Final Report

Federal Agency: Office of Nuclear Physics, DOE

DOE Award number: DE-SC0001473

Project Title: Fundamental Neutron Physics: Theory and Analysis

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Recipient Organization: South Carolina Research Foundation
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Accomplishments:

The goal of the proposal was to study the possibility of searching for manifestations of new physics beyond the Standard model in fundamental neutron physics experiments. This involves detailed theoretical analyses of parity and time reversal invariance violating processes in neutron induced reactions, properties of neutron β-decay, and the precise description of properties of neutron interactions with nuclei. To describe neutron-nuclear interactions, we use both the effective field theory approach and the theory of nuclear reaction with phenomenological nucleon potentials for the systematic description of parity and time reversal violating effects in the consistent way.

A major emphasis of our research during the funding period has been the study of parity violation (PV) and time reversal invariance violation (TRIV) in few-body systems. We studied PV effects in non-elastic processes in three nucleon system using both ”DDH-like” and effective field theory (EFT) approaches. The wave functions were obtained by solving three-body Faddeev equations in configuration space for a number of realistic strong potentials. The observed model dependence for the DDH approach indicates intrinsic difficulty in the description of nuclear PV effects and it could be the reason for the observed discrepancies in the nuclear PV data analysis. It shows that the DDH approach could be a reasonable approach for analysis of PV effects only if exactly the same strong and weak potentials are used in calculating all PV observables in all nuclei. However, the existing calculations of nuclear PV effects were performed using different potentials; therefore, strictly speaking, one cannot compare the existing results of these calculations among themselves.

We calculated nuclear electric dipole moments (EDMs) of deuteron, ^{3}He, and ^{3}H, using TRIV potential in meson exchange model, as well as the potentials derived from EFT with and without explicit pions. Several realistic nucleon-nucleon potentials have been tested to represent the strong interaction. Comparing these results with our calculations of TRIV effects in neutron-deuteron and proton-deuteron scattering, we have shown that both nuclear EDMs and elastic scattering TRIV effects are mostly sensitive to TRIV pion coupling constants. However, while the EDM values are equally sensitive to all isospin parts of the pion coupling constant, the elastic scattering effects are mainly defined by the isoscalar interactions. This fact clearly demonstrates the complementarity of different TRIV effects in three-nucleon systems. Thus, the relative values of these TRIV parameters may vary for different models of CP-violation and, therefore, the measurement of a number of TRIV observables can help to avoid a possible accidental cancelation of TRIV.

We demonstrated that the TRIV effects in neutron transmission through a nuclei target are very unique TRIV observables being free from final state interactions (FSI), and are of the same quality as the EDM experiments. Since these TRIV effects in nuclei are enhanced by about 106 due to resonance enhancement, and may have an additional structural enhancement by about 102, these types of experiments, which can be done at high intensity neutron sources, have a discovery potential of about $102 - 104$ for the improvement of the current limits on the TRIV interactions obtained from the EDM experiments.

We also have performed the outlining and analyzing the basic features and requirements for the experimental proposal to measure TRIV in neutron nucleus scattering at groups at the Spallation Neutron Sources at ORNL (SNS).

These results were presented at number of international conferences, workshops, and seminars, and attracted the attention of two fundamental neutron physics groups at the SNS and J-PARC. Currently, the PI is working in close collaboration with these groups providing theoretical support for a basic study of the main issues related to the experimental proposal to measure TRIV at J-PARC and at the SNS.

A list of published papers:

- Y.-H. Song, R. Lazauskas and V. Gudkov, "Parity violation in radiative neutron capture on the deuteron", Phys. Rev. C86, 055502 (2012).
- S.I. Ando, Y.H. Song, C.H. Hyun, and K. Kubodera , "Spin polarization in gamma d -> anti-n p", EPJ Web Conf. 20, 02003 (2012).
- Y.-H. Song, R. Lazauskas and V. Gudkov, "Nuclear electric dipole moment of three-body systems", Phys. Rev. C87, 015501 (2013).
- V. Gudkov and Y.-H. Song, "Discover potential in a search for time-reversal invariance violation in nuclei", Hyperfine Interact 214, 105 (2013).
- R. Lazauskas, Y.-H. Song and V. Gudkov, "Parity and time-reversal violation in A=2-4 nuclei", EPJ 66, 05014 (2014).
- S. Pastore, R.B. Wiringa, Steven C. Pieper, R. Schiavilla," Quantum Monte Carlo calculations of electromagnetic transitions in 88Be with meson-exchange currents derived from chiral effective field theory", Phys.Rev. C90, 024321 (2014).
- Sonia Bacca, Saori Pastore, "Electromagnetic reactions on light nuclei ", J.Phys. G41, 123002 (2014).
- J. David Bowman and Vladimir Gudkov," Search for Time Reversal Invariance Violation in Neutron Transmission", Phys. Rev. C90, 065503 (2014).
- Kenneth M. Nollett , Gary Steigman, "BBN and the CMB Constrain Neutrino Coupled Light WIMPs", Phys.Rev. D91, 083505 (2015).
- Xilin Zhang, Kenneth M. Nollett, D.R. Phillips, "Halo effective field theory constrains the solar $^{7}Be + p \rightarrow {}^{8}B + \gamma$ rate", Phys. Lett. B751, 535 (2015).
- Xilin Zhang, Kenneth M. Nollett, D.R. Phillips, "How well do we understand $^{7}Be+p\rightarrow{}_{8}B+\gamma$? An Effective Field Theory perspective", EPJ Web Conf. 113, 06001 (2016).
- Y.-H. Song, R. Lazauskas and V. Gudkov, "Time Reversal Invariance Violating and Parity Conserving effects in Neutron Deuteron Scattering", Phys. Rev. C84, 025501 (2011), Erratum: Phys. Rev. C93, 049901(E) (2016).
- S. Inoue, V. Gudkov, M. R. Schindler, and Y.-H. Song, "Screening of Nucleon Electric Dipole Moments in Nuclei", Phys. Rev. C 93, 055501 (2016).
- Y.-H. Song, R. Lazauskas, and V. Gudkov, "Time Reversal Invariance Violating and Parity Conserving Effects in Proton Deuteron Scattering", Phys. Rev. C 93, 065501 (2016).

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The estimated unexpended funds is about $483.38.

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