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Recent Developments in the Production of Carbon Micro-ribbons for CNI Polarimeters at BNL

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The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) is the only collider in the world to collide polarized protons. In order to maximize the polarization of the proton beam in RHIC, it is critical that the polarization is measured during the acceleration process. This is accomplished with Coulomb Nuclear Interference (CNI) polarimeters in the Alternating Gradient Synchrotron (AGS) and RHIC. The targets for the CNI polarimeters are carbon micro-ribbons that are optimized in width for the detectors. The targets used in the AGS CNI polarimeter are 4 $\mu g/cm^2$ thick (25-30 nm) and 50 mm long. The width of these targets is either 75 μm, 125 μm or 250 μm. The targets used in the RHIC CNI polarimeter are the same thickness but only 25 mm long and <10 μm wide. As the beam intensity in RHIC has increased and the beam size has decreased, the lifetime of these targets has become a major issue. Efforts are underway to reduce the resistance of the targets in the hope that it will extend their lifetime. There have also been demands for unique target geometries. The technique to produce 5 mm wide targets and twisted carbon micro-ribbons is discussed.

Keywords: annealing, foil lifetime, graphitization, micro-ribbon targets

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Introduction

The collision of polarized proton is a large part of the experimental program at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). Polarized H- is created in an Optically Pumped Polarized Ion Source (OPPIS) and accelerated in a 200 MeV linear accelerator (Linac). The polarized H- beam is stripped of electrons at the entrance to the Booster Synchrotron and the protons are then captured and accelerated through the Booster, Alternating Gradient Synchrotron (AGS) and finally RHIC. To optimize the polarization of the beam it is critical to measure the polarization along the acceleration chain. During normal operation the polarization can be measured at 4 points; the end of the 200 MeV Linac, in the AGS with a p-Carbon Coulomb Nuclear Interference (CNI) polarimeter [1] and in RHIC using either the CNI polarimeter or the polarized Hydrogen Jet [2]. The location of the polarimeters and acceleration scheme are shown in Figure 1.

The polarized H jet gives an absolute polarization measurement but requires several hours to gather enough statistics. The CNI polarimeter works by detecting the left-right asymmetry of low energy recoil carbon atoms knocked out of thin carbon targets by the polarized proton beam. A measurement with the CNI polarimeter only requires a few seconds to complete, however the analyzing power must be calibrated using the polarized H jet. The relatively quick polarization measurements of the CNI polarimeters have been very valuable in optimizing accelerator parameters to maximize the polarization of the proton beam. Both the AGS and RHIC CNI polarimeters rely on thin carbon targets. The AGS targets are 4 $\mu g/cm^2$ thick (25-30 nm), 50 mm long and either 75 μm, 125 μm or 250 μm wide. The width of the target controls the event rate in the detectors. The RHIC targets have the same thickness (25-30 nm), a length of 25 mm and a width of <10 μm. Both the AGS and RHIC targets are produced by evaporating carbon through a mask onto a substrate [3 - 5].The width of the target is determined by the mask used and the thickness is determined by the length of the evaporation time. In recent years there has been a demand for more specialty targets to better understand the detectors. The target lifetime in RHIC has also become an issue as the beam energy has increased and the beam size has decreased.

5 mm Wide Strip Targets

One of the issues with the carbon micro-ribbon targets are that the orientation of the target to the detectors varies from target to target. The targets usually are twisted along the length of the target, which changes their orientation with respect to the detector. This causes the low energy carbon atoms knocked out by the proton beam to have varying path lengths through the carbon which results in a large energy spread. In order to evaluate the significance of this, a 5 mm wide strip target was made with a known orientation to the detector. The ends of the target frame were bent ~22 degrees to ensure that the target was ~45 degrees with respect to the detectors.

To make the strip target, the frame was mounted in a jig that closed the two open sides of the frame. A 4 $\mu g/cm^2$ Laser Plasma Ablation (LPA) foil [6] was then floated and mounted over the opening. Once the foil had dried the foil was cut using a laser cutter and the frame was removed from the jig. The result was a 5 mm wide strip target with two open edges (Figure 2). Several targets were produced in this manner both for the RHIC and AGS polarimeters.

