Hadron structure from the lattice

The fundamental constituents of the strong nuclear force are quarks and gluons, which themselves bind together to form the familiar building blocks of nuclear physics, protons and neutrons. Understanding the internal structure of hadrons from first principles remains one of the foremost tasks in particle and nuclear physics. This is an active field of research with important phenomenological implications in high-energy, nuclear and astroparticle physics. The static properties of hadrons, from the hybrid structure of quark and meson degrees of freedom to the partonic structure at short distances are encoded in structure functions. Nucleon structure functions and their derivatives, parton distribution functions (PDFs) and generalized parton distribution functions (GPDs), the latter providing three-dimensional images of the nucleon by an extension of the partonic picture introduced by Feynman, teach us how the nucleon is built from quarks and gluons, and how QCD works. Beyond that, the cross section for hadron production at the LHC relies upon a precise knowledge of PDFs. Currently, quark and gluon distribution functions of the proton are not well known at small and large momentum fraction x. This leads to uncertainties in the Higgs production cross section of $5 - 10\%$. In this proposal we compute nucleon structure functions and GPDs on the space-time lattice using novel techniques, which have been developed and tested recently. The advantage over previous approaches is that the calculations are fully nonperturbative, including contributions of higher-twist at large x and large-distance contributions at small x for the first time. Furthermore, the new techniques we have developed offer a new array of physical observables that can be addressed in lattice QCD.

This project will leverage the computational advantage provided by HLRN resources to break new ground in nuclear and particle physics and challenge the current understanding of the fundamental interactions between the building blocks of matter.