# PROTON POLARIMETRY AT RHIC *

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The study of *spin effects* in the interactions of polarized protons at RHIC requires the precise measurement of the colliding beams' polarizations. Fast polarization measurements are performed using polarimeters based on $pC$ elastic scattering. The absolute normalization of the polarimeters is based on $pp$ elastic scattering using a polarized hydrogen gas jet target. During the 2004 polarized proton run a relative precision on the beam polarization of $\Delta P_{beam}/P_{beam} = 6.6\%$ has been obtained. A precision around 5% is anticipated for the 2005 and 2006 RHIC runs.

## 1. Methods and Techniques

The nucleon spin structure and dynamics are studied at RHIC in the collisions of polarized proton beams in a variety of processes[1]. A crucial requirement is the knowledge of the absolute polarization of the RHIC proton beams to 5% of its value and its constant monitoring for normalizing the spin asymmetries measured by the RHIC experiments. There are four types of polarimeters:

(1) fast polarimeters in RHIC based on $pC$ elastic scattering giving relative polarization measurements in less than 30 sec.;
(2) an absolute polarimeter in RHIC based on $pp$ elastic scattering using a polarized hydrogen gas jet target;
(3) local polarimeters at the experiments based on *forward* scattering to measure the effects of the spin rotators at the interaction points;
(4) a fast AGS polarimeter based on $pC$ elastic scattering.

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These polarimeters are also used for the accelerator polarization setup and development, and the study of the spin dynamics in RHIC.

The major requirements for a good and efficient polarimeter are a simple and well understood scattering process with a relatively large cross section and known analyzing power $A_N$, thus to provide robust polarization measurements in a relatively short time. The *polarimetric* processes at RHIC are $pC$ and $pp$ elastic scattering in the so called Coulomb-nuclear interference region at very low momentum transfer $t$, where $A_N \simeq$ a few %.

## 2. Proton-Carbon Polarimeters

Fast beam polarimetry at RHIC and AGS is based on $pC$ elastic scattering at very small proton scattering angles. $pC$ elastic scattering events are identified by detecting the slow recoil carbon ions emerging at almost 90° w.r.t. the incident beam direction. The elastic reaction dominates and the measurement of the recoil ions gives predominantly elastic events with very small backgrounds. Typical recoil carbon ion kinetic energies are $T_R \sim 0.4 - 0.9$ MeV. Carbon events are identified and selected on the basis of the $T_R$–ToF information (see Figure 1) coming from a set of silicon detectors.

In this kinematical region the analyzing power for $pC$ elastic scattering $A_N^{pC}$ is small, around 1.2%. For a $\Delta P_{beam}/P_{beam} \simeq 5\%$ measurement it is necessary to collect data samples of the order of $2 \times 10^7$ events per measurement. A single polarization measurement, however, lasts less than 30 sec., since the $pC$ cross section is very large. During the 2004 run a measurement of $A_N^{pC}$ at 100 GeV using the polarized hydrogen gas jet target has been performed to a precision of about 15%[2]. A *calibration* of $A_N^{pC}$ to 7–8% is expected from the data collected in 2005 and 2006.

The slow recoil carbon nuclei are detected with six silicon detectors installed inside the accelerator beam pipe at about 18 cm from the carbon target. The detectors' strips are oriented along the beam direction. Each strip covers the same polar angle and detects the same physical process in the same kinematical region but at a different azimuthal angle, and it can be viewed as an independent polarimeter. The consistency of the strip by strip asymmetries in Figure 1 proofs the robustness of the polarization measurement. The measurements are performed by sweeping an ultra thin carbon ribbon target of 3–5 $\mu$g/cm$^2$ and less than 10 $\mu$m wide through the beam. A vertical target is typically used.

