A PROPOSED "DELAY LINE" FOR HADRON BEAMS IN RHIC*

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Abstract

A "delay line" has been proposed to be installed in the Blue ring of the Relativistic Heavy Ion Collider (RHIC) to accommodate collisions between asymmetric nuclei. The function of the "delay line" is to provide an additional path length of ~15 cm to the circulating bunches in the Blue ring to synchronize collision with the lower speed beam bunches of the Yellow ring at the interaction points (IP's). The delay line can also be used in the proposed e-RHIC accelerator for the electron-hadron collisions at various energies. This paper serves as a feasibility study to identify any problems whose solution may improve the function of the delay line. Since few solutions may be possible, in this paper we present the layout and the optics of the delay line for on one of these possible solutions and we will discuss the energy range that asymmetric collisions can be performed in the RHIC collider.

INTRODUCTION

Figure 1 is a schematic diagram of the RHIC complex with RHIC at the top of the figure. The blue and yellow rings as shown in the figure intersect at six (IP's). Currently RHIC accommodates collisions at the IP's between hadrons which are of the same species and have the same rigidity. Although RHIC has accommodated collisions between different species like Cu on Au, the ions of the different species are constrained to have the same relativistic γ factor.

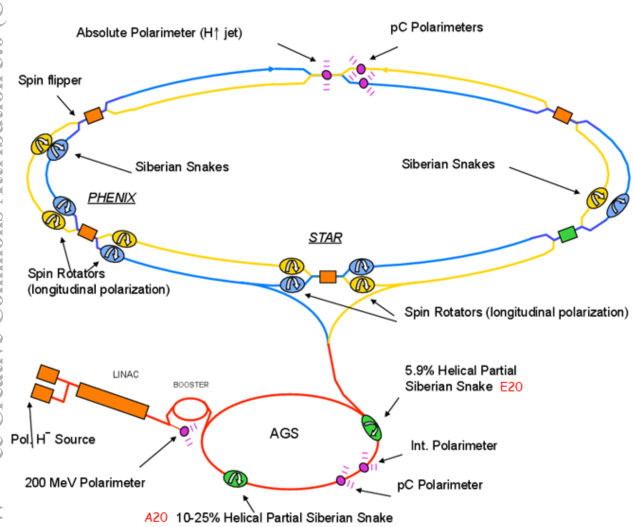

Figure 1: Schematic diagram of the RHIC complex. The two intersecting elliptical rings on the top of the figure represent the blue and the yellow ring of RHIC.

Recently one of the authors brought up the idea of introducing an increase of ~15 cm in the beam orbit of the blue ring at the area of the "12 o'clock" (IP) which is shown at the top of figure 1.

THE MAGNETIC ELEMENTS AND LAYOUT OF THE DELAY LINE

Figure 2 shows a schematic diagram of the layout of the magnets of the 12 o'clock IP region as it is at present without the proposed modification. The diagram on top shows the placement of the magnets at the right hand side of the 12 o' clock IP region, and the bottom diagram shows the placement of the magnets on the left and right side of the 12 o'clock interaction point region.

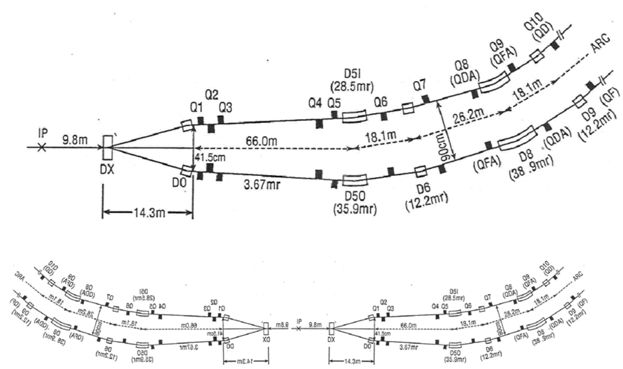

Figure 2: Schematic diagram of the 12 o'clock interaction point region as it appears at present .The top diagram shows the placement of the magnets at the right side of the (IP) and the bottom shows the placement of the magnets at either side of the (IP).

In the rest of this section we describe the modification of the 12 o'clock IP region, and the layout of the magnetic elements which facilitate the increase of the path length of the blue ring and the "beam matching" of the blue and yellow rings. Figure 3 is a schematic diagram of the first phase of the modification which consists of the removal of all magnetic elements along the blue and yellow arrows shown in figure 3.

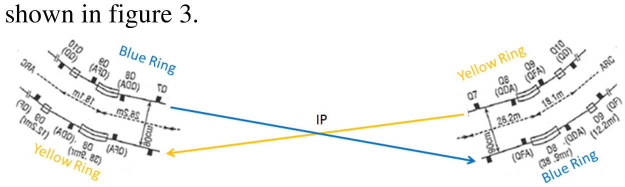

Figure 3: Schematic diagram of the first phase needed to implement the "Delay Line". Notice that all the magnetic elements which are shown in figure 2 and are along the blue and yellow arrows in figure 3 have been removed.

