High-Energy High-Luminosity Electron-Ion Collider eRHIC

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**eRHIC: QCD Facility at BNL**

Add electron accelerator to the existing $2B$ RHIC

Unpolarized and 80% polarized leptons, 5-30 GeV

70% polarized protons 100-250 (325*) GeV

Light ions (d,Si,Cu) Heavy ions (Au,U) 50-100 (130*) GeV/u

Polarized light ions (He³) 167 (215*) GeV/u

Center of mass energy range: 30-175 GeV

Any polarization direction in lepton-hadrons collisions

*We are exploring a possibility of increasing RHIC ring energy by 10% - 30%*
Most Compelling Physics Questions

**spin physics**
- what is the polarization of gluons at small $x$ where they are most abundant
- what is the flavor decomposition of the polarized sea depending on $x$
- determine quark and gluon contributions to the proton spin at last

**imaging**
- what is the spatial distribution of quarks and gluons in nucleons/nuclei
- understand deep aspects of gauge theories revealed by $k_T$ dep. distr'n
- possible window to orbital angular momentum

**physics of strong color fields**
- quantitatively probe the universality of strong color fields in AA, pA, and eA
- understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- how do hard probes in eA interact with the medium
Brief history of eRHIC

• First eRHIC paper, 2000, S.Peggs et al., ~300 papers @JACoW, ~36 Phys. Revs, ~80 NIMs....
• First White Paper on eRHIC/EIC, 2002
• 2003, eRHIC appears in DoE’s “Facilities for the Future Sciences. A Twenty-Year Outlook”
• “eRHIC Zeroth-Order Design Report” with cost estimate for Ring-Ring, 2004
• 2007 – after detailed studies we found that linac-ring (LR) has ~10-fold higher luminosity – LR became the main option
• 2008 – first staging option of eRHIC
• In 2009 – completed technical design, dynamics studies and cost estimate for MeRHIC with 4 GeV ERL
• Present - returned to the cost-effective (green) all in tunnel high-luminosity eRHIC design with staging electron energy from 5 GeV to 30 GeV
MeRHIC - 2007/2008

- Completed 2 technical designs of 3-pass 4 GeV ERL – selected a racetrack over a dog-bone
- Developed injector concept
- Completed isochronous achromatic lattice for the ERL including spreaders and combiners
- Completed development of IR with detector
- Studied in details all aspects of beam dynamics – no showstoppers
- Finally went through a lengthy bottoms-up cost estimate and internal review
- Learned a lot and shelved it
eRHIC: polarized electrons with $E_e \leq 30$ GeV will collide with either polarized protons with $E_e \leq 250^*$ GeV or heavy ions $E_A \leq 100^*$ GeV/u

New detector

Linac 2.45 GeV

Coherent e-cooler

Small gap magnets
5 mm gap
0.43 T @ 30 GeV

* We are exploring a possibility of increasing RHIC ring energy by 10% - 30%

Brookhaven National Laboratory

Office of Nuclear Physics

eRHIC design went through the external review on Aug. 1-3, 2011
Main elements of the concept

- We chose ERL for electrons to reach high luminosity at high energy
- We assumed that we can cool hadron beam 10-fold in both longitudinal and transverse directions using coherent electron cooling
- We take advantage of small beam size in ERL and plan to use small magnets with gaps of 5 mm (and 10 mm at two lowest orbits)
- We had found a solution unique for Linac-ring colliders which would allow us to change energy of colliding hadrons from 50 GeV to 250 GeV
- We took advantage of recent advances in super-conducting quadrupole technology to design IR with $\beta^*$ to 5 cm
- Following success of KEK-B with crab-crossing we accommodated this approach into new IR layout
- We assumed that we can generate up to 50 mA of polarized electrons
- These assumptions bring eRHIC top luminosity to $10^{34}$ cm$^{-2}$ sec$^{-1}$
  - If polarized positrons are needed for the program, we suggest to build positron ring and use ERL for generating and accelerating positrons. Luminosity of this collisions will be much lower, i.e. at $10^{32}$ cm$^{-2}$ sec$^{-1}$ level and not all energies of hadrons could be used in the collisions
eRHIC beam parameters and luminosity

