RHIC pC CNI Polarimeter: Status and Performance from the First Collider Run

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Polarimeters using the proton carbon elastic scattering process in the Coulomb Nuclear Interference (CNI) region were installed in two RHIC rings. Polarization measurements were successfully carried out with the high energy polarized proton beams during the first polarized pp collision run. The physics principles, performance, and the general status of the polarimeters are presented.

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1 Introduction

Colliding high energy polarized protons with high luminosity beams will provide a new access to understand the spin structure of the proton. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) started its operation for the first polarized pp collisions in December, 2001. The RHIC accelerator complex consists of two 3.9 km rings with six interaction points (IP). Two large detectors, STAR and PHENIX reside at six and eight o'clock IP respectively with both longitudinal and transverse polarization. Using the transverse polarization, pp2pp and BRAHMS detectors are located at the 2 o'clock IP while the PHOBOS detector is at 10 o'clock. The polarized protons originate from an intense polarized

H^- source [1], are accelerated through the LINAC, the BOOSTER synchrotron and Alternating Gradient Synchrotron (AGS) ring, and transfered to RHIC with injection energy 24.3 GeV. De-polarization resonances during the acceleration from RHIC injection (24.3 GeV) to a flat top energy (100 GeV) are overcome with two sets of helical dipole magnets called 'Siberian Snakes' [2] installed at ten and four o'clock positions in each RHIC ring. The vertical polarization, which is the stable spin direction for two Siberian Snakes per ring, is maintained during the beam storage at flat top owing to this new technique. The two polarimeters are installed in straight section in the 12 o'clock region for both Blue and Yellow rings and measure vertical and radial beam polarization.

The polarimeters serve as both fast monitors of the beam polarization for the accelerator, and as the primary polarimeters for the normalization of the physics asymmetries for the experiments. Measurements to 10% relative error were made within a few minutes for the 2001/2 run. The beam in each ring was in 55 bunches with alternating polarization sign, $\sim 8 \times 10^{10}$ protons per bunch. Measurements were made at injection (24.3 GeV) and every two hours at the collision energy of 100 GeV. In addition to the fast operation, the obtained information must be broadcast to experiments immediately after the measurements.

Using pC elastic scattering in the Coulomb Nuclear Interference (CNI) region, our polarimeters observe the left-right asymmetries originating from the anomalous magnetic moment of the proton. The analyzing power, A_N, is proportional to the interference term between the electromagnetic spin flip term, $\phi_s^{em}(t)$, and the hadronic spin non-flip term, ϕ_o^h; the terms, $\phi_s^{em}(t)$, and ϕ_o^h are related to the anomalous magnetic moment of the proton and the total cross section of the process respectively. Predicted analyzing power is expected to be a maximum in the CNI region where the momentum transfer squared, $-t$, ranges from 0.001 (GeV/c)^2 to 0.01 (GeV/c)^2. The beam energy dependence of A_N is expected to be small for the RHIC energy range. An experiment [3] was performed to measure the analyzing power of pC CNI process in the AGS ring with the beam energy of 21.6 GeV which is close to the RHIC injection energy. The analyzing power is small, of order 2%. However, due to the large cross section of the process, the figure of merit σA^2 is large.

To identify pC elastic in the CNI region, where the forward proton scatters to a very small angle, our polarimeters detect the recoil carbons, scattered to near 90 degrees, with Si strip detectors (SSD). Observation of only the recoil carbon offers several advantages: the carbon ions arrive at the detectors much later than prompt backgrounds, the relationship between the observed energy and time of flight identifies the recoil as carbon; the recoil kinematics is largely independent of the beam energy so that the polarimeter can be used over the entire RHIC energy range.

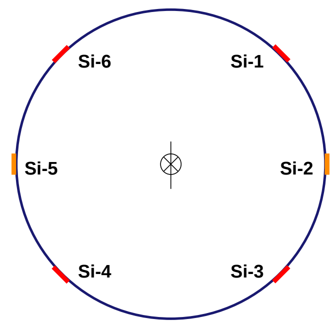

Fig. 1. The schematic geometry layout of the silicon detectors.

