Proposal #
0000214311

U.S. Department of Energy
Office of Science

GrantsGov #
GRANT11640263

APPLICATION/PROPOSAL COVER SHEET

THE ATTACHED APPLICATION/PROPOSAL IS FOR YOUR REVIEW & APPROPRIATE ACTION

INSTITUTION: Old Dominion University Research Foundation, Norfolk, Virginia

TYPE OF REQUEST: New

P.I.: Weinstein, Lawrence

DATE RECEIVED: 4/30/2014 1:53:58 PM

AWARD NO: N/A

SOLICITATION NO: DE-FOA-0000995

TITLE: SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA

TOTAL NUMBER OF PAGES SUBMITTED: 103

ERROR LIST: No Errors

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2. Research & Related Other Project Information
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7. Narrative

OMB Number: 4040-0001
Expiration Date: 06/30/2011

APPLICATION FOR FEDERAL ASSISTANCE

SF 424 (R&R)

3. DATE RECEIVED BY STATE:

State Application Identifier:

1. * TYPE OF SUBMISSION

☐ Pre-application ☒ Application ☐ Changed/Corrected Application

4. a. Federal Identifier:

b. Agency Routing Identifier:

2. DATE SUBMITTED:

Applicant Identifier:

5. APPLICANT INFORMATION

*** Organizational DUNS:** 077945947

* Legal Name: Old Dominion University Research Foundation

Department:

Division:

* Street1: 4111 Monarch Way

Street2: Suite 204

* City: Norfolk

County / Parish:

* State: VA: Virginia

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 23508-2561

Person to be contacted on matters involving this application

Prefix: Mrs. * First Name: Nicole Middle Name:

* Last Name: Swartz Suffix:

* Phone Number: 757-683-7226 Fax Number: 757-683-5290

Email: nswartz@odu.edu

6. * EMPLOYER IDENTIFICATION *(EIN) or (TIN):* 546068198

7. * TYPE OF APPLICANT: M: Nonprofit with 501C3 IRS Status (Other than Institution of Higher Education)

Other (Specify):

Small Business Organization Type ☐ Women Owned ☐ Socially and Economically Disadvantaged

8. * TYPE OF APPLICATION:

☒ New ☐ Resubmission

☐ Renewal ☐ Continuation ☐ Revision

If Revision, mark appropriate box(es).

☐ A. Increase Award ☐ B. Decrease Award ☐ C. Increase Duration ☐ D. Decrease Duration

☐ E. Other (specify):

* Is this application being submitted to other agencies? Yes ☐ No ☒ What other Agencies?

9. * NAME OF FEDERAL AGENCY: Office of Science

10. CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER: 81.049

TITLE: Office of Science Financial Assistance Program

11. * DESCRIPTIVE TITLE OF APPLICANT'S PROJECT:

SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA

12. PROPOSED PROJECT:

* Start Date: 09/01/2014

* Ending Date: 08/31/2017

*** 13. CONGRESSIONAL DISTRICT OF APPLICANT**

VA-003

14. PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR CONTACT INFORMATION

Prefix: Dr. * First Name: Lawrence Middle Name:

* Last Name: Weinstein Suffix: Ph.D.

Position/Title: Professor

* Organization Name: Old Dominion University

Department: Physics Division:

* Street1: 4600 Elkhorn Avenue

Street2:

* City: Norfolk County / Parish:

* State: VA: Virginia Province:

* Country: USA: UNITED STATES * ZIP / Postal Code: 23529-0116

* Phone Number: 757-683-5803 Fax Number: 757-683-3038

* Email: weinstein@odu.edu

SF 424 (R&R) APPLICATION FOR FEDERAL ASSISTANCE Page 2

15. ESTIMATED PROJECT FUNDING

a. Total Federal Funds Requested	535,964.00
b. Total Non-Federal Funds	0.00
c. Total Federal & Non-Federal Funds	535,964.00
d. Estimated Program Income	0.00

16. * IS APPLICATION SUBJECT TO REVIEW BY STATE EXECUTIVE ORDER 12372 PROCESS?

a. YES ☐ THIS PREAPPLICATION/APPLICATION WAS MADE AVAILABLE TO THE STATE EXECUTIVE ORDER 12372 PROCESS FOR REVIEW ON:

DATE:

b. NO ☒ PROGRAM IS NOT COVERED BY E.O. 12372; OR

☐ PROGRAM HAS NOT BEEN SELECTED BY STATE FOR REVIEW

17. By signing this application, I certify (1) to the statements contained in the list of certifications* and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances * and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious. or fraudulent statements or claims may subject me to criminal, civil, or administrative penalities. (U.S. Code, Title 18, Section 1001)

☒ *** I agree**

****The list of certifications and assurances, or an Internet site where you may obtain this list, is contained in the announcement or agency specific instructions.***

18. SFLLL or other Explanatory Documentation

Add Attachment | Delete Attachment | View Attachment

19. Authorized Representative

Prefix: Ms. * First Name: Cynthia Middle Name: A.

* Last Name: Matney Suffix:

* Position/Title: Director of Sponsored Programs

* Organization: Old Dominion University Research Foundation

Department: Division:

* Street1: 4111 Monarch Way

Street2: Suite 204

* City: Norfolk County / Parish:

* State: VA: Virginia Province:

* Country: USA: UNITED STATES * ZIP / Postal Code: 23508-2561

* Phone Number: 757-683-4293 Fax Number: 757-683-5290

* Email: rfawards@odu.edu

* Signature of Authorized Representative	* Date Signed
Nicole Swartz	04/30/2014

20. Pre-application

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED Other Project Information

1. * Are Human Subjects Involved? ☐ Yes ☒ No

1.a If YES to Human Subjects

Is the Project Exempt from Federal regulations? ☐ Yes ☐ No

If yes, check appropriate exemption number. ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

If no, is the IRB review Pending? ☐ Yes ☐ No

IRB Approval Date:

Human Subject Assurance Number:

2. * Are Vertebrate Animals Used? ☐ Yes ☒ No

2.a. If YES to Vertebrate Animals

Is the IACUC review Pending? ☐ Yes ☐ No

IACUC Approval Date:

Animal Welfare Assurance Number

3. * Is proprietary/privileged information included in the application? ☐ Yes ☒ No

4.a. * Does this project have an actual or potential impact on the environment? ☐ Yes ☒ No

4.b. If yes, please explain:

4.c. If this project has an actual or potential impact on the environment, has an exemption been authorized or an environmental assessment (EA) or environmental impact statement (EIS) been performed? ☐ Yes ☐ No

4.d. If yes, please explain:

5. * Is the research performance site designated, or eligible to be designated, as a historic place? ☐ Yes ☒ No

5.a. If yes, please explain:

6. * Does this project involve activities outside of the United States or partnerships with international collaborators? ☒ Yes ☐ No

6.a. If yes, identify countries: United Kingdom

6.b. Optional Explanation:

7. * Project Summary/Abstract 1234-DMPropSummary.pdf Add Attachment Delete Attachment View Attachment

8. * Project Narrative 1235-MiningProp2014Bio.pdf Add Attachment Delete Attachment View Attachment

9. Bibliography & References Cited Add Attachment Delete Attachment View Attachment

10. Facilities & Other Resources Add Attachment Delete Attachment View Attachment

11. Equipment Add Attachment Delete Attachment View Attachment

12. Other Attachments Add Attachments Delete Attachments View Attachments ☐

OMB Number: 4040-0010
Expiration Date: 08/31/2011

Project/Performance Site Location(s)

Project/Performance Site Primary Location

☐ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name: Old Dominion Univeristy

DUNS Number: 0414484650000

* Street1: 5115 Hampton Boulevard

Street2:

* City: Norfolk County:

* State: VA: Virginia

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 23529-0001 * Project/ Performance Site Congressional District: VA-002

Project/Performance Site Location 1

☐ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name:

DUNS Number:

* Street1:

Street2:

* City: County:

* State:

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: * Project/ Performance Site Congressional District:

Budget Period: 1 Duration: 12 months	DOE Funded Person-mos. CAL	ACAD	SUMR	Funds Requested ($) (Salary+Fringe)
A. Senior Personnel: PI/PO, Co-PI's, Faculty and Other Senior Associates — **Total Senior Personnel (1-8)**				0.00
1. Weinstein, Lawrence	0	0	0	0.00
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9. Others (See Attachment for Details)				0.00
B. Other Personnel (Number in Brackets) — **Total Other Personnel**				100,824.00
(1) Post Doctoral Associates	12			74,353.00
(1) Graduate Students		4.5	3	26,471.00
(0) Undergraduate Students				0.00
(0) Secretarial / Clerical				0.00
Total Personnel Costs — **Total Salaries and Wages (A+B)**				100,824.00
C. Permanent Equipment — **Total Permanent Equipment**				0.00
D. Travel — **Total Travel**				10,000.00
1. Domestic Travel Costs (including Canada, Mexico, and U.S. possessions)				6,000.00
2. Foreign Travel Costs				4,000.00
E. Trainee/Participant Costs (Total Participants: 0) — **Total Trainee/Participants**				0.00
1. Tuition/Fees/Health Insurance				0.00
2. Stipends				0.00
3. Trainee Travel				0.00
4. Subsistence				0.00
5. Other				0.00
F. Other Direct Costs — **Total Other Direct Costs**				0.00
1. Materials and Supplies				0.00
2. Publication Costs/Documentation/Dissemination				0.00
3. Consultant Services				0.00
4. Computer (ADP) Services				0.00
5. SubAwards/Consortium/Contractual Costs				0.00
6. Equipment or Facility Rental/User Fees				0.00
7. Alterations and Renovations				0.00
8.				0.00
9.				0.00
10.				0.00
G. Direct Costs — **Total Direct Costs (A through F)**				110,824.00
H. Indirect Costs — **Total Indirect Costs**				58,737.00
		Indirect Cost Rate	**Indirect Cost Base**	
MTDC:		53.00%	110,824.00	58,737.00
I. Direct and Indirect Costs — **Total Direct and Indirect Costs (G+H)**				169,561.00
J. Fee — **Total Fee**				0.00
K. Cost of Project — **Total Cost of Project (I+J)**				169,561.00

Budget Period: 2 Duration: 12 months	DOE Funded Person-mos. CAL	ACAD	SUMR	Funds Requested ($) (Salary+Fringe)
A. Senior Personnel: PI/PO, Co-PI's, Faculty and Other Senior Associates — **Total Senior Personnel (1-8)**				0.00
1. Weinstein, Lawrence	0	0	0	0.00
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9. Others (See Attachment for Details)				0.00
B. Other Personnel (Number in Brackets) — **Total Other Personnel**				106,645.00
(1) Post Doctoral Associates	12			78,853.00
(1) Graduate Students		4.5	3	27,792.00
(0) Undergraduate Students				0.00
(0) Secretarial / Clerical				0.00
Total Personnel Costs — **Total Salaries and Wages (A+B)**				106,645.00
C. Permanent Equipment — **Total Permanent Equipment**				0.00
D. Travel — **Total Travel**				10,000.00
1. Domestic Travel Costs (including Canada, Mexico, and U.S. possessions)				6,000.00
2. Foreign Travel Costs				4,000.00
E. Trainee/Participant Costs (Total Participants: 0) — **Total Trainee/Participants**				0.00
1. Tuition/Fees/Health Insurance				0.00
2. Stipends				0.00
3. Trainee Travel				0.00
4. Subsistence				0.00
5. Other				0.00
F. Other Direct Costs — **Total Other Direct Costs**				0.00
1. Materials and Supplies				0.00
2. Publication Costs/Documentation/Dissemination				0.00
3. Consultant Services				0.00
4. Computer (ADP) Services				0.00
5. SubAwards/Consortium/Contractual Costs				0.00
6. Equipment or Facility Rental/User Fees				0.00
7. Alterations and Renovations				0.00
8.				0.00
9.				0.00
10.				0.00
G. Direct Costs — **Total Direct Costs (A through F)**				116,645.00
H. Indirect Costs — **Total Indirect Costs**				61,822.00
		Indirect Cost Rate	**Indirect Cost Base**	
MTDC:		53.00%	116,645.00	61,822.00
I. Direct and Indirect Costs — **Total Direct and Indirect Costs (G+H)**				178,467.00
J. Fee — **Total Fee**				0.00
K. Cost of Project — **Total Cost of Project (I+J)**				178,467.00

Budget Period: 3 Duration: 12 months	DOE Funded Person-mos. CAL	ACAD	SUMR	Funds Requested ($) (Salary+Fringe)
A. Senior Personnel: PI/PO, Co-PI's, Faculty and Other Senior Associates — **Total Senior Personnel (1-8)**				0.00
1. Weinstein, Lawrence	0	0	0	0.00
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9. Others (See Attachment for Details)				0.00
B. Other Personnel (Number in Brackets) — **Total Other Personnel**				112,834.00
(1) Post Doctoral Associates	12			83,658.00
(1) Graduate Students		4.5	3	29,176.00
(0) Undergraduate Students				0.00
(0) Secretarial / Clerical				0.00
Total Personnel Costs — **Total Salaries and Wages (A+B)**				112,834.00
C. Permanent Equipment — **Total Permanent Equipment**				0.00
D. Travel — **Total Travel**				10,000.00
1. Domestic Travel Costs (including Canada, Mexico, and U.S. possessions)				6,000.00
2. Foreign Travel Costs				4,000.00
E. Trainee/Participant Costs (Total Participants: 0) — **Total Trainee/Participants**				0.00
1. Tuition/Fees/Health Insurance				0.00
2. Stipends				0.00
3. Trainee Travel				0.00
4. Subsistence				0.00
5. Other				0.00
F. Other Direct Costs — **Total Other Direct Costs**				0.00
1. Materials and Supplies				0.00
2. Publication Costs/Documentation/Dissemination				0.00
3. Consultant Services				0.00
4. Computer (ADP) Services				0.00
5. SubAwards/Consortium/Contractual Costs				0.00
6. Equipment or Facility Rental/User Fees				0.00
7. Alterations and Renovations				0.00
8.				0.00
9.				0.00
10.				0.00
G. Direct Costs — **Total Direct Costs (A through F)**				122,834.00
H. Indirect Costs — **Total Indirect Costs**				65,102.00
		Indirect Cost Rate	**Indirect Cost Base**	
MTDC:		53.00%	122,834.00	65,102.00
I. Direct and Indirect Costs — **Total Direct and Indirect Costs (G+H)**				187,936.00
J. Fee — **Total Fee**				0.00
K. Cost of Project — **Total Cost of Project (I+J)**				187,936.00

Cumulative Total	Subtotal	Totals ($)
Section A, Senior/Key Person		0.00
Section B, Other Personnel		320,303.00
Total Number Other Personnel	6	
Total Salary, Wages and Fringe Benefits (A+B)		320,303.00
Section C, Equipment		0.00
Section D, Travel		30,000.00
1. Domestic	18,000.00	
2. Foreign	12,000.00	
Section E, Participant/Trainee Support Costs		0.00
1. Tuition/Fees/Health Insurance	0.00	
2. Stipends	0.00	
3. Travel	0.00	
4. Subsistence	0.00	
5. Other	0.00	
Number of Participants/Trainees	0	
Section F, Other Direct Costs		0.00
1. Material and Supplies	0.00	
2. Publication Costs	0.00	
3. Consultant Services	0.00	
4. ADP/Computer Services	0.00	
5. Subawards/Consortium/Contractual Costs	0.00	
6. Equipment or Facility Rental/User Fees	0.00	
7. Alterations and Renovations	0.00	
8. Other 1	0.00	
9. Other 2	0.00	
10. Other 3	0.00	
Section G, Direct Costs (A thru F)		350,303.00
Section H, Indirect Costs		185,661.00
Section I, Total Direct and Indirect Costs (G+H)		535,964.00
Section J, Fee		0.00
Section K, Total Cost of Project (I+J)		535,964.00

Old Dominion University Research Foundation
BUDGET JUSTIFICATION OF COST DETAIL

SALARIES & WAGES

Post-Doctoral Associate

We are requesting funding for 12 month of effort for the Post-Doctoral Associate based on a 12-month performance period. Amounts charged per project period were calculated as follows: salary/12 = rate per month. Rate per month x number of months in period x percent effort in period = charge per period. The Post-Doctoral Associate's salary is budgeted at $50,000. A 5% salary increase has been projected in each project year.

Graduate Research Assistant

Graduate Research Assistant (GRA) wages are based on a 7.5 month performance period. A GRA may devote up to 50% academic year effort and 100% summer effort to the project each year. Specific wage rates are determined by the academic departments. They are based on the level of the student (masters or doctoral student) and on the number of years of experience the individual has had on research and sponsored projects. The wage rate for the GRA on this project is $25,500. A 5% salary increase has been projected for the Graduate Research Assistant in each project year.

FRINGE BENEFITS (ONR negotiated rate dated November 1, 2013)

Post-Doctoral Associate

FICA, unemployment insurance, worker's compensation, health, dental, life and disability insurance premiums, and annual and sick leave premiums have been budgeted for this position in accordance with current Old Dominion University Research Foundation policies.

Graduate Research Assistant

FICA, worker's compensation, and unemployment insurance premiums have been budgeted for the summer salary of the Graduate Research Assistant. Only worker's compensation has been budgeted on academic year salary.

TRAVEL

The amount of $6,000 per year in domestic travel is requested in **partial** support of meetings of the data mining collaboration and to attend professional and research conferences to discuss and present results of this research. The amount of $4,000 per year in foreign travel is similarly requested for meetings of the collaboration and to discuss and present results at international conferences, not as yet selected.

Three project events requiring travel support are planned each year, all to be held in Norfolk or Newport News, Virginia or at one of the collaborating institutions. These events are as follows,

- One meeting of the steering committee to coordinate the efforts of the data mining collaboration. This meeting will generally be held at Jefferson Lab (Newport News) or Old Dominion University (Norfolk).
- Two collaboration meetings each year to discuss CLAS data analysis techniques and methods, data mining progress, and physics topics. One meeting will generally be held at Jefferson Lab (Newport News) or Old Dominion University (Norfolk) and the other will rotate

among the collaborating institutions. Costs shown below are for travel to Norfolk.

In addition, the data postdoctoral associate will travel to collaborating institutions to coordinate data analysis efforts.

Per Diem and hotel rates are from www.gsa.gov/portal/category/100120 and airfare is from www.expedia.com. For estimating purposes, we priced domestic round-trip flights between Norfolk, VA, and Los Angeles, CA. We priced international round-trip flights between Norfolk, VA, and Glasgow, UK.

Steering Committee Meeting: 2 days, 8 attendees

$976	Per Diem ($61/day x 8 persons x 2 days)
$1,068	Hotel ($89/night x 6 persons x 2 nights)
$2,152	Domestic Airfare ($538 x 4 persons)
$3,562	Foreign Airfare ($1,781 x 2 persons)
$7,758	Total travel for meeting ($3,814 domestic/$5,158 foreign)

Collaboration Meeting: 2 days, 21 attendees

$2,562	Per Diem ($61/day x 21 persons x 2 days)
$3,382	Hotel ($89/night x 19 persons x 2 nights)
$8,070	Domestic Airfare ($538 x 15 persons)
$7,124	Foreign Airfare ($1,781 x 4 persons)
$21,138	Total travel for meeting ($12,448 domestic/$10,316 foreign)

Postdoctoral associate travel: 4 trips, 3 days, 1 person

$732	Per Diem ($61/day x 4 trips x 3 days)
$1,068	Hotel ($89/day x 4 trips x 3 days)
$2,152	Domestic Airfare ($538/trip x 4 trips)
$3,952	Total travel for postdoctoral associate for coordinating data analysis

The travel funds will be allocated as follows:

- Domestic travel:
  - $3,952 postdoctoral associate travel
  - $2,048 support for persons to travel to steering committee and collaboration meetings or to domestic conferences
- Foreign travel:
  - o $2500 support for two to three persons to travel to the steering committee and collaboration meetings
  - o $1500 support for one to two persons to attend conferences

INDIRECT COSTS

Our ONR negotiated agreement dated April 12, 2011, authorizes an on-campus indirect cost rate of 53% of modified total direct costs effective July 1, 2011, through June 30, 2014.

The Short Distance Structure of Nuclei: Mining the Wealth of Existing Jefferson Lab Data

L.B. Weinstein, Old Dominion University (Principal Investigator)
S.E. Kuhn, Old Dominion University (Co-Investigator)
M. Sargsian, Florida International University (Co-Investigator)
M. Strikman, Pennsylvania University (Co-Investigator)

We propose to coordinate and facilitate multi-institution analysis of the immense nuclear target data set from the CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab in order to address the most fundamental questions of nuclear physics: What is the nature of the nucleon-nucleon wave function at short distances? What is the nature of nucleon modification in nuclei and how is it related to the short-distance NN wave function? Can these be described in terms of nucleons and mesons or are non-nucleonic degrees of freedom (quarks and gluons) necessary?

The short-distance structure of nuclei is one of the most important though elusive subjects of experimental nuclear physics. Recent experiments, performed mostly at Jefferson Lab, provided the first direct evidence of short-range correlations (SRC) in nuclei, measured their probabilities, showed that pn- are far more important than pp-correlations, observed significant evidence for modification of bound nucleon structure, and reported the first evidence of color transparency at few-GeV energies. To make further progress, we need a more systematic study, covering a wide range of kinematics and nuclei.

This multi-institution proposal aims to further our understanding of these topics by coordinating analyses of CLAS6 nuclear target data and providing the software infrastructure to make these analyses easier. It builds on the success of the Nuclear Data Mining grant, which developed the software infrastructure to allow easy access to much of the CLAS nuclear target data, and equally importantly, to the software corrections and cuts developed by the CLAS Collaboration.