<table>
<thead>
<tr>
<th></th>
<th>e</th>
<th>p</th>
<th>$^2\text{He}^3$</th>
<th>$^{79}\text{Au}^{197}$</th>
<th>$^{92}\text{U}^{238}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy, GeV</strong></td>
<td>20</td>
<td>250</td>
<td>167</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>CM energy, GeV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>141</td>
<td>115</td>
<td>89</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td><strong>Number of bunches/distance between bunches</strong></td>
<td>74 nsec</td>
<td>166</td>
<td>166</td>
<td>166</td>
<td>166</td>
</tr>
<tr>
<td><strong>Bunch intensity (nucleons) \times 10^{11}</strong></td>
<td>0.24</td>
<td>2</td>
<td>1.3</td>
<td>0.79</td>
<td>0.83</td>
</tr>
<tr>
<td><strong>Bunch charge, nC</strong></td>
<td>3.8</td>
<td>32</td>
<td>10</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>Beam current, mA</strong></td>
<td>50</td>
<td>420</td>
<td>140</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td><strong>Normalized emittance of hadrons, 95%, mm mrad</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td><strong>Normalized emittance of electrons, rms, mm mrad</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>48</td>
<td>80</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td><strong>Polarization, %</strong></td>
<td>80</td>
<td>70</td>
<td>70</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td><strong>rms bunch length, cm</strong></td>
<td>0.2</td>
<td>8.3</td>
<td>8.3</td>
<td>8.3</td>
<td>8.3</td>
</tr>
<tr>
<td><strong>$\beta^*$, cm for (e &amp; hadrons)</strong></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Luminosity per nucleon, \times 10^{34} \text{cm}^{-2}\text{s}^{-1}</strong></td>
<td>0.97</td>
<td>0.65</td>
<td>0.39</td>
<td>0.41</td>
<td></td>
</tr>
</tbody>
</table>

Hourglass effect is included
Luminosity falls as the cube of hadron energy $E_h^3$ because of space charge limit
Luminosity is adjusted the same at energy of electrons from 5 GeV to 20 GeV
e-beam current and luminosity fall as $E_e^{-4}$ at electron energy >20 GeV (Sync.Rad)
eRHIC Luminosity in e-p

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

<table>
<thead>
<tr>
<th>E, GeV</th>
<th>Protons</th>
<th>100</th>
<th>130</th>
<th>250</th>
<th>325</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.62 (3.1)</td>
<td>1.4 (5)</td>
<td>9.7</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.62 (3.1)</td>
<td>1.4 (5)</td>
<td>9.7</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.62 (3.1)</td>
<td>1.4</td>
<td>9.7</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.12</td>
<td>0.28</td>
<td>1.9</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Polarized (and unpolarized) e (80%) – p (70%) luminosities in $10^{33}$ cm$^{-2}$ sec$^{-1}$ units

Limiting factors:
- hadron $\Delta Q_{sp} \leq 0.035$
- hadron $\xi \leq 0.015$
- polarized e current $\leq 50$ mA
- SR power loss $\leq 7$ MW
**eRHIC Luminosity in e-A**

**Reaching high luminosity:**

- high average electron current
- energy recovery linacs; SRF technology
- high current polarized electron source
- cooling of the high energy hadron beams (Coherent Electron Cooling)
- $\beta^* = 5$ cm IR with crab-crossing

**e-A luminosities in $10^{33}$ cm$^{-2}$ sec$^{-1}$ units**

<table>
<thead>
<tr>
<th>Electrons</th>
<th>E, GeV</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au ions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>8.3</td>
<td>11.4</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
<td>8.3</td>
<td>11.4</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.49</td>
<td>1.7</td>
<td>3.9</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.1</td>
<td>0.34</td>
<td>0.77</td>
<td>1.7</td>
<td></td>
</tr>
</tbody>
</table>

**Limiting factors:**

- hadron $\Delta Q_{sp} \leq 0.035$
- hadron $\xi \leq 0.015$
- SR power loss $\leq 7$ MW
**e-beam in ERL**