Twisted Targets

Another method to investigate the effect of target angle was to produce highly twisted carbon micro-ribbon targets. Although in theory the same method could be used to produce untwisted targets, in reality it is very difficult to know exactly when there are no twists along the length of the target. So the solution was to produce targets with several hundred twists to average the target angle over the beam spot.

The micro-ribbon targets were produced as previously described [3 - 5] and hung under the laminar flow hood. The free end was then fixed to a 20 μm wire attached to a 15 mm wooden applicator inserted into an electric drill chuck that was attached to a hand crank with a counter. The drill chuck could then be slowly turned by hand to induce the desired number of turns in the target. As the number of turns imparted to the target increased the length of the target decreased. To compensate for the decreased length without putting tension on the target the drill chuck was occasionally raised by means of a lab jack. The result can be seen in Figure 3. Usually 100 to 300 turns could be imparted to the target without breaking it.

RHIC Target Lifetime

In the past, the average lifetime of a RHIC polarimeter carbon micro-ribbon target was 1-2 weeks. However, increases in beam energy and decreases in beam size have resulted in a dramatic decrease in average target lifetime. For the 2011 experimental run, 12 of the 48 targets survived the entire period. For the 2012 experiment, the targets needed to be replaced twice during the experimental running period resulting in additional work and lost beam time. In order to better understand the environment of the RHIC targets a camera was installed to observe the targets as they pass through the beam. The video showed the targets being heated to extreme temperatures and being distorted by the electrostatic forces of the beam. A captured frame from the video can be seen in Figure 4.

Analysis of the 2011 target lifetime data is shown in Figure 5. It shows a high degree of variability in the number of measurements per target. Although two targets were used for over 300 measurements, 20 targets were used for less than 50 measurements. Targets that were used for less than 10 measurements and were still useable were excluded from the lifetime data. Breaking down the data of those targets used for less than 50 measurements further (Figure 6), shows that 12 (or 25%) of the targets were used for less than 10 measurements before they broke.

A possible explanation for the large number of targets that broke after less than 10 measurements is charge accumulation due to high electrical resistance of the target. Lozowski et al. [4] traced a similar problem to high contact resistance between the target and the frame due to an adhesive. After looking at the target resistance with a variety of frame materials and different adhesives it was found that the resistance of the carbon micro-ribbons themselves was between 200 MΩ and 800 MΩ. Carbon micro-ribbon targets that were exposed to the beam had a resistance of ~1 MΩ. This difference may be due to graphitization of the carbon target by the extreme heating of the target when exposed to the beam as seen in the video.

A literature search revealed several techniques to graphitize carbon stripper foils [7 - 9]. To date several of these methods have been tried and the results are listed below. The targets were heated by placing them close to a tungsten strip in the vacuum chamber. The tungsten was heated to white hot by passing a current of 150 amperes at 7.5 volts through it. The resulting targets were very fragile and broke when the chamber was vented. It was also attempted to anneal the targets with an electron beam of 10 mA and 5 kV. This method broke 90% of the targets tested. The one surviving target showed a decrease of resistance to ~4MΩ, however, the large percentage of targets broken made this method impractical for large scale operation. The final method used was to expose the targets to high intensity light using a camera flash. For the wider AGS targets this resulted in a reduction in resistance to ~0.3 MΩ. The results however, were inconsistent. Sometimes multiple flashes were required to reduce the resistance below 1 MΩ and the camera flash had no effect on the resistance of the narrower RHIC targets.

Additional methods to anneal the targets need to be investigated. These additional methods include heating the targets with a laser, baking the targets in a vacuum oven, heating the targets by passing an electrical current through them and also the use of a more powerful camera flash.

Conclusion

The CNI polarimeters in RHIC and AGS are critical to the acceleration of polarized proton in RHIC. Different target designs were developed to help understand the effect of target orientation relative to the detector. Wide strip targets, for both the AGS and RHIC polarimeters, were produced using a jig and a laser cutter. Also a technique that could produce highly twisted targets was developed. The wide strip targets and the twisted targets were used during the 2012 experimental run.

The lifetime of the RHIC polarimeter targets for the 2011 and 2012 experimental runs were shorter than in previous years. Data for the 2011 experiment showed some targets being used for hundreds of measurements while 25% were used only 10 times before they broke. Analysis of surviving targets showed that those targets exposed to the beam had their resistance lowered by a factor of more than 200. It is hoped that by reducing the resistance before the targets are exposed to the beam will lead to longer lifetimes. Further development of a production method to reduce the resistance of all targets is continuing.

