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# Lowering the RHIC-Injection Lambertson Septum magnet to reduce the strength of the RHIC Injection Kickers

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## Abstract

The present RHIC beam-injection-system and one of its components the Lambertson septum magnet [1] will be used by the EIC project to inject the hadrons from the AGS into the EIC hadron ring for further acceleration. The number of hadron bunches injected to fill the EIC ring will be almost three times as many as compared to the number of bunches to fill RHIC. The increase of the injected bunches requires new type of kickers known as “transmission line” or “strip line” kickers which provide faster rise time of ~18 nsec, but this type of kickers may not be strong enough to provide the kick required to place the injected beam trajectory into the reference orbit of the circulating beam. In this technical note we provide a modification of the RHIC injection system which consists of lowering the Lambertson septum to decrease the strength of the kickers required to place the injected beam into the reference orbit of the circulating beam.

## Introduction

One of the devices of the RHIC beam-injection-system is a Lambertson septum magnet. [1]. The present geometry of the injection system is to inject into RHIC ring the transferred beam from the Alternating Gradient Synchrotron (AGS) at an angle of 3 mrad on the vertical plane which contains the RHIC reference orbit of the circulating beam.

Fig. 1 is a schematic diagram of the RHIC injection system which injects the transferred beam from the AGS into the Y-arc. The top diagram in Fig. 1 is the top view of the injection system and the bottom diagram is the side view. Notice that the “3 mrad” vertical pithing magnets (bottom diagram) bends the beam down by 3 mrad and the injected beam crosses the reference orbit of the circulating beam at an angle of 1.7 mrad.

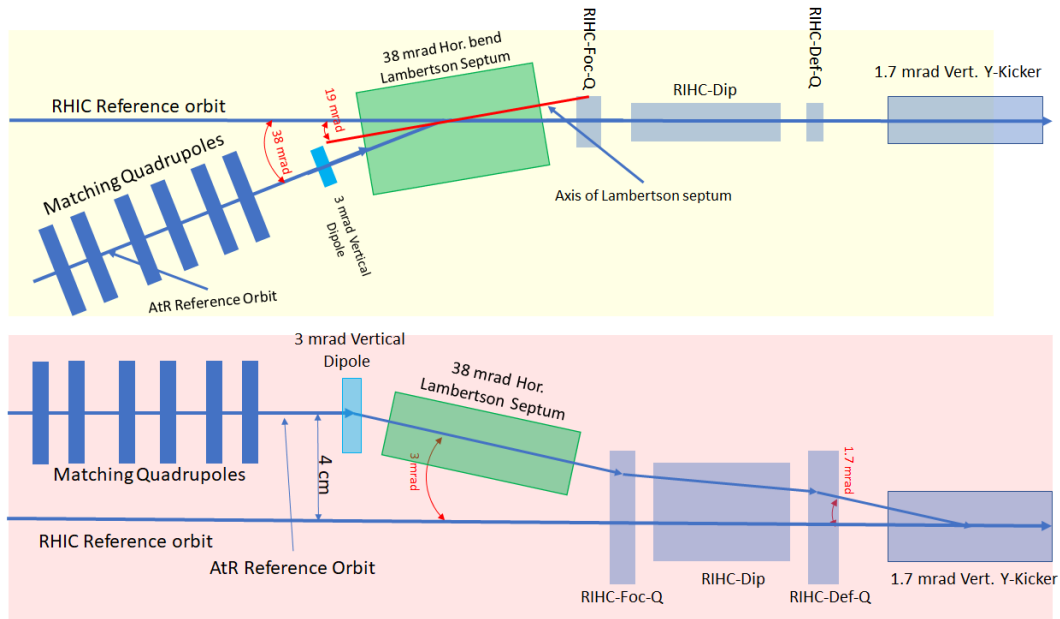
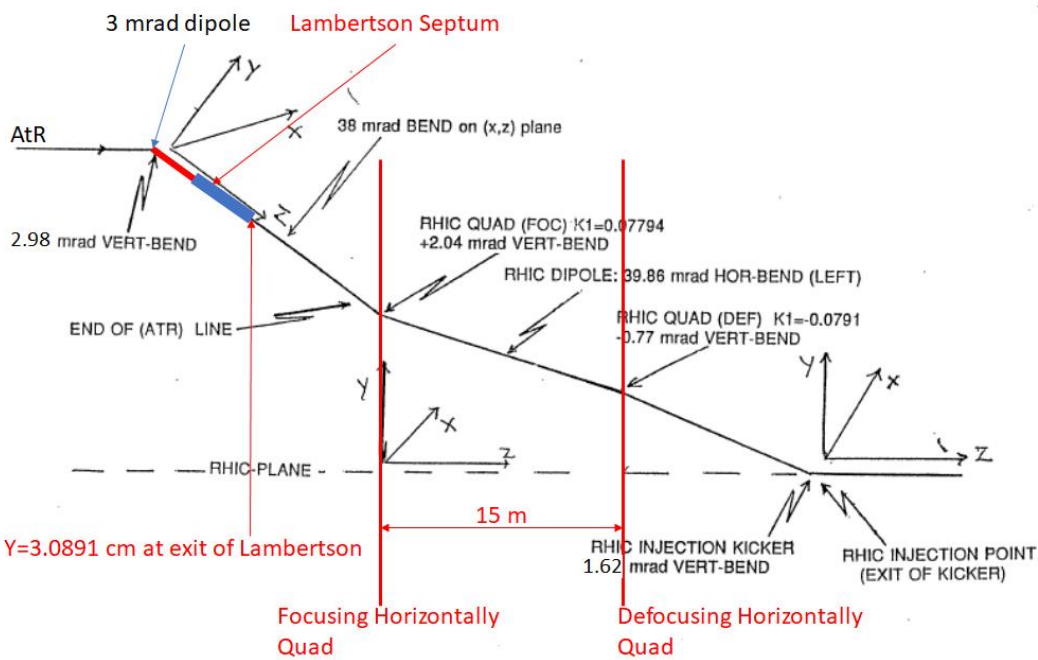


