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K^+-nucleon scattering and exotic $S=+1$ baryons

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The K^+-nucleon elastic scattering process has been reexamined in light of recent measurements which have found a narrow exotic $S=+1$ resonance in their KN invariant mass distributions. We have analyzed the existing database in order to consider the effect of a narrow state on fits to K^+-nucleon observables.

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An analysis of isoscalar and isovector contributions to K^+-nucleon scattering, using K^+p and K^+d data, was published [1] by the VPI group in 1992. The interest in this reaction was driven by a search for possible Z^* resonances. At the time of the VPI analysis, only isovector pole parameters had been reported in the review of particle properties [2] (RPP). Breit-Wigner parameters were available for two isoscalar states. By including K^+d elastic scattering and breakup data, an improved study of the isoscalar component was performed. Both isovector and isoscalar poles were reported. However, the inferred widths were of the order of 100 MeV, and could be "explained" as pseudoresonances whose resonancelike behavior was induced by the opening of channels such as $K^+\Delta$ and K^*N. As a result, these states were removed from the RPP with the statement that "the general prejudice against baryons not made of three quarks and the lack of any experimental activity" precluded any foreseeable progress.

Recent results [3–7] from SPring-8, ITEP, Jefferson Lab, ELSA, and CERN/FNAL have dramatically changed the status of Z^* resonances (now denoted as Θ states). Unlike the broad resonancelike structures seen in previous K^+N analyses, these groups have reported very narrow peaks in their KN mass distributions. The reported masses have been consistent, clustered around 1540 MeV, with widths less than 25 MeV. These results are in remarkable agreement with a chiral soliton prediction of a Θ^+ state at 1530 MeV, with a width less than 15 MeV [8].

In order to understand how this state could have eluded previous studies of K^+N scattering data, we have reanalyzed this reaction, focusing on the 1540 MeV region. While there are suggestions that this state should be seen in the P_{01} partial wave, we have scanned for S-, P-, and D-wave (S_{01}, S_{11}, P_{01}, P_{03}, P_{11}, P_{13}, D_{03}, D_{05}, D_{13}, and D_{15}) structures as well. Width estimates have generally been given as upper limits. For this reason, we have allowed for much lower values. As there have been essentially no new data for this reaction since our last published fit, we have used the 1992 result as a starting point. The fitting strategy and database are fully documented in Ref. [1]. Below, we give only our results from a search for narrow structures.

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In the past, we have performed energy-dependent (ED) and single-energy (SE) fits to the database. The ED approach assumes a mild energy dependence over a wide energy range and will smooth over any narrow structures. In the SE approach, the ED fit is used as a starting point for a fit to data in a restricted energy bin. We have generally allowed the modulus of an individual partial wave to vary in the SE fit, assuming a linear approximation, based on the ED result, over the data bin. Here also a narrow structure can elude detection, particularly if it lies between energies where measurements exist. As a result, we have taken a different approach in this study.

Narrow resonances were added to the VPI analysis using a product S-matrix approach. Starting with the 1992 result, labeled SP92, we allowed a modification

$$T_{\rm New} = T_{\rm SP92} + S_{\rm SP92} T_{\rm RB}, \qquad (1)$$

to the T matrix, due to a (resonance + background) contribution

$$T_{\rm RB} = T_{\rm res} + S_{\rm res} T_{\rm BG}, \qquad (2)$$

wherein the resonance piece was parametrized as

$$T_{\rm res} = \frac{\Gamma/2}{W_R - W - i\Gamma/2}. \qquad (3)$$

The width was given an energy dependence proportional to phase space, normalized to unity at the resonance position. However, for such a narrow state, this detail is not important. For the background, we chose the form

$$T_{\rm BG} = K_{\rm BG}(1 - iK_{\rm BG})^{-1}, \qquad (4)$$

with $K_{\rm BG}$ proportional to $|T_{\rm res}|^2$, to have the greatest effect near the resonance. This additional background piece was added mainly to ensure sufficient flexibility in the parametrization. Parameters in the original SP92 fit were also searched in this study.

