Potential use of eRHIC’s ERL for FELs and light sources

ERL: Main-stream - 5-10 GeV e-
Up-gradable to 20+ GeV e-

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eRHIC - electron-ion colliders
Linac-ring eRHIC

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http://www.agsrhichome.bnl.gov/eRHIC/
eRHIC
with 5-20+ GeV ERL
1.22 km

Light sources
For multiple passes:
vertical separation of the arcs

EBIS
Booster
Linac
AGS
RHIC
IP#12 - main
IP#10 - optional
IP#2 - optional
IP#4 - optional

Electron cooling
Downloaded from sci.hrs.tamu.edu on 2004-06-09
Main Components of ERL

See talk: THBOC04 by I. Ben-Zvi, Thursday @ 12:00

Super conducting RF photo-gun
And high current 5-cell SC RF Cavity
### Beam parameters

**RHIC**
- Ring circumference [m]: 3834
- Number of bunches: 360
- Beam rep-rate [MHz]: 28.15

**Protons: number of bunches**
- 360
- Beam energy [GeV]: 26 - 250
- Protons per bunch (max): $2.0 \cdot 10^{11}$
- Normalized 96% emittance [µm]: 14.5
- RMS Bunch length [m]: 0.2

**Gold ions: number of bunches**
- 360
- Beam energy [GeV/u]: 50 - 100
- Ions per bunch (max): $2.0 \cdot 10^9$
- Normalized 96% emittance [µm]: 6

**Electrons:**
- Beam rep-rate [MHz]: 28.15
- Beam energy [GeV]: 2 – 20
- **Relativistic factor** $\gamma$: $3.9 \cdot 10^3 - 3.9 \cdot 10^4$
- RMS normalized emittance [µm]: 5 - 50
- Beam emittance @ 20 GeV [Å]: 1.25 - 12.5
- Full transverse coherence $\lambda$ [Å]: 1.13
- Photon energy [keV]: 11
- RMS Bunch length [psec]: 30
- Electrons per bunch: 0.1 - 1.0 $\cdot 10^{11}$
- Charge per bunch [nC]: 1.6 - 16
- Average e-beam current [A]: 0.45

**eRHIC**
- Light source option
- Presently, RHIC operates for ~ 28 weeks/year
- The rest of the year the RHIC ion rings do not work ➔
- Time for dedicated LS run

*Presently, RHIC operates for ~ 28 weeks/year. The rest of the year the RHIC ion rings do not work ➔ Time for dedicated LS run.*
D. Kairan, V. Litvinenko (BNL) Z-system for merging low emittance beams

**Chicane and Zigzag merging systems**

**Standard - Chicane**

\[ \varepsilon_x > \varepsilon_y \]

\[ \delta = \frac{E - E_o}{E_o} \]

\[ \delta \propto \text{const} \quad \text{no focusing} \Rightarrow \sum \theta_i = 0; \sum z_i \theta_i = 0 \]

**Optimized - Z-system**

\[ \varepsilon_x = \varepsilon_y \]

\[ \delta = \frac{E - E_o}{E_o} \]

\[ \delta \propto \delta_o + \kappa \cdot z \cdot f(\zeta) \]

(no focusing) \Rightarrow \sum \theta_i = 0; \sum z_i \theta_i = 0; \sum z_i^2 \theta_i = 0

From the SC RF Gun

2.5 MeV

Laser

Separating magnet

15-20 MeV from ERL

Laser

Solenoid

Solenoid
Results of Parmela simulation for 1 nC e-bunch from the cathode to the end of the linac: black dashed curve is for a round beam passing without bends; blue curves are for a compensated chicane, red curves are for Zigzag merging system.

