

# A LOW $\gamma_t$ INJECTION LATTICE FOR POLARIZED PROTONS IN RHIC

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## Abstract

Polarized protons are injected into the Relativistic Heavy Ion Collider (RHIC) just above transition energy. When installation of a cold partial Siberian snake in the AGS required lowering the injection energy by  $\Delta\gamma = 0.56$ , the transition energy in RHIC had to be lowered accordingly to ensure proper longitudinal matching. This paper presents lattice modifications implemented to lower the transition energy by  $\Delta\gamma_t = 0.8$ .

## INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two superconducting storage rings installed side-by-side in the accelerator tunnel. The two rings (“Blue” and “Yellow”) intersect at six locations around the sixfold symmetric machine, as illustrated in Figure 1. The lattice is therefore comprised of three superperiods, each consisting of an outer and an inner arc. Beams are injected into RHIC from the Alternating Gradient Synchrotron (AGS).

To preserve polarization during acceleration of polarized protons in the AGS, RHIC’s pre-accelerator, two partial Siberian snakes are installed. This configuration leads to a certain amount of tilt of the stable spin axis away from the vertical direction. The AGS-to-RHIC transfer line (AtR) is comprised of both horizontal and vertical bends that also result in a tilt of the stable spin direction away from the vertical. Since the stable spin direction in RHIC is vertical, it is essential to keep the net tilt angle due to the combination of snakes in the AGS and vertical bends in the AtR as small as possible. However, the snake setting in the AGS has been optimized for maximum polarization preservation during the ramp, and the geometry of the AtR transfer line is obviously fixed. The only remaining parameter to be changed is therefore the AGS extraction energy, since the tilt angle of the stable spin direction in each AtR dipole depends on the beam energy, represented by the Lorentz factor  $\gamma$ . It was found that lowering the AGS extraction energy such that  $G \cdot \Delta\gamma = -1$ , where  $G \approx 1.79$  designates the anomalous magnetic moment of the proton, greatly reduces the polarization tilt angle at RHIC injection.

Lowering the RHIC injection energy, however, has strong implications on longitudinal bucket matching between the AGS and RHIC, because protons are injected into RHIC just above the transition energy,  $\gamma_t$ . To improve this situation, various schemes to lower  $\gamma_t$  at RHIC injection were considered. This paper describes the various lattice modifications considered in this process.

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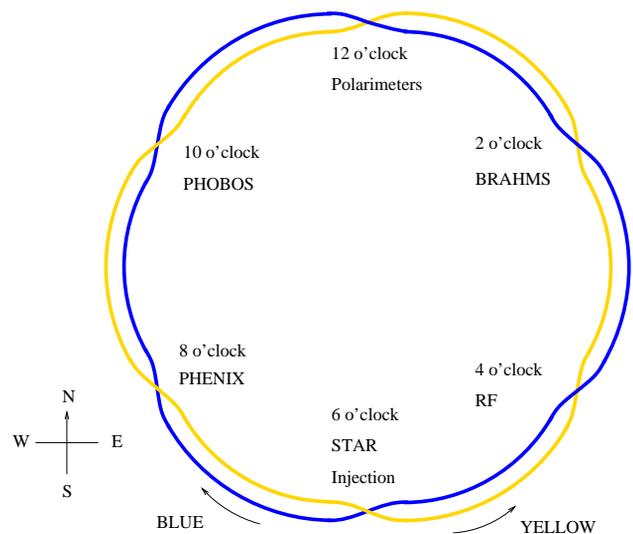


Figure 1: Schematic view of the Relativistic Heavy Ion Collider with its two superconducting storage rings “Blue” and “Yellow,” intersecting at six locations around the ring circumference.

## INJECTION LATTICE MODIFICATIONS

Besides lowering the transition energy at injection by at least  $\Delta\gamma_t = -0.5$ , it is desirable that the associated lattice modifications have as little impact as possible on the periodicity of the injection optics, and also on the optics during acceleration and store in general. It is particularly important not to decrease the available aperture of the machine due to increased  $\beta$ -functions in critical areas. Any lattice modification needs to be compared with the baseline optics, which is shown in figure 2.

### Lowering the Horizontal Tune

In a FODO lattice, the value of the transition- $\gamma$  is approximately proportional to the horizontal tune [2],

$$\alpha = \frac{1}{\gamma_t^2} = \frac{l^2}{\rho R} \frac{1}{\sin^2 \frac{\mu}{2}}, \quad (1)$$

where  $l$ ,  $\rho$ ,  $R$ , and  $\mu$  denote the FODO cell half length, the dipole bending radius, the average machine radius, and the phase advance per FODO cell, respectively. Lowering the horizontal RHIC tune by one full unit therefore produces the desired result, a transition gamma that is  $\Delta\gamma_t = 1.3$  units lower than for the original tunes. Though this scheme results in only a small  $\beta$ -beat at both injection and store (Figures 3 and 4), it has a significant disadvantage in resulting in an entirely new ramp configuration.

