K^+p SCATTERING AND A POSSIBLE Z^* RESONANCE*

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(Received 30 August 1968)

An energy-dependent phase-shift analysis in the kaon laboratory-momentum range below 2.0 BeV/c has been made of K^+p scattering data, supplemented by information from K^+p forward dispersion relations. Evidence for a possible resonance in the $P_{1/2}$ state is presented.

In previous publications[1,2] evidence has been presented for a possible resonance,[3] which we shall call Z_1^*, in the $P_{1/2}$ partial-wave of K^+p scattering. In Ref. 1, this possibility was suggested on the basis of the 135 pieces of K^+p scattering data which existed at that time below a kaon laboratory momentum k_L of 1.5 BeV/c, and experiments[4-6] do indeed show evidence for structure in this region. The analysis of Ref. 2 was based on 341 data points but was still confined to the region $k_L \leq 1.5$ BeV/c, and since the proposed resonance was at the end of this range, some reservations were in order as to its existence. It is the purpose of this note to report that when the analysis of Ref. 2 is extended to 2.0 BeV/c, the solution containing the Z_1^* resonance remains stable and gives a good fit to a recent series of measurements[7] of the elastic K^+p differential cross section in the backward region, $-1.0 \leq \cos\theta \lesssim -0.7$.

The data used in the present analysis are as given in Ref. 2 with the following additions: (1) total-cross-section measurements of Bugg et al.[6] in the region 0.7-2.0 BeV/c, (2) total-cross-section measurements of Abrams et al.[4] from 1.5-2.0 BeV/c, (3) elastic differential cross sections of Chinowsky et al.[8] at 1.96 BeV/c, (4) elastic differential cross sections of Cook et al.[9] at 1.97 BeV/c, and (5) backward-region elastic K^+p differential cross sections in the range $1.0 \lesssim k_L \lesssim 2.0$ BeV/c recently measured by Carroll et al.[7] These data were supplemented, as in Ref. 2, by forward real parts calculated from a forward dispersion relation.[10] The forward real parts constitute only approximately 10% of the total number of fitted data points.

If $f_{l\pm}(s)$ is the partial-wave amplitude for scattering in a state with $J=l\pm\frac{1}{2}$, and $\alpha_{l\pm}(s)$ is the complex phase shift at s, the squared total center-of-mass energy, then

$$f_{l\pm}(s)=\frac{\exp[2i\alpha_{l\pm}(s)]-1}{2ik},$$

$$=\frac{\eta_{l\pm}(s)\exp[2i\delta_{l\pm}(s)]-1}{2ik},$$

where

$$\eta_{l\pm}(s)\equiv\exp[-2\,\mathrm{Im}\alpha_{l\pm}(s)],$$

$$\delta_{l\pm}(s)\equiv\mathrm{Re}\alpha_{l\pm}(s),$$

and k is the magnitude of the center-of-mass three-momentum. The quantities $\delta_{l\pm}(s)$ and $\eta_{l\pm}(s)$ were parametrized using the form given in Ref. 2.[10] Five complex partial waves, $S_{1/2}$ through $D_{5/2}$, were included in the analysis which involved 30 parameters. Starting solutions used were the best three types found in Ref. 2. In more than 400 trial minimizations performed to date only one type of solution with $\chi^2/N_{DF} \lesssim 2.5$ has emerged, the best example of which has $\chi^2/N_{DF}=1.5$ for $N_{DF}=618$. Closer inspection of the fit shows that there are some eight points, spread throughout the range, contributing more than 10 each to χ^2. If these points are removed the solution remains stable, but now $\chi^2/N_{DF}=1.35$ for $N_{DF}=610$.[11]

The two most interesting waves of this solution, $S_{1/2}$ and $P_{1/2}$, are shown in Fig. 1.[12] The $P_{1/2}$ wave of this solution shows possible evidence[3] for a resonance, the parameters of which are M

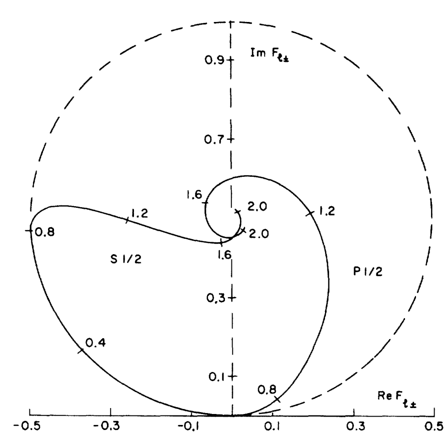

FIG. 1. Argand diagram of the $S_{1/2}$ and $P_{1/2}$ waves of the solution mentioned in the text. The $P_{1/2}$ wave shows possible evidence for a resonance the parameters of which would be $M \simeq 2.0$ BeV, $\Gamma \simeq 220$ MeV, and $\eta \simeq 0.1$.

