Future Stable-beam Accelerators for Nuclear Physics

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Jefferson Lab

SRF2003
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Outline

J-PARC

RHIC
  • RHIC-II
  • eRHIC

JLab
  • 12 GeV
  • 25 GeV
  • eLIC

Waiting on approval & funding from DOE
Japanese Proton Accelerator Research Complex

Collaboration between JAERI and KEK

Complex of accelerators for MANY goals

• Nuclear and particle physics
  • 50 GeV primary beam
  • Secondary beams
    • Kaon, pion, hyperon, neutrino, muon, and anti-proton
• Materials and life sciences
  • Pulsed neutron source (3 GeV, pulsed)
• Accelerator transmutation of radioactive waste
  • Includes an srf linac section
### J-PARC Schedule

**Fiscal year 2000+**

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- **400MeV**: LINAC Phase-I
- **600MeV**: LINAC Phase-I
- **3GeV**: PS Phase-II
- **50GeV**: PS Phase-II

**Phase I is underway**

**Phase II is not yet approved**
RHIC-II
Upgrade in the luminosity of RHIC
eRHIC
Electron-ion collider
RHIC-II

RHIC-II is a luminosity upgrade to RHIC (Relativistic Heavy Ion Collider)

The route is to use electron-cooling.

- Copper - Novosibirsk
- SRF - BNL/JLab collaboration

Anticipated increased average luminosity

- 9x for Au-Au (100 GeV/u): $0.8 \times 10^{27} \Rightarrow 7 \times 10^{27}$
- 3x for $\vec{p} - \vec{p}$ (250 GeV/u): $2.4 \times 10^{32} \Rightarrow 8 \times 10^{32}$
RHIC Luminosity with and without e-cooling

![Graph showing luminosity with and without e-cooling over time.](image)

- **With e-cooling**
- **Without e-cooling**

**Time, hours**

**Au-Au Luminosity ($10^{27}$)**

- With cooling:
  - 0
  - 2e+27
  - 4e+27
  - 6e+27
  - 8e+27
  - 1e+28

- Without cooling:
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
RHIC Electron Cooler R&D

Demonstrate 10 nC, 100–300 mA CW rf photo-cathode electron gun:
High power, 700 MHz 2.5 cell cavity
BNL-LANL collaboration

Develop CW s.c. cavity for high intensity beams:
Large bore, 700 MHz cavity with ferrite HOM dampers and high beam break-up threshold
BNL-JLab collaboration

Demonstrate 10ppm solenoid
BNL
## Energy Recovery Linac – large bore (19 cm diameter)

### FE modeling for acoustics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>$G$</td>
<td>240 $\Omega$</td>
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<tr>
<td>$R/Q$</td>
<td>710 $\Omega$</td>
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<tr>
<td>$Q_{bcs}$</td>
<td>4.9 $10^{10}$</td>
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<tr>
<td>$E_p/E_a$</td>
<td>2.1</td>
</tr>
<tr>
<td>$H_p/E_a$</td>
<td>5.94 mT/MV/m</td>
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</table>

![Graphical representation of the linac structure](image-url)

**Carlo Pagani, Paolo Pierini**

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Energy Recovery Linac – HOM Damping

Ferrite absorber
Energy Recovery Linac – HOM damping

TDBBU results: 4 cavities; ferrite damping; 1 A

1 mm

100 msec
Electron-Ion Colliders

Over the past two decades we have learned a great amount about the hadronic structure.

Some crucial questions remain open:

• What is the structure of the proton and neutron in terms of their quark and gluon constituents?
• How do quarks and gluons evolve into hadrons?
• What is the quark-gluon origin of nuclear binding?

A high-luminosity electron–ion collider has been proposed as a powerful new microscope to probe the structure of matter.
EIC parameters

Center-of-mass energy between 20-45 GeV with energy asymmetry of \( \sim 10 \)

- 3 GeV electrons on 30 GeV/nucleon ions
- 5 GeV electrons on 100 GeV/nucleon ions

Ion species of interest:
- Whole periodic table (theorist dependent)

CW Luminosity:
- \( \gtrsim 10^{33} \text{ cm}^{-2} \text{ sec}^{-1} \) per nucleon (HERA achieved \( \sim 5 \times 10^{32} \))

Polarized beams (electrons and light ions)
- Longitudinal polarization \( \geq 50\% \)
- Transverse polarization of ions extremely desirable
- Spin-flip of both beams extremely desirable

Review article on EIC’s: ICFA Beam Dynamics Newsletter #30; April, 2003; (Wei and Merminga, ed.)
**eRHIC: ring–ring option (baseline)**

- **e- accelerator**
  - 2 GeV injector (pulsed, copper)
  - 10 GeV, 0.5 A e-ring with ¼ of RHIC circumference (similar to PEP II HER)
  - Inject at 2 GeV, operate at 5–10 GeV
  - 15 min. polarization build-up (super-bends)

- **Interaction region**
  - Existing RHIC interaction region allows for typical asymmetric detector
    (similar to HERA or PEP II detectors)
eRHIC: linac-ring option

Replaces electron storage ring with an ERL.