We will search for non-nucleonic degrees of freedom in nuclei by hunting for pre-existing Δ s in deuterium. We will study short distance NN pairs in nuclei by analyzing single and double nucleon knockout data, including both protons and neutrons, to understand the np to pp ratio in heavy nuclei, to characterize the momentum distribution of the NN pairs, and to understand the momentum dependence of pair knockout. We will study the relationship between the non-nucleonic degrees of freedom and short distance NN pairs by measuring the tagged EMC effect.

Many of these analyses are reaching fruition, but need to run extensive simulations of their reactions in order to publish their results. We propose to facilitate these analyses by making more of the CLAS data sets available and by further developing the software infrastructure, especially by developing an easy way to simulate electron-nucleus reactions in CLAS. This proposal, like the original data mining proposal, will provide a lot of physics for a relatively small amount of money by facilitating and coordinating data analyses at a variety of institutions.

SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA

A proposal for 2014 – 2017 submitted to the
U.S. Department of Energy, Office of Nuclear Physics,
Funding Opportunity Announcement: DE-FOA-0000995,
(6a) Medium Energy Nuclear Physics
Program Manager: Dr. Gulshan Rai

by

Old Dominion University Research Foundation (ODURF), 4111 Monarch Way, Suite 204, P. O. Box 6369, Norfolk, VA 23508-2561

L.B. Weinstein (PI), and S.E. Kuhn (co-PI) Old Dominion University, Norfolk VA 23529

Mark Strikman (co-PI), Pennsylvania State University, State College, PA

Misak Sargsian (co-PI), Florida International University, Miami, FL

G. Gavalian and S. Stepanyan,
Thomas Jefferson National Accelerator Facility, Newport News, VA

Eli Piasetzky, Or Hen, Tel-Aviv University, Tel Aviv, Israel

Shalev Gilad, Massachusetts Institute of Technology, Boston, MA

Wim Cosyn and Jan Ryckebusch, Ghent University, Belgium

Michael Wood, Canisius College, Buffalo, NY

David Ireland, I.J. Douglas MacGregor, Derek Glazier,
University of Glasgow, Scotland, UK

Dan Watts, Lorenzo Zana, University of Edinburgh, Scotland, UK

Keith Griffioen, College of William and Mary, Williamsburg VA

Gerard Gilfoyle, University of Richmond, Richmond, VA

Contact and Coordinator: Dr. L.B. Weinstein, Department of Physics, ODU, 4600 Elkhorn Ave, Norfolk VA 23529-0116. (757) 683-5803; fax (757) 683-3038; email: weinstein@odu.edu

Administrative Contact: Julie K. Tyler, Sr. Grant & Contract Administrator; ODURF, 4111 Monarch Way, Suite 204, P. O. Box 6369, Norfolk, VA 23508-2561; (757) 683-7236; fax (757) 683-5290; jktyler@odu.edu

April 30, 2014

1 Project Objectives

We propose to coordinate and facilitate multi-institution analysis of the immense nuclear target data set from the CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab in order to address the most fundamental questions of nuclear physics: What is the nature of the nucleon-nucleon wave function at short distances? What is the nature of nucleon modification in nuclei and how is it related to the short-distance NN wave function? Can these be described in terms of nucleons and mesons or are non-hadronic degrees of freedom (quarks and gluons) necessary? These questions are highlighted in the white paper on "Physics opportunities with the 12 GeV upgrade at Jefferson Lab" [1].

The short-distance structure of nuclei is one of the most important though elusive subjects of experimental nuclear physics. Recent experiments, performed mostly at Jefferson Lab, for the first time gave direct evidence of short-range correlations (SRC) in nuclei, measured their probabilities, showed that *pn*- are far more important than *pp*-correlations, observed significant evidence for modification of bound nucleon structure, and reported the first evidence of color transparency at few-GeV energies. To make further progress, we need a more systematic study, covering a wide range of kinematics and different nuclei.

Since its commissioning over ten years ago, the CEBAF Large Acceptance Spectrometer (CLAS) [2] at Jefferson Lab (JLab) has accumulated an immense data set of electron (and photon) scattering from nuclear targets (see Table 1). We started reanalyzing this data three years ago to address important physics questions that are now coming to the forefront of scientific interest.

Run Period	Beam type	Beam energy (GeV)	Targets	Status
E2a	e	1.16, 2.26, 4.46	^{3}He, ^{4}He, C, Fe	In progress
E2b	e	0.98, 4.46, 4.71	^{3}He, Fe	Available
E6	e	5.77	^{2}H	Available
EG1a	$\vec{e}$	2.5, 4.2	$N\vec{H}_3$, $N\vec{D}_3$, C	
EG1b	$\vec{e}$	1.6 to 5.7	$N\vec{H}_3$, $N\vec{D}_3$, C	
E5	e	2.56, 4.23	^{1}H, ^{2}H	
EG2	e	4.0, 5.0	^{2}H + (C, Al, Ni, Fe, Pb)	Available
E1e	e	2.04	^{2}H	
EG3	γ	< 5.76	^{2}H	
E8 (BoNuS)	e	1.1 to 5.4	^{1}H, ^{2}H	
EG6	e	1.1 to 5.4	^{4}He	

Table 1: CLAS nuclear dataset. The 'status' column refers to data sets that are available in the Data Mining Software.

During those last three years we developed the software infrastructure to allow easy access to those data, and equally importantly, to the software corrections and cuts developed by the CLAS Collaboration. The data sets listed as "Available" in Table 1 have been processed and are available for analysis. Researchers around the world are using this software to analyze these data.

Many of these analyses are now reaching fruition, but need to run extensive simulations of their reactions in order to publish their results. We propose to facilitate these analyses by making more of the CLAS data sets available and by further developing the software infrastructure, especially by developing an easy way to simulate electron-nucleus reactions in CLAS. This proposal, like the original data mining proposal, will provide a lot of physics for a relatively small amount of money by facilitating and coordinating data analyses at a variety of institutions. By doing so, we will also help fulfill the Department of Energy data management mandate which states that "Sharing and preserving data are central to protecting the integrity of science by facilitating replication of results and to advancing science by broadening the value of research data to disciplines other than the originating one and to society at large."

The objective of the initiative described in this proposal is two-fold. We aim to greatly increase our understanding of hard scattering (QCD) effects in nuclei and to do so by putting in place an organizational framework to support a significant and sustained analysis effort.

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2 Project Description

2.1 Introduction

During the last few years, significant progress has been made at Jefferson Lab (JLab) in understanding the short-distance structure of nuclei in general and in short-range correlations (SRC) in nuclei and dynamics of interactions with nuclei at large momentum transfer in particular.

- $A(e, e')$ experiments at $x > 1$ confirmed the existence of the universal structure of two nucleon short-range correlations (SRC) in nuclei and measured the strength of those correlations for a variety of nuclei [3, 4, 5].
- $A(e, e'pN)$ studies have shown that large initial momentum protons ($k \geq k_{fermi} \approx$ 250 MeV/c) all have correlated partner nucleons and that these correlated SRC pairs are predominantly pn rather than pp [6, 7, 8, 9, 10].
- Three body electrodisintegration measurements, ^{3}He$(e, e'pp)n$, measured the relative and total momenta of pp and pn correlated pairs by knocking out the third nucleon and observing the spectator correlated pair [11]. They confirmed the dominance of tensor correlations at intermediate pair relative momenta by measuring the pp to pn ratio as a function of pair total momentum [12, 13].
- Studies of the G_E/G_M ratio for the scattering off a bound nucleon found possible indications of a difference between the bound and free nucleon wave functions [14]. This finding complements results of studies of the EMC effect (which now include the lightest nuclei) which also indicate modification of bound-nucleon structure.
- Detailed studies of D$(e, e'p)n$ in Halls A [15] and B [16, 17] and of D$(e, e'p)X$ in Hall B [18] have yielded new data on the interplay of high-momentum components in the nuclear wave function and final state interactions between the nucleons and (in the latter case) the final state "debris" after an inelastic reaction.
- Comparisons of Short Range Correlation scale factors and the magnitude of the EMC effect for different nuclei indicate that the two are strikingly and linearly correlated [19, 20, 21]. This correlation implies that both SRC and the EMC effect are caused by the same underlying physics.
- High precision studies of meson electro-production from nuclei found evidence for the onset of color transparency in hard large Q^2 processes for both π [22] and ρ [23] production.

These very successful experiments should be followed up by both new experiments at JLab and elsewhere and by exploiting the rich data already collected by CLAS6 at a range of beam energies and targets. This proposal will explore several ways of probing microscopic nuclear dynamics and color transparency phenomena using this already-collected data.

This low cost approach will speed up developments in the field, allowing discovery of novel nuclear phenomena, and giving interested groups the flexibility to explore phenomena not currently anticipated. It will also help in optimizing experiments which will be performed at JLab after the 12 GeV upgrade.

Below we will outline the physics topics we want to study and the proposed mode of operation of the study.

2.2 Study of Short Range Correlations (SRC)

2.2.1 Scientific background

Studying two body correlations in nuclei has been a key part of the Jefferson Lab scientific program from the 1985 CEBAF Pre-Conceptual Design Review (PCDR) to the 2012 Jefferson Lab 12 GeV Upgrade White Paper. We seek to answer the question: What is the nature of the nucleon-nucleon (NN) relative wave function at short distances? Can this be described in terms of nucleons and mesons, or are quarks and gluons necessary?

Short Range Correlated nucleon pairs in nuclei are those where the nucleon centers are separated by less than approximately 1.2 femtometer (fm). In momentum space, an SRC pair is characterized by a large relative momentum ($p_{rel} = |\vec{p}_1 - \vec{p}_2|/2 \geq 250$ MeV/c) and a small center-of-mass (cm) momentum ($p_{cm} = |\vec{p}_1 + \vec{p}_2|$), where large and small are relative to k_F, the Fermi momentum. Studies of (SRCs) in nuclei are important for understanding the short-distance and large-momentum properties of the nuclear ground-state wave function. The separation distances and associated local densities in SRCs are expected to be comparable to those in the cores of neutron stars. SRCs therefore also have far-reaching implications for modeling and understanding cold dense nuclear matter and neutron stars. As we will discuss below, SRC are also a unique way to study the short range nucleon-nucleon interaction. In particular, the study of SRC pairs in nuclei opens a way to study the short-range tensor force and the even shorter range repulsive core.

The study of SRCs in nuclei is almost as old as the study of the shell model. SRCs enter as a key element of Bethe-Bruckner theory, for the early review see [24]. From the very first days it was clear that the picture of independent particles in a mean field needs corrections due to both long-range and short-range correlations between the nucleons. However, for many years, identifying and studying SRCs presented a formidable challenge to both theory and experiment. Experimental studies of the microscopic structure of SRCs were very much restricted due to the difficulty in resolving SRCs when only moderate momentum-transfer kinematics were available, using low and medium energy probes.

Recently, several high-energy, large-momentum-transfer measurements, along with companion theoretical studies, have made tremendous progress in identifying SRC pairs in nuclei and understanding their dynamics.

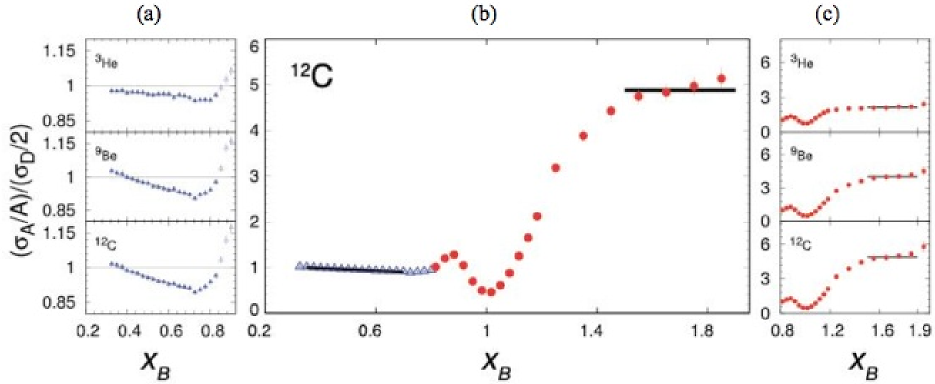

Figure 1: Cross-section ratios (per nuclei) of of various nuclei to deuterium, as a function of Bjorken x (x_B). (a) Ratios for $0.2 < x_B < 0.9$ [28]; (b) Ratios for ^{12}C for $0.3 < x_b < 2$; (c) Ratios for $0.8 < x_B < 1.8$ [5]

Several JLab experiments measured inclusive electron scattering [3, 4, 5] to check the predicted universality of short-range correlations by measuring the ratio of the inclusive cross sections for heavy to light nuclei at high momentum transfer, $Q^2 > 1.4$ (GeV/c)^2, and $x_B > 1$ where scattering off slow nucleons in the nucleus does not contribute. The main advantage of the discussed process is that the long range final state interactions should cancel due to closure, while the local final state interaction in the SRCs is universal and cancels in the ratios [25, 26]. The predicted signal for dominance of the correlations is the scaling of the ratios, a weak dependence on x_B and Q^2 for $1.5 < x_B < 2$, which is clearly observed in the data (see Figure 1c). The measured scale factors indicate that such correlations involve about 20% of the nucleons in ^{12}C and about 25% in heavy nuclei.

While the inclusive data clearly suggest strong local correlations, it required exclusive data to confirm that the inclusive scaling is due to short-range correlations and to measure directly the fraction of nucleon pair types involved. Experimentally, a high-momentum-transfer, small de-Broglie wavelength probe can knock a proton out of a nucleus, leaving the residual nucleus nearly unaffected. If, on the other hand, the struck proton is part of an SRC pair, the high relative momentum in the pair will cause the correlated nucleon to recoil and be ejected with high-momentum almost equal in size and opposite in direction to the initial momentum of the struck proton [26] (see Figure 2).

The triple coincidence ^{12}C(p, ppn) measurement at beam momenta between 6 and 9 GeV/c at Brookhaven National Laboratory [8, 9, 10] identified np SRC pairs and demonstrated that 92^{+8}_{-18}% of the protons in ^{12}C with 'initial' momenta above 275 MeV/c are partners in np SRC pairs [10]. The JLab ^{12}C$(e, e'pN)$ experiment showed that nearly all protons in ^{12}C with momentum in the range 300 to 600 MeV/c have a correlated nucleon

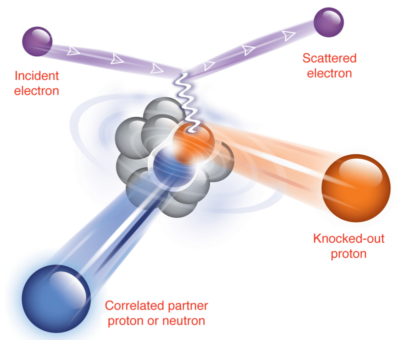

Figure 2: Illustration showing the $A(e, e'pN)$ reaction. The incident electron couples to the proton in a nucleon-nucleon pair via a virtual photon. In the final state, the scattered electron and knocked-out proton are detected along with the correlated nucleon that is ejected from the nucleus. For the BNL measurement the incident and scattered electron should be replaced by a proton and the detected correlated nucleon was only a neutron.

partner with roughly equal and opposite momentum [6, 7]. It was also found, by comparing neutron-proton (np) to proton-proton (pp) yields, that the np SRC pairs outnumber the pp pairs by a factor of 18±5. Considering isospin symmetry only, one would expect the number of nn SRC pairs in ^{12}C to be equal to the number of pp SRC pairs. These measurements were performed at relatively small pair cm momentum.

The ratios from the BNL and JLab measurements were used to calculate the fraction of SRC pairs that are nn, np, or pp, see Figure 3. To obtain a comprehensive picture of the structure of ^{12}C, we can combine the results in Fig. 3 with inclusive $^{12}\text{C}(e, e')$ measurements [4, 5], which showed that 20±5% of the nucleons in ^{12}C are members of SRC pairs. Fig. 4 shows pictorially that (80±5)% of ^{12}C nucleons are low-momentum independent or long-range correlated nucleons, (18±5)% belong to np SRC pairs, and pp and nn SRC pairs each contain (1±0.3)% of the nucleons.

This small ratio of pp to np pairs was explained by three theoretical groups [29, 30, 31]. At relative momenta of $300 < p_{rel} < 500$ MeV/c and small cm momenta, there is a strong minimum in the pp momentum distribution. This minimum is filled in by tensor forces in the np momentum distribution. This clearly shows that the small measured pp-SRC/np-

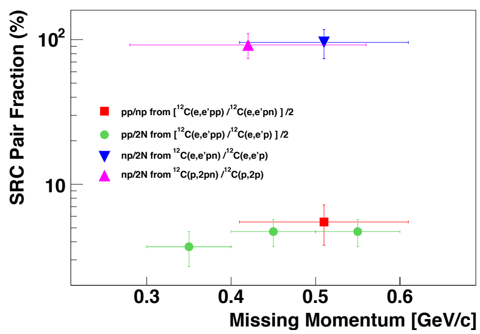

Figure 3: The ratio of SRC pairs as determined from exclusive high momentum transfer measurements [10, 7].

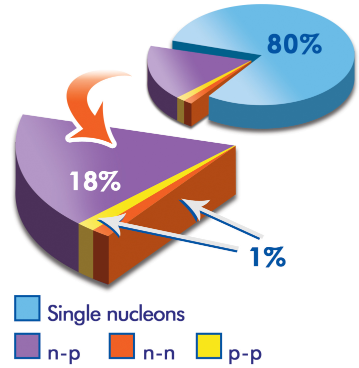

Figure 4: The average fraction of nucleons in the various ground state configurations of ^{12}C.

SRC ratio is the result of the NN tensor force.

It is important to emphasize here that the kinematics of the BNL and JLab experiments are very different. In the BNL experiment, the struck nucleon has initial momentum along the beam and $-t \sim 5$ GeV^2, while in the JLab experiment the struck nucleon has initial momentum opposite the beam and the transferred momentum is $Q^2 = 2$ GeV^2. Still the SRC decay model [10] describes both data sets well. This gives us confidence that the basic mechanism of the reaction at high momentum transfer is now reasonably well understood.

CLAS has also measured the distorted relative and total correlated pair momentum distributions in ^{3}He$(e, e'pp)n$ at momentum transfers of $Q^2 \approx 0.7$ and 1.5 GeV^2, by choosing kinematics where the virtual photon is absorbed on one nucleon (the leading nucleon) and the spectator correlated pair decays [11, 13]. When all three detected nucleons have large momenta ($p_N > 250$ MeV/c), there are peaks in the lab-frame Dalitz plot where the leading nucleon has most of the transferred energy, ω, and the two other nucleons each have less than 20% of ω. The effect of rescattering of the leading nucleon was reduced by requiring that its momentum perpendicular to the momentum transfer, $\vec{q}$, be less than 300 MeV/c. In this case, the two other nucleons a) are predominantly back-to-back, b) have little cm momentum parallel to $\vec{q}$, and c) are relatively isotropic. This indicates that they are spectators to the reaction. The resulting relative and total momentum distributions can be seen in Fig. 5. The one-body calculation (which includes direct knockout of the

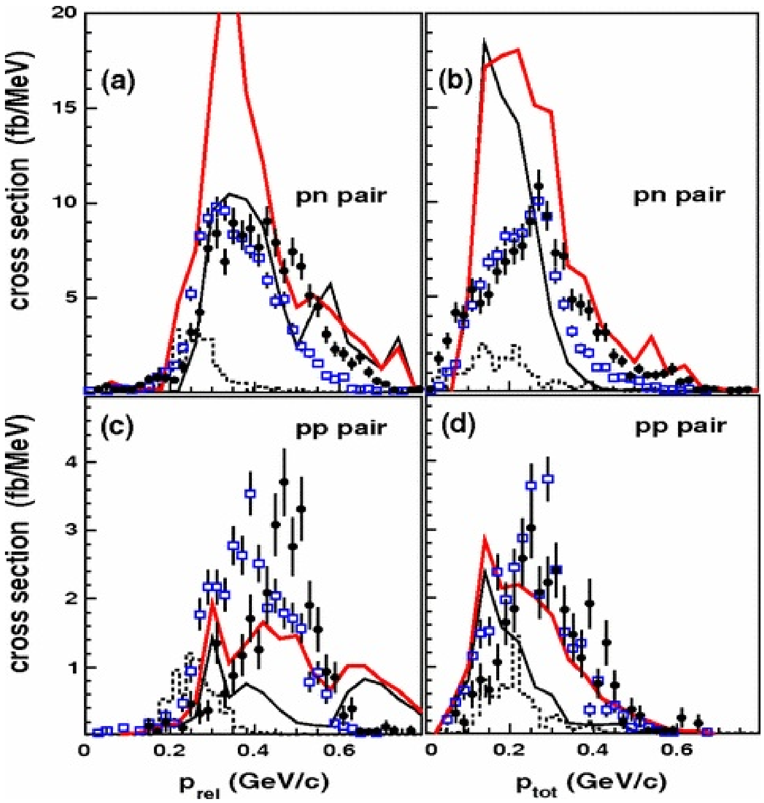

Figure 5: (a) Cross section vs relative momentum p_{rel} of the pn pairs [13]. Solid points show the data at $Q^2 \approx 1.5$ GeV^2), blue open squares show the data at $Q^2 \approx 0.7$ GeV^2 [11], the dashed histogram shows the Golak one-body calculation, the thin solid line shows the Laget one-body calculation, and the thick solid red line shows the Laget full calculation; (b) the same for the total momentum p_{tot}; (c),(d) the same for pp pairs. All quantities are in the lab frame. The $Q^2 \approx 0.7$ GeV^2 data have been reduced by a factor of 5.3 (the ratio of the cross sections) for comparison.

leading nucleon plus the continuum reinteraction of the spectator pair) describes the data qualitatively. The momentum distributions are the same (except for a scale factor) for the two momentum transfers.