Figure 1. Top view (top diagram) and side views (bottom) of the RHIC injection system.



Study the effect of lowering the septum magnet

Figure 2. Same as the side view of the RHIC injection system in Fig. 1 with some numerical values on the injection angles as provided by the MADX computer code which models the RHIC injection system.

Figure 2 shows the injected reference trajectory from the AtR. A 3 mrad magnet bends down the injected beam which intersects the reference RHIC orbit at the middle of the RHIC kickers at an angle of 1.62 mrad. Subsequently the RHIC kickers kick the beam and place it along the RHIC reference orbit. The

future EIC collider will increase the number of the injected bunches by a factor of three. This means that the spacing of the injected bunches into the EIC will be reduced to  $\sim 40$  nsec. The present RHIC injection kicker has a rise time of 90 nsec therefore it has to be replaced by fast  $\sim 18$  nsec strip line type of kickers. However the strip line kickers may not provide the required 1.62 mrad kicking strength to place the injected beam on the reference orbit. In this technical note we suggest a change of the geometry of the RHIC injection system to lower the 1.62 mrad required kicker strength.

### Proposed modification

The proposed modification consists of lowering the Lambertson septum magnet as shown in Fig. 3. The green trace in Fig. 3 shows the new trajectory of the injected beam after the Lambertson magnet is lowered. Two conditions should be satisfied by the injection system when the Lambertson magnet is lowered. First the injected beam should intersect the reference orbit of the EIC ring at the same point (middle of the kickers) as the one prior to lowering the septum magnet, and second the inclination of the Lambertson magnet should change to be parallel to the injected beam trajectory (green trace) in Fig. 3. The second condition mentioned above requires that the septum magnet is aligned with the green injection trajectory. For this condition to be satisfied the “3 mrad” vertical bending magnet upstream of the Lambertson magnet, must be moved further upstream from its current location and provide reduced strength. It is the purpose of the next section to calculate the distance which the “3 mrad” pitching magnet has to be moved upstream and the strength of this pitching magnet as a function of the vertical distance  $\Delta y$  the Lambertson magnet will be displaced.

