Accelerator Design of High Luminosity Electron-Hadron Collider eRHIC

V. PTITSYN

ON BEHALF OF ERHIC DESIGN TEAM:


E. POZDEYEV (FRIB, MSU), E. TSENTALOVICH (MIT-BATES)
RHIC + Electron accelerator = eRHIC

Quark splits into gluon

Gluon splits into quarks

Increasing resolution

High precision microscope for the nucleons and nuclei:

✓ resolving nucleon spin puzzle
✓ 3-D tomography of nucleons
✓ non-linear QCD regime of high gluon densities (saturation)
Design choices

Compared with HERA, eRHIC will have:
- Polarized proton and $^3$He
- Heavy ion beams
- Wide variable center-of-mass energy range
- Considerably higher luminosity

- 10 GeV storage ring
- ZDR in 2004
- Fundamental luminosity limits:
  - Beam-beam
  - SR power loss (total and per m)

- Large allowed beam-beam on electrons
- Electron energy beyond 10 GeV
- Simple energy staging by increasing the linac length
- No e-polarization issues with spin resonances

$\xi_e \sim 0.1$

$\xi_e \sim 1$

$L_{\text{peak}}, \text{cm}^{-2}\text{s}^{-1} \approx 5 \times 10^{31}$

$\approx 4 \times 10^{32}$

up to $1.5 \times 10^{34}$
Luminosity

Reaching high luminosity:
- high average electron current ($50 \text{ mA} = 3.5 \text{ nC} \times 14 \text{ MHz}$):
  - energy recovery linacs; SRF technology
  - high current polarized electron source
- cooling of the high energy hadron beams (Coherent Electron Cooling)
- $\beta^* = 5 \text{ cm IR with crab-crossing}$

Polarized e-p luminosities in $10^{33} \text{ cm}^{-2} \text{s}^{-1}$ units

<table>
<thead>
<tr>
<th>Electrons</th>
<th>Protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>E, GeV</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>0.077</td>
</tr>
<tr>
<td>10</td>
<td>0.077</td>
</tr>
<tr>
<td>20</td>
<td>0.077</td>
</tr>
<tr>
<td>30</td>
<td>0.019</td>
</tr>
</tbody>
</table>

Limiting factors:
- hadron $\Delta Q_{sp} \leq 0.035$
- hadron $\xi \leq 0.015$
- polarized e current $\leq 50 \text{ mA}$
- SR power loss $\leq 8 \text{ MW}$
All-in tunnel staging approach uses two energy recovery linacs and 6 recirculation passes to accelerate the electron beam.

Staging: the electron energy will be increased in stages, from 5 to 30 GeV, by increasing the linac lengths.

Up to 3 experimental locations
Compact magnets

- More than 14,000 magnets in electron beam lines
- Small gap -> efficient and inexpensive -> low cost eRHIC
- Dipole, quadrupole and vacuum chamber prototypes have been constructed
- Magnetic measurements: dipole prototype meets specification

50 mA polarized electron source

- Mechanical design has been developed
- Ready for prototype construction
- Alternative development by MIT: large cathode gun (E. Tsentalovich).
  Also ready to built the prototype

BNL Gatling Gun:
- the current from multiple cathodes is merged

Y. Hao, G. Mahler, V. Litvinenko

Gap 5 mm total
0.3 T for 30 GeV

I. Ben-Zvi
X. Chang

PANIC 2011
**PoP of Coherent Electron Cooling**

- CEC- revolutionary beam cooling technique
- PoP experiment in RHIC by the collaboration: BNL, Jefferson Lab, Tech-X Corporation
- Projected dates: 2013-2014
- Aim: demonstration of cooling of 40 GeV Au ion beam

**Energy Recovery Linac**

- ERL test facility. E=20 MeV
- The energy recovery with high beam current (up to 0.5 A CW)
- First tests start later this year
Design Study Highlights

- Energy loss and energy spread compensation.
- How small can be beam pipe size?
- Surface roughness effect (extruded Al pipe)
- Measurements of CSR shielding effect on the energy spread (V. Yakimenko, et al.)

- Beam-beam simulations: disruption, kink instability, parameter fluctuations.
- Hadron beam kink instability feedback (Y. Hao, et al.)

- HOM tolerances from BBU simulations
- Up to 12.3 MeV/m real estate gradient
- Compact cryomodule; No quadrupoles in the linacs

- New design of 704 MHz cavity (BNL III):
  - reduced peak surface magnet field
  - strong HOM damping
  (I. Ben-Zvi, et al.)
Electron polarization in eRHIC

- High polarized beam current produced by the e-gun. (DC gun with strained-layer super-lattice GaAs-photocathode)
- Direction of polarization are switch by changing helicity of laser photons in and arbitrary bunch-by-bunch pattern
- Linac accelerator -> No depolarizing resonances!
- Only longitudinal polarization is needed in the experimental detector(s)

Beam polarization vector rotates in the horizontal plane during the acceleration.

The conditions for the longitudinal polarization orientation in possible experimental points:

- IP8:  $E_e = N \times 0.077922 \text{ GeV}$
- IP6:  $E_e = N \times 0.075690 \text{ GeV}$

$\vec{p}_e$ stays in horizontal plane and rotates in arcs around vertical direction

$\phi(\Theta) = \phi_0 + \alpha \int_0^\Theta \gamma(\theta) d\theta$

$\phi_d, \gamma_d$
The design of high-lumi IR with $\beta^*=5$ cm

- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture $\text{Nb}_3\text{Sn}$ focusing magnets
- Arranged free-field electron pass through the hadron triplet magnets
- Integration with the detector: efficient separation and registration of low angle collision products
- Gentle bending of the electrons to avoid SR impact in the detector
- Easy to vary the beam energies in wide ranges.
The design of eRHIC is well advanced.

The eRHIC luminosity in ERL-based design reaches above $10^{34}$ cm$^{-2}$ s$^{-1}$.

The electron lattice and interaction region design have been developed, and critical beam dynamics issues have been evaluated.

Considerable progress on crucial R&D items has been achieved: polarized source; compact magnets; cavities and cryomodule.

Important conceptual tests are in preparation: CeC and the ERL facility.

Detailed cost estimate to the end of 2011.