- **Linac 2.45 GeV**
- **Coherent e-cooler**
- **PHENIX**
- **eSTAR**
- **New detector**

- 0.60 GeV
- 27.55 GeV
- 30.0 GeV
- 5.50 GeV
- 10.4 GeV
- 15.3 GeV
- 20.2 GeV
- 25.1 GeV
- 30.0 GeV
- 7.95 GeV
- 12.85 GeV
- 17.75 GeV
- 22.65 GeV
- 27.55 GeV
- 3.05 GeV
- 7.95 GeV
- 25.1 GeV
- 20.2 GeV
- 15.3 GeV
- 10.4 GeV
- 5.50 GeV

**Office of Nuclear Physics**
Splitter/Combiner/Linac

Blue Yellow

Tunnel Wall

Blue Yellow

Top View

Side View

Combiner

ARCS

ARCS

ARCS

ARCS

Splitter

LINAC

L = 201 m

\[ \Delta E = \text{values}\]

3.05 GeV

7.95 GeV

12.85 GeV

17.75 GeV

22.65 GeV

27.55 GeV

0.6 GeV

5.5 GeV

10.4 GeV

15.3 GeV

20.2 GeV

25.1 GeV

30 GeV

@ 10 o'clock

Accelerating bunches

Decelerating bunches
Staging of eRHIC: $E_0: 5 \rightarrow 30$ GeV

All energies scale proportionally by adding SRF cavities to the injector.

All magnets would be installed from the day one and we would be cranking power supplies up as energy is increasing.

<table>
<thead>
<tr>
<th>$E/E_0$</th>
<th>0.0200</th>
<th>0.1017</th>
<th>0.1833</th>
<th>0.2650</th>
<th>0.3467</th>
<th>0.4283</th>
<th>0.5100</th>
<th>0.5917</th>
<th>0.6733</th>
<th>0.7550</th>
<th>0.8367</th>
<th>0.9183</th>
<th>1.0000</th>
</tr>
</thead>
</table>
eRHIC: polarized protons

RHIC only polarized proton collider in the world:
Polarization: up to 65% achieved at 100 GeV
Polarization: up to 40% at 250 GeV

Promise: 70% at 325 GeV
Polarized protons $\rightarrow 70\%$

<table>
<thead>
<tr>
<th>Polarization Source</th>
<th>Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPPIS source</td>
<td>$\sim 80%$</td>
</tr>
<tr>
<td>AGS extraction</td>
<td>$\sim 65-70%$</td>
</tr>
<tr>
<td>RHIC, 250 GeV</td>
<td>$\sim 45-50%$</td>
</tr>
</tbody>
</table>

Polarization loss happens after 100 GeV

Improvements in Run 11:
- AGS: jump quads improved considerably the slope of the polarization dependence on the bunch intensity
- RHIC: betatron tunes placed further away from the 0.7 higher-order spin resonance and the vertical realignment of all magnets led to better polarization transmission on the ramp

Possible future developments:
- Working point near integer (allowed by recent success of 10 Hz orbit feedback):
  - Fewer high-order spin resonances
  - Reduced strength of those resonances
- Increased number of the Snakes

For isolated spin resonance (Courant-Lee). The Snake efficiency may depend also on their locations.
Polarized $^3\text{He}^{+2}$ for eRHIC

- Larger $G$ factor than for protons
- RHIC Siberian snakes and spin rotators can be used for the spin control, with less orbit excursions than with protons.
- Spin dynamics at the acceleration in the injector chain and in RHIC has to be studied.

