The scattering of electrons from nuclei is the best source of precise information about nuclear sizes and their electromagnetic properties. The atomic nucleus was discovered by Rutherford scattering of alpha particles but the electron is a much better nuclear probe since it is a point particle and can penetrate the nucleus. For very low energies the scattered electron can "see" just the total charge of the nucleus and the electron scattering can be described by the simple Rutherford formula. As the energy of the electrons increases, the scattering process proves more complicated because relativistic effects become important already in the very kinematics. Additionally, the scattering involves nuclear recoil and the possibility that the nucleus splits into two or more smaller parts. Now the incident electron "sees" and interacts with charges and currents (magnetic moments) inside the nucleus. A proper description of electron scattering in the several GeVs energy region (where the total energy of electrons is several thousand times bigger than their rest energy and comparable to the rest energy of the nuclear target) requires a relativistic framework encompassing not only the electron but also the nuclear system.

The neutrino is also a good probe but its interaction with the atomic nuclei is extremely weak. The important fact is that electron and neutrino scattering are closely related and it is possible to treat both in a similar manner. Namely, electrons and neutrinos interact with electromagnetic and weak nuclear charges and currents. The full nuclear charges and currents receive dominant contributions from the charges and currents of individual nucleons. Other important parts, the so-called many-nucleon currents, represent processes where nucleons act together while responding to the electroweak probe. The two-nucleon currents (most important among the many-nucleon currents) cannot be chosen arbitrarily but they must be consistent with the interactions that bind nucleons together in a nucleus and are responsible for the final state interactions of parts of the broken nucleus.

The two major problems that we want to address in our project is thus the derivation and use of the relativistic interactions and consistent nuclear currents (including two-nucleon currents) in electron and neutrino scattering off few-nucleon targets. This will enable us to study the role of two-nucleon contributions in the full nuclear current in various kinematic regimes in order to find observables and kinematics sensitive to the properties of two-nucleon currents and identify kinematics where the properties of the single-nucleon contributions in the nuclear current operator are overwhelming. The latter aspect of electron and neutrino scattering is also very important, since the properties of the neutron cannot be investigated by direct electron-neutron or neutrino-neutron scattering due to the lack of free neutron target in nature.

Electrons, neutrinos, nucleons and nuclei are equipped with an internal angular momentum (spin), usually linked to their magnetic moments. Beams and targets in nuclear reactions can be then polarized or unpolarized. It often happens in nuclear reactions that particles’ spins change their directions. Such phenomena are called polarization effects, by analogy to the properties of light. In our project we plan to investigate these features of electron- and neutrino- induced reactions with the deuteron (atomic nuclei) as such efforts are in line with modern research directions, in particular keeping in mind the scientific programs at Jefferson Lab (Newport News). Polarization observables (for example beam and target asymmetries, proton and neutron polarizations in the deuteron breakup induced by electrons and neutrinos) contain richer information about the role of non-nucleonic degrees of freedom in nuclei, reaction mechanisms and nuclear structure than that acquired with unpolarized particles. The strong interactions, which bind the nucleons together respect the space- and time-reflection symmetries, contrary to the weak interactions induced by neutrinos. Studying of polarization observables will enable us to verify some fundamental properties of the strong and weak interactions. Moreover, essentially only through polarization phenomena can one access the electroweak form factors of the neutron.

We have already investigated electron and neutrino scattering off the deuteron but without two-nucleon currents. We have also the experience in building the relativistic nucleon-nucleon potentials, using the polarization observables to reach the neutron properties as well as in investigating of few-nucleon systems. We strongly believe that our research program has very solid foundations and that we have the potential to achieve the assumed project aims.