

A New Relative Proton Polarimeter for RHIC*

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Abstract

An innovative polarimeter based on proton carbon elastic scattering in the Coulomb Nuclear Interference (CNI) region has been installed and commissioned in the Blue ring of RHIC during the first RHIC polarized proton commissioning in September, 2000. The polarimeter consists of ultra-thin carbon targets and four silicon detectors. All elements are in a 1.6 meter vacuum chamber. This paper summarizes the polarimeter design issues and recent commissioning results.

1 *P-C* CNI ELASTIC SCATTERING

Small angle elastic scattering of hadrons in the Coulomb-Nuclear Interference(CNI) region has long been advocated for polarimetry[1]. The predicted analyzing power is not large but due to the large cross section, the figure of merit σA^2 is large. The analyzing power is also predicted to be largely independent of energy for energy above a few GeV. At high energies, it is expected that hadronic spin flip is small, which in turn formulates the basis of this prediction. However, for *p-C* CNI, a typical $(-t)$ value of 0.002 to 0.01 GeV² results at high energy in a very small angle of the forward scattered proton relative to the beam direction and also a very low kinetic energy of the Carbon recoil of about 0.1-1 MeV. It is impossible to measure the forward scattered proton without drastically reducing the beam size at the target. It therefore necessitates reliance only on the measurement of the recoil Carbon nuclei to identify elastic scattering. The low energy carbon nuclei would stop in most targets. The very thin ribbon carbon target developed at IUCF[2] 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. The known analyzing power, large cross section and advantages of a solid ribbon target makes this process ideal

for a fast primary polarimeter for RHIC[3]-[4]. An AGS experiment was carried out to measure the *p-C* CNI asymmetry. These experimental results show that the recoil carbon from CNI scattering can be detected with silicon strip detectors (SSD). The *p-C* elastic scattering was identified by only detecting low energy recoil carbon nuclei. Given the success of AGS test, it was justified to develop a *p-C* CNI polarimeter for RHIC.

2 OVERALL DESIGN

The SSD had a thickness of 400 μm and was segmented into twelve strips. This segmentation provides angular information and reduces the event rate per strip which becomes exceedingly high at full luminosity. The surface of the SSD had a special feature of a very thin Boron implantation with small aluminum evaporation electrodes so that low energy recoil carbon could penetrate the surface without being hindered by the electrodes.

The warm straight section between Q3 and Q4 at section 12 in RHIC was assigned for installation of polarimeters in both Blue and Yellow rings. Both target chambers are located near Q4 where the vertical and horizontal lattice β functions are small, thus reducing the effect of multiple scattering on emittance dilution. Circulating beams are in opposite directions in the two rings. Both target chambers have been placed upstream of each other and therefore, the detectors for both polarimeters are not in each other's scattering showers.

It is desirable for the polarimeter to measure both horizontal and vertical beam polarization profiles, which requires separate targets scanning both vertically and horizontally. Since the thin carbon target has a relative short life time at the full RHIC beam luminosity, it was decided to mount more than one ribbon on the driving mechanism (spaced so that the beam sees one ribbon at a time) to provide redundancy in the case of ribbon breakage. The current design of target holder is capable of holding 4 targets. Three targets were mounted and one target holder is left empty for background check. The target holder drawing is

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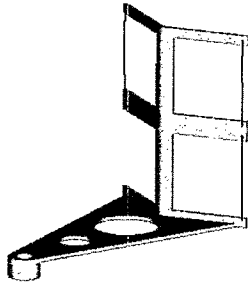


Figure 1: Metal target frame and the ceramic V plate. The ceramic plate reduces impedance impact. The holes in the V shape reduce the inertia of the target assembly. A typical target is a $5 \mu\text{m}$, $5 \mu\text{g}/\text{cm}^2$ ultra-thin carbon ribbon. It is 3 cm long.

shown in Fig. 1.

The target box radius is 16 cm, the minimum allowed to host the target driving assembly. In manipulating polarization in RHIC, information on both vertical and horizontal components of beam polarization are needed. In addition to one pair of detectors sitting on the horizontal plane, two pairs of detectors sitting at 45° have been added. These pairs are capable of measuring both transverse components. At full RHIC design intensity, the bunch width is about 2 ns and bunch spacing is 106 ns. To avoid the prompt background, the carbon nuclei should arrive at the detectors between two bunches, i.e., within 100ns. The Si detector can detect recoil carbon with kinetic energy as low as 100keV, which can travel about 15cm in 100ns. Therefore, the distance between detectors and interaction point is set as 15cm.

