 Possible $\Sigma NN$ resonances in the $^3\text{H}(e,e'K^+)$ reaction

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Abstract. In a recent JLab $^3\text{H}(e,e'K^+)$ experiment a structure near the $\Sigma NN$ 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 $\Sigma NN$ spectrum can be resolved.

1 Introduction

In a recent JLab $^3\text{H}(e,e'K^+)$ experiment, in which the $^3\text{H}(e,e'K^+)\Lambda nn$ reaction was exploited to investigate the existence of a threshold $^3\Lambda n$ resonance that would place constraints upon the $\Lambda n$ scattering length, a structure was observed in the spectrum near the $\Sigma NN$ threshold that was interpreted to be a $\Sigma NN$ resonance [1, 2]. Because the electromagnetic operator does not conserve isospin, such a $\Sigma NN$ resonance could have isospin $T=0$, 1, or 2. Garcilazo argued in 1987, on the basis of rank-one separable potentials, that no $T=2$ $\Sigma NN$ 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 $T=0$ and $T=1$ Faddeev-type resonance results

In 1993 Afnan et al. found, while exploring $\Lambda d$ elastic scattering using a separable potential model for the $NN$ interaction and the $\Lambda N-\Sigma N$ coupled channel interaction, that a near-threshold $T=0$ $\Sigma NN$ 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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result. The $T = 3/2 \Sigma N$ 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 $\Sigma NN$ model threshold at 77 MeV. [The thresholds due to the different masses of the $(\Sigma^-, \Sigma^0, \Sigma^+)$ 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 $\Lambda d$ and $\Sigma d$ scattering [10]. They concluded that the $T = 0$ and $T = 1$ spin-$1/2$ channels of the $\Sigma NN$ system were the only channels exhibiting attraction. By examining the Fredholm determinant for the $\Sigma NN$ system, they concluded that only the $T = 1$ channel was sufficiently attractive to support a near-threshold 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 $\Sigma NN$ resonance information

In 1992 Barakat et al. reported a null result in a $^3\text{He}(K^- \pi^+)$ in-flight $K^-$ experimental search at BNL (Brookhaven National Laboratory) for a $\Sigma^- np$ resonance [11]. This was motivated by the $^4\text{He}(K^- \pi^-)$ at-rest experiment performed with $K^-$ stopping in a He bubble chamber [12] and later in-flight $^4\text{He}(K^- \pi^\pm)$ experiments [13]. That is, a $^4\Sigma^\pm$ 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 $^3\text{He}(K^- \pi^+)$ result of no resonance [14]. However, their model results indicated that one should see a $T = 1$ resonance in the conjugate $^3\text{He}(K^- \pi^-)$ reaction.

Thus, various theoretical calculations have provided indications that $T = 0$ and $T = 1$ resonances could be seen in the $\Sigma NN$ 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 $^3\text{H}(e,e'K^\pm)$ reaction [1].

### 4 Recent Faddeev results

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

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

which lies below the $\Sigma NN$ 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 $\Sigma NN$ 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 $\Sigma NN$ 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 \( \Sigma NN \) 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 \( \Sigma NN \) 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 \( ^3\text{He},e'e'K^+\Sigma NN \) spectrum near the \( \Sigma NN \) 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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References