ATOMIC BEAM POLARIZATION MEASUREMENT OF THE RHIC POLARIZED H-JET TARGET

A. NASS, D. GRAHAM, A. KPONOU, G. MAHLER, Y. MAKDISI, W. MENG, J. RITTER, A. ZELENSKI

Brookhaven National Laboratory, Upton, USA

M. CHAPMAN, W. HAEBERLI, T. WISE

Department of Physics, University of Wisconsin-Madison Madison, USA

S. KOKHANOVSKI, V. ZUBETS

INR, Moscow, Russia

The RHIC polarized H-Jet measures the polarization of the RHIC proton beam via elastic scattering off a nuclear polarized atomic hydrogen beam. The atomic beam is produced by a dissociator, a beam forming system and sextupole magnets. Nuclear polarization is achieved by exchanging occupation numbers of hyperfine states using high frequency transitions. The polarization was measured using a modified form of a Breit-Rabi polarimeter, including focusing magnets and another set of high frequency transitions. The sampling of a large part of the beam and low noise electronics made it possible to measure the polarization to a high degree of accuracy in a very short time (1 min). Using this system, we measured no depolarization of the atomic beam due to the RF fields of the bunched proton beam. Time-of-Flight measurements were done using a fast chopper and a QMA at the position of the RHIC interaction point, to determine the areal density of the atomic beam seen by the RHIC beam.

1. The H-Jet Setup

The H-Jet experiment consists of nine vacuum chambers in a vertical arrangement (see T. Wise et al. these proceedings). The hydrogen gas is dissociated in a RF-dissociator and expands through a cold nozzle into the vacuum of the first chamber. A high brilliance beam is formed using a skimmer and a collimator. Based on the Stern-Gerlach principle, sextupole magnets are used to separate atoms with electron spin state +1/2 (hyperfine states $|1\rangle$ and $|2\rangle$) and -1/2 ($|3\rangle$ and $|4\rangle$). These magnets also focus the atomic beam into the target region. Nuclear polarization is achieved using high frequency transitions (HFT) by exchanging the occupation numbers of the hyperfine states. After passing the RHIC beam the sextupoles of the so-called Breit-Rabi polarimeter (BRP) focus a large part (1/3) of the atomic beam into the BRP-detector. The efficiencies of the HFTs and thus the polarization of the atomic beam are determined by comparing the detector signals while running several combinations of these transitions.

The HFTs consist of a resonator cavity in case of the strong field transition (SFT) of a high frequency coil in case of the weak field transition (WFT). All transitions are immersed in a static magnetic field whose strength and gradient along the atomic beam path can be individually adjusted. For the upper transitions a magnetic shield had to be build to reduce the large z-field of the main target holding field magnet and avoid non adiabatic regions (see below). This shield reduces the pumping in this region, and possibly a plasma was created inside the SFT cavity which slowed down the turn on of this transition but didn't affect the polarization of the atoms. To solve this problem the dissociator was pulsed for a short time (10ms) to reduce the gas density inside the cavity.

2. The Accuracy of the BRP Measurement

The sampling of approximately 1/3 of the atomic beam [1] and a high signal to noise ratio (noise reduction, amplification, proper grounding, background subtraction with chopper) lead to a very precise measurement (relative error $< 0.1\%$). Operating different HFTs the efficiencies of these transitions (WFT: $(1-\varepsilon_{1-3})$, SFT: $(1-\varepsilon_{2-4})$, BRP-WFT: $(1-\varepsilon'_{1-3})$, BRP-SFT: $(1-\varepsilon'_{2-4})$) are determined in a short time ($<$ 1 min). Since the remaining atoms in states $|3\rangle$ and $|4\rangle$ are rejected due to the beam blockers, the polarization of the atoms can be calculated:

$$P^{+} = \frac{1+(\cos\theta)\frac{N_2}{N_1} - 2(\cos\theta)\varepsilon_{2-4}\frac{N_2}{N_1}}{1+\frac{N_2}{N_1}} \quad (1)$$

$$P^{-} = \frac{-1-(\cos\theta)\frac{N_2}{N_1} + 2\varepsilon_{1-3}\frac{N_2}{N_1}}{1+\frac{N_2}{N_1}} \quad (2)$$

where N_2/N_1 is the transmission ratio of state $|2\rangle$ and $|1\rangle$ through the sextupole system and $\theta = \arctan B_c/B$ (B_c=50.7 mT, B-target holding field). The very stable polarization values of the atoms for the 2004 run were $P^{+} = 0.957 \pm 0.001$ and $P^{-} = -0.959 \pm 0.001$ (Fig. 1).

