Director’s Accelerator R&D Review
CASA Summary/ELIC

Geoffrey Krafft
On behalf of the members of the
Center for Advanced Studies of Accelerators
March 20, 2009
OUTLINE

• Introduction to the CASA Department
• CASA Goals and Talks
• ELIC (Goal I)
  • Project
  • Staging
  • Luminosity Studies
  • Cost Estimates
• Compact Sources
  • THz Sources
  • MIT CUBIX
• Education
CASA DEPARTMENT

• Staff
  • 10 Scientific Staff (most > 10 years experience) + Director
  • 7 Graduate Students
  • Rough equality between theory and experiment

• Clients
  • 12 GeV Project
  • 6 GeV Operations
  • EIC Project
  • FEL Department
  • Smaller HEP-funded projects (roughly 15% of effort)
Five CASA Goals

1. Design a future Electron Ion Collider (EIC) appropriate for Jlab (Krafft)

2. Study current limiting phenomena in SRF Linacs and Energy Recovery Linacs (ERLs), including mitigation techniques (Tiefenback)

3. Develop instrumentation and beam-based measurement procedures for SRF Linacs (Tiefenback)

4. Develop, in collaboration with the FEL Dept, a design for a 4th Generation Light Source based on an SRF Linac

5. Study large-aperture Recirculating Linear Accelerators (RLAs) based on SRF Linacs (Bogacz)
ELIC Study Group & Collaborators


Staff and Users

W. Fischer, C. Montag - Brookhaven National Laboratory

V. Danilov - Oak Ridge National Laboratory

V. Dudnikov - Brookhaven Technology Group

P. Ostroumov - Argonne National Laboratory

V. Derenchuk - Indiana University Cyclotron Facility

A. Belov - Institute of Nuclear Research, Moscow, Russia

V. Shemelin - Cornell University
ELIC Design Goals

- **Energy**
  - Center-of-mass energy between 20 GeV and 100 GeV
  - Energy asymmetry of ~ 10,
  - 3 GeV electron on 30 GeV proton/15 GeV/n ion up to 10 GeV electron on 250 GeV proton/100 GeV/n ion

- **Luminosity**
  - >10^{33} up to 3×10^{34} cm^{-2} s^{-1} per interaction point

- **Ion Species**
  - Polarized H, D, ^3\text{He}, possibly Li
  - Up to heavy ion A = 208, fully stripped

- **Polarization**
  - Longitudinal polarization at the IP for both beams
  - Transverse polarization of ions
  - Spin-flip of both beams
  - All polarizations >70% desirable
Design Choices for ELIC

- Use a Ring-Ring (R-R) collider design – take advantage of CEBAF as a full energy polarized electron injector

- Energy Recovery Linac (ERL)-Ring or Circulator Ring- Ring designs have little luminosity advantage and are challenging: high current polarized electron source
  - ERL-Ring: 2.5 A
  - Circulator ring: 20 mA
  - State-of-art: 1.0 mA

- 12 GeV CEBAF Upgrade polarized source/injector already meets beam requirement of Ring-Ring design

- CEBAF-based R-R design has high luminosity and high polarization
ELIC Ring-Ring Design Features

- Unprecedented high luminosity
  - Enabled by short ion bunches, low $\beta^*$, high rep. rate
  - Large synchrotron tune
  - Require crab crossing

- Electron cooling is an essential part of EIC

- Four IPs (detectors) for high science productivity

- "Figure-8" ion and lepton storage rings
  - Ensure spin preservation and ease of spin manipulation
  - No spin sensitivity to energy for all species
Achieving High Luminosity in ELIC

ELIC Design Luminosity

$L \sim 3.0 \times 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ (250 GeV protons x 10 GeV electrons)