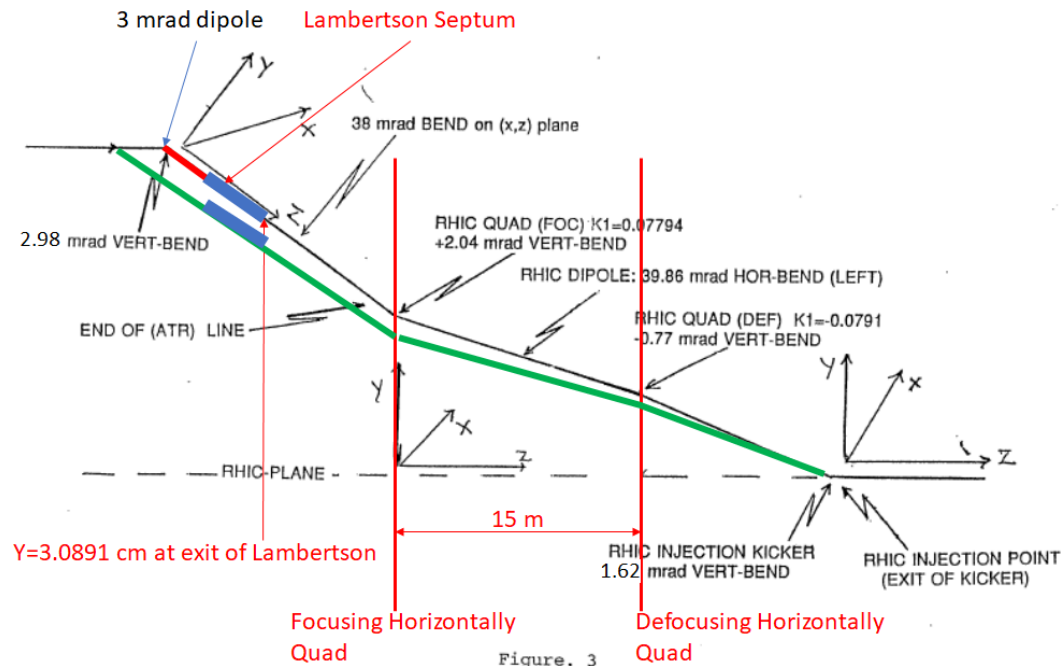


Figure 3. Same as the side view of the RHIC injection system in Fig. 2 with the green trace showing schematically the trajectory of the injected beam when the Lambertson magnet is lowered. Note the injection point of the injected beam is the same before and after the lowering of the magnets.

## General considerations of the proposed modification.

Fig. 4 provides information on the vertical injection angle and of the vertical y-coordinate of the injected beam at the exit of the Lambertson magnet as it is at the present time.

As an answer to the question: “Is there enough space between the injected and the circulating beams to allow the lowering of the Lambertson magnet without interfering with the circulating beam”? The following answer is given.

During the Magnetostatic design of the Lambertson magnet [1] one of the main tasks was to minimize the magnetic field at the region of the circulating beam. This was partly done by the use of a vacuum tube for the circulating beam of Permaloy-80 magnetic material whose purpose was to shield the circulating beam from the main magnetic field of the Lambertson magnet. This tube did reduce the magnetic field in the circulating beam region [1] below the earth’s field but at the same time it increased the septum thickness as shown in Fig. 5 to a value of 1.45 cm. Table 1 summarizes the thicknesses of the materials that comprises the 1.45 cm septum thickness.

The vertical beam size of the circulating beam or the injected beam at the exit of the Lambertson magnet is  $3\sigma_y=4.5$  mm.

Table 1. The thickness of the material that comprise the septum of the Lambertson magnet and the beam size.

Circ. Beam Pipe [mm]	Inj beam pipe [mm]	Air gap [mm]	Septum Iron [mm]	Septum Thick [mm]	$3\sigma_y$ beam size [mm]
1.3	2.0	2.5	8.5	14.5	4.5

By removing the beam pipe of the circulating beam the septum thickness decreases by the sum of the vacuum pipe thickness (1.3 mm) and the air gap between the pipe and the bore hole (2.5 mm) of the Lambertson magnet for a total (1.3 mm+2.5 mm)=3.8 mm. This is shown schematically in Fig. 6 which is a schematic drawing of the septum region at the exit of the Lambertson magnet. Left drawing is the septum thickness (14.5 mm) before the removal of the vacuum pipe of the circulating beam, Right is the septum thickness (10.5) mm after the removal of the vacuum pipe.

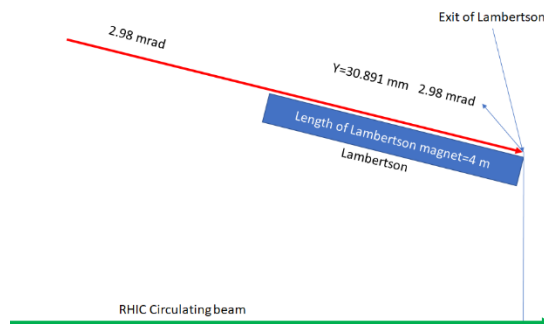


Figure 4. This figure provides information on the vertical injection angle and of the vertical y-coordinate of the injected beam at the exit of the Lambertson magnet as it is at the present time.

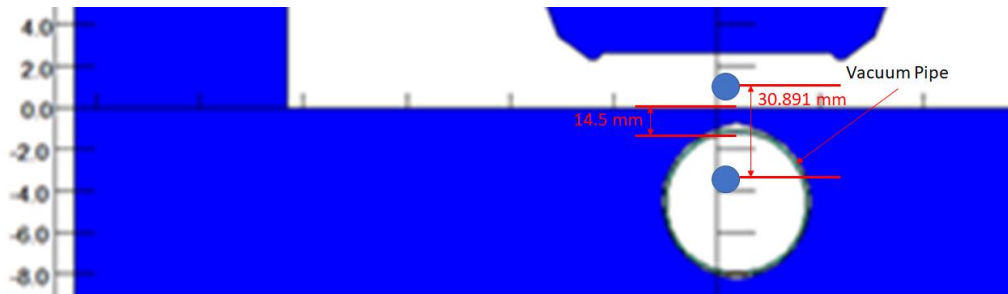


Figure 5. A cross section of the Lambertson magnet at the exit of the magnet. The vacuum pipe of the circulating beam increases the septum thickness.

