PROCEEDINGS OF SCIENCE

Development of a Polarized He^3 Beam Source for RHIC with EBIS

James D. Maxwell[∗†]
Thomas Jefferson National Accelerator Facility
E-mail: jmaxwell@jlab.org

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, particularly with the advent of a future electron-ion collider. Polarized He^3 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 He^3 and utilizing the existing Electron Beam Ionization Source at RHIC. We aim to deliver approximately $1.5 \cdot 10^{11}$ doubly ionized 3He atoms per pulse at 70% polarization into RHIC. The source is under development at MIT and initial tests of the principle are underway at BNL. Tests of MEOP polarization in magnetic fields above 1 T have yielded over 80% He^3 polarization, and have lead to a new design for an EBIS upgrade to allow polarized He^3 operation.

XVIth International Workshop in Polarized Sources, Targets, and Polarimetry, PSTP2015,
14-18 September 2015,
Bochum, Germany

∗Speaker.
†For the BNL-MIT Polarized He^3 Ion Source Collaboration

PoS(PSTP2015)003

1. Introduction

A polarized neutron beam would provide a crucial tool in the exploration of nucleon structure, especially with the advent of an electron–ion collider. The small magnetic moment of deuterium precludes its direct use in RHIC, but polarized ^{3}He offers an attractive alternative. Nearly 90% of the time, ^{3}He is found in its spatially symmetric S-state, in which its protons are in a singlet and the nuclear spin is carried by the neutron. In the context of spin asymmetries then, a polarized ^{3}He beam can act as a surrogate for a polarized neutron beam, whose magnetic moment allows manipulation in the RHIC rings[1].

1.1 Source Design

Our design[2] leverages the existing Electron Beam Ion Source (EBIS)[3], which allows the ionization and extraction of nearly any atomic species. Gas introduced into EBIS is ionized by a 10 A electron beam and trapped in a 5 T solenoid field. Drift tubes in the solenoid apply trapping and extraction electric potentials, allowing EBIS to deliver nearly 5×10^{11} charges per pulse. EBIS has provided Cu^{11+}, Au^{32+} and U^{39+} and $^3 3He^{2+}$ for recent RHIC runs and 12 different species for NASA's space radiation laboratory.

Metastability exchange optical pumping[4] offers an convenient method to provide EBIS with pure samples of polarized ^{3}He gas at the required rates. In MEOP, an RF discharge excites a small portion of the ^{3}He atoms from ground into the 2S metastable state. A circularly polarized laser then pumps 2S to 2P transitions in the metastable population, at the same time either increasing or decreasing the magnetic quantum number by 1 in the aligning magnetic field. 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. MEOP has traditionally been performed at low field (30 G) and pressure (1 torr), although recent development has shown this technique can be performed at much higher magnetic fields and pressures[5].

The most significant depolarizing mechanism to be encountered during the introduction of polarized gas into EBIS will come from transverse magnetic field gradients. The short time scale before extraction and very high field inside EBIS result in very small expected depolarization inside the EBIS trap. However, performing MEOP in the space near the 5 T magnet, as well as transferring the polarized gas into EBIS, may be subject to significant depolarization from magnetic field gradients. Fig. 1 shows the expected relaxation time in and around the EBIS solenoid, as calculated from an EBIS field map and relaxation formula from Schearer and Walters[6]. In finding a place to perform optical pumping at near 1 torr, we face the map on the left, while during transfer of the gas at low pressure, when the mean free path of the gas is constrained by the transfer tube, we face the map on the right.

2. Development Status

Our efforts have been concentrated on the polarization and transfer of polarized gas in regions of fields and gradients similar to those in and around EBIS. Our tests have aimed to assess the

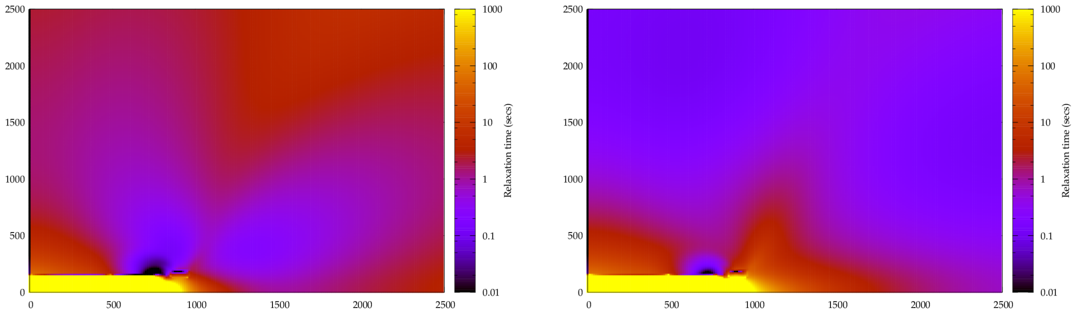

Figure 1: A map in mm of the expected polarization relaxation time of helium 3 at 1 torr (left) and below 0.01 torr (right) due to magnetic field gradients in the space in and around the EBIS 5 T solenoid magnet.

viability of two options for the final source design: to polarize in the stray field below 100 G, or to polarize in or near EBIS at very high magnetic field.

