Possible ΣNN resonances in the ^{3}H(e,e′K$^+$) reaction

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Abstract. In a recent JLab ^{3}H(e,e'K$^+$) experiment a structure near the ΣNN threshold was observed, which was interpreted to be a T = 1 resonance. Using separable NN and $\Lambda N - \Sigma N$ potentials in the Faddeev equations, we demonstrate that it is possible that both T = 0 and T = 1 resonances may have been excited. Moreover, their pole positions, in our model calculation, are sufficiently close to one another that it is unlikely that these resonances in the ΣNN spectrum can be resolved.

1 Introduction

In a recent JLab experiment, in which the ^{3}H(e,e′K$^+$)Λnn reaction was exploited to investigate the existence of a threshold $^3_\Lambda$n resonance that would place constraints upon the Λn scattering length, a structure was observed in the spectrum near the ΣNN threshold that was interpreted to be a ΣNN resonance [1, 2]. Because the electromagnetic operator does not conserve isospin, such a ΣNN resonance could have isospin T = 0, 1, or 2. Garcilazo argued in 1987, on the basis of rank-one separable potentials, that no T = 2 ΣNN bound state or resonance should exist [3]. This agreed with the 1982 analysis of Dover and Gal [4]. Stadler *et al.* later demonstrated that there was little possibility of a T = 2 bound state or narrow resonance based upon the Jülich one-boson exchange potential [5]. This confirmed Garcilazo's result and demonstrated the usefulness of separable potential calculations regarding low-energy properties of three-body systems. However, continuum Faddeev-type calculations were needed to address the existence of T = 0 and T = 1 resonant states.

2 Past $\mathrm{T} = 0$ and $\mathrm{T} = 1$ Faddeev-type resonance results

In 1993 Afnan *et al.* found, while exploring Λd elastic scattering using a separable potential model for the NN interaction and the $\Lambda N - \Sigma N$ coupled channel interaction, that a near-threshold T = 0 ΣNN resonance could exist [6]. (These calculations were performed using a code initially developed for $^3_\Lambda$H bound-state calculations [7].) The position of the poles, on the second Riemann sheet of the complex energy plane, were determined by examining the eigenvalues of the kernel of the Faddeev equations using contour rotation methodology. Four different $\Lambda N - \Sigma N$ potential models were explored; here we consider only the TGE-*B* model

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[8] result. The T = 3/2 ΣN interaction was constructed to fit the Nijmegen 1989 effective range parameters [9].

The pole position for this T = 0 resonance is

$$75.5 - 8.34i \text{ MeV},$$

which lies near the ΣNN model threshold at 77 MeV. [The thresholds due to the different masses of the (Σ^-, Σ^0, Σ^+) triplet were not distinguished in this model calculation.]

A decade later Garcilazo *et al.* utilized a separable potential approximation to a chiral constituent quark model of the hyperon-nucleon interaction to explore Λd and Σd scattering [10]. They concluded that the T = 0 and T = 1 spin-1/2 channels of the ΣNN system were the only channels exhibiting attraction. By examining the Fredholm determinant for the ΣNN system, they concluded that only the T = 1 channel was sufficiently attractive to support a near-threhsold resonance. Presumably, had they explored a larger energy range for the T = 0 channel, they would have found a resonance in that channel, also.

3 Additional ΣNN resonance information

In 1992 Barakat *et al.* reported a null result in a ^{3}He(K$^-$,π^+) in-flight K$^-$ experimental search at BNL (Brookhaven National Laboratory) for a $\Sigma^- np$ resonance [11]. This was motivated by the ^{4}He(K$^-$,π^-) at-rest experiment performed with K$^-$ stopping in a He bubble chamber [12] and later in-flight ^{4}He(K$^-$,$\pi^\pm$) experiments [13]. That is, a $^4_\Sigma$He state was observed by Hayano *et al.*

In 2014 Harada *et al.* performed a distorted wave impulse approximation calculation that agreed with the BNL ^{3}He(K$^-$,π^+) result of no resonance [14]. However, their model results indicated that one should see a T = 1 resonance in the conjugate ^{3}He(K$^-$,π^-) reaction.

Thus, various theoretical calculations have provided indications that T = 0 and T = 1 resonances could be seen in the ΣNN spectrum. In terms of charge states, the $\Sigma^- nn$ system, having the lowest threshold, was suggested to be the most likely candidate in the recently reported ^{3}H(e,e$'$K$^+$) reaction [1].

4 Recent Faddeev results

As noted above, an s-wave separable potential ΣNN T = 0 pole was found in Ref.[6]. The pole position is

$$75.5 - 8.34i \text{ MeV},$$

which lies below the ΣNN model threshold of 77 MeV. In the Garcilazo *et al.* separable potential approximation to the chiral quark model, the T = 0 channel was found to be attractive but not sufficiently so as to support a pole near the ΣNN threshold. This difference with our calculation provides an indication of the model dependence in the system.

We have now extended our Faddeev separable potential calculation to search for the T = 1 pole position in our model. We find that pole position to be

$$76.9 - 6.44i \text{ MeV},$$

which lies closer to the ΣNN threshold than does our T = 0 pole.

The Garcilazo *et al.* model can be considered to be more sophisticated than our s-wave separable potential model in that it includes a tensor force in both the NN and YN interactions. We, therefore, extended our model to include an NN tensor force. The T = 0 pole is essentially unaffected, as one would anticipate. The T = 1 pole moved slightly closer to the ΣNN threshold. We note that in our calculation we also allowed for $L = 2$ for the spectator particle when two-body tensor interactions are included. In Ref.[10] only $L = 0$ for the spectator particle was included.

Thus, in our TGE-B model calculation we find both a T = 0 and a T = 1 pole in the ΣNN spectrum, poles that are rather close to one another in position and have similar widths. Our results agree qualitatively with those of Ref.[10] and Ref.[14] for the T = 1 resonance.

5 Summary

The primary conclusions from our model calculations are (*i*) that one may see both a T = 0 resonance as well as a T = 1 resonance in the ^{3}H(e,e$'$K$^+$)ΣNN spectrum near the ΣNN threshold and (*ii*) that the two resonances in our model reside too close to one another to be easily resolved experimentally.

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