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# *Stripping foils at RHIC*

**D.B. Steski, P. Thieberger**

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**Collider-Accelerator Department**

**Brookhaven National Laboratory**
P.O. Box 5000
Upton, NY 11973-5000
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# Stripping foils at RHIC

**D.B. Steski*, P. Thieberger**

*Brookhaven National Laboratory, Upton, NY 11973, USA*

Abstract

There are two major science programs at the Relativistic Heavy Ion Collider (RHIC). These are the heavy ion program, which collides beams of fully stripped ions, and the polarized proton program. A wide variety of stripper foils and carbon targets are used throughout the RHIC accelerator chain to facilitate these collisions. Each stripper and target has unique properties and functions. Those characteristics will be discussed, as well as recent efforts to improve their performance.

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*Keywords:* Carbon-C, Micro-ribbon target; Vacuum deposition

## 1. Introduction

There are two distinct programs at the Relativistic Heavy Ion Collider (RHIC), each with its own requirement for stripper foils and targets. Ion beams for the Heavy Ion Program originate at the Tandem Van de Graaff and collide fully-stripped ions in RHIC. This program has mainly collided gold ions but has also collided copper ions and deuterons-on- gold ions. The discussion of stripper foils will be confined to the gold-on- gold collisions since this comprises the majority of the program and also is the most challenging with regards to stripper foils.

The beam for the Polarized Proton Program originates at the Linear Accelerator (Linac) and passes through a single stripper foil as it is injected into the Booster Synchrotron. However, two thin carbon targets are used periodically to measure the polarization of the proton beam in the accelerator chain. The characteristics of these targets will be presented, as well as recent attempts to improve the Linac-to-Booster (LTB) stripper used for polarized protons.

## 2. Heavy Ion Program

The gold ions pass through four stripping locations (Fig. 1) before injection into RHIC. These ions begin in the −1 charge state and are accelerated to the center terminal of the tandem Van de Graaff. In the center terminal, the gold ions pass through the first stripper (S1) and are stripped to the +12 charge state. After acceleration back to ground potential

* Corresponding author. Tel +1 631 344 4581 fax: +1 631 344 4583
E-mail address: Steski@bnl.gov (D.B. Steski)

the approximately 1 MeV/nucleon gold ions pass through the second stripper (S2) at the object point of a pair of 90° double focusing bending magnets. After the stripper the bending magnet selects the +31 charge state.

The $Au^{+31}$ ions are injected into the Booster Synchrotron for further acceleration. After acceleration to approximately 100 MeV/nucleon, the beam is extracted from the Booster into the Booster-to-AGS (BTA) transfer line. In BTA the gold ions are stripped again (S3) to the +77 charge state. After acceleration in the AGS the ~10 GeV/nucleon gold ions pass through the final stripping stage (S4) and are injected into RHIC as fully-stripped Au ions. Each stripping stage will be discussed in more detail.

## 2.1. Terminal Stripping (S1)

The first stripping stage is the most difficult. The terminal stripper is located in the high voltage terminal, inside the pressure vessel of the Tandem Van de Graaff. For acceleration of Au ions the terminal is held at 14 MV. The stripping foil is a 2 $\mu g/cm^2$ carbon foil mounted on a 22 mm × 9.4 mm rectangular frame. The carbon is coated with collodion [1] to give it strength during the mounting procedure. This foil strips the negative Au ions to $Au^{+12}$ with an efficiency of approximately 20%.

Because of the low energy of the Au ions, the carbon foils become unusable after only a short exposure to beam. In order to avoid unacceptable run delays, many steps have been taken over the years to increase the number of foils and their lifetime. There are two foil ladders mounted in the center terminal, each capable of holding 300 foils. The foils are oscillated perpendicularly to the ion beam to spread the beam exposure over a wider area and increase the foil lifetime by a factor of 3. The period of oscillation is 1 minute.