The minimum target box length of 50.8 cm is determined by the relative positions of target, viewport, and detector sockets. Due to impedance constraints, two 5:1 transition sections are attached at both sides and make the total length of the target chamber 1.6 m. The top viewport is used for target installation and target position monitoring. Total of six silicon strip detectors can be used. They are located upstream of the target assemblies in an effort to reduce background due to forwarding scattering particles from target. A 3-D plot of target box is shown in Fig. 2. To reduce the

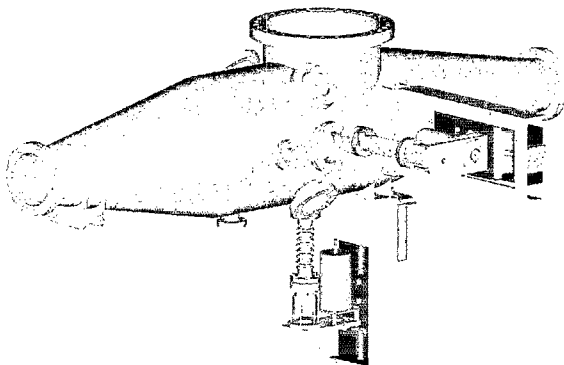


Figure 2: RHIC p -C CNI polarimeter target box. Beam goes from the left to the right.

impact on beam impedance, the radius of the box should be as close as possible to that of the beam pipe, i.e., 6.5 cm. Extensive impedance study has been done with MAFIA and can be found in Ref [5]. It shows that current design meets the RHIC impedance requirement. At full intensity, the emittance blowup is expected to be negligible over the full energy range.

3 COMMISSIONING RESULTS

Only one helical Siberian snake[6] was installed in year 2000. The stable spin direction is in the horizontal plane with snake on and in the vertical direction with snake off. The injected beam from AGS is in the vertical direction. It is necessary to have the snake off during injection and then to have it adiabatically turn on such that beam polarization follows the stable spin direction, subsequently turning from vertical to horizontal. Four silicon detectors installed obliquely, as shown in Fig. 3, can measure both transverse components. These detectors provide measurements of both vertical polarization (left-right) $=((1+2)-(3+4))$, and radial polarization (up-down) $=((1+3)-(2+4))$, with the detectors as depicted in Fig. 3.

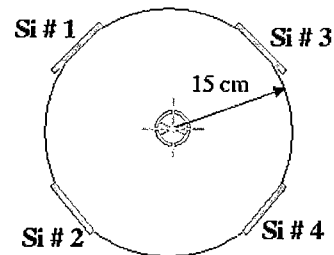


Figure 3: Cross section of the target chamber. Beam is going into the paper and hits the carbon target in the center of the beam pipe. The carbon target is $5.5 \mu\text{g}/\text{cm}^2$ thick and $11.6 \mu\text{m}$ wide. The wider target was used to increase event rate.

The commissioning was done by injecting 6 proton bunches with alternating polarization, for example, $\uparrow\downarrow\uparrow\downarrow$. There were about 3×10^{10} protons per bunch with a separation of about $2 \mu\text{s}$. Injection energy was 24.3 GeV ($G\gamma = 46.5$, where $G=1.7928$ is anomalous magnetic moment for proton).

The identification of a carbon band is shown in Fig. 4 as energy vs. time-of-flight plots, of the eight center strips of one silicon detector. All 48 silicon strips worked flawlessly, as there was very little background, as shown for the reconstructed mass in Fig. 5. An alpha peak can be seen clearly (presumably quasi-elastic p-alpha scattering). The energy was calibrated using observed carbon and alpha mass peaks. The commissioning showed that p -C CNI scattering can be identified with little background.

When the data are combined as discussed above to measure vertical and radial polarization, the vertical polarization of the injected beam was observed (see Fig. 6). Details of the polarization measurements can be found in Ref. [7].

