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Development of a Polarized ^{3}He Ion Source for RHIC

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Adding a polarized neutron beam to complement the polarized proton program at RHIC would make possible a host of valuable measurements of nucleon structure. Polarized ^{3}He offers an effective polarized neutron beam which is accessible with RHIC spin manipulation. We are developing such a source leveraging metastability exchange optical pumping of ^{3}He and utilizing the existing Electron Beam Ionization Source at RHIC. We aim to deliver approximately 1.5×10^{11} doubly ionized ^{3}He atoms per pulse at 70% polarization. The source is under development at MIT and an initial test of the principle at BNL is planned for the fall. The source design will be described and the status of the test summarized.

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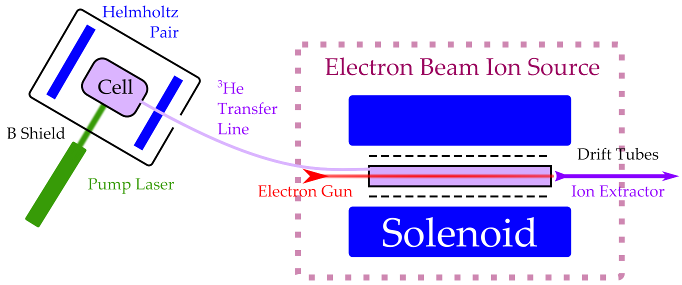

Figure 1: Diagram of proposed polarized ^{3}He ion source for RHIC.

1. Introduction

The addition of a polarized neutron beam source to the Relativistic Heavy Ion Collider at Brookhaven National Laboratory would present promising opportunities for the study of nucleon structure. Polarized neutron collision measurements of transverse spin asymmetries in Drell-Yan scattering would allow a search of the predicted sign switch for u and d quark flavors in the Sivers function[1]. In a future electron–ion collider, precision tests of the Bjorken sum rule[2] could be carried out with both proton and neutron beams.

Polarized ^{3}He presents an attractive candidate for a polarized neutron beam for RHIC. ^{3}He appears in its spatially symmetric S state, where the protons are in a spin singlet, at nearly 90% probability. Since nuclear spin in this state is carried by the neutron, when taking spin asymmetries polarized ^{3}He is effectively a polarized neutron. Although the small magnetic moment of the deuteron makes its spin manipulation difficult, the magnitude of the ^{3}He magnetic moment is close to that of the proton, making ^{3}He manageable for RHIC spin with the addition of extra siberian snakes. While RHIC Spin currently makes use of 2 snakes in each ring, a total of 6 snakes in each ring will suitably calm RHIC's depolarizing resonances for ^{3}He [3].

2. Source Design

This proposal would polarize ^{3}He using metastability exchange optical pumping and leverage RHIC's new Electron Beam Ion Source (EBIS) as a pre-injector. As shown in figure 1, the helium will be polarized in an external cell at near 1 torr, shielded from the EBIS stray field, and transferred into EBIS at 10^{-7} torr where it will be ionized and extracted. We aim to obtain $\sim$70% nuclear polarization using a 30 G holding field and 10 W laser, and plan to deliver 1.5×10^{11} ^{3}He^{++} ions per 20 μsec pulse for injection into RHIC.

The Electron Beam Ion Source is a flexible, new pre-injector for RHIC which consists of a 1.5 m, 5 T trapping solenoid; a 20 keV, 10 A electron gun; high voltage drift tubes; an electron collector; and an ion extractor[4]. As seen in figure 2, atoms in the trap are ionized by the electron beam and held in the trap by a trapping potential until an extraction potential pulse draws them into the extractor. EBIS is capable of ionizing and extracting any atomic species except hydrogen, and can switch between species in 1 second. The source has successfully provided ions for the NASA Space Radiation Lab, as well as U^{39+} and both Au^{32+} and Cu^{11+} with rapid switching for RHIC runs.

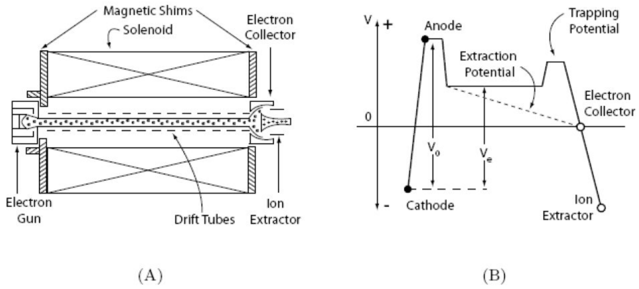

Figure 2: (A) Cross sectional diagram of EBIS. (B) The electric potential along the axis of the source.

2.1 ^{3}He Polarization

Metastability exchange optical pumping (MEOP)[5] is a decades old technique which has seen improvement in recent years with advances in pumping lasers and new research for its use in medical imaging techniques. MEOP polarizes optimally under a small holding magnetic field ($\sim$30 G) and when the pressure of the gas in the pumping cell is near 1 torr. An electric discharge excites a small portion of the ^{3}He atoms in the pumping cell from ground into the 2S metastable state. A circularly polarized laser then pumps 2S to 2P transitions in the metastable population, either increasing or decreasing the magnetic quantum number by 1. The resulting polarization of the metastable state atoms is then transferred back to the ground state atoms by metastability exchange collisions, allowing the polarization of the entire sample to be enhanced.