<table>
<thead>
<tr>
<th></th>
<th>$^3\text{He}^{+2}$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$, GeV</td>
<td>2.808</td>
<td>0.938</td>
</tr>
<tr>
<td>$G=(g-2)/2$</td>
<td>-4.18</td>
<td>1.79</td>
</tr>
<tr>
<td>$E/n$, GeV</td>
<td>16.2-166.7</td>
<td>24.3 - 325</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>17.3 - 177</td>
<td>25.9 - 346</td>
</tr>
<tr>
<td>$</td>
<td>G\gamma</td>
<td>$</td>
</tr>
</tbody>
</table>
Electron polarization in eRHIC

- Only longitudinal polarization is needed in the IPs
- High quality longitudinally polarized e-beam will be generated by DC guns with strained-layer super-lattice GaAs-photocathode
- Direction of polarization will be switch by changing helicity of laser photons in and arbitrary bunch-by-bunch pattern
- We continue relying on our original idea (©VL 2003) to rotate spin integer number of 180-degrees between the gun and the IP
- With six passes in ERL the required condition will be satisfied at electron energies: $E_e = N \cdot 0.07216 \text{ GeV}$
- It means that tuning energy in steps of 72 MeV (0.24% of the top energy of 30 GeV) will provide for such condition
- Energy spread of electrons should kept below 6 MeV to have e-beam polarization in IP above 80%

*The GaAs-GaAsP cathode achieved a maximum polarization of 92\(\pm\)6% with a quantum efficiency of 0.5%
Highly polarized electrons from strained-layer super-lattice photocathodes, T. Nishitani et al., J. OF APPL. PHYSICS 97, 094907 (2005)
Loss budget for 6 pass scheme

![Graph showing energy loss with and without compensation for different pass schemes.](image)

- Without compensation
- 2nd harmonic compensator on 6 passes
- 2nd harmonic on 4 passes
- 2nd harmonic on 3 passes
- 2nd harmonic on 2 passes
- 2nd harmonic on 1 pass

Energy of recirculating pass, GeV

Relative energy difference between accelerating and decelerating bunches
eRHIC high-luminosity IR with $\beta^*=5$ cm

- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture Nb$_3$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

© D.Trbojevic, B.Parker, S. Tepikian, J. Beebe-Wang
Design Details for First IR Magnet

- Magnet structure is aligned with e-beam.
- Magnet offset is optimized for neutrons, circulating beam and early analysis for off-momentum charged particle measurement.

\[ B_0 = 2.701 \text{T} \]

Gradient = -85.74 T/m and \( L_{\text{mag}} = 1.95 \text{ m} \)
Reduced Field Region for e-

Even with 6.2 T coil peak field and 2.4 T, $|B|_{\text{max}}$ in the outer yoke, the field inside this shielded region is a fraction of a Gauss.

Plot of $|B|$ (Tesla) for the Yoke and Two Layer Shield Structure

“eRHIC IR Magnet Designs,” Brett Parker, BNL-SMD
Dipoles needed to have good forward momentum resolution
- Solenoid no magnetic field @ r ~ 0
- DIRC, RICH hadron identification \( \rightarrow \pi, K, p \)
- high-threshold Cerenkov \( \rightarrow \) fast trigger for scattered lepton
- radiation length very critical \( \rightarrow \) low lepton energies
“No crabbing”
“Ideal crabbing”

Invented at BNL, pioneered at KEK’s B-factory
RHIC lattice

$L_r = 9.48 \text{ m}$

$R_{12} = 16.7 \text{ m}$

$V_{\perp}[MV] \approx 15.5 \cdot \frac{E_p[GeV]}{325} \frac{\lambda_{rf}[m]}$

$\beta(m)$ vs. path length (m)