ELIC Luminosity Concepts

- High bunch collision frequency ($f=0.5 \text{ GHz}$)
- Short ion bunches ($\sigma_z \sim 5 \text{ mm}$)
- Super strong final focusing ($\beta^* \sim 5 \text{ mm}$)
- Large beam-beam parameters ($0.01/0.1 \text{ per IP}, 0.025/0.1 \text{ largest achieved}$)
- Need high energy electron cooling of ion beams
- Need crab crossing
- Large synchrotron tunes to suppress synchro-betatron resonances
- Equidistant phase advance between four IPs
## ELIC (p/e) Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>GeV 250/10, 150/7, 50/5</td>
</tr>
<tr>
<td>Figure-8 ring</td>
<td>km 2.5</td>
</tr>
<tr>
<td>Collision freq</td>
<td>MHz 499</td>
</tr>
<tr>
<td>Beam current</td>
<td>A 0.22/0.55, 0.15/0.33, 0.18/0.38</td>
</tr>
<tr>
<td>Particles/bunch</td>
<td>10⁹ 2.7/6.9, 1.9/4.1, 2.3/4.8</td>
</tr>
<tr>
<td>Energy spread</td>
<td>10⁻⁴ 3/3</td>
</tr>
<tr>
<td>Bunch length, rms</td>
<td>mm 5/5</td>
</tr>
<tr>
<td>Hori. emit., norm.</td>
<td>μm 0.70/51, 0.42/35.6, .28/25.5</td>
</tr>
<tr>
<td>Vertical emit., norm.</td>
<td>μm 0.03/2.0, 0.017/1.4, .028/2.6</td>
</tr>
<tr>
<td>β*</td>
<td>mm 5/5</td>
</tr>
<tr>
<td>Vert. b-b tune-shift</td>
<td>0.01/0.1</td>
</tr>
<tr>
<td>Peak lum. per IP</td>
<td>10³⁴ cm⁻²s⁻¹ 3.0, 1.2, 1.1</td>
</tr>
<tr>
<td>Number of IPs</td>
<td>4</td>
</tr>
<tr>
<td>Luminosity lifetime</td>
<td>hours 24</td>
</tr>
</tbody>
</table>

Electron parameters are red
**ELIC (A/e) Design Parameters**

<table>
<thead>
<tr>
<th>Ion</th>
<th>Max Energy ($E_{i,max}$) (GeV/nucleon)</th>
<th>Luminosity / n (7 GeV x $E_{i,max}$) $10^{34}$ cm$^{-2}$ s$^{-1}$</th>
<th>Luminosity / n (3 GeV x $E_{i,max}/5$) $10^{33}$ cm$^{-2}$ s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>150</td>
<td>3.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Deuteron</td>
<td>75</td>
<td>3.0</td>
<td>2.2</td>
</tr>
<tr>
<td>$^3$He$^{+2}$</td>
<td>100</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>$^4$He$^{+2}$</td>
<td>75</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>$^{12}$C$^{+6}$</td>
<td>75</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>$^{40}$Ca$^{+20}$</td>
<td>75</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>$^{208}$Pb$^{+82}$</td>
<td>59</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>

* Luminosity is given per nucleon per IP
Figure-8 Rings – Vertical ‘Stacking’
IP Magnet Layout and Beam Envelopes

- **IP**: 0.5m 3.2kG/cm
- **3.8m**: 0.2m
- **8.4cm 10cm Vertical intercept**
- **1.8m 20.8kG/cm 0.6m**
- **2.55kG/cm 0.6m**
- **14.4cm 16.2cm Vertical intercept**
- **3m 12KG/cm**
- **22.2 mrad 1.27 deg**
- **22.9cm Vertical intercept**

**Equation**: $$\beta^* \text{ OK}$$
**Optimization**

- IP configuration optimization
- “Lambertson”-type final focusing quad
- Crab crossing angle $\Rightarrow 22 \text{ mrad}$
Lambertson Magnet Design

Cross section of quad with beam passing through

Magnetic field in cold yoke around electron pass.

