# Commissioning CNI Proton Polarimeters in RHIC*

H. Huang†, A. Bravar, Z. Li, W.W. MacKay, Y. Makdisi, S. Rescia, T. Roser, B. Surrow,
Brookhaven National Laboratory, Upton, NY 11973, USA
G. Bunce, A. Deshpande, Y. Goto, M. Ishihara, K. Kurita,
RIKEN BNL Research Center, Upton, NY 11973, USA
O. Jinnouchi, N. Saito, RIKEN, Wako, Saitama, 351-0198, Japan
I.G. Alekseev, V.P. Kanavets, D.N. Svirida, ITEP, Moscow, 117259, Russia
R. Cadman, H. Spinka, D. Underwood, Argonne National Laboratory, Argonne, IL 60493, USA
D.E. Fields, University of New Mexico, Albuquerque, NM 87131, USA
K. Imai, J. Tojo, Kyoto University, Kyoto, 606-8502, Japan
W.R. Lozowski, Indiana University Cyclotron Facility, Bloomington, IN 47408, USA
G. Igo, J. Kiryluk, J. Wood, UCLA, Los Angles, CA 90095, USA
S. Dhawan, V. Hughes, Yale University, New Haven, CT 06511, USA

*Abstract*

Two polarimeters based on proton carbon elastic scattering in the Coulomb Nuclear Interference (CNI) region have been installed and commissioned in the Blue and Yellow rings of RHIC during the first RHIC polarized proton collider run. Each polarimeter consists of ultra-thin carbon targets and six silicon detectors. With newly developed wave form digitizers, they provide fast and reliable polarization information for both rings.

## 1 INTRODUCTION

For polarization monitoring during Relativistic Heavy Ion Collider (RHIC) polarized proton operation, a fast and reliable polarimeter is required that produces a polarization measurement having a 10% relative error within a few minutes. The idea of using $p + C$ elastic scattering in the Coulomb-Nuclear Interference region (CNI) was suggested for the fast polarimeter a few years ago [1]-[2]. The predicted analyzing power 3-4% is not large but due to the large cross section, the figure of merit $\sigma A^2$ is large. The analyzing power is also predicted to be largely independent of energy for RHIC energies. An AGS experiment (E950) was carried out to measure the $p$-$C$ CNI asymmetry[3]. These data show that the recoil carbon from CNI scattering can be cleanly detected with silicon strip detectors (SSD). The $p$-$C$ elastic scattering was identified by only detecting low energy recoil carbon nuclei. The analyzing power was calibrated at 21.6 GeV/c with polarization measurement of AGS E925, which used carbon, $CH_2$ and liquid hydrogen targets to measure beam polarization extracted from AGS [4].

A CNI polarimeter was installed and commissioned in RHIC Blue ring in 2000. The overall design is given in Ref. [5]. The commissioning was done by injecting 6 proton bunches with alternating polarization, for example, ↑↓↑↓↑↓. There were about 3 $\times 10^{10}$ protons per bunch with a separation of about $2\mu s$. Injection energy was 24.3 GeV ($G\gamma = 46.5$, where $G$=1.7928 is the gyromagnetic anomaly of proton). The AGS E950 readout, FERA ADCs and TDCs, were used for this run. All 48 silicon strips worked flawlessly, as there was very little background. The energy was calibrated using the observed carbon and alpha mass peaks. The commissioning showed that $p$-$C$ CNI scattering can be identified with little background. Four silicon detectors installed at $45°$ can measure both transverse components. The data were then combined to derive vertical and radial polarization, and the vertical polarization of the injected beam was observed. Reversing the injected beam polarization pattern resulted the measured beam polarization reversed. As a cross-check, unpolarized beam was injected and zero polarization was observed in RHIC.

## 2 WAVE FORM DIGITIZERS

In the 2000 run, there was considerable dead time with these electronics: readout of a full buffer took 1.5s. In 2001, there were 55 bunches in each ring and $10^{11}$ (at injection) polarized protons per bunch. The bunch spacing is 212 ns. The rates in this scenario compared to the 2000 commissioning are about 10 times greater per bunch and 100 times greater overall. The dead time in this situation for the AGS-type readout would be 99%, and it will not be possible to distinguish two hits in the same strip, which will occur at a few percent frequency. Considering the raw asymmetry is around 1%, with 2% average analyzing power and polarization of 50%, overlapping events present a very serious problem.