2.1 Low Field Polarization

In the low field MEOP option, polarization would be performed in the stray field of the 5 T magnet, below 100 G, and the gas would be transferred through the stray field into the EBIS solenoid. Candidate locations for the polarizer are expected to have less than 10 second relaxation times, as seen in Fig. 1, so correction of the field would be necessary to reach the goal polarization of 70%. We expect an anti-Helmholtz coil magnet could provide adequate correction for field gradients in the region in and around the polarizer.

A MEOP polarizer was built at MIT to undertake initial investigations at low field, including the measurement of polarized ^{3}He via RF discharge light[7] and the observation of diffusion of polarized gas through depolarizing gradients[8]. A second pumping setup at BNL has allowed tests in the stray field of the spare EBIS 5 T solenoid. With the polarizer at a candidate location outside the 5 T spare solenoid, polarization was attempted using the stray field itself as the only aligning magnetic field. While a short relaxation time of 6 seconds was measured, closely matching the expected value from Fig. 1, the steady-state polarization reached 28% as the optical pumping laser was increased in power to near 10 W. Adding a 30 G field along the axis of the polarizer using a small solenoid increased both the polarization to 38% and the relaxation time to about 20 seconds.

Our low field tests indicate that polarization in the stray field and transfer into EBIS is feasible, although perhaps not easy or optimal. The achieved polarization will be compromised, however little, by depolarizing field gradients.

2.2 High Field Polarization

In a high field MEOP case, the polarizer would be located close to or within the 5 T EBIS field, removing the need to transfer through the stray field. Although study of helium polarization at high pressures and magnetic fields is relatively new, polarizations exceeding 80% have been reported using fields of 1.5 T and higher[10]. In our tests a sealed cell with 1 torr of ^{3}He was placed in the uniform field region of the EBIS spare solenoid, and polarization was attempted at 1 to 4 T with 3 W of optical pumping power. To allow polarization measures at high magnetic field a probe laser polarimeter has been developed following a technique pioneered at the Kastler-Brossel Laboratory in Paris[9]. Polarization is measured with a probe laser tuned to probe specific 2S to 2P transitions, allowing the monitoring aligned and anti-aligned states by observing the absorption of the light. The high field polarization apparatus is shown in figure 2.

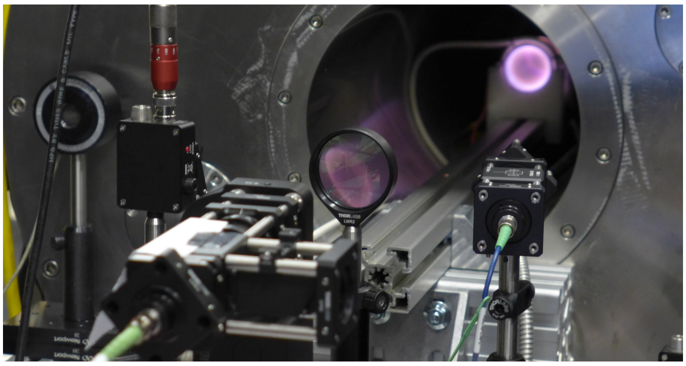

Figure 2: Sealed ^{3}He cell inside the 5 T spare EBIS solenoid with very bright RF discharge. In the foreground are the pumping laser guide and optics, with the probe laser guide and optics, and photodiode package to their right and left, respectively.

Preliminary results of steady-state polarization above 1 T have been quite encouraging. Figure 3 shows achieved steady-state He^3 polarization in two sealed cells at varied magnetic fields, here shown with 10 percent error-bars to indicate the preliminary nature of these measurements. The polarization is plotted versus the relaxation time of the polarization after optical pumping is stopped; this relaxation time is largely a function of discharge intensity. Although these sealed cells never reached higher than 60% during polarization at 30 G, at 2, 3 and 4 T, 80% nuclear polarization was reached with relative ease by ensuring very low RF discharge levels.

