RHIC Polarized Protons
Operations and Plans

Run-6 luminosity and polarization performance

Towards RHIC Spin plan performance
RHIC – first polarized hadron collider

Without Siberian snakes: $\nu_{sp} = G\gamma = 1.79 \text{ E/m} \rightarrow \sim 1000$ depolarizing resonances

With Siberian snakes (local 180° spin rotators): $\nu_{sp} = \frac{1}{2} \rightarrow$ no first order resonances
Luminosity and polarization

Major improvements: Cold AGS snake: 65% polarization at \(1.5 \times 10^{11}\) proton / bunch
Little pressure rise in RHIC with NEG coated vacuum pipes

FOM = LP^4
Strong Partial Siberian Snake in AGS

Challenges:
1. SC element in warm machine
2. Lattice disturbances

\[ \cos(180° \nu_{sp}) = \cos(\delta/2) \cdot \cos(180° G\gamma) \]
New AGS helical snakes

- 25% s.c. helical snake build at BNL SMD (AIP)
  - Commissioned in 2005, reliable operation in 2006

- 6% helical snake build at Tokana Industries funded by RIKEN

- Warm snake avoids polarization mismatch at AGS injection and extraction.
- Cold strong snake eliminates all depolarizing resonances in AGS.
Two snakes in AGS

- Two snakes give larger spin tune gap
- AGS stable with $Q_y = 8.98$!
- Ramp measurement with AGS pC CNI polarimeter shows no obvious residual depolarization
- With strong partial snakes weak depolarization from horizontal intrinsic resonances
Results of AGS polarization development

- 65% polarization and $1.5 \times 10^{11}$ protons/bunch with two partial snakes in the AGS. [2002: 30% $0.7 \times 10^{11}$; 2003: 40% $0.7 \times 10^{11}$; 2004: 50% $0.7 \times 10^{11}$; 2005: 50% $1.1 \times 10^{11}$]
- Snake setup with best polarization: 10% cold snake, 5.9% warm snake.
- Four compensation quads around warm snake improved dynamic aperture
- Little intensity dependence of polarization with this setup.
- Remaining polarization loss:
  - ~ 10% due to vertical (~5%) and horizontal (~5%) intrinsic resonances
  - ~ 1% due to injection and extraction mismatch
  - ~ 10% polarization loss unexplained.
- For next year:
  - upgrade AGS quadrupoles to move horizontal tune also into spin tune gap
  - minimize space charge emittance growth at AGS injection: less polarization loss from intrinsic resonances
  - improve polarimeter calibration and polarization ramp measurement to identify and confirm residual polarization loss.
Siberian Snake in RHIC Tunnel

Siberian Snake: 4 superconducting helical dipoles, 4 Tesla, 2.4 m long with full 360° twist

Funded by RIKEN, Japan
Designed and constructed at BNL
## Run-6 polarized proton runs

<table>
<thead>
<tr>
<th>Beam energy</th>
<th>100 GeV</th>
<th>11 GeV</th>
<th>31.2 GeV</th>
<th>250 GeV</th>
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<tbody>
<tr>
<td>Purpose</td>
<td>Physics operation</td>
<td>Machine test</td>
<td>Physics operation</td>
<td>Machine test</td>
</tr>
<tr>
<td>Time</td>
<td>12 weeks</td>
<td>1 day</td>
<td>2 weeks</td>
<td>1 week</td>
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<td>Participating experiments</td>
<td>PHENIX STAR</td>
<td>PHENIX STAR BRAHMS</td>
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<td>Run coordinator</td>
<td>Vadim Ptitsyn</td>
<td>Todd Satogata</td>
<td>Vadim Ptitsyn</td>
<td>Mei Bai</td>
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</tbody>
</table>
Run-6 100 x 100 GeV Integrated luminosity

Run6 100 x 100 GeV pp Integrated Luminosity (Final Delivered) for Physics

- STAR
- PHENIX

min
max
one week shutdown
% Calendar time in store after setup

Rest of the time:
~20% machine tuning/ramping
~15% failures
~10% machine development and accelerator physics experiments
~ 5% maintenance and access
Polarization at 100 GeV

The graph shows polarization for Run 6, 100x 100 GeV - final. The average % polarization for each store is plotted against dates from 2/12/06 to 6/12/06. The data points are connected by lines indicating trends over time. Two average polarizations are indicated: Run-5 with 49% and 45%. The graph is part of the Brookhaven National Laboratory's documentation.
### Polarized protons performance at 100 GeV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
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<tr>
<td>No. of bunches</td>
<td>--</td>
<td>55</td>
<td>55</td>
<td>56</td>
<td>106</td>
<td>111</td>
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<tr>
<td>bunch intensity</td>
<td>$10^{11}$</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.9</td>
<td>1.3</td>
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<tr>
<td>store energy</td>
<td>GeV</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>$\beta^*$</td>
<td>m</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>peak luminosity</td>
<td>$10^{30}$cm$^{-2}$s$^{-1}$</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>35</td>
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<tr>
<td>average luminosity</td>
<td>$10^{30}$cm$^{-2}$s$^{-1}$</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>20</td>
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<tr>
<td>Collision points</td>
<td>--</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>average polarization, store</td>
<td>%</td>
<td>15</td>
<td>35</td>
<td>46</td>
<td>47</td>
<td><strong>60-65%</strong></td>
</tr>
</tbody>
</table>
250 GeV development

