Confirmation of Dip-Bump Structure in Backward π^--d Elastic Scattering: Possible Evidence for Dibaryon Resonances

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The backward differential cross section for π^--d elastic scattering has been measured at incident momenta between 420 and 1160 MeV/c. The data show two bumps at around 670 and 1100 MeV/c, two dips near 630 and 980 MeV/c, and a break at 550 MeV/c. The result of a phenonomenological fit is consistent with the existence of three dibaryon resonances in this energy region. A theoretical calculation of Kanai *et al.* agrees well with the data below 800 MeV/c, but the agreement becomes worse above 800 MeV/c.

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One of the exciting topics in hadronic as well as nuclear physics is the possible existence of dibaryon resonances (DB's). There have so far been accumulated considerable amounts of data which suggest several DB's in a few dibaryonic channels.[1] In fact, striking structures have been found in the total cross sections and various spin parameters for polarized proton-nucleon scattering.[1,2] These structures have been ascribed to a few DB states by several authors from their precise analyses.[3] On the other hand, recent measurement of the np total cross section shows no evidence for narrow resonances in a mass range below 2.23 GeV.[4] Similarly, no marked structure is found in the reaction $pn \to pp\pi^-$ in a range from 2.17 to 2.30 GeV.[5]

In the reaction $\gamma d \to pn$, a prominent structure in the proton polarization has been found and a couple of DB's are claimed to account for the structure.[6] The situation is, however, still controversial in this process; our recent cross-section measurement is not consistent with the predictions with conjectured DB's.[7] A similar conclusion is also obtained in measurements of the asymmetry ratios Σ and T.[8,9]

Since the DB's suggested in N-N scattering have in general small elasticities, the study of DB's must be extended to scattering processes other than N-N. An example is π-d scattering, for which a variety of data have recently been obtained at meson factories mainly below 400 MeV/c. These are the ordinary angular distribution of $d\sigma/d\Omega$,[10,11] the backward cross section,[12] the vector analyzing power,[13] and the tensor polarization.[14,15] The majority of them reveal some shortcomings of conventional Faddeev-type calculations[16] and the necessity of a certain extra component which might be due to DB's.[17]

At higher energies, Keller *et al.*[18] found an indication of structures near 700 and 900 MeV/c in the backward cross section. They suggested that the structures might be accounted for either by the NN^* component of the deuteron or by the existence of DB's. At 1 to 2 GeV/c, Abramov *et al.*[19] measured the backward cross section which showed a wide structure around $\sqrt{s} \simeq 2.9$ GeV. However, at momenta higher than 400 MeV/c, the available data were still poor.

We present here new high-precision data of the backward cross section for π^--d elastic scattering at pion laboratory momenta $p_{\rm lab}$ between 420 and 1160 MeV/c, corresponding to a range of $\sqrt{s}$ between 2.28 and 2.82 GeV. As dramatically shown in π^--p scattering,[20] the method of studying resonances in the backward excitation function is much more sensitive to a small admixture of resonance components than the usual method of measuring the total cross section. In this experiment the scattering angle is taken to be $-1.0 < \cos\theta_{\rm c.m.} < -0.96$, with an average value of -0.99.

The experiment was performed at the National Laboratory for High Energy Physics (KEK) proton synchrotron. The experimental layout is shown in Fig. 1. The unseparated beam with a momentum resolution of $\Delta p/p = 1.5\%$ was led to a liquid-deuterium target of 5.5 cm diam and 20 cm long. A gas Cherenkov counter discriminated electrons in the beam and the counters B1 and B2 defined

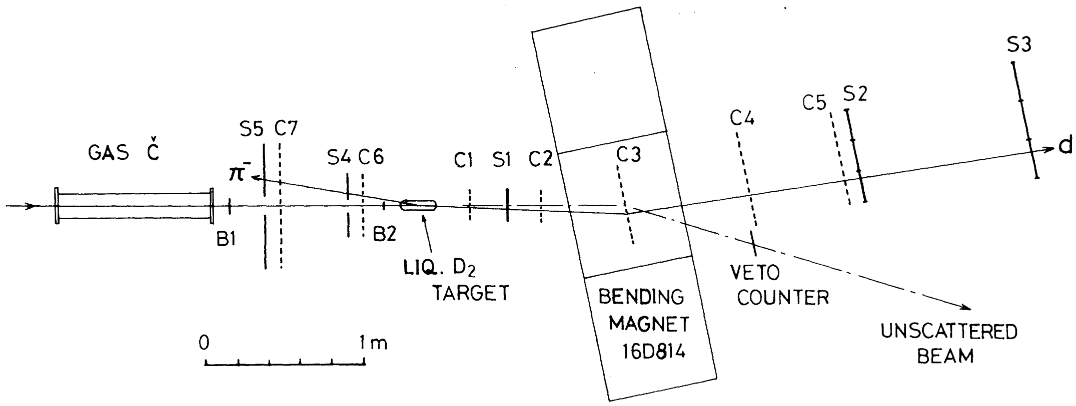

FIG. 1. Plan view of the experimental arrangement. The multiwire proportional chambers C1 and C2 are of anode-readout type with 2-mm spacing, while C3 to C7 are of two-dimensional cathode-readout type. The scintilation counters S1 to S5 are used to trigger events. The magnet is of H type with a large aperture (40×80 cm^2).

the beam size. Typical beam intensities were 10^4 pions/burst at 500 MeV/c and 10^5 pions/burst at 1 GeV/c.

