# New Studies of Short-Range Correlations and Their Effects on Nuclei

Final Technical Report
November 29, 2018


Patricia Solvignon-Slifer *Principal Investigator*
Karl J. Slifer *Co-Principal Investigator*


---


| | | |
|---|---|---|
| **Applicant/Institution** | : | University of New Hampshire |
| **Street Address/City/State/Zip** | : | 51 College Road, Service Building, |
| | : | Durham, NH 03824-3585 |
| **Contact** | : | Karl J. Slifer |
| **Telephone Number** | : | 603-862-2827 |
| **Email** | : | karl.slifer@unh.edu |
| **Administrative Point of Contact** | : | Cheryl Moore |
| **Telephone Number** | : | 603-862-1992 |
| **Email** | : | cheryl.moore@unh.edu |



| | | |
|---|---|---|
| **DOE/Office of Science Program Office** | : | Nuclear Physics (NP) |
| **Topic Area Program Manager** | : | Dr. Gulsham Rai |
| **DOE Award Number** | : | DE-SC0014168 |
| **Research Area** | : | Medium Energy Nuclear Physics |
| **Grant Period** | : | July 15, 2015 - July 14, 2018 |

# Contents

**1 Project Overview** **1**

**2 Project Goals and Motivation** **2**
2.1 Short Range Correlations . . . . . 2
2.2 Tensor Spin Observables . . . . . 3
2.3 Polarized Target Development . . . . . 3

**3 Summary** **6**

**1 Appendix: Bibliography** **8**

# 1 Project Overview

This document reports on accomplishments and progress of grant DE-SC0014168 during the period between July 15, 2015 and July 14, 2018. The project was motivated by one of the top science questions for the $21^{st}$ century [1]:

*What is the relation between short-range correlations and the partonic structure of nuclei?*

The principal investigator Patricia Solvignon-Slifer passed on May 27, 2016. Her death was a devastating loss for our field. In recent years, she had emerged as one of the brightest young scientists at Jefferson Lab, and established an impressive program to investigate the nature of nucleon short range correlations. Her excellence was recognized by her inclusion in the QCD Long Range Plan discussion, with an Early Career Award, and with a Jefferson Lab/UNH Bridge appointment. She passed before she could see this remarkable program to completion, but she left a clear blueprint to illuminate the nature of short range correlations (SRC), how they are linked to the EMC effect, and what role the tensor force plays.

The flagship experiment of Solvignon's program, E12-11-112 ("tritium SRC"), was identified as *high impact* by PAC41. The results will help illuminate tensor force dominance and the isospin dependence in 2N and 3N short range correlations. Two of Patricia's graduate students, Nathaly Santiesteban and Shujie Li, were stationed at Jefferson Lab and played central roles in the tritium run. The SRC Experiment took 4 days of data in Spring 2018 and another 30 calendar days in the Fall. Although the experiment only recently finished, detector calibrations are already complete and we have begun to analyze the data. $^3$H/$^3$He ratios have been produced, but are extremely preliminary. Shujie Li has a central role in the tritium run group as the principal collaborator responsible for the experimental run plan, and is performing the main $^3$H/$^3$He ratio analysis. Nathaly S. is analyzing the quasi-elastic data to extract the elastic form factor.

Patricia Solvignon-Slifer also played a major role in the formation of the tensor polarized spin observables program (E12-13-011 and E12-15-005) at Jefferson Lab. Each of these experiments require the development of a tensor polarized target. Towards this goal, we have established a new Dynamic Nuclear Polarization lab at the University of New Hampshire. The low temperature liquid helium evaporation refrigerator at the heart of this DNP system was constructed and commissioned using funds from this grant in 2017 and is now fully operational.

The research initiated by Patricia was interrupted before completion, but she established a program that is already producing exciting results and excellent PhD students. We discuss some

of the initial highlights in this final technical report, although we anticipate that the program she established will continue to produce high impact results long beyond the scope of this grant.

# 2 Project Goals and Motivation

Over the last decade, data gathered on short range correlations (SRC) and the EMC effect have stimulated tremendous progress in our understanding of the nuclear force. In particular, the tensor force was found to be the major factor in the formation of N-N short range correlations. More recently a connection between the N-N SRC probabilities and EMC effect amplitudes was first observed. However the real origin and characteristics of this connection have not been convincingly determined experimentally or theoretically. We aim to help answer the fundamental question on the nature of the short range interactions and their implications at the nucleonic and partonic levels. The main goals are :

1. The preparation, running and analysis of the Jefferson Lab inclusive SRC experiment E12-11-112 (**Solvignon**, lead spokesperson). This experiment will investigate the isospin dependence of 2N and 3N SRC through the $^3$He/$^3$H cross section ratio. It was listed as "high impact" by PAC41.