Paul Brindza
Beam-Beam Effect in ELIC

Transverse beam-beam force
- Highly nonlinear forces
- Produce transverse kicks between colliding bunches
- Can cause size/emittance growth or blowup
- Can induce coherent beam-beam instabilities
- Can decrease luminosity and its lifetime

ELIC Case
- Highly asymmetric colliding beams (10 GeV/2.5 A on 250 GeV/1 A)
- Four IPs and Figure-8 rings
- Strong final focusing ($\beta^*$ 5 mm)
- Short bunch length (5 mm)
- Employs crab cavity
- Vertical b-b tune shifts are 0.087/0.01
- Very large electron synchrotron tune (0.25) due to strong RF focusing
- Equal betatron phase advance (fractional part) between IPs
Beam-Beam Simulations

• Simulation Model
  • Single/multiple IPs, head-on collisions
  • Strong-strong self consistent Particle-in-Cell codes, developed by J. Qiang of LBNL
  • Ideal rings for electrons & protons, including radiation damping & quantum excitations for electrons

• Scope
  • 10k ~ 30k turns
  • 0.05 ~ 0.15 s of stored time (12 damping times) → reveals short-time dynamics with accuracy

• Simulation results
  • Equilibrium at 70% of peak luminosity, $1.9 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}$, the loss is mostly due to the hour-glass effect
  • Luminosity increase as electron current linearly (up to 6.5 A), coherent instability observed at 7.5 A
  • Simulations with 4 IPs and 12-bunch/beam showed stable luminosity and bunch sizes after one damping time, saturated luminosity is $1.8 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}$ per IP, very small loss from single IP and single bunch operation

Supported by SciDAC
Opportunities for Staging

A medium energy EIC becomes the low energy ELIC ion complex

Lower energies and symmetric kinematics provide new science opportunities complementary to ELIC/eRHIC:

• Valence quarks/gluon structure beyond JLab 12 GeV
• Asymmetric sea for $x \sim \frac{M_{\pi}}{M_N}$
• GPDs, transverse spin at $x \sim 0.1$

Accelerator Advantages/Benefits

• Bring ion beams and associated technologies to JLab
• Have an early ring-ring collider at JLab
• Provides a test bed for new technologies required by ELIC
• Develop expertise and experience, acquire/train technical staff
MEIC & Staging of ELIC

The tunnel houses 3 rings:
- Electron ring up to 5 GeV/c
- Ion ring up to 5 GeV/c
- Superconducting ion ring for up to 30 GeV/c

<table>
<thead>
<tr>
<th>Stage</th>
<th>Maximum Momentum (GeV/c)</th>
<th>Ring Size (m)</th>
<th>Ring Type</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Proton</td>
<td>Electron</td>
<td>Ion</td>
</tr>
<tr>
<td>1</td>
<td>Low Energy</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Medium Energy (MEIC)</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Medium Energy</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>High Energy (ELIC)</td>
<td>250</td>
<td>10</td>
</tr>
</tbody>
</table>
Medium Energy EIC Features

• High luminosity near-symmetric collider

• CM energy region up to 24.5 GeV (30x5 GeV)