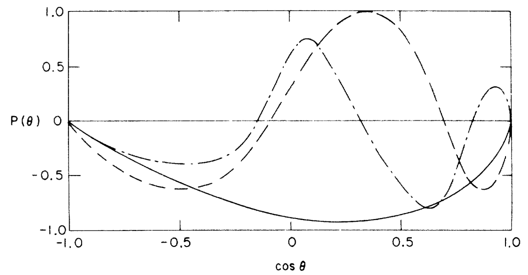

FIG. 2. Predicted recoil-nucleon polarization in elastic K^+p scattering. Solid line, 1.0 BeV/c; dashed line, 1.5 BeV/c; and dash-dotted line, 2.0 BeV/c.

$\simeq 2.0$ BeV, $\Gamma \simeq 220$ MeV, and $\eta \simeq 0.1$. The mass of this state corresponds roughly to the shoulder at ~1.45 BeV/c seen in the 180° cross section.[13] The other interesting feature of Fig. 1 is the S-wave phase shift which has become positive and reaches ~70° at $k_L = 2.0$ BeV/c. This fact may possibly be associated with the shoulder ~2.0 BeV/c observed in the 180° cross section.[13]

Although the values of χ^2/N_{DF} obtained are improbable from a purely statistical viewpoint, nevertheless the solution itself reproduces the overall shape of the data rather well. For example, fits to the backward-region data of Carroll et al.,[7] and the 180° cross section from threshold to 2.0 BeV/c, are shown in Figs. 2 and 3 of Ref. 7. As was emphasized in Ref. 2, a critical test of the solution presented here can be made by measuring the recoil-proton polarization in elastic K^+p scattering. In Fig. 2 we show our predictions for this quantity (defined as in Ref. 2) at 1.0, 1.5, and 2.0 BeV/c.

In a multienergy phase-shift analysis of the present type, where η and δ are parametrized independently, the correct dynamical relationship between these two quantities is not necessarily preserved.[14] For this reason an attempt is underway to analyze the data using a parametrization based on partial-wave dispersion relations. However, although we have used simple parametric forms, and although we cannot rule out the appearance of other phase-shift solutions at this stage, we emphasize that the resonance solution presented here is still a viable form giving an acceptable fit to all K^+p data below 2.0 BeV/c and forward dispersion relations.

I wish to thank the authors of Ref. 7 for permission to use their backward-region K^+p data prior to its publication.

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

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[1] A. T. Lea, B. R. Martin, and G. C. Oades, Phys. Letters 23, 380 (1966).

[2] A. T. Lea, B. R. Martin, and G. C. Oades, Phys. Rev. 165, 1770 (1968).

[3] Evidence for a resonance is conventionally taken to be the existence of an amplitude which traverses all, or most, of an anticlockwise circle on an Argand diagram. However, we cannot exclude the possibility that such a behavior is produced by other, nonresonant mechanisms. [See C. Schmid, Phys. Rev. Letters 20, 689 (1968); P. D. B. Collins, R. C. Johnson, and E. J. Squires, Phys. Letters 27B, 22 (1968); C. B. Chiu and A. Kotanski (unpublished).] Hence our use of the qualification "possible".

[4] R. J. Abrams et al., Phys. Rev. Letters 19, 259 (1967); R. L. Cool et al., Phys. Rev. Letters 17, 102 (1966).

[5] J. Tyson et al., Phys. Rev. Letters 19, 255 (1967).

[6] W. M. Bugg et al., Phys. Rev. 168, 1466 (1968).

[7] A. S. Carroll et al., preceding Letter [Phys. Rev. Letters 21, 1282 (1968)].

[8] W. Chinowsky et al., Phys. Rev. 139, B1411 (1965).

[9] V. Cook et al., Phys. Rev. 129, 2743 (1963). Some of the points in the extreme forward direction measured in this experiment (particularly those obtained by the hodoscope arrangement) were rebinned to bring them into better agreement with the rest of the data. The differential cross sections from this experiment, as well as those of Ref. 8, were renormalized to the more recent accurate total sections of Refs. 4 and 6.

[10] The details are given in Ref. 2.

[11] A value of $\chi^2/N_{DF} \sim 2$ is comparable with those obtained in conventional energy-dependent πN phase-shift analyses. [See, e.g., B. H. Brandsen et al., Phys. Rev. 139, B1566 (1965).]

[12] The other waves show no interesting structure and $|\delta| \lesssim 20°$ throughout the momentum range.

[13] See Fig. 3 of Ref. 7.

[14] Thus, for example, in the case of the $P_{1/2}$ wave the value of η does not rise after δ has passed through $\frac{1}{2}\pi$ as might be expected, even though such a behavior is allowed by the parametrization (hence the "fish-hook" appearance of the Argand diagram for this wave), although without a detailed dynamical model of the interaction this behavior cannot be entirely ruled out.