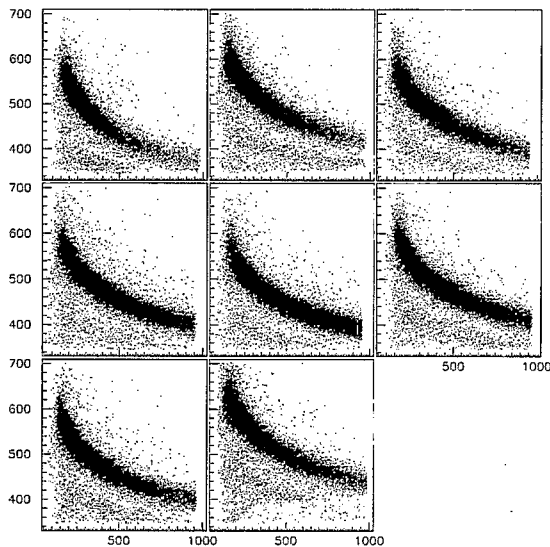


Figure 4: Scatter plot between the ADC values (horizontal axis, unit is ADC channels) and the time of flight (vertical axis, unit in ns) for Si detector 1. Only center eight strips were used in the analysis.

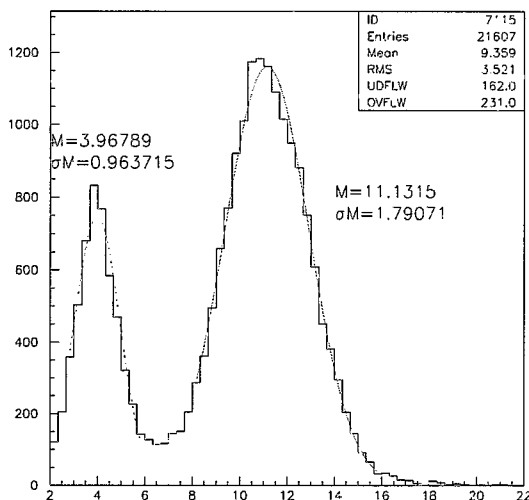


Figure 5: Mass spectrum. The horizontal axis is in the unit of GeV and vertical axis gives the event counts.

4 NEW DAQ SYSTEM

With the current electronics, there was considerable dead time: readout of a full buffer took 1.5s. The next run will be the first to take data with colliding polarized protons, as there will be 60 bunches in each ring and 10^{11} polarized protons per bunch is expected. The bunch spacing will be 212 ns. The rates in this scenario compared to the commissioning will be about 10 times greater per bunch and 100 times greater overall. The deadtime 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 percent frequency. Considering the raw asymmetry is around one percent, with 2% average analyzing power and polarization of 50% expected, the overlapping event is

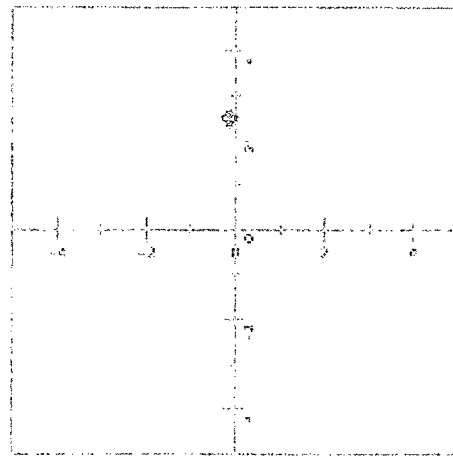


Figure 6: Plot of polarization vectors at $G\gamma = 46.5$. The figure shows measured asymmetry with vertically polarized beam injected into the Blue ring with no snake energized. The amount of polarization from the asymmetry is estimated to be about $19 \pm 1\%$ (statistical error only).

a very serious problem.

The proposed method is to use Wave Form Digitizers (WFD). 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 WFD data is exactly what is needed and is complete. The clock frequency is set according to the rise time, which can be intentionally set short to improve double pulse resolution. The proposal is to take about 30 ns of data for each pulse, with digitization every 3 ns with no deadtime. A pulse is defined as a change in pulse height (differential measurement). A prototype WFD module[8] was tested during the commissioning run and worked as expected.

5 SUMMARY

The p -C CNI polarimeter is ideal for high energy proton polarimetry: fast measurement, low cost and compact size. Another p -C CNI polarimeter has been installed in the Yellow ring. To accommodate the higher beam intensity of the future, the DAQ system will be upgraded by utilizing the WFD readout.

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