• High polarization for both electron and light ion beams

• Natural injection path to high energy ELIC

• Minimal R&D required
  • Space charge effect for low ion energy
  • Beam-Beam effect
# MEIC Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>5/5</th>
<th>10/5</th>
<th>30/5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Momentum</td>
<td>GeV/c</td>
<td>5/5</td>
<td>10/5</td>
<td>30/5</td>
</tr>
<tr>
<td>Circumference</td>
<td>m</td>
<td>407</td>
<td>407</td>
<td>407</td>
</tr>
<tr>
<td>Beam Current</td>
<td>A</td>
<td>0.16/1</td>
<td>0.42/1</td>
<td>0.43/1</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>GHz</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Particles per Bunch</td>
<td>10^{10}</td>
<td>0.2/1.25</td>
<td>0.52/1.25</td>
<td>0.54/1.25</td>
</tr>
<tr>
<td>Bunch Length</td>
<td>cm</td>
<td>5/0.25</td>
<td>5/0.25</td>
<td>5/0.25</td>
</tr>
<tr>
<td>Normalized Hori. Emittance</td>
<td>mm mrad</td>
<td>0.27/120</td>
<td>0.26/120</td>
<td>0.39/120</td>
</tr>
<tr>
<td>Normalized Vert. Emittance</td>
<td>mm mrad</td>
<td>0.27/12</td>
<td>0.26/12</td>
<td>0.39/12</td>
</tr>
<tr>
<td>Horizontal $\beta^*$</td>
<td>cm</td>
<td>0.5/2</td>
<td>0.5/1</td>
<td>0.5/0.5</td>
</tr>
<tr>
<td>Vertical $\beta^*$</td>
<td>cm</td>
<td>0.5/20</td>
<td>0.5/10</td>
<td>0.5/5</td>
</tr>
<tr>
<td>Beam Size at IP (x/y)</td>
<td>$\mu$m</td>
<td>15.7/15.7</td>
<td>11/11</td>
<td>7.8/7.8</td>
</tr>
<tr>
<td>Horizontal B-B Tune Shift</td>
<td></td>
<td>0.006/0.004</td>
<td>0.006/0.006</td>
<td>0.004/0.01</td>
</tr>
<tr>
<td>Vertical B-B Tune Shift</td>
<td></td>
<td>0.006/0.37</td>
<td>.01/0.1</td>
<td>0.004/0.1</td>
</tr>
<tr>
<td>Laslett Tune Shift</td>
<td></td>
<td>0.1/small</td>
<td>0.07/small</td>
<td>0.05/small</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$10^{33}$ s^{-1} cm^{-2}</td>
<td>0.4</td>
<td>2.1</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Electron parameters are red
Interaction Region: Simple Optics

### Beta functions

![Beta function graphs]

- $\beta^\text{max} \sim 9 \text{ km}$
- $\beta_\perp^* = 5 \text{ mm}$
- $f \sim 7 \text{ m}$

### Beam envelopes ($\sigma_{\text{RMS}}$) for $\varepsilon_N = 0.2 \text{ mm mrad}$

![Beam envelope graphs]

- $\sigma^* = 14 \mu\text{m}$

### Triplet based IR Optics

- first FF quad 4 m from the IP
- typical quad gradients $\sim 12\text{ Tesla/m}$ for 5 GeV/c protons
- beam size at FF quads, $\sigma_{\text{RMS}} \sim 1.6 \text{ cm}$
# MEIC and ELIC Costs (2009 M$)

<table>
<thead>
<tr>
<th>Description</th>
<th>MEIC</th>
<th>ELIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV/c)</td>
<td>30x5</td>
<td>250x10</td>
</tr>
<tr>
<td>Peak luminosity ($10^{33}$s$^{-1}$cm$^{-2}$)</td>
<td>4.4</td>
<td>30</td>
</tr>
<tr>
<td>IPs and Detectors</td>
<td>1/1</td>
<td>4/1</td>
</tr>
<tr>
<td>Ring Size</td>
<td>400</td>
<td>1800</td>
</tr>
<tr>
<td>Ion injector (source, RFQ, Linac, LEBT, MEBT, civil, etc.)</td>
<td>74.5</td>
<td>74.5</td>
</tr>
<tr>
<td>Prebooster/Low energy collider (including civil)</td>
<td>23.8</td>
<td>23.8</td>
</tr>
<tr>
<td>Large booster/Medium energy collider (no civil)</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Small electron ring (for low &amp; medium EIC)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Storage-collider ring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civil</td>
<td></td>
<td>79.9</td>
</tr>
<tr>
<td>Electron ring (including RF, spin rotators)</td>
<td></td>
<td>125.7</td>
</tr>
<tr>
<td>Ion ring (including CLH, snakes)</td>
<td></td>
<td>210.1</td>
</tr>
<tr>
<td>Electron cooler</td>
<td>16</td>
<td>19.5</td>
</tr>
<tr>
<td>Others (IP beamline, experiment Halls, transport line from CEBAF)</td>
<td>42.6</td>
<td>89.6</td>
</tr>
<tr>
<td>Labor</td>
<td>22.5</td>
<td>67.6</td>
</tr>
<tr>
<td>Total</td>
<td>225.4</td>
<td>690.6</td>
</tr>
<tr>
<td>With PED, overhead (15%) and contingency (30%)</td>
<td>395.6</td>
<td>1209.4</td>
</tr>
<tr>
<td>Detector allowance</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Pre-ops, R&amp;D</td>
<td>26.7</td>
<td>89.1</td>
</tr>
<tr>
<td>Total Project Cost (TPC)</td>
<td>497.3</td>
<td>1398.5</td>
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</table>
## Key R&D Issues

