Cluster effective field theory applied to light nuclear systems

UNIVERSIDAD NACIONAL DE COLOMBIA

Ayda Bernal · Juliana Prada · Joel Bernal

Director: Carolina Pinilla

Grupo de Física Nuclear UN

Abstract

Cluster effective field theories (EFTs) offer a systematic, first-principles framework for deriving nuclear potentials from fundamental symmetries, enabling prediction rather than phenomenological fitting of nuclear observables. We apply cluster EFT to light nuclei to obtain non-local leading-order (LO) potentials, solve the two-body Schrödinger equation for bound and scattering states, and calculate structure and elastic-scattering observables.

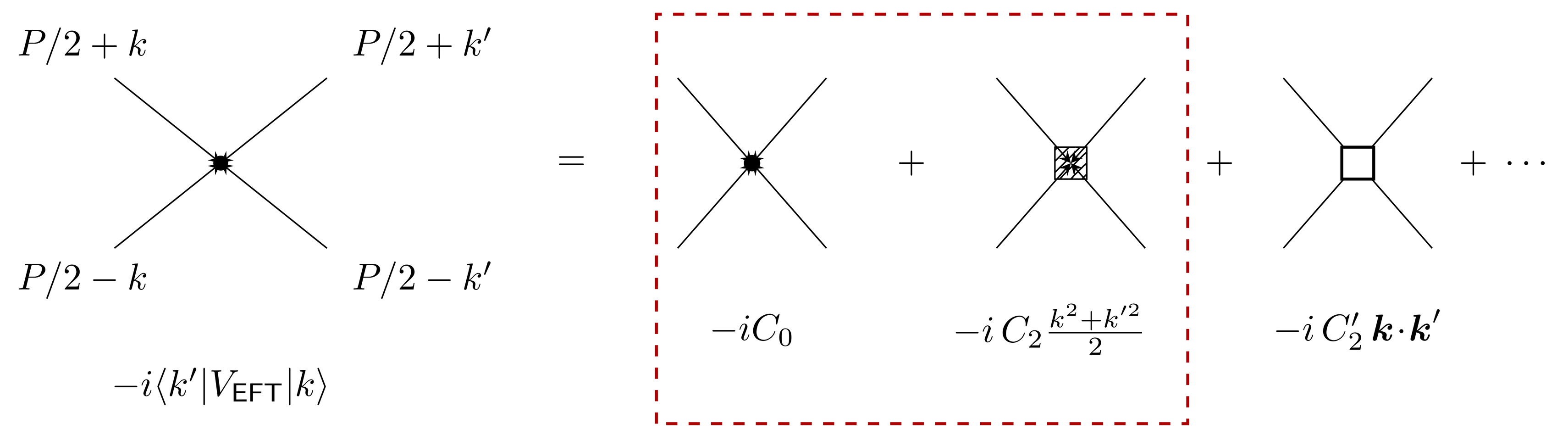
Nuclear EFT potential

The EFT Lagrangian density with the most general local interactions is

$$\mathcal{L}_{\text{eft}} = -\frac{C_0}{2}(\psi^\dagger\psi)^2 + \frac{C_2}{16}\left[(\psi\psi)^\dagger\left(\psi\,\overleftrightarrow{\nabla}^2\,\psi\right) + \text{h.c.}\right] + \frac{C_{2'}}{8}\left(\psi\,\overleftrightarrow{\nabla}\,\psi\right)^\dagger\cdot\left(\psi\,\overleftrightarrow{\nabla}\,\psi\right),$$

where C_i are the Low Energy Constants (LECs).

In momentum space



LO

$|a| \gg R \sim$ Unnatural case

Expanding in partial waves

$$V_l(k,k') = \left[\sum_{i,j=0}^{1} k^{2i}\lambda_{ij}^{(l)}k'^{2j}\right]k^l k'^l g(k)g(k'),$$

where $g(k)$ is the momentum-regulator function.

This is the most general non-relativistic two-body effective potential.