2. Preparation for E12-13-011 and E12-12-005 ( the tensor b1 and Azz experiments ) and development of the deuteron tensor polarized target. A deeper understanding of tensor structure in spin-1 systems will help clarify how the gross properties of the nucleus arise from the underlying partons. This provides novel information about gluon contributions, quark angular momentum, and the polarization of the quark sea that is not accessible in spin-1/2 targets. PAC41 stated that E12-12-005 "*would further explore the nature of short range pn correlations in nuclei, the discovery of which has been one of the most important results of the JLab 6 GeV nuclear program.*"

## 2.1 Short Range Correlations

Patricia Solvignon-Slifer played a key role in the tritium target development, and was the principle scientist responsible for developing and defending the physics motivation of experiment E12-11-112. Her two students Nathaly Santiesteban and Shujie Li took their theses data on this experiment. Shujie Li has been stationed at Jefferson Lab for several years and played a large role in the preparation. Nathaly moved to Jefferson Lab in June 2017 and quickly established herself as a key contributor. The experiment ran in Hall A in 2017-2018 and is currently under analysis.

Nathaly Santiesteban received the UNH Harper Fellowship which recognizes graduate students who 'exemplify academic merit and achievement'. She was also awarded 'Best Speaker 1$^{st}$ Place' for her presentation on 'Solid Polarized Target Experiments' at the 31$^{st}$ annual HUGS summer school. Prior to moving to Jefferson Lab, Nathaly's focus at UNH has been in our polarized target lab, in support of the tensor spin program. Her main contributions have been to design a 1 K helium evaporation refrigerator, and the insulating vacuum chamber. She has developed expertise in vacuum technology and leak detection. She has also designed and constructed an electronic housing for our NMR system. During target cooldowns at UNH, Nathaly has principle responsibility for mechanical pumps and vacuum measurement devices. She contributes to Labview coding, 3D printing and organization of the lab. She has written detailed laboratory technical

notes on: General Good Vacuum Practices, Low Temperature Indium Seals, Evaporative Fridge Design, and Low Temperature Epoxy. She is also the UNH student representative on the Graduate Curriculum Committee and Machine Shop Committee. She defended her thesis proposal in June 2017 and advance to PhD candidacy. At JLab, she is presently responsible for the BCM calibration, boiling study and VDC.

Shujie Li is stationed at Jefferson Lab for the tritium SRC experiment. She has measured the dead-time of the JLab constructed Flash ADC modules with high frequency random signals. Her primary contribution to the SRC/tritium run has been her work on the single arm simulation (SIMC) for rate calculations. She updated the detector geometry and target information, added energy loss and multiple scattering to the simulation, and compared target and focal plane variables from simulation and previous data. This was all checked against dummy target data from previous experiments, and she then used the updated simulation to calculate the runplan rates for E12-11-112. As part of her preparation for SRC, Shujie played an important auxiliary role in running the E12-014-012 ("Argon") experiment. This experiment ran in spring 2017 and has a similar configuration to the SRC experiment, sans the tritium target. Shujie worked on the BCM/BPM and raster calibrations, the PID study, a tracking and trigger efficiency study, target boiling, the DAQ and the carbon foil momentum scan. She continues the EMC effect world data re-analysis which she began with Patricia Solvignon, and recently incorporated new Hall C EMC data into the nuclear matter extrapolation. She is also responsible for the E12-11-112 Cherenkov, trigger and optics.

E12-11-112 is completed, and Nathaly S. and Shujie Li are playing a central role in the analysis as described above. Shujie will focus her thesis on the inclusive SRC data taken at 4.4 GeV in 2017 and Nathaly will focus on the Quasielastic data at 2.2 GeV in 2018. Both are expected to spend 2019 and atleast part of 2020 analyzing this data. We anticipate preliminary results for the 4.4 GeV data will be ready in 2019, and the preliminary quasielastic data in 2020.

### 2.2 Tensor Spin Observables

Patricia Solvignon-Slifer played a significant role in the study of tensor spin observables. She was a spokeperson for both approved experiments and an integral part of the small team that developed and defended the experimental proposals.

E12-13-011 will measure the deuteron tensor structure function $b_1$, and probe the tensor-polarized quark and antiquark distribution functions, and E12-15-005 will measure the tensor asymmetry $A_{zz}$ in the $x > 1$ region, to explore the nature of short-range correlations in nuclei. Fig. 1 shows the projected results for these two experiments.

