

# $K^+N$ scattering data and exotic $Z^+$ resonances

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## Abstract

Given the growing evidence for an exotic  $S=+1$  resonance, seen in kaon, photon and neutrino induced reactions, we reexamine the existing  $K^+p$  and  $K^+d$  database in order to understand how such a state could have been missed in previous studies. The lack of structure in this database implies a width of an MeV or less, assuming a state exists near 1540 MeV.

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## I. A BRIEF HISTORICAL PERSPECTIVE

Twenty years ago, many groups were involved in the study of unconventional states. The 1984 edition of the PDG review contains sections discussing  $Z_0$  and  $Z_1$  ( $I = 0, 1$ )  $K^+N$  resonances, as well as dibaryons ( $B=2$ ). The reported states had widths of 100 MeV or more and came to be understood as ‘pseudo-resonances’, structures arising from the coupling to inelastic channels ( $N\Delta$  in the case of dibaryons,  $K^*N$  and  $K\Delta$  in the case of  $Z$ -resonances).

Search the 2002 edition of the Review and you will only see mention of exotic baryonic states in an obscure Non-qqq section of the Note on  $N$  and  $\Delta$  resonances. In the area of dibaryons, most recent studies have focused on narrow states, as these cannot be so easily discounted as the broad states. The recently discovered  $Z$  resonance (now almost universally called the  $\Theta(1540)$ ) has generated great interest as it too is narrow, and the first determination of its mass and width (limit) agreed with a prediction of Diakonov, Petrov, and Polyakov [1].

## II. EVIDENCE FOR AN $S=+1$ STATE

Two types of experiments now exist. Those (recent) measurements claiming structures in their  $K^+n$  or  $K^0p$  mass distributions, and the (much older) experiments, mainly  $K^+p$  and  $K^+d$ , which existed prior to these measurements. Both may be valuable in understanding the  $\Theta$ .

### A. Recent experiments

Mass determinations for the  $\Theta$  have been very consistent, falling in the range  $1540 \pm 10$  MeV. Width determinations so far have given just upper limits, based on the experimental resolution. For the photon and neutrino induced results, the width limit [2] has been roughly  $\Gamma < 20$  MeV, while for the ITEP  $K^+Xe \rightarrow K^0pXe$  experiment, a limit of  $\Gamma < 9$  MeV was given [3].

## B. Hints from the $K^+p$ and $K^+d$ database

The  $K^+$  scattering database shows remarkably little evidence for a structure near 1540 MeV (corresponding to a lab momentum of 440 MeV/c). An examination of the  $K^+d$  total cross sections led Nussinov to place a limit [4] of  $\Gamma < 6$  MeV on the  $\Theta$  width. By re-analyzing the database, using the VPI KN PWA code, a tighter limit of 1-2 MeV has been claimed [5]. Haidenbauer and Krein have added a narrow  $I=0$   $J^P = \frac{1}{2}^+$   $\Theta(1540)$  to their KN meson-exchange model and conclude [6] that either the width must be considerably less than 5 MeV, or the resonance must lie much closer to threshold. All of these estimates are based on a general lack of structure at energies corresponding to the  $\Theta$ .

These remarks also apply to the  $\Theta^{++}$  which has been predicted to exist in order to have an isotensor  $\Theta$  [7] and an isospin-violating decay to KN, thus explaining the narrow width. No evidence is seen in the  $I=1$  total cross sections in the neighborhood of the  $\Theta^+$  energy.

## C. The Nussinov estimate reexamined

Somewhat tighter limits on the width can be obtained if the estimate of Nussinov is carefully examined. The limit  $\Gamma < 6$  MeV is based on there being 2-4 mb fluctuations in the  $K^+d$  total cross sections for energies corresponding to the  $\Theta(1540)$  mass. The measurements of Carroll and Bowen cover this region, and both have data near 440 MeV/c. Although there are normalization issues, the deviations from a linear behavior are certainly less than 1 mb in both cases. This alone reduces the Nussinov estimate to  $\Gamma < 1.5$  MeV. [Deviations of 2-4 mb *are* visible near 600 MeV/c].

Further corrections to the Nussinov estimate have been made by Cahn and Trilling [8]. These include the use of proper kinematic relations and a more realistic treatment of the deuteron. These modifications, together with an even more conservative limit on fluctuations (1.5 mb) lead to a width limit of less than an MeV.

## D. The Haidenbauer-Krein estimate

A simple consideration of Clebsch-Gordon coefficients shows that the effect of a narrow  $I=0$  resonance should be twice as large in the  $I=0$  total cross section, as compared to the

$K^+d$  total cross section. This is evident in the Haidenbauer-Krein plot of their model versus experimental data.

To be more realistic, however, the comparison between models and  $I=0$  data, extracted from  $K^+d$  scattering measurements, should be modified. The extraction process implicitly assumes there are no sharp structures in the underlying KN interactions. To compensate, it is therefore more reasonable to apply the broadening due to Fermi motion to the model result. This still allows a strong limit.

### III. KN PARTIAL-WAVE ANALYSIS

Our 1992 KN PWA analyzed both  $K^+p$  and  $K^+d$  data [9], finding broad counterclockwise motion in the  $P_{01}$ ,  $D_{03}$ ,  $P_{11}$ , and  $D_{15}$  Argand diagrams. No narrow structures were reported. In order to search for missing states, resonances with varying masses and widths were inserted into the S-, P-, and D-waves. These waves were then refitted to data, in order to see whether an improved description was possible.

For widths of 10 MeV or more, values in line with the resolution-limited estimates, the fit  $\chi^2$  in some cases doubled, even though the effect was localized and the fit extended to 1.1 GeV or 2.65 GeV, depending on the isospin. The fit remained worse until widths were reduced below the few MeV level, at which point a narrow structure could fall into data gaps, having little influence.

We also examined the  $\chi^2$  contributions due to experiments closest to the resonance position, as these values become more suspect for very narrow widths. Discounting these points, we continued to see no improvement in the fit to the remaining database.

One should note that this test would not be possible for a missing state above the inelastic threshold. In that case, as in the  $\pi N$  elastic scattering analysis, a missing state could be understood in terms of a small branching fraction to the elastic channel.

### IV. FUTURE WORK

If the  $\Theta(1540)$  exists and has a width of an MeV or less, future measurements will have to carefully address the problems associated with beam momentum uncertainty and spread, as well as Fermi motion if deuteron targets are used. The loss of meson beam facilities

(including the associated manpower, expertise, and infrastructure) will make this task more difficult.

It must be emphasized that we have only given upper limits to the  $\Theta$  width. It is not reasonable to calculate coupling constants and make predictions based on a fixed width of  $O(10 \text{ MeV})$ .

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