Relating theory with observables

Bound states are determined by their energies and asymptotic normalization coefficients (ANCs), while scattering ones are defined by their phase shifts as they store all the information about the nuclear interaction in the scattering state. They do not only retain information about the potential, but also act as a bridge between our theory and the observables, which store the real-life physics.

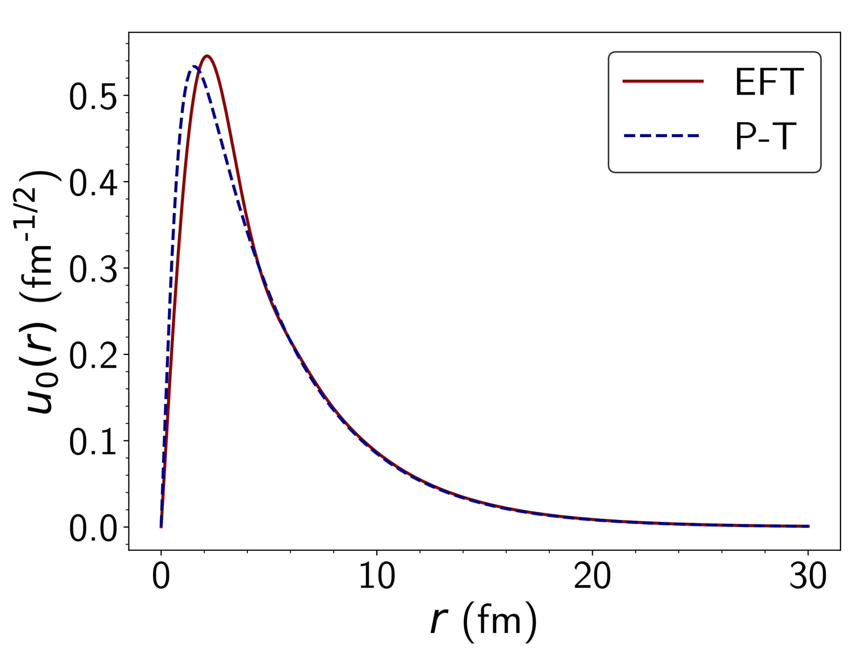
Elastic scattering $$\frac{d\sigma}{d\Omega} = \left|\frac{1}{2ik}\sum_{l=0}^{\infty}(2l+1)P_l(\cos\theta)\left(e^{2i\delta}-1\right)\right|^2.$$

Electric transitions $$\frac{dB(E\lambda)}{dE} = \frac{2l_f+1}{2l_i+1}\frac{\mu k}{(2\pi)^3\hbar^2}\left|\left\langle\varphi_{l_f,k}\,\middle\|\,\mathcal{M}(E\lambda)\,\middle\|\,\varphi_{l_i}\right\rangle\right|^2.$$