<table>
<thead>
<tr>
<th>Item</th>
<th>Task</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Forming the Ion Beam</td>
<td>Choose/optimize ion injection scheme</td>
<td>No new hardware development</td>
</tr>
<tr>
<td>Cooling of Ion Beams</td>
<td>Develop circulator cooler</td>
<td>ERL/Circulator Ring/Kicker development</td>
</tr>
<tr>
<td>Crab Cavity Development</td>
<td>Single and Multi-cell RF deflectors</td>
<td>KEK cavity OK for MEIC</td>
</tr>
<tr>
<td>Traveling Focusing Scheme</td>
<td>Choose scheme, optimize, and simulate</td>
<td>Needed only for lowest energy stage (15 GeV/c or lower)</td>
</tr>
<tr>
<td>Beam-Beam Effect</td>
<td>Expand existing simulations</td>
<td>Better simulations require more machine bunches</td>
</tr>
<tr>
<td>Beam Dynamics of Crab Crossing Beams</td>
<td>Simulations</td>
<td></td>
</tr>
</tbody>
</table>
ELIC Research Plans

• Recently submitted to DOE, in conjunction with BNL, for inclusion as “stimulus” funding (15.4 M$ over 5 year grant period)

• Items
  • Common Items
    • Coherent Electron Cooling (BNL) 8.0 M$
    • ERL Technology (JLAB) 8.5 M$
    • Polarized $^3$He Source (BNL) 2.0 M$
    • Crab Cavities (JLAB) 2.8 M$
  • ELIC Specific Items
    • Space Charge Effects Evaluation 0.9 M$
    • Spin Tracking Including Beam-Beam Force 1.6 M$
    • Simulations and Traveling Focus Scheme 1.6 M$
JLAB “Common” Items

- Energy Recovery Technology for 100 MeV level electron beam.
  - Demonstrate beam properties and robust sustainability at high electron current for a device compatible with circulator cooling ring
  - Conduct experiments at JLAB FEL

  **Total labor: 20 FTE – years ($ 4.0 M)**
  **M&S: $4.5 M**
  **Duration: 5 years**
  **Subtotal: $8.5M**

- Crab cavities
  **Issue:** The ELIC design is based on the use of crab cavities to reach luminosity at the $10^{35}$ cm$^{-2}$ sec$^{-1}$ level. Multi-cell crab cavities at 1.5 GHz have not been designed yet, and their effect on the electron and ion beam dynamics needs to be quantified.

  A. Prototype two 1500 MHz crab cavities
  B. Develop and test phase and amplitude stability scheme(s).

  **A. Labor: 4 FTE – year ($ 0.8 M)**
  **M&S: $200K**
  **B. Labor: 4 FTE – year ($ 0.8 M)**
  **M&S: $1.0M**

  **Subtotal: $2.8M**
“ELIC Specific” Items

- Ion Space charge simulations (in collaboration with SNS)
  - Explore “painting” technique for stacking via simulations
  - Experimental investigation in SNS.
    A. Total labor: 1.5 FTE – years ($0.3 M)
      Duration: 1 year
    B. Labor: 0.5 FTE – year ($0.1 M)
      M&S: $500K for diagnostics development
Subtotal: $0.9M