Recently, the foil lifetime was improved by almost a factor of 3 by changing the type of carbon used for the stripper. Prior to the last experimental run, the foils were made by the Arc Discharge (AD) method. The foil consumption rate was 10-12 foils/day, depending on beam usage. The Arc Discharge foils were replaced with Laser Plasma Ablation (LPA) [2] foils and the foil lifetime increased dramatically. Figure 2 compares the integrated beam current (in arbitrary units) of 6 AD foils versus 5 LPA foils. The integrated current was measured by a beam transformer downstream of the 90° bending magnets and was reset to zero for each new foil inserted into the beam. As can be seen from figure 2, the integrated current for the AD foils corresponds to approximately 9000 –10,000 counts, while the integrated current for the LPA foils averaged about 25,000 counts. Calibrating the beam transformer and accounting for the stripping efficiencies of S1 and S2, the AD foils stripped $1.2x10^{15}$ gold ions before failure while the LPA foils stripped $3.1x10^{15}$ gold ions. With the LPA foils the consumption rate dropped to 3-4 foils/day and beam reliability has dramatically improved.

## 2.2. Object Foil (S2)

The second stripping stage, which is located outside of the pressure vessel at ground potential, strips the $Au^{+12}$ ions to $Au^{+31}$. The stripping efficiency is approximately 15%.

Because of the higher beam energy the foil lifetime is typically 3-4 days. The object foils are made using the Arc Discharge (AD) method and coated with collodion [1] for strength. They are 8 μg/cm² carbon mounted on a frame with a 19 mm diameter aperture.

The foil ladder contains 110 foils and is oscillated perpendicularly to the beam to increase the lifetime. Unlike the terminal foil oscillator, the object foil oscillator is variable with control of the speed and amplitude of the oscillation. Because the object foils are located at ground potential, the foils can be changed in an 8-hour maintenance period, if required. As with S1, the lifetime of the object foils might very well be increased dramatically if the AD foils were replaced with LPA foils, but this has not been tested.

### 2.3. BTA foil (S3)

The third stripping stage, located between the Booster Synchrotron and the Alternating Gradient Synchrotron (AGS), strips the $Au^{+31}$ to $Au^{+77}$ with 65% efficiency. This stripper, originally a 24.2 mg/cm² carbon foil, has been replaced with a stripper composed of a 6.4 mg/cm² Al foil followed by a 9.2 mg/cm² vitreous carbon foil [3]. The issue was not lifetime, as the old carbon foils lasted many years in this location, but energy loss in the foil and foil uniformity. Using the new Al-C combination foil resulted in 1/3 less energy loss and reduced the energy spread from 92 MeV to 32 MeV. This resulted in an overall increase in the transfer efficiency from 53% to 58% and in higher RHIC luminosity, due mostly to the reduced energy spread.

### 2.4. ATR Foil (S4)

The final stripping stage is located between the AGS and RHIC. It removes the last two electrons from the $Au^{+77}$ ions, resulting in $Au^{+79}$ with an efficiency of 99.8%. Recently, the old 522 mg/cm² $Al_2O_3$ stripper was replaced with a much thinner 48.9 mg/cm² tungsten foil [3]. The new stripper has reduced the angular spread by 50% and has reduced the losses due to nuclear fragmentation from 4% to 0.1%.

## 3. Polarized Protons

In contrast to the acceleration of gold ions, the polarized proton beam passes through a single stripping stage located in the Booster Synchrotron. It converts the polarized $H^-$ from the Linac to polarized protons for injection into the Booster. In addition to the Linac-to-Booster (LTB) stripper, thin carbon films are used at two other locations in coulomb-nuclear-interference (CNI) polarimeters to measure the polarization of the proton beam.

### 3.1. LTB Stripper

The polarized protons are injected into the Booster by passing the polarized $H^-$ beam through a 100 μg/cm² carbon foil. The carbon foil was made using the Arc Discharge method and has been reliably used for many years.