2 Experimental Setup

Our polarimeters consist of a carbon target and six silicon strip detectors with a schematic shown in Fig. 1. Very thin carbon ribbon targets have been developed at IUCF [5]. Typically the target size is 2.5 cm length with 3.5-$\mu g/cm^2$ thick (150 Å) and 5-μm width. The ultra thin target is indispensable in order to allow the low energy recoil carbons to get out of the target. The targets can be rotated into the beam, with a choice of 3 vertical and 3 horizontal targets. Each detector consists of twelve 12 mm $\times$ 2 mm silicon strips, 24 mm width in total. The six detectors are mounted inside of the vacuum chamber with readout pre-amplifier boards directly attached to the chamber detector ports through vacuum feed-through connectors. Figure 2 shows a scatter plot of time of flight versus energy for one silicon strip in the polarimeter. The silicon detectors are 15 cm from the target, and the RHIC bunch length was about 3 ns for this run, which is from the commissioning run in 2000 [4]. The inset in the figure shows the mass distribution derived from velocity and energy (note that the TOF in the figure includes an offset of 40 ns). The carbon and α peaks are clear, with little background under the carbon peak.

The beam polarization is measured by counting the number of events in the carbon band in each strip versus the azimuthal angle of the strip around the beam (Fig. 1). A vertical polarization generates a left-right asymmetry in the detectors and a radial polarization generates an up-down asymmetry.

The rates are very high, so we chose a readout system without dead time based on wave form digitizers (WFDs) [6]. The WFDs consist of a high frequency video ADC chip (used for laptop screens) and a Xilinx FPGA. The waveform from each strip was digitized every 2.4 ns, and pulse height and time of flight, compared to the RHIC rf clock, was determined in real time, and compared to a look up table which accepted the carbon band (as in Fig. 2). On-board scalers kept the number of events for each strip, and for each beam bunch. The 55 beam bunches of polarized protons in RHIC for the 2001/2 run, spaced 212 ns apart, alternated in polarization

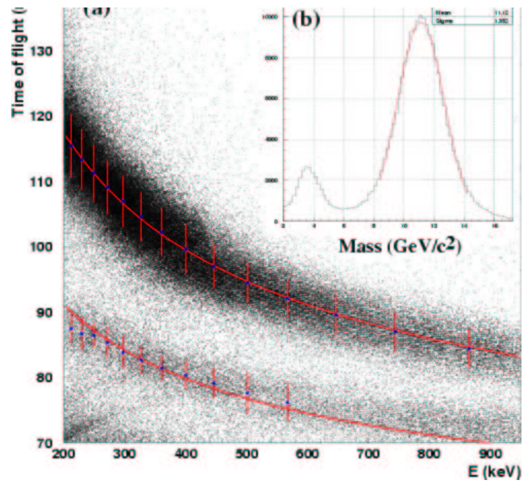

Fig. 2. (a) The time of flight is plotted as a function of kinematic energy of the detected particle. (b) Sub-figure shows the projected mass distribution. A Carbon mass peak (11.18 GeV/c^2) is clearly separated from an alpha mass peak (3.7 GeV/c^2).

sign. Therefore, the on-board scalers collected data for both signs, and for bunches set up with zero polarization, for each strip. The WFDs were introduced for the 2001/2 run and 48 strips were read out, 8 for each detector (Fig. 1). Also, the orientation of the strips for the left and right detectors (Fig. 1) were set up with the strips along the beam direction, to measure scattering angle. The 45° detectors were oriented vertically to reduce the azimuthal acceptance for each strip, reducing the rate compared to the 90° central strips. For the 2001/2 run, we typically had 4×10^{12} protons in each ring, and 2×10^7 carbon elastic events were collected in about 20 seconds. The data were then transfered to a PC, the asymmetry and various monitor asymmetries were calculated, and the result was sent automatically to the accelerator and experiments in minutes. ^{241}Am alpha sources are installed just aside of two Si detectors (Si-2,Si-5). They shine on the three Si detectors on the opposite side of the chamber. Alpha signals (5.46 MeV) are attenuated by 20 db to get into the energy range of our measurement. The energy calibration runs were carried out for every eight days. A detailed description is given in [6], including results from a dedicated polarimeter run.

