Towards 100% polarization in the Optically-Pumped Polarized Ion Source at RHIC.

Anatoli Zelenski, BNL

• The OPPIS polarization technique.
• Polarization losses in a multi-step spin-transfer process.
• OPPIS performance in 2006-07 Runs.
• Polarized Sources and Targets Workshop PST-2007 at BNL.

PAC 2007, Albuquerque, June 29, 2007
Design goal - 70% Polarization, $L_{\text{max}} = 1.6 \times 10^{32} \text{ s}^{-1}\text{cm}^2$, $50 < \sqrt{s} < 500 \text{ GeV}$
Workshop on high-energy spin physics,
Protvino, IHEP, September, 1983

Yaroslav Derbenev
“Siberian snake” proposal.

Anatoli Zelenski
A new polarized source technique. Equal intensity for polarized and unpolarized proton beams.
Optically-Pumped Polarized H⁻ Ion Source at RHIC.

RHIC OPPIS produces reliably 0.5-1.0 mA (maximum 1.6 mA) polarized H⁻ ion current.

Pulse duration 400 us.
Polarization at 200 MeV P = 85-90 %.

Beam intensity (ion/pulse)

routine operation:

Source - $10^{12}$ H⁻/pulse
Linac (200 MeV) - $5 \cdot 10^{11}$
Booster - $2 \cdot 10^{11}$, 50% - scraping.
AGS - $1.7 \cdot 10^{11}$
RHIC - $1.5 \cdot 10^{11}$ (p/bunch).

A beam intensity greatly exceeds RHIC limit, which allowed strong beam collimation in the Booster, to reduce longitudinal and transverse beam emittances.
500 uA current. At 200 MeV, 85-hole ECR Source for the maximum polarization.

Faraday rotation polarization signal.

12\cdot10^{11} \text{-polarized } H^-/pulse.
Polarized injector, 200 MeV linac and injection lines.

Polarization direction is adjusted vertically in the 750 keV beamline by the solenoidal spin-rotator.

200 MeV linac

200 MeV polarimeter

OPPIS
SPIN-TRANSFER POLARIZATION IN PROTON-Rb COLLISIONS.

Laser-795 nm Optical pumping
\( Rb: NL(Rb) \sim 10^{14} \text{ cm}^{-2} \)

Na-jet ionizer cell:
\( NL(Na) \sim 3 \times 10^{15} \text{ cm}^{-2} \)

Proton source

\( \text{H}^+ \)

\( \text{Rb}^+ \)

Sona transition

Ionizer cell

\( \text{H}^- \)

1.5 kG field

ECR-29 GHz \( \text{H}^+ \) source

Supercconducting solenoid 25 kG

Charge-exchange collisions: \( \sigma \sim 10^{-14} \text{ cm}^2 \)

Electron to proton polarization transfer

Laser beam is a primary source of angular momentum:

10 W (795 nm) \( \rightarrow \) \( 4 \times 10^{19} \) hv/sec \( \rightarrow \) 2 A, \( \text{H}^0 \) equivalent intensity.
1-quartz liner Ø40 mm; 2- ECR-cavity; 3-three-grid multihole proton extraction system; 4- boron-nitride cups; 5-”Kalrez” O-rings. Longitudinal magnetic field distribution for optimal OPPIS operation.
Magnetic field maps for Oxford Instr. and Toshiba solenoids.

**Bz-field component at the solenoid axis.**
Optical pumping of Rb charge-exchange vapor cell.

Optical pumping by $\sigma^+$: $\Delta m_j = 1$
Spontaneous radiation: $\Delta m_j = 0, 1$. 
Sodium-jet ionizer cell.

Transversal vapor flow in the N-jet cell. Reduces sodium vapor losses for 3-4 orders of magnitude, which allow the cell aperture increase up to 3.0 cm.

Reservoir- operational temperature. Tres. $\sim$500 °C.
Nozzle- Tn $\sim$500 °C.
Collector- Na-vapor condensation: Tcoll. $\sim$120 °C
Trap- return line. T $\sim$ 120 – 180 °C.
H⁻ beam acceleration to 35 keV at the exit of Na-jet ionizer cell.

Na-jet cell is isolated and biased to −32 keV. The H⁻ beam is accelerated in a two-stage acceleration system.
## Depolarization factors in the OPPI S.

