ESNT

Effective Field theory and Strong interaction with accurate error estimation

Lundi 8 au vendredi 26 avril 2024

Bât 703, room 135 DPhN CEA Saclay, Orme des Merisiers

https://esnt.cea.fr/Phocea/Page/index.php?id=118

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Monday 8th - **Martin Schäfer** *(Nuclear Physics Institute of the Czech Academy of Sciences)*
Opening and relevant physical problems -Introduction on EFTs

[14h] Ubirajara van Kolck *(European Centre for Theoretical Studies in Nuclear Physics and Related Areas -ECT*)*
Why EFT should not be Escoffier's veal in your nuclear cooking

[15h] Lorenzo Contessi *(IJCLab)*
Towards the description of larger systems with renormalizable EFTs

Tuesday 9th [14h15] Mirko Bagnarol *(The Racah Institute of Physics)*
Five-body calculation of n-4 He scattering at next-to-leading order π/ EFT

Wednesday 10th
[11h] Mehdi Drissi *(Dpt of Physics, TRIUMF)*
Accelerating Variational Monte Carlo calculations with decision geometry

[14h15] Tafat Weiss-Attia *(The Racah Institute of Physics)*
Perturbative application of next-to-leading order pionless EFT for $A \leq 3$ nuclei in a finite volume

Thursday [14h15] Andrea di Donna *(Universitá degli studi di Trento)*
Neural quantum states for hypernuclear systems with contact theories

Friday [14h15] Johannes Kirscher *(Department of Physics, SRM University)*
The 4-body coupled-channel problem with zero-range interactions

ESNT working group 13-26 April

SCIENTIFIC ISSUE

Effective Field Theories (EFTs) changed significantly the design and development of nuclear interactions. These theories are constructed in orders of decreasing importance, allowing for the use of a limited number of operators and reduced complexity to achieve the desired level of precision in nuclear predictions. Nowadays, EFTs have become increasingly sophisticated, often performing with the same or even better accuracy than realistic models that rely on dozens of phenomenological parameters [1]. Furthermore, EFTs provide a systematic path for improvement and a means of estimating theoretical uncertainty. These two qualities are growing in importance in nuclear applications, as well as in related areas such as nuclear astrophysics and beyond standard model studies. Here the uncertainty associated with the nuclear interactions cannot be ignored and the ability to quantify the precision of nuclear predictions is crucial for obtaining meaningful results (see, e.g., Ref [2]).

However, only properly renormalizable EFTs can rigorously justify theoretical errors [3], while non renormalizable theories can only offer rough and a-posteriori estimations, such as Bayesian analysis [4]. This limitation arises from the fact that non-renormalizable theories lack a clear asymptotic realization (e.g., in terms of a large, approaching infinity, cut-off), which can lead to the creation of different versions of the same interaction at the same order, not all of which are equivalent. This proliferation of many 'similar' EFTs at each order makes comparisons challenging.

On the other hand, renormalizable EFTs provide a clear roadmap for improvement and error control. The flexibility in defining the theory, such as adjusting the cut-off or regulator, can be advantageous because any realization is equivalent. However, renormalizable EFTs present a challenge: the first-order interaction may not precisely reproduce physical observables. In particular, it has been observed that mixed symmetry bound states, such as bound states of multiple fermions, cannot be accurately described at the leading order (LO) by renormalizable contact EFTs [5–8] and similarly in EFT with perturbatively included pions [9]. This outcome does not hinder the theory's convergence, and such states can be recovered by including subleading orders of the interaction. However, to maintain the order by-order renormalizability, subleading contributions must be incorporated into perturbation theory.

This problem raises a practical question: how to apply perturbations to unbound states in systems composed of multiple particles? Furthermore, many-body methods are not designed for use within a perturbative scheme and are better suited for non-perturbative calculations. Therefore, until now, perturbative theories have not been realistically applicable for practical calculations, and only the non-renormalizable version of the theory has been employed.

Over the past year, at IJCLab, a new method to address this challenge has been developed. This method involves the controlled improvement of the LO interaction to effectively include subleading contributions order by order. The technique is known as the 'improved action method' and has been adapted from the high-energy physics community, where a similar approach is used to expedite the convergence of lattice calculations [10]. This method maintains the properties of renormalizable EFTs but establishes a way to incorporate subleading contributions non-perturbatively, making it easier to leverage the many-body methods available in the field.

The novel approach has the potential to combine rigorous error control with practicality. The method has already been tested in the two-body nuclear sector and in few-body atomic systems, yielding promising results. Our collaborative group is keen to further explore its applicability in larger systems and at higher orders of the interaction. Since the requirement to be equivalent to the standard formulation of renormalizable EFT necessitates extensive benchmarking and demands both theoretical and numerical expertise, this task is far from trivial. Achieving this goal can only be realized through close collaboration among experts in the field and the establishment of a robust network to develop the various facets of the method.

