RHIC p-CARBON POLARIMETER TARGET LIFETIME ISSUE*

H. Huang, I.G. Alekseev, E. Aschenauer, G. Atoian, A. Basilevsky, K.O. Eyser, A. Fernando, D. Gassner, D. Kalinkin, J. Kewisch, G. Mahler, Y. Makdisi, S. Nemesure, A. Poblaguev, W. Schmidke, D. Steski, D. Svirida, T. Tsang, K. Yip, A. Zelenski
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

RHIC polarized proton operation requires fast and reliable proton polarimeter for polarization monitoring during stores. Polarimeters based on p-Carbon elastic scattering in the Coulomb Nuclear Interference(CNI) region has been used. Two polarimeters are installed in each of the two collider rings and they are capable to provide important polarization profile information. The polarimeter also provides valuable information for polarization loss on the energy ramp. As the intensity increases over years, the carbon target lifetime is getting shorter and target replacement during operation is necessary. Simulations and experiment tests have been done to address the target lifetime issue. This paper summarizes the recent operation and the target test results.

INTRODUCTION

The collision of polarized proton beams at RHIC (at up to $\sqrt{S}$ = 510 GeV energy) provides a unique physics opportunity for studying spin effects in hard processes at high luminosities, including the measurement of the gluon polarization and the quark and anti-quark spin flavor composition.

RHIC is the first polarized proton collider where the Siberian snakes were successfully implemented to maintain polarization during beam acceleration [1]. The fast polarization measurements are critical for the accelerator setup and physics programs during the physics stores. The pC CNI polarimeters in RHIC are based on elastic proton scattering with low momentum transfer in the CNI region and measurement of asymmetry in recoil carbon nuclei production [2]. This process has a large cross-section and sizable analyzing power of a few percents which has weak energy dependence in the 24-255 GeV energy range. A very thin (5-10 μg/cm^2, 5-10 μm wide) carbon ribbon target in the high intensity circulating beam produces high collision rate and a highly efficient DAQ system acquires up to 5×10^6 carbon events /sec. The absolute beam polarization was measured with a polarized H-jet polarimeter which is also based on elastic proton-proton scattering in the CNI region [3]. These calibration measurements have been done at various energies, such as 24 GeV, 31 GeV, 100 GeV, 250 GeV and 255 GeV. The results showed weak energy dependence, especially above 100 GeV. The simultaneous measurements in pC and H-jet polarimeters provide the calibration for pC polarimeter analyzing power. A typical store would result a ±3% statistical error in the polarized jet measurement. The fast pC polarimeter measures polarization profiles in both transverse planes, which are used to derive the polarization at collision points for experiments. The pC polarimeter also measures possible polarization losses during the energy ramp and possible polarization decay during the RHIC store.

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POLARIMETER ASSEMBLY

RHIC polarimeters have evolved in past ten years [4]. Two identical polarimeter vacuum chambers are located in the warm RHIC sections which are separated for the two rings and have the separate vacuum systems. Due to the complexity of the chamber and the electronics, it is not practical to bake the chamber. A non-evaporable getter cartridge pump is added to each chamber to provide additional continuous pumping. As a result, the pump down speed is greatly improved, which allows the target replacement during maintenance day. A full intensity physics store can be resumed within 24 hours (vacuum down to 10^{-9} Torr).

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 lifetime at the full RHIC beam luminosity, it would be advantageous to mount multiple targets on the driving mechanism (spaced so that the beam sees one ribbon at a time) to extend the time between maintenance periods. Each polarimeter consists of six horizontal targets and six vertical targets. Simulation shows that the expected equilibrium temperature at 255 GeV with full loaded intensity (2.4×10^{13}) for a typical carbon ribbon target would be around 1800°K. It is generally inadvisable to run the fiber at temperatures exceeding 2000°K, which is the onset of thermionic emission, since this would shorten the lifetime of the fiber.

The large aspect ratio of the thin carbon target (2.5 cm long, 10 μm wide and 25-50 nm thick) is essential for polarization measurement. First, it increases heat dissipation rate so that the target can survive the high intensity beam. Second, it reduces multiple scattering for recoil carbon ions and also keep the event rate within the detectors and DAQ capabilities. However, the ultra thin target is very fragile and has limited lifetime. Good targets survive in the RHIC beam for 50-100 measurements at the full beam intensity and 255 GeV. The ultra-thin carbon target production procedure was developed at Indiana University [5] and it is a routine now at BNL [6]. The target positioning accuracy is about ±0.5 mm and limited by the target straightness. The accuracy is required due to limited detector acceptance.