<table>
<thead>
<tr>
<th>Depol. Factor</th>
<th>Process</th>
<th>Estimate</th>
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<tbody>
<tr>
<td>$P_{Rb}$</td>
<td>Rb polarization</td>
<td>0.98 - 0.99</td>
</tr>
<tr>
<td>$S$</td>
<td>Rb polarization spatial distribution</td>
<td>0.97 - 0.98</td>
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<tr>
<td>$B_{H2}$</td>
<td>Proton neutralization in residual gas.</td>
<td>0.94 - 0.97</td>
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<tr>
<td>$E_{LS}$</td>
<td>Depolarization due to spin-orbital interaction.</td>
<td>0.98 - 0.98</td>
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<tr>
<td>$E_S$</td>
<td>Sona-transition efficiency</td>
<td>0.96 - 0.99</td>
</tr>
<tr>
<td>$E_{ioniz.}$</td>
<td>Incomplete hyperfine interaction breaking in the ionizer magnetic field.</td>
<td>0.95 - 0.98</td>
</tr>
<tr>
<td>$X$</td>
<td>Polarization dilution by molecular hydrogen ions in the ECR source.</td>
<td>1.00 - 1.00</td>
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</table>

Total: $0.82 - 0.90$

$(0.9/0.8)^4 \sim 1.6$
• BNL OPPIS reliably delivered polarized H⁻ ion beam (P= 82-86%) in the 2006 run for the RHIC spin program.

• A beam intensity greatly exceeds RHIC bunch intensity limit, which allowed strong beam collimation in the Booster, to reduce longitudinal and transverse beam emittances.
Polarized beams in RHIC.

1.5-1.7 p/bunch, P ~65-70%

Maximum RHIC bunch intensity ~1.5 $10^{11}$ p/bunch

Polarization -65%

10·$10^{11}$ (maximum $40·10^{11}$) polarized H⁻ /pulse, P =85%

5·$10^{11}$ polarized H⁻ /pulse at 200 MeV, P =85%

2·$10^{11}$ polarized protons /pulse at 2.3 GeV

1.5-1.7 p/bunch, P ~65-70%
Proton polarization vs. Rb vapor thickness.

Rb cell upgrades:
A new vacuum chamber.
A new cooling system.
A new deflecting plates.

A new short Rb cell
Long Rb cell

Proton polarization, %

Rb vapor thickness, $10^{13}$ atoms/cm$^2$
Longitudinal “deflecting” plates.

Optically-pumped Rb vapor cell

-5.0 kV, (pulsed)

Ground

H^+

Rb

H^0

Sona-shield
Polarization measurement in 200 MeV polarimeter.

- 86.7%
- 200 $\mu$A $\times$ 400 $\mu$s pulse at 200 MeV
- $\sim 4.8 \cdot 10^{11}$ H$^+$/pulse
- 86.4%
Polarization measurements in 200 MeV polarimeter.
Polarization transfer from electrons to protons.

ECR-zone

Steel plate

Correction coil

Sona-transition
Bz-field component in the Sona-transition region.

Multiple charge-exchange: \( H^0 \rightarrow H^- \rightarrow H^0 \rightarrow H^- \)
Polarization vs Correction Coil current with a new Sona-shield.
Calculated magnetic field profiles in the Sona transition region.

Correction coil currents correspond to polarization oscillation peaks.
Polarization oscillations vs. Correction Coil current.
Polarization oscillations in the Sona-transition.

Polarization at 200 MeV vs. Correction Coil current.
Correction coil scan.
12 mm collimator
Ionizer -250 A, 1.8 kG
Polarization vs. ionizer solenoid current with the 12mm collimator.

Maximum polarization from the correction coil scans, collim. -12 mm.

- 160 A ↔ 1.16 kG, 81.6% (95.9%)
- 200 A ↔ 1.45 kG, 84.9% (97.0%)
- 250 A ↔ 1.81 kG, 88.1% (98.1%)

23 mm collimator.

- 200 A ↔ 1.45 kG, 82.5% (97.0%)
- 250 A ↔ 1.81 kG, 84.5% (98.1%)

A new ionizer solenoid:

- 250 A ↔ 1.98 kG, 90.0% (98.4%)
## Status: Running

**Reading**

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<th>RIGHT</th>
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<th>CLK+</th>
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**Averaging Interval**

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<th>ALPHA</th>
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<td>5</td>
<td>91.2+/-1.5%</td>
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</table>

- **Left arm events (++, -):** 762.0 - 3.0, 2483.0 - 20.0, 30.48 - 0.12, 99.32 - 0.8
- **Right arm events (+, -):** 3473.0 - 25.0, 863.0 - 1.0, 130.92 - 1.0, 34.52 - 0.04

