Physics potential of polarized light ions with EIC@JLab

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Duration: 2 years Budget: \( \sim $160K/\text{year} \)

Demonstrate feasibility of precision nuclear physics measurements using polarized light ions \( ^2\text{H}, ^3\text{He} \) and **forward spectator tagging** with the JLab medium–energy Electron–Ion Collider design

- Fundamental nuclear physics questions identified in EIC White Paper: Neutron spin structure, nuclear binding in QCD, collective quark/gluon fields
- Innovative method enabled by unique capabilities of JLab EIC design, promises qualitative advances
- Benchmark results available for next NSAC Long–Range Plan (exp. 2014/15)
Context and Motivation

- Medium–energy EIC design $\sqrt{s} = 20–70$ GeV
  - Polarized light ions, esp. deuterium $^2\text{H}$
  - Forward and far–forward detection

- Spectator tagging with light ions
  - Neutron partonic structure:
    - Spin, sea quark flavor decomposition
  - Bound nucleon in QCD:
    - Controlled nuclear environment
  - Collective quark/gluon fields:
    - Multiple scattering, coherent recoil

- Great physics potential
  - Qualitatively new, never studied at collider

Uses unique capabilities of JLab EIC design:
- Polarized $^2\text{H}$, lower energy facilitates detection
- Polarized $^2\text{H}$ not available at BNL eRHIC

Complementary to heavy ions at LHC, RHIC
- Different physics focus, detection methods, technology challenges
Tasks

• Develop **physics models** for deep–inelastic processes with polarized light ions and tagged spectators at EIC energies

• Implement in a documented and extensible **Monte–Carlo (MC) platform** with schematic modeling of EIC@JLab beam optics and forward detectors

• Perform detailed **process simulations**, quantify physics impact of forward spectator tagging, and optimize forward detectors

Personnel

• Theory senior visitors
  
  Prof. Misak Sargsian (Florida Int. U.), 5 weeks/year
  Dr. Vadim Guzey (PNPI), 8 weeks/year
  Critical expertise, ready physics models and codes, extensive preparations

• Experimental physics postdoc at 50% FTE
  
  MC implementation and simulation
  Focal point of project, supervised by JLab investigators
  Shared with ODU Nuclear Physics group, candidates identified

• JLab staff investigators
  
  Weiss 10% FTE: Project coordination, model testing, documentation
  Higinbotham 10% FTE: Code development, MC simulations
  Nadel–Turonski: Postdoc supervision, liaison with EIC accelerator/detector development
  Melnitchouk: Supervision, expertise with nuclear deep–inelastic scattering
# Schedule and Milestones

## Year 1

<table>
<thead>
<tr>
<th>Months</th>
<th>Theory visitors</th>
<th>Postdoc</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Sargsian (1 week), readying unpol. $^2$H physics model + code</td>
<td>Implementation forward and far–forward tracking modules in GEMC fast MC</td>
<td><strong>Feasibility of spectator tagging with unpol. $^2$H; Neutron structure bound nucleon (codes, tech. report)</strong></td>
</tr>
<tr>
<td>3-4</td>
<td>Guzey (2 months), development pol. $^2$H physics model + code</td>
<td>Implementation unpol. $^2$H physics model in event generator framework</td>
<td></td>
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<tr>
<td>5-6</td>
<td>Guzey (2 months), development pol. $^2$H physics model + code</td>
<td>Simulation/evaluation upolarized $^2$H</td>
<td></td>
</tr>
<tr>
<td>7-8</td>
<td>Sargsian (1 month), development polarized $^3$He physics model + code</td>
<td>Implementation polarized $^2$H in event generator framework</td>
<td></td>
</tr>
<tr>
<td>9-10</td>
<td>Sargsian (1 month), development polarized $^3$He physics model + code</td>
<td>Simulation/evaluation pol. $^2$H with initial tracking design, proof feasibility</td>
<td><strong>Feasibility of neutron spin structure with pol. $^2$H spectator tagging (codes, tech. report, publication)</strong></td>
</tr>
<tr>
<td>11-12</td>
<td>Sargsian (1 month), development polarized $^3$He physics model + code</td>
<td>Implementation/simulation polarized $^3$He, first comparison $^2$H and $^3$He</td>
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</tbody>
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## Year 2

