Mapping the tower of nuclear effective field theory

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Abstract

This PhD project aims to advance nuclear physics in two primary areas. First, it seeks to validate nuclear Hamiltonians developed via Effective Field Theories (EFTs), evaluating their ability to systematically model nuclear structure and reactions across the nuclear chart. Second, it will investigate the hierarchical structure of EFTs by linking high-resolution EFT Hamiltonians to lower-resolution models. This bridging effort aims to connect fundamental nuclear forces to mean-field, offering a constructive framework for accurately modeling nuclear structure, even in heavy-mass systems, based on foundational theories. Expected outcomes include new insights and improvements to state-of-the-art parametrizations for multi-body nuclear observables.

Nuclear physics is entering an era where many-body methods, particularly *ab initio* approaches that begin with protons and neutrons as the fundamental constituents, have advanced to such a degree that their accuracy is now primarily constrained by uncertainties in the effective Hamiltonian itself. Nuclear EFT methods are now the state-of-the-art tool for nuclear physicists, allowing them to derive the interactions between these constituents while bypassing the ”complexities” of the non-perturbative low-energy QCD regime. These methods rely on a data-driven approach to capture the behavior of nucleons at the relevant momentum scales of the nuclear binding energy. However, the current power counting schemes are approaching their limitations, and it may soon be necessary to rely on a more hierarchical, tower of EFTs to accurately describe nuclear phenomenology.

Nuclear data repositories already contain a wealth of scattering observables that probe various degrees of freedom across a wide range of momentum scales of the incoming hadron beam. These datasets have been meticulously analyzed by evaluators for decades, and accurate interpretations using the R-matrix formalism (or plentful of others) for non-overlapping resonant scattering have flourished. However, very little is known about the systematic application of EFT postulates to scattering systems across the full range of available data. The advantage of this approach is that it allows for the clear identification of the relevant fields of the problem and the construction of a systematically improvable Lagrangian. If the theory reaches the limits of its validity, it will collapse in a controlled manner, signaling the emergence of a new degree of freedom.

The goal of this internship is to address the current gap in the systematic interpretation of low-energy nuclear data using EFT in its simplest form, which involves a cluster-neutron (or other impinging hadron) interaction. Practically, this means solving the scattering problem with an effective two-body Hamiltonian and extracting, through a fit to global data, the systematic evolution of the theory's low-energy constants across the nuclear chart. This approach will enable the study of the evolution of cluster EFT across the nuclear chart, recover regions of established phenomenology, and extend the frontier of early attempts to model the nuclear continuum.

Upon continuation into a PhD program, the knowledge gained during the internship will prove invaluable. We aim to push the frontier in two directions. First, the tools developed in the internship can be used to generate families of accurate Hamiltonians based on NN data. The *ab initio* tools developed at CEA will allow us to validate, refine, or reject certain Hamiltonians, clarifying which subsets are capable of accurately reproducing many-body physics and improving control over calculations. Second, we plan to explore the tower of EFTs. By starting from protons and neutrons, we can apply the powerful concept of EFT matching, where different EFTs are systematically connected, beginning with more fundamental theories and progressing towards simplified versions. Ultimately, we hypothesize that this analysis will help establish a link to the nuclear mean field, where nucleonic degrees of freedom coalesce into an independent set organized by an everage potential (mean-field).