Measuring Polarization of Proton Beams at RHIC

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for the RHIC Spin Group

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Physics Objectives and Facilities

- Two operational detectors STAR and PHENIX
- Measure transverse and longitudinal spin asymmetries
- Understand gluon polarization in the proton spin structure

\[
\frac{1}{2} = \frac{1}{2} \Delta \Sigma + L_z + \Delta g
\]

\( \Delta \Sigma \sim 15\% \) – quark contribution
\( \Delta g = ? \) – gluon contribution
\( L_z = ? \) – orbital motion

- Study quark-gluon plasma

- Relativistic Heavy Ion Collider (RHIC) operational since 2000
- Provides polarized proton beams
- Wide range of energies 24 GeV to 250 GeV
- Also unpolarized heavy ion beams 
  Au-Au, d-Au, Cu-Cu

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RHIC and AGS Polarimeters

- Hydrogen jet (H-jet) polarimeter provides absolute polarization
- Four p-Carbon polarimeters provide:
  - Beam polarization profile
  - Polarization decay in store
  - Bunch and store polarization for the experiments

Polarimeter at Alternatig Gradient Synchrotron (AGS) is similar to RHIC p-Carbon polarimeter

PHENIX and STAR local polarimeters monitor spin direction at collision points
Measuring Beam Polarization

- The kinematics of elastic scattering is fully defined by the recoil products
- The momentum transfer \( t = (p_{\text{in}} - p_{\text{out}})^2 = -2ME_{\text{kin}} \)

Analyzing power \( A_N \) is defined by the interference between the electromagnetic and strong amplitudes

- In the experiment we measure asymmetry \( \varepsilon \)

\[
\varepsilon = \frac{N_L - N_R}{N_L + N_R}, \quad \varepsilon = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}
\]

- Measured polarization \( P = \varepsilon / A_N(t) \), where \( A_N(t) \) is the analyzing power

Model predictions

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The polarized jet target is vertical.

Target polarization cycles $\uparrow / - / \downarrow$ every 500/50/500 seconds.
Hydrogen Jet Polarimeter: Kinematics

- Both beams separated by $\sim 4$ mm intersect the hydrogen jet target
- The beam and the target are both protons:

$$P_{\text{beam}} = -\frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{target}}} \times P_{\text{target}}$$

- $P_{\text{target}}$ is measured by a Breit-Rabi polarimeter
- After correction for molecular contamination in the jet

$$P_{\text{target}} \approx 92 \pm 2\%$$

- Elastic events are easily identified from non-relativistic equation

$$t_{\text{ToF}} = L \sqrt{\frac{m_p}{2E_{\text{kin}}}}$$

and recoil angle $\Theta$

- Asymmetry $\varepsilon = \frac{N_L - N_R}{N_L + N_R}$
- Two polarimeters in each ring
- The readout system is multiplexed between the two pairs
- Each polarimeter employs six vertical and six horizontal ultra thin carbon targets
• Typical target size is $2.5\text{cm} \times 5\mu\text{m} \times 30\text{nm}$

• Targets are made by vacuum evaporation-condensation onto glass substrate

• Two stepping motors are used to move the assembly and to rotate the targets into the beam
• Detectors calibrated with $\alpha$ source ($^{241}\text{Am}$, 5.5 MeV)
• The $\alpha$ signal is attenuated by 5 to fit the carbon dynamic range
• The $\alpha$'s do not probe the surface of the detector where the carbon ions stop
Unaccounted energy losses ⇒ “effective dead-layer”
Calibration parameters the **time offset** $t_0$ and the **effective dead layer thickness** $x_{DL}$ extracted from the non-relativistic equation:

$$E_{meas} + E_{loss} = \frac{MC}{2} \times \frac{L^2}{(t_{meas} + t_0)^2},$$

where $E_{loss} = E_{loss}(E_{meas}, x_{DL})$ is an energy loss parameterization for carbon
p-Carbon Polarimeters: Monitoring Stability

- Detector stability is monitored by looking at how parameters evolve in time
- Non-statistical fluctuations can be associated with machine development

- Based on the reconstructed kinematics we measure beam polarization
In 2010 the system was upgraded to address the rate problems
- Faster current sensitive preamplifiers replaced charge sensitive ones
- The effective signal width decreased from few 10's ns to \( \sim 10 \) ns
Solving Problems: $t_0$ Time Offset

- To monitor the time offset $t_0$ additional scintillators were installed.
- The PMT gain is adjusted to match prompt MIPs.

Final conclusion is to be made on the benefits for the future use.
• Precise target position is not necessary if the beam is assumed to have a gaussian profile

\[ I(x) = I_{\text{max}} e^{-\frac{x^2}{2\sigma_I^2}}, \quad P(x) = P_{\text{max}} e^{-\frac{x^2}{2\sigma_P^2}} \]

\( x \) can be either time or distance

• The intensity and polarization can be related as

\[ \frac{P}{P_{\text{max}}} = \left( \frac{I}{I_{\text{max}}} \right)^r \quad \text{with} \quad r = \frac{\sigma_I^2}{\sigma_P^2} \]
• Special ramp-up/ramp-down study confirmed the widening of the polarization profile
• Note: The “400 GeV” point corresponds to actual energy of 100 GeV after a ramp-down from 250 GeV
# Overview of RHIC Polarimeters

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<thead>
<tr>
<th></th>
<th>H-jet Polarimeter</th>
<th>p-Carbon Polarimeters</th>
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</thead>
<tbody>
<tr>
<td><strong>Target</strong></td>
<td>Polarized atomic hydrogen gas jet target</td>
<td>Ultra thin carbon ribbon</td>
</tr>
<tr>
<td><strong>Calibration</strong></td>
<td>Self-calibrating due to known target polarization</td>
<td>Normalized to H-jet due to lack of direct energy scale calibration</td>
</tr>
<tr>
<td><strong>Event Rate</strong></td>
<td>$\sim 20$ Hz</td>
<td>$\sim 2$ MHz</td>
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<tr>
<td></td>
<td>Stat. uncertainty $\sim 8%$ in 6–8 hour fill</td>
<td>Stat. uncertainty $\sim 2%$ per measurement</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td>Continuous throughout a store</td>
<td>Few minutes every few hours</td>
</tr>
<tr>
<td><strong>Role</strong></td>
<td>• Average beam polarization</td>
<td>• Fast online feedback</td>
</tr>
<tr>
<td></td>
<td>• Calibration for other polarimeters</td>
<td>• Beam profile</td>
</tr>
<tr>
<td></td>
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<td>• Bunch by bunch polarization</td>
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<td></td>
<td>• Store by store polarization for the experiments</td>
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Summary

- *pp* elastic scattering in CNI region is well suited for polarimetry in wide beam energy range
- RHIC polarimeters are non-destructive, unique, and complement each other
- Upgrade for Run 2011 eliminated some problems
  - The benefit from the prompt monitors is under investigation
- Polarimeters provide feedback for the accelerator team:
  - Beam emittance
  - Horizontal and vertical beam polarization profiles
  - Polarization loss in transfer
  - Beam polarization decay
- Currently all polarization measurements rely on the H-jet polarimeter
  - Desired redundancy in polarization measurement can be achieved if p-Carbon polarimeters are calibrated by other means
- An ongoing effort aims to better understand the systematic effects in polarization measurements
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