Acknowledgments

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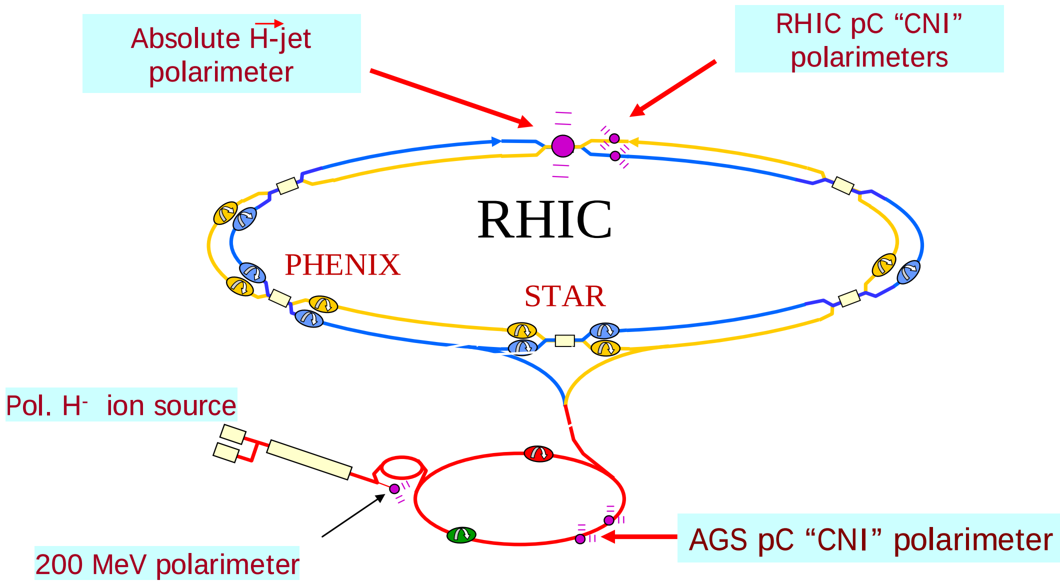

Figure 1: Polarimeter locations and acceleration scheme used for polarized protons in RHIC.

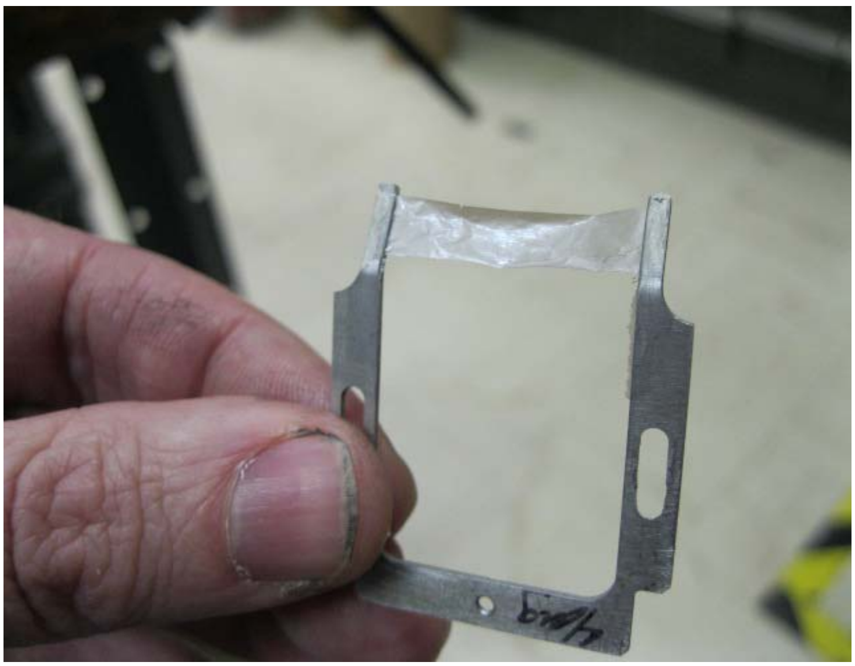

Figure 2: A 5 mm wide strip target with the ends angled.

