RHIC operational status and upgrade plans

Wolfram Fischer

Thanks to many at BNL.

European Particle Accelerator Conference, Edinburgh
27 June 2006
Outline

1. Status
   - Achieved performance
   - Performance limits

2. Upgrades
   - Enhanced Design parameters
   - Electron Beam Ion Source (EBIS)
   - RHIC II (electron cooling)
   - eRHIC
Relativistic Heavy Ion Collider

- 2 superconducting rings
- 3.8 km length
- operation since 2000
- 5 experiments so far, test QCD
- only operating ion collider (up to gold 100 GeV/n)
- only operating polarized proton collider
RHIC running modes

- Au–Au 10, 28, 31, 65, 100 GeV/n
- d–Au 100 GeV/n
- Cu–Cu 11, 31, 100 GeV/n
- polarized p–p 11, 31, 100, 205, 250 GeV

Some modes only for days – fast machine setup essential.

Important control experiment in physics program
Delivered luminosity increased by 2 orders of magnitude in 5 years.

Delivered to PHENIX, one of RHIC’s high-luminosity experiments.

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Show nucleon-pair luminosity for ions: $\mathcal{L}_{NN}(t) = A_1 A_2 \mathcal{L}(t)$
(can compare different ion species, including protons)
Typical year (Run)

~30 weeks of cryo operation

½ week warm-up
12 weeks p↑-p↑ physics
2 ½ weeks set-up p↑-p↑

11 weeks of A-A physics
2 ½ week set-up A-A
1 ½ week cool down 80K to 4K
Calendar time in store after setup

Rest of the time:
~20% machine tuning/ramping
~15% failures
~10% machine development and accelerator physics experiments

F. Pilat et al., THPCH197
Performance limit: IBS for heavy ions

Beam and luminosity lifetime for Au – Au dominated by IBS

\[ \tau^{-1} \propto \frac{Z^4}{A^2 N_B} \]

[Factor 10 between Au an p]

- Debunching requires continuous abort gap cleaning
- Luminosity lifetime requires frequent refills
- Ultimately need cooling at full energy
Recently demonstrated longitudinal stochastic cooling in bunch of $2 \times 10^9$ protons at 100 GeV
($\sim 1\%$ of normal p intensity, $\sim$ normal Au intensity)

M. Brennan
M. Blaskiewicz

Expect to stop debunching of Au beams $\rightarrow$ 20-50\% more luminosity

Longitudinal profile of a bunch

15 ns after 90 min of cooling

initially
Performance limit: transition crossing

Crossing transition with slowly ramping sc. Magnets (all ions except protons)

→ Instability limits bunch intensities for ions (~$1.5 - 2.0 \times 10^{11}$ e)

→ Instability is fast ($\tau = 15$ ms), transverse, single bunch (electron clouds can lower stability threshold)

- $\gamma_t$-jump implemented
- Octupoles near transition
- Chromaticity control (need $\xi$-jump for higher bunch intensities)

Longitudinal distribution after transverse instability (courtesy C. Montag)
Performance limit: dynamic pressure rise

Dynamic pressure rise caused by electron clouds

Upgraded warm and cold vacuum system:
- installed 430m of NEG pipes (~700m warm sections)
- reduced pressure in cold section to 1e-7 Torr before cool-down

Dynamic pressure currently not a concern in operation
Performance limit: polarization of protons

Equipment for polarized beam

Snakes change spin direction → used to avoid depolarizing resonances

Superconducting helical magnet in AGS – most complex magnet ever built by Superconducting Magnet Division
Performance limit: polarization of protons

First operational use of AGS cold snake in 2006

- Raised AGS polarization from 60% to 65%
- Removed intensity dependence of polarization

Polarization by machine

- Source → 85%
- AGS extraction → 65%
- RHIC store
  - 100 GeV (no loss) → 65%
  - 205 GeV (in 2005) → 30%
  - 250 GeV (yesterday!) → 47%

H. Huang et al. MOPCH100


Blue only, current record energy for p↑
Performance limit: beam-beam for p↑- p↑

- Total beam-beam induced tune spread reached $\Delta Q_{bb,\text{tot}} = 0.012$
- Other sources of tune spread: $\Delta Q \approx 0.005$
  - nonlinear chromaticity (correction planned for next year)
  - triplet errors (locally corrected)
- Sources for orbit and tune modulation

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RHIC upgrades

Upgrade goals

- More luminosity and polarization
- More flexibility and reliability

Four main upgrades planned:

1. Enhanced Design parameters
2. Electron Beam Ion Source (EBIS)
3. RHIC II (electron cooling)
4. eRHIC
**Upgrade 1: Enhanced Design (~2008*)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>unit</th>
<th>Achieved</th>
<th>Enhanced design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Au-Au operation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>GeV/n</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>No of bunches</td>
<td>...</td>
<td>45</td>
<td>111</td>
</tr>
<tr>
<td>Bunch intensity</td>
<td>$10^9$</td>
<td>1.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Average $\mathcal{L}$</td>
<td>$10^{26}\text{cm}^{-2}\text{s}^{-1}$</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Should be possible in next Au-Au run</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **p↑-p↑ operation** |          |          |                 |
| Energy             | GeV       | 100      | 250             |
| No of bunches      | ...       | 111      | 111             |
| Bunch intensity    | $10^{11}$ | 1.4      | 2.0             |
| Average $\mathcal{L}$ | $10^{30}\text{cm}^{-2}\text{s}^{-1}$ | 20     | 150             |
| Polarization $P$   | %          | 65       | 70              |

