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RECONFIGURATION OF RHIC STRAIGHT SECTIONS FOR THE EIC

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Abstract

The Electron-Ion Collider (EIC) will be built in the existing Relativistic Heavy Ion Collider (RHIC) tunnel with the addition of electron acceleration and storage rings. The two RHIC rings will be reconfigured as a single Hadron Storage Ring (HSR) for accelerating and storing ion beams. The proton beam energy will be raised from 255 to 275 GeV to achieve the desired center-of-mass energy range: 20–140 GeV. It is also mandatory to operate the HSR with a constant revolution frequency over a large energy range (41–275 GeV for protons) to synchronize with the Electron Storage Ring (ESR). These and other requirements/challenges dictate modifications to RHIC accelerators. This report gives an overview of the modifications to the RHIC straight sections together with their individual challenges.

INTRODUCTION

The EIC [1], a discovery machine to be built at the Brookhaven National Laboratory, will collide electrons and various species of ions (protons to uranium ions) in a wide center-of-mass energy range (20–140 GeV). It is designed to provide luminosity of up to $10^{34}\ \mathrm{cm^{-2}s^{-1}}$, with high polarization (time-averaged polarization of ~ 70%) of both electron and light ion beams. One interaction region (IR) will be built within the scope of the project while maintaining the possibility of adding a second IR later. The electron injector, Rapid Cycling Synchrotron (RCS), and ESR will be added in the existing RHIC tunnels. Modifications will also be made to the RHIC accelerators to provide the required ion beams for collisions.

The HSR will be built on the basis of the two existing RHIC accelerators [2], however, with additional requirements. One requirement is that the path length of the HSR is adjustable such that the revolution frequency of ion bunches in a wide energy range (41–275 GeV for protons) can be matched exactly to that of the electron bunches. To achieve that, one needs to adjust the path length in two ways: by switching between an inner and an outer arc of the two RHIC accelerators (Fig. 1) to operate hadron beams at ~41 GeV and 100–275 GeV respectively, as well as by shifting the beam orbit radially off the center of the HSR to have the desirable path length for hadron beams in the energy range of 100–275 GeV [3]. The HSR will be operating at 3 times the RHIC beam current, 10 times shorter bunches and lower vertical beam emittance than RHIC. To achieve and maintain the required beam emittance, a coherent electron cooling device is planned to be installed at IR2. In addition, we need to remove the DX magnets (Fig. 1) to increase the proton beam energy from 255 to 275 GeV.

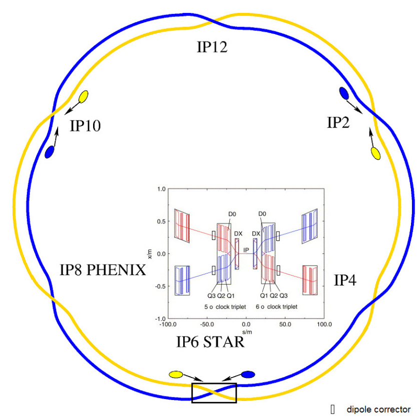

Figure 1: The schematic layout of RHIC with an expanded view of the STAR experimental area (IR6). The layout of the other straight sections in RHIC is similar to that at IR6. The path length of an outer arc is longer than that of an inner arc by 42 cm.

Figure 2 shows the schematics of the HSR. Hadron beams travel counterclockwise in the HSR, same as the beam does in the Yellow RHIC ring. Therefore, the HSR consists mostly of the Yellow RHIC arcs. The injection point in HSR moved from the current location in the Yellow ring at sector 5 to IR4 for adequate space for the kicker modules. The beam from the ATR (AGS to RHIC transfer line) will go over the HSR ring to merge into the Blue arc before reaching septum and kickers in IR4 [4]. The inclusion of the other two blue arcs will be explained in detail in the following section.

THE FUNCTIONALITY OF THE HSR STRAIGHT SECTIONS

Both RHIC and HSR comprise arcs that extend ~ $\pi/3$ angle and straight sections that connect the arcs. The straight sections host the final focusing triplets, warm spaces be-

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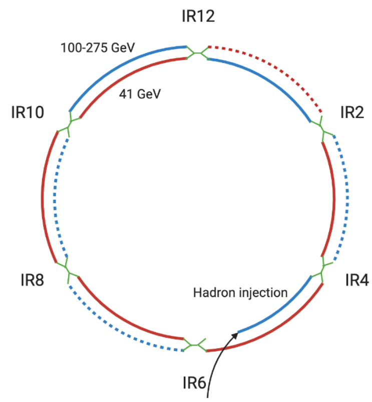