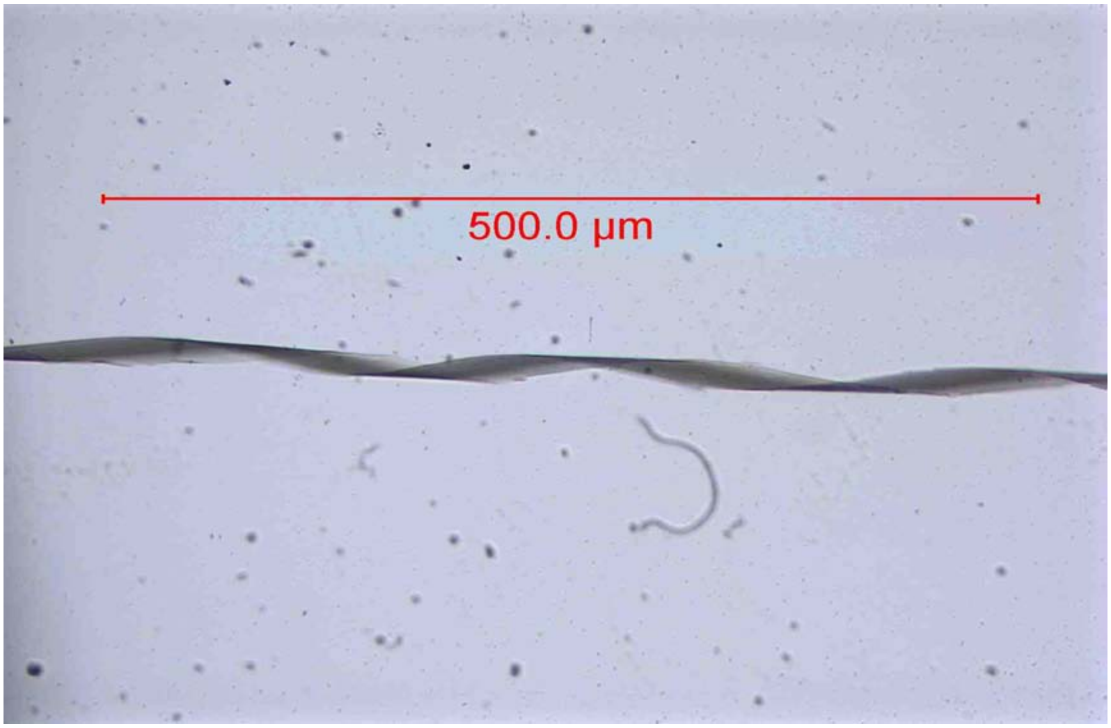

Figure 3: Twisted RHIC target with 100 turns shown at 200X magnification.

Figure 4: Frame from video showing a RHIC target heated and distorted by the proton beam.