Recently it was suggested [4] to customize the geometry of the foil to reduce scatter of the proton beam during the multi-turn injection of the proton beam. The idea is to minimize the size of the foil to reduce the number of circulating particles hitting the foil during injection. Two foils have been made using diamond-like carbon (DLC) foils from the TRIUMF Carbon Foil Laboratory [5]. One foil is a 30 mm × 50 mm strip and the second is a 20mm × 30mm rectangle supported by four 5 mm wide legs (figure 3). Both of these foils were produced by gluing a 65 mm × 50 mm × 100 μg/cm2 carbon foil to the frame and then using a high-powered laser to cut the desired geometry. Because the polarized proton beam makes several passes through the foil during the multi-turn injection process, by customizing the foil geometry it is hoped that scattering due to the foil will be reduced and the emittance growth of the ion beam limited. These new foils will be tested in the spring of 2009.

### 3.2. AGS Polarimeter targets

The Coulomb Nuclear Interference (CNI) polarimeter [6] in the AGS uses thin carbon ribbons to measure the polarization of the proton beam in the AGS. The AGS polarimeter targets are 4 $\mu g/cm^2$ thick and 50 mm long. The width of the ribbon is controlled by the width of the evaporation mask used. To present, three different ribbon widths have been produced (125 μm, 250 μm and 600 μm). The lifetime of these targets is several months. The technique for producing these ribbons is relatively easy and has been described elsewhere [7].

### 3.3. RHIC Polarimeter targets

There is a similar CNI polarimeter [6] in RHIC for measuring the polarization of the beam; however, to limit the count rate in the detectors, the width of the carbon ribbons is much narrower. The RHIC polarimeter targets are 4 $\mu g/cm^2$ thick, but only 25 mm long and approximately 6-10 μm wide. Because of the small width, the production [7] of these targets is very challenging and development is ongoing to increase the efficiency of the process.

The lifetime of these ribbons is only 1-2 weeks which posses a problem for extended experimental runs. In order to overcome this limitation a second CNI polarimeter has been installed in each ring. Each polarimeter holds 12 ribbons (6 horizontal and 6 vertical) for a total of 24 ribbons in each ring.

## 4. Conclusion.

The RHIC accelerator chain employs a wide variety of strippers and thin targets to characterize and collide the beams in RHIC. In recent years there has been a concerted effort to improve foil lifetime and performance. Careful selection of the stripper material and its thickness has resulted in longer foil lifetimes, reduced beam scattering and improved overall efficiencies. This effort is continuing with the new LTB foils that will be tested in 2009.

**References**


[1] Collodion, Flexible, Mallinckrodt Baker Inc., Phillipsburg, NJ, 08865
[2] P. Maier-Komor et al., Nucl. Inst. Meth. A438 (1999) 73-78
[3] P. Thieberger et al., Phys. Rev. ST Accel. Beams 11, 011001 (2008)
[4] Deepak Raparia (private communication)
[5] TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, Canada, V6T 2A3
[6] H. Huang et al., proceedings EPAC 2008 to be published
[7] W.R. Lozowski et al., Nucl. Inst. Meth. A 590 (2008) 157-163

