» Proton Polarimetry with the Hydrogen Jet Target at RHIC in Run 2015«

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Polarized Protons in RHIC

AGS
LINAC
BOOSTER
Polarized Source
200 MeV Polarimeter
Strong Snake
RF Dipole
AGS pC Polarimeter
AGS Internal Polarimeter
Hydrogen Jet Polarimeter
PHENIX
STAR
Siberian Snakes
Spin Rotators
Tune Jump Quads
Helical Partial Snake
Spin Flipper
Carbon Polarimeters
RF Dipole
AGS Internal Polarimeter
Polarizer
Improvement in Beam Polarization

Consistent improvement in delivered luminosity and beam polarization.

Beam energies:
up to 255 GeV

Figure of merit for double helicity observables:
\( \sim L \cdot P^4 \)

recent RHIC run 2015
\[ s_z = \pm \frac{1}{2} \hbar \Rightarrow P = \frac{n^\uparrow - n^\downarrow}{n^\uparrow + n^\downarrow} \]

\[ A_N = \frac{d\sigma_{\text{left}} - d\sigma_{\text{right}}}{d\sigma_{\text{left}} + d\sigma_{\text{right}}} \]

\[ \varepsilon = A_N \cdot P = \frac{N_L - N_R}{N_L + N_R} \]

\((*)\) perpendicular to polarization vector
Carbon polarimeters
Two per ring
Fast measurement
$\delta P/P \approx 4\%$
Beam polarization profile
Polarization decay (time dependence)

Hydrogen jet polarimeter
Polarized target
Continuous operation
$\delta P/P \approx 5 - 8\%$ per fill
Elastic Recoil Protons

Recoil proton from elastic scattering
Independent of beam energy, species

Non-relativistic: $T_{kin} = \frac{1}{2}mv^2$

target width: $\sigma_T = 0.3$ cm
bunch length: $\sigma_B = 1.0$ ns

detector thickness

atomic hydrogen target
proton beam
100/250 GeV

Si strip detectors
$\approx$ 75 cm from interaction point

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Independent of beam energy, species

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target width: $\sigma_T = 0.3$ cm
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detector thickness
Detector Setup

Set of eight Hamamatsu Si strip detectors
12 strips, each 3.75 mm wide, 500 μm thick
Uniform dead layer ≈ 1.5 μm
Elastic proton recoil selection:
After energy and $T_0$ calibration
\[ |M_{\text{miss}} - m_p| < 100 \text{ MeV}/c^2 \]
\[ |\Delta t| < 5 \text{ ns} \]

Fit to ALL data, plotted under the distributions in each detector

Si-strips:
red – central to blue – downstream
Detector Alignment

Magnetic holding field for target polarization changes acceptance of detectors on left and right sides

Outer correction field is adjusted for compensation

For missing proton mass:

\[
\sin \theta = \frac{p'}{2 \cdot m_p \cdot p_B} (2 \cdot E + 2 \cdot m_p - T_R)
\]

Compare with geometry of detector (averaged over 12 strips)

p+Au and p+Al operation had a significant beam angle on the jet target

Missing mass:

\[
M_{miss}^2 = \left( E + m_p - E' \right)^2
\]

Non-relativistic recoil:

\[
p' = \sqrt{2m_pT_R}
\]
Asymmetries & Polarization

\[ \varepsilon = A_N \cdot P \]

\[ P_{Beam} = -\frac{\varepsilon_{Beam}}{\varepsilon_{Target}} P_{Target} \]

1. Polarization independent background

\[ \varepsilon = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow} + 2 \cdot N_{bg}} \Rightarrow \frac{\varepsilon_B}{\varepsilon_T} = \frac{N_{B\uparrow} - N_{B\downarrow}}{N_{T\uparrow} - N_{T\downarrow}} \]

2. Polarization dependent background

\[ \varepsilon = \varepsilon_{inc} - r \cdot \varepsilon_{bg} \]

background fraction \( r = \frac{N_{bg}}{N} \)
Abort gaps are not aligned at polarimeter location

Use abort gaps for background and clean signal identification
Δ𝑡: difference of measured time-of-flight to elastic signal, \( t(T_R) \)

\( Δm_{miss} \): difference of missing mass to scattered proton (geometry after alignment correction)