3 Polarimeter performance

Figure 3 shows polarization measurements for a typical fill. Ordinarily the measurements were taken at injection energy, right after the acceleration to 100 GeV, then two hours each during the store at flat-top. In some cases the injection energy

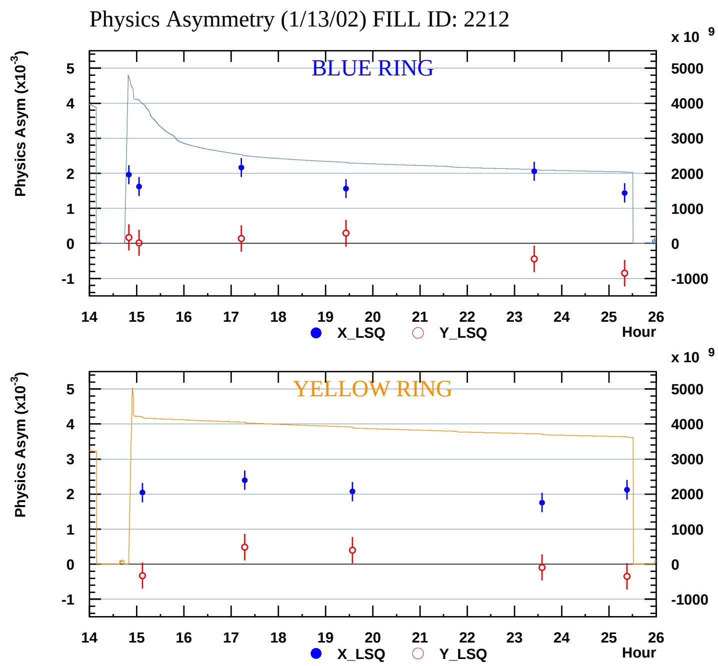

Fig. 3. Measured physics asymmetries along with the polarized proton intensity as a function of the beam lifetime for a typical fill (Jan. 13th, 2002 fill 2212). Upper (Lower) figure shows Blue (Yellow) ring. Closed points represent the vertical asymmetry X_{lsq} and the open points show the radial components Y_{lsq}; the scale is found at left axis. All the measurements are taken at 100 GeV store except for the first Blue measurement, i.e. run 669 was taken at injection energy. The solid curves represent the number of total protons in the ring with the right-handed axis displaying its intensity scale.

measurements for the Yellow ring were omitted in order to expedite the acceleration. Although the intensity dropped during the store, the physics asymmetries (closed points) were stable. The false asymmetries (open points), which should be zero, fluctuated around zero. Each measurement point contains 2×10^7 carbon events corresponding to approximately 10% relative error for a 20% polarization.

Many systematic error studies have been carried out. Referring to Fig. 1, the 90° detectors are sensitive to vertical polarization, and the 45° detectors can be used to measure vertical polarization (left-right asymmetry) and radical polarization (up-down asymmetry). The results for left-right asymmetry between the 90° and 45° detectors were compared (after correction by $\sqrt{2}$ for the smaller analyzing power of the 45° detectors). Since no radial polarization was expected (with two Siberian Snakes per ring, the stable polarization direction is vertical), the up-down asymmetry directly measure a false asymmetry. A cross asymmetry was formed

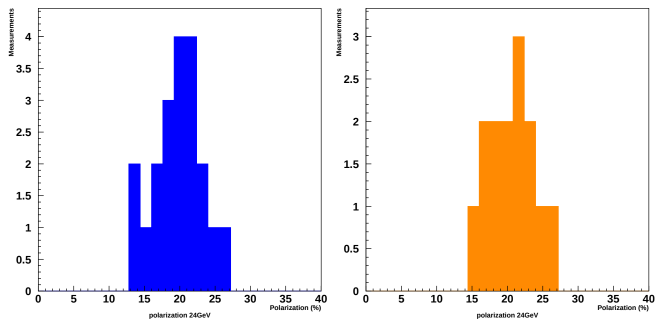

Fig. 4. Polarization values at injection energy 24.3 GeV. Left (Right) figure shows a distribution for Blue (Yellow) ring.