Charged particles in the final state were detected by a two-arm spectrometer. The forward arm detected positive particles emerging at laboratory angles between 0.5° and 7°, and measured their momentum and time of flight between S1 and S3. The backward arm measured particles scattered into the backward direction in coincidence with the forward ones. The forward deuterons were unambiguously separated from protons and other background by use of a two-dimensional plot of momentum versus time of flight. On the other hand, once the direction of the scattered pion was given, the momentum vector of the recoil deuteron was uniquely determined from elastic kinematics. One could therefore easily obtain a difference $\delta\theta$ between the calculated and the measured values of deuteron angle and a similar difference δp for the magnitude of deuteron momentum. The wanted elastic events were then clearly isolated from background in a scatter plot of $\delta\theta$ vs δp.

The raw data were corrected for (i) track reconstruction efficiency (92%); (ii) effect of d-d interactions in the target vessel (5% to 15%, depending on deuteron momentum); (iii) beam contamination mainly due to muons (4%); and (iv) empty-target contribution (2%). The total systematic error was estimated to be on the order of 5%.

The results thus obtained are shown in Fig. 2, where errors are statistical only. Similar data from other experiments[12,14,18,19] are also shown for comparison. The most striking feature of the data is the appearance of a clear dip-bump structure; there are two dips around 630 and 980 MeV/c, and two bumps in the vicinity of 670 and 1100 MeV/c. In addition, a break is observed at 550 MeV/c. Around 900 to 1000 MeV/c, our data differ from others', but no reason has been found for the present apparatus to have any event loss at these particular momenta.

Except for these dips and bumps, the general

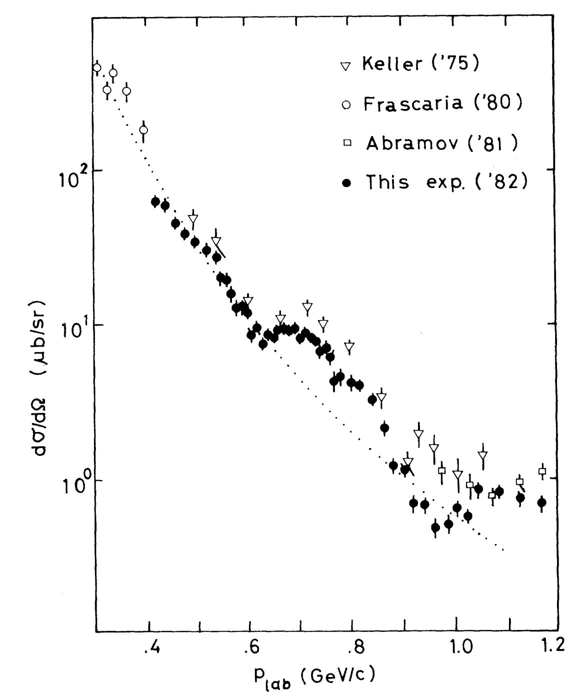

FIG. 2. Differential cross section for π^--d elastic scattering at backward angles (average value of $\cos\theta_{c.m.}$ being -0.99) as a function of laboratory pion momentum p_{lab}. The dotted curve is proportional to p_{lab}^{-6}.

TABLE I. Summary of best-fit values for the parameters of Eq. (1). $a = 0.713\ (\mu b)^{1/2}$, $\chi^2/\mathrm{d.f.} = 1.39$.

Mass M (GeV)	Width Γ (MeV)	c $[(\mu b)^{1/2}\ \mathrm{GeV}/c]$	δ (deg)
2.362	317	4.66	68.4
2.429	103	1.20	−89.7
2.722	223	0.81	17.8

trend of the data is well described by a phenomenological fit which is proportional to p_{lab}^{-6}, as shown by the dotted curve in Fig. 2. We therefore try to fit the data by assuming a background amplitude proportional to p_{lab}^{-3} and a few DB terms of the Breit-Wigner form:

$$f_{\pi d}(180°) = a p_{\mathrm{lab}}^{-3} + \sum_j \frac{1}{p^*} \frac{c_j(\Gamma_j/2)e^{i\delta_j}}{M_j - s^{1/2} - i\Gamma_j/2}, \quad (1)$$

where p_{lab} is in units of GeV/c, and p^* is the c.m. momentum. By varying all the parameters, we get a result shown by the solid curve in Fig. 3, with three DB terms. An inclusion of the fourth DB hardly improves the fit. The best-fit values of the parameters are summarized in Table I. Since we have no *a priori* choice for the background, these values should be regarded as an approximate measure and would provide a set of initial values for further analysis. In fact, if we choose $p_{\mathrm{lab}}^{-2.5}$ instead of p_{lab}^{-3} as a background, which gives a slightly worse fit, the corresponding change in DB masses is within 20 MeV, but the widths of the first and third DB's increase by about 100 and 50 MeV, respectively.