Following the removal of the magnetic elements from the 12 o'clock IP region, the task is to install new sets of magnetic elements along the lines indicating by the yellow and blue arrows in figure 3. The function of these

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sets of magnetic elements is to optically match the circulating beam in each ring and also provide the required increase of the path length along the blue ring.
Figure 4 shows schematically the location of these sets of the magnetic elements to be installed along the yellow and blue lines shown in figure 3. In the next two subsections we discuss in some detail the function of each set of magnetic elements.

Magnetic Elements of the Yellow Section

At the exit of the yellow ring we install a set of dipoles and quadrupoles (large yellow rectangle top right of figure 4) to bend the beam to the left by 49 mrad along the yellow line and also generate an achromatic beam. Following this section of the line which generates an achromatic beam a set of quadrupoles are installed (yellow narrow rectangles top right of figure 4). The function of these quadrupoles is to transport the beam along the straight section of the interaction region and match the beam to the circulating beam of the yellow ring by using the same set of qudrupoles (yellow narrow rectangles bottom left of figure 4) and a set of dipoles and quadrupoles (large yellow rectangle bottom left of figure4) which bend the beam to the right by 49 mrad inside the yellow ring and also match it to the circulating beam. The beam optics of this section of the yellow line will be discussed in a separate section below.

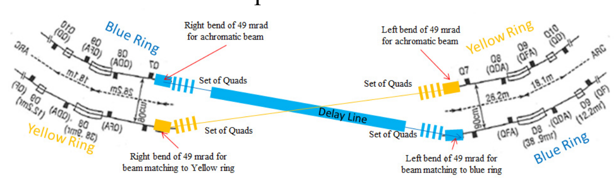

Figure 4: Schematic diagram and layout of the magnet sets proposed to be installed along the yellow and blue lines. A more detailed description of each set of magnets proposed to be installed is discussed in the text.

Magnetic Elements of the Blue Section

The blue section employs similar sets of magnets as the yellow section, with the exception of the "delay section". For completion we discuss the placement of the sets of magnets in the blue section as we did in the yellow section. At the exit of the blue ring we install a set of dipoles and quadrupoles (large blue rectangle top left of figure 4) to bend the beam to the right by 49 mrad along the blue line and also generate an achromatic beam. Following this section of the line which generates achromatic beam a set of quadrupoles are installed (blue narrow rectangles top left of figure 4). The function of these quadrupoles is to transport the beam along the straight section of the interaction region and match the beam to the circulating beam of the blue ring. This matching is accomplished by using the same set of qudrupoles (blue narrow rectangles bottom right of figure 4) and a set of dipoles and quadrupoles (large blue rectangle bottom right of figure 4) which bend the beam to the left by 49 mrad inside the blue ring and also match it to the circulating beam. The long blue rectangle labeled as "delay line" is a set of dipoles which deflect the beam along the vertical plane, fist down and then up. Figure 5 shows the dipole arrangement of the "delay line". The relative coordinates of the dipole magnets are generated by using the survey command of the MAD computer code. The proposed "delay line" will be installed in the location of the long blue rectangle shown in figure 4. Each of the blue rectangles in figure 5 represents a dipole, and the delay line bends the beam down and then upwards. The beam optics of this section of the blue line will be discussed in a separate section below.

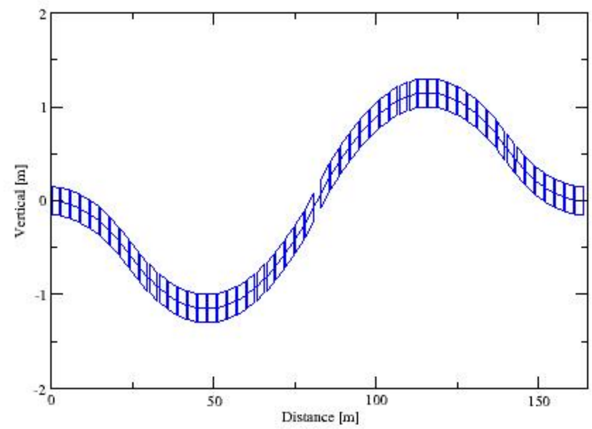

Figure 5: The layout of the proposed "delay line" to be installed in the location of the long blue rectangle shown in figure 4. The blue rectangles shown in this figure are dipole magnets.

CONSTRAINTS OF THE DELAY LINE

In this section we discuss the constraints associated with the delay line. Depending on the time delay required for a particular experiment the delay line should provide a variable delay from 0 to a maximum available. This requires that the magnets of the delay line are "warm" with maximum field of 2.0 T and also movable, to be placed along a straight line to provide 0 delay or follow the curve shown in figure 5 to provide maximum delay. Although the available length in the IP region is 200 m in this study we use ~164 m with the rest of the space to be used by the set of quads and the achromatic sections as discussed in the earlier section. The magnet placement shown in figure 5 can be on the vertical plane or horizontal plane. The vertical plane placement restricts their maximum displacement to 1.5 m with the horizontal plane providing a larger displacement which at the same time requires a longer longitudinal space than the 164 m accepted as available.

