NEXT-TO-LEADING ORDER CONSIDERATIONS IN ANALYSIS OF η-NUCLEUS INTERACTION* **

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Next-to-leading order corrections to using Watson final-state interaction theory to extract η-nucleus scattering length from measurements are discussed. For certain classes of η-nucleus reactions, the need to take into account interference effects due to the presence of two competing processes is also elucidated.

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1. Introduction

The strong interest in eta (η) meson, one of the topics of this symposium, arose from the prediction of the existence of eta-mesic nucleus [1, 2]. Unlike the captures of $\pi^{\pm}$ and $K^{\pm}$ by a nucleus, the formation of an η-mesic nucleus is free from the electromagnetic interaction. However, this charge neutrality of the η makes it very difficult to produce a high-flux η beam in the laboratory. To overcome this handicap, researchers are attempting to use final-state interaction to unravel information about η-nucleus interaction. In Section 2, we will discuss possible next-order corrections to this approach.

Furthermore, because a bound η cannot exit from the nucleus as a free (*i.e.* a physical) η, the detection of η-mesic nuclei must be carried out by measuring other relevant particles. One such successful experiment is the

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COSY-GEM experiment [3] in which the particles π^-, p, ^{3}He were measured in triple coincidence in the reaction $p+\ ^{27}\mathrm{Al}\ (\rightarrow\ ^3\mathrm{He}+\ ^{25}\mathrm{Mg}_\eta) \rightarrow \pi^- + p +\ ^3\mathrm{He} + X$, with X denoting the unmeasured particles. The 'missing energy' was then calculated and the binding energy of η in ^{25}Mg was obtained. We will discuss in Section 3 how the current experimental error bars make it necessary to take into account corrections to the leading-order calculation.

There are many other next-to-leading order corrections in η-nucleus physics. Discussing all of them is beyond the scope of the present short note and will, therefore, be given elsewhere.

2. Final-state interaction

The final-state interaction (FSI) approach is particularly useful to extract information on particles that cannot be readily made available as beams in the laboratory. For example, the interaction

$$\pi + N \rightarrow \pi + \pi + N \tag{1}$$

has been used in the literature to extract the $\pi\pi$ interaction by means of FSI.

In Watson's FSI formulation, the s-wave T matrix of the transition from the initial state (denoted by 'i') to the final state (denoted by 'f') is given by

$$T_{\mathrm{fi}} \simeq c\, \mathcal{T}_{\mathrm{fi}} f(k)\,, \tag{2}$$

where c is a constant, $\mathcal{T}_{\mathrm{fi}}$ is the transition matrix without the presence of FSI, and $f(k)$ is the s-wave FSI amplitude. Near the threshold of the final state,

$$f(k) = \frac{1}{1/a - ik} \tag{3}$$

with a and k being, respectively, the scattering length and the channel momentum of the final state. Equations (2) and (3) were employed in Refs. [4–6] to extract the η-^{3,4}He scattering lengths from the data of the reactions

$$p + d \rightarrow\ ^3\mathrm{He} + \eta \tag{4}$$

and

$$d + d \rightarrow\ ^4\mathrm{He} + \eta\,. \tag{5}$$

We would like to mention that Joachain [7] has shown that Eq. (2) is a result of neglecting all the "intermediate" channels that are allowed by energy conservation. We have also noted that with the inclusion of intermediate channels, the simple algebraic product $\mathcal{T}_{\mathrm{fi}} f(k)$ in Eq. (2) will be replaced by a corresponding matrix product.

To this end, we mention that in reactions denoted by Eqs. (4) and (5), the intermediate channels π^3He and π^4He are, respectively, allowed by energy conservation. Because their coupling to the η-channel is not small, we suggest that the effects of these intermediate channels be investigated.

3. Interference effects on the measured η binding energy spectrum

In our analysis [8] of the COSY-GEM experiment [3], we showed the important interference effects between the amplitude due to the formation of η-bound state (which we denote $f_{\rm bd}$) and the amplitude due to η-nucleus scattering without the formation of bound state (which we denote $f_{\rm sc}$) [8]. The "existence" of these two processes arises from the fact that the experiment could not differentiate them because the experimental energy resolution of the binding energy $|E|$ was about 5 MeV, nearly the same as the binding energy of η in ^{25}Mg.