- Spin Track Studies for ELIC
  - A. Full electron and ion spin tracking/including vertical bend in electron ring
  - B. Beam-beam effect on spin depolarization
    A. Total labor: 2.0 FTE – years ($0.4 M)
      Duration: 2 years
    B. Labor: 6 FTE – year ($1.2 M)
      Duration: 5 years
Subtotal: $1.6M

- Studies Traveling Focus Scheme
  - Feasibility studies for the scheme (essential for ELIC staging)
  - Develop experimental proof-of-principle program
    Total labor: 3 FTE – years ($0.6 M)
    Duration: 2 years
Subtotal: $0.6M

- Simulation studies supporting ELIC project
  Issue: Use simulations to evaluate electron-ion beam-beam effects, including the kink instability, e-beam disruption and beam emittance growth in the collider. Investigate conventional electron cooling for both magnetized and non-magnetized schemes. For electron cooling based on a circulator ring, investigate beam cooling interactions and space charge stability of the electron beam in the circulator ring.
    Total labor: 5 FTE-years ($1.0 M)
    Duration: 5 years
Subtotal: $1.0M
THz Source Layout

- Cathode
- Buncher
- Wiggler
- SRF Cryomodule
# Compact Linac Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gun Voltage</td>
<td>250</td>
<td>kV</td>
</tr>
<tr>
<td>Bunch Charge</td>
<td>&lt;10</td>
<td>pC</td>
</tr>
<tr>
<td>Drive Laser Pulse Length (σ)</td>
<td>22</td>
<td>psec</td>
</tr>
<tr>
<td>Beam Current</td>
<td>100</td>
<td>µA</td>
</tr>
<tr>
<td>Buncher Amplitude</td>
<td>9</td>
<td>kV</td>
</tr>
<tr>
<td>SRF Amplitude</td>
<td>25</td>
<td>MV</td>
</tr>
<tr>
<td>SRF Frequency</td>
<td>1497</td>
<td>MHz</td>
</tr>
<tr>
<td>Extracted Energy</td>
<td>48</td>
<td>MeV</td>
</tr>
</tbody>
</table>
Transverse Beam Size @ 10 pC

![Graph showing transverse beam size at 10 pC with solenoids highlighted.](image-url)
Longitudinal Beam Size @ 10 pC
**Photoinjector and linac with 1 beamline**

- SRF photoinjector
  - 200 MHz @ 4K

- RF amp
  - 4 MeV

- RF amp
  - 25 MeV cryomodule

- Compression chicane

- Inverse Compton scattering

- Coherent enhancement cavity with Q=1000 giving 5 MW cavity power

- 5 kW cryo-cooled Yb:YAG drive laser

- 30 kW beam dump

- X-ray beamline

Electron beam of ~1 mA average current at 10-30 MeV (future upgrade to ~50 MeV)

8 m

**Courtesy: William Graves**
Intensity Profile of 12 keV X-rays with 0.1% bw

Emittance = 0.7 mm-mrad

\[ \sim 10^{12} \text{ photons/sec @ 100 MHz in 0.1\% BW} \]

Courtesy: William Graves
Electron Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Single-shot</th>
<th>High average flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunable energy [MeV]</td>
<td>4 – 30 (~50 MeV upgrade)</td>
<td></td>
</tr>
<tr>
<td>Bunch charge [pC]</td>
<td>1000</td>
<td>10</td>
</tr>
<tr>
<td>Repetition rate [Hz]</td>
<td>1-10</td>
<td>10^8</td>
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<tr>
<td>Average current [mA]</td>
<td>10^{-5}</td>
<td>1</td>
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<tr>
<td>Normalized emittance [mm-mrad]</td>
<td>2</td>
<td>0.1</td>
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<tr>
<td>FWHM bunch length [ps]</td>
<td>2</td>
<td>0.3</td>
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<tr>
<td>RMS energy spread [keV]</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Courtesy: William Graves
EDUCATION EFFORTS

