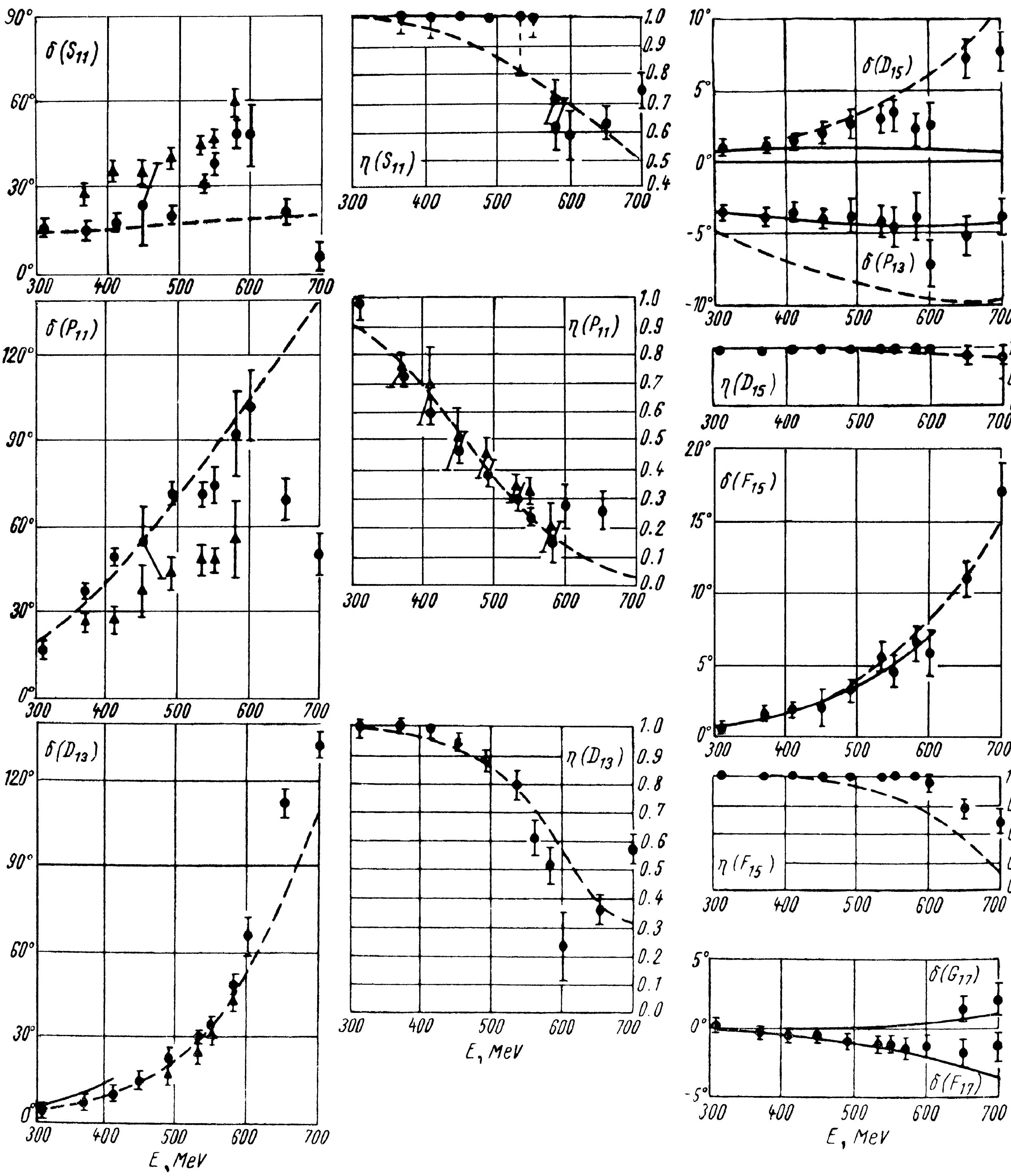


Fig. 2. $\pi\, p$ phases (δ) and elasticities (η) for $I = 1/2$:
● our solution *I*, ▲ our solution *II*, —— DHL predictions [1], – – – – Poper [3], —·— modified DHL.

that they agree so well with experiment, is therefore further evidence for the $F_{37}$ assignment.