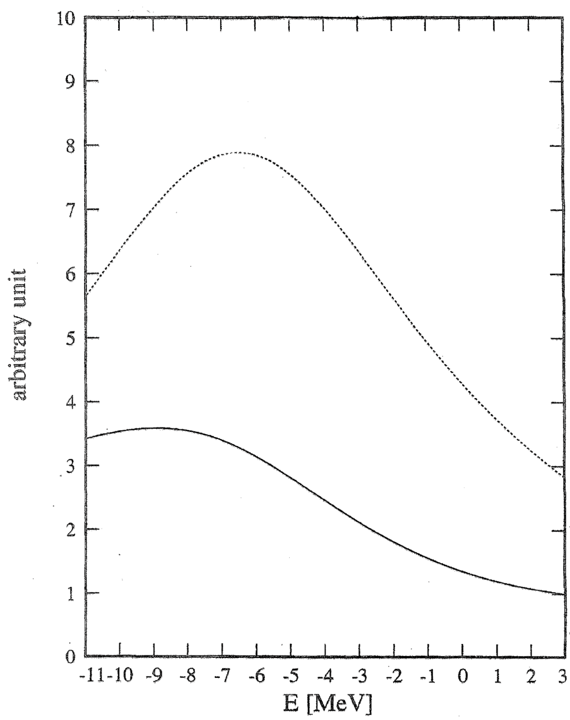

Fig. 1. The spectra of E of η bound in ^{25}Mg, calculated with $f_{\rm bd}$ only (dashed curve) and with $f_{\rm bd} + f_{\rm sc}$ (solid curve).

In this note we further show that this interference effect is nucleus-dependent. To illustrate more clearly this dependence, we omit the N^*–nucleus interaction discussed in Ref. [8]. In Fig. 1, we show the effect of interference on the observed binding-energy spectrum of η bound in ^{25}Mg in the COSY-GEM experiment discussed in Section 1. In Fig. 2, we show the effect on the binding-energy spectrum of η bound in ^{14}N, resulted from the hypothetical reaction $p + {}^{16}\mathrm{O} \to {}^{3}\mathrm{He} + {}^{14}\mathrm{N}_{\eta} \to \pi^- + p + {}^{3}\mathrm{He} + X$ (X is not measured). From Fig. 1 one sees that the interference enhances the apparent binding in ^{25}Mg, causing E to change from -6.5 MeV to -9.5 MeV. However, Fig. 2 shows that the interference weakens the apparent binding in ^{14}N, causing E to change from -2.6 MeV to -1.7 MeV. This nucleus-dependence is mainly related to the different dependences of the amplitudes f_{bd} *versus* f_{sc} on the nuclear mass number.

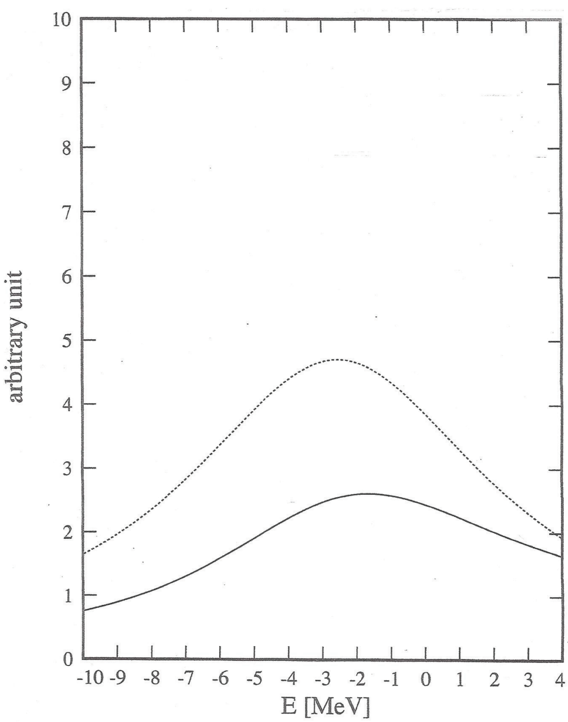

Fig. 2. The spectra of E of η bound in ^{14}N, calculated with f_{bd} only (dashed curve) and with $f_{\mathrm{bd}} + f_{\mathrm{sc}}$ (solid curve).

At this point, we would like to mention that similar interference between processes involving, respectively, bound and unbound η might equally occur in using FSI to infer the η-nucleus scattering length. We recall that in experiments of Refs. [5] and [6], the energy resolution of the recoiled nuclei is of the order of MeVs which is comparable to, or greater than the magnitude of the calculated binding energies of η in He (if such binding does exist). Hence, the measured data may well contain both data from η scattering and from the decay of bound η.

Another method of identifying a physical η in the final state is to measure the 2-pion decay branch of the η [9] and then determine the η-nucleus scattering length from the experiment. However, one still needs to ascertain that the energy resolution of the 2π-measurement is much smaller than the expected η binding energy.

4. Summary

We have pointed out two types of next-to-leading order considerations to be included in the analysis of η-nucleus data. One type is due to the limitation of experimental resolution and, hence, will become unimportant when energy resolution is improved. The other type comes from the existence of intermediate π channels coupling strongly to the η channel. The existence of these intermediate physical channels is independent of the accuracy of the experimental energy resolution. Hence, investigating its effect on FSI with the use of a generalized Watson theory is important.

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