Because the CLAS measurement covered a large range in both relative and cm (total) pair momenta, it also measured the dependence of the pp to pn pair ratio on the pair cm momentum (see Fig. 6). Note that the ratio is very small at low pair cm momentum, consistent with the results mentioned above, and increases to the pair counting limit at large cm momentum. This result is not consistent with the simple ratio of bound state

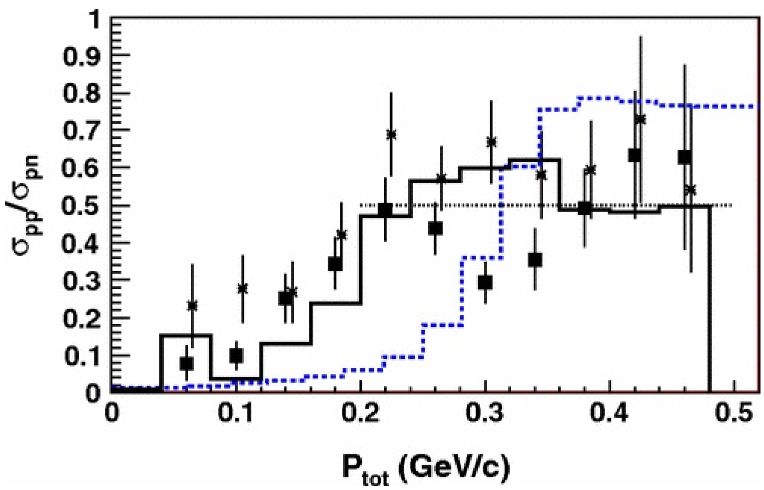

Figure 6: Ratio of pp to pn spectator pair cross sections as a function of pair total (cm) momentum, integrated over $0.3 < p_{rel} < 0.5$ GeV/c. The black squares show the data [12, 13], the solid histogram shows the ratio of the Golak one-body calculation and the blue dashed histogram shows the ratio of the Golak bound state momentum distributions [32]. The black stars show the data integrated over $0.4 < p_{rel} < 0.6$ GeV/c. The dotted line at 0.5 shows the simple-minded pair counting result. The data and the one-body calculation have been multiplied by 1.5 to approximately account for the ratio of the average electron-proton and electron-neutron elementary cross sections.

momentum distributions but it is well described by the results of a calculation by Golak *et al.* which includes direct knockout of the leading nucleon plus the continuum interaction of the spectator pair [32]. This is another indication of the importance of tensor correlations. At low cm momentum, the pp pair has a minimum at $p_{rel} \approx 400$ MeV/c while the corresponding minimum for the np pair is filled in by tensor forces. As the cm momentum increases, the pp pair minimum is predicted to fill in, also due to tensor forces.

A current data-mining analysis [33] measured the ratio of two-proton knockout $(e, e'pp)$ to one-proton knockout $(e, e'p)$ in nuclei from C to Pb to measure the proportion of high-momentum protons with a correlated proton partner. Previous measurements of C$(e, e'p)$, $(e, e'pp)$, and $(e, e'pn)$ [6, 7] showed that all high-momentum protons ($p \geq 300$ MeV/c) in carbon had a correlated partner nucleon and that those nucleons were almost entirely neutrons. The new analysis shows that np-SRC pairs continue to dominate, even in heavy asymmetric nuclei such as Pb. The continued dominance of np pairs means that there are equal numbers of high momentum protons and neutrons and that therefore the average proton has a greater momentum than the average neutron. The analysis generalizes this behavior to imbalanced interacting two-component Fermi gases.

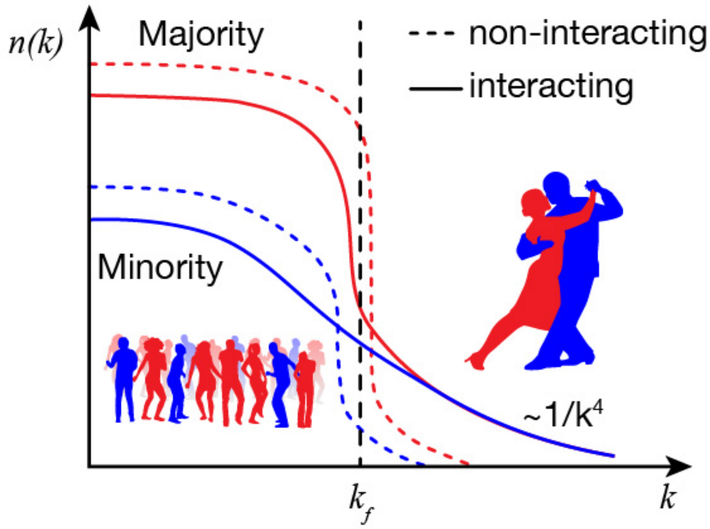

Figure 7: A schematic representation of the main characteristics of the momentum distribution of two-component imbalanced Fermi systems. The dashed lines show the standard non-interacting system while the solid lines show the effect of including a short-range interaction between different Fermions. In ^{208}Pb neutrons and protons are the majority and minority fermions, respectively. The pictures illustrate the analogy that if there are fewer boys than girls at a dance party, the average boy will dance more than the average girl, and hence have larger average momentum, assuming boy-girl interaction dominance.

The following section lists a few research avenues that could yield new information on SRC using already accumulated data. Analysis of this data should provide information complementary to the published and planned measurements.

2.2.2 More detailed study of 2N-SRC

The large set of available data allow also to improve our knowledge of 2N-SRC by looking for $(e, e'p)$ or $(e, e'n)$ events in coincidence with a recoil high momentum proton or neutron. The exclusive measurement of Hall A [6, 7] are being extended to:

1. Study the A dependence.

   Study correlations in the scattering off other nuclei than ^{12}C. The correlations should be a universal phenomena except for rescattering and absorption effects for heavier nuclei.

2. Check the Q^2 dependence.

   If the process is $(e, e'p)N$ due to the decay of an SRC after removal of a proton, then it should have the same Q^2 dependence as $(e, e'p)$. This is an important check that we understand the recoil particle production mechanism.

3. Study the dependence on isospin.

   Study in more detail the isospin ratio np-SRC / pp-SRC as a function of the c.m. momentum of the pair and compare to the calculations of double momentum distributions [29, 31]. This can be done using the large acceptance of CLAS.

4. Measure the momentum dependence

   Measure the relative and cm momentum distributions of pp and np pairs in nuclei.

5. Compare real to virtual photon induced breakup of the SRC pair.

   For example, look at the process in nuclei of $\gamma + n \to \pi^- p$ at large angles in association with backward proton production.

2.2.3 Study of the deuteron system

The deuteron, as the simplest nuclear system, serves the dual role of an "effective free neutron target" [34, 35, 36, 37] and as a testing ground for sophisticated models of nucleon-nucleon interactions and scattering mechanisms [38, 39]. Electron scattering off the deuteron has been used as a means to extract information on its nuclear structure, including the D-wave ($L = 2$) contribution to the ground state wave function [40, 41]. On the other hand, experiments that look for modifications of nucleon structure due to nuclear binding have also used (or plan to use) the deuteron as a testbed [18, 42]; see also the next section. In all of these cases, a thorough and detailed understanding of the scattering mechanism is necessary. Any claims of evidence for non-nucleonic degrees of freedom require a state-of-the-art benchmark calculation for the reaction under study, including final state interaction (FSI) effects.

In addition, the previously observed scaling of the ratios for inclusive (e, e') scattering at $x > 1$ [5] indicates that the properties of 2N SRC in nuclei (which are predominantly $I = 0$) are similar to the SRC in the deuteron. Hence these correlations could be studied using scattering off the deuteron.

In particular quasi-elastic scattering off the deuteron has been studied [43] as an ideal reaction to disentangle various contributions to the reaction mechanism, like relativistic effects, non-nucleonic components of the deuteron wave function, meson-exchange (MEC) and isobar (IC) currents, and FSI between the outgoing nucleons. Recent experiments [44, 45] have focussed on higher momentum transfers, where one-nucleon currents are expected to dominate the cross section. Because of the continuing (and growing) importance of the deuteron as an effective neutron target [46, 47], a particular important question is whether there is a kinematic region where the simple picture of the Plane Wave Impulse Approximation (PWIA) works reasonably well, in which the virtual photon is absorbed by only one nucleon inside the deuteron while the other is an unperturbed spectator to the reaction. Alternatively, one wants to test state of the art models of FSI to ascertain that they can yield a reliable description of the reaction mechanism. In this quest, polarization degrees of freedom are particular interesting, yet few experiments exist.

From a practical point of view, quasi-elastic scattering off a polarized deuteron target (with or without detection of a final state proton) is often used as a direct measure of the product of beam and target polarization for spin structure function experiments. This requires that the theoretical asymmetry for this process is well-known, an assumption that should be tested experimentally.

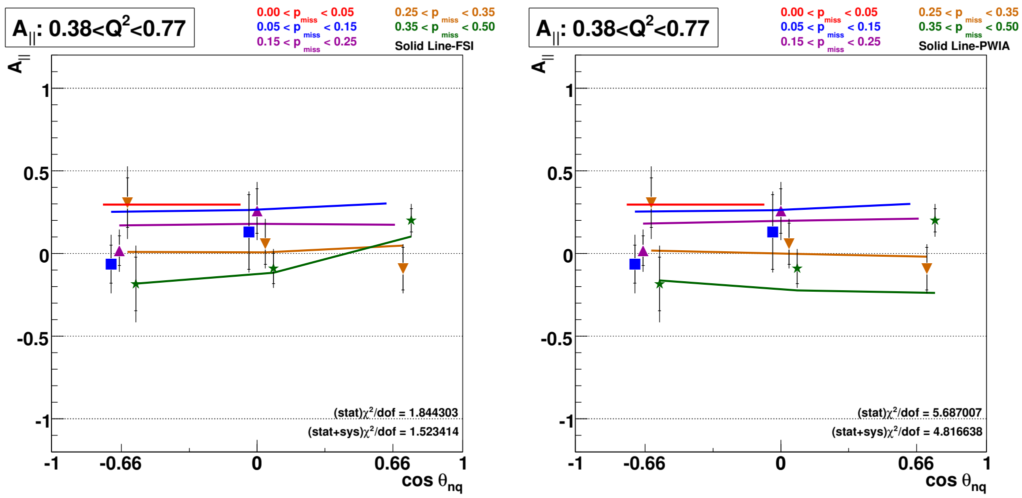

Figure 8: $A_{||}$ for Beam Energy of 2.5 GeV and one Q^2 bin. The data are shown versus the cosine of the angle between the inferred "spectator" neutron direction and the momentum transfer vector. There are 5 sets of data for 5 bins in spectator momentum (indicated by different symbols and colors). Statistical errors are shown as horizontal crosses, while the total length of the vertical error bars indicate the combined systematic and statistical uncertainties. The five curves are from the theoretical calculation of [48], color-coded for the corresponding momentum bins. The left-hand side shows the curves for the model including FSI, while the right-hand side panel shows the same model including only PWIA contributions.

Recently, very sophisticated calculations for the reaction mechanism in quasi-elastic deuteron break-up have become available that include both fully relativistic effects and a realistic treatment of FSI, including spin degrees of freedom, up to the highest energies available at Jefferson Lab [48, 49, 50]. These calculations can be tested using existing

CLAS data on both unpolarized and polarized deuterons. A first analysis in this direction (of the double spin asymmetry $A_{||}$ in ^{2}H$(e, e'p)n$, using CLAS eg1b data) has been recently completed as part of a Ph.D. thesis in our group [51]. Figure 8 shows the results for a single bin in Q^2 and 2.5 GeV beam energy; one can clearly see the dependence of $A_{||}$ on the momentum of the "spectator" neutron (5 different sets of symbols and colors). The full calculation including FSI (left panel) yields an overall good description of the results, while PWIA alone (right panel) does less well at high spectator momenta. A publication of these results is presently under CLAS collaboration review. These studies are planned to be extended to additional data sets available from the EG4 and EG1-DVCS runs with CLAS. Furthermore, we can also analyze the electron beam helicity–dependence of the cross section for ^{2}H$(e, e'p)n$ (the so-called "fifth structure function") which is uniquely sensitive to FSI, using CLAS data on unpolarized deuterium (E5, E6, EG2, E1e). We have already begun a preliminary analysis in this direction using E6 data, while the E5 data have been analyzed by another group of CLAS collaborators [53].

In addition to quasi-elastic scattering, there is also great interest in the ^{2}H$(e, e'p_b)X$ reaction, where the detected proton is moving in the backward direction ("spectator") and the final state mass of the struck neutron is either in the resonance or the DIS region. This reaction has been (and will be) used to look for momentum-dependent modifications of neutron structure [18, 42] as well as (for low spectator momenta) to extract the nearly free neutron structure function [37, 46]. Again, a realistic understanding of FSI effects is necessary to draw unambiguous conclusions from such data. Models for these FSI effects have been developed by members of the data mining collaboration [52] and successfully applied to the e6 data. These models are presently being compared to the results from the "BONuS" experiment [37]. Future extensions of this work to other data sets (E5, EG2, E1e) and potentially polarized structure functions (EG1, EG4, EG1-DVCS) are possible and planned as part of this proposal.

2.2.4 A search for non-nucleonic decays of the SRC via Δ-isobar production

A basic question in nuclear and particle physics is whether (and where) one can observe unambiguous deviations from the nucleons only picture of nuclei, requiring explicit consideration of non-nucleonic degrees of freedom in the nuclear wave function.

Studies of the last few years have established that short range correlations play an important role in nuclear structure and that the non-nucleonic degrees of freedom which manifest themselves in the EMC effect are dominated by the contribution of the SRCs [19].

Hence one of the goals of this proposal is to observe and discover direct evidence of non-nucleonic degrees of freedom in nuclei. We expect that study of SRCs, which involve two nucleons that are close to each other and carry high relative momenta, is one of the most promising strategies to achieve this goal.

The most likely baryonic non-nucleonic degrees of freedom are $N\Delta$ and $\Delta\Delta$ admixtures in SRC pairs. These components have the smallest mass gap (components with dynamic pions are suppressed by the chiral dynamics). Though these components are expected to contribute only $\approx 1\%$ per nucleon, they are expected to have a much broader relative momentum distribution than mean field or SRC-pair nucleons. This will allus to look for their production in kinematics forbidden for scattering off a free nucleon. (This strategy will also allow us to look for more complicated quark structures like six quark states as they have a significant overlap with $N\Delta, \Delta\Delta$ states).

The tantalizing indication of the significant rate of the Δ^{++}, Δ^0 production at $\alpha > 1$ was reported a long time ago by members of ARGUS group at DORIS (DESY) [56] but these studies were never followed up. Authors reported the ratio

$$\frac{\sigma(e + A \to \Delta^{++} + X)}{\sigma(e + A \to p + X)} = (4.5 \pm 0.6 \pm 1.5) \cdot 10^{-2} \tag{1}$$

for the interaction of the quasi real photons in electron - air interactions at $E_e = 5$ GeV and comparable rates of Δ^{++} and Δ^0 production (which is natural for SRC in nuclei with A between 12 and 16).

We will look for non-nucleonic components of SRC in several channels: by measuring the decays of Δ's with light cone fraction $\alpha > 1$; by measuring the production of a leading Δ^{++} in electron scattering in reactions like $e+{}^2\text{H}\to e+\Delta^{++}+\Delta^-$ and $e+{}^3\text{He}\to e+\Delta^{++}+nn$; by comparing Δ^0 and Δ^{++} knockout from nuclei; and by analyzing tagged structure functions of nuclei (described in a later section).

A particularly clean system to look for such *intrinsic* Delta degrees of freedom is the deuteron, which is the simplest nucleus and for which detailed microscopic wave functions based on purely nucleonic degrees of freedom exist [39, 54, 41]. Because the deuteron has isospin 0, Delta can only occur in pairs, either $\Delta^0\Delta^+$ or $\Delta^-\Delta^{++}$. While these configurations contribute only a very small fraction to the overall deuteron wave function, they may be enhanced in its high-momentum tail (due to short-range and tensor correlations). Experimentally, it may be possible to extract information on these configurations by studying the reaction ${}^2\text{H}(e, e'\Delta)\Delta$, where one of the two Deltas is moving backwards with fairly high momentum, $p > 0.3$ GeV/c, relative to the direction of the momentum transfer vector $\vec{q}$. For either of the two cases listed above, there is one Delta that decays into two charged particles (either $\Delta^{++} \to p\pi^+$ or $\Delta^0 \to p\pi^-$) which can be detected by CLAS, while the other Delta can be reconstructed from the missing mass.

We have done a very preliminary study of this reaction, as part of an undergraduate Senior Thesis [55]. Figure 9 shows the angular distributions of both Δ^{++} and Δ^0 from these channels, using the CLAS e6 data set which has already been incorporated into the data mining database. To draw meaningful conclusions from these data, we will have to develop a full Monte Carlo simulation of this reaction in CLAS, to accurately estimate the ratio of probabilities for various Delta charge states to be emitted in the forward and backward directions. We also plan to increase the data sample by adding data from the other CLAS run periods including deuteron targets: E5, EG2, E1e, and E8 ("BONuS"). With the ability to cross-check our results from different experimental set-ups (and different

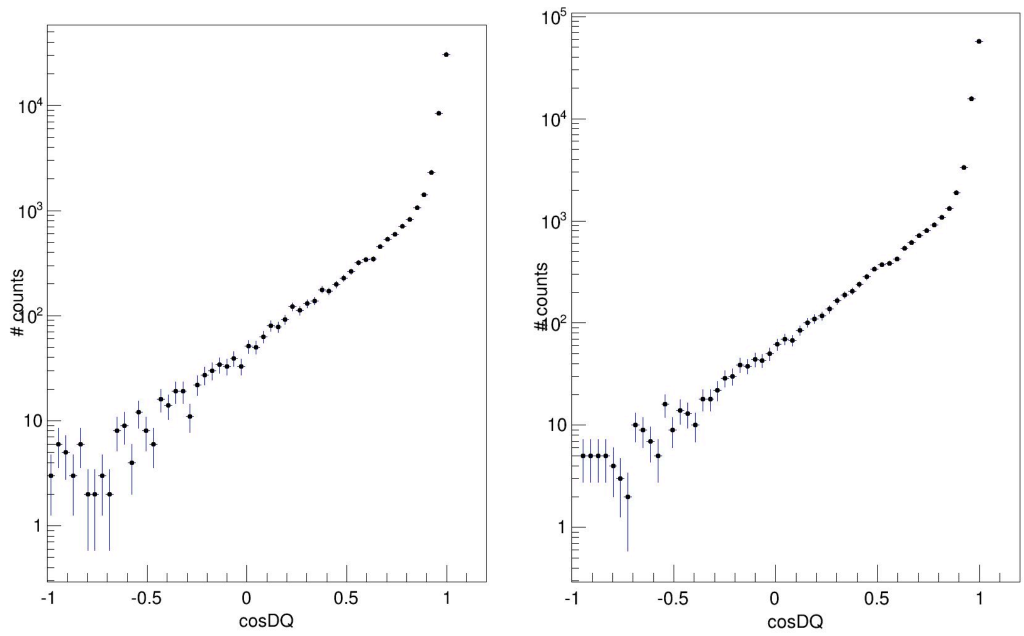

Figure 9: Preliminary angular distributions of final state Δ^{++} (left) and Δ^0 (right) relative to the direction of the virtual photon, from CLAS E6 data.

beam energies), we expect to be able to either find an unambiguous signal of "pre-existing Deltas" in the deuteron or to put a significant upper limit on their presence in the deuteron ground state.

Further searches for non-nucleonic components in the SRC will include:

1. <u>Search for backward emitted $\Delta^{++}(\pi^+, p), \Delta^+(\pi^0, p), \Delta^0(\pi^-, p)$, and $\Delta^-(\pi^-, n)$</u>

   We propose to look for Δ electroproduction at backward angles (relative to $\vec{q}$) at both $x > 1$ and $x < 1$, possibly even in coincidence with the forward protons/neutrons from the decay of forward angle Δs. Based on the inclusive data on electron - air interactions at $E_e = 5$ GeV obtained at DESY using the ARGUS detector (published only as a DESY preprint [56]), one can expect that the production rates of fast backward Δ^{++} or Δ^0 should be about 5% of the fast backward proton rate for the same light-cone fractions of nucleon and Δ.

   Measuring the x and Q^2 dependence of the reaction in addition to the momentum and angle dependence of the forward particles should allow us to separate the contribution of the decays from the contribution of background multistep processes.

2. <u>Search for forward Δ^{++} production at $x > 1$</u>

In this kinematics (Δ^{++} carrying most of the virtual photon momentum) we plan to look for knockout of isobars from SRC. Since the momentum distribution of Δ's is broader than that of nucleons, we expect this process to be enhanced for $x \geq 1.3$ where the virtual photon is absorbed by a fast moving baryonic constituent of the nucleus. At the same time we will explore the $x \sim 1$ kinematics where production of the Δ^{++} from two step processes like $\gamma^* + p \rightarrow \Delta^+$ followed by $\Delta^+ + p \rightarrow \Delta^{++} + n$ is enhanced in order to understand the contribution of these two step processes. To ensure the knocked-out Δ is moving fast relative to the rest of the nucleus we will require $Q^2 \geq 1.5$ GeV^2.