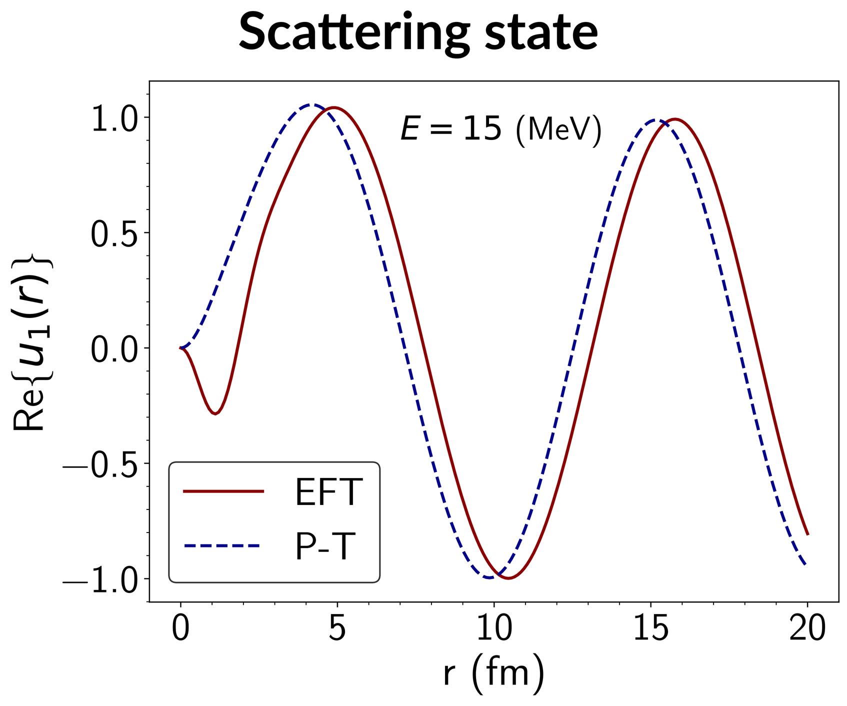
n+p system

EFT calculations were compared against local ones that made use of a Pösch-Teller (P-T) nuclear potential model [1].