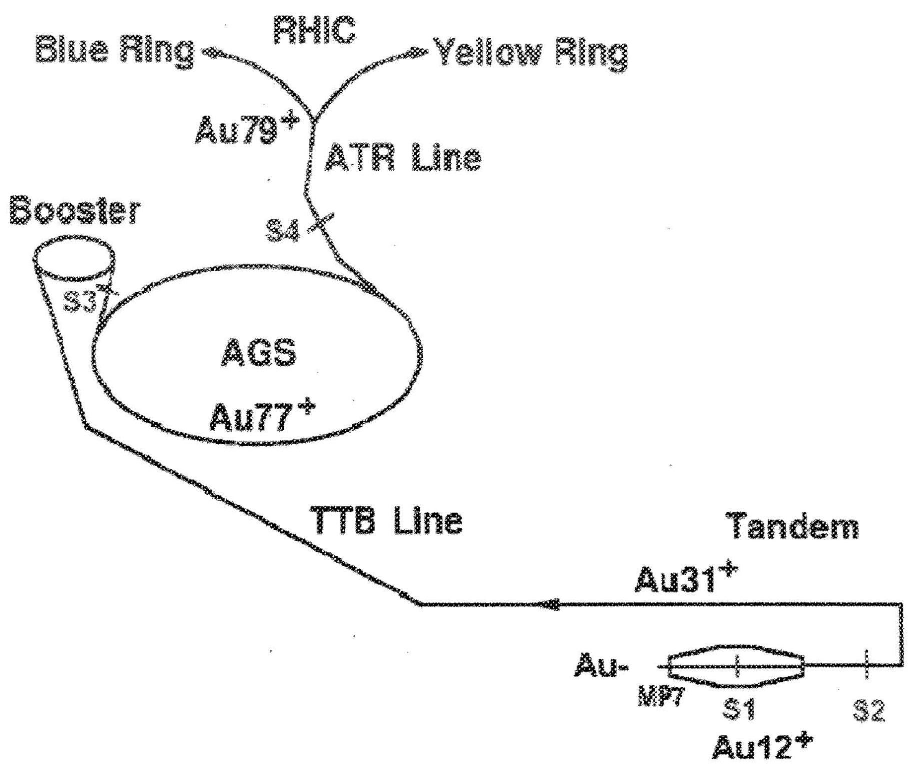


Figure1: Acceleration Scheme of Au ions with stripping locations labeled

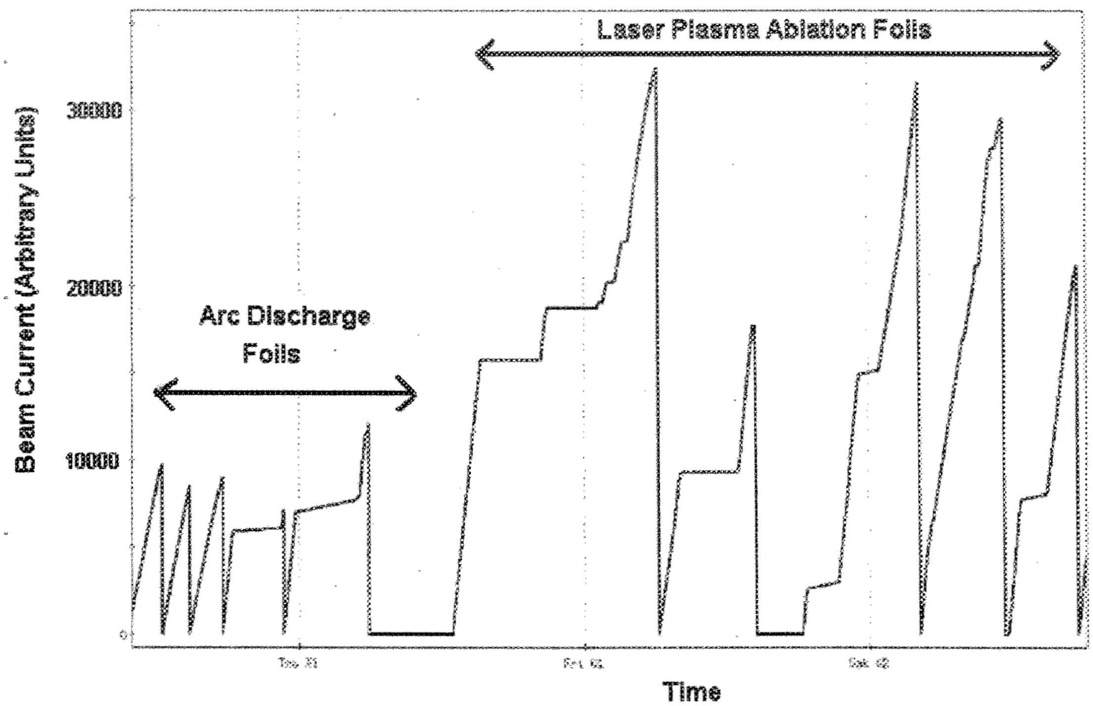


Figure 2: Integrated beam current for Arc Discharge Foils and LPA foils