3. Delta production on nuclei

We propose to look at the properties of the $\Delta^0(1232)$ generated from a quasi-free neutron in a ^{3}He target [57]. This work is complementary to previous CLAS analyses using the free proton target, and will allow the study of the Δ resonance region in a different isospin channel. We would look at angular distributions of the decay products from the reaction $^3\mathrm{He}(e, e'p\pi)2p$ (mainly the $p\pi^-$ channel). Information on the 'shape' of the Δ^0 can be extracted by measuring the dominant magnetic dipole (M1) and the interference from the electric quadrupole (E2) and Coulomb quadrupole (C2). We plan to investigate the Q^2 range of $0.1 - 0.4$ (GeV/c)^2. Theoretical comparisons will be made with MAID predictions.

The analysis will complete work already begun, and will use existing E-89-017 data acquired with CLAS during the $e2b$ run period, in June 2002, with a ^{3}He cryogenic target and a beam energy of 0.982 GeV. The study will be extended to the higher energy data to provide a greater Q^2 range.

2.2.5 A search for 3N SRC

The scaling of the (e, e') ratios for $x > 2$ [4, 27] and analysis of the data on fast backward nucleon production [26] suggest that, in addition to 2N SRC, higher order correlations should be present (though with a much smaller probability on the order of 10% of 2N SRC). The current uncertainties in the study of SRC in nuclei allow a small fraction of the $(e, e'p)$ events to be associated with multi-nucleon SRC. 3N-SRC are probably the most populated multi-nucleon SRC. We propose to look for 3N-SRC by identifying events with two high energy recoil nucleons. This can be done inclusively and also in coincidence with the scattered electron. In particular, if the two backward nucleons are produced in processes where the electron scatters off a forward moving nucleon, then a "Doppler" type shift in the scattered electron distribution is expected to smaller x.

We will also investigate the 3-body effects in the $^3\mathrm{He}(e, e'p)n$ reaction at relatively low energy and momentum transfer, $0.1 \leq \nu \leq 0.5$ GeV and $0.35 \leq |\vec{q}| \leq 0.80$ GeV/c with a beam energy of 1 GeV [58]. At this beam energy we can comparise our data with the

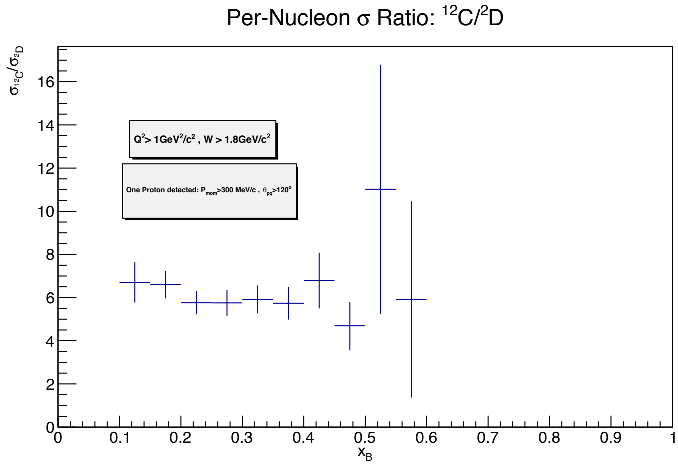

Figure 10: Tagged EMC ratio: Preliminary $(e, e'p_b)$ cross-section ratios (per nucleon) of C to deuterium with a fast backward proton, as a function of Bjorken x (x_B). The data is cut on $Q^2 > 1$ GeV^2, $W > 1.8$ GeV, $p_p > 300$ MeV/c and $\theta_{pq} > 120°$ where W is the proton at rest plus virtual photon invariant mass. The data is not acceptance corrected.

newest generation of Faddeev calculations that are valid at low energy transfers, and also provide tests of the Laget model in previously untested kinematic regimes.

2.3 Nucleon properties in nuclei

Another outstanding question is whether the nuclear medium alters the structure of bound nucleons and, if so, how? The neutron lifetime in nuclei is certainly different. The first evidence for nucleon structure modification was the EMC effect [59], in which deep-inelastic scattering (DIS) from nuclear quarks is significantly different than from quarks inside a free nucleon (see Figure 1a). The per-nucleon DIS cross section ratio of nucleus A to deuterium decreases approximately linearly for $0.3 < x_B < 0.7$ where $x_B = Q^2/2m\nu$. The slope of this ratio in this region increases with A but does not scale simply with average nuclear density. Despite a world-wide effort in experiment and theory, the origins of the EMC effect remain unclear.

Recent phenomenological comparisons [19, 20, 21] show that the strength of the EMC effect in different nuclei is linearly related to the short range correlations scale factor, $a_2(A/d)$. This linear relation indicates, but does not prove, that the EMC effect is caused by local modifications of nucleon structure occurring when two would-be nucleons make a close encounter and briefly comprise a system of density high enough to be comparable to that of neutron stars.

If the nucleon structure modification measured by the EMC effect occurs primarily in nucleons belonging to SRC pairs, this should be reflected in the "tagged" EMC ratio, the per-nucleon cross section ratio of nucleus A to deuterium for DIS scattering with an associated fast backward proton ($p_p > 300$ MeV/c, $\theta_{pq} > 120°$). A fast backward proton almost always comes from the breakup of a correlated pair. Detecting the fast backward proton therefore implies that the DIS reaction occured on the other nucleon in the correlated pair. If the nucleons in deuterium and nucleus A both belong to correlated pairs, then both are equally modified and the EMC ratio should be approximately equal to the ratio of the number of correlated pairs in the two nuclei (a_2) and should be independent of x_B.

Barak Schmookler of MIT is analyzing EG2 data as part of the data mining collaboration to determine the tagged EMC ratio for C, Fe, and Pb. Fig. 10) shows that the preliminary tagged EMC ratio for C is independent of x_B and its value of ≈ 6 is similar to the carbon-deuterium cross section ratio in the SRC region of ≈ 5 [5]. Analysis of this data is continuing.

2.4 Study of nuclear transparency (FSI)

2.4.1 Scientific background

In QED, the suppression of small dipole interactions due to the internal screening of charges is well known. This was demonstrated experimentally by measuring the reduced energy deposited from an e^+e^- pair in the vicinity of their creation point in a π^0 decay, known as the King-Perkins-Chudakov effect. The first reported measurement in 1955 used cosmic rays and emulsions [60]. Much more recently, a group from CERN measured the energy deposited by an e^+e^- pair produced by high energy photons as a function of their distance from the production point [61].

In QCD there should be a similar suppression of the strong interaction of small size singlet wave packets. This is called color transparency (CT). This prediction about hadron interactions in the nuclear medium needs to be addressed by experiments.

Nuclear transparency is defined as the ratio of the cross section per nucleon in the nucleus to that from a free nucleon. If in the elementary process hadrons are produced in a compressed configuration and travel some distance through nuclei in a compressed configuration (due to a sufficiently large Lorentz factor) then CT predicts that these compressed hadrons will interact less and thus have a larger nuclear transparency than uncompressed hadrons. An example of such elementary process is production of a leading meson by a longitudinally polarized virtual photon: $\gamma_L^* + N \to$ "*meson*" + *baryon* for which the factorization theorem is proved [62].

Measurements of nuclear transparency therefore allow us to study both microscopic dynamics of the hard processes and the space-time evolution of small color singlet wave packages. Since CT is a necessary condition for factorization of exclusive hard processes it is important to verify its validity and the conditions under which it plays a role in hadronic physics.

For the nuclear transparency to show an effect due to CT, there are three conditions that need to be fulfilled. These are the questions that need to be answered by measurements:

1. Is the strong interaction of small neutral (colorless) objects suppressed?

2. Can we produce/find hadrons in small configurations (known as Point Like Configurations - PLC)?

3. Can we freeze the PLC long enough to observe the suppression of its interaction?

If the answers to all of the above questions are positive, then we can expect CT to be relevant. If CT is relevant it opens more questions that can be addressed by measurements:

5. Where is the onset of CT?

6. How does it depend on the process?

7. What is the time/space structure of the transition from the PLC to a 'normal' hadron?

At JLab energies, the requirement of *coherence*, namely that the wave packet does not expand to a normal size while traveling the distance $r_{NN} \sim 2$ fm between two nearby nucleons, is given by the condition

$$l_{coh} \approx 0.4 \div 0.8\text{fm} \cdot p_h/\text{GeV} \gg r_{NN} \qquad (2)$$

It implies that effects should be rather small, but could be amplified if special kinematic conditions are chosen where r_{NN} is smaller.

A large number of experiments have been carried out over the last few decades that can determine nuclear transparency. A word of caution: the nuclear transparency is affected by other phenomena that can mimic a CT signature. None of these measurements exclude CT, but the question is to what level they provide evidence of CT.

The best evidence for CT comes from studies with very high energy probes where the freezing condition is well satisfied even for heavy nuclei. Fermilab experiment E791 measured the coherent diffractive dissociation of 500 GeV/c pions into di-jets [63]. This measurement shows a platinum to carbon cross section ratio which is consistent with CT predictions and is very different from the $A^{2/3}$ expected for typical soft pion-nucleus diffractive interactions ($\sigma \sim A^{\alpha}$, $\alpha = 1.6 \pm 0.1$). That cross section ratio is also supported by a measurement of the longitudinal and transverse distributions of the di-jets that are also in good agreement with the prediction of the CT theory [64]. Further indications for the relevance of CT to describe the interactions of high energy mesons with nuclei can be obtained from the J/ψ photoproduction measurements at SLAC and Fermilab, as well as the exclusive vector meson production (ep→epVM) at HERA [65, 66, 67].

We only mention, but do not discuss, a wide range of coherent and non coherent ρ^0 production measurements done at Fermilab/E665, HERMES/DESY since in these experiments either accuracy of the measurements was not high enough or the production of the hadrons in the final state was not excluded. It is also worth mentioning that for meson production at small enough x, the nuclear transparency also changes due to the increase of essential longitudinal distances with decreasing x. This leads to nuclear transparency being a complicated function of both the transverse size (CT ?) and of x (for fixed Q^2) (see ref [68, 69] and references quoted in them).

High precision studies of meson electro-production from nuclei found evidence for the onset of color transparency at momentum transfers Q^2 of a few GeV^2 for both π [22] and ρ [23] production. The measurements of the Q^2 and A dependence show deviations from traditional Glauber calculations and better agreement is obtained with prediction of the CT models which include space-time evolution of the wave package with coherence length given by Eq.2 [70, 71] with $l_{coh} \approx 0.6$ fm $\cdot p_h$/GeV. This implies that the onset of CT is at a relatively low Q^2 of a few (GeV/c)^2.

The situation in the baryon sector is much less clear. The onset of CT should be at higher Q^2 for baryons than for mesons. There are also no high energy measurements for baryons. The measurements at lower energies are sparse and not conclusive. The $(e, e'p)$ measurements from Bates, SLAC, and JLab at $Q^2 \leq 8$ (GeV/c)^2 are consistent with little or no Q^2 dependence [72, 73, 74, 75, 76].

On the other hand, $(p, 2p)$ data from BNL show a very strong Q^2 dependence [77]. The nuclear transparency is consistent with a Glauber approximation at $Q^2 \sim 5$ (GeV/c)^2, increases to a maximum at $Q^2 \sim 8$ (GeV/c)^2, and than decreases at $Q^2 \sim 10$ (GeV/c)^2. It is not clear whether this Q^2 dependence is a result of CT, CT plus something else, or no CT. In the $(p, 2p)$ case we have 3 nucleons that may be sensitive to CT effects and therefore the sensitivity should be larger than for the $(e, e'p)$ reaction. This extra sensitivity could explain the fact that the $(p, 2p)$ transparency increases up to $Q^2 \sim 8$ (GeV/c)^2 but the $(e, e'p)$ transparency does not. See the reviews of different approaches to the explanation of the energy dependence of nuclear transparency in $(p, 2p)$ reactions in [78, 79].

The meson production data mentioned above seem to indicate color transparency effects even at JLab energies. At JLab energies a careful study of nuclear transparency may lead to observation of effects that can be related to chiral transparency, *i.e.:* suppression of the pion cloud and its interaction with the nuclear medium at and close to the point that a hadron is being produced in a hard reaction. We will discuss below some options that can be studied using the proposed data mining with the available CLAS data.

1. Measurement of nuclear transparency at low momentum transfers

   We are analyzing data on nuclear transparencies to provide baseline data for subsequent deviations due to color transparency. The data mining collaboration has also published results for the measurement of transparency ratios for protons from short range correlated pairs [80].

2. Study on the deuteron at transverse kinematics

   We propose to look for the $ed \to e'pn$ and the $ed \to e'p\Delta^0$ reaction in the transverse kinematics that is dominated by rescattering. The Δ^0 should be produced in the final state by pion exchange. The onset of chiral transparency should suppress this production and can be studied by comparing the ratio of $(ed \to e'pn)/(ed \to e'p\Delta^0)$ as a function of Q^2.

3. Resonance vs. non-resonance production

   We propose to study the virtual photon production of leading mesons, for example $\pi^+\pi^-$ and ρ-mesons on nuclei and compare the A dependence of these two channels. The expectation is that due to the small formation time at JLab energies, absorption effects in the nonresonance channel will be significantly larger since the resonance (the ρ-meson) interacts with the medium with about the same cross section as a pion and has a larger transparency than two independent pions. The interplay between the radius of the nucleus to be crossed and the effective formation length might be revealed by a study of the A and Q^2 dependence of the relative production of these two channels. We would like to compare the effective $\rho - N$ cross section to $2\sigma_{\pi N}$. We will also investigate some other channels like $\pi^+\pi^-\pi^0$ where the effect should be amplified.

   If the difference in A-dependence is significant, then it should be possible to use it in the program of resonance searches both with CLAS and in future experiments in Hall D.

4. S_{11} production

   The same idea could be used for the production of baryon resonances. Namely, we suggest to study the nuclear transparency of the S_{11} produced in a hard process as a function of A and Q^2 to map its transparency in the nuclear medium and to compare it to the transparency of a nucleon.

2.5 Meson Hadronization

We seek to understand quantitatively how a struck deconfined quark forms into a colorless hadron. The CLAS hadronization program is extensive (18 channels by 8 institutions) with the goal of understanding the formation of both mesons and baryons over a large region of the hadron spectrum. This spectrum includes both strange and non-strange hadrons. The contribution of Canisius College is the more massive ω and f_1 mesons.

Nuclei are used as spatial analyzers of hadronization from semi-inclusive deep inelastic electron scattering. The variables to be investigated are the broadening of the mesons transverse momentum and the multiplicity. When a quark is removed from a hadron, the string or flux-tube is stretched over a space-time region. When enough energy is stored in the string, a quark-antiquark pair forms from the vacuum and the string breaks into two strings. For light quarks, the string length is typically less than 1 fm. See Ref. [81] for a recent review. This simple description is too simplistic to explain measurements by the HERMES collaboration of electro-production at high Q2 of pions, kaons, and protons in nitrogen and krypton which clearly indicated more attenuation in nuclei than expected [82]. After the HERMES results, more theoretical models have been developed. These models include the gluon bremsstrahlung model [83], twist-4 perturbative QCD [84], quark energy loss [85], and the Arleo model [86]. More data is needed test these various models.

2.6 Theoretical Support of Data Mining Initiative

The theory support for the data mining initiative will focus on three topics: (i) development of the models for the nuclear spectral functions containing multi-nucleon short range correlations, (ii) developing models for non-nucleonic components of the nuclear wave function related to the short-range correlations, and (iii) development of the Monte-Carlo event generators based on these theoretical models which will be used for analyses of the CLAS data sensitive to the short-range multi-nucleon correlations and non-nucleonic components like the $\Delta\Delta$ component of the deuteron wave function.

2.6.1 Electroweak two-nucleon knockout: a tool to probe the short-distance structure of stable nuclei

One of the theoretical goals related to the processes analysed so far is computing absolute cross sections for two-nucleon knockout reactions following the electromagnetic excitation of stable nuclei at high four-momentum transfers Q2. Both developing such a model and the question of how to compare with data poses formidable challenges as they involve problems of high dimensionalities. A realistic model needs to account for the different two-body reaction mechanisms and account for the correlated short-range structure of the nuclear target, thus allowing to study the interplay between the various mechanisms and guarantee reliable extraction of the observables. While there are sophisticated models available, including some which were developed in the Ghent group in the nineties [87, 88], their range of applicability is restricted to low four-momentum transfers which is outside the kinematics accessed in the kinematics accessible to the data mining initiative. To date, schematic models have been used to interpret the recent two-nucleon knockout data, with extracted results open to interpretation and open to corrections not addressed in the current models.

A recent study [89] predicts that the mass dependence of the $A(e, e'pp)$ cross sections is much softer than the $Z(Z-1)/2$ dependence based on naive proton-pair counting. The Data Mining Initiative at Jefferson Lab has access to $(e, e'pN)$ data for C, Al, Fe and Pb. The Ghent group is working on calculations to quantify the mass dependence of the $(e, e'pp)$ cross sections for those four target nuclei and kinematics matching the experiment. These model calculations are highly dimensional (there are three particles in the final state!) and adopt a factorization assumption which is suitable to study mass dependences. In a next step, they wish to compute the absolute cross sections for $(e, e'pp)$ and $(e, e'pn)$ reactions at high four-momentum transfers. The plan is to implement a non-relativistic model for the dynamics and address the kinematics relativistically, with a relativistic extension planned in a second stage. A realistic model needs to account for the different possible two-body reaction mechanisms (direct knockout, final-state interactions, delta excitations, meson exchange currents) and account for the short-range structure of the nuclear target. To encode the short-range structure of the nuclear target, the two-body cluster approximation outlined below will be used. The nuclear dynamics will be implemented in an unfactorized approach which implies that the cross sections are computed starting from the amplitudes.

2.6.2 Correlated one-body and two-body momentum distributions for the whole nuclear mass range

The computation of one-body and two-body momentum distributions has reached a very high level of sophistication. Ab-initio methods with variational wave functions can be used to compute the momentum distributions for nuclei up to $A = 12$ [90]. Also for atomic mass number infinity, or nuclear matter, exact calculations can be performed. Momentum distributions for mid-heavy and heavy nuclei cannot be computed with exact methods to date. The Ghent group is developing an approximate practical way of computing the short-range contributions to one-body and two-body momentum distributions for stable and unstable nuclei over the entire mass range. The practical approximate method they propose is based on a cluster expansion method and preserves some fundamental properties like the normalization conditions.

Momentum distributions contain the information about the momentum decomposition of the single-nucleon and nucleon-pair motion in nuclei. Several reactions analysed in the data mining project are probing those momentum distributions. As a wide range of target nuclei are available, it is of the utmost importance to possess a flexible nuclear-structure model which can deal efficiently with the short-range dynamics for a large variety of nuclei – from light to heavy for stable and unstable nuclei. In addition, even in the most sophisticated calculations, variations in the available results for momentum distributions are observed for several parameterizations of the NN forces. The underlying reason is that nucleon-nucleon scattering does not constrain the short-distance structure of the nucleon-nucleon interaction. One of the long-term goals of the reactions described here is that they can provide better constraints for the short-range components of the NN force.

A time-honored method to account for correlations is to shift the complexity induced by the correlations from the wavefunctions to the operators [91]. In a recent publication it was argued that recent experimental data from Jefferson Lab indicate that SRC can be understood as a local phenomenon [92]. This observation provides good arguments for justifying low-order cluster expansions and allows one to account for nuclear SRC as pair correlations. The two-body cluster approximation is an efficient way of computing the contributions from central, tensor and spin-isospin correlations to the nuclear one-body and two-body momentum distributions. Recent benchmark calculations by the Ghent group with pair correlations in a harmonic-oscillator basis indicate that the proposed method is effective in reproducing the results of the variational Monte-Carlo calculations of Ref. [90], which require enormous computer resources and have not been extended beyond $A = 12$ to date. The proposed method can also be extended to include triple correlations. The two-body cluster approximation could be a novel and efficient method to account for nuclear SRC in a systematic fashion throughout the whole nuclear mass range and the resulting momentum distributions could be used in several analyses of the data mining project.

2.6.3 Three Nucleon Correlations

One of the main motivations of data-mining activities are the studies of short-range properties of nuclear structure. During the previous period the significant effort was given to the investigation of the properties of two-nucleon short range correlations (SRCs) in asymmetric nuclei where new properties of the high momentum component of nuclear momentum distributions have been found based on the dominance of tensor part of the strong interaction at sub-fermi inter-nucleon distances [93, 94, 33]. In the proposed research the Penn State and FIU groups are planning to continue our studies of SRCs extending them to the region of three-nucleon correlations. The knowledge of 3N SRCs are very limited with electron induced experimental data being rather fragmentary[4, 5]. Independent evidence exists from proton induced processes [95]. The data mining collaboration has a unique opportunity to analyze the available inclusive data in the the region of $x_{Bj} > 2$ as well as probing spectator nucleons in semi-inclusive reactions with light-cone momentum fraction $\alpha > 1.5$. For analysis of such data the Monte-Carlo simulations are needed based on realistic models of the nuclear spectral function that includes both 2N and 3N SRCs. With graduate students Oswaldo Artilles and Adam Freese we are planning to develop a Nuclear Spectral function based on the Light Cone description of 2N and 3N SRCs.

This research as well as experience gained with the data mining initiative will be essential for developing further the multi-nucleon SRC program for the 12 GeV Nuclear Physics program of JLab.

2.6.4 Theoretical Studies of $\Delta - \Delta$ Component of the Deuteron Wave Function

During the previous period of the Data-Mining Initiative a first attempt was made to probe the $\Delta - \Delta$ component in the deuteron wave function. The expectations for the possibility of direct measurement of this $\Delta - \Delta$ component increased due to recent studies which established that short range correlations play an important role in nuclear structure and the non-nucleonic degrees of freedom which manifest themselves in the EMC effect are dominated by the contribution of SRCs. Thus we expect that the study of the SRCs is one of the most promising strategies to achieve the goal of probing $\Delta\Delta$ components in the deuteron.