### 2.3 Polarized Target Development

The study of nucleon and nuclear structure relies heavily on polarized targets. Cryogenically cooled solid ammonia ($NH_3$, $ND_3$) is the material of choice for most polarized proton and deuteron experiments, due to its high polarizability and radiation resistance. It has been used at Jefferson Lab, Fermilab, HiGs and many other nuclear physics research labs in more than 20 experiments since 1990, and this trend will continue for the foreseeable future.

Our Dynamic Nuclear Polarization (DNP) lab became fully operational in 2018. The DNP target requires a low temperature helium bath to optimize polarization. Towards this goal, we constructed and commissioned a new 1 K helium evaporation refrigerator in 2017 with support from

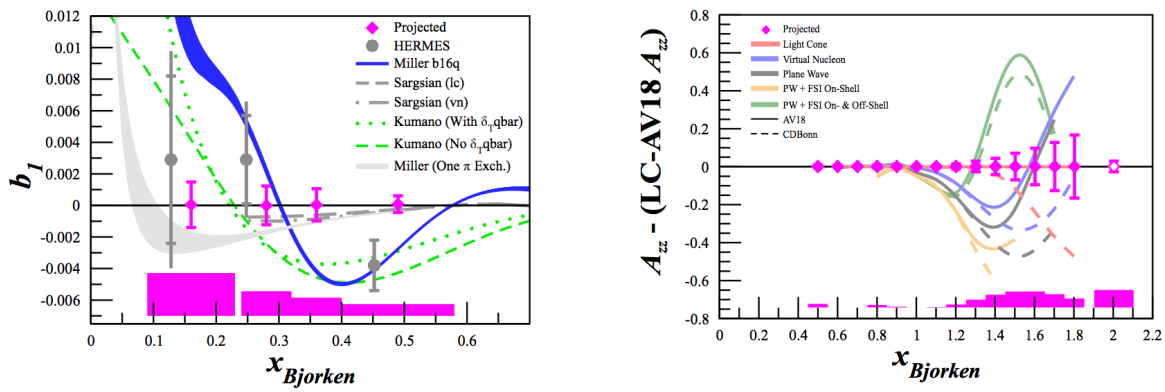


Figure 1: **LEFT:** Existing $b_1$ world data are shown alongside conventional nuclear physics models (gray), effects from sea antiquark polarization (green), six-quark, hidden-color models (blue), and projected uncertainties in the upcoming Jefferson Lab experiment (pink). **RIGHT:** Projected statistical and systematic uncertainties for $A_{zz}$ are shown alongside modern relativistic calculations, and calculations with on- and off-shell effects. This plot is normalized to the light cone $A_{zz}$ calculation using the AV-18 potential to emphasize how projected uncertainties compare to models.

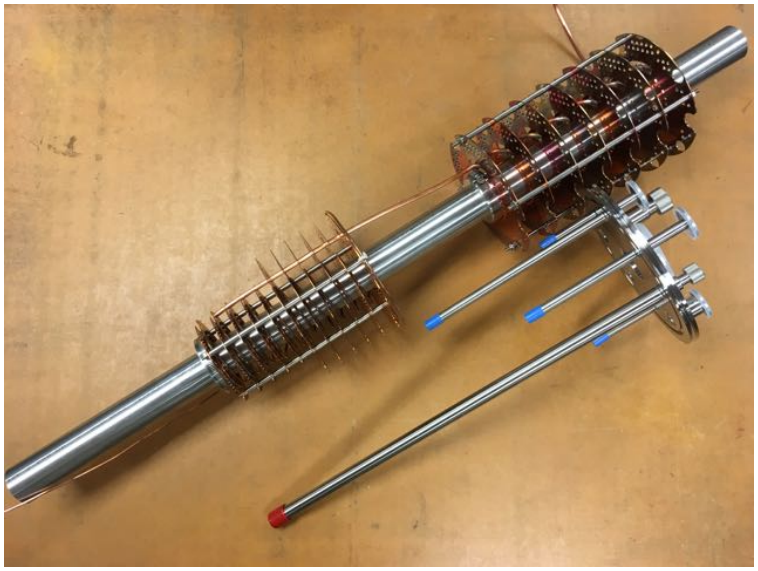

Figure 2: Radiation baffles, heat exchanger and cryostat plate prior to mounting in the refrigerator.