The time-of-flight and recoil carbon energy measurements are required for elastic scattering identification. The silicon-

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strip detectors are used in the polarimeters since they allow measurements of energy and arrival time of Carbons in the RHIC ring vacuum environment. The late arrival time of the recoiled carbons is advantageous since the detection can be done with much less noise after all beam-induced disturbances are gone. In addition to one pair of detector sitting in the horizontal plane, two pairs of detectors sitting at 45° are added, which allow measurement of both vertical and radial polarization components. At full RHIC designed intensity, the rms bunch length is about 2 ns and bunch spacing is 106 ns. To avoid the prompt background, the carbon nuclei should arrive the detectors between two bunches. The Si detector can detect carbons with kinetic energy as low as 200 keV, which can travel about 20 cm in 100 ns. The distance between detectors and interaction point is set as 18 cm. There are RF shields at the surface of the chamber to cover the detector ports to reduce the impedance impact [7].

The preamplifier boards are mounted on the polarimeter vacuum chamber and directly connected to the vacuum feedthroughs to minimize the distance to the signal source. The amplified analogue signals are transferred through the RHIC tunnel on coaxial cables for about 90 m to a counting room located next to the tunnel. A wave form digitizer is utilized in the DAQ to handle the high-rate and minimize dead-time.

TARGET LIFETIME ISSUES

Usually, a good carbon target breaks after usage of 50 to 100 times. But the variation of target lifetime is relative large: many targets have been lost before seeing beam, or just broke after a few uses. This is especially the case when a target was lost at store, and a new target has to be used right away. Polarimeter chamber has to be opened to replace targets during maintenance day twice in past two polarized proton operations. The broken targets were checked under microscope. About 2/3 of the broken targets were broken near the ends. The rest 1/3 were broken near the center. A lot efforts were put in to understand the mechanism for the target breakage. It was found that the targets survived beam operation are graphitized and have smaller resistances, about a few MΩ while the resistance of unexposed targets is a few hundreds MΩ. It was also found that the exposure to flash light can greatly reduce the target resistance. About 1/3 targets used in run13 were exposed to high power flash light to reduce the resistance. Since some new targets lost at store in first a few uses, one hypothesis is that the targets need to be "conditioned" with modest beam intensity before using at store energy. This is the similar effect as the high power flash, but probably more powerful. In run13, all targets have been used first at injection with gradually increased total intensities: 0.5, 1 and 2×10^{13}. Then they were put into use at store. However, this effort did not yield significant improvement in the target lifetime. The target temperature is expected to be around 1500-2000°K, visible light emission is expected at these temperatures. The polarimeter target chamber has several viewports to check targets during maintenance day.

Figure 1: A glowing target when crossing beam. The central bright spot is due to beam.

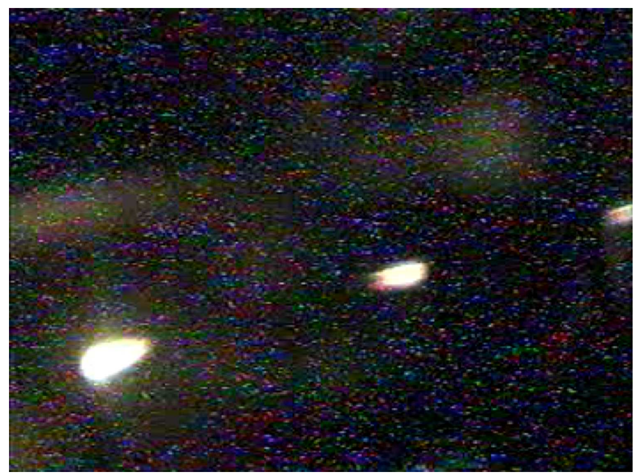

Figure 2: A target with glowing ends when it is off beam. Note that the nearby target end (on the right side) is also glowing in the dark. Due to the limited aperture, the camera can not cover more targets.

A few cameras were installed to take video when targets crossing beam. The observation surprised all of us. The glowing light was brightest when the target crossed the beam center. This is understandable, as beam heating generates high temperature and black body radiation could be the main source of the glowing light from target portion hit by beam. In addition, the ends glow when the beam is far away (a few cm) from the target. Figure 1 showed the captured picture of a glowing target when it crossed the beam center. Figure 2 is when target was far away from beam and at park position, where the target sat for hours between polarization measurements. The persistent glowing over a store (8-10 hours) could be a source of relative short target lifetime for these targets.

