CSC-RUB PhD Project Proposal

Title: Isospin-breaking effects in few-nucleon systems

Sector of research: Theoretical nuclear physics

Degree awarded: Dr. rer. nat.

Keywords: Chiral effective field theory, Nuclear interactions, Ab Initio few-body methods

Supervisor of PhD project:
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Prof. Dr. Miriam Fritsch, Institute of Experimental Physics I, Faculty of Physics and Astronomy

Research focus of supervisor:

My research interests focus on understanding the structure, properties and dynamics of strongly interacting hadronic and nuclear systems. The ultimate goal is to establish a rigorous, fully microscopic and predictive theoretical approach to low-energy nuclear physics firmly rooted in Quantum Chromodynamics, the underlying quantum field theory of the strong interactions. This ambitious goal is being accomplished by employing contemporary analytical methods (effective field theories, chiral perturbation theory, dispersion theory, large-Nc expansion) in combination with state-of-the-art computational techniques and large-scale numerical simulations to handle the quantum mechanical many-body problem. Other topics of interest include hadronic molecules, electroweak reactions, low-energy Dark Matter searches, chiral extrapolations, finite-volume methods, pion production reactions, etc.

Publications: Five representative publications:

1. E. Epelbaum, H.-W. Hammer, U.-G. Meißner, Modern Theory of Nuclear Forces, Rev. Mod. Phys. 81 (2009) 1773. [With over 1300 citations according to INSPIRE, this is the most frequently cited review article in the field of chiral effective field theory for nuclear systems.]


Publication/presentation record (numbers as of August 23, 2021):

- Over 250 refereed publications
- **INSPIRE**: h-index of 56, total of 12688 citations, 1, 2, 6 and 22 papers with 1000+, 500+, 250+ and 100+ citations
- **ADS**: total research impact (tori-index) of 69.1, age-adjusted tori index (riq) of 346
- **Google scholar**: h-index of 61 (44 since 2016)
- Over 150 invited talks at international conferences and workshops (including 23 plenary), 3 panel discussions, 14 invited advanced lecture series, 17 colloquia, numerous seminars

### Summary of research plan

**Background:** Over the last few years, considerable progress has been achieved towards deriving and applying high-precision nuclear interactions in chiral effective field theory. The two-nucleon potentials developed in our group provide a very good description of the neutron-proton and proton-proton scattering data below pion-production threshold. Combined with the three-nucleon potentials (also developed by our group), these interactions are widely used in ab initio studies of nuclear structure, reactions and matter.

**Study objective:** The goal of this PhD project is to complement these studies by performing detailed investigations of isospin-breaking effects in few-nucleon systems. This would provide access to neutron-neutron interactions, for which no experimental data are available. Using the systematic framework of chiral effective field theory in combination with a careful error analysis will allow one to confront our understanding of isospin breaking at the hadronic/nuclear level (e.g. understanding the binding energy difference of mirror nuclei) and to perform a model-independent determination of the neutron-neutron scattering length. These studies may also shed new light on the much-speculated tetra-neutron state and on some long-standing discrepancies in the three-nucleon continuum.

**Expected Results:** Constraints on neutron-neutron interactions, theoretical constraints on the existence of the tetra-neutron bound/resonance state, impact of isospin-breaking three-nucleon interactions on e.g. the spectra and stability of neutron-rich nuclei. The results of these studies, carried out within the LENPIC-Collaboration, will be published in scientific journals.

**Methods:** Chiral effective field theory, Faddeev equations for three-nucleon scattering, ab-initio few-body methods. The available infrastructure comprises local workstations for carrying out three-body calculations. Supercomputing resources at Research Centre Jülich are also available.

**Candidate Requirements:** MSc in theoretical physics as well as some knowledge of quantum field theory, nuclear and particle physics are required. Experience in computational physics and programming skills are advantageous. Good English language skills are also required.

**Motivation for CSC application:** The PhD candidate would benefit from working in one of world’s leading groups for research related to chiral effective field theory and its applications to nuclear systems. You will actively participate in international research networks including the Sino-German Collaborative Research Centre 110 “Symmetries and the Emergence of Structure in QCD”, the Low Energy Nuclear Physics International Collaboration (LENPIC) and the Nuclear Lattice Effective Field Theory (NLEFT) Collaboration. In addition to various advanced courses in quantum field theory, nuclear and particle physics offered by our department on a regular basis,
you would be able to benefit from the personal competence training program offered by the RUB Research School.