RHIC Polarimetry

A. Bazilevsky
For the RHIC Polarimetry Group

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RHIC and Polarimetry

Absolute Polarimeter (H jet)

RHIC pC Polarimeters

Siberian Snakes

Rotators

Solenoid Snake

AC Dipole

Cold Snake

LINAC BOOSTER

RHIC pC Polarimeters

BRAHMS & PP2PP (p)

AGS pC CNI Polarimeter

Warm Snake

Siberian Snakes

Cold Snake

Warm Snake
Polarization Measurements

H-Jet
Absolute polarization

p-Carbon
Polarization profile
Polarization vs time in a fill
Bunch-by-bunch polarizations
Fill-by-fill polarizations

Local Polarimeters
Monitor spin direction at collision regions
(Confirmation of long. polarization)
Capable to monitor polarization decay vs time in a fill and bunch-by-bunch polarization
HJet

Left-right asymmetry in elastic scattering:
Interference between electromagnetic and hadronic amplitudes in the Coulomb-Nuclear Interference (CNI) region

Beam and target are both protons

\[ A_N(t) = \frac{\mathcal{E}_{\text{target}}}{P_{\text{target}}} = \frac{\mathcal{E}_{\text{beam}}}{P_{\text{beam}}} \]

\[ P_{\text{beam}} = -P_{\text{target}} \frac{\mathcal{E}_{\text{beam}}}{\mathcal{E}_{\text{target}}} \]

\[ A_N \approx \text{Im} \left( \phi_{\text{em}}^* \phi_{\text{had}} + \phi_{\text{had}}^* \phi_{\text{em}} \right) / \left| \phi_{\text{had}} \right|^2 \]

RHIC proton beam

H-jet target

Forward scattered proton

Recoil proton

\[ t = (p_{\text{out}} - p_{\text{in}})^2 < 0 \]

\[ \Delta P_{\text{beam}} / P_{\text{beam}} \approx \Delta P_{\text{target}} / P_{\text{target}} \oplus \Delta \mathcal{E}_{\text{target}} / \mathcal{E}_{\text{target}} \oplus \Delta \mathcal{E}_{\text{beam}} / \mathcal{E}_{\text{beam}} < 5\% \]

\( P_{\text{target}} \) is provided by Breit Rabi Polarimeter
\[ H = p^{+} + e^{-} \]

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Hyper fine structure

Separating Magnet (Sextuples)

RF transitions (WFT or SFT)

H\textsubscript{2} desociater

Holding magnet

Separating magnet

Ion gauge

P\textsuperscript{+} OR P\textsuperscript{−}

\[ A \]

Atomic Beam Source

Scattering chamber

Breit-Rabi Polarimeter

2nd RF-transitions for calibration

HJet target system
HJet: $P_{\text{target}}$

Source of normalization for polarization measurements at RHIC

Nuclear polarization of the atoms measured by BRP: $95.8\% \pm 0.1\%$

Correct for H$_2$, H$_2$O contamination.

$P_{\text{target}} = 92.4\% \pm 1.8\%$

Polarization cycle
$ (+/ 0/ - ) = (500/50/500) \text{ seconds}$

Very stable for entire run period!
HJet: Identification of Elastic Events

Array of Si detectors measures $T_R$ & ToF of recoil proton. Channel # corresponds to recoil angle $\theta_R$. Correlations ($T_R$ & ToF ) and ($T_R$ & $\theta_R$) $\rightarrow$ the elastic process.
HJet:
Example from Run6

\[
\frac{P_{\text{beam}}}{P_{\text{target}}} = \frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{target}}}
\]

Measures average over beam profile polarization with fill-by-fill stat. uncertainty ~10%

Data accumulated for a few fills provide normalization for pC polarimeter with uncertainty <5%
HJet

Agreement within stat. errors
HJet performance is very stable through the Years
Background is small and doesn’t change from Year to Year, for
Blue and Yellow (within 2-3%)

⇒ Beam polarization is measured reliably by HJet
Hjet: Two Beam Mode

Successfully tested in Run8

- Background level is the same as in single beam mode
- Will allow to monitor both beam polarizations by HJet simultaneously in all fills
HJet: $A_N$ in pp

$$A_N^{pp} = \frac{E_{\text{target}}}{P_{\text{target}}}$$

$$A_N \approx \text{Im} \left( \phi_{SF}^{em} \phi_{NF}^{had} + \phi_{SF}^{had} \phi_{NF}^{em} \right) / \left| \phi_{NF}^{had} \right|^2$$