<table>
<thead>
<tr>
<th>Months</th>
<th>Theory visitors</th>
<th>Postdoc</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Guzey (2 months), development diffractive/exclusive $^2$H, coherent $^4$He Sargsian (1 week), joint work on shadowing, final–state interaction</td>
<td>Optimization far-forward tracking $^3\delta p/p$, detailed simulations pol. $^2$H and $^3$He</td>
<td><strong>Physics impact of pol. $^2$H and $^3$He in neutron spin structure</strong></td>
</tr>
<tr>
<td>3-4</td>
<td>Guzey (2 months), development diffractive/exclusive $^2$H, coherent $^4$He Sargsian (1 week), joint work on shadowing, final–state interaction</td>
<td>Detailed comparison pol. $^2$H and $^3$He for neutron spin structure</td>
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</tr>
<tr>
<td>5-6</td>
<td>Guzey (2 months), development diffractive/exclusive $^2$H, coherent $^4$He Sargsian (1 week), joint work on shadowing, final–state interaction</td>
<td>Implementation diffractive $^2$H in event generator framework, detailed simulation</td>
<td></td>
</tr>
<tr>
<td>7-8</td>
<td>Sargsian (1 month), development tensor pol. $^2$H physics model + code</td>
<td>Implementation coherent $^4$He in event generator, detailed simulations</td>
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<tr>
<td>9-10</td>
<td>Sargsian (1 month), development tensor pol. $^2$H physics model + code</td>
<td>Evaluation coherent/diffractive channels</td>
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<tr>
<td>11-12</td>
<td>Sargsian (1 month), development tensor pol. $^2$H physics model + code</td>
<td>Implementation tensor pol. $^2$H, detailed simulation</td>
<td><strong>Comprehensive assessment of physics impact of spectator tagging</strong></td>
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Natural progression from simple and ready channels to more challenging development
Easy synchronization of theory and experimental efforts
MC implementation of simple channels (unpol. $^2$H) can start immediately
Expected results

1. Physics models for high–energy scattering processes on light ions (\(^2\text{H}, ^3\text{He}, ^4\text{He}\)) with tagged spectators, implementing state–of–the–art theoretical methods, available as cross section parametrizations and user codes

2. Fast MC generator for spectator–tagging processes with EIC@JLab, with schematic modeling of the EIC beam optics and forward detectors, as unified extensible package with full documentation, available to future users

3. Quantitative assessment of physics impact of spectator tagging with EIC@JLab (neutron spin structure, flavor decomposition, coherent quark/gluon fields in QCD) documented in publications, technical reports and summary plots

Relevance for JLab

- Timely: Next two years critical for EIC project, new LRP expected 2014/15
- Specific: Develops unique capabilities of JLab EIC design in pol \(^2\text{H}\), forward detection
- Innovative: Qualitative advances, never explored at collider
- User interest: Extends JLab 6/12 GeV fixed–target nuclear physics program in short–range correlations, BONUS experiment
  Manifst interest in ODU group (Ch. Hyde, S. Kuhn); Hampton U. Group (A. Accardi)
  LDRD project would enable/seed long–term collaborative effort!
- Synergies: Parton density extraction
  CTEQ–JLab Accardi et al., JAM project Melnitchouk et al. Use available tools for QCD fits.
- Long term: Precision nuclear structure calculations using Effective Field Theory
  Epelbaum et al. Methods can be extended to breakup in forward high–energy processes. Workshop Bochum U. 1-3 July 2013
Supplementary material
Budget

Requested project funding per year

JLab personnel (Weiss 10% FTE, Higinbotham 10% FTE, salary+fringe) .......... 34,393
Postdoc 50% FTE (salary+fringe, joint appt. with ODU, no overhead) ............ 37,395
Visiting scientists (Guzey 2 months, Sargsian 1 month, salary + fringe) ............ 33,334
Travel (one international round trip Guzey, two domestic round trips Sargsian,
lodging + per diem for Sargsian’s kick-off visit) ................................. 4,000
Total direct costs ................................................................. 109,122

Total LDRD request (incl. G&A) ............................................ 163,683
EIC@JLab integrated interaction region

No other magnets or apertures between IP and FP!

Hadron detection in three stages:

1. Encap with 50 mrad crossing angle
2. Small dipole covering angles up to a few degrees
3. far forward, up to one degree, for particles passing the accelerator quads

Focal Point: 
\[ D \sim 1 \text{ m} \]
\[ \beta \sim 1 \text{ m} \]