Our polarizer uses a 10 W, 1083 nm fiber laser collimated to cover the 2.5 cm radius pumping cell. To allow polarization in a region near EBIS and its 5 T field, magnetic shielding is being built to ensure gradients of no more than 30 mG/cm exist in the pumping volume. With the stray field reduced, a 30 cm Helmholtz pair magnet inside the shielding will provide the 30 G field necessary to polarize. Polarization measurements will be performed by observing the circular polarization of the 668 nm discharge light [6] and measuring the absorption of 1083 nm probe laser light [7].

2.2 Polarized Gas Transfer and Depolarization

Once polarized in the magnetically shield pumping cell, the gas must be transferred into EBIS for ionization and extraction. The pressure will first be stepped down from 1 torr through a calibrated capillary leak to 10^{-7} torr, the operating pressure of EBIS. It will then travel out of the shielded area, through the stray field of the 5 T solenoid, and into the ionization space of EBIS. Once inside EBIS, the 10 A electron beam will doubly ionize nearly 100% of the gas.

The loss in polarization after leaving the pumping cell is expected to be small. Making transfer lines out of glass and avoiding magnetic materials in their proximity will ensure relaxation due to the transfer will be negligible during the roughly 1 msec it spends traveling into EBIS. Once the gas enters the 5 T field of EBIS, its relaxation time due to field gradients will be effectively infinite. The ionization process is also expected to result in negligible relaxation, as the cross sections for depolarization due to charge exchange between singly and doubly ionized ^{3}He, due to

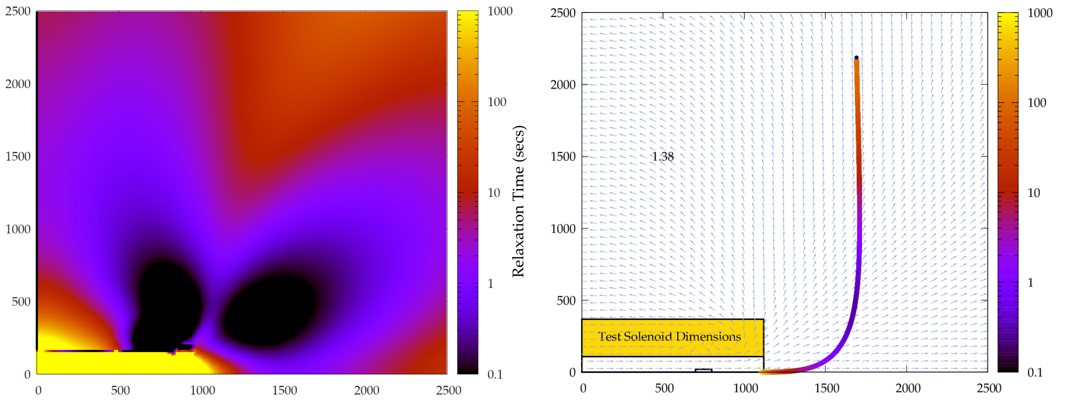

Figure 3: Left: Polarization relaxation time in the EBIS stray field (distance in mm). Right: field map and proposed path into the test solenoid, with an average relaxation time of 1.38 sec.

recombination with electrons in the beam to create singly ionized ^{3}He, and due to spin exchange are all small.

The relaxation of the gas as it travels through the stray field of the magnet, however, may be significant. Using the a field map of the solenoid, we can map the relaxation time of the gas at any given position in the stray field[8], as shown at left in figure 3. To reach the solenoid, at the bottom left of the figure, from the pumping cell, which will be in the top right of the map, regions with larger gradients and thus faster relaxation times which should be avoided. However, there are candidate paths through the stray field which result in average relaxation times greater than 1 second, seen at right of figure 3, much longer than the travel time for a given gas atom.

3. Depolarization Test Design

To observe the polarization performance in the stray field and relaxation in transfer into EBIS, a test has been designed to use a spare 5 T solenoid at Brookhaven. The proposed test, shown in figure 4, will include a polarization cell and 30 G holding magnet inside magnetic shielding, a glass transfer line approximately 2 m long, and a test cell inside the solenoid's 5 T field. As a measurement of the polarization with the gas at 10^{-7} torr would be very difficult, we intend to test the depolarization during transfer using an open transfer line with free communication of the gas between the pumping and test cells at 1 torr. By polarizing the sample in the pumping cell, we can observe the polarization as it diffuses into the test cell and quantify the relaxation due to the stray field. Should initial tests show that the relaxation during transfer is too great, further shielding and holding coils are being investigated to cover the full path through the stray field.