Light filters with different spectrum ranges were put into one camera. The idea was to get the relative strength of the light emission at different wave length ranges. Comparing with black body radiation power distribution, one can get

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the nature of the light (black body radiation or not) and the temperature. The glowing light spectrum at the target tails when crossing the beam or at park position does not consistent with black body radiation. But to make detail spectral analysis, a spectrometer is needed.

One possible mechanism to explain the glowing target tails is the induced electric-magnetic fields due to the beam passing by. The target chamber is like a RF cavity and the target frame is like an antenna. The induced high frequency electrical fields move electrons back and forth along the target frame as weel as targets. Heat is generated due to the resistance of the targets, which in turn causes black body radiation and emit lights.

At store energy(250 or 255 GeV), the high frequency RF cavities (200 MHz) were turned on to generate shorter bunches for luminosity gain. The high peak current associated with the short bunches should make the glowing worse. Indeed, the 200 MHz cavity was ramped to lower value and the glowing light disappeared. This observation is consistent with the induced field hypothesis, as higher peak current with higher 200 MHz cavity voltage is expected to induce stronger electric fields. In run13, the 200 MHz cavity voltage was ramped down during the polarization measurements. This procedure not only reduced the glowing light, but also reduced the electronic noises in the preamp circuitry. The ramping down 200 MHz cavity voltage only reduces the light during measurements when the effect is strongest. The target glowing at park position is still a problem. Due to the space constraint, only half of the targets can be parked far enough from the beam. The other half targets have to endure the chronic effect of the induced electric-magnetic fields throughout the stores. These targets indeed have shorter lifetime compared to the other half which could be parked further away. To prolong the target lifetime for these half and probably to all targets, something needs to be done.

SIMULATION OF TARGET HEATING

If the problem is due to the induced electric-magnetic fields, the effect should be proportional to the electric fields along the target wire. One possible solution is to provide surface for the field lines to "spread out". These surface should have smooth curvature to avoid sharp edges. One design is to add fins to both ends of the target frame. In general, the larger the surface, the larger the reduction, but the fins must fit into the limited space in the tank and the clearance from the target-beam interaction region to the Si detectors have to be maintained, too.

The simulations were done with CST-studio [8]. The real mechanical drawing of the polarimeter chamber (as shown in Fig. 3) was used in the simulation. The peak current of beam is used in the simulation. Three cases of target relative to beam positions were simulated: the first one was when a target crossing the beam center; the second and third ones were when all targets were away from the beam by 2.5 cm transversely at either inner or outer positions. There was not much difference in the last two cases.

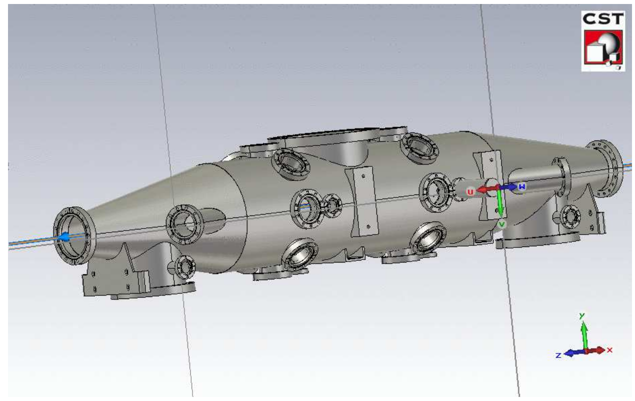

Figure 3: The 3D drawing of the polarimeter chamber. The tape structure (5:1) is to reduce the impedance impact on the overall RHIC ring impedance budget. The two view ports on both tape structure are used to monitor the target operation. The big view port on the top is for target installation. Three cameras are mounted on these view ports to monitor the polarimeter target operation. There are two sets of six Si detectors ports surrounding the chamber on both sides of the big view port. There are vertical and horizontal targets for each set.

