Physics potential of A > 1 nuclear experiments with JLab 22 GeV

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2 year project, cost 139K + 165K = 304K

Goal: Demonstrate impact of key A > 1 nuclear experiments on new science questions opened up with JLab 22 GeV: Repulsive core of NN interaction, nuclear binding in 3D quark/antiquark distributions, gluonic fields in light nuclei.

Distribute simulation tools for further physics development and detector simulations

New A > 1 science with JLab 22 GeV

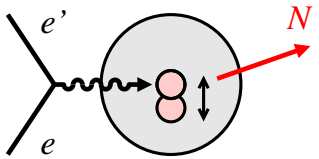
Understanding emergence of NN forces and nuclear bound states from QCD central to DOE NP program

Electron scattering at multi-GeV energies proved to be essential tool

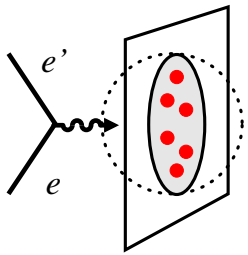
JLab 6 / 12 GeV: NN tensor correlations at ~1 fm, isospin-dependent EMC effect

JLab 22 GeV: New science questions

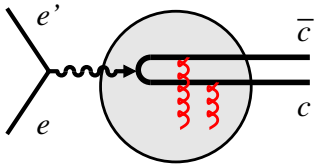
Repulsive core of NN interaction at < 1 fm:
Responsible for stable nuclei, saturation, dense matter EoS



Nuclear binding in 3D quark/antiquark distributions:
Novel approaches to NN interactions, antishadowing



Gluonic fields in light nuclei:
Direct insight in QCD substructure of NN interactions



Opened up by unique combination of energy and luminosity

Intellectual merit and community interest: 22 GeV science summary arXiv:2306.09360

R&D plan

Physics question	Key measurements
Repulsive core of NN interaction	•Deuteron photo/electrodisintegration at high momentum, incl. ΔΔ •S/D wave separation using polarized deuteron •3He breakup to 3N
3D distributions of nuclear quarks/antiquarks	•Coherent and incoherent nuclear DVCS on deuteron •Antishadowing with tagged DIS and DVCS on deuteron
Gluonic fields in light nuclei	•Gluonic form factors of D/3He/4He with coherent J/ψ production •Quarkonium-nucleon interaction from incoherent J/ψ production

Key measurements selected for potential impact, feasibility, readiness

→ Exclusive final states, nuclear breakup processes, few-body dynamics

For each key measurement:

- Develop/implement cross section model and event generator
- Perform MC simulations for physics analysis (schematic modeling of detectors)
- Quantify impact, assess feasibility, optimize conditions (kinematics, observables)
- Organize/distribute simulation tools according to best practices for scientific software (GitHub)

Details depend on particular measurement: need for model development, readiness (→ proposal)
Joint effort by theorists + experimentalists + software expert. Unique expertise in team
Adapt/extend existing tools, esp. computer codes for eA scattering with nuclear breakup

Milestones

Core of NN interactiion

6 months	•Deuteron photo/electrodisintegration physics model and MC implemented
12 months	•Deuteron photo/electrodisintegration 22 GeV MC simulations performed and impact studied •Deuteron photo/electrodisintegration code prepared for release •3He breakup physics model partially implemented
18 months	•3He physics model and MC fully implemented
24 months	•3He breakup 22 GeV MC simulations performed and impact studied •3He breakup code prepared for release

3D nuclear quarks/antiquarks

12 months	•Coherent deuteron DVCS cross section model with antishadowing developed
18 months	•Tagged deuteron DVCS cross section model developed •Coherent deuteron DVCS MC simulations performed and analyzed
24 months	•Incoherent deuteron DVCS MC simulations performed and analyzed

Gluon fields in light nuclei

12 months	•Coherent J/ψ production physics model and MC implemented
18 months	•Coherent J/ψ production MC simulations performed and impact studied

Expected results

Specific outcomes

- Publications quantifying/assessing the impact of the key A > 1 nuclear experiments on the new physics questions opened up with 22 GeV (repulsive core of NN interaction, 3D distributions of nuclear quarks/antiquarks, gluonic fields in light nuclei), based on state-of-the-art theoretical methods and MC simulations

- Computer codes implementing physics models for the key A > 1 nuclear experiments at 22 GeV (deuteron breakup, 3He breakup, coherent/tagged DVCS, J/ψ production), documented and tested, organized and shared according to best practices (GitHub, continuous integration)

Broader impact

- Guide further development of the JLab 22 GeV science program: identification/selection of key measurements, assessment of impact, conceptual formulation

- Enable/stimulate user efforts in JLab 22 GeV program development: LDRD project as focal point to which users can connect and attach their own efforts. LDRD team will actively reach out to users in JLab's A > 1 nuclear program and involve them in scientific discussions and follow-up projects.