We can use two polarimetry techniques to measure the polarization relaxation during the transfer into the test EBIS solenoid. First, diffusion rate equations will allow the inference of the polarization in the test cell using polarization measurements in the pumping cell from discharge light; this follows a method used in a helium target at Bates [9]. This technique will involve measuring relaxation rates in the pumping cell with and without diffusive contact with the test cell, as well as destroying the polarization in the pumping cell and observing polarized gas from the test cell

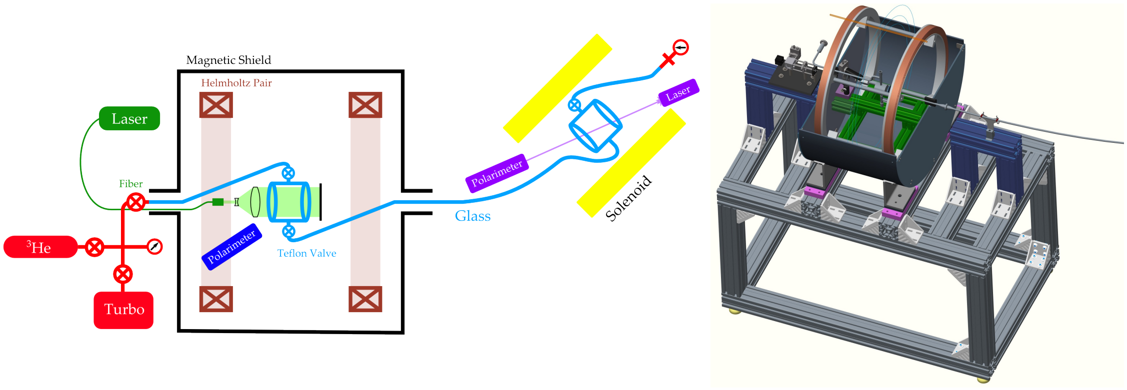

Figure 4: Left: BNL depolarization test setup, not to scale. Right: rendering of test polarizer and stand.

diffusing back into the pumping cell. Second, a direct measurement of the polarization in the EBIS cell can be performed using the optical absorption[7] — a measurement which would not otherwise be possible with a discharge polarimeter due to the high magnetic field.

4. Current Progress and Plans

In preparation for the depolarization test at Brookhaven, we have built a protoype polarizer in a lab at MIT, seen at left in figure 5. The new magnet, turbo-pump, getter, laser, RF discharge and data acquisition systems to be used in the test are all operational. The borosilicate glass cells and transfer lines have been produced by a local glassblower; both cells are approximately 100 cm^3, with the test cell elongated to allow a longer path for the laser absorption polarimeter. Polarization is measured with a new liquid crystal retarder based polarimeter[10], which we developed from off-the-shelf parts to be smaller, more accurate and more convenient than traditional rotating quarter-wave plate polarimeter. We have achieved over 70% nuclear polarization in the pumping cell; at right in figure 5 shows achieved polarization as a function of pumping laser power, as well as the offset needed to correct for laser light incident on the new polarimeter. The magnetic shielding and test stand are currently in production at BNL

We plan to move the polarizer to Brookhaven to commence the first tests with the spare 5 T solenoid in December of this year. Should the transfer of polarized gas through the stray field prove successful, we hope to transfer polarized gas into the operational EBIS to attempt ionization and extraction next year.

The BNL–MIT Polarized ^{3}He Source Collaboration consists of J. Alessi, E. Beebe, J. Farrell, A. Pikin, J. Ritter and A. Zelenski from Brookhaven National Lab, and C. Epstein, E. Mace, J. Maxwell and R. Milner from MIT. This work is supported by the DOE Office of Nuclear Physics R&D program for Next Generation Nuclear Physics Accelerator Facilities and the MIT Department of Physics.

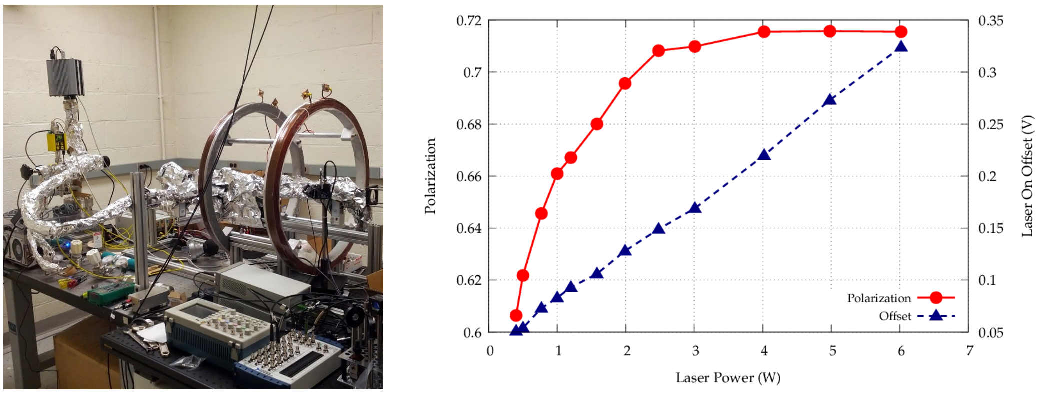

Figure 5: Left: test polarizer in MIT lab. Right: polarization achieved in pumping cell versus laser power, and polarimeter offset correction needed due to added laser light.

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