In contrast with traditional chicane where horizontal emittance suffers some growth as result of the bending trajectory, the Z-system (zigzag) the emittances are equal to each other and are very close to that attainable for the straight pass.
# Beam parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>20 GeV</td>
<td><strong>Energy</strong></td>
<td>10 GeV</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>3.91E+04</td>
<td>$\gamma$</td>
<td>1.96E+04</td>
</tr>
<tr>
<td><strong>Circumference</strong></td>
<td>3834 m</td>
<td><strong>Circumference</strong></td>
<td>3834.00 m</td>
</tr>
<tr>
<td><strong>R, average</strong></td>
<td>610.20 m</td>
<td><strong>R, average</strong></td>
<td>610.20 m</td>
</tr>
<tr>
<td>% fill</td>
<td>65.55%</td>
<td>% fill</td>
<td>65.55%</td>
</tr>
<tr>
<td><strong>R magnets</strong></td>
<td>400.00 m</td>
<td><strong>R magnets</strong></td>
<td>400.00 m</td>
</tr>
<tr>
<td>B</td>
<td>1.67 kGs</td>
<td>B</td>
<td>0.83 kGs</td>
</tr>
<tr>
<td><strong>N TBA cells</strong></td>
<td>150.00</td>
<td><strong>N cells</strong></td>
<td>150.00</td>
</tr>
<tr>
<td>$\varepsilon_{\text{norm}}$</td>
<td>9.50E-07 m rad</td>
<td>$\varepsilon_{\text{norm}}$</td>
<td>9.50E-07 m rad</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.243 Å rad</td>
<td>$\varepsilon$</td>
<td>0.485 Å</td>
</tr>
<tr>
<td>Bunchlength</td>
<td>from 0.1 to 2 psec</td>
<td>Bunchlength</td>
<td>from 0.1 to 2 psec</td>
</tr>
<tr>
<td><strong>Damping time</strong></td>
<td>1.45E-02 sec</td>
<td><strong>Damping time</strong></td>
<td>1.16E-01 sec</td>
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<tr>
<td><strong>Revolution time</strong></td>
<td>1.28E-05 sec</td>
<td><strong>Revolution time</strong></td>
<td>1.28E-05 sec</td>
</tr>
<tr>
<td>$\Delta \varepsilon_{(TBA)}$</td>
<td>0.016 Å rad 6.70%</td>
<td>$\Delta \varepsilon_{(TBA)}$</td>
<td>0.001 Å 0.10%</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.259 Å rad</td>
<td>$\varepsilon$</td>
<td>0.486 Å</td>
</tr>
<tr>
<td>RMS energy spread</td>
<td>2.54E-05</td>
<td>RMS energy spread</td>
<td>4.49E-06</td>
</tr>
</tbody>
</table>

25 meters TBA cell
High gain distributed optical klystron

V.N. Litvinenko

\[ 1 / 4 \pi \chi \rho > \sigma \gamma / \gamma, \]

\[ dX/d\tau = -iY\kappa, \]
\[ dY/d\tau = Z(1 + B)\kappa, \]
\[ dZ/d\tau = -X\kappa, \]

\[ \mu_{DOK} \approx \mu_{SASE} \cdot \kappa \cdot \frac{3\sqrt{1 + B \cdot e}}{6} \]

\[ L_{G\ DOK} \approx L_G \cdot \left\{ \frac{1}{e^4} \cdot \frac{4\pi L_G}{\lambda_w} \cdot \frac{\sigma_\gamma}{\gamma} / \kappa^{3/2} \right\} \]

DOK reduces the gain length **2.2 fold** at 20 GeV
and **5 fold** at 10 GeV for eRHIC 0.5-1 Å FELs
Average lasing power is a problem!

@ 1Å (12 keV)
It is from 0.6 MW to 1.3 MW

<table>
<thead>
<tr>
<th>Energy, GeV</th>
<th>20</th>
<th>15</th>
<th>10</th>
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</thead>
<tbody>
<tr>
<td>Wavelength, Å</td>
<td>0.5</td>
<td>1</td>
<td>0.87</td>
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<tr>
<td>Bunch length, psec</td>
<td>0.2</td>
<td>0.2</td>
<td>0.27</td>
</tr>
<tr>
<td>Peak Current, kA</td>
<td>5</td>
<td>5</td>
<td>3.75</td>
</tr>
<tr>
<td>Wiggler period, cm</td>
<td>2.5</td>
<td>3</td>
<td>2.5</td>
</tr>
<tr>
<td>SASE gain length, m</td>
<td>7.5</td>
<td>4.3</td>
<td>5.5</td>
</tr>
<tr>
<td>SASE Saturation length, m</td>
<td>100</td>
<td>60</td>
<td>76</td>
</tr>
<tr>
<td>Saturation power, GW</td>
<td>7.7</td>
<td>19</td>
<td>6.4</td>
</tr>
<tr>
<td>DOK, gain length, m</td>
<td>3.5</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>DOK, saturation length, m</td>
<td>47</td>
<td>19</td>
<td>21</td>
</tr>
</tbody>
</table>
Brightness Average & Peak

- eRHIC FELs
- eRHIC SR
- LCLS
- SASE FELs
Oscillators and HGHG vs. SASE FELs

Precision vs. *Crude* Power

\[ \Delta \lambda / \lambda = 10^{-6} \Rightarrow @1\text{Å} \quad t_{coh} = 0.3 \text{ psec} \]

OK-4 - $7 \cdot 10^{-5}$ RMS;
- 0.015 nm @ 218 nm

Lasing Line at 218.65 nm
RMS linewidth: 0.0157 nm (including resolution)

TESLA - $5 \cdot 10^{-3}$ RMS
- 0.55 nm @ 108 nm
Optics-Free FEL Oscillator

- Use lower energy low current e-beam with low emittance and low energy spread for the feed-back
- The feed-back-beam is modulated and carries-on the modulation to the entrance of the FEL
- Fully tunable! Line-width of oscillator
Conclusions

• High current 10-20 GeV ERL considered as a possible electron accelerator for eRHIC electron-hadron collider

• 10-20 GeV ERL will be very bright and powerful light source both in parasitic and dedicated modes of operation

• Sub-angstrom FEL can be successfully driven by the ERL in SASE or HGHG modes (L~100m), DOK or OFFO mode (~50m)

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