from the 45° detectors, which must be a false asymmetry. False asymmetries were measured also by mixing the bunches to obtain zero polarization. The results for different bunches were compared by normalizing the number of events in each detector for each bunch by the number of events for each detector observed for a standard or "good bunch". This normalized distribution for each bunch was fit with a ($constant\ +\ \epsilon \times \sin\phi$) distribution where ϕ is the azimuthal position of each detector, and $\phi = 0$ is vertical (Thereby allowing an asymmetry from vertical polarization). The χ^2 for this fit showed that a small number of bunches had anomalous behavior and were removed from the polarimeter analysis. Anomalies for bunches were also studied by calculating specific luminosities for each bunch at the polarimeter (N_{total}/I_{bunch} where I_{bunch} is the bunch current from the wall current monitor), and also at the experiments ($N_{total}/I_{Blue}I_{Yellow}$). N_{total} refers to polarimeter total counts, and to experiment counts in a luminosity monitor respectively. The anomalous bunches from these analysis matched well (for STAR, see [7]) and they were removed from the polarization and the asymmetry analysis. These studies indicate a level of systematic error at between 0.5 to $1 \times \sigma_{statistical}$. The statistical error is $\triangle\epsilon$ ($\epsilon = P \times A_N$) $= 2 \times 10^{-4}$ per measurement. For $A_N = 0.013$, the systematic error for false asymmetries is between $\triangle P_{systematic} = (0.8 \text{ to } 1.6) \times 10^{-2}$ per measurement. The systematic error from our knowledge of A_N is under study for 24.3 GeV and is not known for 100 GeV. This systematic error affects the scale of the polarimeters, and does not create a false asymmetry.

Figure 4 shows the polarization values at injection energy from long store ($>$ 4 hours) fills after Jan. 5th. Analyzing power at injection energy is determined from Ref. [3]. The adopted values are, $(1.27 \pm 0.11) \times 10^{-2}$ for Blue and $(1.33 \pm 0.15) \times 10^{-2}$ for Yellow. The values are slightly different due to the different magnitude of carbon energy loss in the dead layer of silicon strip detectors; the energy loss slightly changes the definition of the $-t$ range.

$15 \sim 27\%$ polarization was observed for both rings.

4 Issues and plans

There are several concerns that must be resolved before next year. One is the systematic errors that some bunches contribute to create the false asymmetry. From data, some bunches were observed to have unphysical ratio between six detectors. The understanding of their mechanism and criteria to discard them is needed. Another issue is the bunch by bunch polarization. Our data for the bunch by bunch analysis is limited by statistics from the previous runs. Further study on this issue is still in progress. High statistics measurements are expected for the coming run. The last concern is the serious gain drops of the silicon strip detectors. There were significantly large leakage current due to silicon radiation damage which effectively reduces the bias voltage on silicon that affects the signal shape. The replacement of the silicons and hardware improvements are planned.

For the future run, determination of the absolute analyzing power at 100 GeV is a crucial thing to be done, since our knowledge on the analyzing power of CNI polarimeter is limited to the injection energy (24.3 GeV). Absolute calibration using the polarized hydrogen jet target is planned and is in preparation towards the first operation in 2004. For the moment, a calibration using a down ramp is adopted as the second best way. As a procedure, the usual polarization measurements are performed at injection, after ramp to 100 GeV, then after down ramp again. If the polarization is found to be the same at 24.3 GeV, after the down ramp vs. at injection, we can use this polarization value at 100 GeV to calculate the analyzing power at 100 GeV. If we measure lower polarization after the down ramp, we will develop bounds on the analyzing power at 100 GeV.

5 Summary

The RHIC pC CNI polarimeter proved itself in the successful first polarized proton collision run 2001/2. It worked beautifully throughout the run period. Reliable high statistics (20×10^6 events) measurements were carried out in 1 minute measuring periods, owing to the successful operation of newly adopted wave form digitizer modules. The polarimeter results were broadcast to the experiments immediately after the measurements. Two Siberian snakes per ring worked well, and stable proton polarizations at 100 GeV were measured with little or no loss in magnitude over the store. Further detailed off-line analysis is in progress and several interesting challenges are expected for the up coming run.

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