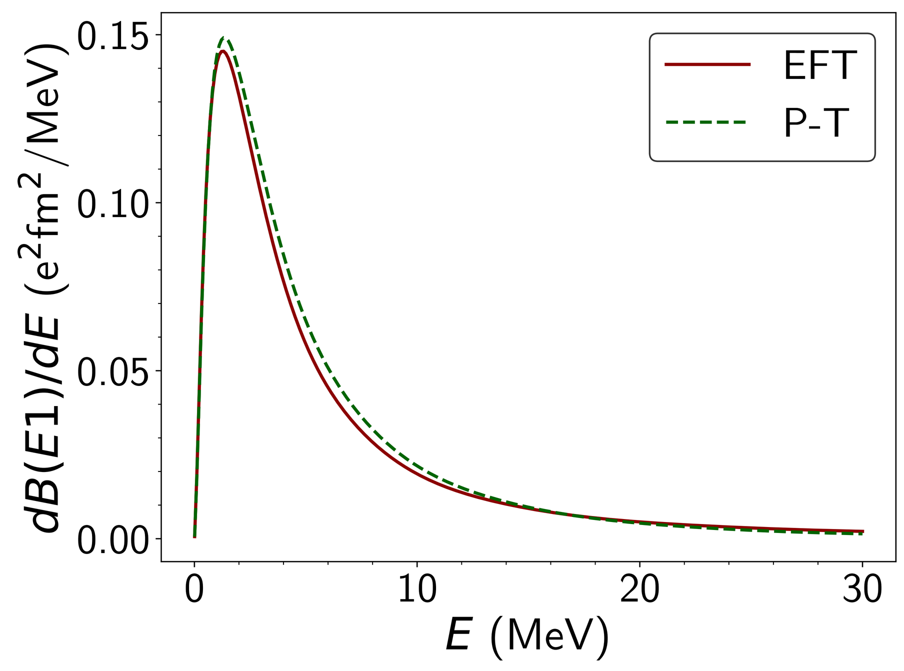
Ground state



Scattering state



Dipole strenght functions



Observables

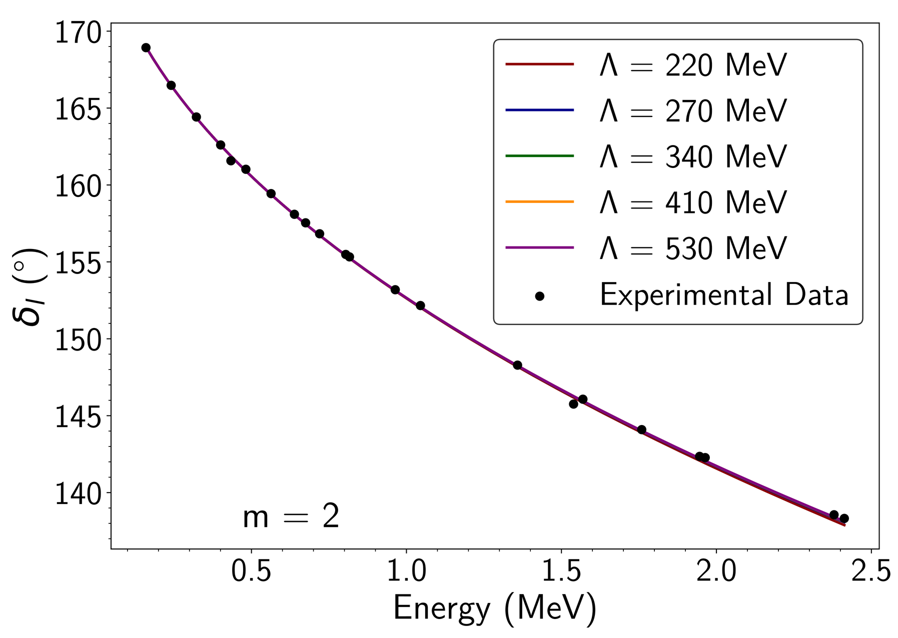
	EFT	P-T
$E_{\text{g.s.}}$(MeV)	−2.19	−2.22
r_{rms}(fm)	3.93	3.82
ANC (fm$^{-1/2}$)	0.861	0.862
$B(E1)$(e^{2}fm^2)	0.85	0.87

α-n system

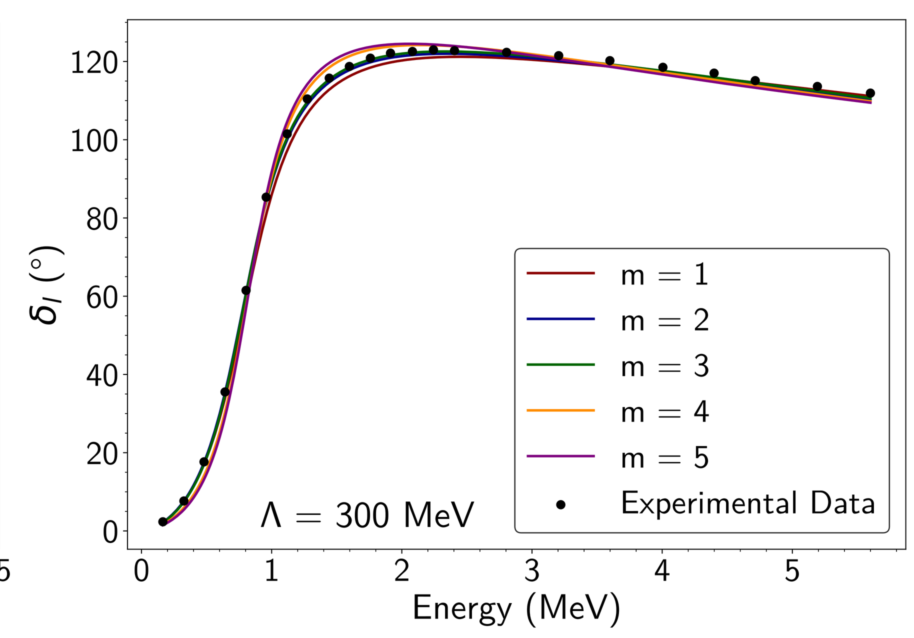
Phase shifts

EFT calculations were compared with experimental phase shifts extracted from total cross sections in [2].