The solution is to use new Wave Form Digitizers (WFD)[6]. A WFD provides the evolution of the pulse and its complete history. It also yields the shape of the pulse assisting in identification of the detected particle. WFD readout is ideal for this application, since no information other than energy and time on the event are available and required. The WFDs were programmed to obtain energy and time information and then to sum for scalar type in-

* Work supported in part by the U.S. Department of Energy.
† Email:huanghai@bnl.gov

formation of the WFD hits in the carbon band. This reduced the data size to minimal levels, and the need for a fast readout was mitigated. The WFD block diagram is shown in Fig. 1. The digitized pulse shape from the

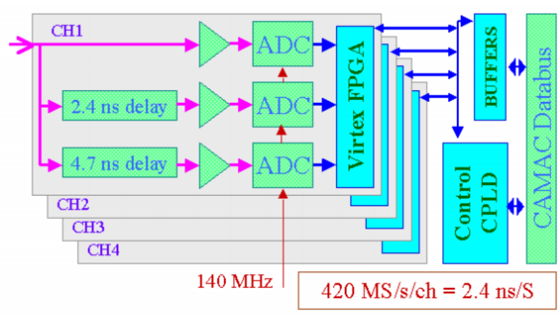


Figure 1: WFD block diagram. Each WFD has 4 channels. The 140MHz clock signal is five times of the rf frequency 28MHz.

ADCs is treated in the FPGA chip "on-the-flight", so the signal amplitude, integral and arrival time for each bunch crossing are determined. The carbon events are selected using preprogrammed look-up tables based on the appropriate time/amplitude correlations. As soon as a carbon event appears, several on-board scalar-type histograms are filled according to the signal amplitude and corresponding bunch number and polarization signature. Checking the integral/amplitudes correlation allows to reject and separately take into account the double pulsed and noise events. Because all the data treatment is done in the FPGA chip, there is no data flow between the modules and the host computer during the data taking, resulting in an acquisition system with zero dead time. FPGA flexibility allows fast changes in the design, including histogram parameters, to achieve better performance.

## 3 HARDWARE AND SOFTWARE

There are twelve 1.2cm$\times$2mm silicon strips in each RHIC Si detector, similar to what was used in AGS. Before this run, the Si strips were mounted perpendicular to the beam direction to give the angular information. It turned out that this angular information was not essential to analyze the data. For this run, the four 45$^\circ$ detectors were parallel to the beam direction. This arrangement increased the acceptance of the polarimeter. The layout of six Si detectors are illustrated in Fig. 2.

Two $^{241}$Am radiative sources were installed in each polarimeter chamber. They were mounted next to the Si detector in the horizontal plane and shine on the three Si detectors at the opposite side. They were very useful for Si detector energy calibration.

There were about 1000 polarization measurements over the eight weeks running time. With 55 bunches and total intensity of 3.5$\times$10$^{12}$ per ring, the measuring time was less than a minute at store to get 20 million events. Beam

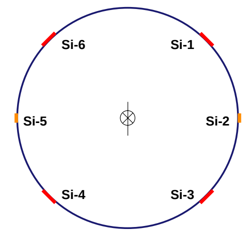


Figure 2: The layout of silicon detectors for 2001 run. The two $^{241}$Am radiative sources were installed next to Si detectors Si-2 and Si-5, respectively.

intensities were higher at injection, so the measuring time was about the same.

The very thin ribbon carbon target developed at IUCF[7] was crucial to the $p$-$C$ CNI polarimeter: both for survival in the RHIC beam and to get the carbon nuclei out of the target in the CNI region, as the recoil carbon carries only hundreds of keV kinetic energy. A typical target size is 5$\mu$g/cm$^2$ and 5$\mu$m wide. Six (three horizontal and three vertical) carbon ribbon targets were mounted in each polarimeter chamber. The carbon fiber target could be scanned through the circulating beam to measure polarization profiles in both transverse directions. Due the limited time, the vertical polarization profile was only measured once in Yellow ring and the results were not conclusive. Target heating was not a problem for the running conditions of this year. Over the eight week run, one target was lost in the middle of run. Since the target control did not move the target out of beam automatically, it is possible that the lost target was left in the beam for a long time.

The WFDs could only cover 48 channels this year. Signals from the central eight strips out of twelve strips from each Si detectors were processed. The same WFDs were used for the Blue and Yellow rings, so one can not measure polarization in both rings at the same time. Given the fact that the measurement only took one minute and polarization was stable through store, this was not a problem.

Even though the carbon target is ultra-thin, it generated measurable background at the experiments. Before each polarization measurement, all experiments were notified to put their DAQ systems in standby. The target was moved into the desired position and data taking started. After reaching the pre-defined statistical error, the data taking stopped and the asymmetry and bunch pattern information were sent to users automatically through CDEV [1] protocol. The target was then moved out. The flow chart is shown in Fig. 3.

## 4 COMMISSIONING RESULTS

The first polarized proton collider run in RHIC took place from Dec. 2001 to Jan. 2002. With two snakes

[1]The CDEV (common device) C++ class library is an object-oriented framework that provides a standard interface between an application and one or more underlying control packages or systems.

