Proton Polarimetry with Carbon Targets
Status, Possibilities, Questions

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\[ \vec{p} + \vec{p} \@ RHIC \]

- Hydrogen Jet Polarimeter
- Carbon Polarimeters
- Siberian Snakes
- Spin Flipper
- Spin Rotators
- Tune Jump Quads
- Helical Partial Snake
- Strong Snake
- RF Dipole
- AGS Internal Polarimeter
- AGS pC Polarimeter
- 200 MeV Polarimeter
- LINAC
- Booster
- PHENIX
- STAR
- Polarized Source
RHIC Performance

- up to 120 bunches
- 106 ns bunch separation
- $\sigma_{x,y} \approx 0.2 - 0.5$ mm
- $> 10^{11}$ protons per bunch
Polarization Measurement

Polarization: \[ P = \frac{n^\uparrow - n^\downarrow}{n^\uparrow + n^\downarrow} \quad s_z = \pm \frac{1}{2} \hbar \]

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

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

**Carbon polarimeters**
- Two per ring
- Fast measurement
  \[ \sigma \approx 4\% \]
- Beam polarization profile

**Hydrogen jet**
- Polarized target
- Continuous operation
  \[ \sigma \approx 5 - 8\% \text{ per fill} \]
Polarization Profile

\[
P_{\text{coll}} = \frac{\int dx dy P(x, y) I_B(x, y) I_Y(x, y)}{\int dx dy I_B(x, y) I_Y(x, y)}
\]

\[
P_{\text{jet}} = \frac{\int dx dy P(x, y) I_B(x, y)}{\int dx dy I_B(x, y)}
\]

\[
P_{\text{sweep}} = \frac{\int dy P(y) I_B(y)}{\int dy I_B(y)}
\]

- Jet target polarization is flat (in beam overlap)
- Vertical and horizontal Carbon targets available

For Gaussian profiles

\[
I = I_{\text{peak}} \cdot e^{-i \vec{r}^2 / \sigma_I^2}
\]

\[
P = P_{\text{peak}} \cdot e^{-i \vec{r}^2 / \sigma_P^2}
\]

Profile parameter \( R = \frac{\sigma_I^2}{\sigma_P^2} \)
Recoil Protons

elastic proton-proton scattering

atomic jet target

proton beam

log scale

signal region

background region
Carbon Polarimeters

Ultra thin Carbon ribbon Target (5 \( \mu g/cm^2 \))

Si strip detectors (TOF, \( E_C \))

vacuum evaporation-condensation onto glass
Recoil Carbon

- Carbon energies are smaller than recoil protons
- Detector geometry doesn’t help with kinematics
- Background is different from protons
- Need to calibrate $E_{\text{meas}}, E_{\text{loss}},$ and $t_0$

\[ E_{\text{kin}} = \frac{1}{2} m_c \left( \frac{d}{t_{\text{flight}}} \right)^2 \]

\[ E_{\text{kin}} = E_{\text{meas}} + E_{\text{loss}} \]

\[ t_{\text{flight}} = t_{\text{meas}} + t_0 \]
Energy Calibration

Two different $\alpha$-sources
$E_\alpha(\text{Gd}) = 3.183$ MeV
$E_\alpha(\text{Am}) = 5.486$ MeV

Routinely done after each fill for p+C polarimeters

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

$\Delta E_\alpha(\text{Am}) = 0.72 \cdot \Delta E_\alpha(\text{Gd})$

$\Delta E_p = 0.44 \cdot \Delta E_\alpha(\text{Gd}) \cdot E [\text{MeV}]^{-0.64}$

$c \cdot A = E_{\text{meas}} = E_{\text{kin}} - \Delta E$

= example strip =

![Diagram showing energy calibration results and stopping power graphs.]
Detector Setup & Targets

- Six targets per polarimeter
- Vertical or horizontal targets (detector position is the same)
- Targets are swept through the proton beam
Target in Beam

- Beam heats up the target to glow
  - Targets graphitize from operation
- Target is electrostatically attracted to the beam
  - Mechanical stress on target, can break → need replacement
  - Material in beam is hard to control
- Induced charge from wake field on target ends
  - Change to insulated ladder construction
Significant polarization profiles are observed

\[ R = \frac{\sigma_I^2}{\sigma_P^2} \approx 0.1 - 0.2 \]

in units of intensity \( \sigma_{x,y} \)
Polarization losses are correlated to:

- acceleration
- emittance
- profile

Provide experiments with:

\[
P = P_0 + \frac{dP}{dt} t
\]

\[
R = R_0 + \frac{dR}{dt} t
\]

Typical values:

\[
\frac{dP}{dt} = -1\%/h
\]

\[
\frac{dR}{dt} = 5\%/h
\]
Fill Pattern

- Raw asymmetry per bunch
- Confirm bunch fill pattern reliably
- Averaged over all measurements in a fill

Example
Fill 17370
Normalization Hjet (2013)

Target $P = 92\%$

Single Fill

Kinematic distributions for consistency checks
Fast feedback to RHIC operations
over 150 RHIC fills in 2013

Beam polarization
Normalization p+C

Normalization is done for different polarimeters:

B2Dn, B1Up, Y1Dn, Y2Up

- Normalization depends on target thickness
- Energy loss in target
Gain Stability

Calibration with Am $\alpha$-source

Correlation with bias current

- Also affects $E_{loss}$ before active detector volume
- Mainly large scatter, no clear time dependence
- Related with “RHIC operation”

Y1D in 2013 detectors 1-6

dedicated calibration study after run 13 operation
Bias Current

\[ I_{bias} \] increases with target operation

several sweeps for profile scan (APEX studies)
Systematic Uncertainties

Scale uncertainty
- Normalization from the hydrogen jet target
- Molecular content in atomic target
- Polarization in-/dependent background

Fill-to-fill uncertainties
- Target properties
- Beam profile and target sway
- Beam related correlations of detector properties

\[ \frac{\sigma_p}{P} \approx 3\% \]
\[ \frac{\sigma_p}{P} \approx 5 - 8\% \]
**Summary / Outlook**

- Polarizations in RHIC are measured from 24 up to 250 GeV
  - fast p+C targets for monitoring, polarization profiles, and polarization decay,
  - a polarized atomic hydrogen jet for normalization

- Polarization measurements are crucial feedback already during beam development.

- The 2013 data provided unprecedented possibilities to study correlations and background.

- Scale uncertainty is dominated by the molecular fraction of the hydrogen jet target

- Proton bunches will be changed by coherent electron cooling

- In e+p collisions, a new local polarimeter will have to replace the ZDC (forward neutron asymmetries)