Alternating Gradient Synchrotron Department
Relativistic Heavy Ion Collider Project
BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

Spin Note

AGS/RHIC/SN No. 014
(January 19, 1996)

RHIC Spin Project - Acceleration of Polarized Protons

T. Roser

December 18, 1995

For Internal Distribution Only

RIKEN Symposium on Spin Structure of the Nucleon,
RIKEN, Japan, 12/18-19/95.

BNL-62448

RHIC Spin Project - Acceleration of Polarized Protons*

Thomas Roser
Brookhaven National Laboratory, Upton, N.Y. 11973, USA

1 Spin Dynamics and Siberian Snakes

To achieve high energy polarized proton collisions polarized beams first have to be accelerated which requires an understanding of the evolution of spin during acceleration and the tools to control it. The evolution of the spin direction and the orbital motion of a polarized beam in external magnetic fields is governed by the Thomas-BMT equation and the Lorentz force equation:

$$\frac{d\overrightarrow{P}}{dt} = -\left(\frac{e}{\gamma m}\right)\left[G\gamma\overrightarrow{B_\perp} + (1+G)\overrightarrow{B_\parallel}\right] \times \overrightarrow{P}; \; \frac{d\overrightarrow{v}}{dt} = -\left(\frac{e}{\gamma m}\right)\left[\overrightarrow{B_\perp}\right] \times \overrightarrow{v}$$

where the polarization vector P is expressed in the frame that moves with the particle. From comparing these two equations it can readily be seen that, in a pure vertical field, the spin rotates $G\gamma$ times faster than the orbital motion. Here $G = 1.7928$ is the anomalous magnetic moment of the proton and $\gamma = E/m$. In this case the factor $G\gamma$ then gives the number of full spin precessions for every full revolution, a number which is also called the spin tune ν_{sp}.

The acceleration of polarized beams in circular accelerators is complicated by the presence of numerous depolarizing resonances. During acceleration, a depolarizing resonance is crossed whenever the spin precession frequency equals the frequency with which spin-perturbing magnetic fields are encountered. There are two main types of depolarizing resonances corresponding to the possible sources of such fields: imperfection resonances, which are driven by magnet errors and misalignments, and intrinsic resonances, driven by the focusing fields.

By introducing a 'Siberian Snake' [1], which is a 180° spin rotator of the spin about a horizontal axis, the stable spin direction remains unperturbed at all times as long as the spin rotation from the Siberian Snake is much

*Work performed under the auspices of the U.S. Department of Energy

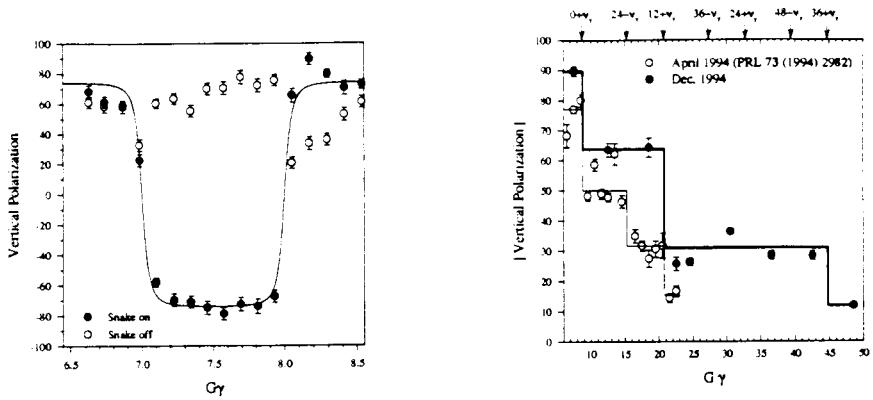

Figure 1: Results of AGS partial Snake test. See text for details.

larger than the spin rotation due to the resonance driving fields. Therefore the beam polarization is preserved during acceleration. Such a spin rotator can be constructed by using either solenoidal magnets for low energy beams or a sequence of interleaved horizontal and vertical dipole magnets producing only a local orbit distortion for high energy beams.

2 Polarized Proton Acceleration at the AGS

In two polarized beam runs at the AGS it was recently shown that a 5% Snake is sufficient to avoid depolarization due to the imperfection resonances without using the traditional harmonic correction method up to the required RHIC transfer energy of 25 GeV. The left side of Fig.1 shows the evolution of the beam polarization as the beam energy and therefore $G\gamma$ is increased[2]. As predicted the polarization reverses the sign whenever $G\gamma$ is equal to an integer. On the right side the achieved polarization as a function of beam energy is shown. The only polarization loss occurred at the location of the intrinsic resonances for which pulsed quadrupoles are required for the tune jump method. During the first run the pulsed quadrupoles were not available. During the second run in December 1994 it was shown that it is possible to use the tune jump method in the presence of the partial Snake. A new record energy for accelerated polarized beam of 25 GeV was reached with about 12 % beam polarization left. Again no polarization was lost due to the imperfection resonances and depolarization from most intrinsic resonances was avoided with the tune jump quadrupoles. However, as can be seen, significant amount of polarization was lost at $G\gamma = 0+\nu_y$, $12+\nu_y$ and $G\gamma = 36+\nu_y$. The first two of these three resonances were successfully crossed previously and it will require further study to explain the unexpected polarization loss. The strength of the tune jump quadrupoles is not sufficient to jump the last resonance. We attempted to induce spin flip at this resonance[3] but were so far only partially successful.