3. Depolarization Effects

If the change of direction of magnetic field in the rest frame of the atoms along the atomic beam path is too rapid, **Majorana depolarization** can occur. To avoid this the field changes have to be adiabatic, i.e. slow compared to the Larmor time $t_L \sim 1/B$. Therefore directional changes in a low field have to be more gradual than in a higher field. Fig. 2 shows this behaviour in the HFT region as a function of the target magnetic field which is penetrating into this region. The measurement was done with the SFT and WFT above the RHIC interaction point, operating at maximum efficiency. While changing the target magnetic field, the changing signal in the detector, which is directly related to the depolarization, was monitored.

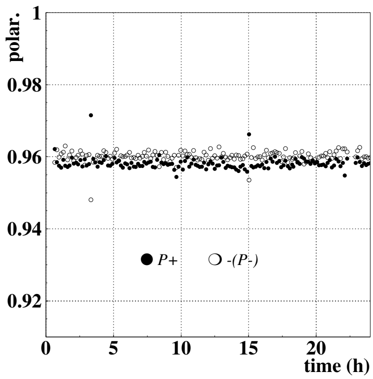

Fig 1. The polarization measurement over one day.

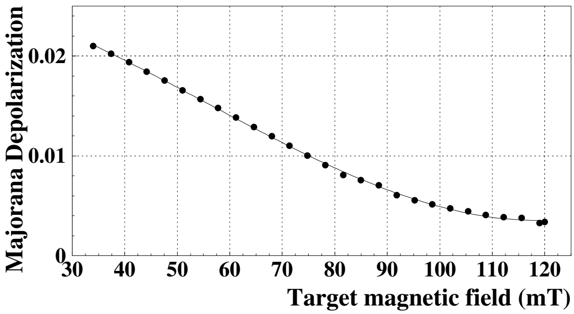

Fig 2. Majorana depolarization in the HFT region (H-Jet working point 120 mT).

Beam induced depolarization can occur due to the transient magnetic fields transverse to the beam direction of the bunched RHIC proton beam. These result in closely spaced depolarizing resonances in the usable range of the surrounding target holding field. Therefore a high uniformity of that field is required over the range of the transient fields (required and achieved for the H-Jet: $\Delta B/B = 5 \cdot 10^{-3}$). No depolarization at the 0.1% level was detected with 60 proton bunches and 10^{11} protons per bunch in RHIC. The measurement was done using SFT and WFT and monitoring the zero signal at the detector.

4. Time-of-Flight (TOF) Measurements and H-Jet Density

These measurements were done using a fast chopper (up to 300 Hz) in chamber #4 and a QMA at the position of the RHIC beam interaction point. The TOF signal is affected by the opening function of the chopper window. Since this influence decreases at higher motor speeds, the flight time was measured at different chopper speeds, and an extrapolation to infinite speed was made to determine the non-affected distribution. The mean velocity was (1562 ± 50) m/s for the working point of the dissociator (nozzle temperature $T =$ 75 K, hydrogen flux $Q = 60$ sccm). The variation of the dissociator parameters (T, Q) showed only small ($\pm$50 m/s) variation in the velocity spectrum since it is almost fixed by the transmission of the sextupole magnets. Taking the measured intensity [2] ($12.4 \cdot 10^{16}$ atoms/s) and beam profile [2] (FWHM = 5.8 mm), the areal density of the H-Jet can be calculated to be $(1.3 \pm 0.2) \cdot 10^{12}$ atoms/cm^2.

References

1. T. Wise et al., Design of a polarized Atomic H source for a Jet Target at RHIC, and A. Zelenski et al., Polarized H-Jet Polarimeter For Absolute Proton Polarization Measurement in RHIC, *AIP Conference Proceedings 675, 15th International Spin Physics Symposium, Upton, NY, (2002), Yousef Makdisi, Alfredo U. Luccio, and William W. MacKay eds.*
2. A. Zelenski et al., Absolute Polarized H-Jet Polarimeter Development for RHIC, *PST 2003 Workshop on Polarized Sources and Targets, Novosibirsk, Russia.*