THE RHIC HYDROGEN JET LUMINESCENCE MONITOR*

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Abstract

A hydrogen jet polarimeter was developed for the RHIC accelerator to improve the process of measuring polarization. Particle beams intersecting with gas molecules can produce light by the process known as luminescence. This light can then be focused, collected, and processed giving important information such as size, position, emittance, motion, and other parameters. The RHIC hydrogen jet polarimeter was modified in 2005 with specialized optics, vacuum windows, light transport, and a new camera system making it possible to monitor the luminescence produced by polarized protons intersecting the hydrogen beam. This paper describes the configuration and preliminary measurements taken using the RHIC hydrogen jet polarimeter as a luminescence monitor.

INTRODUCTION

Luminescence is the production of light without heat. From the earliest days of partially evacuated glass tubes it was observed that light would be emitted if the tube was placed near a sparking electric source. This phenomenon was dubbed “electric light” [1]. Light is produced when electrons surrounding the gas atoms return to their initial state after excitation. There are several spectral series of these emitted photons including the Lyman, Paschen, and Balmer; each with characteristic amplitude and frequency. These series are dependent upon the amount and composition of the gas, as well as the level of excitation. The gas source can be injected or residual and the characteristic spectra are well documented.

A hydrogen jet polarimeter was added to RHIC to calibrate the existing Coulomb Nuclear Scattering (CNI) polarimeters in 2004 [2]. The polarimeter produces a free atomic hydrogen jet beam which crosses the RHIC beam at the interaction region. Polarization is determined by proton scattering as measured by silicon recoil detectors. It was postulated that the circulating polarized proton beam interacting with the hydrogen in the jet would also produce light. The polarimeter was modified and an external structure was added to collect and measure the light. Several iterations produced the interesting results presented here.

JET OPERATION

The jet polarimeter is located in the 12 o’clock region of RHIC at the center of the two intersecting beam paths. The purpose of the jet is to measure polarization by elastic collisions. The hydrogen jet polarimeter consists of 3 major stages [3] arranged as a series of a vertical vacuum chambers (Figure 1).

The top 5 vacuum chambers make up the Atomic Beam Source (ABS) followed by the scattering region. The lower 3 chambers make up the Breit-Rabi polarimeter.

A brief summary of the operation is presented here: For the ABS, hydrogen enters the top of the polarimeter and into the dissociator. Portions of the tube are cooled with a water jacket. This dissociator is a design enhanced by the addition of a high power Leybold 120RGS cryocooler. This cools the last 12 cm of the dissociator to 60K which enhances performance. A combination of RF and spin flipping magnets dissociate the diatomic hydrogen into a polarized atomic beam.

The exit of the ABS nozzle is 120cm from the RHIC beam interaction region. In the intersecting region, both beams arrive at the same time and are intentionally separated by 10mm on the diagonal to avoid collision. The entire jet assembly can be moved horizontally to position the hydrogen jet beam with respect to the intersecting RHIC beams. The polarization of each beam can be measured individually.

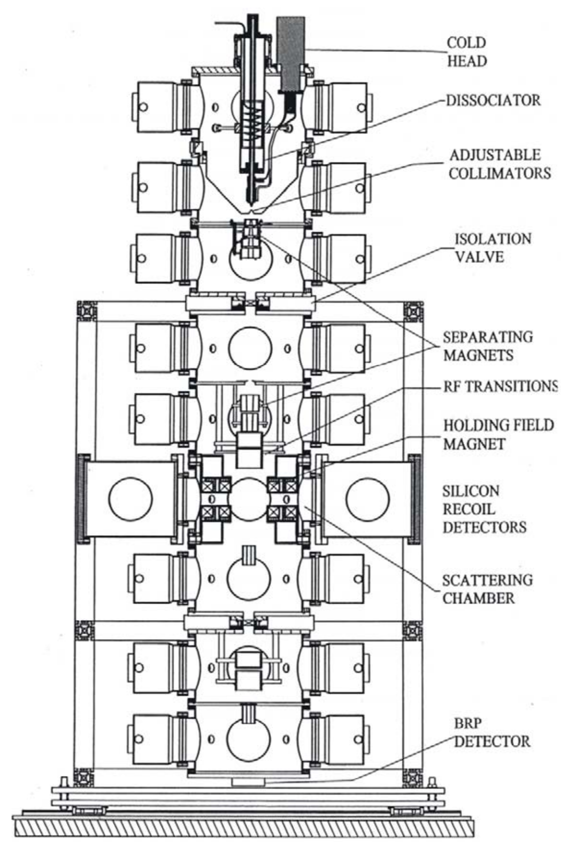

Figure 1: Hydrogen jet polarimeter layout.

