Letter of intent: **LEARN- Learning Electromagnetic Structure in Light Nuclei with AI**

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1. Research objectives

Light nuclei play a central role in the earliest stages of element synthesis, serve as laboratories for testing fundamental interactions, and provide critical insights into quantum mechanics and the Standard Model of particle physics. Advances in nuclear theory have led to significant progress in the calculation of nuclear structure and reactions for increasingly complex systems. However, several challenges remain—challenges where emerging technologies such as artificial intelligence (AI) offer promising new avenues for advancement. We propose establishing a virtual network of theorists specializing in light nuclei to apply AI methods to electromagnetic observables [1], enhancing the precision, scope, and impact of nuclear theory. The focus will be on electromagnetic response functions, which are essential for interpreting data from major experimental facilities and directly support their scientific programs.

The computation of nuclear response functions requires in principle access to the continuum spectrum of a nucleus, which is hardly achievable beyond the lightest systems (3 or 4 nucleons). To circumvent this problem, integral transforms are widely employed [2]. They involve convoluting the response function with an appropriately chosen kernel, allowing the computation of an expectation value on the ground state. The response function is then recovered through an inversion procedure, which can be improved using AI tools [3]. In this project, we will build on this approach and apply it to the study of selected, experimentally relevant observables.

At MAMI and the upcoming MESA facility, an extensive experimental program is underway to measure electron scattering on ^{16}O and $^{40}Ca/^{40}Ar$, providing essential constraints for the long-baseline neutrino program. Theoretical interpretation of these measurements relies on methods such as integral transforms [4], which effectively handle the continuum dynamics involved. Similar techniques can also be applied to investigate the photodissociation of neutron-rich nuclei like ^{6}He, which will be explored at FAIR through heavy-ion reactions.

AI can be key also in the development of new many-body methods. Recently, response functions have been computed using a variational Monte Carlo method that combines neural-network quantum states with integral transforms [5]. While, so far, the photodissociation cross sections of ^{2}H and ^{4}He [5] has been addressed, we plan to expand the reach of this approach to neutron-rich nuclei that can be tackled at FAIR.

Electromagnetic response functions also play a critical role in muonic atom research. At PSI, the QUARTET collaboration has proposed measuring the 1S–2P transition in muonic atoms to extract nuclear charge radii of light nuclei with unprecedented precision [6]. Achieving this precision requires accurate theoretical knowledge of two-photon exchange corrections, which represent the dominant source of uncertainty. In particular, the inelastic component of the two-photon exchange is linked to sum rules of electromagnetic response functions [7], making the calculation of these functions essential. Recent studies have demonstrated that AI tools can effectively compute dipole response functions across a broad range of nuclei [8]. We aim to tailor and optimize these AI-based approaches for light nuclei to improve estimates of two-photon exchange corrections in muonic systems.

Finally, another challenge is the uncertainty quantification of theoretical calculations where chiral effective field theory is used. Bayesian approaches have been recently introduced [9,10] for the lightest nuclei, but more work needs to be done to address this issue thoroughly for the heavier systems mentioned above. We believe that creating an international theory network centered in Europe will help us to make progress on this front.

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2. Connection to Transnational Access infrastructures (TAs) and / or Virtual Access projects (VAs)

This project aims to establish a virtual network of theorists specializing in nuclear structure and reactions of light nuclei, with the goal of advancing research that leverages emerging AI technologies. By applying these tools to the modeling of electromagnetic observables, the network seeks to enhance the predictive power and interpretative capacity of nuclear theory. The theoretical study of electromagnetic properties of light nuclei is essential for supporting and interpreting experimental data from facilities such as MAMI/MESA, GSI/FAIR (Germany) and PSI (Switzerland). Therefore, this project can be seen both as a TA and a VA.

3. Estimated budget request

Travel budget 20K Euro/ year = 80K Euro

1 x Postdoc Position for 3 years = 230K Euro.

4. Participating and partner institutions

Johannes Gutenberg University Mainz, Germany, (Sonia Bacca)
Hebrew University, Israel (Nir Barnea)
Chalmers University of Technology, Sweden (Joanna E. Sobczyk)
Pisa University, Italy (Laura Marcucci, Michele Viviani)
Valencia University, Spain, and Argonne National Laboratory, USA (Alessandro Lovato)
Valencia University, Spain, and Fermi National Laboratory, USA (Noemi Rocco)
Washington University St. Louis, USA (Saori Pastore)