RHIC plans towards higher luminosity

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RHIC – a High Luminosity (Polarized) Hadron Collider

Operated modes (beam energies):
- Au–Au: 4.6, 10, 28, 31, 65, 100 GeV/n
- d–Au: 100 GeV/n
- Cu–Cu: 11, 31, 100 GeV/n
- p↑–p↑: 11, 31, 100, 205, 250 GeV

Achieved peak luminosities (100 GeV, nucl.-nucl.):
- Au–Au: $140 \times 10^{30}$ cm$^{-2}$ s$^{-1}$
- p↑–p↑: $35 \times 10^{30}$ cm$^{-2}$ s$^{-1}$
Gold Ion Collisions in RHIC

Beam Energy = 100 GeV/u

9 GeV/u
Q = +79

1 MeV/u
Q = +32

RHIC

AGS

BOOSTER

TANDEMS
RHIC heavy ions collisions

a “Mini-Bang”
Nuclear matter at extreme temperatures and density

Produce and explore a new state of matter

a. Formation phase -
   parton scattering
b. Hot and dense phase -
   → strongly interacting hot dense material
   (sQGP, “perfect liquid”)
c. Freeze-out –
   emission of hadrons
Polarized Hadron collider

- **PHENIX (p)**
  - AGS Linac Booster
  - Pol. H⁻ Source
  - 200 MeV Polarimeter

- **AGS**
  - Helical Partial Siberian Snake
  - Spin Rotators (longitudinal polarization)
  - Solenoid Partial Siberian Snake

- **STAR (p)**
  - Spin Rotators (longitudinal polarization)

- **RHIC pC Polarimeters**
  - Absolute Polarimeter (H jet)

- **BRAHMS (p)**
  - Spin flipper

- **AGS Polarimeters**
RHIC Spin Physics

- Spin structure functions of gluon and anti-quarks
- Parity violation in parton-parton scattering
- Requires high beam polarization and high luminosity
RHIC design and achieved parameters for 100 GeV/n (A₁ and A₂ are the number of nucleons in the ions of colliding beams)

<table>
<thead>
<tr>
<th>species</th>
<th>No of bunches</th>
<th>Ions/bunch ([10^9])</th>
<th>(\beta^*) [m]</th>
<th>Polarization, average</th>
<th>(L_{\text{store,avg}}) ([\text{cm}^{-2}\text{s}^{-1}])</th>
<th>(A_1A_2L_{\text{store,avg}}) ([\text{cm}^{-2}\text{s}^{-1}])</th>
<th>(A_1A_2L_{\text{peak}}) ([\text{cm}^{-2}\text{s}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au-Au</td>
<td>56</td>
<td>1.0</td>
<td>2</td>
<td>2×10^{26}</td>
<td>8×10^{30}</td>
<td>31×10^{30}</td>
<td></td>
</tr>
<tr>
<td>p-p</td>
<td>56</td>
<td>100</td>
<td>2</td>
<td>4×10^{30}</td>
<td>4×10^{30}</td>
<td>5×10^{30}</td>
<td></td>
</tr>
</tbody>
</table>

Enhanced Design Parameters (by 2009)

| Au-Au   | 111           | 1.0             | 0.9           | 8×10^{26}         | 31×10^{30}      | 140×10^{30}     |
| p\uparrow-p\uparrow | 111   | 200             | 0.9           | 70%               | 60×10^{30}      | 60×10^{30}      | 90×10^{30}     |

Achieved operational values (as of 2007)

| Au-Au   | 103           | 1.1             | 0.8           | 14×10^{26}        | 54×10^{30}      | 140×10^{30}     |
| p\uparrow-p\uparrow | 111   | 130             | 1             | 60%               | 20×10^{30}      | 20×10^{30}      | 35×10^{30}     |
| d-Au    | 55            | 120/.7          | 2             | 2×10^{28}         | 8×10^{30}       | 28×10^{30}      |
| Cu-Cu   | 37            | 4.5             | 0.9           | 80×10^{26}        | 32×10^{30}      | 79×10^{30}      |
2007 RHIC run with Au ions