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The Breit Rabi polarimeter measures the hydrogen jet polarization to be 95.1% with a theoretical limit of 96.1%. For the purposes of the luminescence monitor, the cross section of the atomic hydrogen beam is most important. The cross section of the beam is measured to be 5.5 mm measured by compression tube [4]. The tube is scanned across the beam. Inside the tube, the hydrogen atoms recombine to form diatomic hydrogen and the pressure rise is measured. A second verification of the beam geometry is found by scanning the RHIC beam across the jet and has confirmed the measurement with the compression tube. The cross section is shown in Figure 2. The purity of the atomic beam is $H^0/(H2+ H^{0)}$ is 98.5%. Other impurities such as water and oxygen are present and have not yet been accurately measured.

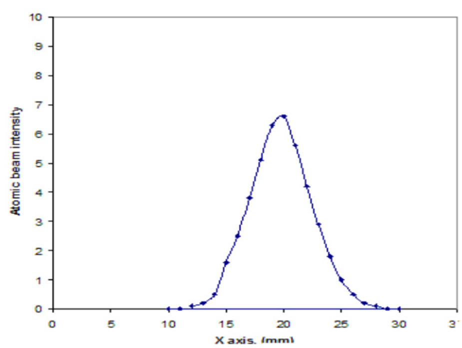

Figure 2: Atomic beam profile.

LUMINESCENCE MONITOR

Concept and Initial Tests

The spectral lines of hydrogen are well documented with primary peaks in the Balmer series at 434nm, 486.0nm, and 656.2nm. What was not known for this experiment was the anticipated number of photons for the 100GeV polarized proton beam. Initially, several iterations were attempted to collect light by various methods [5]. Ultimately, a Mead Pictor 416 XT astronomical Peltier cooled imager was selected due its sensitivity at the desired frequency spectrum. The imager can reach a temperature of -12^0C.

The camera was temporarily mounted in a light tight enclosure on the side of the jet scattering chamber for proof of principle. The jet enclosure was modified by replacing a blank off port with a quartz window. Figure 3 shows the initial configuration. Several images were taken successfully that were produced from the luminescence of the hydrogen beam (Figure 4). Some images were taken over the course of several minutes showing relative motion of the "blue" and "yellow" beams. The camera was then removed and taken to the lab for calibration.

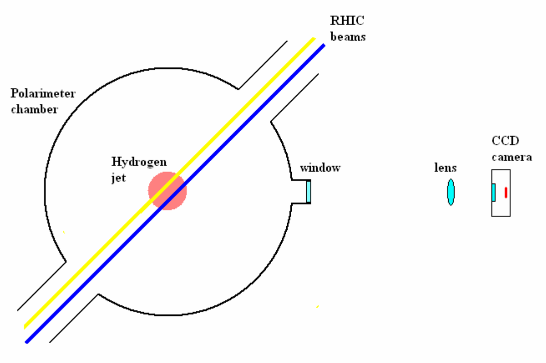

Figure 3: Initial configuration.

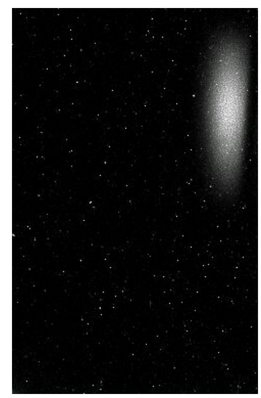

Figure 4: RHIC first beam data.

Calibration

A preliminary optics layout was designed and a mockup was built to test the camera's sensitivity (Figure 5). The camera was tested with a fiber coupled 650 nm LED to determine photon sensitivity of the entire optical system. It was discovered the CCD was damaged and condensation formed when the unit cooled down. In addition, the proper orientation of the image was determined. Although the original images were interesting, they could not be calibrated to determine the exact number of photons and the interaction cross section. The camera was returned for repair and upgrade that included replacement of the CCD with a newer model making it equivalent to the Pictor 416 XTE and replacement of the desiccant element. The camera sensitivity was measured upon return.

