Polarized Protons in RHIC

- Layout of the RHIC and injectors.
- RIKEN contributions to RHIC Spin program.
- Intro to accelerator physics.
  - Spin dynamics.
  - Depolarizing resonances.
- Hardware: Siberian snakes and rotators.
- 1st polarized proton run.
- Future plans.
- Summary: successes of RIKEN/BNL Collaboration.
LINAC: Linear Accelerator
AGS: Alternating Gradient Synchrotron
RHIC: Relativistic Heavy Ion Collider
RIKEN Contributions to RHIC Spin

Superconducting Helical Siberian Snakes
Superconducting Helical Spin Rotators (PHENIX and STAR)

Total of 48 helical dipoles

Special probe for magnetic measurements of helical dipoles
Power supplies and quench circuits for Snakes and Rotators
Polarimeters (Subject of following talk by Dr. K. Kurita)

Domo Arigato Gazaimashita.
Particle Trajectories in Magnetic Fields

Dipole magnets bend the beam around the ring.

Quadrupole magnets focus the beam for stability.

Spin Physics Program Celebration
Waldo MacKay 30 April, 2002
Transport and Betatron Oscillations

Alternate focusing and defocusing lenses for stability.

Horizontal Betatron Oscillation
with tune: \( \nu_h = 6.3 \),
i.e., 6.3 oscillations per turn.

Vertical Betatron Oscillation
with tune: \( \nu_v = 7.5 \),
i.e., 7.5 oscillations per turn.

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Waldo MacKay       30 April, 2002
Simple Model of Proton

Gyroscope + Bar magnet + Charge = "proton"

Magnetic Spin
Dipole Moment

Polarization: Average spin of the ensemble of protons.
In the local rest frame of the proton, the spin precession of the proton obeys the Thomas-Frenkel equation:

\[
\text{Torque: } \frac{d\vec{S}^*}{dt} = \frac{q}{\gamma m} \vec{S}^* \times \left[ (1 + G\gamma)\vec{B}_\perp + (1 + G)\vec{B}_\parallel \right] \quad \text{TF}
\]

\[
\text{Force: } \frac{d\vec{p}}{dt} = \frac{q}{\gamma m} \vec{p} \times \vec{B}_\perp \quad \text{Lorentz}
\]

(This is a mixed description: \( t \), and \( \vec{B} \) in the lab frame, but spin \( \vec{S}^* \) in local rest frame of the proton.)

\[
G = \frac{g - 2}{2} = 1.7928, \quad \gamma = \frac{\text{Energy}}{mc^2}.
\]
Example with 6 precessions of spin in one turn:

\[ G\gamma + 1 = 6. \]

Spin tune: number of precessions per turn relative to beam’s direction.
So we subtract one:

\[ \nu_{\text{spin}} = G\gamma \propto \text{energy}, \]

i.e., 5 in this example.
Depolarizing Resonances

Resonance Condition:

\[ \nu_{\text{spin}} = N + N_v \nu_v, \]

where \( N \) and \( N_v \) are integers.

Magnetic Field

Protons moving into screen

Magnetic Lens (quadrupole)
Vertically focusing

\[ \Theta \]

Protons moving into screen

\[ \nabla \]

Force
Depolarizing Resonances

Intrinsic Resonances in RHIC
Qx=29.19 Qy=28.23 Emv=10 π

Will depolarize beam during acceleration.

Solution: Snakes
● 2 snakes: spin is up in one half of the ring, and down in the other half.

● Spin tune: $\nu_{\text{spin}} = \frac{1}{2}$
  (It’s energy independent.)

● “The unwanted precession which happens to the spin in one half of the ring is unwound in the other half.”
Accelerator Complex for Protons

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Helical Dipoles
Trajectory and Spin through Snakes

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Construction of Cold Masses
Installation of Rotators
## Performance of 1st Run

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
<th>1st Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.M. Energy [GeV]</td>
<td>500</td>
<td>200</td>
</tr>
<tr>
<td>$L_{\text{peak}} \ [\times 10^{30} \text{ cm}^{-2} \text{s}^{-1}]$</td>
<td>200</td>
<td>1.5</td>
</tr>
<tr>
<td>Polarization</td>
<td>70%</td>
<td>25%</td>
</tr>
<tr>
<td>Polarization direction</td>
<td>Vert. &amp; Long. †</td>
<td>Vert.</td>
</tr>
<tr>
<td>Protons/bunch $\ [\times 10^{11}]$</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td>bunches/ring</td>
<td>112</td>
<td>55</td>
</tr>
<tr>
<td>$\beta^*$ [m]</td>
<td>1†</td>
<td>3</td>
</tr>
<tr>
<td>Emittance $\pi \epsilon_95% [\pi \mu m]$</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

† STAR and PHENIX only.
High Intensity Polarized H\(^-\) Source

KEK OPPIS*
upgraded at TRIUMF
70 \rightarrow 80\% Polarization
15 \times 10^{11} \text{ protons/pulse}
at source
6 \times 10^{11} \text{ protons/pulse}
at end of LINAC

*Optically Pumped Polarized Ion Source
Comments on Injector Performance

- Source: Worked beautifully.
- Booster: No depolarization.
- AGS: Polarization loss larger in FY02 due to lower ramp rate and higher bunch intensity
  - Failed main magnet power supply.  
    (Repair by Fall’02.)
- AGS: New partial superconducting helical snake should give polarization $\sim 70\%$. 

![Graph showing polarization vs. $G\gamma$](image)
RHIC Beam Polarization

Beam Currents [$\times 10^{11}$ protons]

Injection

Measured Asymmetry

Time [hours]

~25% (preliminary)
Future Plans

Preparations for Next Run

• Next time: spin rotators at STAR and PHENIX for longitudinal polarization.

• New CNI† polarimeter in AGS to improve tuning AGS for higher polarization.

Beyond Next Run

• Polarimeter using Polarized Hydrogen Jet target for absolute calibration of CNI polarimeters in RHIC.

• New Superconducting Helical Partial Snake in AGS to improve polarization transmission.

†CNI: Coulomb Nuclear Interference.
Successes from RIKEN/BNL Collaboration

- First superconducting helical snakes. (Work very well!)
- Polarized protons accelerated to highest energy.
- First collider with polarized protons! $\sqrt{s} = 200$ GeV
- CNI polarimeters work beautifully. (See next talk by Dr. Kurita.)