Goals

In the last years, several researchers started to work in the direction of developing renormalizable EFTs to be applied in realistic calculations beyond the leading order and their application to few-body systems. Finite nuclei, nuclear reactions, nuclear matter, hypernuclei, and lattice-nuclear-physics [11–15] are only a few of the fields that are interested and might be touched by the improved action technology. The proposed working group aims to connect the researchers engaged in this direction.

The goals of the project include:

- Defining the current state of the field.
- Establishing a standardized framework for defining interactions to ensure consistency in theories.
- Developing a subleading power counting scheme applicable to both few- and many-body systems.
- Building a pool of expertise for fitting and testing interactions in realistic systems.
- Defining task assignments and achievable collaboration milestones.
- Promoting the exchange of technologies and expertise to provide a comprehensive understanding of the project and its subcomponents for all participants.

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Summary of the talks

Monday 8th

Martin Schäfer *(Nuclear Physics Institute of the Czech Academy of Sciences)*
Opening and relevant physical problems -Introduction on EFTs

[14h] Ubirajara van Kolck *(European Centre for Theoretical Studies in Nuclear Physics and Related Areas - ECT*)*
Why EFT should not be Escoffier's veal in your nuclear cooking
In modern nuclear physics, often the framework of effective field theories (EFTs) is invoked in the derivation of potentials and currents only to be subsequently discarded, much like the fabled veal in a pheasant recipe attributed to the chef Escoffier. This procedure has been phenomenologically successful, despite abandoning the very motivation for using EFT for nuclei - a manifest independence on assumptions about the details of the QCD dynamics.
I will discuss the importance of renormalization and naturalness, and describe some current attempts to extend nuclear EFTs beyond the alpha particle.

[15h] Lorenzo Contessi *(IJCLab)*
Towards the description of larger systems with renormalizable EFTs

Tuesday 9th [14h15]
Mirko Bagnarol *(The Racah Institute of Physics)*
Five-body calculation of n-4 He scattering at next-to-leading order π/ EFT
We present the first five-body calculations of s-wave n-4 He scattering within leading order and next-to-leading order (NLO) pionless effective field theory, and discuss incoming p-wave calculations on three to five body systems within the same framework. We also discuss the harmonic oscillator trap technique that led us to efficiently converge five body calculations and that allowed us to reach a relative numerical precision as low as ~1% in our scattering parameter predictions.

Wednesday 10th

[11h] Mehdi Drissi *(Dpt of Physics, TRIUMF)*
Accelerating Variational Monte Carlo calculations with decision geometry
Recently, Variational Monte Carlo (VMC) solutions to the quantum many-body problem have experienced tremendous progress in accuracy thanks to the use of neural quantum states (NQS). While more and more sophisticated ansatz have been designed to tackle a wide variety of many-body problems, little progress has been made on their optimization process.
In this talk, I will revisit the Kronecker Factored Approximate Curvature (KFAC), one of the main optimizers used for the most challenging many-body systems. After exposing how KFAC is fundamentally unfit for VMC with NQS, I will discuss the design of a novel optimization strategy based on decision geometry. As a test bench, I will consider a NQS modelling polarized fermions interacting in an harmonic trap. Preliminary results will be reported, showing how this new optimizer outperforms KFAC in terms of stability, accuracy and speed of convergence.
Beyond VMC, the versatility of this approach suggests that decision geometry could provide a solid foundation for accelerating a broad class of machine learning problems.

[14h15] Tafat Weiss-Attia *(The Racah Institute of Physics)*
Perturbative application of next-to-leading order pionless EFT for A ≤ 3 nuclei in a finite volume
We employ pionless EFT with perturbative inclusion of the next-to-leading order (NLO) to predict few-body observables from the finite-volume spectrum of A ≤ 3 nuclei confined in a box. To this end, we fit finite-volume NLO pionless EFT to finite-volume energies generated from a phenomenological NN interaction and the theory is then solved in free space. As a benchmark, we also apply the Luscher formalism directly to the finite-volume data. Through a comprehensive analysis, we explore the characteristics of order-by-order predictions of the pionless EFT fitted within a finite volume, investigate the limitations of the different extrapolation techniques used, and derive recommended box sizes required for reliable predictions.

Thursday 11th

[14h15] Andrea di Donna *(Universitá degli studi di Trento)*
Neural quantum states for hypernuclear systems with contact theories

Friday 12th

[14h15] **Johannes Kirscher** *(Department of Physics, SRM University)*
The 4-body coupled-channel problem with zero-range interactions
We analyze the dependence of the four-body scattering problem on the two- and three-body scales relevant at the leading order of a zero-range expansion of the interaction. We focus on the sensitivity of transitions between configurations that represent rearrangement reactions in the course of low-energy collisions. Furthermore, we study the effect of particle statistics for those coupled channels.