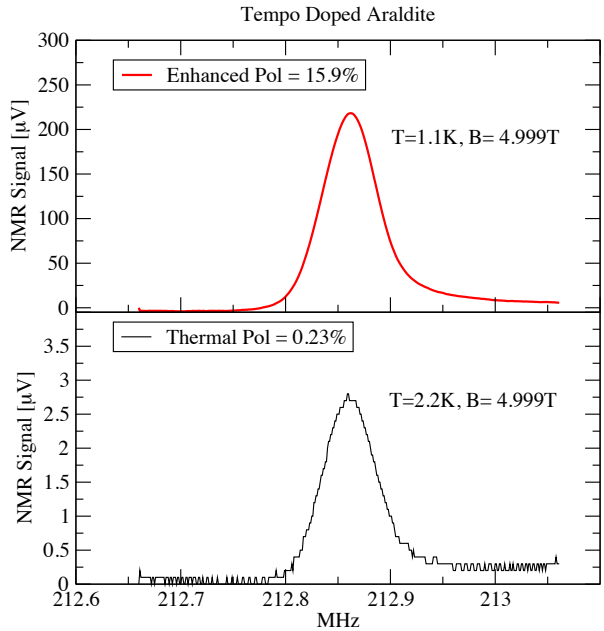


Figure 3: First successful NMR signal observed in the UNH Polarized Target System.

this grant. A 7000 $m^3$/h Pfeiffer Roots pump system powers our helium evaporation refrigerator, which was based on the initial design of the Jefferson Lab target group, but significantly modified to run with our system. The heat exchanger, radiation baffles, needle valves and supporting structure was constructed in the UNH Physics Department machine shop. The liquid helium separator pot and vacuum jacket were constructed offsite by the Kurt J. Lesker Company.

The refrigerator performs as designed at 1.1 K. In September 2018, we used this refrigerator in the DNP system to dynamically enhance the polarization of a proton target to 15.9% as shown in Fig. 3. We now are working to optimize the sample polarization, but these initial results demonstrate that our system is fully operational.

## 3 Summary

Over the last three years we prepared for and ran the tritium SRC experiment. The data quality appears excellent and all the main goals of the experiment were accomplished. The data analysis by Nathaly Santiesteban and Shujie Li will continue and we eagerly await the opportunity to publish the final results. During this time, we also brought our polarized target lab to full operation, in support of our long term effort to investigate Tensor Spin Observables. We thank the Department of Energy, Medium Energy Nuclear Physics for their generous support. It has seeded an exciting research program that will continue long into the future as a fitting legacy for Patricia Solvignon-Slifer.

**Milestones and Accomplishments**

A list of major activities over the last three years is provided in the following table.

| | **Highlights of the Last Three Years** |
|---|---|
| **2018** | |
| Sep | Tritium SRC experiment E12-11-112 completed successfully. |
| Sep | Dynamic Nuclear Polarization enhancement demonstrated. |
| **2017** | |
| Dec | 'High Impact' Tritium SRC experiment E12-11-112 began.<br>Shujie Li responsible for tritium SRC rate calculations.<br>Nathaly Santiesteban successfully defended her thesis proposal on the tritium SRC experiment, and was elevated to candidacy. |
| **2016** | |
| Oct | Nathaly Santiesteban was awarded the Harper fellowship for academic excellence. |
| Jul | The Tensor $A_{zz}$ experiment's conditional approval was raised from $C_2$ to $C_1$ and received $A^-$ physics rating. |
| Jun | Nathaly Santiesteban took first prize at the JLab HUGS school for her presentation on 'Solid Polarized Target Experiments'. |
| **2015** | |
| Dec | The Tensor Spin program was mentioned in the DOE Long Range Plan as an important advancement in croygenic and polarized target facilities. |
| Oct | Shujie Li was awarded the Harper fellowship for academic excellence. |
| Aug | We reached 1 Kelvin in a horizontal helium evaporation refrigerator.<br>Target NMR polarimetry operational. Labview software controls written for thermometry, vacuum monitoring, superconducting solenoid control. Low temperature (4K) thermometry calibrated. 7 Tesla field established in superconducting solenoid. |
| Jul | The Tensor $A_{zz}$ experiment was conditionally approved $C_2$.<br>We published the E01-012 $g_2$ results. |
| May | Patricia Solvignon received the DOE Early Career Research Award. |
| Jan | Patricia Solvignon lead the grant to establish the JSA travel fund for Extra Child Care (ExCare). |

# 1 Appendix: Bibliography

## References

[1] T. J. Hallman, Associate Director for Nuclear Physics, DOE Office of Science, "Perspectives on the Future of Nuclear Physics in the United States", BNL Distinguished Lecture Series June 13, 2012.