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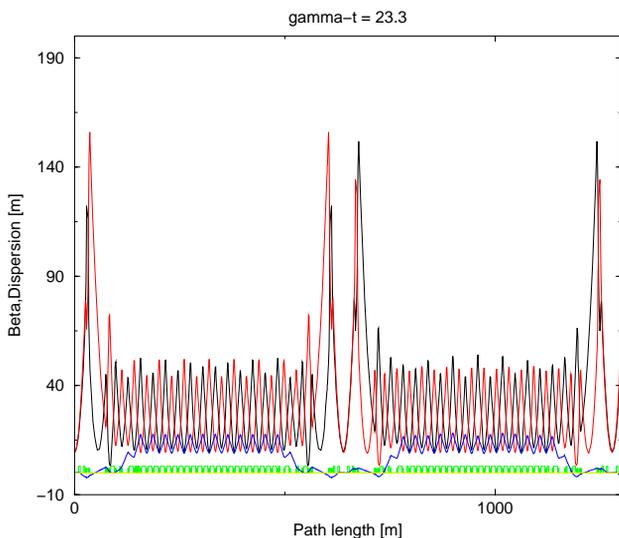


Figure 2: Baseline optics of one third of the RHIC ring, comprised of an inner and an outer arc.

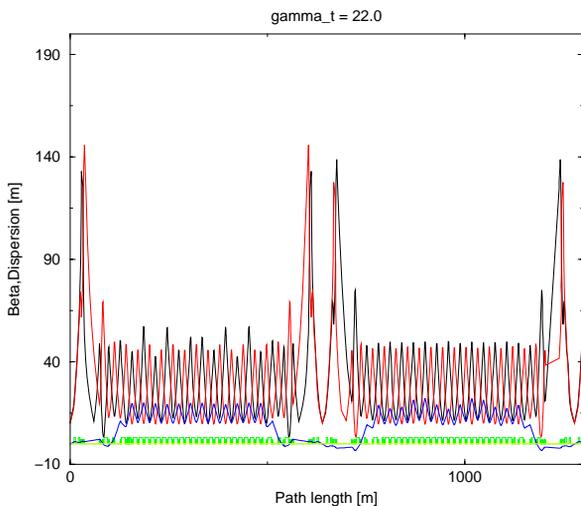


Figure 3: Injection lattice (one superperiod) with the horizontal tune lowered by one unit.

### Utilizing the $\gamma_t$ -Jump Quadrupoles

Since all ion beams other than protons are injected in RHIC below the transition energy, RHIC is equipped with a dedicated  $\gamma_t$ -jump quadrupole system [3, 4] to cross transition energy during the acceleration ramp. This system consists of a set of four quadrupoles (“G”) near the center of each arc, and a pair of quadrupoles (“Q”) at the end of each arc where the dispersion function is near zero, as shown in Figure 5. The “G” quadrupoles near the arc center modify the dispersion and therefore  $\gamma_t$ , while the “Q” magnets at the end of the arcs compensate the associated tune change.

This system is capable of lowering the transition energy at proton injection by more than one unit in  $\gamma_t$ . However, the resulting  $\beta$ -beat (Figures 6 and 7) is rather large. Fur-

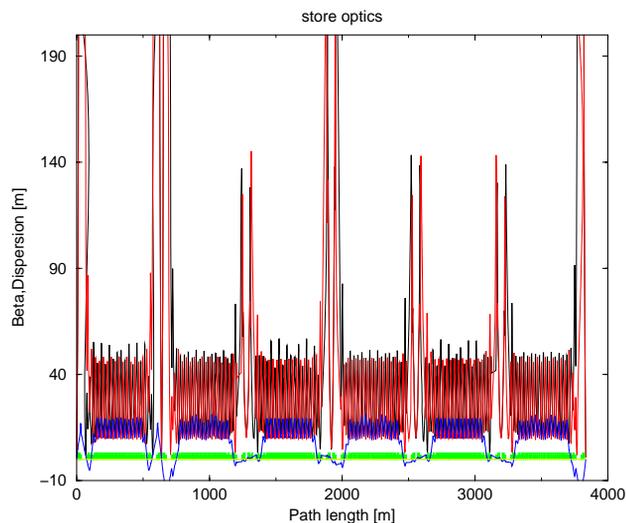


Figure 4: Store lattice with the horizontal tune lowered by one unit. Three interaction regions are squeezed to low  $\beta$  for experiments STAR, PHENIX, and the polarimeter.

thermore, the optics becomes non-periodic, because the  $\gamma_t$ -quadrupoles “G” responsible for the change of transition energy are located off-center in the arcs.

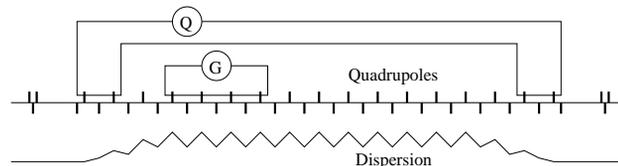


Figure 5: Arrangement of two  $\gamma_t$  quadrupole families “G” and “Q” in one of the six RHIC sextants for a first-order transition jump.