100 GeV: calculations with no hadronic spin flip amplitude contribution are consistent with data

24 GeV: calculations with no hadronic spin flip amplitude contribution are not consistent with data

$A_N$ almost constant vs beam energy $\rightarrow$
Reliable polarimetry in wide range of beam energies

More data to come:
24 GeV: take more data in Run9/10
31 GeV: finalize analysis of data from Run6
250 GeV: take data in Run9/10
pC:

Left-right asymmetry in elastic scattering: Interference between electromagnetic and hadronic amplitudes in the Coulomb-Nuclear Interference (CNI) region

\[ P_{\text{beam}} = \frac{-\varepsilon_N}{A_N^{PC}} \]

\[ \varepsilon_N = \frac{N_L - N_R}{N_L + N_R} \]

Ultra thin Carbon ribbon Target (5 µg/cm²)

Si strip detectors (TOF, E_c)
$A_N \approx C_1 \phi_{\text{flip}}^{em} \phi_{\text{non-flip}}^{had} + C_2 \phi_{\text{non-flip}}^{em} \phi_{\text{flip}}^{had}$

$pC$: $A_N$

Elastic scattering: interference between electromagnetic and hadronic amplitudes in the Coulomb-Nuclear Interference (CNI) region

$E_{beam} = 21.7$ GeV

unpublished

$E_{beam} = 100$ GeV
pC: goals/strategy

Polarization measurements for experiments

**Target Scan mode**
Provides polarization at beam center, polarization profile, average polarization over profile

20-30 sec per measurement
For stat. precision 2-3%

4-5 measurements per fill, per ring
Controls polarization decay vs time in a fill

Polarization profile, both vertical and horizontal

Normalized to HJet measurements over many fills
Knowledge on polarization profile in one transverse direction is required

**Fill-by-fill polarization**
Knowledge on polarization profile in both transverse directions is required

Feedback for accelerator experts

Beam emittance measurements, bunch-by-bunch
Polarization
Polarization profile, both vertical and horizontal
Polarization at injection (and polarization loss in transfer)
Polarization on the ramp (and polarization loss during ramp)
pC: polarization in a fill

Example from Run6

Some fills may show polarization decay vs time
Run6: average polarization drop during a fill 0.3-0.4% per hour
pC: Polarization Profile

Examples of pC measurements in Run5

Beam polarization profile is different for different beams, different fills ⇒ Correction for **average polarization** depends on beam/fill
Average Polarization

\[
\langle P \rangle = \frac{\int P(x, y)I(x, y)dx\,dy}{\int I(x, y)dx\,dy}
\]

\[
\langle P \rangle = \frac{\int P(x_0, y)I(x_0, y)dy}{\int I(x_0, y)dy}
\]

\[
\langle P \rangle = \frac{\int P(x, y)I_1(x, y)I_2(x, y)dx\,dy}{\int I_1(x, y)I_2(x, y)dx\,dy}
\]

\(P(x,y)\) – polarization profile, \(I(x,y)\) – intensity profile
# Average Polarization

\[
P(x) = P_{\text{max}} \cdot \exp\left(-\frac{x^2}{2\sigma_p^2}\right) \quad I(x) = I_{\text{max}} \cdot \exp\left(-\frac{x^2}{2\sigma_I^2}\right) \quad R = \frac{\sigma_I^2}{\sigma_p^2}
\]

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<th>Equation</th>
<th>Explanation</th>
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<td>H-Jet</td>
<td>[ \langle P \rangle = \frac{\int P(x, y)I(x, y)dx}{\int I(x, y)dx,dy} = \frac{P_{\text{max}}}{\sqrt{1 + R_X}} ]</td>
<td>If target positioned at beam peak intensity/polarization</td>
</tr>
<tr>
<td>pC</td>
<td>[ \langle P \rangle = P_{\text{max}} ]</td>
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<td>Collider Experiment</td>
<td>[ \langle P \rangle = \frac{\int P(x, y)I_1(x, y)I_2(x, y)dx,dy}{\int I_1(x, y)I_2(x, y)dx,dy} \approx \frac{P_{\text{max}}}{\sqrt{1 + \frac{1}{2}R_Y}} ]</td>
<td>If ( \sigma_{i1} = \sigma_{i2} = \sigma_i )</td>
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Corrections due to polarization profiles are different when normalizing pC to H-Jet and when propagating pC measurements to experiments. Polarization profile in both trans. directions (X,Y) required.
pC: Polarization Profile