The likely most important baryonic non-nucleonic degrees of freedom in nuclei are SRC containing Δ isobars ($N\Delta, \Delta\Delta$). This is because the mass gap is the smallest in this case (components with dynamic pions are suppressed by the chiral dynamics). Though these components are expected to be on the level of 1% per nucleon they are expected to have a much broader distribution over the relative momenta than nucleons in mean field and even in SRC so their production in the kinematics forbidden for the scattering off a free nucleon appears to be an optimal strategy even though the rates are small. (This strategy is also allows to look for more complicated quark structures like six quark states as they have a significant overlap with $N\Delta, \Delta\Delta$ states).

We will continue developing models for non-nucleonic components of the nuclear wave function related to the short-range correlations to provide experimentalists with signatures of preexisting Δ components in nuclei and to help interpret measurements of Δ knockout from nuclei and differentiate between preexisting Δ components and Δ production.

2.6.5 Modeling Light-Cone Density Matrix of $\Delta\Delta$ Component of Deuteron Wave Function

Together with graduate student Shankar Adhikari we are working on modeling $\Delta\Delta$ components of the deuteron wave function based on the diagrammatic method in which such components are accounted for through the $NN \to \Delta\Delta$ transition in the ground state wave function of the deuteron. Based on this density matrix we are planning to calculate the cross section of $e + d \to e'\Delta + \Delta$ reaction and provide this in the form of a Monte-Carlo event generator for analysis of the forthcoming data.

This model will give us an estimate of the $\Delta\Delta$ component based on the baryonic degrees of freedom and indirectly it will allow us to estimate the possible role of the hidden-color component in the deuteron wave function. This model will allow also to confirm or reject the feasibility of such studies using the deuteron target and refine the strategy for future studies after the 12 GeV upgrade of JLab.

2.7 Data Mining Software Framework

The goal of the Data Mining Software Framework is to (1) collect the data from nuclear target experiments using the CLAS detector, (2) collect the associated cuts and corrections used to analyze that data, and (3) provide non-expert users with a software environment for easy analysis of this data using the associated cuts and corrections.

We are collecting the processed nuclear-target experiment data. This data contains particle momenta, positions, and detector energies and times. However, it still needs a multitude of experiment-specific cuts and corrections. Therefore we are also collecting the cuts and corrections that were painstakingly developed by the CLAS Collaboration for the initial round of publications using these data sets. We are assembling the data and its associated cuts and corrections and making it available through a single web-based interface. This will allow the data miners to analyze data without needing to know the intricate details of which specific data set they are analyzing, which specific momentum correction to apply, or which specific fiducial cut to use. Merely by specifying the desired beam energy, the desired target, and the standard cuts and corrections, the non-expert user will be able to analyze the data. Expert users will be able to implement their own analysis routines within the analysis framework.

This software framework will also be ideal for data archiving, preserving the CLAS nuclear target data for future research. This framework is easily extensible to other Jefferson Lab data sets.

2.7.1 CLARA Distributed Computing Service

To develop the software framework for providing data access to our collaborators we used CLARA. CLARA is a cloud computing environment developed at Jefferson Lab for data analysis. The framework is based on public subscribe protocol and implements a Service Oriented Architecture (SOA), which allows users to run "services" on the host platform. Services process the data and the result is passed to the user.

The developed framework sorts the data by experiment, target used and the initial beam energy and stores meta-data on the server. A user program can search through the meta-data for available experimental data and download the list of files that need to be analysed. A "service" on the host platform is responsible for parsing user requests and providing lists of files that match users search criteria.

After retrieving lists of files, a user initiates analysis of the data by choosing the topology of the events of interest (e.g., $(e, e'p\pi+)$), and by choosing a "service" to analyse the data. Each data analysis service implements the specific code for one particular experiment. The "service" reads the data from the host system, processes the data through the particle identification algorithm (specific for each experiment), then performs corrections (momentum corrections, vertex correction, fiducial cuts) and, if the data matches the requested topology, transmits data to the client program.

Since not all the files for a particular experiment are located on the same server, and since the analyses are running in multi threaded mode, the data are not analysed in sequence. A complex bookkeeping algorithm was implemented to keep track of the pieces of files that were processed, so that an interrupted analysis can be resumed.

2.7.2 Progress

The project started with implementation of the software infrastructure for common analysis of the data from several experiments. We developed a new, more efficient, data format and implemented compression for data streams to save disk space. A common environment (framework) was developed to generalize cuts and corrections for different experiments. The tasks accomplished are listed below:

- Implementation of compressible efficient data format for CLAS6 data (iG5).
- Implementation of a tagged file system for generating searchable meta-data for experimental data sets stored on ODU servers. User interface development for searching and sorting the data.
- Existing data converted into iG5 data format and transferred to ODU servers.
- Separate "services" were implemented for each experiment to analyse the data (apply cuts and corrections).

The data mining software is currently running on ODU machines and provides access to the CLAS data to all collaborating universities. The available data is shown in Table 1.

2.7.3 Future Plans

With the development of our unified framework we facilitated the analysis of CLAS data by non-experts. The data is easily downloadable, and physics analysis tools are provided within our framework. We will implement the remaining data sets within the framework, together with their associated cuts and corrections.

The next step required for extraction of physics results is simulations, especially to account for the complicated CLAS acceptances. The CLAS detector simulation is implemented using the GEANT-3 software package written in FORTRAN. The simulated files have to be processed by the CLAS reconstruction package (RECSIS), which is also implemented in FORTRAN. The standard software in CLAS is compiled and tested on Jlab machines and libraries and resource files are all stored on local disks. In order to run a full Monte Carlo simulation users run scripts on Batch Farm machines to produce detector simulated files and then reconstruct the events using RECSIS. This process is computationally intensive and depending on privileges assigned to the user can take months to run.

Installation of the whole chain of simulation packages on user computers is a difficult task requiring compilation of many libraries and downloading many dependency files. The software is not properly packaged for external installations.

We plan to build on the success we had with the Service Oriented Architecture platform we used for CLAS data distribution, by creating a CLAS Monte-Carlo server at ODU which will allow users to run data simulation and reconstruction on demand. CLAS simulation chain (GSIM and RECSIS) will be installed on one (or several) of our nodes (32 cores each). The software will present itself as a Monte-Carlo service specific for each experiment, user's client program will send data (containing 4-vectors of generated particles), the service will run GSIM then RECSIS and will send back data containing reconstructed particle information. The data flow through the network will be very small since only 4-vector information will be passed.

This proposed unified simulation framework will make CLAS data analysis even more efficient for non-expert users.

2.8 Data Mining Collaboration Activities

There are three separate sets of activities carried out by the Data Mining Collaboration. Most members of the collaboration will use the Data Mining Software Framework to analyze CLAS data for a multitude of reaction channels. Other members of the collaboration, primarily Gagik Gavalian and the proposed data mining postdoc, will incorporate the remaining CLAS6 nuclear target data into the Data Mining Software Framework and will continue to develop the analysis and simulation codes that will make analysis and simulation of the data much easier. The theory collaborators will work on developing the theoretical framework for interpretting the data and on simplified theoretical models useful for event generators for data simulation.

We will follow the standard CLAS procedures to get any new analyses and papers based on them approved by the CLAS Nuclear Physics Physics Working group and the collaboration as a whole.

2.9 Organization

The overall effort will be supervised by a “steering committee” consisting of the Principal Investigators and some senior members of the data mining collaboration. This committee will guide the analysis efforts, directing them toward the most promising channels. It will decide about allocation of resources and will prioritize tasks for the postdoc we are requesting in this proposal. The committee will meet regularly in person or using phone conferencing.

The entire collaboration will meet once or twice each year at Jefferson Lab or at collaborating institutions. These meetings will be open to all interested parties, and will be partially supported by the travel funds requested here. The steering committee will organize these meetings.

The technical administration of the grant funds (if this proposal is successful) will be done by Old Dominion University, To simplify the review of the present proposal, all funding requests are presented by Old Dominion University at this time.

3 Personnel

This grant proposal is requesting funds for a post doctoral research associate and a graduate student to help coordinate and facilitate multi-institution analysis of existing data on nucleon behavior at short distances. It is also requesting travel funds to help coordinate this research effort.

The post doctoral research associate will concentrate on three tasks, (1) incorporating more CLAS nuclear target data sets along with their associated cuts and corrections into the data mining software infrastructure, (2) extending the data mining software infrastructure to make it far easier to simulate experimental acceptances, and (3) to provide guidance in analyzing CLAS data to the data mining collaboration.

The graduate student will help the post doc in the above tasks and also analyze data herself, focussing on correlations in deuterium and ^{3}He.

Researchers at many institutions are already using the data mining software infrastructure and analyzing data on the short distance structure of nuclei. This grant proposal is requesting funds to help coordinate these efforts. In the following, we list each of the institutions that expect to benefit from the facilitation and coordination funded by this proposal, and the nature of their commitments to the overall research effort.

3.1 Old Dominion University

The major participants from ODU are Profs. Weinstein, and Kuhn. We have already one graduate student (Marianna Kachatryan) who will be analyzing the ratio of proton to neutron knockout in ^{3}He as a function of nucleon momentum for her PhD thesis. We expect to take on one more graduate student to work on analysis topics connected to this program.

Our main interest and expertise is in the area of short-range correlations, studied through direct observation of spectator nucleons or nucleon pairs in D$(e, e'p)$X and ^{3}He$(e, e'pp)$n. We pioneered the experimental link between short range correlations and the EMC effect [19] and have published many results on nucleon knockout from light nuclei [11, 13, 18]. We are poised to expand this analysis to the complete existing data set. We are also studying (both experimentally and theoretically) polarization observables in deuteron break-up $\vec{d}(\vec{e}, e'p)$n.

3.2 Jefferson Lab

Gagik Gavalian developed the highly successful and widely used Data Mining Software Framework. Partly as a result of this success, he was hired by Jefferson Lab. He will guide the efforts to incorporate the remaining CLAS6 nuclear target data into the Data Mining Software Framework and will continue to develop the analysis and simulation codes that will make analysis and simulation of the data much easier.

Dr. Stepanyan is a Jefferson Lab senior staff member who has an appointment as "Jefferson Lab Professor" at Old Dominion, with full faculty privileges. He provides much-needed expertise in CLAS analysis techniques and software.

3.3 Tel Aviv University

The Tel Aviv group includes Prof. E. Piasetzky, a major participant in this project, as well as a postdoc, Dr. R. Shneor, and two graduate students, Or Chen and Igor Korover. This group is supported by a dedicated grant from the Israel Science Foundation and has its focus on studies of short range correlations (SRC) in nuclei [6, 7, 8, 9, 10]. We plan in the coming years to contribute to the analysis of available data from Hall A and Hall B (as part of this data mining proposal) in parallel to preparing and performing a new SRC experiment [97] in Hall A . At Tel Aviv University we also have Prof. L. Frankfurt, a world leading theory expert in this field, with whom we plan to consult extensively.

3.4 College of William and Mary

The senior member from this group is Prof. Keith Griffioen, who has extensive experience running and analyzing experiments with CLAS. The group will also include one or more graduate students. The main interest will be using deuteron data to study short-range correlations and color transparency.

3.5 Pennsylvania State University

This group is led by Prof. Mark Strikman and includes Leonid Frankfurt who has worked extensively on the connection of nuclear and particle physics. Therefore, his group is uniquely poised to provide theoretical support for this initiative. The group has initiated the use of the light-cone formalism for the description of high energy processes with nuclei. They plan to develop light-cone approximations for the many nucleon decay functions and find optimal strategies for looking for various types of non-nucleonic degrees of freedom.

3.6 Florida International University

Dr. Misak Sargsian together with graduate students Adam Freese, Oswaldo Artiles and Shankar Adhikari will support the whole data mining initiative by providing Physics event generators and universal Monte Carlo programs for studies of inclusive and semi-exclusive experiments aimed at probing multi-nucleon short-range correlations and non-nucleonic components in the nuclear wave function. They will provide also theoretical guidance on FSI and tagged structure functions.

3.7 Massachusetts Institute of Technology

The senior members from MIT is Dr. Shalev Gilad. He is interested in continuing his program of investigating the properties of nuclei, including short range correlations, within the context of this proposal. He is currently supervising one graduate student, Barak Schmookler, who is analyzing data on the tagged EMC effect, the ratio of electron scattering cross sections with a backward nucleon (the “tag”) in various nuclei to that of deuterium.

3.8 Universities of Glasgow and Edinburgh

The personnel from Glasgow who are supporting this project are: Dave Ireland, Derek Glazier and Douglas MacGregor. Additional interest and support from Edinburgh will be provided by Daniel Watts.

D. Ireland will work on Δ^0 electroproduction in ^{3}He. D. Glazier will provide help in running simulations, and will be in charge of the Fadeeev calculations for comparison with the 3-Nucleon Forces results. D. MacGregor will provide Glagow input in the short-range correlations studies. He will assist D. Ireland with the data analyses, normalization issues, and physics interpretation.

D.Watts and L. Zana will look at multiproton knockout reactions to assess the production rates and masses of unobserved nuclei and provide data to calibrate nuclear transport models, which are used widely (e.g. neutrino oscillation experiments). We will also look at high multiplicity hadron knockout in searches for particles having non-standard quark configurations.

3.9 Ghent University

The theoretical nuclear physics group at Ghent University is led by Prof. Jan Ryckebusch and currently includes one post-doc (Wim Cosyn) and three PhD students (Maarten Vanhalst, Camille Colle, Sam Stevens) that are working on models of interest to the data mining initiative. They have models available to account for FSI in quasi-elastic and deep-inelastic scattering reactions off nuclei. Recently, the group developed an approximate method to count the number of correlated pairs over the whole nuclear mass range. This model has already been tested against several of the data mining analyses during the first phase of the project. Work in progress of interest to the project includes 1) the generation of correlated one- and two-body momentum distributions over the whole nuclear mass range using a local cluster approximation and 2) the development of an unfactorized two-nucleon knockout cross section model that could be applied in Monte Carlo simulations of $A(e, e'NN)$ reactions.

3.10 University of Richmond

The University of Richmond group consists of one senior faculty member (Dr. G.P.Gilfoyle) and 1-4 undergraduates doing research full-time during the summer and part-time during the academic year. The group is focused first on the analysis of the deuteron data from the E5 run period to extract the fifth structure function (beam helicity-dependent) in quasielastic kinematics. This work is far along and is currently under CLAS Collaboration review. We are proposing to study the neutron magnetic form factor G_M^n at low Q^2 for the same E5 data set. Some results for G_M^n have already been published from a portion of this data set, but the low-Q^2 region still needs to be analyzed. Undergraduates working on this project would begin in the summer of 2014 or 2015.

3.11 Canisius College

The Canisius College group is led by Dr. Michael H. Wood, whose primary area of investigation is the behavior of mesons inside the nuclear medium. The other members of the group are 1–3 undergraduate students conducting research full-time in the summers and part-time during the academic year. Dr. Wood has published on searches for medium modification of the ρ, ω and ϕ mesons in cold, dense nuclei. He is presently studying the hadronization of the ω and f_1 mesons with CLAS data. The events with the decay topology of $\pi^+\pi^-\pi^0$ have been filtered using the current version of the Data Mining Software. Andrew Beiter, a Canisius College undergraduate student, is applying cuts to achieve the cleanest sample of ωs in order to extract the yields from targets of deuterium, carbon, iron, and lead. From the yields, the multiplicity and spread in the transfer momentum will be determined. Over the next three years, the Data Mining Software will be employed to extract the channels of ω decaying into $\pi^0\gamma$ and the f_1 decaying into 4 charged pions. Working at a primarily undergraduate institution, the data mining software is critical in reducing the learning curve and allowing the students to focus on analysis immediately.

A Appendix 1. Biographical Sketches

Biographical Sketch for Dr. Lawrence Weinstein

(a) **Education and Training**

Yale University, New Haven, CT	Physics	B.S. 1981, cum laude
MIT, Cambridge, MA	Nuclear Physics	Ph.D. 1988
MIT, Lab for Nuclear Science	Sponsored Research Staff	1988-1991

(b) **Research and Professional Experience**

Old Dominion University	Eminent Scholar	2012-
Old Dominion University	University Professor	2007-
Old Dominion University	Professor of Physics	2003-
Old Dominion University	Assc. Prof. of Physics	1998-1993
Old Dominion University	Asst. Prof. of Physics	1992-1998
MIT, Laboratory for Nuclear Science	Research Scientist	1991-1992

(c) **Honors and Awards**

Virginia Outstanding Faculty Award	2009
ODU College of Sciences, Faculty Excellence Award	2005
Fellow, American Physics Society	2004

(d) **Publications**

M.M. Sargsian, J. Arrington, W. Bertozzi, W. Boeglin, C. Carlson, D. Day, L. Frankfurt, K. Egiyan, R. Ent, S. Gilad, K. Griffioen, D.W. Higinbotham, S. Kuhn, W. Melnitchouk, G.A. Miller, E. Piasetzky, S. Stepanyan, M. Strikman, and L. Weinstein: "Hadrons in the Nuclear Medium", J. Phys. G.: Nucl. Part. Phys. **29**, R1 (March 2003).

B.A. Mecking et al. (CLAS collaboration, see Ref. [20]): "The CEBAF Large Acceptance Spectrometer (CLAS)", Nucl. Instr. Meth A **503**, 513 (May 2003).

R.A. Niyazov, et al. (the CLAS Collaboration, see Ref. []), "Two-Nucleon Momentum Distributions Measured in ^{3}He(e,e'pp)n", Phys Rev Lett **92,** 052303 (2004).

K. Sh. Egiyan, et al. (the CLAS Collaboration see Ref. [4]), "Measurement of 2- and 3-Nucleon Short Range Correlation Probabilities in Nuclei", Phys Rev Lett **96**, 082501 (2006)

R. Shneor, et al. (the Hall A Collaboration see Ref. [6]), ``Investigation of Proton-Proton Short-Range Correlations via the ^{12}C(e,e'pp) Reaction'', Phys Rev Lett **99**, 072501 (2007).
R. Subedi, et al. [see Ref. [6]), ``Probing Cold Dense Nuclear Matter'', Science **320**, 1476 (2008).

L.B. Weinstein, et al., "Short Range Correlations and the EMC Effect", Phys. Rev. Lett. **106**, 052301 (2011).

O. Hen, E. Piasetzky and L. B. Weinstein, "New data strengthen the connection between Short Range Correlations and the EMC effect," Phys. Rev. C **85**, 047301 (2012).

J. Dudek, et al. (see Ref [2]), "Physics opportunities with the 12 GeV upgrade at Jefferson Lab", Eur. Phys. J. A (2012) **48**: 187.

O. Hen, et al. [The CLAS Collaboration], "Measurement of transparency ratios for protons from short-range correlated pairs", Phys. Lett. B **722**, 63-68 (2013).

O. Hen, D. Higinbotham, G. Miller, E. Piasetzky and L.B. Weinstein, "The EMC Effect and High Momentum Nucleons in Nuclei", International Journal of Modern Physics E **22,** 1330017 (2013).

(e) **Synergistic Activities**

L. Weinstein and J. Adam, "Guesstimation, Solving the World's Problems on the Back of a Cocktail Napkin", Princeton University Press, Princeton, NJ, 2008. Fourth Printing, 2009. Gave many talks on Guesstimation to high schools, social clubs, the general public, physics departments, and scientific conferences.

Editor, Fermi Questions column, The Physics Teacher, 2007-present.

Involved many undergraduate students in research, including data analysis, detector development, and testing. Supervised five undergraduate senior thesis projects.

Supervised many high school students in their senior mentorship projects. Projects included data analysis, magnet design and construction, etc.

Organized Virginia Children's Festival booths, physics demo shows and pumpkin drops. Delivered many physics presentations to thousands of middle and high school students.

(f) **Collaborators and other Affiliations**

(i) Members of the CLAS Collaboration and co-authors in the publication list. Main collaborators in the last five years include J. Arrington (Argonne), W. Brooks (Universidad Tecnica Federico Santa Maria, Chile), V. Burkert (Jefferson Lab), S. Gilad (MIT), J. Gomez (Jefferson Lab), O. Hen (Tel Aviv U), J. Jaros (SLAC), J.M. Laget (CEA Saclay), E.Piasetzky (Tel Aviv U), B. Raue (Florida International U), S. Stepanyan (Jefferson Lab), J. Watson (Kent State), S. Wood (Jefferson Lab)

(ii) Graduate advisor (both thesis and postdoctoral): Prof. William Bertozzi, MIT.

(iii) Graduate students advised (last five years): Megh Niroula (2010, unaffiliated), D. Adikaram (2014). Postdoctoral fellows advised: Dr. R. Bennett (Princeton Research Group)

Dr. Sebastian Kuhn, Professor of Physics and Eminent Scholar, ODU

Education and Training

University of Bonn	Diplom in Physics (comparable to M.S.)	March 1982
University of Bonn	Dr. rer. nat. (Ph.D.) in Physics	January 1986

Research and Professional Experience

2008 –	Eminent Scholar	Old Dominion University
2003 –	Professor of Physics	Old Dominion University
1997 – 2003	Associate Professor of Physics	Old Dominion University
1992 – 1997	Assistant Professor of Physics	Old Dominion University
1988 – 1992	Acting Assistant Professor	Stanford University
1986 – 1988	Visiting Postdoctoral Fellow	Lawrence Berkeley Laboratory

Honors and Awards

2010-2014	Chair elect, Chair and Past Chair of the Jefferson Lab Users Group Board of Directors
2009–2010	Elected to Executive Committee, APS Topical Group on Hadronic Physics
April 2008	Recipient of the Annual Research Prize at Old Dominion University
Nov. 2007	Elected as Fellow of the American Physical Society
Aug. 2007	Designated Eminent Scholar by Old Dominion University
July 1986	Recipient of a NATO postdoctoral fellowship

Selected Publications: (Total of over 140 publications in refereed journals with over 10000 citations.)