• Two Jefferson Lab Professors at Old Dominion University
  • 2 USPAS Courses
    • Recirculated and Energy Recovered Linacs
    • Introduction to SRF
  • 2 Old Dominion University Courses
    • Introduction to Accelerator Physics (1 semester)
    • Low Temperature Physics (1 semester)
• 2 CASA staff are undergraduate student advisors (REU and SULI)
• 7 CASA Staff are graduate student advisers for students from 4 different institutions
• With H. Areti, J. Delayen, and A. Hutton, working to create a Center for Accelerator Science and Technology (CAST) at ODU
# CASA GRADUATE STUDENTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Advisor</th>
<th>Research Area</th>
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<tbody>
<tr>
<td>M. Spata</td>
<td>ODU</td>
<td>Krafft</td>
<td>Nonlinear Beam Optics in the Spreaders/Recombiners</td>
</tr>
<tr>
<td>Alicia Hofler</td>
<td>ODU</td>
<td>Evtushenko</td>
<td>SRF Gun and Injector Optimization</td>
</tr>
<tr>
<td>Chuyu Liu</td>
<td>Peking</td>
<td>Krafft</td>
<td>Electron Beam Diagnostics</td>
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<tr>
<td>Hisham Sayed</td>
<td>ODU</td>
<td>Bogacz</td>
<td>Chromatic Correction of Low $\beta^*$ Collider Optics</td>
</tr>
<tr>
<td>Ryan Bodenstein</td>
<td>UVA</td>
<td>Tiefenbach</td>
<td>Operational Diagnostics Development at CEBAF*</td>
</tr>
<tr>
<td>Ilkyung Shin</td>
<td>UConn</td>
<td>Yunn</td>
<td>Multipass BBU and Feedback</td>
</tr>
</tbody>
</table>

CASA is training the next generation of Accelerator Scientists

*MS Student
Summary

• The ELIC collider promises to accelerate a wide variety of polarized light ions and unpolarized heavy ions to high energy, enabling a unique physics program.

• Low/medium energy stages enable a rich physics program not covered by a high-energy collider.

• The initial design studies indicate that luminosity of the intermediate colliders can exceed \(1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}\). This luminosity utilizes staged ion beam cooling and crab crossing.

• The R&D plans supporting ELIC have been recently updated and re-submitted.

• CASA is strongly committed to education in Accelerator Physics
Optimization of Figure-8 Rings Lattices

**Dipoles:**
- $L_b = 170$ cm
- $B = 73.4$ kG
- $\rho = 102$ m

**Quadrupoles:**
- $L_b = 100$ cm
- $G = 10.4$ kG/cm

**Phase Advancement/cell:**
- $\Delta \phi_x = 60^\circ$
- $\Delta \phi_y = 60^\circ$

**Electrons**

**Dipoles:**
- $L_b = 100$ cm
- $B = 3.2$ kG
- $\rho = 76$ m

**Quadrupoles:**
- $L_b = 60$ cm
- $G = 4.1$ kG/cm

**Phase Advancement/cell:**
- $\Delta \phi_x = 120^\circ$
- $\Delta \phi_y = 120^\circ$

**Ions**

**Dipoles:**
- $L_b = 100$ cm
- $B = 60$ kG

**Quadrupoles:**
- $L_b = 150$ cm
- $G = 2.4$ kG/cm

**Phase Advancement/cell:**
- $\Delta \phi_x = 60^\circ$
- $\Delta \phi_y = 60^\circ$
Chromatic Correction with families of Sextupoles

Cancellation of geometric aberrations generated by sextupoles through ‘pairing’ them with a minus identity transformation between them

Alex Bogacz and Hisham Sayed Thesis
HAMPTON08 Contributions

<table>
<thead>
<tr>
<th>Author</th>
<th>Talk</th>
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<td>Krafft</td>
<td>ELIC Overview</td>
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<tr>
<td>Bogacz</td>
<td>ELIC Optics</td>
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<tr>
<td>Derbenev</td>
<td>Cooling Methods</td>
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<tr>
<td>Sayed</td>
<td>Chromaticity Correction</td>
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<tr>
<td>Brindza</td>
<td>Interaction Region Magnet Design</td>
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<td>Musson</td>
<td>Fast Kickers</td>
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<tr>
<td>Zhang</td>
<td>Beam-Beam Interaction</td>
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<tr>
<td>Grames</td>
<td>Polarized Electron Sources</td>
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</table>