BEAM OPTICS

In this section we discuss the beam optics of the yellow line which does not provide any delay, and that of the blue line which provides the delay. Both optics are based on the set of magnetic elements discussed in the previous section and are performed with the MAD computer code. The beam parameters at the entrance and exit of the

Yellow and Blue beam lines have been provided from Ref [1]. In the optics we constrain the beam to be achromatic at the exit and entrance of the achromatic sections.

Yellow Beam Line Beam Optics

The function of the beam line section of the IP region which corresponds to the Yellow ring is to match the beam parameters at the exit of the Yellow ring at the top right of figure 3 to the beam parameters of the Yellow ring at the bottom left of figure 3. Although the values of the beam parameters may change depending on the lattice used in each hadron run, the two sets of achromatic section and the two sets of the quadrupoles can match any reasonable set of beam parameters of the Yellow ring [1].
The location of the elements of this line remains fixed. Figure 6 shows the beta functions ($\beta_{x,y}$) and the dispersion functions ($\eta_{x,y}$) along the Yellow beam line section.

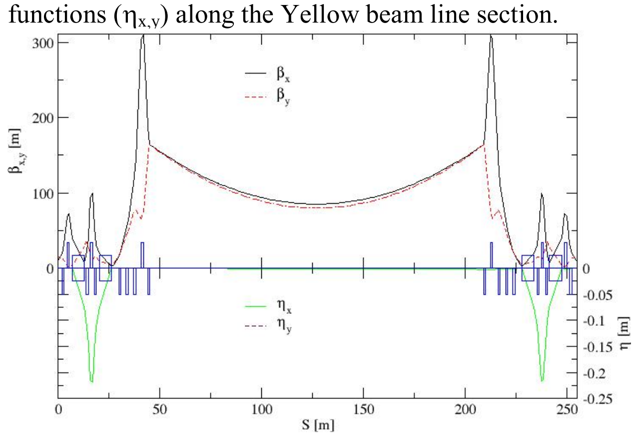

Figure 6: The beta functions ($\beta_{x,y}$) and the dispersion functions ($\eta_{x,y}$) along the Yellow line. The beam is achromatic between the two achromatic sets of elements.

The five narrow rectangles at the left and right of the centreline, correspond to the quadrupole set mentioned earlier. The other rectangles represent the quadrupoles and dipoles of the achromatic section of the line. The beam is achromatic between the two achromatic sets of elements.

Blue Beam Line Beam Optics

The function of the Blue line section of the IP region is twofold, first to match the beam parameters at the exit of the Blue ring at the top left of figure 3 to the beam parameters of the Blue ring at the bottom right of figure 3, and second to provide the required path length by adjusting the position of the dipoles which comprise the "delay line" as shown in figure 5. Figure 6 shows the beta functions ($\beta_{x,y}$) and the dispersion functions ($\eta_{x,y}$) along the Blue line section.
The set of the rectangles at the centre of figure 7 are the dipole magnets which comprise the delay line. The five narrow rectangles which appear to be separated at the left and right of the centreline, correspond to the set of quadrupoles mentioned earlier. The other rectangles represent the quadrupoles and dipoles of the achromatic section of the line. The vertical dispersion along the delay line section varies according to the strength of the dipoles.

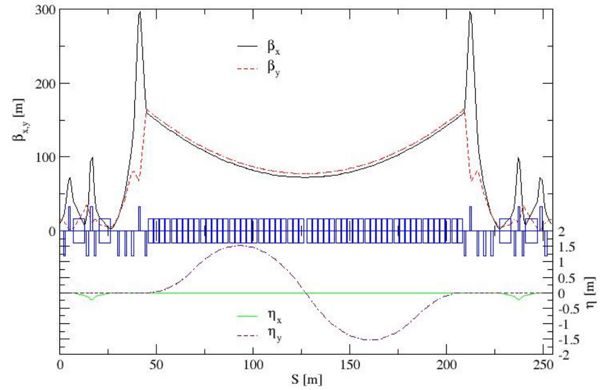

Figure 7: The beta functions ($\beta_{x,y}$) and the dispersion functions ($\eta_{x,y}$) along the Yellow beam line section. The beam has a vertical dispersion due to the dipole magnets.

RANGE OF THE DELAY

In Table 1 we summarize the maximum delay achieved by the delay line. The maximum delay achieved is based on the constraints which are mentioned in an earlier section.
Namely we constrain the length of the delay line to 164 [m] and the maximum vertical displacement to 1.5 [m] as shown in columns 2 and 3 of Table 1.

Table 1: The Maximum Delay (column 4) for a Given Beam Rigidity Range

Rigidity Range [Tm]	Length [m]	Vertical [m]	Max-Delay [cm]
0 to 627	164	1.5	15.8
627 to 837	164	1.5	15.8 to 9.0

CONCLUSIONS

We study the feasibility of introducing a path increase to the circulating beam of the Blue ring of RHIC. We present the results of one of the possible solutions.

REFERENCES

[1] S. Tepikian, private communication.