$\theta = 0.6 \text{ mrad}$

$\theta = 6 \text{ mm}$

325 GeV p or 130 GeV/u Au
High luminosity (small $\beta^*$), Hourglass & Vertex cuts

All requires very short hadron bunches

eRHIC $\sim$ 5 cm

In present RHIC $\sim$ 50 cm
Electron-hadron frequency matching & Lumi sharing

- In eRHIC electrons are ultra-relativistic \( (\gamma_e \geq 10^4) \) but they are colliding with barely relativistic \( (\gamma_h \sim 10^2) \).
- It means that rep-rate of the hadron changes with there energy and in ring-ring scenario it would require to change the circumference of the ring.
- In ERL-based eRHIC case the condition is easier to satisfy - we can switch harmonic ratio between the hadron beam hadron beam rep-rate and SRF frequency, i.e. skipping a bucket.
- We plan to select few top energies (e.g. 325, 250, 150 & 100 GeV/u) and have the pass length adjusted using two straight section bypasses. Maximum path-length change required in this case is only 15 cm and can be accommodated in one straight.
- It is important to note that this condition would not satisfy centered collisions in more than one IR- i.e. passing time through the center of other IR could be of by as much as 20-40 cm.
- It is not a problem! Since eRHIC would operate in luminosity sharing mode, only ONE IR will have collision at any moment. Thus, we can share eRHIC luminosity between in real time in any desirable ratio (i.e. 0.87 : 0.12: 0.01 is possible).

\[ f_{\text{rev}_e} = \frac{m_e f_{\text{rev}_p}}{h_e} \]

From this: \( f_{\text{rev}_e} = \frac{m_e f_{\text{rev}_p}}{h_e} \)
## Main Accelerator Challenges

In red - increase/reduction beyond the state of the art

<table>
<thead>
<tr>
<th>eRHIC at BNL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarized electron gun - 10x increase</td>
</tr>
<tr>
<td>Coherent Electron Cooling - New concept</td>
</tr>
<tr>
<td>Multi-pass SRF ERL</td>
</tr>
<tr>
<td>5x increase in current</td>
</tr>
<tr>
<td>Crab crossing</td>
</tr>
<tr>
<td>Polarized $^3$He production</td>
</tr>
<tr>
<td>Understanding of beam-beam affects</td>
</tr>
<tr>
<td>$\beta^*=5$ cm</td>
</tr>
<tr>
<td>Multi-pass SRF ERL</td>
</tr>
<tr>
<td>Feedback for kink instability suppression</td>
</tr>
</tbody>
</table>
eRHIC R&D highlights

- Polarized gun for e-p program - LDRD at BNL + MIT
- Development of compact magnets - LDRD at BNL, ongoing
- SRF R&D ERL - ongoing
- Beam-beam effects, beam disruption, kink instability suppression, etc.
- Polarized He$^3$ source
- Coherent Electron Cooling including PoP - plan to pursue
Coherent Electron Cooling (CeC)

At a half of plasma oscillation

\[ q_{\text{FEL}} = \int \rho(z) \cos(k_{\text{FEL}} z) \, dz \]

\[ q = -Ze \cdot (1 - \cos \varphi_1) \]

\[ \varphi_1 = \omega_p / c \gamma \]

\[ q_{\text{peak}} = -2Ze \]

\[ \rho_k = kq(q_1); \quad n_k = \frac{\rho_k}{2\pi \beta \epsilon_k} \]

\[ R_{\text{D}} = \frac{c \sigma_k}{\gamma^2 \omega_p} \]

\[ \lambda_{\text{D}} = \frac{2R_{\text{D}}}{\lambda_{\text{FEL}}} \]

Density

\[ \omega_p = \sqrt{4\pi n_e e^2 / \gamma m_e} \]

\[ q = -Ze \cdot (1 - \cos \varphi_1) \]

\[ \varphi_1 = \omega_p / c \gamma \]

\[ q_{\text{peak}} = -2Ze \]

Dispersion section (for hadrons)

Amplifier of the e-beam modulation in an FEL with gain \( G_{\text{FEL}} \sim 10^2 - 10^3 \)

\[ \Delta E_h = -e \cdot E_0 \cdot l_2 \cdot \sin \left( k_{\text{FEL}} D \cdot E - E_0 \right) \]

\[ \left( \frac{\sin \varphi_2}{\varphi_2} \right) \cdot \left( \frac{\sin \varphi_1}{2} \right) \cdot Z \cdot X \]

\[ E_0 = 2G_o e \gamma_0 / \beta \epsilon_{\text{lin}} \]