Figure 2: The schematic of the HSR. The blue curves represent the Blue RHIC ring arcs while the red curves represent the Yellow RHIC ring arcs. The solid curves are the RHIC arcs to be used in the HSR, the dashed curves are the RHIC arcs not to be used in the HSR. The inner and the outer arc from IR12 to IR10 are for beam operation at 41 GeV and 100–275 GeV respectively.

tween these triplets and the Q4 quadrupoles that mark the beginning of the continous cold sections. Most of the arcs will stay intact except for the addition of beam screens [5] to the beam pipe for higher current operation, and upgrade of the beam position monitor pick-up. Operation with the EIC beam requires to upgrade all the RHIC superconducting magnets reused in the EIC HSR with a beam screen to reduce resistive-wall impedance and suppress electron cloud (like the triplets) and reactivate the NEG coating of the RHIC warm sections that remain in place for the EIC HSR to suppress electron cloud [5]. The straight sections accommodate beam devices for beam injection, extraction, instrumentation, beam cooling and so on.

The EIC experimental detectors will be located in the IR6 [6], where the STAR experiment is now. A secondary experimental area [7], if to be built, will sit in the IR8, where the PHENIX experiment is. To avoid interference with these two experimental areas, the ATR Y line will stay for beam injection towards IR4, therefore, the hadron beam goes counter-clockwise. The septum [8] and stripline injection kicker modules need more space than what's available at the current injection point, so they will be placed at IR4 [9]. The crossover of the ESR and HSR at IR4 and IR12 is realized by tilting the ESR plane by 200 µrad angle with respect to the line passing IP6 and IP8, the primary and the potential secondary collision points. At the time of this report, efforts are ongoing to place the hadron polarimeters, H-jet and pC, at the IR4 region in addition to the injection devices and the warm HSR RF cavities. The IR2, where the Low Energy RHIC electron Cooler (LEReC) and Coherent electron Cooling Proof of Principle experiment are, is reserved for the HSR Strong Hadron Cooling devices [10]. The HSR collimation system is planned in IR12 [11] and the beam dump in IR10 [12] will stay to be used for the HSR. Both IRs will host the switch yards for switching beam operation at high and low energies.

SELECTION OF ARCS FOR THE HSR

Even though the HSR is composed of mostly the yellow RHIC arcs, it is necessary to use a few blue RHIC arcs as well. There is some cost associated with the reversal of the protection diodes in the superconducting dipoles and quadrupoles when a blue arc is used, so the use of them, if deemed as necessary, is meticulously reviewed. The reasons for using these blue arcs are deliberated in the following.

Consideration of available space led us to use the IR12-IR10 arc for energy switching. To switch to 41 GeV operation, one needs two switch-yards (>10 m space for each) to direct the beam to an inner arc for a shorter path length. The arc section from IR2 to IR12 was used for energy switching in the old baseline design [1]. However, it is impossible to provide space at IR2 for the switch-yard with the Strong Hadron Cooling taking the whole straight section and part of the dispersion suppression section. With IR6 and IR8 as the experimental areas, there is no space available to build switch-yards in these locations. Therefore, the only option left is to use the IR12-IR10 arcs for the energy switching.

It is required/justified to use the blue arc from IR2 to IR12 instead of the yellow arc from the SHC design point of view. First of all, there isn't enough space to fit the SHC beamline if one uses yellow arcs on both sides of the IR2. The superconducting magnet of the hadron beamline will interfere with the ESR beamline. Secondly, a symmetric layout and lattice (using blue + yellow arc configuration) is preferred from the SHC hadron lattice design.

The selection of arcs will affect the placement of subsystems in the straight sections, for example the collimation system, RF system and instrumentations. With switch-yards at IR10 and IR12, subsystems placed near sector 11 and 12 will only be available to either high energy or 41 GeV.

POLARITY OF QUENCH PROTECTION DIODE AND MAGNET

Each superconducting quadrupole and dipole is equipped with a quench protection diode in parallel circuit with its forward direction aligned with the direction of the magnet current. The purpose of the diodes is to enable the current from the other superconductive magnets in a string to bypass a quenching (resistive) magnet. If a magnet becomes resistive the forward voltage on the diode quickly rises and the diode conducts. Once the diode conducts it heats up in milliseconds and its forward voltage drops. To run blue arcs with a reversed current in the HSR, we will reverse the diode polarity to retain their magnet protection function.

For any given magnet, if either the current flowing direction (in other words power supply polarity) or beam direction changes, the polarity of the magnet changes (for example, a focusing quadrupole becomes a defocusing quadrupole and vice versa). If both of them change, then the polarity of the magnet stays.

