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polarimeter***

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Improvements of the target lifetime in the RHIC polarimeter

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Abstract

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) is the only collider in the world to collide polarized protons. It is critical to the RHIC experimental program that the polarization of the proton beam is measured. This is accomplished with the Coulomb Nuclear Interference (CNI) polarimeter. The targets used in the RHIC CNI polarimeter are 50 nm thick, 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 decreased dramatically. During the 2013 polarized proton experimental run, the targets needed to be replaced twice. This resulted in additional work and lost beam time. Before the 2015 experimental run, metal shields were installed around the ends of the targets which greatly improved the target lifetime. The results from the 2015 experimental run and plans for the 2017 experimental run will be discussed.

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1. Introduction

The spin physics program at RHIC offers unique opportunities to understand the spin of the proton. In order to maximize the polarization of the stored proton beam in RHIC it is critical to measure the polarization along the acceleration chain. The beam polarization can be measured at the 4 polarimeters located as follows; at the end of the 200 MeV Linac, in the Alternating Gradient Synchrotron (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] (see Figure 1).

The polarized H jet gives an absolute polarization measurement but requires ~8 hours to gather enough events to achieve low statistical errors of 2-3%. In contrast, a measurement with the CNI polarimeter, which measures the beam polarization by detecting the asymmetry of low energy recoil carbon atoms knocked out of thin carbon targets by the polarized protons,

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only requires a few seconds. The analyzing power of the CNI polarimeter must be calibrated using the polarized H jet. The quick polarization measurements of the CNI polarimeters allows the optimization of accelerator parameters to maximize the polarization of the proton beam.

Figure 1: Polarimeter locations in the accelerator chain used to inject polarized protons in RHIC.

The RHIC CNI polarimeter relies on thin carbon targets with a thickness of 50 nm, a length of 25 mm and a width of $<10\ \mu\text{m}$. The 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 and the thickness is measured using a quartz crystal monitor.

Two identical polarimeter vacuum chambers are situated in the warm section of RHIC, one in each ring. Each vacuum chamber contains 2 polarimeters with target ladders in the horizontal and vertical plane for a total of 8 target ladders (Figure 2). Each target ladder holds 6 targets for a total of 48 targets in both rings.

Figure 2: Drawing of one of the polarimeter vacuum chambers with the vertical target ladders shown.

In recent years the target lifetime in RHIC has decreased as the beam luminosity has increased. Replacing the targets during the 20 week experimental run is disruptive to the research program and needs to be avoided if possible. A large effort was recently devoted to understand the failure mechanism of the targets and what could be done to increase the target lifetime.

2. Target life time data 2009 - 2013

During the 2009 and 2011 polarized proton runs, one set of 48 targets lasted the entire experimental period. However in 2012 and 2013, the set of 48 targets needed to be replaced twice, requiring venting of the polarimeter vacuum chamber, resulting in lost experimental time and additional manpower costs. In order to better understand the failure mechanism video cameras were installed on the viewports of the polarimeter chambers to observe the targets during polarization measurements.

The video camera images showed that the targets were greatly deformed during the polarization scan (Figure 3) due to the electric field of the beam. This results in the excess length of loose targets being attracted to the center of the beam and also additional stress on the targets.

Figure 3: Overhead view of a horizontal target intercepting a polarized proton beam moving from the bottom to the top of the figure. Polarimeter target distorted by the electric field of the beam.

Another observation from the video cameras was the high temperature to which the targets are heated when interacting with the beam. Simulations had shown that the equilibrium temperature of the target would be approximately 1800° K so it was not surprising to see the center of the target glowing white hot when crossing the beam. What was more surprising was to see the ends of the targets also glowing even when the target was not intercepting the beam (Figure 4). The ends of neighboring targets could also be seen to be glowing.

A possible explanation of target ends glowing is induced electric-magnetic fields due to the beam. The targets act like an antenna and the induced high frequency electric fields from the beam could move electrons along the target length, resulting in resistive heating. At the collider store energy, a 200 MHz cavity is turned on to shorten the beam pulse length and increase the luminosity. The higher peak currents associated with the shorter bunch length should exacerbate the end heating of the targets. It was observed that the end of the targets would cease to glow when the voltage of the 200 MHz cavity was reduced. This observation is consistent with the idea of induced fields in the target.

Figure 4: The ends of the target glowing before the target intercepts the beam.

Analyzing the target usage data from the 2011 polarized proton experimental run, a great variation in the target lifetime was observed. Although 6 targets had been used for over 200 measurements, 28 targets were used for fewer than 50 measurements before breaking (Figure 5). Analyzing these 28 targets further, it was found that 21 targets (44%) were used for less than 10 measurements before target failure (Figure 6). Similar results were obtained with the 3 sets of targets used during the 2013 run, with respectively 23, 18 and 19 of the three sets of 48 targets surviving less than 10 measurements. The average number of measurements per target was approximately 27 despite several targets lasting over 100 measurements and one surviving 228 measurements.

Figure 5: The number of measurements per target for the 2011 experimental run.

Figure 6: Distribution of those targets used for less than 50 measurements.

After removal from the vacuum chamber the broken targets were inspected under a high power microscope. It was observed that 2/3 of the targets were broken at one of the target ends and the rest were either broken in the middle or it could not be determined where the target broke. This was additional evidence that the heating at the ends -was prematurely weakening the targets.

3. Simulation and testing target fins

Simulations were performed using CST-studio [6] to see if the ends of the targets could be shielded from the beam induced fields. It was found that by adding rounded fins to the ends of the targets the electric fields could be greatly reduced (Figure 7).

Figure 7: Showing the simulated reduction in induced electric field with and without fins

To test these results several targets with and without the added fins were installed during the 2014 experimental run. No polarized proton running was planned during 2014, but an Au beam of similar charge intensity could be used to simulate the proton beam. Targets with and without the added fins were position 1.5 cm away from the Au beam and the resulting glow of the targets ends was observed. Figure 8 clearly illustrates that the resulting heating was greater for the target without the fins.

Figure 8: The target ends glowing a) without and b) with fins when the polarimeter target was parked 1.5 cm from the Au beam in RHIC

4. 2015 Target lifetime results

Before the 2015 polarized proton run, the fins were reengineered (Figure 9a) to be 12.5 mm diameter and 3 mm thick. For ease of installation, the fins slip over the target frame ends after the target is mounted and held in place with a set screw. The diameter of the fin was limited to 12.5 mm to prevent shadowing of the recoil carbon ions from the targets on the polarimeter detectors (Figure 9b). Because of the limited space only 4 of the 6 targets on each ladder could accommodate fins. The two bottom positions did not have fins installed.

Figure 9: Reengineered fins a) and b) installed on the polarimeter target frames.

The results of adding the fins was dramatic. The targets with the fins installed had less heating of the targets ends as indicated by less glowing. The average lifetime of the targets with fins was 142 measurements per target while the lifetime of those targets without fins was 53 measurements. Only 4 targets with fins broke with fewer than 20 measurements and one target survived 396 measurements. Most importantly, only one set of 48 targets was needed for the entire 2015 experimental run.

5. Conclusion

By adding the fins to the end of the polarimeter targets we have significantly reduced the beam induced heating of the ends of the targets and have significantly increased the target lifetime. The average number of measurements before target failure increased from 27 in 2013 to 142 measurements in 2015 for those targets with fins installed. For the upcoming 2017 polarized proton experimental run the fins will again be installed on 4 of the 6 polarimeter targets as was done in 2015.

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