Advantages vs ring-ring
- Flexibility for electron polarization flips
- Removes e-beam disruption constraints

Needs more than x100 leap in polarized electron source technology
12 GeV
Upgrade the present accelerator from 6 GeV to 12 GeV

25 GeV
Upgrade the 12 GeV accelerator to 25 GeV

eLIC
Use the 5 GV of linac as the basis for an EIC
Advances in understanding of hardonic matter using JLab’s 6 GeV electron accelerator.

- Detailed mapping of the charge structure of the neutron
- Detailed mapping of electro-magnetic structure of the proton
- Dirth of strange quarks in the proton
- Discovery of the penta-quark.

New windows would be opened by increasing to 12 GeV

- Exotic mesons (hybrids of gluonic flux tubes and quarks)
- Route to possible explanation of quark confinement
- Symmetry tests of the Standard Model
- Short-range behavior of QCD
Two 1.1 GeV linacs

New cryomodules deliver ≥100 MV and will require development of new rf controls.
12 GeV cryomodule

Specifications

• 7-cell cavities
• Average accelerating field: 19.2 MV/m
• $Q_0$: $>8 \times 10^9$

Status:

• 1st cryomodule with 7-cell cavities operating in CEBAF
• 2nd will soon be installed in JLab FEL
• “100 MV” cryomodule
  • Being constructed
  • Exploring cavity shape options for overall system optimization
## Cavity Designs for 12 GeV

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<th>HG</th>
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<td>$\phi_{\text{equator}}$ [mm]</td>
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<td>180</td>
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<tr>
<td>$\phi_{\text{iris}}$ [mm]</td>
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<tr>
<td>$k_{cc}$ [%]</td>
<td>3.3</td>
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<tr>
<td>$E_{\text{peak}}/E_{\text{acc}}$</td>
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<tr>
<td>$B_{\text{peak}}/E_{\text{acc}}$ [mT/(MV/m)]</td>
<td>4.6</td>
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<td>$R/Q$ [$\Omega$]</td>
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<td>129</td>
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<td>$G$ [$\Omega$]</td>
<td>274</td>
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<td>$R/Q\cdot G$ [$\Omega\cdot\Omega$]</td>
<td>26k</td>
<td>30k</td>
<td>36k</td>
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**Poster:** Kneisel, et al
25+ GeV CEBAF

27.5 GeV Install sc beam transport

Two 1.1 GV linacs

Twenty 100+ MV cryomodules

CHL-"N"

Twenty 100+ MV cryomodules

27.5 GeV

25 GeV

Two 2.5 GV linacs

Could be used for an EIC driver

Thomas Jefferson National Accelerator Facility
electron-Light-Ion Collider (eLIC) at JLab

Could do a linac-ring

• Same luminosity as eRHIC
• Same leap needed in injector performance

Alternative: hybrid between ring-ring and linac-ring

• Store the electron beam for ~100 turns in a circulator ring (CR)
• Potential advantages:
  • Electron beam disruption less of a problem than for ring-ring
  • Reduces average current in linac by 100x (pulsed beam in linac)
    • Reduces requirement on electron source by 100x
    • BBU/HOM problems easier by 100x ⇒ cavities are easier
• Don’t know how far circulator ring concept can really be pushed ⇒ needs accelerator physics R&D
eLIC with a Circulator Ring

5 GeV electrons
50-100 GeV light ions

CEBAF with Energy Recovery

Injector

Beard Dump

Solenoid

Booster

Snake

IR

SRFQDL CCL
### R&D Needs for EIC’s

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<td>Luminosity</td>
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<td>$10^{33}$</td>
<td>$10^{33}$ $10^{34}$ $10^{35}$</td>
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<td>e-cooling</td>
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<td>Yes</td>
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<tr>
<td>“¼A” cw gun</td>
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<td>“½A” cavities</td>
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<td>Radiative</td>
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<td>—</td>
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<td>polarization</td>
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<tr>
<td>e-gun current</td>
<td>—</td>
<td>130 mA</td>
<td>5 mA 16 mA 25 mA</td>
<td>JLab</td>
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<td>(~1 mA now)</td>
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<td>High-energy, high-current energy recovery</td>
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Thomas Jefferson National Accelerator Facility

Harwood, SHF 03, 6/108
SRF R&D

Electron cooling

- 705 and 1497 MHz
- Cutting-edge SRF performance is not critical
- HOM damping: \(~\frac{1}{2}A\)

Linacs

- 705 and 1497 MHz
- “Floor gradient” (MV per meter of tunnel) is important
- Heat load reduction
  - Increase $Q_0$
  - Optimize shape
- HOM damping
  - Linac-ring: >130 mA
  - CR-ring: 25 mA
Summary

New fixed-target and collider facilities are being built or designed in Japan and the US.

SRF is integral to all the US facilities.

Plenty of R&D opportunities