**Polarization (P, dP):**

- **Right (single) polarization (P, dP):** 0.970867, 0.00857756
- **Left (single) polarization (P, dP):** 0.85541, 0.0207752
- **Polarization (L/R) (P, dP):** 0.856941, 0.000236641

**Ave Pol (last 20 cycles) (P, dP):** 0.992385, 0.178412

**Up polarization:** 0.951075

**Down polarization:** -0.877242
Polarization measurement in AGS, Run 06.

Run 32602 ver 1, \( P = 67.7 \pm 2.5 \), Ave. Int. = \( 1.509 \times 10^{11} \)

\[ \varepsilon_{\text{phys}} = 0.00779 \pm 0.00029 \]

\( \chi^2 / \text{ndf} = 0.66 \)

67.7%
Polarization measurement in AGS at 24 GeV, Run 06.

Run 31282 ver 1, $P = 72.7 \pm 2.5$, Ave. Int. = $0.564 \times 10^{11}$

$\varepsilon_{phys} = 0.00842 \pm 0.00029$

$\chi^2/ndf = 1.16$
Polarization measurements in RHIC at 100 GeV.

Run 7892.102

Pol = 0.680 +/- 0.024

Const = 1.000 +/- 0.000
Amp = 0.017 +/- 0.000
Phi (deg) = 0.5 +/- 2.9
Ch2/NDf = 0.167

Polarization Vector
Ave. A_N = 0.01220
BLUE AREA
X0 = 0.0083 +/- 0.0003
Y0 = -0.0004 +/- 0.0004
BLUE LINES
X1 = 0.000 +/- 0.0004
RED LINES
X2 = 0.0084 +/- 0.0004
GREEN LINES
Y2 = -0.0005 +/- 0.0004
Pink/Black Lines: Cross Asymmetries
OPPI S with the “Fast Atomic Hydrogen Source”

- The ECR source has a comparatively low emission current density and high beam divergence. This limits further current increase and gives rise to inefficient use of the available laser power for optical pumping.

- In pulsed operation, suitable for application at high-energy accelerators and colliders, the ECR source limitations can be overcome by using instead a high brightness proton source outside the magnetic field.

- Atomic hydrogen beam current densities greater than 100 mA/cm² can be obtained at the Na jet ionizer location (about 180 cm from the source) by using a very high brightness fast atomic beam source developed at BINP, Novosibirsk, and tested in experiments at TRIUMF, where more than 10 mA polarized H⁻ and 50 mA proton beam intensity was demonstrated.
The source produced 3 A ! pulsed proton current at 5.0 keV.

\(~20-50 \text{ mA } \text{H}^+ \text{ current. } \text{P}=75-80\%\)
\(~10 \text{ mA} , \quad \text{P} \geq 90\% .\)
\(~300 \text{ mA} \text{ unpolarized } \text{H}^+ \text{ ion current.}\)
He–ionizer cell serves as a proton source in the high magnetic field.
A polarized H- ion current of a 10 mA (peak) was obtained in 1999!
OPPIS with the “Fast Atomic Hydrogen Source”.

• Higher polarization is also expected with the fast atomic beam source due to: a) elimination of neutralization in residual hydrogen; b) better Sona-still transition efficiency for the smaller ~ 1.5 cm diameter beam; c) use of higher ionizer field (up to 3.0 kG), while still keeping the beam emittance below $2.0 \pi \text{ mm·mrad}$, because of the smaller beam – 1.5 cm diameter.

• All these factors combined will further increase polarization in the pulsed OPPIS to:

  over 90% and the source intensity to over 10 mA.

A new superconducting solenoid is required.

• The ECR-source replacement with an atomic hydrogen injector will provide the high intensity beam for polarized RHIC luminosity upgrade and for future eRHIC facilities.
• Date: September 10-14, 2007
• Brookhaven National Laboratory
• Focussed discussions on:
  • Polarized Ion, Electron and He-3 polarized sources.
  • Polarized internal targets.
  • Polarimetry.
• Invited speakers. Round – table discussions.
• Posters on status and summary talks.
• One day – lectures for students and BNL staff at BNL.
• Expected number of participants ~80 (~20 students).
• Publication in AIP Proceedings.
OPPI S upgrade with the atomic H injector.

- Atomic H injector produces an order of magnitude higher brightness beams than ECR proton source.

- A 5-10 mA H+ ion current can be easily obtained with the smaller, about 12 mm in diameter beam. This reduces most of possible polarization losses and produce smaller emittance polarized beam.

- Neutralization in the residual gas is much smaller too.

- All these factors combined will increase polarization to over 90%.

Major purchase will be a new superconducting solenoid ~$150 k.