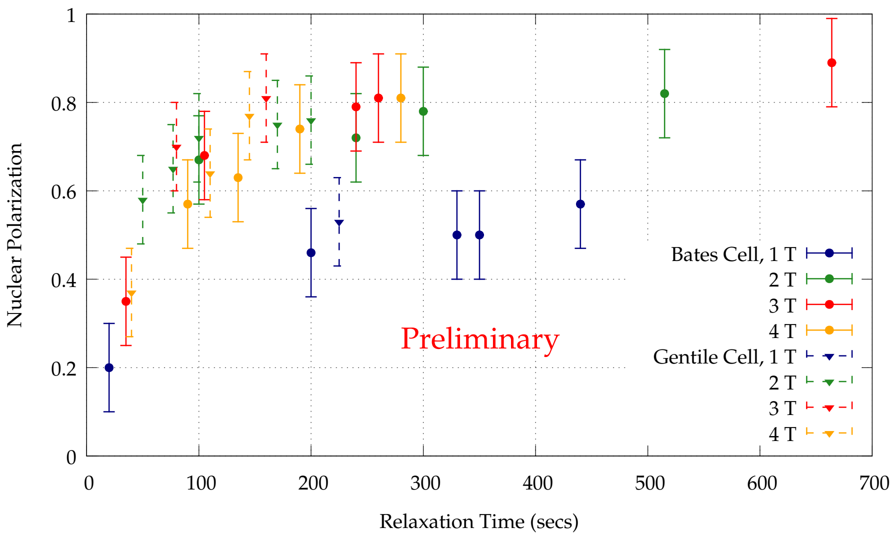

Figure 3: Steady state polarizations achieved versus relaxation time due to discharge intensity in two sealed cells at 1, 2, 3 and 4 T fields in the EBIS spare solenoid. The 10% errorbars are to indicate the preliminary nature of the measurements and do not reflect their expected accuracy.

We have concluded from the high field tests that polarizing in or near the 5 T operating field offers the most attractive route to an effective polarized source using EBIS. At high field, the meta-stability exchange and optical pumping mechanisms still function. Although the magnetic field decouples the electronic and nuclear spin states, slowing the pumping process, it also slows the routes for nuclear depolarization. Adding to this the ability to optically pump one transition cleanly once the electronic states are split, the achieved polarization is quite high. By locating the polarizer inside the EBIS main field, polarization loss due to traversing field gradients is eliminated.

3. Next Steps

With the success of the polarization tests above 1 T, we have begun to pursue a design for a polarized source with high field MEOP. The new design, shown in figure 4, is a modular addition to EBIS, which extends the high field region and trap into a new superconducting solenoid, in which the polarizing apparatus is held. This would not only allow polarized helium, but the lengthened trap will also improve ionization efficiency with other types of ions. Using spare EBIS components such as the test stand and spare solenoid, the modular nature of the source will allow tests polarization, ionization and extraction without interfering with the busy EBIS operating schedule. We are pursuing funding to support equipment purchases, and a tentative procurement and construction schedule aims for tests of the complete system in roughly three to four years.

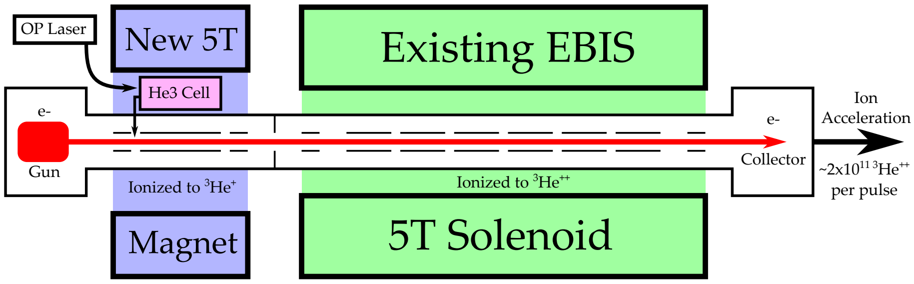

Figure 4: Schematic of possible EBIS upgrade design, which would extend the ion trap into a new high field solenoid, allowing polarization and extraction of He^3 at near 5 T.

Acknowledgments

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. The BNL-MIT Polarized He^3 Ion Source Collaboration consists of J. Alessi, E. Beebe, A. Pikin, J. Ritter, and A. Zelenski from BNL's Collider Accelerator Department, and J. Maxwell, C. Epstein, and R. Milner from the MIT Laboratory for Nuclear Science.

References

[1] Bai, Courant *et al.*, BNL-96726-2012-CP (2012).

[2] A. Zelenski, J. Alessi, ICFA Beam Dynamics Newsletter **30**, 39 (2003).

[3] A. Pikin *et al.*, **5**, 09 (2010).

[4] Colegrove *et al.*, Phys. Rev. 132 (1963)

[5] A. Nikiel *et al.*, European Physical Journal D, **67**, 200 (2013).

[6] L. D. Schearer and G. K. Walters, Phys. Rev., 139(5A):A1398-A1402 (1965).

[7] J. Maxwell *et al.*, Nuclear Instruments and Methods: A, **764**, 215 (2014).

[8] J. Maxwell *et al.*, Nuclear Instruments and Methods: A, **777**, 194 (2015).

[9] Courtade *et al.*, Eur. Phys. J. D **21** (2002).

[10] Abboud *et al.*, Europhys. Lett. **68** (4) (2002).