The largest systematical uncertainties on $P_{beam}$ come from the absolute polarimeter calibration ($A_N^{pC}$), and the absolute energy of the recoil carbon

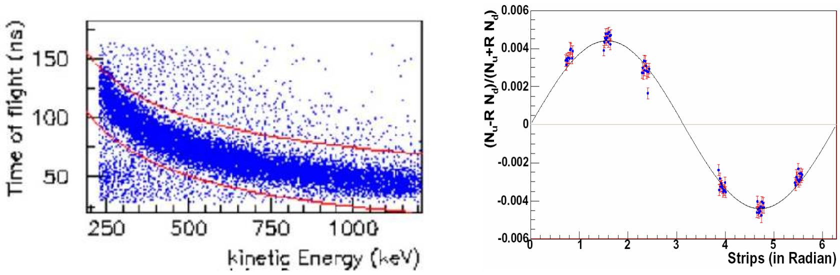


Figure 1. Left: ToF vs. $T_R$ for detected carbon ions. Polarimeter channel by channel asymmetry fitted with a sinus curve.

ions, which are not completely independent. The difficulty resides in the fact that only a fraction of the recoil carbon energy is observed, part of it being deposited in the entrance window of the detector, and part being lost due to charge collection efficiencies. Other uncertainties from the event selection criteria, backgrounds, beam polarization profiles, etc. are small compared to these ones. Typical errors associated with each individual *pC* polarimeter measurement are around 15% of the measured $P_{beam}$ value. This uncertainty is reduced by a large factor (almost 3) by continously cross calibrating the *pC* polarimeters with the absolute gas jet target polarimeter.

## 3. The Polarized Gas JET Target

An absolute polarimeter, based on *pp* elastic scattering in the CNI region, using a polarized hydrogen gas jet target, has been installed in 2004. This polarimeter provides the continuous calibration of the fast *pC* polarimeters. The identical spin-1/2 particle symmetry in *pp* elastic scattering allows for the direct transfer of $P_{target}$ to $P_{beam}$:

$$P_{beam} = P_{target} \times \frac{\varepsilon_{beam}}{\varepsilon_{target}} \quad ,$$

where $\varepsilon_{beam}$, $\varepsilon_{target}$ are the *left - right pp* scattering asymmetries obtained by averaging over the target polarization and beam polarization directions, respectively (see Figure 2). This procedure is also known as the *self-calibration* method, and is independent of theoretical assumptions. The same events from the same data set, but with different spin sorting, are used for evaluating $\varepsilon_{beam}$ and $\varepsilon_{target}$. That significantly suppresses most of systematical uncertainties in the asymmetry ratio $\varepsilon_{beam}/\varepsilon_{target}$ and in the extraction of $P_{beam}$.

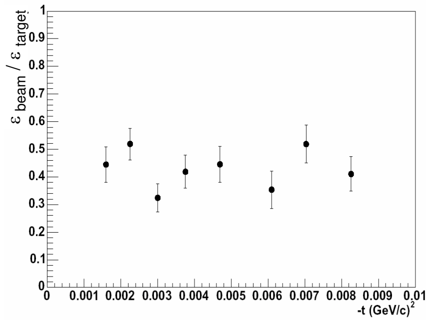


Figure 2. $\varepsilon_{beam}/\varepsilon_{target}$ as a function of $t$.

As for $pC$ scattering in the CNI region, the scattered beam protons were not detected. In this kinematical region the elastic process is fully constrained by the recoil particle only, thus the detection of the scattered beam proton is not mandatory. The recoil protons were detected using an array of large area silicon detectors inside recoil arms located to the right and left of the jet target axis. Recoil protons were identified on the basis of the $T_R$–ToF relation. Elastic scattering events were selected on the basis of the $\vartheta_R$–$T_R$ relation, where $\vartheta_R$ is the recoil polar angle. The observed background in the selected $pp$ elastic scattering sample was less than 5%.

The polarized hydrogen gas jet target[3] crossed the RHIC beams from above with its polarization directed vertically. The target is located at one of the RHIC interaction regions. The circulating proton beams were displaced so that only one beam interacted with the target, typically alternating between beams one to two times per week. The target polarization is $0.924 \pm 0.018$ (the dilution from molecular hydrogen is included in this figure) with a density in excess of $10^{12}$ $p/\text{cm}^2$ in its center, and a FWHM profile of less than 6 mm.

During the 2004 polarized $pp$ run $\Delta P_{beam}/P_{beam}$ has been measured to 6.6%. This measurement was statistically limited. The systematic error comes mainly from backgrounds in the selected $pp$ elastic sample and was around 4%. In 2005 and 2006 a much larger data sample has been collected and a relative precision on $P_{beam}$ better than 5% is expected.

## References

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