Run7 RHIC AuAu  Integrated Luminosity for Physics
(singles corrected)

thru store 9024
ending 10:37 21 June

Integrated Luminosity [b^(-1)]

date

A. Drees
TUOCKI 02
Major upgrades

1. Electron Beam Ion Source (EBIS)
2. Stochastic cooling
3. Electron cooling for RHIC-II
4. Low-energy RHIC operation
5. eRHIC
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↑
Electron Beam Ion Source (EBIS)

- New high brightness, high charge-state pulsed ion source, ideal as source for RHIC
- Produces beams of all ion species including noble gas ions, uranium (RHIC) and polarized He\(^3\) (eRHIC)
- Achieved \(1.7 \times 10^9\) Au\(^{33+}\) in 20 \(\mu\)s pulse with 8 A electron beam (60% neutralization)
- Construction schedule: FY2006 – 09

J. Alessi et al. FRYAB02

[Image of EBIS test stand]
Microwave stochastic cooling

M. Blaskiewicz, M. Brennan et al.

• Longitudinal cooling of low intensity proton bunch at 100 GeV was first demonstrated in 2006.

• Longitudinal cooling for Au ions was made operational in Yellow ring in 2007.

• Longitudinal cooling in Blue ring – under development.

• Design work started on transverse cooling.
Longitudinal stochastic cooling in Yellow ring

M. Blaskiewicz et al., WEYC02

Cooling ON

Longitudinal beam profile from Wall Current Monitor

Zs=2, fill 8794

current (Amps)

-15 -10 -5 0 5 10 15
time (ns)
RHIC performance for Au ions

2004 run
intensity loss

2007 run
(with longitudinal stochastic cooling in Yellow ring)

luminosity loss
## RHIC II – major luminosity upgrade

<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><strong>$p^\uparrow- p^\uparrow$ 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>
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<tr>
<td>Average $\mathcal{L}$</td>
<td>$10^{30}\text{cm}^{-2}\text{s}^{-1}$</td>
<td>150</td>
<td>400</td>
</tr>
<tr>
<td>Polarization $\mathcal{P}$</td>
<td>%</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

Already achieved and exceeded
RHIC II – luminosity (nucleon-pair) projection

- Proton-proton (p-p) and proton-antiproton (p-\bar{p}) collisions
- Ion-ion collisions (A-A)
- Lepton-proton (e-p) and lepton-ion (e-A) collisions (e^- and e^+)
- Spin polarized beams

Peak luminosity per IP \([10^{30} \text{ cm}^{-2} \text{ s}^{-1}]\)

- ISR p-p
- SPS p-\bar{p}
- ISR A-A
- Tevatron I p-\bar{p}
- Tevatron II p-p
- RHIC p-p
- RHIC p-\bar{p}
- RHIC A-A
- RHIC Enhanced (design)
- LHC p-p (design)
- eRHIC e-\bar{p} (design)


Last update: 21 June 2007

Courtesy W. Fischer

Alexei Fedotov, June 26 2007, PAC07
Electron Cooling

RHIC II

I. Ben-Zvi et al. WEOCKI03 with references to other RHIC-II presentations
Electron cooling section at RHIC 2 o’clock IP

Each electron beam cools ions in Yellow ring of RHIC then the same beam is turned around and cools ions in Blue ring of RHIC.
Energy Recovery Linac (ERL) for RHIC-II

Cooling of Au ions at 100 GeV/n:
• 54.3 MeV electron beam
• 5nC per bunch
• rms emittance < 4 µm
• rms momentum spread < 5×10⁻⁴

D. Kayran, THPAS096
Cooling of Au ions for RHIC-II (simulations)

Ion bunch intensity $N_i = 1 \times 10^9$
with electron cooling
$\langle L \rangle = 7 \times 10^{27} \text{ cm}^2\text{s}^{-1}$

BETACOOL (JINR, Russia) simulation.
included effects: intra-beam scattering, electron cooling, particle loss in collisions ("burn-off"), loss from rf bucket.

number of bunches: 111
initial $\varepsilon_{95\%,n} = 15 \mu\text{m}$
rms momentum spread $5 \times 10^{-4}$
$\beta^* = 0.5\text{m}$
Electron cooling for RHIC-II: bunch length control (simulations)

Maintaining short bunch length.