Data were analyzed with resonances covering a grid of (fixed) mass and width values, in order to see which values were favored [9] in a particular partial wave. From an initial scan with masses in the range between 1520 and 1560 MeV, with widths from 1 to 10 MeV, one feature was immediately obvious. The addition of states with widths above 5 MeV resulted in an enormous increase in χ^2, often more than doubling the χ^2/data found in a fit from threshold to $T_{\rm lab}$ =1.1 GeV (χ^2/data=3198/1746) for isoscalar waves, and threshold to $T_{\rm lab}$=2.65 GeV (χ^2/data=4872/3663) for isovector waves. The effect on χ^2 is illustrated in Fig. 1(a) for the

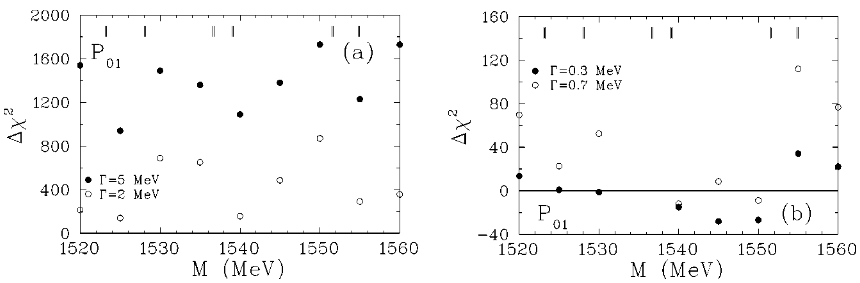

FIG. 1. Change of overall χ^2 due to insertion of a resonance into P_{01} for M=1520–1560 MeV with (a) Γ=2 and 5 MeV and (b) Γ=0.3 and 0.7 MeV, using KN plane wave approximation (PWA) [1]. Energies where measurements exist are labeled by vertical bars (for references, see Ref. [1]). In Fig. 1(b) the 1535-MeV values for $\Delta\chi^2$ are off scale.

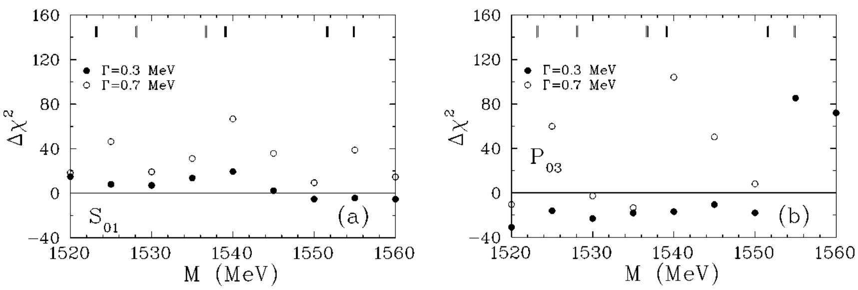

FIG. 2. Change of overall χ^2 due to insertion of a resonance into (a) S_{01} and (b) P_{03} for M =1520–1560 MeV with Γ=0.3 and 0.7 MeV using KN PWA [1]. Energies where measurements exist are labeled by vertical bars (for references, see Ref. [1]).

P_{01} partial wave. Similar results were found for other partial waves. This is in agreement with a claim by Nussinov [10], based on a lack of pronounced structure in the K^+d total cross section. In Ref. [10], the conservative estimate $\Gamma_{\Theta^+} < 6$ MeV was given. A limit of $\Gamma_{\Theta^+} < 9$ MeV was given in the ITEP bubble chamber measurements of Ref. [4].

We found no χ^2 improvement associated with the addition of resonances in the S, P, and D waves, unless the inserted structures had widths of order 1 MeV or less. However, for very narrow widths, a lack of data at energies corresponding to the Θ^+ was a limiting factor. (In our search for narrow N' states in the πN elastic scattering reaction, we found that it was generally possible to insert keV-width states, without serious effect, if they filled gaps in the database [9].) In Fig. 1(b), we again plot the change in χ^2 associated with resonances (in the P_{01} wave) having widths below 1 MeV. The location of available data is also indicated. Unfortunately, the Θ^+ mass, near 1545 MeV, falls in a data gap. As a result, we have little sensitivity to the Θ^+, if its width is much below an MeV. In Fig. 2, we show similar mappings for the S_{01} and P_{03} partial waves, also for the case of sub-MeV widths. The P_{01} plots have the most suggestive dips near the Θ^+ mass, but with such sparse data coverage this cannot be considered as definitive proof. Plots of isovector waves for the widths displayed in Figs. 1 and 2 show no regions of negative $\Delta\chi^2$.

In summary, based upon a reanalysis of the existing K^+N database, we find that Θ^+ widths beyond the few-MeV level are excluded, confirming a claim based on total cross section data [10]. The existence of a Θ^+ in the P_{01} state, with a width of an MeV or less, is possible. We see no evidence for a Θ^{++} in the existing K^+p scattering data. As the Θ^+ has been seen in both K^+n and K^0p mass distributions, our assumption of a state decaying solely to KN seems reasonable. However, a more definitive conclusion will have to await further measurements.

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