Scan C target over the beam cross:

1. Directly measure $\sigma_I$ and $\sigma_P$:
   \[ R = \frac{\sigma_I^2}{\sigma_P^2} \]

2. Obtain $R$ directly from the $P(I)$ fit:
   \[
   \begin{cases}
   P(x) = P_{\text{max}} \cdot \exp\left(-\frac{x^2}{2\sigma_P^2}\right) \\
   I(x) = I_{\text{max}} \cdot \exp\left(-\frac{x^2}{2\sigma_I^2}\right)
   \end{cases}
   \]
   \[
   P = P_{\text{max}} \cdot \left(\frac{I}{I_{\text{max}}}\right)^R
   \]

Precise target positioning is NOT necessary
pC: Polarization Profile

\[ P = P_{\text{max}} \cdot \left( \frac{I}{I_{\text{max}}} \right)^R \]

Run6 data: R vs fill

\[ R(L) \text{ in one fill} \]

\[ R = 0.29 \pm 0.07 \]

\[ R \sim 0.1–0.3 \Rightarrow 5–15\% \text{ different polarization seen by HJet and by experiments} \]
pC: Polarization vs Fill

Run6 results

Normalized to Hjet
Corrected for polarization profile

\[
\frac{\delta P_B}{P_B} = 4.7\% \\
\frac{\delta P_Y}{P_Y} = 4.8\% \\
\frac{\delta (P_B P_Y)}{P_B P_Y} = 8.3\%
\]
Hjet+pC: Run8 Analysis

Fast (~online) analysis – during the run

Expected $A_N$ from RUN4

$A_N = \epsilon_{\text{TARGET}} / 0.924$

$\epsilon_{\text{target}}$ and $\epsilon_{\text{beam}}$ from HJet

Beam polarization from HJet

$pC$ vs fill

$pC$: Polarization vs fill normalized, profile corrected

Offline analysis is almost completed and results will be released soon
pC: Upgrade

Detector upgrade
  • Photo-diode instead of Si strips

Target upgrade
  • Possibility of using nano-tubes under investigation

pC vacuum chamber upgrade
  • Two polarimeter setups per ring
  • Double number of targets (to avoid a need to open chamber to install new targets during the run)
  • Reduce the time required for successive measurements of horiz. and vert. profiles
  • Allows installation and testing new detectors for higher rate capabilities
PHENIX Local Polarimeter

Utilizes spin dependence of very forward neutron production (PLB650, 325):

ZDC (energy) + SMD (position)
PHENIX Local Polarimeter

Asymmetry vs $\phi$

Spin Rotators OFF
Vertical polarization

Spin Rotators ON
Current Reversed
Radial polarization

Spin Rotators ON
Correct Current !
Longitudinal polarization!

Monitors spin direction in PHENIX collision region
STAR Local Polarimeter

Utilizes spin dependence of hadron production at high $x_F$:

$3.3 < |\eta| < 5.0$ (small tiles only)

Monitors spin direction in STAR collision region
Capable to precisely monitor polarization vs time in a fill, and bunch-by-bunch
Summary

RHIC Polarimetry consists of several independent subsystems

**Hjet:**
- Absolute polarization measurements
- Absolute normalization for other RHIC Polarimeters

**pC:**
- Separate for blue and yellow beams
- Normalization from HJet
- Polarization vs time in a fill
- Polarization profile
- Fill-by-fill polarizations for experiments

**PHENIX and STAR Local Polarimeters:**
- Monitor spin direction (through trans. spin component) at collision
- Polarization vs time in a fill (for trans. pol. beams)
- Polarization vs bunch (for trans. pol. beams)

Reliably provides RHIC beam polarizations
- With relative uncertainty better than 5%

Continuously developing
- Detector and target system upgrade to deal with high beam intensities, and to improve efficiency and reliability
RHIC CNI Polarimetry Group: a factory of CNI Polarimetry experts

Each Run (Year) new students/postdocs are involved in the data monitoring and data analysis. They

- Learn
- Contribute
- Leave (to use newly gained expertise in other projects)

A call for new volunteers to work on Run9/10 etc.

- Please come, learn, become an expert, contribute
- New challenges every Run/Year
- Physics is coming out (with more statistics, reduced systematics, different energies)
Backups
H-jet system

- Height: 3.5 m
- Weight: 3000 kg
- Entire system moves along x-axis $-10 \sim +10$ mm to adjust collision point with RHIC beam.