Position of elastic proton signal is independent of energy and detector

Vertical stripes are a remnant of the spatial detector resolution

Punch through cuts are already applied

Define **signal** and **background** regions by missing mass

\[ |M_{miss} - M_p| < 50 \text{ MeV}/c^2 \]

\[ |M_{miss} - M_p| > 120 \text{ MeV}/c^2 \]
Signal & Background III

- inclusive (normalized to peak)
  $$|M_{miss} - m_p| < 50 \text{ MeV}/c^2$$

- background (normalized to signal at $18 < \Delta t < 25$ ns)
  $$|M_{miss} - m_p| > 120 \text{ MeV}/c^2$$

- background fraction
  - Background in yellow abort gap (should be clean blue signal)
  - Signal in blue abort gap (should be only background from yellow beam)

Example (blue beam, $2 < E_{kin} < 3$ MeV)

The normalization is same as above → only for comparison of shape and source of background
Background Sources

Example (blue beam, $3 < E_{kin} < 4$ MeV)

From $p + Au$ operation

Typical bunch shape of Au-beam seen in full background, dominates *early* background

*Late* background mainly from signal beam

Using signal cuts in blue abort gap:

$$|M_{miss} - m_p| < 50 \text{ MeV}/c^2$$

Fill-by-fill background fraction depends on conditions of both beams → important for beam polarization measurement

Background fraction $r = \frac{N_{bg}}{N}$
Asymmetry Examples

From $\vec{p} + Au$ operation

Blue beam (proton on jet target)

Clear asymmetry within $\Delta t = \pm 5$ ns

Background asymmetry consistent with zero
Analyzing Power: $A_N(\vec{p} + p)$

Atomic hydrogen target polarization $P = 96\%$

Molecular component $R_{H_2} = 3\%$ (by mass)

Global uncertainty from target polarization not included

$-t$-range can be extended with punch-through protons
Analyzing Power: $A_N(\vec{p} + A)$

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$-t$-range can be extended with punch-through protons

→ A. Poblaguev
Longitudinal Bunch Profile: $p + p$

- Full run 15 statistics: $p + p$
- $1 < T_R < 7$ MeV
- Comparison of inclusive and clean bunches
- Beam intensity: normalized number of events
- First measurement of longitudinal bunch profile
- No significant longitudinal polarization profile has been found.
Longitudinal Bunch Profile: $p + Au$

- Full run 15 statistics: $p + Au$
- $1 < T_R < 7$ MeV
- Comparison of inclusive and clean bunches
- Beam intensity: normalized number of events
- No significant effect from colliding bunches can be seen.
Final Beam Polarizations

Atomic hydrogen target polarization 96%
$H_2$ content 3% (mass)

Ratio of target/beam asymmetries
$1 < E_{\text{recoil}} < 7$ MeV (six bins)
Fit to constant

Use fixed $A_N$ for $p + p$

Use fill by fill ratio for $p + A$
Luminosity Weighted Polarization

\[ P = \frac{\int P(x, y, t) \cdot I_B(x, y, t) \cdot I_Y(x, y, t) \, dx \, dy \, dt}{\int I_B(x, y, t) \cdot I_Y(x, y, t) \, dx \, dy \, dt} \]

Experiments

HJET Polarimeter

Carbon Polarimeter

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

beam width

Polarization vs. Sigma Units
Polarization Decay & Profile

Example fill 18894

Fill Id

Polar. Decay, \( \frac{dP}{dt}, \%/\text{hour} \)

\( R \)

Polarization, %

Pol. Profile R

Time in Fill, hours

Time in Fill, hours
Summary

- Polarimetry at RHIC
  - Essential input for experiments
  - Fast feedback during collider operation

Fast polarization measurement with Carbon targets
  - Polarization decay and transverse profile

Absolute normalization with polarized hydrogen jet target

- Analyzing power with new detectors in 2015 → improved precision and systematic studies
- New asymmetries from elastic proton-heavy-ion scattering
- Longitudinal polarization profile
- Final beam polarizations are fully background corrected
Elastic Proton-Proton Scattering

\[ \varphi(s, t) = \langle \lambda_C \lambda_D | \varphi | \lambda_A \lambda_B \rangle \]

\[
\varphi_1(s, t) = \left( + \frac{1}{2} + \frac{1}{2} |\varphi| + \frac{1}{2} + \frac{1}{2} \right) \\
\varphi_2(s, t) = \left( + \frac{1}{2} + \frac{1}{2} |\varphi| - \frac{1}{2} - \frac{1}{2} \right) \\
\varphi_3(s, t) = \left( + \frac{1}{2} - \frac{1}{2} |\varphi| + \frac{1}{2} - \frac{1}{2} \right) \\
\varphi_4(s, t) = \left( + \frac{1}{2} - \frac{1}{2} |\varphi| - \frac{1}{2} + \frac{1}{2} \right) \\
\varphi_5(s, t) = \left( + \frac{1}{2} + \frac{1}{2} |\varphi| + \frac{1}{2} - \frac{1}{2} \right)
\]

\[
A_N \ \frac{ds}{dt} = - \frac{4\pi}{s^2} \text{Im} \left[ \varphi_5^{em*}(s, t) \varphi_+^{had}(s, t) + \varphi_5^{had*}(s, t) \varphi_+^{em}(s, t) \right]
\]

no-flip amplitude: \[ \varphi_+ (s, t) = \frac{1}{2} \left[ \varphi_1 (s, t) + \varphi_3 (s, t) \right] \]