Note also that the second DB whose parameters are most stable for the change of background is consistent with the $^1G_4(2430)$ which has recently been suggested by Bolger *et al.*[13] Many other DB's have been predicted theoretically in this mass range,[21] but no clear identification is possible because of a lack of spin and parity assignment.

Next, let us compare the data with theoretical calculations. In spite of a number of Faddeev-type calculations at lower momenta,[16,17] we have only two calculations in this region. One is due to Kondratyuk and Lev,[22] who emphasized the importance of an intermediate state with a meson (e.g., η, ρ, ...) being produced almost on the mass shell. Their result quoted from Ref. 19 is shown by the dashed curve in Fig. 3. This curve reproduces the structure near 700 MeV/c qualitatively but not quantitatively as a coherent sum of the single-scattering term and a double one with an η-meson intermediate state. The other is a

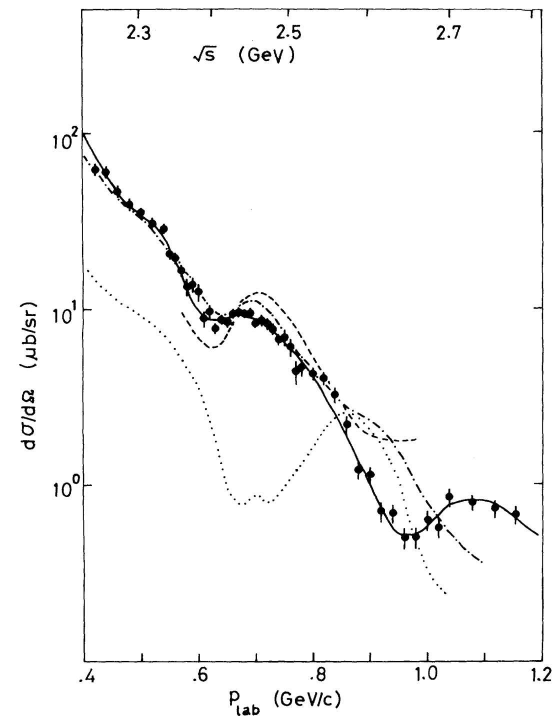

FIG. 3. Comparison of the present data with a phenomenological fit [solid curve using Eq. (1) with three DB's in Table I], the calculation of Kondratyuk and Lev (Ref. 22) (dashed curve) quoted from Ref. 19, and that of Kanai *et al*. (Ref. 23) (dot-dashed curve with four DB's in Table II). The dotted cuve is the nonresonance background of Kanai *et al.*

calculation of Kanai *et al.*,[23] in which a few DB terms are used along with a nonresonant background calculated from the Glauber model. The result, with four DB's whose parameters are listed in Table II, is shown by the dot-dashed curve in Fig. 3. Although the parameters were optimized with old data, the curve still gives a good fit to the present data below 800 MeV/c, but above 800 MeV/c it behaves entirely differently. The dotted curve in Fig. 3 represents the background contribution from the Glauber amplitude alone.

TABLE II. Summary of the resonance parameters of Kanai *et al.*, Ref. 23.

J^P	Mass (GeV)	Width (MeV)	Phase angle (deg)
2^+	2.136	56	101.4
3^-	2.260	181	−23.6
2^-	2.288	139	−72.7
4^+	2.508	122	64.2

in Fig. 3 represents the background contribution from the Glauber amplitude alone.

As a completely different interpretation, the structure might be of geometrical origin such as size resonances. In this case, one would have a structure at a fixed momentum transfer, but the existing data of angular distribution, though still poor, do not show such an indication.

In conclusion the presence of a striking dip-bump structure is observed in backward $\pi^- $-$d$ elastic scattering. A naive interpretation of the structure is a smooth background plus a few DB terms; our phenomenological fit is consistent with this interpretation. The calculation of Kanai *et al.* shows a good fit to the data below 800 MeV/c, but not above 800 MeV/c. For the structure around 700 MeV/c, however, the effect of the η-meson intermediate state might give an alternative explanation. To be more definite, much more elaborate calculations must be made by taking new experimental information into account on the one hand, and a variety of measurements including spin parameters should be required on the other.

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