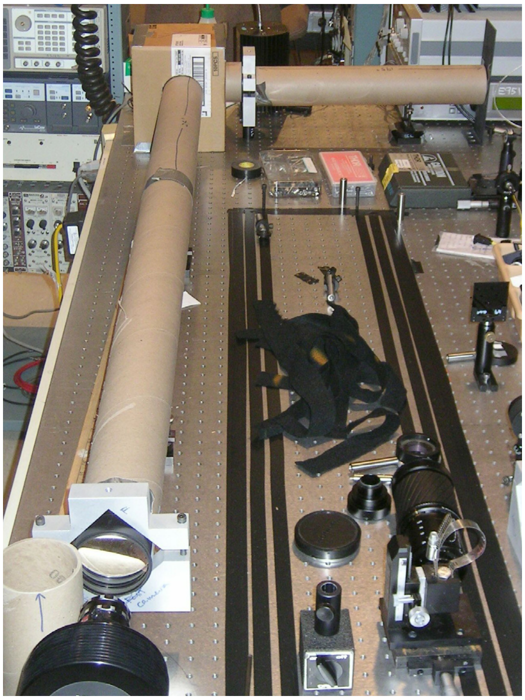

Figure 5: Camera calibration setup.

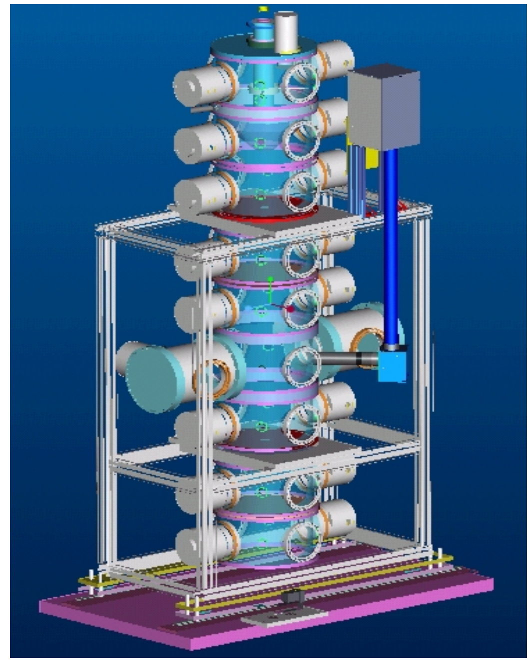

Figure 6: Jet with external modification.

Optics and Modification to Jet

There were several parameters that drove the optics design [6,7]: (1) The camera needed to be a sufficient distance from the centerline of the beam to reduce radiation damage.; (2) The field of view needed to be several centimeters with a magnification of .25 to view both of the RHIC beams with some room for alignment error; (3) The eye relief needed to be several centimeters to allow a filter wheel between the last lens and the camera.

Based on the physical geometry of the hydrogen jet and available mounting locations, the resulting design ended up with a total optical path length of 247.5 cm, an effective focal length of 10 cm and a magnification of .25. A single first-surface elliptical mirror installed at a 45 degree angle was necessary to place the camera up more than 1.5m from the beam centerline (Figure 6).

Once mounted on the polarimeter, calibration of the optics system was difficult, as there was no physical object in the center of the chamber upon which to focus. However, there was an RF image-current carrier composed of a box with wires to either side of center. Based on calculations of the optics system and images obtained of the near and far wires, a theoretical center-focus was determined and used for beam studies (Figure 7).

The entire light-tube and enclosure was constructed of optical quality flat-black anodized aluminum. A complementary cooling system for the camera utilized a fan and labyrinth to preclude stray light from entering the system.

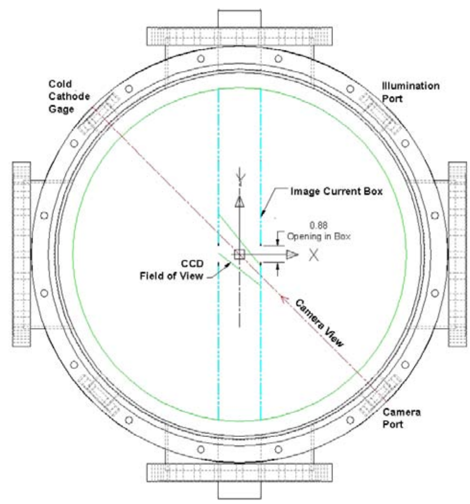

Figure 7: Image current box in relation to light path.

Figure 8 shows the relation of the parts inside the camera box. The Mead Pictor camera is at the top of the box followed by a remote controlled filter wheel with 3 filters. Two of the filters are for the atomic beam at 656.0nm and 486.0nm. The third filter is for the molecular line at 320 nm. Below that is a focusing lens mounted on a remotely controlled moveable stage. It was hoped that an online diatomic hydrogen impurity measuring tool could be developed. Figure 9 shows the sensitivity of the camera with a peak at 600.0nm [8]. The atomic line was determined to be too low for this instrument.

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Figure 8: Camera box.