- *"Measurement of the structure function of the nearly free neutron using spectator tagging in inelastic $^2H(e, e'p_s)X$ scattering with CLAS"*, S. Tkachenko, N. Baillie, S. E. Kuhn, J. Zhang, J. Arrington, *et al.* [CLAS Collaboration], *Phys. Rev. C* **89**, (2014).
- *"Spin Structure Functions; in 'New Insights into the Structure of Matter: The First Decade of Science at Jefferson Lab' "*, J.-P. Chen, A. Deur, S. Kuhn and Z.-E. Meziani, *J. Phys. G Conf. Ser.* **299**, 012005 (2011).
- *"Measurement of the neutron F_2 structure function via spectator tagging with CLAS"*, N. Baillie, S. Tkachenko, J. Zhang, P. Bosted, S. Bültmann, M. E. Christy, H. Fenker, K. A. Griffioen, C. E. Keppel, S. E. Kuhn, W. Melnitchouk, V. Tvaskis *et al.* [CLAS Collaboration], *Phys. Rev. Lett.* **108**, 142001 (2012).
- *"Spin structure of the nucleon – status and recent results"*, S.E. Kuhn, J.-P. Chen and E. Leader, *Prog. Part. Nucl. Phys.* **63**, 1-50 (2009).
- *"BoNus: Development and use of a radial TPC using cylindrical GEMs"*, H. Fenker, N. Baillie, P. Bradshaw, S. Bültmann, V. Burkert, M. Christy, G. Dodge, D. Dutta, R. Ent, J. Evans, R. Fersch, K. Giovanetti, K. Griffioen, M. Ispiryan, C. Jay-alath, N. Kalantarians, C. Keppel, S. Kuhn, G. Niculescu, I. Niculescu, S. Tkachenko, V. Tvaskis and J. Zhang, *Nucl. Instr. Meth. A* **592**, 273-286 (2008).
- *"Experimental Study of Exclusive $^2H(e, ep)n$ Reaction Mechanisms at High Q^2"*, K. S. Egiyan, G. Asryan, N. Gevorgyan, K. A. Griffioen, J. M. Laget, S. E. Kuhn *et al.* [CLAS Collaboration], *Phys. Rev. Lett.* **98**, 262502 (2007).

- *"Electron scattering from high-momentum neutrons in deuterium"*, A. V. Klimenko, S. E. Kuhn, C. Butuceanu, K. S. Egiyan, K. A. Griffioen, *et al.* [CLAS Collaboration], *Phys. Rev. C* **73**, 035212 (2006).
- *"Hadrons in the nuclear medium"*, M.M. Sargsian, J. Arrington, W. Bertozzi, W. Boeglin, C. Carlson, D. Day, L. Frankfurt, K. Egiyan, R. Ent, S. Gilad, K. Griffioen, D.W. Higinbotham, S. Kuhn, W. Melnitchouk, G.A. Miller, E. Piasetzky, S. Stepanyan, M. Strikman, and L. Weinstein, *J. Phys. G* **29**, R1 (2003).

Selected Invited Talks: (Over 50 invited talks; 9 in the last 3 years.)

- *"Collinear Structure Functions of the Nucleon: Status and Future"*, 10th Latin American Symposium on Nuclear Physics and Applications, Montevideo (Uruguay) December 1-6, 2013.
- *"Nucleon Spin Results from Jefferson Lab"*, Fall Meeting of the APS Division of Nuclear Physics (DNP 2013), Newport News (VA) October 23-26, 2013.

Synergistic Activities:

- Involved several undergraduate students in my research, including analysis of CLAS nuclear data (E6). Supervised Senior Thesis projects.
- Participated in science fairs, open houses and other outreach activities; wrote articles popularizing research for general circulation newspapers and a book chapter.

Collaborators: Members of the CLAS Collaboration and coauthors in the publication list. Main collaborators in the past five years include H. Avakian (Jefferson Lab), N. Baillie (Hampton U), P. Bosted (William and Mary), W. Brooks (Universidad Tecnica Federico Santa Maria, Chile), S. Bültmann (ODU), V. Burkert (Jefferson Lab), J.-P. Chen (Jefferson Lab), M. E. Christy (Hampton U), D. Crabb (UVirginia), A. Deur (Jefferson Lab), H. Fenker (Jefferson Lab), R. Fersch (CNU), K. A. Griffioen (William and Mary), H. Hakobyan (Universidad Tecnica Federico Santa Maria, Chile), N. Kalantarians (Hampton U), C. E. Keppel (Jefferson Lab), Eric Leader (Imperial College, London), W. Melnitchouk (Jefferson Lab), Z.-E. Meziani (Temple U.), R. Minehart (UVirginia).

Graduate and Postdoctoral Advisors: Prof. F. Hinterberger, University of Bonn, Prof. H. Weller, Duke Univ. and Prof. R. Arnold, American Univ.

Doctoral Students: Nevzat Guler (Ph.D. 2009, now at Spectral Sciences Inc), Svjatoslav Tkachenko (Ph.D. 2009, now at U Virginia), Michael Mayer (Ph.D., 2013, now at Penn State).

Name: Misak Sargsian
Position Title: Professor
Organization: Florida International University

Education:

1983 - Diploma Theoretical Physics, Yerevan State University, Armenia
1993 - Ph.D.Theoretical Physics, Yerevan Physics Institute, Armenia

Professional Experience:

August 2012 - present	Professor, Department of Physics Florida International University, Miami
August 2005 - August 2012	Associate Professor, Department of Physics Florida International University, Miami
May 1999 - August 2005	Assistant Professor, Department of Physics Florida International University, Miami
May 1998 - April 1999	Research Associate, Department of Physics University of Washington, Seattle
March 1997 - April 1998	Alexander von Humboldt Research Fellow Department of Physics Technical University of Muenchen, Germany
May 1993 - February 1997	Postdoctoral Research Associate Department of Nuclear Physics, School of Physics and Astronomy Tel Aviv University, Israel
February 1988 - April 1993	Research Associate Laboratory of Photo-Nuclear Studies Yerevan Physics Institute, Armenia

Professional Activities, Awards:

2010	Elected APS Fellow from Division of Nuclear Physics
2010,2012	Elected vice chairman (2010) and chairman (2012) of Gordon Research Conferences on Photonuclear Reactions
2007 - 2009	Program Committee of APS, Division of Nuclear Physics
1997 - 1998	Alexander von Humboldt Fellowship

Publications most closely related to the proposed project:

1 M. M. Sargsian, "New Properties of High Momentum Distribution of Nucleons in Asymmetric Nuclei," Phys. Rev. C **89**, 034305 (2014)

2 W. Cosyn, W. Melnitchouk and M. Sargsian, "Final-state interactions in inclusive deep-inelastic scattering from the deuteron," Phys. Rev. C **89**, 014612 (2014).

3 A. J. Freese and M. M. Sargsian, "Probing Vector Mesons in Deuteron Break-up Reactions," Phys. Rev. C **88**, 044604 (2013)

4 J. Arrington, D. W. Higinbotham, G. Rosner, M. Sargsian, "Hard probes of short-range nucleon-nucleon correlations", Prog. Part. Nucl. Phys. **67**, 898 (2012).

5 W. Cosyn, M. Sargsian, " Final-state interactions in semi-inclusive deep inelastic scattering off the Deuteron", Phys. Rev. **C84**, 014601 (2011).

6 C. G. Granados, M. M. Sargsian, "Hard breakup of the deuteron into two Δ-isobars", Phys. Rev. **C83**, 054606 (2011).

7 M. M. Sargsian, "Large Q^2 Electrodisintegration of the Deuteron in Virtual Nucleon Approximation", Phys. Rev. **C82**, 014612 (2010). -0.24cm

8 M. M. Sargsian and C. Granados, "Hard Break-Up of Two-Nucleons from the 3He Nucleus," Phys. Rev. C **80**, 014612 (2009).

9 L.L. Frankfurt, M.M. Sargsian, M.I. Strikman, "Recent Progress in Studies of Short Range Correlation in Nuclei and their Implication for Nuclear, Particle Physics and Astrophysics", Int. J. Mod. Phys. A **23**, 2991 (2008).

10 E. Piasetzky, M. Sargsian, L. Frankfurt, M. Strikman and J. Watson, "Evidence for the Strong Dominance of Proton-Neutron Correlations in Nuclei," Phys. Rev. Lett. **97**, 162504 (2006).

Synergistic Activities

Supervising graduate research of following students:

Adam Freese, Oswaldo Artiles, Shankar Adhikari and Dhiraj Maheswari.

Research Collaborators

1 John Arrington, Argonne National Laboratory

2 Wim Cosyn, Gent University, Belgium

3 Douglas Higinbotham, Jefferson Lab

4 Wally Melnitchouk, Jefferson Lab

5 Guenther Rozner, University of Glasgow and FAIR Darmstadt

6 Reinhard Schumacher, Carnegie Mellon University

Previous Graduate Students and Postdocs

1 Tigran Abrahamyan, Florida International University (Graduate Student)

2 Wim Cosyn, Gent University, Belgium (Postdoc)

3 Carlos Granados, University of Uppsala, Sweden (Graduate Student)

Name: Mark Strikman
Position Title: Professor
Organization: Pennsylvania State University
Education:

1972 - M.S. Theoretical Physics, Leningrad State University, U.S.S.R.
1978 - Ph.D.Theoretical Physics, Leningrad Nuclear Physics Institute, U.S.S.R.
1988 - Professor Habilitation, Theoretical Physics, Leningrad Nuclear Physics Institute, U.S.S.R.

Professional Experience:

December 2012	Distingished Professor, Department of Physics The Pennsylvania State University, University Park
July 1995	Professor, Department of Physics The Pennsylvania State University, University Park
July 1992 - June 1995	Associate Professor, Department of Physics The Pennsylvania State University, University Park
August 1991 - June 1992	Visiting Professor, Department of Physics The Pennsylvania State University, University Park
August 1990- June 1991	Visiting Professor, Department of Physics University of Illinois at Urbana-Champaign
1990 – 1991	Leading Member, Lab. of Theoretical Physics Leningrad Institute of Nuclear Physics, Gatchina
1986 – 1990	Senior Member, Lab. of Theoretical Physics Leningrad Institute of Nuclear Physics, Gatchina
1975 - 1986	Research Associate, Lab. of Theoretical Physics Leningrad Institute of Nuclear Physics, Gatchina

Fellowship: Fellow of APS, Nuclear Physics Division, 1997
Membership: American Physical Society, Since 1992
Awards: a.v.Humboldt prize for senior scientists, 1999, 2008

Publications most closely related to the proposed project

1 M. Alvioli and M. Strikman, "Color fluctuation effects in proton-nucleus collisions," Phys. Lett. B **722**, 347 (2013) [arXiv:1301.0728 [hep-ph]].

2 D. Dutta, K. Hafidi and M. Strikman, "Color Transparency: past, present and future," Prog. Part. Nucl. Phys. **69**, 1 (2013) [arXiv:1211.2826 [nucl-th]].

3 L. Frankfurt and M. Strikman, "QCD and QED dynamics in the EMC effect," Int. J. Mod. Phys. E **21**, 1230002 (2012) [arXiv:1203.5278 [hep-ph]].

4 M. Alvioli, H. J. Drescher and M. Strikman, "A Monte Carlo generator of nucleon configurations in complex nuclei including Nucleon-Nucleon correlations," Phys. Lett. B **680**, 225 (2009) [arXiv:0905.2670 [nucl-th]].

5 L. Frankfurt, M. Sargsian and M. Strikman, "Recent observation of short range nucleon correlations in nuclei and their implications for the structure of nuclei and neutron stars," Int. J. Mod. Phys. A **23**, 2991 (2008) [arXiv:0806.4412 [nucl-th]].

6 E. Piasetzky, M. Sargsian, L. Frankfurt, M. Strikman and J. W. Watson, "Evidence for the strong dominance of proton-neutron correlations in nuclei," Phys. Rev. Lett. **97**, 162504 (2006) [nucl-th/0604012].

7 L. L. Frankfurt, M. M. Sargsian and M. I. Strikman, "Feynman graphs and Gribov-Glauber approach to high-energy knockout processes," Phys. Rev. C **56**, 1124 (1997) [nucl-th/9603018].

8 L. L. Frankfurt and M. I. Strikman, "Hard Nuclear Processes and Microscopic Nuclear Structure," Phys. Rept. **160**, 235 (1988).

9 L. L. Frankfurt and M. I. Strikman, "High-Energy Phenomena, Short Range Nuclear Structure and QCD," Phys. Rept. **76**, 215 (1981).

Coauthors of the last 48 months: M. Alvioli (ECT, Trento and Perugia U.), M. Yu. Azarkin (Lebedev Institute) O. Benhar (Rome U.), M. Bleicher (Frankfurt Institute for Advanced Studies) , B. Blok (Technion, Israel), C. Ciofi degli Atti (Perugia U.) Yu. Dokshitzer (University Paris VI), I.M. Dremin (Lebedev Institute), D. Dutta (Mississippi State U.), M. Ericson (Lyon, IPN and CERN), K.J. Eskola (Jyvaskyla U.), L. Frankfurt (Tel Aviv University), A. Gillitzer (Institut fur Kernphysik, Julich), V. Guzey (Petersburg Nuclear physics Institute (PNPI)), M.Guzzi (Southern Methodist Un.), K. Hafidi (Argonne NL), H. Holopainen (Frankfurt U., FIAS), H. Honkanen (PSU) E. Kryshen(PNPI), S.Kumano (KEK), A.B. Larionov (Frankfurt Institute for Advanced Studies), A. Miller (Washington U., Seattle), P. M. Nadolsky (Southern Methodist Un), V. Rebyakova (St. Petersburg Polytechnic Inst.), Ted C. Rogers (YITP, Stony Brook), P.Schweitzer (Connecticut U.), W. Vogelsang (Tubingen U.), B.Wang (Southern Methodist U.), C. Weiss (Jefferson Lab), U.Wiedemann (CERN), M. Zhalov(PNPI).
Synergistic activities: QCD, Short-range correlations, Color transparency
Thesis adviser Leonid Frankfurt, Tel Aviv University
postdoctoral adviser None

Former graduate students: V. Guzey (postdoctoral advisers T.Thomas, Adelaide Un.; M.Polyakov, Bochum Un.), T.Rogers (postdoctoral advisers: P. J. Mulders (Vrije U., Amsterdam, G.Sterman, SUNY, Stony Brook)

Former postdoc: M. Alvioli (ECT*, Perugia University)

Biographical Sketch for Dr. Gagik Gavalian

(a) Education and Training

Yerevan State University	Physics	M.S.	1996
University of New Hampshire	Physics	Ph.D.	2004

(b) Research and Professional Experience

Jefferson National Laboratory	Staff Scientist II	2014-present
Old Dominion University	Research Assistant Professor	2007-2014
Old Dominion University	Postdoctoral Research Associate	2004-2007
University of New Hampshire	Graduate Student in Physics	1999-2004
Yerevan Physics Institute	Research Associate	1993-1999

(c) Publications

1. **"Observation of a narrow structure in $p(\gamma, K_s)X$ via interference with Φ-meson production"**
   M.J. Amaryan, G. Gavalian *et al.*, Phys. Rev. C**85**, 035209 (2012)

2. **"Electromagnetic Decay of the Σ°(1385) to $\Lambda\gamma$"**
   D. Keller *et al.* [CLAS Collaboration], Phys. Rev. D **83**, 072004 (2011)

3. **"Beam Spin Asymmetries in DVCS with CLAS at 4 .8 GeV"**
   G. Gavalian *et al.* [CLAS Collaboration], Phys. Rev. C **80**, 035206 (2009) [arXiv:0812.2950 [hep-ex]]

4. **"A Precise Measurement of the Neutron Magnetic Form Factor GMn in the Few-GeV2 Region"**
   J. Lachniet *et al.* [CLAS Collaboration], Phys. Rev. Lett. **102**, 192001 (2009) [arXiv:0811.1716 [nucl-ex]]

5. **"First measurement of direct $f_0(980)$ photoproduction on the proton"**
   M. Battaglieri *et al.* [CLAS Collaboration],Phys. Rev. Lett. **102**, 102001 (2009) [arXiv:0811.1681 [hep-ex]]

6. **"Measurement of unpolarized semi-inclusive pi+ electroproduction off the proton"**
   M. Osipenko *et al.* [CLAS Collaboration], Phys. Rev. D **80**, 032004 (2009) [arXiv:0809.1153 [hep-ex]]

7. **"Exclusive ρ^0 electroproduction on the proton at CLAS"**
S. A. Morrow *et al.* [CLAS Collaboration], Eur. Phys. J. A **39**, 5 (2009) [arXiv:0807.3834 [hep-ex]]

8. **"Search for the photo-excitation of exotic mesons in the pi+pi+pi- system"**
M. Nozar *et al.* [CLAS Collaboration], Phys. Rev. Lett. **102**, 102002 (2009) [arXiv:0805.4438 [hep-ex]]

9. **"First measurement of target and double spin asymmetries for polarized e^- polarized $p \to ep\pi^\circ$ in the nucleon resonance region above the Delta(1232)"**
A. S. Biselli *et al.* [CLAS Collaboration], Phys. Rev. C **78**, 045204 (2008) [arXiv:0804.3079 [nucl-ex]]

10. **"Electroexcitation of the Roper resonance for $1.7 < Q^2 < 4.5GeV^2$ in $ep- > en\pi^+$"**
I. G. Aznauryan *et al.* [CLAS Collaboration], Phys. Rev. C **78**, 045209 (2008) [arXiv:0804.0447 [nucl-ex]]

(d) **Synergistic Activities**

Coordinating cloud data reconstruction software development for upcoming CLAS detector system.

Supervised software development for cloud data distribution for data mining project.

Supervised several graduate students on CLAS data analysis, and Monte-Carlo simulations.

Participated in development of CLAS reconstruction software.

Participated in science fairs, open houses, children's festivals, and other outreach activities.

(e) **Collaborators and other Affiliations**

(i) Thesis advisor: Maurik Holtrop (UNH), Post doc mentor: M. Amarian (ODU).

(ii) All collaborators are listed as authors in the publication list. Main collaborators over the past 4 years: Moskov Amaryan (ODU), Harut Avagyan (Jefferson Lab), Volker Burkert (Jefferson Lab), M. Polyakov (University of Bochum, Germany), Stepan Stepanyan (Jefferson Lab), Larry Weinstein (ODU).

(iii) Graduate Students advised: Georgie Mbianda

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Curriculum Vita

1. Education

Degree	Institution	Date
Ph.D.	Yerevan State University, Yerevan, Armenia	1996
M.S./B.A.	Yerevan Physics Institute, Yerevan, Armenia	1979

2. Professional Experience

Position	Institution	Dates
Senior Scientist	Thomas Jefferson National Accelerator Facility, Newport News, Virginia, U.S.A.	2003 - present
Jefferson Lab Professor of Physics	Old Dominion University, Norfolk, Virginia, U.S.A.	2009 - present
Research Professor	Old Dominion University, Norfolk, Virginia, U.S.A.	2001 - 2003
Research Professor	Christopher Newport University, Newport News, Virginia, U.S.A.	2000 - 2001
Visiting Scientist	Thomas Jefferson National Accelerator Facility	1997 - 2000
Staff Scientist	Yerevan Physics Institute	1979 - 1997

Selected publications in refereed journals

1. “Measurement of Deeply virtual Compton scattering beam-spin asymmetries”, F.X. Girod et al., CLAS Collaboration, Phys. Rev. Lett. **100**, 162002 (2008)
2. “First measurement of coherent phi-meson photoproduction on deuteron at low energies”, T. Mibe et al., CLAS Collaboration, Phys. Rev. **C 76**, 052202 (2007)
3. “Measurement of 2- and 3-nucleon short range correlation probabilities in nuclei”, K.S. Egiyan et al., CLAS Collaboration, Phys.Rev.Lett. **96** (2006) 082501.
4. “Search for the Theta+ pentaquark in the reaction gamma d ---> p K- K+ n” B. McKinnon et al., CLAS Collaboration, Phys. Rev. Lett. **96**, 212001 (2006)
5. “Energy calibration of the JLab bremsstrahlung tagging system”, S. Stepanyan et al., Nucl. Instrum. Meth. **A 572**, 654 (2007)
6. “First observation of exclusive deeply virtual Compton scattering in polarized electron beam asymmetry measurements” S. Stepanyan et al., CLAS Collaboration, Phys. Rev. Lett. **87**, 182002 (2001)
7. “The P(33)(1232) resonance contribution into the amplitudes M**3/2(1+), E**3/2(1+), S**3/2(1+) from an analysis of the p(e,e-prime p) pi0 data at Q**2 = 2.8, 3.2, and 4-(GeV/C)**2

within dispersion relation approach", I.G. Aznaurian (Yerevan Phys. Inst.), S.G. Stepanian, Phys.Rev. **D59** (1999) 054009
8. "The CLAS Forward Electromagnetic Calorimeter", M. Amarian et al., Nucl. Instrum. Meth. **A 460**, 239 (2001).

Synergistic Activities:
Detector Development: (a) Radial time projection chamber based on GEM technology for detection of low energy alpha-particles, (b) scintillation hodoscope based on silicon photo multipliers for electron detection, (c) PbO_4W crystal calorimeter with APD readout for detection of electrons and photons at small angles.