  Successful example: 2014-15 JLab LDRD developing light-ion physics program at EIC [Webpage]

- Computer codes published under LDRD will be valuable resources for community, can be used also in analysis of 12 GeV A > 1 experiments

Importance / Novelty

- Physics simulations of key 22 GeV measurements needed in next 1-2 years for pre-CDR and further program development. LDRD project will make essential contribution.
- Strong user interest in A > 1 nuclear physics at JLab. Dedicated community, future plans. (PAC52: 9 new proposals for A > 1 experiments!) Developing A > 1 program with 22 GeV will be essential for engaging users in upgrade initiative.
- Simulations in LDRD project will focus on physics analysis and can be performed with schematic modeling of detector effects. They can be followed up by full detector-level simulations outside the LDRD project, using the tools developed under the project.

Novelty

- New science questions opened up with 22 GeV: NN core, 3D nuclear distributions, gluonic fields
- Novel approaches explored, e.g. quark antishadowing with tagged/exclusive processes
- Developing science program for future facility

Roles / Effort / Budget justification

Team Member	Role	Project Contribution	Effort	Cost Y1	Cost Y2	Cost total
Christian Weiss	PI	Develop/implement physics models, lead physics analysis of simulations; oversee project as PI	0.25 FTE			
Hanjie Liu	Co-I	Develop MC generators, perform MC simulations and physics analysis	0.25 FTE			
Anil Panta	Co-I	Organize/maintain simulation software, prepare release (GitHub)	0.1 FTE			
Doug Higinbotham	Contributor	Co-supervise nuclear breakup simulations and analysis	—			
FX Girod	Contributor	Co-supervise graduate student in nuclear DVCS simulations and analysis	—			
Total staff			0.6 FTE	111	113	224
Grad. student exp. physics TBD	Temp. labor	Perform nuclear DVCS simulations	3 months in Y2	—	19	19
Wim Cosyn, Misak Sargsian, Mark Strikman	External advisors (travel only)	Provide expert advice on physics models and existing simulation tools. Consult in analysis of results and impact studies.	Visit 2 weeks/ year	5.5	5.5	11

Budget

Jefferson Lab LDRD Proposal Budget					
	PI Name:				
	Indirect Rates		Proposal Title:		
CATEGORY	FY25	FY26	LDRD REQUEST FY25 ($)	LDRD REQUEST FY26 ($)	TOTAL ($)
Direct Costs					
Labor - Fringe			70,765	72,004	142,769
Labor - Non-Fringe					0
Fringe	48.25%	48.25%	34,144	34,742	68,886
Stats	8.75%	8.75%	6,192	6,300	12,492
Total for Personnel			**111,101**	**113,046**	**224,147**
POs/Contracts/PCards < or = $300K Cap (Materials, Supplies, Equip, EDP, Contracted Services)					0
Temp Labor/University Relations Labor < or = $300K cap				19,250	19,250
URO <$300k Offsite					0
Non-POs (Travel, Training, Reg Fees, Other)			5,800	5,800	11,600
Machine Shop (Multiply estimated number of hours by rate noted)	$79.75	$79.75			0
POs/Contracts > $300K Cap (Materials, Supplies, Equip, EDP, Contracted Services)					0
Temp Labor/University Relations Labor > $300K cap					0
URO >$300K Cap Offsite					0
Total Direct Costs			**116,901**	**138,096**	**254,997**
Indirect Costs					
Material Handling	6.12%	6.12%	0	1,178	1,178
Facilities & Infrastructure	19.49%	19.49%	21,654	25,784	47,438
G&A Not Applicable	0.00%	0.00%	0	0	0
Total Indirect Costs			**21,654**	**26,962**	**48,616**
TOTAL LDRD REQUEST			**138,555**	**165,058**	**303,613**
TOTAL BUDGET					**303,613**