* First 250 GeV $p\uparrow-p\uparrow$ physics run currently scheduled for 2009.
Upgrade 1: Enhanced Design (~2008)
Upgrade 2: Electron Beam Ion Source (EBIS)

- Current ion pre-injector: upgraded Model MP Tandem (electrostatic)
- Plan to replace with: Electron Beam Ion Source, RFQ, and short linac

→ Can avoid reliability upgrade of Tandem
→ Expect improved reliability at lower cost
→ New species: U, $^3$He↑
Upgrade 2: Electron Beam Ion Source (EBIS)

Tandem-to-Booster: 840m
EBIS-to-Booster: 30m
Upgrade 2: Electron Beam Ion Source (2009)

Schematic of RHIC EBIS

<table>
<thead>
<tr>
<th>quantity</th>
<th>unit</th>
<th>RHIC EBIS</th>
<th>Test EBIS achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>e-beam current</td>
<td>A</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>e-beam energy</td>
<td>keV</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>ion trap length</td>
<td>m</td>
<td>1.5</td>
<td>0.7</td>
</tr>
<tr>
<td>trap charge capacity</td>
<td>$10^{11}$</td>
<td>11</td>
<td>5.1</td>
</tr>
<tr>
<td>charge yield (Au)</td>
<td>$10^{11}$</td>
<td>5.5 (10 A)</td>
<td>3.4 (8 A)</td>
</tr>
<tr>
<td>pulse length</td>
<td>$\mu$s</td>
<td>≤40</td>
<td>20</td>
</tr>
<tr>
<td>yield Au$^{32+}$</td>
<td></td>
<td>3.4</td>
<td>&gt; 1.5</td>
</tr>
</tbody>
</table>

Test EBIS of ½ length achieved ½ of required yield, yield scales with trap length
## Upgrade 3: RHIC II – electron cooling (≥ 2012)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>unit</th>
<th>Enhanced design</th>
<th>RHIC II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Au-Au operation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>GeV/n</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>No of bunches</td>
<td>…</td>
<td>111</td>
<td>111</td>
</tr>
<tr>
<td>Bunch intensity</td>
<td>$10^9$</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Average $\mathcal{L}$</td>
<td>$10^{26}\text{cm}^{-2}\text{s}^{-1}$</td>
<td>8</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$9\times$</td>
</tr>
<tr>
<td><strong>p↑- p↑ operation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>No of bunches</td>
<td>…</td>
<td>111</td>
<td>111</td>
</tr>
<tr>
<td>Bunch intensity</td>
<td>$10^{11}$</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Average $\mathcal{L}$</td>
<td>$10^{30}\text{cm}^{-2}\text{s}^{-1}$</td>
<td>150</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$3\times$</td>
</tr>
<tr>
<td>Polarization $\mathcal{P}$</td>
<td>%</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>
Upgrade 3: RHIC II – electron cooling ($\geq$ 2012)
Upgrade 3: **RHIC II – electron cooling (≥ 2012)**

Use non-magnetized cooling (no solenoidal field)  
(demonstrated with 8.9 GeV antiprotons in Fermilab Recycler – Nagaitsev et al.)

For 100 GeV Au beams need:  
• 54 MeV electron beam  
• 5nC per bunch  
• rms emittance < 4 μm  

→ 2.7 MW beam power  
→ need Energy Recovery Linac (ERL)

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I. Ben-Zvi et al. TUZBPA01

Courtesy D. Kayran
Upgrade 3: **RHIC II – electron cooling (≥ 2012)**

Cooling section:
110m long, $\beta_{x,y} \approx 400m$

D. Trbojevic et al. MOPCH102
Upgrade 3: RHIC II – electron cooling (≥ 2012)

Simulated luminosities (A. Fedotov)

For:
• Beam-loss only from burn-off (luminosity)
• Constant emittance (cooling)

\[ \mathcal{L}(t) = \frac{\mathcal{L}(0)}{(1 + t/\tau)^2} \]

\( \tau \approx 5 \text{ h for Au-Au} \)

Store length limited by burn-off
Upgrade 4: eRHIC (≥ 2014)

**Main features:**

- High-luminosity electron-ion collider
  - $10^{32}-10^{34}$ cm$^{-2}$s$^{-1}$ for $e^\uparrow$-$p^\uparrow$
  - $10^{30}-10^{32}$ cm$^{-2}$s$^{-1}$ for $e^\uparrow$-$A(\uparrow)$

- 30-100 GeV center-of-mass energy

- Longitudinally polarized electrons, protons, possibly light ions

- Currently working on
  - Ring-ring option  (B-factory like e-ring)
  - Linac-ring option  (higher luminosity potential)

V. Ptitsyn et al. MOPLS058
Upgrade 4: eRHIC ($\geq 2014$)
Upgrade 4: eRHIC (≥ 2014)

Major R&D items:
- electron accelerator (ring or linac)
- high intensity polarized electron gun
- interaction region optimization
- beam dynamics problems (beam-beam, electron clouds)

For multiple passes:
vertical separation of the arcs
Summary RHIC

Status:

• Since 2000, 4 ion combinations, 8 energies
• Luminosity/year increased by 2 orders of magnitude
• Protons with 65% polarization at 100 GeV

Planned upgrades:

2. EBIS (modern pre-injector, U and $^3$H↑ – 2009)
3. RHIC II (order of magnitude increase in Au-Au $\mathcal{L}$ – ≥2012)
4. eRHIC (high luminosity electron-ion collider – ≥2014)