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Even though it comes at a cost, we chose to change the polarity of magnet power supplies and the diodes for the blue arcs in the HSR. The blue arc between IR6 and IR4 is an exception because it only runs at ~ 10 % of the current needed for top energy. Since the beam direction changes as well in these blue arcs, the polarity of the magnets will stay the same. As a result, the horizontal/vertical dipole correctors are still paired with the focusing/defocusing quadrupoles.

Table 1 shows beam direction and current direction for RHIC. It is worth noting that focusing quadrupoles and defocusing quadrupoles are on the return bus and supply bus separately. Therefore, one offset quadrupole power supply was sufficient to change the global tune.

Table 1: Beam Direction and Current Direction for the Blue and Yellow Quadrupoles in RHIC

Quads	Beam Direction	Current Direction	Electrical Bus
BQv	CW	CW	B supply
BQh	CW	CCW	B return
YQv	CCW	CCW	Y supply
YQh	CCW	CW	Y return

Table 2 shows the beam directions and current directions applicable to any Blue arcs to be used in the HSR. The Blue arc magnet (including arc and IR magnets) polarity stays as shown in Table 2. The defocusing quads will stay on the Y supply bus, and focusing quad on the Y return bus, which is consistent with the existing Yellow ring scheme. Therefore, one offset power supply is sufficient for tune control.

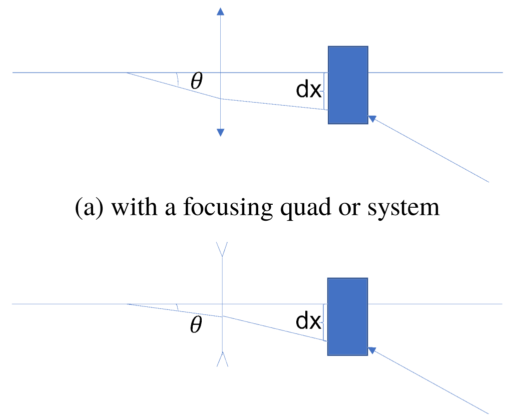
Table 2: Beam Direction and Current Direction for the Blue Quadrupoles to be Used in the HSR

Quads	Beam Dir.	Current Dir.	Diode Flip	Magnet Pol.	Elec. Bus
BQv	CCW	CCW	Yes	Stay	Y supply
BQh	CCW	CW	Yes	Stay	Y return

REPLACING THE COLD D0 MAGNETS WITH WARM DIPOLE MAGNETS

With DX magnets removed, D0 magnets will have to direct beam to one of the D0 magnets on the other side of the non-colliding IRs, or both in the case of switching between low (41 GeV) and high energy (100–275 GeV) operation. The associated modifications to these D0 magnets are complicated: these D0 magnets will need to be mechanically shifted at one end (yawed), independently powered and the cryo connection has to be modified accordingly. We are proposing to replace these D0 magnets to be used in the HSR with warm magnets to simplify associated changes needed for these magnets. The replacement is planned for IR10, 12 and 4 only because D0 magnets in other IRs will be removed.

There are additional benefits replacing the D0 magnets with warm dipole magnets. One benefit of removing the cold D0 is to simplify the cryogenic piping connection and free more space for the beamscreen and BPM connections forward of Q1. This will also provide more space for the ESR and HSR crossings thanks to the smaller transverse size of the warm magnets. Moreover, this will help resolve the interference of the HSR and the ESR at IR12, and the warm magnet aperture can be customized to avoid the limited aperture of D0 at IR4 for injected and stored beam.



(a) with a focusing quad or system

(b) with a defocusing quad or system

Figure 3: Schematic of a horizontal injection system: with the blue box representing a septum magnet, lines with arrows at the ends as quadrupoles, the flat line as the circulating beam, and the injected beam coming from the right side, the kickers are located at the place where the two beams merge.

REDUCE THE NUMBER OF KICKERS BY ADDING WARM QUADRUPOLES

Figure 3 shows the schematics of injection systems with a focusing quad in-between the kicker and the septum in (a), and with a defocusing quad in-between in (b). The two configurations have their advantages respectively. If kicker strength is not a concern and/or space is limited, the configuration with focusing quad is preferred because it merges the two beams in a short distance. If it is desirable to reduce the kicker strength, then configuration shown in (b) is better because a smaller kick angle is required to achieve the same separation of the two beams in the septum.

Beams are injected at ~80 T m in the HSR which requires a large number of stripline kickers and high voltages. The existing triplets in RHIC IR4 focus the beam in both planes so it did not help reducing required kicker strength. Therefore, we propose to add warm quads near the triplets so the combination of them defocus the beam in the horizontal plane.

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