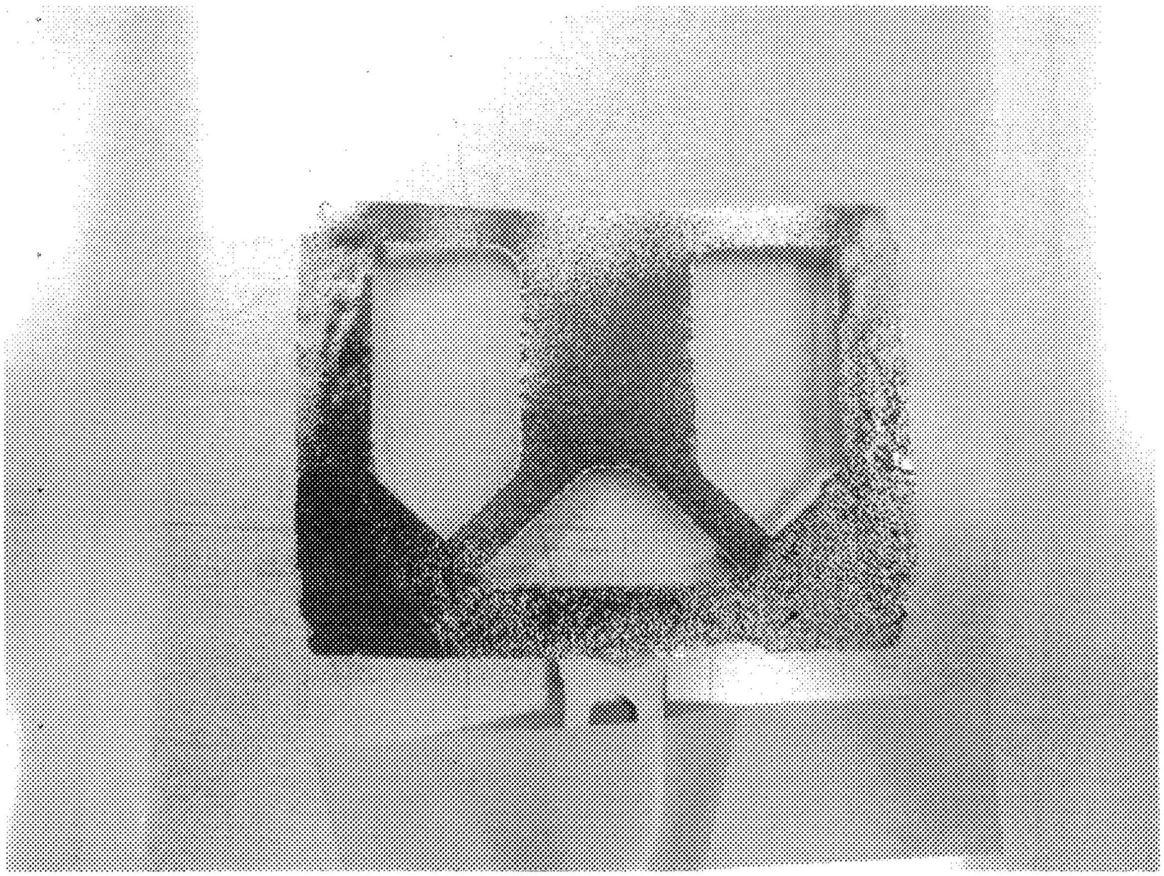

Figure 3: New LTB foil with customized geometry with overall dimensions of 30 mm × 20 mm attached to the foil frame by 5mm wide legs.