Advised many Undergraduate in the SULI/JLAB program

Cospokesperson of the Heavy Photon Search (HPS) experiment in Jefferson Lab Hall B

Collaborators and other Affiliations:

(i) Thesis advisor: K. Egiyan (deceased)
(ii) Collaborators: The CLAS Collaboration, the HPS Collaboration and authors listed on publications. Main collaborators in the last five years include Marco Battaglieri (INFN/Genova, Italy), Natalia Dashyan (Yerevan Physics Institute, Armenia), Raffaella deVita (INFN/Genova, Italy), Raphael Dupre (INP/ORSAY, France), Michel Guidal (IPN/ORSAY, France), Kawtar Hafidi (Argonne National Laboratory), Maurik Holtrop (University of New Hampshire), and John Jaros (SLAC).
(iii) Graduate students mentored: R. Paremuzyan (Yerevan, 2010)

Biographical Sketch

Eli Piasetzky

Education and Training
Tel Aviv University Physics B.Sc. 1974
Tel Aviv University Physics M.Sc. 1978
Tel Aviv University Physics Ph.D 1981
Tel Aviv University Archeology B.A. 1999

Research and Professional Preparation
Tel Aviv University Institute for Nuclear Physics Director 2007 -
Tel Aviv University The wolfson chair in experimental physics 2006-
Tel Aviv University Nuclear Phyics dep. Chair 2000 - 2002
Tel Aviv University Nuclear Phyics dep. Chair 1996 – 1998
Tel Aviv University Professor 1992 –
Brokhaven Nat. Lab. Visiting Physicist 1992
Tel Aviv University Nuclear Phyics dep. Chair 1989 – 1991
Tel Aviv University Assoc. Professor 1987 – 1992
Tel Aviv University Senior Lecturer 1984 – 1987
Los Alamos Nat. Lab. Staff Member 1982 – 1984
Los Alamos Nat. Lab. Post-doctorate 1981 – 1982

Publications

Publications closely related to proposed project

1. *n-p Short-Range Correlations from (p, 2p + n) Measurements*, A. Tang, J. W. Watson, J. Aclander, J. Alster, G. Asryan, Y. Averichev, D. Baxton, V. Baturin, N. Bukhtoyarova, A. Carroll, S. Gushue, S. Heppelmann, A. Leksanov, Y. Makdisi, A. Malki, E. Minina, 1. Navon, H. Nicholson, A. Ogawa, Yu. Panebratsev, E. Piasetzky, A. Schetkovsky, S. Shimanskiy, and D. Zhalov, Phys. Rev. Lett **90**, 042301 (2003).

2. *Evidence for the Strong Dominance of Proton-Neutron Correlations in Nuclei,* E. Piasetzky, M. Sargsian, L. Frankfurt, M. Strikman and J. W. Watson, Phys. Rev. Lett. **97**, 162504 (2006).

3. *Investigation of Proton-Proton Short-Range Correlations via the 12C(e,e'pp) Reaction,* R. Shneor, P. Monaghan, R. Subedi, B. D. Anderson, K. Aniol, J. Annand, J. Arrington, H. Benaoum, F. Benmokhtar, P. Bertin, W. Bertozzi, W. Boeglin, J. P. Chen, Seonho Choi, E. Chudakov, E. Cisbani, B. Craver, C. W. de Jager, R. J. Feuerbach, S. Frullani, F. Garibaldi, O. Gayou, S. Gilad, R. Gilman, O. Glamazdin, J. Gomez, J.-O. Hansen, D. W. Higinbotham, T. Holmstrom, H. Ibrahim,1 R. Igarashi, E. Jans, X. Jiang, Y. Jiang, L. Kaufman, A. Kelleher, A. Kolarkar, E. Kuchina, G. Kumbartzki, J. J. LeRose, R. Lindgren, N. Liyanage, D. J. Margaziotis, P. Markowitz, S. Marrone, M. Mazouz, D. Meekins, R. Michaels, B. Moffit, S. Nanda, C. F. Perdrisat, E. Piasetzky, M. Potokar, V. Punjabi, Y. Qiang, J. Reinhold, B. Reitz, G. Ron, G. Rosner, A. Saha, B. Sawatzky, A. Shahinyan, S. Širca, K. Slifer, P. Solvignon, V. Sulkosky, N. Thompson, P. E. Ulmer, G. M. Urciuoli, E. Voutier, K. Wang, J. W. Watson, L. B. Weinstein, B. Wojtsekhowski, S. Wood, H. Yao, X. Zheng, and L. Zhu,Phys. Rev. Lett., **99**, 072501 (2007)

4. *Probing Cold Dense Nuclear Matter,* R. Subedi, R. Shneor, P. Monaghan, B. D. Anderson, K. Aniol, J. Annand, J. Arrington, H. Benaoum, F. Benmokhtar, W. Boeglin, J.-P. Chen, Seonho Choi, E. Cisbani, B. Craver, S. Frullani, F. Garibaldi, S. Gilad, R. Gilman, O. Glamazdin, J.-O. Hansen, D. W. Higinbotham, T. Holmstrom, H. Ibrahim, R. Igarashi, C. W. de Jager, E. Jans, X. Jiang, L. J. Kaufman, A. Kelleher, A. Kolarkar, G. Kumbartzki, J. J. LeRose, R. Lindgren, N. Liyanage, D. J. Margaziotis, P. Markowitz, S. Marrone, M. Mazouz, D. Meekins, R. Michaels, B. Moffit, C. F. Perdrisat, E. Piasetzky, M. Potokar, V. Punjabi, Y. Qiang, J. Reinhold, G. Ron, G. Rosner, A. Saha, B. Sawatzky, A. Shahinyan, S. Širca, K. Slifer, P. Solvignon, V. Sulkosky, G. M. Urciuoli, E. Voutier, J. W. Watson, L. B. Weinstein, B. Wojtsekhowski, S. Wood, X.-C. Zheng, L. Zhu, Science, **320,** 1476 (2008).

5. *Short Range Correlations and the EMC Effect,* L.B.Weinstein, , E. Piasetzky, D.W. Higinbotham, J. Gomez, , O. Hen, R. Shneor, Phys. Rev. Lett.106:052301,2011

<u>*Other significant publications*</u>

1. *Energy Dependence of Nuclear Transparency in C(p,2p) Scattering*, A. Leksanov, J. Alster, C. Asryan, Y. Averichev, D. Barton, V. Baturin, N. Bukhtoyaxova, A. Carroll, S. Heppelmann, T. Kawabata, Y. Makdisi, E. Minina, I. Navon, A. Malki, H. Nicholson, A. Ogawa, Yu. Panebratsev, E. Piesetzky, A. Schetkovsky, S. Shimanskiy, A. Tang, J. W. Watson, H. Yoshida, and D. Zhalov, Phys. Rev. Lett. **87**, 312301 (2001).

2. *Nuclear transparency in 90^o C. M. quasielastic A (p,2p) reactions*, J. Aclander, J. Alster, G. Asryan, Y. Averiche, D. S. Barton, V. Baturin, N. Buktoyarova, G. Bunce, A. S. Carroll, N. Christensen, H. Courant, S. Durrant, C. Fang, K. Gabriel, S. Cushue, K. J. Heller, S. Heppelmann, I. Kosonovsky, A. Leksanov, Y. 1. Makdisi, A. Malki, I. Mardor, Y. Mardor, M. L. Marshak, D. Martel, E. Minina, E. Minor, 1. Navon, H. Nicholson, A. Ogawa, Y. Panebratsev, E. Piasetzky, T. Roser, J. J. Russell, A. Schetkovsky, S. Shimanskiy, M. A. Shupe, S. Sutton, M. Tanaka, A. Tang, 1. Tsetkov, J. Watson, C. White, J-Y. Wu, and D. Zhalov, Phys. Rev. C **70**, 015208 (2004).

3. *Proton Electromagnetic Form Factor at low Q_2*, G. A. Miller, E. Piasetzky, G. Ron, Phys. Rev. Lett. 101 082002 (2008).

4. *The proton elastic form factor ratio GE/GM at low momentum transfer*, R. Guy et al., Phys. Rev. Lett. 99 202002 (2007).

Synergistic Activities

(1) Member of the organizing committee and the International Advisory Committee for International Conferences (PANIC08, and others in Israel, Europe, and USA. ; (2) Proposal reviewer for the ISF and BSF.; (3) Principal Investigator on two ISF and one BSF proposals.

Collaborators & Other Affiliations

<u>*Collaborators*</u>

W. Bertozzi (MIT), L. Frankfurt (Tel Aviv), S. Gilad (MIT), R. Gilman (Rutgers), D. Higinbotham (JLab), M. Sargsian (Florida Int. U), M. Strikman (Penn State), J. Watson (Kent State), S. Wood (JLab)

<u>*Thesis Advisor and Postgraduate-Scholar Sponsor*</u>

Graduate Students: A. Malki, O. Hen, I. korover , N. Bubis, I. Yaron, M. Braverman (School of Physics all at Tel Aviv University).
Postdoctoral Fellows sponsored: Jonathan Dumas

Biographical Sketch

SHALEV GILAD

Professional Preparation

Stanford University	Physics	B.Sc.	1971
University of California, Berkeley	Physics	M.Sc.	1972
Tel Aviv University	Physics	Ph.D.	1978
Massachusetts Institute of Technology	Nuclear Physics	postdoc	1982-5

Appointments

MIT	Principal Research Scientist	1994 – present
MIT	Research Scientist	1990 – 1994
Cubital, Ltd.	Chief Scientist	1988 – 1990
Indigo, Ltd.	Senior Physicist	1986 – 1988
Scitex Corp.	Senior Physicist	1985 – 1986
Israeli Aircraft Industries	Senior Physicist	1979 – 1982

Publications

Publications closely related to proposed project

1. *Measurement of the ^{3}He(e,e'p)pn Reaction at High Missing Energies and Momenta*, F. Benmokhtar, K. A. Aniol, W. Bertozzi, W. U. Boeglin, F. Butaro, J. R. Calarco, J. –P. Chen, E. Cisbani, A. Cochran, S. Dietrich, P. Djawotho, W. Duran, M. B. Epstein, J. M. Finn, K. G. Fissum, A. Frahi-Amroun, S. Frullani, C. Furget, F. Garibaldi, O. Gayou, S. Gilad, R. Gilman, C. Glashausser, O. Hansen, D. W. Higinbotham, A. Hotta, B. Hu, M. Iodice, R. Iommi, C. W. de Jager, X. Jiang, M. K. Jones, J. J. Kelly, S. Kox, M. Kuss, J. –M. Laget, J. J. LeRose, R. A. Lindgren, N. Liyanage, R. W. Lourie, S. Malov, D. J. Margaziotis, P. Markowitz, F. Merchez, R. Michaels, J. Mitchell, J. Mougey, E. Penel, C. F. Perdrisat, A. V. Punjabi, G. Quéméner, R. D. Ransome, R. Roché, M. Rvachev, J. –S. Real, F. J. Sabatie, A. Saha, S. Strauch, R. Suleiman, T. Tamae, J. A. Templon, R. Tieulent, H. Uono, P. E. Ulmer, G. M. Urciuoli, S. van Verst, E. Voutier, K. Wijesooriya, B. Wojtsekhowski, Phys. Rev. Lett. **94**, 082305 (2005); http://prola.aps.org/abstract/PRL/v94/i8/e082305

2. *Investigation of Proton-Proton Short-Range Correlations via the ^{12}C(e,e'pp) Reaction,* R. Shneor, P. Monaghan, R. Subedi, B. D. Anderson, K. Aniol, J. Annand, J. Arrington, H. Benaoum, F. Benmokhtar, P. Bertin, W. Bertozzi, W. Boeglin, J. P. Chen, Seonho Choi, E. Chudakov, E. Cisbani, B. Craver, C. W. de Jager, R. J. Feuerbach, S. Frullani, F. Garibaldi, O. Gayou, S. Gilad, R. Gilman, O. Glamazdin, J. Gomez, J.-O. Hansen, D. W. Higinbotham, T. Holmstrom, H. Ibrahim,1 R. Igarashi, E. Jans, X. Jiang, Y. Jiang, L. Kaufman, A. Kelleher, A. Kolarkar, E. Kuchina, G. Kumbartzki, J. J. LeRose, R. Lindgren, N. Liyanage, D. J. Margaziotis, P. Markowitz, S. Marrone, M. Mazouz, D. Meekins, R. Michaels, B. Moffit, S. Nanda, C. F. Perdrisat, E. Piasetzky, M. Potokar, V. Punjabi, Y. Qiang, J. Reinhold, B. Reitz, G. Ron, G. Rosner, A. Saha, B. Sawatzky, A. Shahinyan, S. Širca, K. Slifer, P. Solvignon, V. Sulkosky, N. Thompson, P. E. Ulmer, G. M. Urciuoli, E. Voutier, K. Wang, J. W. Watson, L. B. Weinstein, B. Wojtsekhowski, S. Wood, H. Yao, X. Zheng, and L. Zhu,Phys. Rev. Lett., **99**, 072501 (2007);

http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=PRLTAO000099000007072501000001&idtype=cvips&gifs=yes

3. *Probing Cold Dense Nuclear Matter,* R. Subedi, R. Shneor, P. Monaghan, B. D. Anderson, K. Aniol, J. Annand, J. Arrington, H. Benaoum, F. Benmokhtar, W. Boeglin, J.-P. Chen, Seonho Choi, E. Cisbani, B. Craver, S. Frullani, F. Garibaldi, S. Gilad, R. Gilman, O. Glamazdin, J.-O. Hansen, D. W. Higinbotham, T. Holmstrom, H. Ibrahim, R. Igarashi, C. W. de Jager, E. Jans, X. Jiang, L. J. Kaufman, A. Kelleher, A. Kolarkar, G. Kumbartzki, J. J. LeRose, R. Lindgren, N. Liyanage, D. J. Margaziotis, P. Markowitz, S. Marrone, M. Mazouz, D. Meekins, R. Michaels, B. Moffit, C. F. Perdrisat, E. Piasetzky, M. Potokar, V. Punjabi, Y. Qiang, J. Reinhold, G. Ron, G. Rosner, A. Saha, B. Sawatzky, A. Shahinyan, S. Širca, K. Slifer, P. Solvignon, V. Sulkosky, G. M. Urciuoli, E. Voutier, J. W. Watson, L. B. Weinstein, B. Wojtsekhowski, S. Wood, X.-C. Zheng, L. Zhu, Science, **320,** 1476 (2008); http://www.sciencemag.org/cgi/search?src=hw&site_area=sci&fulltext=cold+dense+nuclear+matter&search_submit.x=0&search_submit.y=0&search_submit=go

Other significant publications

1. *Recoil Polarization Measurements for Neutral Pion Electroproduction at $Q^2 = 1$ (GeV/c)^2 Near the Delta Resonance*, J. J. Kelly, O. Gayou, R. E. Roché, Z. Chai, M. K. Jones, A. J. Sarty, S. Frullani, K. Aniol, E. J. Beise, F. Benmokhtar, W. Bertozzi, W. U. Boeglin, T. Botto, E. J. Brash, H. Breuer, E. Brown, E. Burtin, J. R. Calarco, C. Cavata, C. C. Chang, N. S. Chant, J.-P. Chen, M. Coman, D. Crovelli, R. De Leo, S. Dieterich, S. Escoffier, K. S. Fissum, V. Garde, F. Garibaldi, S. Georgakopoulos, S. Gilad, R. Gilman, C. Glashausser, J.-O. Hansen, D. W. Higinbotham, A. Hotta, G. M. Huber, H. Ibrahim, M. Iodice, C. W. de Jager, X. Jiang, A. Klimenko, S. Kozlov, G. Kumbartzki, M. Kuss, L. Lagamba, G. Laveissière, J. J. LeRose, R. A. Lindgren, N. Liyanage, G. J. Lolos, R. W. Lourie, D. J. Margaziotis, F. Marie, P. Markowitz, S. McAleer, D. Meekins, R. Michaels, B. D. Milbrath, J. Mitchell, J. Nappa, D. Neyret, C. F. Perdrisat, M. Potokar, V. A. Punjabi, T. Pussieux, R. D. Ransome, P. G. Roos, M. Rvachev, A. Saha, S. Širca, R. Suleiman, S. Strauch, J. A. Templon, L. Todor, P. E. Ulmer, G. M. Urciuoli, L. B. Weinstein, K. Wijesooriya, B. Wojtsekhowski,, X. Zheng, and L. Zhu, Phys. Rev. **C75**, 025201 (2007); http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=PRVCAN000075000002025201000001&idtype=cvips&gifs=yes

Synergistic Activities

(1) Referee of Phys. Rev. and Phys. Lett. manuscripts; (2) Co-principal Investigator on three Israel-US BSF proposals.

Collaborators & Other Affiliations

Collaborators

W. Bertozzi (MIT), J.–P. Chen (JLab) L. R. Gilman (Rutgers U), D. Higinbotham (JLab), E. Piasetzky (Tel Aviv), M. Sargsian (Florida Int. U), M. Strikman (Penn State), J. Watson (Kent)

Graduate and Postdoctoral Advisors

Ph.D.: J. Alster (Tel Aviv U); Postdoctoral: R. Redwine (MIT)

Thesis Advisor and Postgraduate-Scholar Sponsor

Graduate Students: A. Puckett, X.-H Zhan, J. Huang, N. Muangma, K. Pan (MIT) career total 12; Postdoctoral Fellows sponsored: V. Sulkovsky, B. Moffit, N. Sparveris (career total 15)

Biographical Sketch for Jan Ryckebusch

(a) Education and Training

Ghent University, Belgium	Physics	M.Sc	1984
Ghent University, Belgium	Nuclear Physics	Ph.D	1988

(b) Research and Professional Experience

Ghent University, Belgium	Postdoctoral Research Fellow	1988-1989
University of Malawi, Malawi	Lecturer	1989-1991
Ghent University, Belgium	Postdoctoral Research Fellow	1991-1995
Ghent University, Belgium	Senior Research Scientist	1995-2000
Ghent University, Belgium	Assistant Professor	2000-2003
Ghent University, Belgium	Associate Professor	2003-2006
Ghent University, Belgium	Full Professor	2006-

(c) Selected publications

- J. Ryckebusch, M. Waroquier, K. Heyde, J. Moreau and D. Ryckbosch
  An RPA model for the description of one-nucleon emission processes and application to ^{16}O(γ,N) reactions
  Nuclear Physics **A476** (1988) 237-271.

- J. Ryckebusch, M. Vanderhaeghen, L. Machenil and M. Waroquier
  Effects of the final state interaction in (γ,pn) and (γ,pp) processes
  Nuclear Physics **A568** (1994) 828-854.

- J.Ryckebusch, V. Van der Sluys, K. Heyde, H. Holvoet, W. Van Nespen M. Waroquier and M. Vanderhaeghen
  Electroinduced two-nucleon knockout and correlations in nuclei
  Nuclear Physics **A624** (1997), 581-622.

- S. Janssen, J. Ryckebusch and T. Van Cauteren
  Kaon photoproduction: background contributions, form factors and missing resonances
  Physical Review C **65** (2002), 015201 (9 pages).

- J. Ryckebusch, D. Debruyne, P. Lava, S. Janssen, T. Van Cauteren and B. Van Overmeire
  Relativistic formulation of Glauber theory for $A(e,e'p)$ reactions
  Nuclear Physics **A728** (2003), 226-250.

