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Halo Effective Field Theory of ^{6}He

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Abstract. ^{6}He has a cluster structure with a tight ^{4}He (α) core surrounded by two loosely bound neutrons (n) making it a halo nucleus. The leading-order (LO) Halo Effective Field Theory (EFT) [1, 2] calculations using momentum-space Faddeev equations pertinent to a bound ^{6}He were carried out in [3]. In this work, we investigate ^{6}He up to next-to-leading order (NLO) within Halo EFT.

1 Introduction

In halo nuclei, the valence nucleon distribution extends much further out relative to the size of the tightly bound core. The cluster structure of ^{6}He exhibits separation of scales and is suitable for a Halo EFT treatment [1, 2]. ^{6}He constitutes a Borromean three-body system, i.e., no two of the three bodies bind independently, but all three together can form a bound state.

2 Three-body formalism

The valence neutrons of ^{6}He interact with the α-core predominantly through a p-wave ($^2P_{3/2}$) resonance while the interaction between the two neutrons is in the relative $^1S_0$ partial wave. The three-body t-matrix for the scattering (unphysical) of a neutron off the $n\alpha$ pair can be represented as a set of Feynman diagrams shown in figure 1. In [3], the authors find that a three-body input is required for

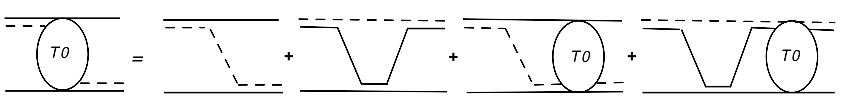

Figure 1. Integral equation for the LO three-body t-matrix. The binding of ^{6}He is represented as the pole of this t-matrix at negative energy. Solid (Dashed) line represents neutron (α). Double solid line (Solid and dashed) line represents LO nn ($n\alpha$) dimer propagator.

a consistent renormalization of the LO integral equation. (Cf. the calculation in a different Halo EFT power counting of Ref. [4].) After introducing a three-body force, they show that the renormalized

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LO Faddeev components F_n and F_α are cutoff independent for large cutoffs. The Faddeev component F_n (or equivalently $T0$) will serve as an input to the NLO three-body t-matrix as shown in figure 2. Therefore, having an approximate analytic form of $F_n(q)$ will be useful for the NLO calculations. We provide an analytic fit that closely resembles the actual F_n at large q and can be represented as

$$F_n(q) \cong 945\frac{1}{q^{0.49}} \times \cos(0.925q^{0.088}\ln(q) + 0.15). \tag{1}$$

3 NLO calculations

The NLO piece of the ${}^1S_0$ nn dimer propagator, the NLO piece of the ${}^2P_{3/2}$ $n\alpha$ dimer propagator and the contact $n\alpha$ vertex in the ${}^2S_{1/2}$ channel enter the NLO three-body amplitude, $T1$, for the $nn\alpha$ system. $T1$ can be represented diagrammatically as shown in figure 2. We have investigated

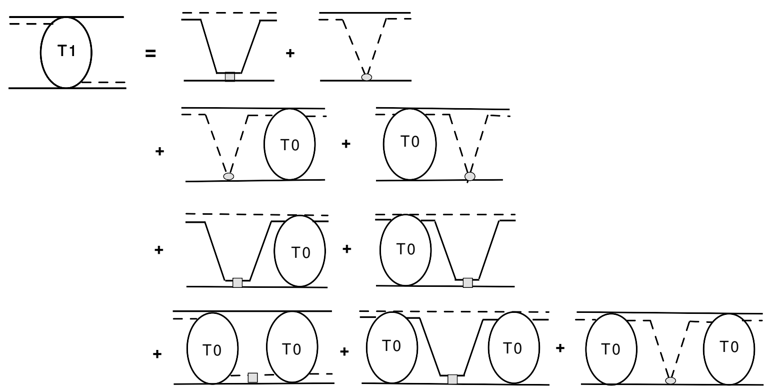

Figure 2. Diagrams that contribute to the NLO three-body t-matrix. Solid (Dashed) line represents neutron (α). Double solid line (Solid and dashed) line represents nn ($n\alpha$) dimer. Propagators with gray squares represent the NLO pieces of the nn and $n\alpha$ dimers respectively. The gray ovals represent the ${}^2S_{1/2}$ $n\alpha$ vertex.

the divergences associated with each of the above NLO diagrams. The last three diagrams have the highest degree of divergence, and are the only ones relevant when considering NLO contributions in the bound-state problem. We will renormalize these diagrams using an NLO three-body $nn\alpha$-counterterm. With the renormalized result in hand, we will study the NLO Faddeev components and investigate how the NLO corrections affect the ^{6}He radii. Finally, we will also explore the role of the ${}^2P_{1/2}$ channel of the $n\alpha$ interaction in the binding of ^{6}He.

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