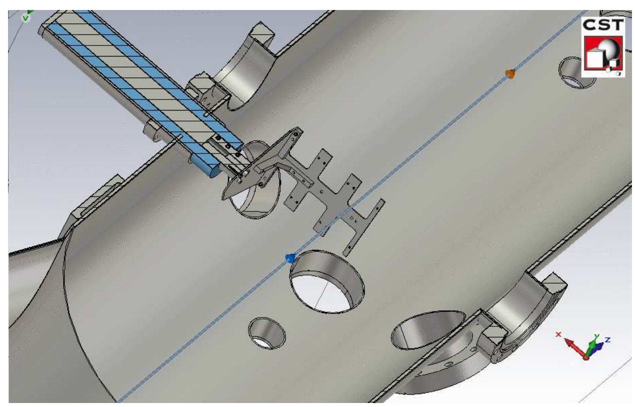

Figure 4: The detail of one horizontal target assembly. The vertical target assembly(the smaller hole at the bottom) was not included in the simulation.

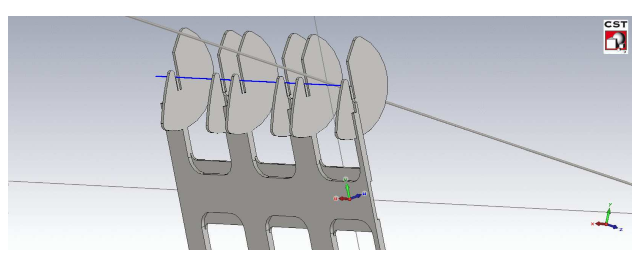

Figure 5: The details of the target frame fins. The shape is designed to have smooth curvature and enough clearance in the chamber. The half elliptical shape allows it to be mounted on every target, but a full elliptical shape should reduce the electric fields further.

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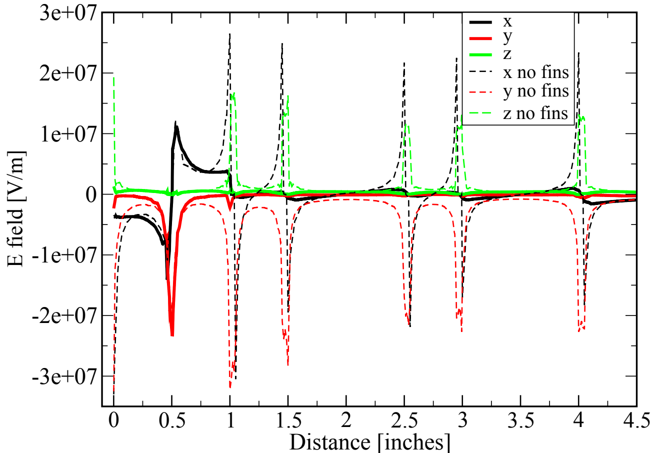

Figure 6: The simulated electric fields when target is in the center of beam (at 0.5 in location). Here z is along beam moving direction, y is the vertical direction and x is radial out direction. The solid lines are for the case with fins and the dashed lines are for the case without fins.

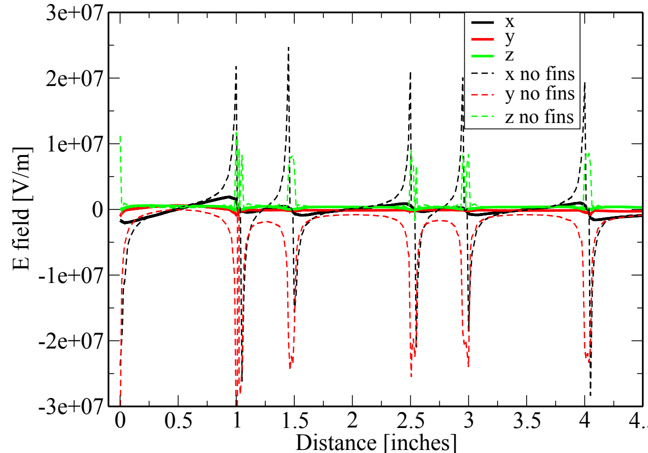

Figure 7: The simulated electric fields when target is out of beam. The coordinate system is the same as in Fig. 6.

In each case, the target with and without fins (as shown in Fig. 5) were simulated to see the effects. Note that the fins are in half elliptical shape and a slit in the middle allows it to be pushed into place. As Fig. 6 shows, the electric fields are very strong near the end of the target frames, even for the targets which are not in the beam. Further more, Fig. 7 shows that the electric fields are strong even when all targets are out of beam. These simulation results are consistent with the observation shown in Figs. 1-2, where the glowing light is visible for the target ends in the beam or out of beam. By comparing Figs. 6 and 7, it seems that the fields at all target ends are similar for both in and out of beam cases. The simulations suggest that the lifetime of targets not in use could be shortened. This was also consistent with the observation. As expected, the simulation results showed that the electric fields at the edge of target frames were greatly reduced for the case with fins. The reduction factor is about 10-20.