Also, shaping of the longitudinal distribution is possible.
High-energy Electron Cooling system for RHIC-II

1. Provides cooling of various ion species at 100 GeV/nucleon.
2. Delivers luminosity required by RHIC-II upgrade.
3. Maintains short bunch length which is important for detectors.
4. Provides pre-cooling of protons (above transition energy) to required transverse and longitudinal emittances.
5. Provides cooling of various ion species at other collisions energies in the range of 25-100 GeV/nucleon.
Low-energy RHIC operation

There is substantial and growing interest in RHIC heavy ion collisions with c.m. energy in the range $\sqrt{s_{NN}} = 5$-50 GeV/nucleon

- Corresponds to Au beams in RHIC of $\gamma = 2.68$ to 26.8
- Nominal Au injection is $\gamma = 10.52$, already below design $\gamma = 12.6$

RIKEN workshop (BNL, March 9-10, 2006):
“Can we discover the QCD critical point at RHIC?”

Suggested energy scan: $\sqrt{s_{NN}} = 5, 6.3, 7.6, 8.8, 12.3, 18, 28$ GeV/nucleon

Test runs at low energies were done (T. Satogata et al.).

- Pre-cooling of ion beam in AGS for efficient injection into RHIC at lowest energies (with significant potential for luminosity gain) is under investigation.
Low-energy RHIC operation: 2.5-25 GeV/n

Landmark study. Physicists have seen a smooth transition from bound quarks to quark-gluon plasma (dotted line). They now hope to find the point beyond which the transition becomes violent (white line).
Low-energy RHIC operation: June 11, 2007 test Run at $\sqrt{s} = 9.1$ GeV/n ($\gamma=4.93$)

T. Satogata et al. TUPAS103
Electron-Ion collider (eRHIC)

Electron accelerator

Polarized leptons
3-20 GeV

70% beam polarization goal

RHI C

Polarized protons
50-250 GeV

Heavy ions (Au)
50-100 GeV/n

Polarized light ions (He³)
167 GeV/n
Two accelerator design options developed in parallel (2004 Zeroth-Order Design Report):

1. ERL-based design “Linac-Ring”:
   - Superconducting energy recovery linac (ERL) for the polarized electron beam.
   - Peak luminosity of $2.6 \times 10^{33}$ cm$^{-2}$s$^{-1}$ with potential for even higher luminosities.
   - Uses electron cooling to pre-cool heavy ions and protons.
   - R&D for a high-current polarized electron source needed to achieve the design goals.

2. “Ring-Ring” option:
   - Electron storage ring for polarized electron or positron beam.
   - Technologically more mature with peak luminosity of $0.47 \times 10^{33}$ cm$^{-2}$s$^{-1}$
eRHIC
(Linac-ring approach: V. Litvinenko et al.)

Main ERL (2 GeV per pass)

Four e-beam passes

PHENIX

STAR

e-cooling
(RHIC II)

AGS

EBIS

BOOSTER

LINAC
Summary

RHIC upgrades are designed to provide

*a comprehensive “QCD Laboratory”*

to study

- the nature of quark-gluon matter

- the detailed properties of the “glue” that binds matter in these various forms

- the full understanding of how complex QCD structures combine to form the observed properties of the proton
Acknowledgements

We are grateful to the members of Brookhaven’s Collider-Accelerator Department whose work is summarized in this presentation.

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