### The Hybrid Solution

To overcome the drawbacks of the two schemes presented above, a hybrid solution was designed. In this scheme, the horizontal phase advance in the arcs is lowered to lower the transition energy. The associated tune change is compensated by the  $\gamma_t$ -quadrupoles “Q” near the ends of the arcs. Since these quadrupoles are located in regions with negligible dispersion, they have no effect on the transition energy. Due to the symmetric location of these quadrupoles the resulting optics retains its periodicity, as Figure 8 illustrates. Furthermore, the maximum  $\beta$ -function in the arcs does not exceed the value for the regular lattice for transition energy changes up to  $\Delta\gamma_t = -0.8$ ; therefore the available aperture remains uncompromised.

### CONCLUSION

Based on the studies presented in the previous section, the hybrid solution utilizing the main arc quadrupoles and

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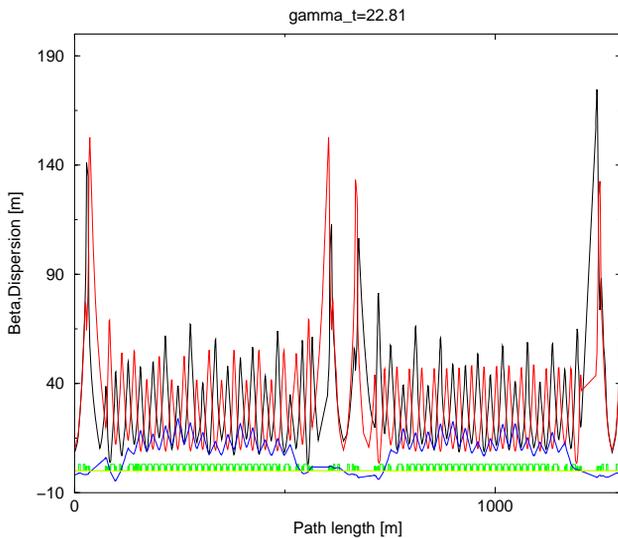


Figure 6: Lattice with transition lowered using the transition jump quadrupoles,  $\Delta\gamma_t = -0.5$ .

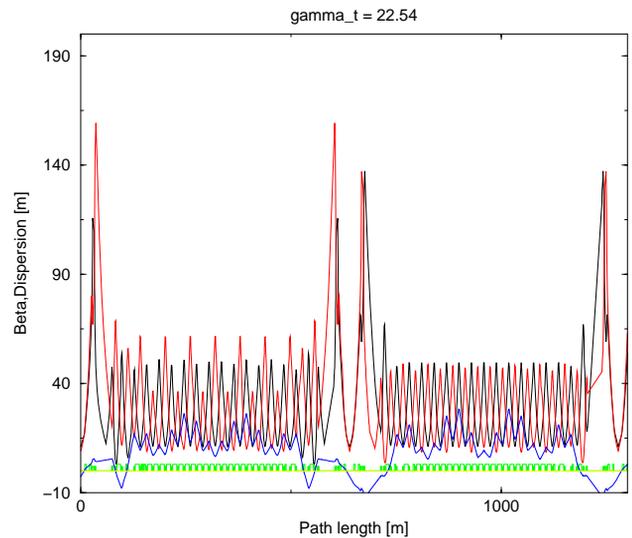


Figure 8: Optics of the hybrid solution, with  $\Delta\gamma_t = -0.8$ .

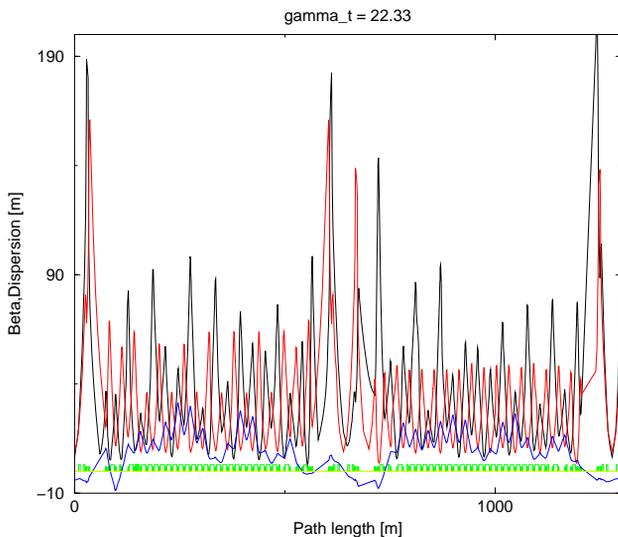


Figure 7: Lattice with transition lowered using the transition jump quadrupoles,  $\Delta\gamma_t = -1.0$ .

the “Q” transition jump quads was implemented in RHIC Run-6. While the transition energy is shifted by  $\Delta\gamma_t = -0.8$  at injection, the regular optics is restored early in the acceleration ramp. Thus the impact of this scheme on the machine operations is kept at a minimum.

### ACKNOWLEDGEMENTS

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