- Achieved at least 45% polarization at 250 GeV (using 100 GeV analyzing power)
- No beam loss on ramp
- Some polarization loss on ramp

Preliminary online data
100 GeV analyzing power

Some polarization loss at resonance around 138 GeV
Towards “Enhanced Luminosity” (Midterm/spin plan)

100 x 100 GeV until 2008:
Goal: \( <L> = 60 \times 10^{30} \, \text{cm}^{-2} \text{s}^{-1} \) (3 x achieved)
70 % polarization; 100hrs/week at store

“Enhanced RHIC Task Force”
Need 10 weeks pp / year to reach goal!

250 x 250 GeV: Start physics in 2009
Machine development in 2007 and 2008
Goal: \( <L> = 150 \times 10^{30} \, \text{cm}^{-2} \text{s}^{-1} \)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>No of bunches</td>
<td>...</td>
<td>55</td>
<td>55</td>
<td>56</td>
<td>106</td>
<td>111</td>
<td>111</td>
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<tr>
<td>Ions/bunch, initial</td>
<td>(10^{11})</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.9</td>
<td>1.3</td>
<td>1.8</td>
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<td>Average beam current/ring</td>
<td>mA</td>
<td>48</td>
<td>48</td>
<td>52</td>
<td>119</td>
<td>187</td>
<td>243</td>
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<tr>
<td>(\beta^*)</td>
<td>m</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td>Peak luminosity</td>
<td>(10^{30} , \text{cm}^{-2} \text{s}^{-1})</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>35</td>
<td>61</td>
</tr>
<tr>
<td>Average store luminosity</td>
<td>(10^{30} , \text{cm}^{-2} \text{s}^{-1})</td>
<td>1.5</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>20</td>
<td>41</td>
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<tr>
<td>Time in store</td>
<td>%</td>
<td>30</td>
<td>41</td>
<td>41</td>
<td>56</td>
<td>49</td>
<td>58</td>
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<tr>
<td>Maximum luminosity/week</td>
<td>pb(^{-1})</td>
<td>0.2</td>
<td>0.6</td>
<td>0.9</td>
<td>1.9</td>
<td>7.0</td>
<td>14.3</td>
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<tr>
<td>Minimum luminosity/week</td>
<td>pb(^{-1})</td>
<td>7.0</td>
<td>7.0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Maximum integrated luminosity</td>
<td>pb(^{-1})</td>
<td>0.5</td>
<td>1.6</td>
<td>3</td>
<td>13</td>
<td>45</td>
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<td>Minimum integrated luminosity</td>
<td>pb(^{-1})</td>
<td>63</td>
<td>63</td>
<td></td>
<td></td>
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<tr>
<td>AGS polarization at extraction</td>
<td>%</td>
<td>35</td>
<td>45</td>
<td>50</td>
<td>55</td>
<td>65</td>
<td>70</td>
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<tr>
<td>RHIC store polarization, average</td>
<td>%</td>
<td>15</td>
<td>35</td>
<td>46</td>
<td>47</td>
<td>65</td>
<td>65</td>
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<tr>
<td>Maximum LP(^4)/week</td>
<td>nb(^{-1})</td>
<td>0</td>
<td>9</td>
<td>40</td>
<td>90</td>
<td>1250</td>
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<tr>
<td>Minimum LP(^4)/week</td>
<td>nb(^{-1})</td>
<td>1250</td>
<td>1250</td>
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</tbody>
</table>
Luminosity 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 Run-7)
  - triplet errors (locally corrected)
  - electron cloud?
- New working point close to integer?
Luminosity Limit – Dynamic Pressure Rises

• All operational relevant pressure rises can be explained by electron clouds
• Installation of NEG (non-evaporative getter) coated beam pipes dramatically improved beam intensity limit
• Already tested goal intensity of 111 bunches with $2 \times 10^{11}$ proton / bunch
Summary

Very successful Run-6 polarized proton run:

- Luminosity increased 3 times
- New record polarization of 65%
- First polarized beam at 250 GeV; > 45% polarization

Planned for next 2 years:

- Another factor of 3 increase in luminosity
- Increase polarization from 65% to 70%

Start operation at 250 x 250 GeV in 2009