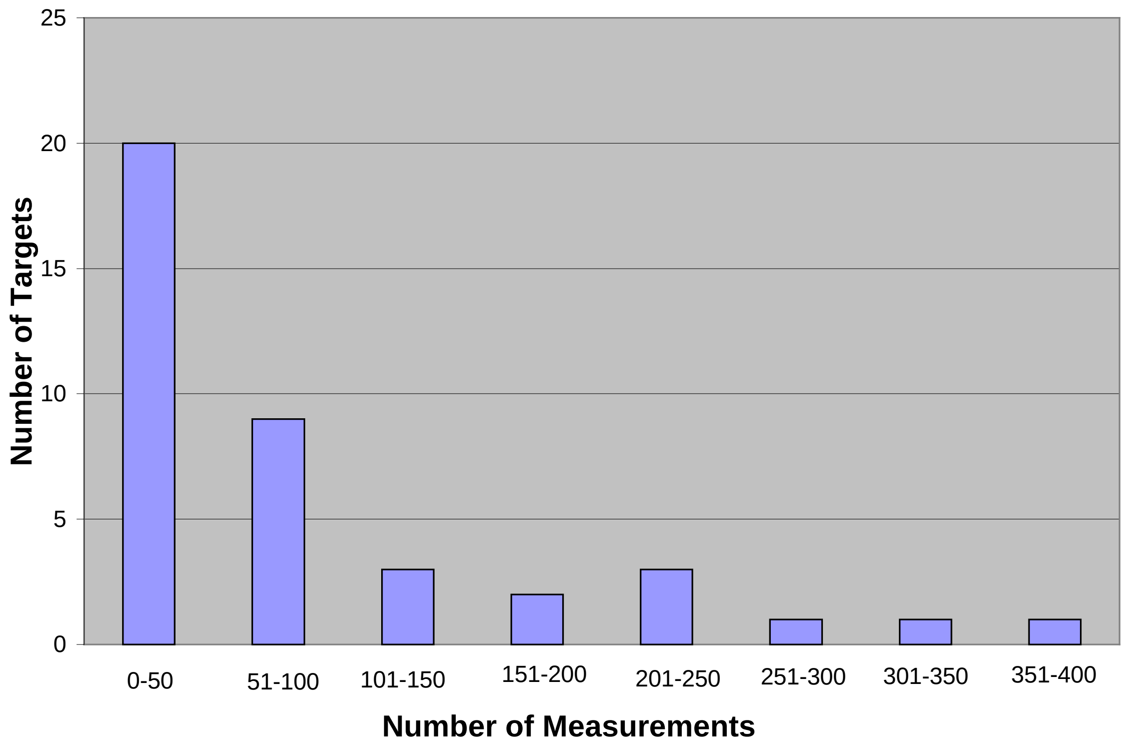

Figure 5: Target lifetime data for 2011, showing how many times a target was used for measurements. Those targets that were used for less than 10 measurements and were still useable were excluded from the data.

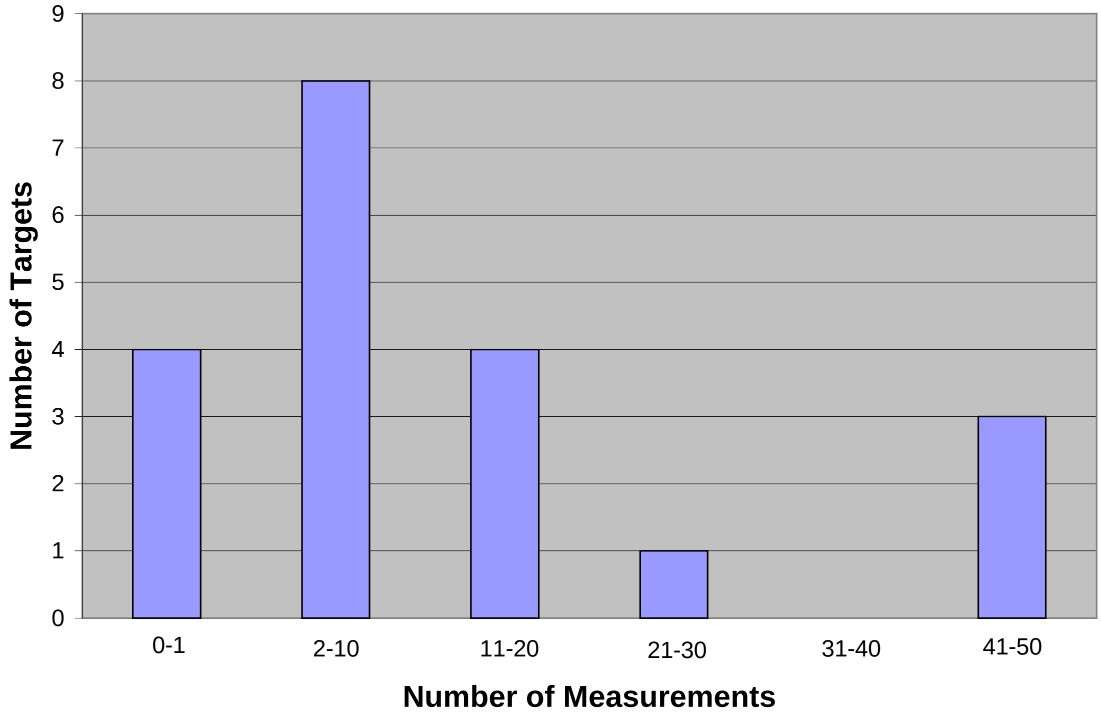

Figure 6: Target lifetime data for those targets used for 50 or less measurements. Again the surviving targets used less than 10 times were excluded from the data.