\( A_{\perp} = 2\pi \beta_{\perp} e / \gamma_0 \)

\[ k_{\text{FEL}} = 2\pi / \lambda_{\text{FEL}}; \quad k_{\text{cm}} = k_{\text{FEL}} / 2\gamma_0 \]

\[ n_{\text{amp}} = G_o \cdot n_k \cos(k_{\text{cm}} z) \]

\[ \Delta \varphi = 4\pi e n \Rightarrow \varphi = -\varphi_0 \cdot \cos(k_{\text{cm}} z) \]

\[ \vec{E} = -\vec{\nabla} \varphi = -\vec{w} E_o \cdot X \sin(k_{\text{cm}} z) \]

\[ E_o = 2G_o \gamma_0 \frac{e}{\beta \epsilon_{\text{lin}}} \]

\[ 30X = q / e = Z(1 - \cos \varphi_1) \]

![Diagram of Coherent Electron Cooling (CeC) with Hadrons Modulator, E-beam Amplification in FEL, and Kicker Section](image)
Coherent Electron Cooling demonstration experiment at RHIC IR2

Goal - cool a single 40 GeV/u Au ion bunch in RHIC

### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species in RHIC</td>
<td>Au ions, 40 GeV/u</td>
</tr>
<tr>
<td>Electron energy</td>
<td>21.8 MeV</td>
</tr>
<tr>
<td>Charge per bunch</td>
<td>1 nC</td>
</tr>
<tr>
<td>Train</td>
<td>1 bunches</td>
</tr>
<tr>
<td>Rep-rate</td>
<td>78.3 kHz</td>
</tr>
<tr>
<td>e-beam current</td>
<td>0.078 mA</td>
</tr>
<tr>
<td>e-beam power</td>
<td>1.7 kW</td>
</tr>
</tbody>
</table>
Mismatch, tuning of $e\beta^*$

The experiment also can demonstrate the effect of mismatch due to the beam-beam interaction and its relation with the electron design optics.
The Feedback Scheme

Beam-Beam Parameters: $d_e = 5.7, \, \xi_p = 0.015$

$\xi_p \, d_e < 4 \nu_s / \pi$

Studied:

- Electron beam energy losses and energy spread caused by the interaction with the beam environment (cavities, resistive walls, pipe roughness)
- Incoherent and coherent synchrotron radiation related effects: energy losses, transverse and longitudinal emittance increase of the electron beam
- Electron beam patterns; ion accumulation
- Electron beam break-up, single beam and multi-pass
- Electron beam-ion and intra-beam scattering effects
- Electron beam disruption
- Frequency matching......

Still under discussion:

- How small can be the electron beam pipe gap?
- De-bunching and reduction of the energy spread of the electron beam at the dump.
- Length of the electron bunches and the need for harmonic cavities
- Detailed beam dynamics with CeC
- Effect of crab cavities on beam dynamics...
August 2011 Review

• 1) Frank Zimmermann (CERN)
• 2) Jean Delayen (ODU)
• 3) George Ganetis (BNL)
• 4) Hsiao-chaun Hseuh, (BNL)
• 5) Valery Lebedev (FNAL)
• 6) Matt Poelker (Jlab)
• 7) Eduard Pozdeyev (MSU/NSCL)
• 8) Peter Wanderer (BNL)

• From the report:
  • The committee is very impressed by the ingenious design of eRHIC. The design includes a number of outstanding and novel elements.
  • The committee is highly satisfied with the material presented, covering most of the relevant subjects. The committee did not see any significant holes in the concept.
  • Plus about 40 recommendations
Milestones & Goals

• Main milestones
  – **Finish eRHIC cost estimate** Spring of 2012
  – **External review of the estimate** Summer of 2012
  – **Address concerns of the reviews** End of 2012
  – **Complete start-to-end eRHIC ERL simulations** 2013
  – **Complete beam-beam simulations** 2014
  – **Complete magnet prototyping** 2015
  – **Demonstrate coherent e-cooling** 2016-17
Summary

• eRHIC design progresses well
  – Accelerator design is completed
  – And went through the External review
  – Cost estimate is underway
  – Follow-up on the committee recommendations is in progress

• Physics of the collider is well understood
  – No show-stoppers were found
  – Many processed can be studied or simulated from first principles

• Number of novel concepts require extensive R&D

• Next 3-5 years will be critical for completing R&D and be ready for full eRHIC design

• Backup slides