Extensive revaluations of dispersion relations using these phases are now in progress, and we hope to use them to extend the analysis to higher energies.

The most interesting features which emerge are the peculiar nature of the $P_{11}$ «resonance», the charpness and inelasticity of the $D_{13}$ re-

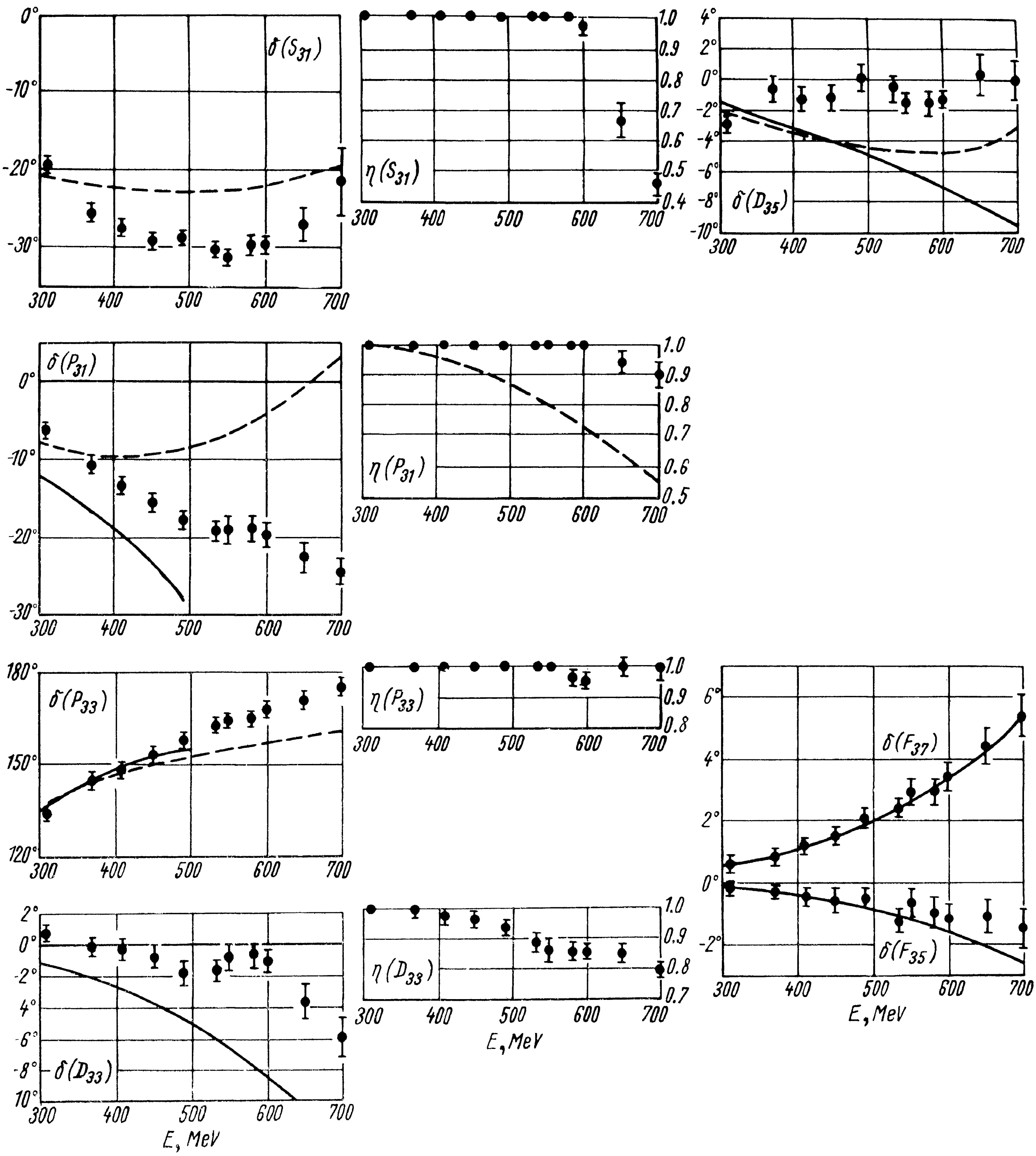


Fig. 3. π p phases and elasticities for $I = 3/2$, same notation.

sonance, and the confirmation of the Ball-Frazer mechanism in $S_{11}$.

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