EXPERIMENTAL RESULTS

There was no polarized proton beam planned for 2014 and this also provided an opportunity to test the modification of target frame with other beams. Targets mounted on the frames with and without fins have been installed before the run started. To save time, a round shape aluminum fins were used (as shown in Fig. 8). It should have stronger effect than half elliptical one. Due to its shape, only four out of six target positions have the required clearance. A bunch of targets with and without fins were installed.

Both Au and He ion beams were used this year to compare the targets with and without fins. There is no chance for a carbon target to survive Au beam crossing. Instead, targets were put about 1.5 cm away from beam center at end of physics store. The glowing light is definitely stronger for

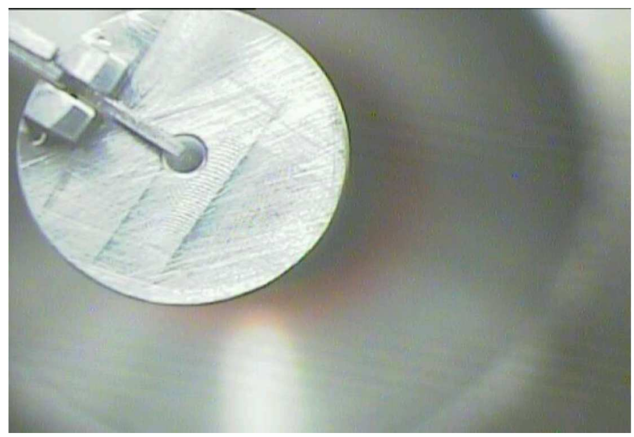

Figure 8: The fin used in the experiment test.

target frames without fins. Figs. 9 and 10 clearly showed the effect. When the targets were moved away from beam by more than 3 cm, the light disappeared for both type of targets. Unfortunately, due to the limiting space inside the polarimeter chamber, about half of the targets can not be parked that far from beam. Additional protections are needed for these targets.

Different Au beam peak current was used to compare the two type targets. The light is dimmer with smaller peak current. In all cases, the targets with fins have weaker glowing light. The voltage of 200 MHz RF cavity was also ramped down from 650 kV to 100 kV. The light disappeared for both targets with and without fins. This is expected, as the lower voltage corresponds to lower peak current. The induced electric fields are strongly peak current dependent.

For He beam, the charge is small enough, so that the carbon target can cross the beam and survive. The peak current for He beam is twice as high as Au beam. During the test, there was no glowing light from the ends of the targets with fins. Unfortunately, the targets without fins were broken during the target switching while all targets were outside beam. Two big light flashes were seen. It was

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Figure 9: The target with fins at position 1.5 cm away from beam.

Figure 10: The target without fins at position 1.5 cm away from beam.

confirmed that the two targets without fins were gone (no beam loss detected when the two targets crossed the beam), while the targets with fins survived. The target switch had been fine with gold beam, but gold beam has lower peak current. It could be that when the target frames moved to certain location, it generated a resonance condition. There is no simulation for this situation done yet. Nevertheless, it is encouraging that the targets with fins did get protection from this resonance condition. After this experiment, the target motion history in the past has been checked, since the peak current of proton beam is higher than He beam in general, and this could happen for proton beam, too. From the logged data in last run, we never switched targets at store between these two positions with beam at store.

Figure 11: A bright flash from the target without fins happened when switching targets. All targets were outside He beam during this operation.

SUMMARY

The pC CNI polarimeters in RHIC provide fast polarization (with polarization profile) measurements. The analyzing power of this polarimeter has been calibrated by the simultaneous polarization measurements in the absolute H-jet polarimeter at various energies. This polarimeter is ideal for high-energy proton polarimetry: fast measurement, low cost and compact size.

As intensity increases, the target lifetime becomes an important issue. Observed continuous glowing light from target ends outside beam implies that the temperature is high and this could damage target. The experimental results showed that the targets with fins do get weaker light, which in turn implies better lifetime. In addition, the target breakage of targets without fins gave another strong reason to install the fins as the fins can protect targets. The plan is to install the fins for all possible targets in the coming polarized proton operation.

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