- M.C. Martínez, P. Lava, N. Jachowicz, J. Ryckebusch, K. Vantournhout, J.M. Udías
  Relativistic models for quasi-elastic neutrino scattering
  Physical Review C **73** (2006) 024607 (12 pages)

- T. Corthals, J. Ryckebusch and T. Van Cauteren
  Forward-angle $K^+\Lambda$ photoproduction in a Regge-plus-resonance approach
  Physical Review C **73** (2006), 045207 (13 pages)

- B. Clasie, X. Qian, J. Arrington, R. Asaturyan, F. Benmokhtar, W. Boeglin ,P. Bosted ,A. Bruell ,M. E. Christy ,E. Chudakov ,W. Cosyn ,M. M. Dalton ,A. Daniel ,D. Day ,D. Dutta ,L. El Fassi ,R. Ent ,H. C. Fenker ,J. Ferrer ,N. Fomin ,H. Gao ,K. Garrow ,D. Gaskell ,C. Gray ,T. Horn ,G. M. Huber ,M.K. Jones ,N. Kalantarians ,C.E. Keppel ,K. Kramer ,A. Larson ,Y. Li ,Y. Liang ,A. F. Lung ,S. Malace ,P. Markowitz ,A. Matsumura ,D. G. Meekins ,T. Mertens ,G. A. Miller ,T. Miyoshi ,H. Mkrtchyan ,R. Monson ,T. Navasardyan ,G. Niculescu ,I. Niculescu ,Y. Okayasu ,A. K. Opper ,C. Perdrisat ,V. Punjabi ,A. W. Rauf ,V. M. Rodriquez ,D. Rohe ,J. Ryckebusch ,J. Seely ,E. Segbefia ,G. R. Smith ,M. Strikman ,M. Sumihama ,V. Tadevosyan ,L. Tang ,V. Tvaskis ,A. Villano ,W.F. Vulcan ,F.R. Wesselmann ,S.A. Wood ,L. Yuan ,X.C. Zheng
  Measurement of Nuclear Transparency for the $A(e, e'\pi^+)$ Reaction
  Physical Review Letters **99** (2007) 242502

- Lesley De Cruz, Tom Vrancx, Pieter Vancraeyveld, Jan Ryckebusch
  Bayesian inference of the resonance content of $p(\gamma, K^+)\Lambda$
  Physical Review Letters **108** (2012), 182002

- Maarten Vanhalst, Jan Ryckebusch, Wim Cosyn
  Quantifying short-range correlations in nuclei
  Physical Review C **86** (2012), 044619 (14 pages)

(d) Synergistic Activities

- Organisation of international conferences and workshops: May 1995 (Ghent), June 1997 (Glasgow, Schotland), June 2001 (Lund, Sweden), March 2002 (Münster, Germany), November 2002 (Ghent), March 2004 (Köln, Germany), August 2007 (Ghent, Belgium), October 2007 (Newport News, USA), May 2008 (Brussels, Belgium), June 2014 (Trento, Italy)

- October 2004-December 2009: Member of the Committee "Nuclear and High-Energy Physics" of the Fund for Scientific Research-Flanders

- October 2004-October 2010: Program director for the "Bachelor in Physics and Astronomy" and "Master in Physics and Astronomy" programs at Ghent University (there are over 250 students enrolled in these programs)

(e) Graduate Students & Postdoctoral Associates

- Graduate Students: Dr. D. Debruyne, Dr. S. Janssen, Dr. W. Van Nespen, Dr. T. Van Cauteren, Dr. P. Lava, Dr. T. Corthals, Dr. B. Van Overmeire, Dr. A. Van Dyck, Dr. C. Praet, Dr. W. Cosyn, Dr. K. Vantournhout, Dr. S. Standaert, Dr. P. Vancraeyveld, Dr. L. De Cruz, J. Vlietinck, T. Vrancx, M. Vanhalst, V. Pandey, B. Vandermarliere, C. Colle, S. Stevens

- Postdoctoral Associates: Dr. S. Janssen, Dr. T. Van Cauteren, Dr. .K. Van Houcke, Dr. W. Cosyn, Dr. M. Martínez, Dr. O. Lalakulich

Biographical Sketch: Michael H. Wood

(a) Education and Training

The Catholic University of America	Physics	B.S., 1994
University of North Carolina at Chapel Hill	Physics	M.S.,1997, Ph.D.,2000
University of South Carolina	Nuclear Physics	2000-2004, 2007-2008
University of Massachusetts, Amherst	Nuclear Physics	2004-2007

(b) Research and Professional Experience

September 2008 - Present	Canisius College, Assistant Professor
September 2006 - December 2007	Christopher Newport University, Adjunct Professor
October 2007 – July 2008	University of South Carolina, Research Scientist
July 2004 - July 2007	University of Massachusetts, Postdoctoral Fellow
August 2000 – July 2004	University of South Carolina, Postdoctoral Fellow

(c) Publications

1. M. H. Wood, Phys. Teach. **49**, 158 (2011).
2. M. H. Wood, R. Nasseripour, M. Paolone, C. Djalali, D. Weygand, et al. (CLAS Collaboration), Phys. Rev. Lett. **105**, 112301 (2010).
3. M. H. Wood, C. Djalali, R. Nasseripour, D. Weygand, et al. (CLAS Collaboration), IJMPA 24, 309 (2008).
4. M. H. Wood, R. Nasseripour, C. Djalali, D. Weygand, et al. (CLAS Collaboration), Phys. Rev. C **78**, 015201 (2008)
5. R. Nasseripour, M. H. Wood, D. Weygand, C. Djalali, et al. (CLAS Collaboration) , Phys. Rev. Lett. **99,** 262302 (2007)
6. S. Stepanyan, S. Boyarinov, H. Egiyan, L. Guo, D. Dale, M. Gabrielyan, L. Gan, A. Gasparian, A. Glamazdin, B. Mecking, I. Nakagawa, A. Teymurazyan and M. H. Wood, NIM A **572**, 654 (2007).

(d) Synergistic Activities

1. Wrote *Abbey Physics* with Dr. Herbert T. Wood. The book is an introductory textbook for high school physics students. Self-published on the Apple iBookstore under the ISBN 978-1-62847-263-9.
2. Developed the reconstruction and simulation software for the CLAS Collaboration. The PI and his students are leading the development for the Pre-shower Calorimeter (PCAL) software. The PCAL is a new detector being built for the 12-GeV upgrade at JLab.
3. Teaching a course on "*The Theory of Almost Everything*". Taught the course every Fall semester since 2011. Developed the course as an introduction to grand, unified theories for non-science majors, who are members of the Honors Program. The students learn the concepts behind Special Relativity, General Relativity, and the Standard Model of Particle Physics.
4. Presented student research at the Ignatian Scholarship Day at Canisius College. This program is held annually at the college to showcase the research and scholarship of the students at the college.
5. Presented posters with students at the 2013 Fall Meeting of the Division of Nuclear Physics of the American Physical Society, October 23-26, 2013.

(e) Collaborators and Other Affiliations

1. Collaborators: All collaborators are listed as authors in the publication list. Main

collaborators over past 5 years – William Brooks (Universidad Tecnica Federico Santa Maria, Chile), Chaden Djalali (University of Iowa), Gerald Gilfoyle (University of Richmond), Kawtar Hafidi (Argonne National Laboratory), Lawrence Weinstein (Old Dominion University), Dennis Weygand (Jefferson Lab).

2. Graduate Advisors: Edward Ludwig and Hugon Karwowski (University of North Carolina at Chapel Hill). Post-graduate advisors: Chaden Djalali and David Tedeschi (University of South Carolina), Rory Miskimen (University of Massachusetts, Amherst).
3. Undergraduate Students Advised: Andrew Beiter, Craig King, Michael Lanighan, Angelo Licastro, Robert Makin, Jerod Sikorskyj, Danielle Stewart, Nicolas Tyler (Canisius College), and Alexander Piaseczny (University of Buffalo).

Biographical Sketch for Dr. I J Douglas MacGregor

(a) **Education and Training**
University of Glasgow, UK Maths & Natural Philosophy B.Sc. (1^{st} class) 1978
University of Glasgow, UK Nuclear Physics Ph.D. 1982
Chartered Physicist C.Phys. 1986
Fellow Institute of Physics,UK F.Inst.P. 1995

(b) **Research and Professional Experience**
University of Glasgow, UK Reader 2002-
University of Glasgow, UK Senior Lecturer 1994-2002
University of Glasgow, UK Lecturer 1984-1994
University of Manchester,UK Research Associate 1982-1983

(c) **Publications**
I J D MacGregor and R Kaiser (Eds): “Hadron Physics”, Proc. 58^{th} Scottish Summer School in Physics, Scottish Graduate Series 58 (2006) Taylor & Francis CRC Press, ISBN 1584887052, pp496.
I Pomerantz et al: “Hard Two-Body Photodisintegration of ^{3}He”, Phys. Rev. Lett. 110 (2013) 242301:1-7.
J Robinson, IJD MacGregor et al: “Measurements of ^{12}C(γ,pp) photon asymmetries for E_γ= 200–450 MeV”, Eur. Phys. J. A, 49 (2013) 65:1-9.
DG Middleton, et al: “Investigation of the Exclusive ^{3}He(e,e'pn)p Reaction”, Phys. Rev. Lett. 103 (2009) 152501:1-5.
DP Watts, et al: “The dependence of the ^{12}C(γ_{pol},pd) reaction on photon linear polarization”, Phys. Lett. B 647 (2007) 88-93.
DG Middleton et al: “First measurements of the ^{16}O(e,e'pn)^{14}N reaction”, Eur. Phys. J. A 29 (2006) 261-270.
DP Watts et al: “Three-nucleon mechanisms in photoreactions”, Phys. Lett. B 553 (2003) 25-30.
CJY Powrie, et al: “Polarised Photon Measurements of the ^{12}C(γ_{pol},pp) and (γ_{pol},pn) Reactions for E_γ=160-350 MeV”, Phys. Rev. C 64 (2001) 034602:1-9
B Krusche et al: “In-medium properties of the D13(1520) nucleon resonance”, Phys. Rev. Lett. 86 (2001) 4764-4767
DP Watts et al: “The ^{12}C(γ,NN) reaction studied over a wide kinematic range”, Phys. Rev. C 62 (2000) 014616:1-15.

(d) **Synergistic Activities**
1. Membership of relevant learned societies: European Physical Society, Nuclear Physics Board (2007-); Scientific Secretary (2009-2012); Chair elect (2013); Chair (2014-) UK Institute of Physics, Nuclear & Particle Physics Division Board (1986-1993, 2001-2012); Honorary Secretary (2005-2009); Chair (2009-2012); Nuclear Physics Group Board (1989-1994, 2000-2005); Chair (2001-2005); UK West of Scotland Physics Education Group Board (1984-1990)
2. Organisation of relevant conferences: 2004 58th Scottish Summer School in Physics, Hadron Physics Conference, St Andrews, UK; 2009 European Physical Society, European Nuclear Physics Conference, Bochum, Germany (Hadron physics selection committee); 2011 Institute of Physics, Nuclear and Particle Physics Division Conference, Glasgow, UK; 2011 Rutherford Centennial Conference, Manchester, UK, 2012; European Physical Society,European Nuclear Physics

Conference, Bucharest, Romania (Hadron physics selection committee); Baryons 2013, Glasgow, UK
3. Membership of CLAS Service Work Committee, Membership of Steering Committee: Mainz A2 Crystal Ball collaboration

(e) **Senior Collaborators, last 48 months**
J Ahrens[1], JO Adler[2], C Barbieri[3], R Beck[4], HP Blok[5], A Braghieri[6], D Branford[7], WJ Briscoe[8], H de Vries[5], MO Distler[1], J Friedrich[1], C Giusti[6], K Hansen[2], WHA Hesselink[5], D Hornidge[10], E Jans[5], R Kaiser[16], VL Kashevarov[11], F Klein[4], B Krusche[12], L Lapikás[5], DM Manley[13], V Metag[14], BMK Nefkens[15], M Ostrick[1], RO Owens[16], P Pedroni[6], SN Prakhov[15], JW Price[15], G Rosner[9], B Schoch[4], B Schroder[2], DI Sober[15], A Starostin[15], I Supek[17], A Thomas[1], T Walcher[1], DP Watts[7]
Affiliation: [1]Mainz, [2]Lund, [3]Surrey, [4]Bonn, [5]NIKHEF/Amsterdam, [6]Pavia, [7]Edinburgh, [8]George Washington, [9]GSI, [10]Saskatoon, [11]Lebedev, [12]Basel, [13]Kent State, [14]Giessen, [15]UCLA, [16]Glasgow, [17]Zagreb

(f) **Graduate Students & Postdoctoral Associates, last 5 years (current affiliation Glasgow unless specified)**
Graduate Students: Dr J Robinson, Dr D Howdle, Dr J Mancell, Dr S Al-Jebali, Mr S Gardner, Mr J Sjoegren, Mr R Macrae, Mr B Strandberg
Postdoctoral Associates: Dr JRM Annand, Dr K Livingston, Dr JC McGeorge Dr D Protopopescu, Dr B McKinnon, Dr D Hamilton, Dr DI Glazier, Dr G Yang

Biographical Sketch: Dr. Gerard P Gilfoyle

Education and Training	Ph.D., University of Pennsylvania, 1985 - 'Resonant Structure in $^{13}C(^{13}C,^{4}He)^{22}Ne$', H.T. Fortune, adviser. A.B., cum laude, Franklin and Marshall College, 1979.
Research and Professional Experience	2008-present - Clarence E. Denoon Professor of Science, University of Richmond. 2004-present - Professor of Physics, University of Richmond. 2002-2003 - Scientific Consultant, Jefferson Laboratory. 1999-2000 - AAASe Defense Policy Fellow. 1994-1995 - Scientific Consultant, Jefferson Laboratory. 1993-2004 - Associate Professor of Physics, University of Richmond. Summer, 1988 - Visiting Research Professor, University of Pennsylvania. 1987-1993 - Assistant Professor, University of Richmond. 1985-1987 - Postdoctoral Research Fellow, SUNY at Stony Brook.

Selected Listing of Refereed Publications

1. M. Moteabbed *et al.* (The CLAS Collaboration), 'Demonstration of a novel technique to measure two-photon exchange effects in elastic $e^{\pm}p$ scattering, Phys. Rev. C 88, 025210 (2013).

2. V. Gyurjyan, D. Abbott, J. Carbonneau, G. Gilfoyle, D. Heddle, G. Heyes, S. Paul, C. Timmer, D. Weygand, E. Wolin, 'CLARA: A contemporary approach to physics data processing', J.Phys.Conf.Ser. 331 (2011) 032013.

3. J. Lachniet, A. Afanasev, H. Arenhövel, W. K. Brooks, G. P. Gilfoyle, D. Higinbotham, S. Jeschonnek, B. Quinn, M. F. Vineyard *et al.* (The CLAS Collaboration), 'Precise Measurement of the Neutron Magnetic Form Factor G_M^n in the Few-GeV^2 Region' Phys. Rev. Lett. **102**, 192001 (2009).

4. M. Battaglieri, R. De Vita, V. Kubarovsky *et al.*, (The CLAS Collaboration), 'Search for $\theta^+(1540)$ pentaquark in high statistics measurement of $\gamma p \to \overline{K}_0 K^+ n$ at CLAS', Physical Review Letters 96, 042001 (2006).

5. B. Mecking *et al.*, (The CLAS Collaboration), 'The CEBAF Large Acceptance Spectrometer', Nucl. Instr. and Meth., **503**/3, 513 (2003).

6. G.P.Gilfoyle and J.A.Parmentola, 'Using Nuclear Materials to Prevent Nuclear Proliferation', Science and Global Security **9**, 81 (2001).

Selected Presentations

1. "Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab", presented at the Workshop on High-Energy Physics in the LHC Era", Valparaiso, Chile, Dec 17, 2013.

2. "Few-body physics with CLAS", presented at the 21st European Conference on Few-Body Problems in Physics, Salamanca, Spain, Aug 30, 2010.

3. "Precise Measurement of the Neutron Magnetic Form Factor", presented to the Physics Division at Argonne National Laboratory, June 1, 2009.

Synergistic Activities

2006 - 2010 - Chair, Nuclear Physics Working Group, CLAS Collaboration.
2006 - present - CLAS Coordinating Committee.
2005 - Reviewer, National Science Foundation (Nuclear Physics).
2003 - present - Southeastern Universities Research Association Trustee.
2002 - 2003 - American Physical Society Task Force on Countering Terrorism.

Collaborators: Members of the CLAS Collaboration and coauthors in the publication list. Major recent collaborators include D. Abbott (Jefferson Lab), A. Afanasev GWU), H. Arenhövel (Johannes Gutenberg-Universitt Mainz, Germany), W. Brooks (Universidad Tecnica Federico Santa Maria, Chile), J. Carbonneau, V. Gyurjyan, and D. Higginbotham, (Jefferson Lab).

Graduate and Postdoctoral Advisors: H.T. Fortune (U. Penn) and R.L. McGrath (Stonybrook).

Graduate and Postdoctoral Advisees: None.

B Appendix 2. Current and Pending Support

Current and Pending Support - Old Dominion University Group

A Current Support

1	Source of Support:	Department of Energy
	Project Title:	From Quarks to Nuclei
	Investigators:	M. Amarian, S. Bültmann, G.E. Dodge, C.E. Hyde, S.E. Kuhn (PI), and L.B. Weinstein
	Amount Awarded:	$2,188,000
	Period Covered:	March 15, 2014 – March 14, 2017
	Effort:	2 months summer (S. Kuhn, L. Weinstein)
	Location:	Old Dominion University
2	Source of Support:	Department of Energy
	Project Title:	SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA
	Investigators:	S.E. Kuhn (co-PI), and L.B. Weinstein (PI)
	Amount Requested:	$443,000
	Period Covered:	Sept 1, 2011 – August 31, 2014
	Effort:	0 months (S. Kuhn, L. Weinstein)
	Location:	Old Dominion University

B Pending Support

1	Source of Support:	Department of Energy
	Project Title:	SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA
	Investigators:	M. Amarian, S.E. Kuhn, and L.B. Weinstein (PI)
	Amount Requested:	$535,964
	Period Covered:	Sept 1, 2014 – August 31, 2017
	Effort:	0 months (S. Kuhn, L. Weinstein)
	Location:	Old Dominion University

Current and Pending Support - Pennsylvania State University Group

A Current Support

1	Source of Support:	Department of Energy
	Project Title:	Theoretical studies in high-energy nuclear physics
	Investigator:	M. Strikman
	Amount Awarded:	$450,000
	Period Covered:	January 1, 2014 - December 31, 2017
	Effort:	2 months summer
	Location:	Pennsylvania State University
2	Source of Support:	Department of Energy
	Project Title:	SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA
	Investigators:	M. Strikman (co-PI)
	Amount Requested:	$443,000
	Period Covered:	Sept 1, 2011 – August 31, 2014
	Effort:	0 months
	Location:	Pennsylvania State University

B Pending Support

1	Source of Support:	Department of Energy
	Project Title:	SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA
	Investigator:	M. Strikman
	Amount Requested:	$535,964
	Period Covered:	Sept 1, 2014 – August 31, 2017
	Effort:	0 months
	Location:	Pennsylvania State University

Current and Pending Support - Florida International University Group

A Current Support

1	Source of Support:	Department of Energy
	Project Title:	Theoretical Studies of High-Energy Electro-Nuclear Processes
	Investigator:	M. Sargsian (PI)
	Amount Awarded:	$270,000
	Period Covered:	April 15, 2013 – April 14, 2016
	Effort:	2 months summer (M. Sargsian)
	Location:	Florida International University
2	Source of Support:	Department of Energy
	Project Title:	SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA
	Investigators:	M. Sargsian (co-PI)
	Amount Requested:	$443,000
	Period Covered:	Sept 1, 2011 – August 31, 2014
	Effort:	0 months
	Location:	Florida International University

B Pending Support

1	Source of Support:	Department of Energy
	Project Title:	SHORT DISTANCE STRUCTURE OF NUCLEI - MINING THE WEALTH OF EXISTING JEFFERSON LAB DATA
	Investigators:	M. Sargsian (co-PI)
	Amount Requested:	$535,964
	Period Covered:	Sept 1, 2014 – August 31, 2017
	Effort:	0 months (W. Boeglin, M.Sargsian)
	Location:	Florida International University

C Appendix 3. Bibliography and References Cited

References

[1] Jozef Dudek, Rolf Ent, Rouven Essig, K. S. Kumar, Curtis Meyer, R. D. McKeown, Zein Eddine Meziani, Gerald A. Miller, Michael Pennington, David Richards, Larry Weinstein, Glenn Young and Susan Brown, "Physics opportunities with the 12 GeV upgrade at Jefferson Lab", Eur. Phys. J. A (2012) **48**: 187.

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D Appendix 4. Facilities and Other Resources

The ODU group has recently moved into a new, state-of-the art laboratory space including various computational resources (including a computer farm). The University supports the group with a 1/2 FTE computer support person, a 1/2 FTE technician, secretarial staff and graduate student funding.

The William and Mary nuclear and particle physics group maintains an active set of laboratories for the construction and testing of detector systems for use in experiments at Fermilab, JLab, and other facilities as well as multi-node computer farms for Monte Carlo simulations. The department maintains a fully equipped and staffed machine shop with CNC machining and in-house design capability. W&M has fast internet access to Jefferson Lab, which facilitates data transfers and provides good access to JLab computer resources from campus. W&M will also all provide the administrative support required for the activities outlined in this proposal.

The FIU group will provide adequate storage and computing resources for data analysis and Monte-Carlo simulations. Presently our group has a 48×2.4GHz computer cluster which could be used for data simulations.

The Glasgow/Edinburgh group will be able to use their group's computer cluster at Glasgow (> 200 CPU cores) and possibly the Grid for the higher level analyses of stage 3 (acceptance calculations, comparison with theory). They should also be able to make use of funds from their rolling grant to attend collaboration meetings and other analysis meetings in connection with this initiative.

The nuclear and particle physics laboratory at Richmond is supported by 32-node, 384-core computing cluster with 5 TByte of main storage and 500 GByte on each remote node. The system is for the primary use of the nuclear physics group and has also been utilized by five members of the CLAS Collaboration outside of the University of Richmond for software development and data analysis. The cluster is supported and maintained by our group and the Richmond information services staff. It will be available to the members of the data-mining collaboration. In addition, the University of Richmond has routinely supported 1-2 summer stipends for undergraduates in nuclear and particle physics. We expect this support to continue.

Because of the importance of this initiative, Jefferson Lab has agreed to support the proposed effort by offering office space and equipment, computer support, and participation by a Hall B staff member (see attached letter).

E Appendix 6. Letters of Support

Jefferson Lab
Thomas Jefferson National Accelerator Facility
Exploring the Nature of Matter

April 28, 2014

Dear Dr. Gulshan Rai:

As leader of Hall B within Jefferson Lab's Physics Division, I am fully supportive of the proposed initiative to extract new results for QCD Nuclear Physics from existing data sets. CLAS has measured electron scattering from a large range of nuclear targets over a wide range in incident energies. These data have already provided important new insights on short-range correlations and on the dynamics of hadron formation in nuclei. Since these experiments typically used inclusive, (e,e'), triggers, the same data sets can be re-analyzed for additional physics topics. By combining the data from all of these different data sets, we expect to greatly extend our knowledge of such topics as short-range correlations non-nucleonic degrees of freedom in the nucleus, modifications of bound nucleon structure and color transparency effects.
Because of the importance of this initiative for maximizing the output of physics from data already collected at Jefferson Lab, I am willing to support it in the following ways:

- Providing space and office equipment to host the postdoc to be hired for the software development and reanalysis effort proposed here

- Obtaining support from the Computer Center for data retrieval, storage and general computing

- Allowing up to 25% of the research time of one Hall B staff member to be allocated to work on this initiative

- Agreeing to share costs with one of the collaborating institutions (Old Dominion) for support of one graduate student.

Volker Burkert

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