Users recommend go to 0.5 GHz bunch repetition rate (Peak Luminosity to $2.6 \times 10^{34} \text{ cm}^{-2}\text{sec}^{-1}$)
ELIC Low Beta Optics with Chromatic Corrections

Hisham Kamal Sayed$^1,2$
Alex Bogacz$^1$

1 Jefferson Lab
2 Old Dominion University
β Chromaticity correction with sextupoles

β- functions around the interaction region, the green arrows represent the sextupoles pairs.

Horizontal dispersion

Vertical dispersion

The phase advance, showing the –I transformation between the sextupoles pairs

Hisham K. Sayed EIC Meeting Hampton University 2008
Phase space in vertical plane before and after applying the correction scheme

Vertical plane \( \Delta p/p \approx 0.0006 \)

- Initial phase space
- Phase space after two pass through 2 IR’s No correction
- Phase space after two pass through 2 IR’s after correction
Electron Cooling with a Circulator Ring

Effective for heavy ions (higher cooling rate), difficult for protons.

- **State-of-Art**
  - Fermilab electron cooling demonstration (4.34 MeV, 0.5 A DC)
  - Feasibility of EC with bunched beams remains to be demonstrated

- **ELIC Circulator Cooler**
  - 3 A CW electron beam, up to 125 MeV
  - SRF ERL provides 30 mA CW beam
  - Circulator cooler for reducing average current from source/ERL
  - Electron bunches circulate 100 times in a ring while cooling ion beam
  - Fast (300 ps) kicker operating at 15 MHz rep. rate to inject/eject bunches into/out circulator-cooler ring
Fast Kicker for Circulator Cooling Ring

- Sub-ns pulses of 20 kW and 15 MHz are needed to insert/extract individual bunches.
- RF chirp techniques hold the best promise of generating ultra-short pulses. State-of-Art pulse systems are able to produce ~2 ns, 11 kW RF pulses at a 12 MHz repetition rate. This is very close to our requirement, and appears to be technically achievable.
- Helically-corrugated waveguide (HCW) exhibits dispersive qualities, and serves to further compress the output pulse without excessive loss. Powers ranging from up to 10 kW have been created with such a device.
- Collaborative development plans include studies of HCW, optimization of chirp techniques, and generation of 1-2 kW peak output powers as proof of concept.
- Kicker cavity design will be considered.

Estimated parameters for the kicker

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>MeV</td>
<td>125</td>
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<tr>
<td>Kick angle</td>
<td>10^{-4}</td>
<td>3</td>
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<tr>
<td>Integrated BdL</td>
<td>GM</td>
<td>1.25</td>
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<tr>
<td>Frequency BW</td>
<td>GHz</td>
<td>2</td>
</tr>
<tr>
<td>Kicker Aperture</td>
<td>Cm</td>
<td>2</td>
</tr>
<tr>
<td>Peak kicker field</td>
<td>G</td>
<td>3</td>
</tr>
<tr>
<td>Kicker Repetition Rate</td>
<td>MHz</td>
<td>15</td>
</tr>
<tr>
<td>Peak power/cell</td>
<td>KW</td>
<td>10</td>
</tr>
<tr>
<td>Average power/cell</td>
<td>W</td>
<td>15</td>
</tr>
<tr>
<td>Number of cells</td>
<td></td>
<td>20 20</td>
</tr>
</tbody>
</table>

16 MHz Sweep VCO

9-10 GHz

5.5 GHz TWTA 300 W

Dispensive Element

Helically Corrugated Waveguide

Pulse Generator

1 kW Output Pulse

kicker