S-Wave



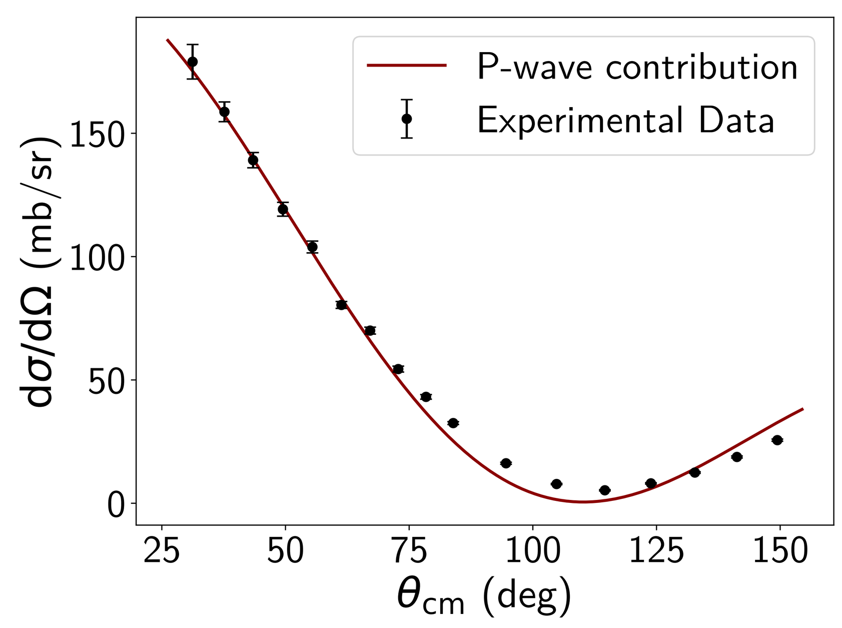
P-Wave



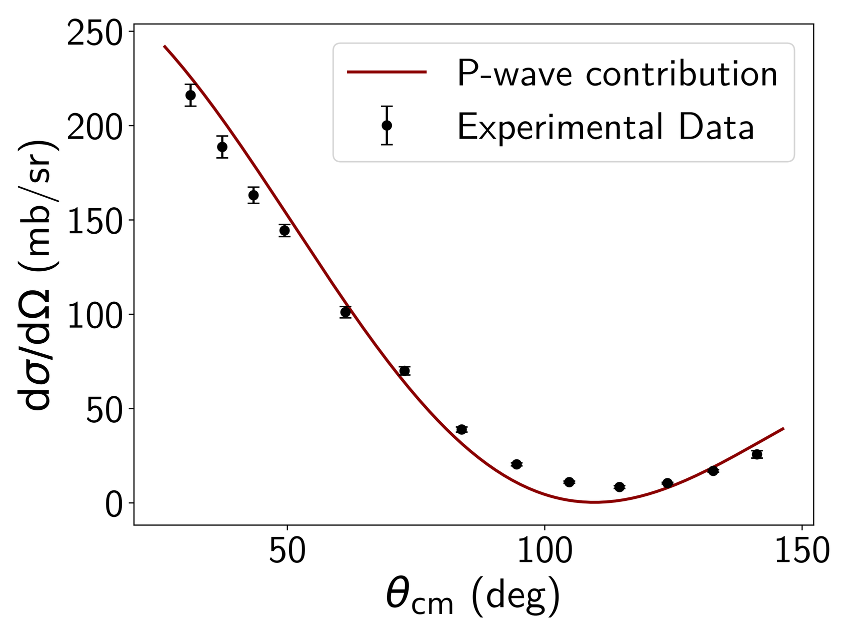
Elastic angular distribution

EFT calculations were compared with experimental data obtained from [3] available in the EXFOR database.

E_{lab} = 20.97 (MeV)



E_{lab} = 17.6 (MeV)



Ongoing and future work

Several aspects of the research remain to be explored, as outlined below.

1. Extension of Cluster EFT to Next-to-Leading Order (NLO).
2. Assessment of theoretical limits through the study of heavier nuclear systems.
3. Incorporation of Coulomb interactions into the EFT Hamiltonian.
4. Analysis of the tritium system and calculation of the astrophysical S-Factor.
5. Ab initio determination of Effective Range Parameters (ERPs).

References

[1] J. A. Lay et al., Phys. Rev. C 82, 24605 (2010).

[2] R. A. Arndt and L. D. Roper, Phys. Rev. C 1, 903 (1970)

[3] J. Seagrave et al., Ann. Phys. 74, 250 (1972)