Transverse single-spin asymmetries are driven by an interference of amplitudes and can be compared to Regge theory.
- Reconstruction
  - Energy calibration
  - Time of flight adjustment
  - Geometry alignment
  - Pedestal noise QA
- Signal selection
  - Remove punch through hits
  - Missing mass $|M_{miss} - M_p| < 50 \text{ MeV}/c^2$
  - Time of flight $|\Delta t| < 5 \text{ ns}$
- Asymmetry calculation
  - Inclusive and signal bunches
  - Background asymmetry correction
- Beam polarization calculation
  - Asymmetry ratio $1 < E_{recoil} < 7 \text{ MeV}$
Energy Calibration

Calibrations are done every few days:
- Gain
- Entrance window (dead layer)

Two different $\alpha$-sources

\[ E_{\alpha}(Gd) = 3.183 \text{ MeV} \]
\[ E_{\alpha}(Am) = 5.486 \text{ MeV} \]

Resolution of peak finding is within 1 ADC count

Stopping power for protons and $\alpha$-particles from NIST database:

\[ \Delta E_{\alpha(Am)} = 0.72 \cdot \Delta E_{\alpha(Gd)} \]
\[ \Delta E_P = 0.44 \cdot \Delta E_{\alpha(Gd)} \cdot E [\text{MeV}]^{-0.64} \]
Kinematics

12 strips per detector

Removed peak in prompt hits at low ADC/TDC region

Using elastic p-recoil signature for time-of-flight offset determination

- Slow drift with time (detector/read-out)
- Big jumps when changing the DAQ system

example detector

Si-strips: red – central to blue – downstream
Stopped Recoil Protons

Normalized waveform rise ($4.5 < E < 5.5 \text{ MeV}$) in each detector

Slopes $\delta_{ADC}$ calculated in six $TDC$ bins around $\frac{1}{2} ADC_{\text{max}}$

Independent of DAQ system (CAMAC/VME)

Remove punch-through particles:

$$(\delta_{ADC} < -0.5) \land (\delta_{ADC} < 8.5 - 1.5 \times T_{\text{kin}})$$
$\vec{p} + p$, yellow beam
$\vec{p} + Au$, yellow beam
\[ \hat{p} + Au, \text{ blue beam} \]
$\vec{p} + \text{Al}$, yellow beam
$\vec{p} + \text{Al, blue beam}$
Background Normalization (18 < $\Delta t$ < 25 ns)
Background Fraction ($|\Delta t| < 5$ ns)
Beam Polarizations

Online results from 2015, no background correction included

$p+Au$ operation

- **Period 1**: 0.584 +/- 0.007
- **Period 2**: 0.556 +/- 0.004
- **Period 3**: 0.487 +/- 0.004

$p+Al$ operation

- **Period 1**: 0.606 +/- 0.007
- **Period 2**: 0.580 +/- 0.005
- **Period 3**: 0.559 +/- 0.004

**Note**: The data for $p+Al$ operation includes only the first two periods due to a change in experimental conditions.
Noise threshold cut: $0.20$ for $p + p$, $0.15$ for $p + A$

$p + A$ may still have some issues with high background fractions and changing beam conditions.
Summary p+Al

Beam polarizations

Full run 15 statistics, p+Al

Comparison of inclusive and clean bunches
Pedestal Noise

The noise is mainly on one side of the detector (outside).

It changes the waveform quality (slope) for low energies and leads to asymmetric loss of events.

\[ \langle \text{rms}_{\text{ped}}^{\uparrow} \rangle - \langle \text{rms}_{\text{ped}}^{\downarrow} \rangle \]

(*) can use a fit for VME data, but resolution of CAMAC is too small.
Polarization Decay & Profile

The graph shows the decay rate of polarization over time, with data points indicating the rate of change in polarization per hour. The x-axis represents Fill Id, and the y-axis shows the polarization decay rate (%/hour). The data points are scattered across the graph, with error bars indicating the variability in the measurements.