Additional Light Monitors

The camera box was modified in early 2006 to accommodate a light spectrometer. The advantage of this device is that it can measure the amount of light at a range of frequencies. The box was modified by the addition of a plunging mechanism to allow the spectrometer head to be inserted into the light path. After the measurement is taken, the spectrometer head can be withdrawn restoring the light path to the camera.

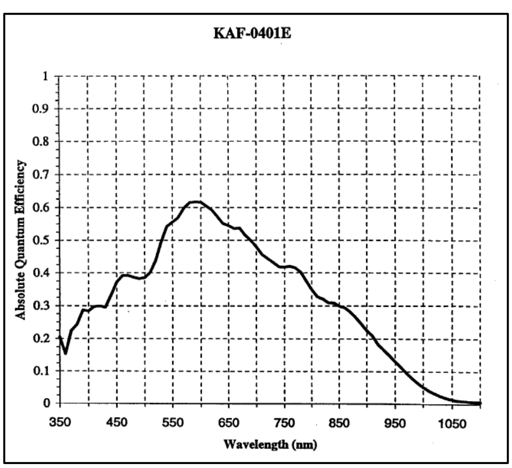

Figure 9: Camera sensitivity profile.

Results and Future Work

The result of the experiment proved interesting. Moving images on the order of minutes were taken that showed the motion of the two beams with respect to each other during injection and ramping. Also, the hydrogen jet column itself was moved to see the relative position of the "blue" beam and the "yellow" beam.

The hydrogen jet and the RHIC circulating beams have roughly cylindrical cross sections. The light is therefore produced intersection of two cylinders. Information pertaining to the circulating beam is lost in the x axis, because the beam length is much greater than the hydrogen jet diameter. Only information in the y-axis columns is meaningful for the size of the circulating RHIC beam. Information obtained in the x axis is related to the width of the jet. Figure 10 shows an image that is processed so that color is represents the amplitude. Figure 10 also shows the width of the jet as measured by the luminescence monitor is in good agreement with the compression tube.

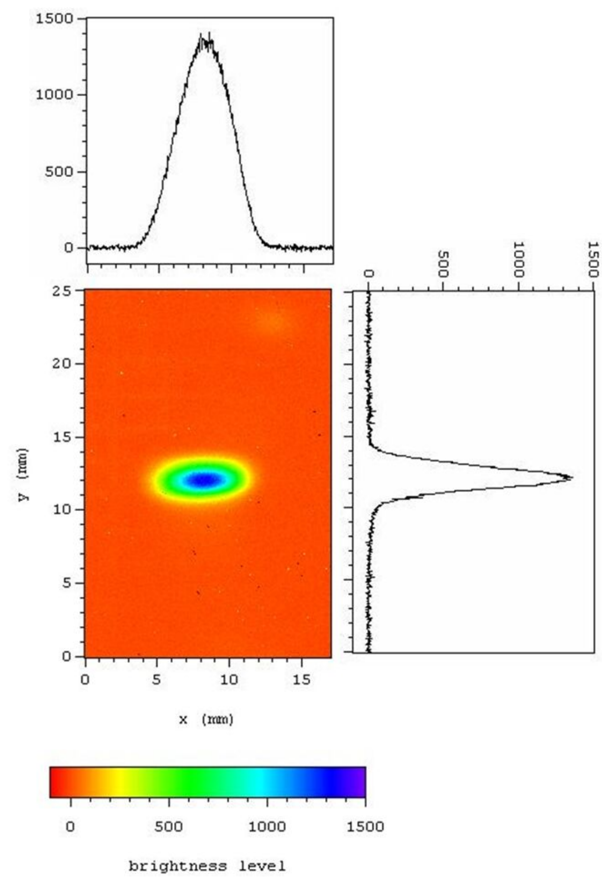

Figure 10: CCD Image Post Processed with jet measured as 6.5mm FWHM in x-axis and 1.6mm FWHM in the y axis. The camera has a full 16-bit (65535) brightness level [9].

Figure 10 shows the y axis projection of the beam as produced by the luminescence monitor. The beam height is measured to be 1.6mm FWHM which is in good agreement with the value anticipated at this location. Independent verification of this measurement has been achieved with the IPMs at RHIC. Based on the calibrated number of photons per pixel per brightness level, one can obtain the total photon production and the luminescence cross section. A design manual has been posted on the web showing moving images and additional references [10].

Future work will include trying to get meaningful data from the spectrometers. The spectrometers can yield important information from the hydrogen jet including the ratio of H^0/H2, oxygen and water impurities. It is hoped that this information can provide an online tuning instrument for the jet operators.

ACKNOWLEDGEMENTS

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