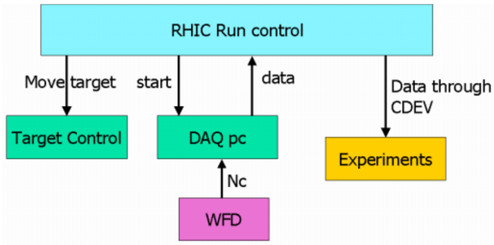


Figure 3: Flow chart of the RHIC polarimeter control system.

in each ring, the stable spin direction is vertical in RHIC and independent of beam energy. Polarized beams were successfully accelerated to 100 GeV [8]. The polarization was measured at AGS extraction and RHIC injection for each RHIC fill. The spin transmission efficiency of AGS to RHIC transfer line is 96% at $G\gamma = 46.5$. The polarization measured at the RHIC injection tracked the AGS polarimeter measurement (at $G\gamma = 46.5$). This is shown in Fig. 4.

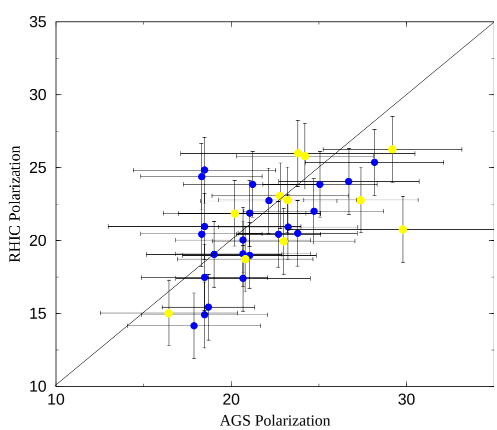


Figure 4: Comparison of polarization measured at the AGS polarimeter(at $G\gamma = 46.5$) and the RHIC injection for part of the run. The diagonal line is plotted for a ratio of one. The blue (yellow) dots are polarization measured at Blue (Yellow) ring injection.

To calibrate the analyzing power of the CNI polarimeter at any energy above injection, the polarized hydrogen jet target will be needed but it would not be ready until 2004. An alternative way is to ramp down the energy and measure the asymmetry again at injection. If the asymmetry after down ramp is similar to the measurement before the up ramp, polarization is preserved. The analyzing power at storage energy can then be extracted from the asymmetries measured at injection and store. If this is not the case, then the extraction of analyzing power at store would not be straightforward. In several down ramp attempts, beam did not survive back to injection, because the chromaticity was not well controlled during the down ramp. Although the analyzing power at 100 GeV for the RHIC polarimeter is unknown, it is expected to be similar at injection energy. Under this assumption the polarization measured at store was typically about 20-25%. One example is shown in Fig.5.

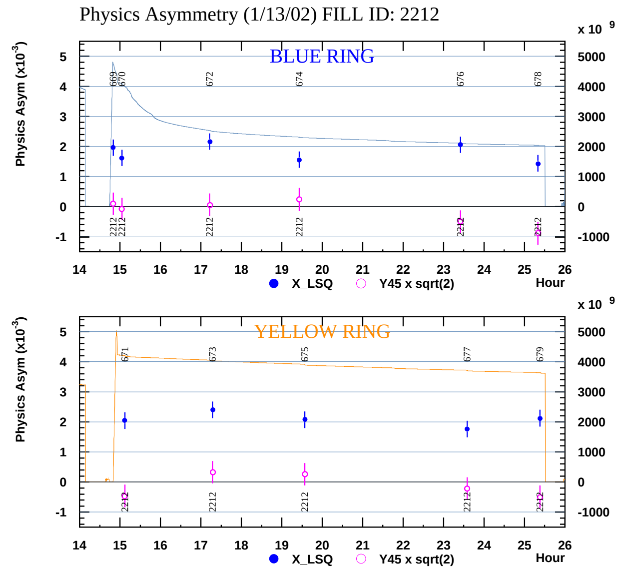


Figure 5: Beam intensity and measured asymmetry in the Blue and Yellow rings for a typical store. The solid curves are the beam intensities. The solid dots are physics asymmetries and the open circles are false asymmetries (radial component of the polarization vector) which should be zero. The 3-digit numbers are polarimeter run numbers. Among runs, Run 669 was taken at injection and others were at store. The asymmetries stayed as constant statistically.

## 5 SUMMARY

It was demonstrated that the CNI polarimeter can be used to monitor polarization of high energy proton beams in an almost non-destructive manner. The detection of the recoil carbon with silicon detectors using both energy and time-of-flight information showed excellent particle identification. WFDs worked well with high data rate. Further data analysis is underway and some modification is expected before the next run.

## 6 REFERENCES

[1] N.H. Buttimore, *et al.*, Phys. Rev. D59 (1999) 114010.

[2] B.Z. Kopeliovich and T.L. Trueman, hep-ph0012091.

[3] J. Tojo, et al., submitted to Phys. Rev. Lett.

[4] C. Allgower, *et al.*, Phys. Rev. D65 (2002) 092008.

[5] H. Huang, *et al.*, Proc. of PAC 2001, p.2443.

[6] S. Dhawan, private communication.

[7] W.R. Lozowski and J.D. Hudson, NIM in Physics Research A334, 173(1993).

[8] T. Roser, *et al.*, these proceedings.