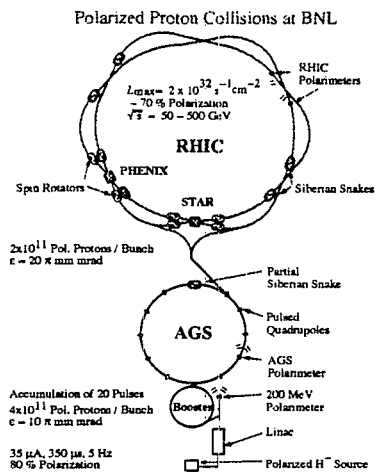

Figure 2: The Brookhaven hadron facility complex, which includes the AGS Booster, the AGS, and RHIC.

3 Polarized Proton Acceleration at RHIC

By using Siberian Snakes the stage is set for the acceleration of polarized proton beams to much higher energies. Polarized protons from the AGS are injected into the two RHIC rings to allow for up to $\sqrt{s} = 500\,GeV$ collisions with both beams polarized[4]. Fig. 2 shows the lay-out of the Brookhaven accelerator complex highlighting the components required for polarized beam acceleration.

Of particular interest is the design of the Siberian Snakes (two for each ring) and the spin rotators (four for each collider experiment) for RHIC. Each Snake or spin rotator consists of four $2.4\,m$ long, $4\,T$ helical dipole magnet modules each having a full 360 degree helical twist[5]. Using helical magnets minimizes orbit excursions within the extend of the Snake or spin rotator which is most important at injection energy. A prototype helical dipole magnet is now under construction at Brookhaven.

With one or two Snakes all depolarizing resonances should be avoided since the spin tune is a half-integer independent of energy. However, if the spin disturbance from small horizontal fields is adding up sufficiently between the Snakes depolarization can still occur. This is most pronounced when the spin rotation from all the focusing fields add up coherently which is the case at the strongest intrinsic resonances. At RHIC two Snakes can still cope with the strongest intrinsic resonance.

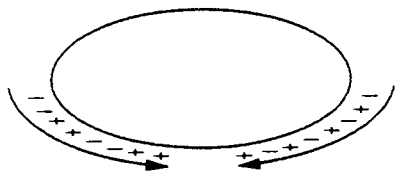

Figure 3: The pattern of the polarization signs of the bunches in the two counter-rotating beams in RHIC

The installation of two polarimeters is planned that are capable of measuring the polarization of the circulating beam in each ring independently at various stages during the acceleration cycles. These polarimeters utilize the asymmetries in inclusive π^- production and consist of $5\,\mu m$ diameter carbon fiber fixed targets and single arm magnetic spectrometers.

Since the proposed asymmetry measurements are high precision measurements, frequent polarization sign reversal is imperative to avoid systematic errors. Possible sources for systematic errors are luminosity variations, crossing angle variations, and detector efficiency variations. Each bunch can be filled independently, so the "pattern" of polarization direction for the bunches can be arranged to give all possible spin combinations for the colliding bunches. Fig. 3 illustrates a possible pattern for the bunch polarizations of the colliding beams. Although this will greatly reduce systematic errors it is still true that one pair of bunches would always collide with the same combination of polarization signs during the whole lifetime of the stored beams which is at least several hours. To eliminate the possibility of systematic errors from this situation we are planning to flip the spin of all bunches periodically using an artificial spin resonance.

References

[1] Ya.S. Derbenev et al., Part. Accel. **8**, 115 (1978).

[2] H.Huang et al., Phys. Rev. Lett. **73**, 2982 (1994)

[3] T. Roser, in Proc. of the 10th Int. Symp. on High Energy Spin Physics, Nagoya, Japan, p. 429 (1992).

[4] Proposal on Spin Physics Using the RHIC Polarized Collider (R5), submitted to the BNL PAC August 1992; update September 1993.

[5] V.I.Ptitsin and Yu.M.Shatunov, Helical Spin Rotators and Snakes, Proc. 3. Workshop on Siberian Snakes and Spin Rotators (A.Luccio and T.Roser Eds.) Upton, NY, Sept. 12-13,1994, BNL-52453, p.15