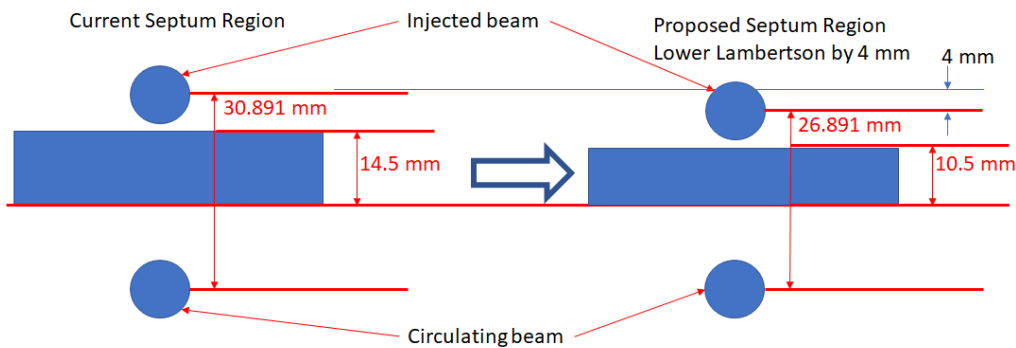


Figure 6. Schematic drawing of the septum region at the exit of the Lambertson magnet. Left is the septum thickness (14.5 mm) before the removal of the vacuum pipe of the circulating beam, Right is the septum thickness of 10.5 mm after the removal of the vacuum pipe.

### Calculations of the position of the magnets after the modification.

The geometry which describes the injection system is a 3D one and the calculations to determine the position that the vertically bending magnet has to be moved upstream and also to determine the angle of bend have to be done in 3D geometry, it is very good approximation though for this technical note to assume that the beam lies on the vertical plane and there is no horizontal bending by the septum magnet. When the location of the magnets at the injection region is finalized after the lowering of the septum magnet, the computer code MAD will be used to calculate the coordinates of the magnets location in a global 3D coordinate system for the surveyors to use.

By removing the pipe of the circulating beam the septum thickness decreases therefore the septum magnet can be lowered by 4 mm. Fig 7 is a schematic diagram of the Lambertson region showing some dimensions and angles related to the septum position before and after the septum is lowered by 4 mm. These quantities appear in Table 2.

Table 2. Some quantities related to the position and orientation of the Lambertson magnet before and after it is lowered by 4 mm.

Original position of Lambertson			Lowering of Septum by 4 mm		
Dist. Circ. Inj. [mm]	Pitch angle [mrad]		Dist. Circ. Inj. [mm]	Pitch angle [mrad]	
30.9	2.98		26.9	2.59	

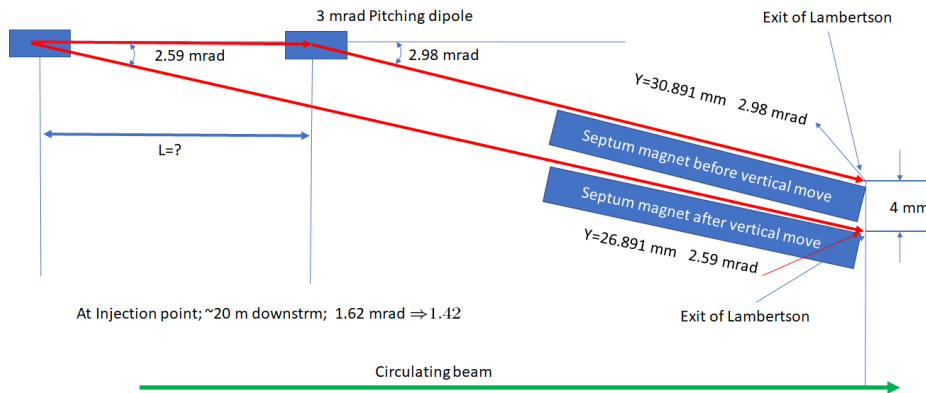


Figure 7. The original location and orientation of the septum magnet superimposed on the new position and orientation after the septum has been lowered by 4 mm.

The new position of the “3 mrad” pitching magnet is calculated by using the layout of magnets in Fig. 8. As it was mentioned earlier these calculations provide a good approximation of the location of the “3 mrad” pitching magnet and of the pitching angle of Lambertson septum. More detailed calculations will be performed using the survey module of the MADX computer code.

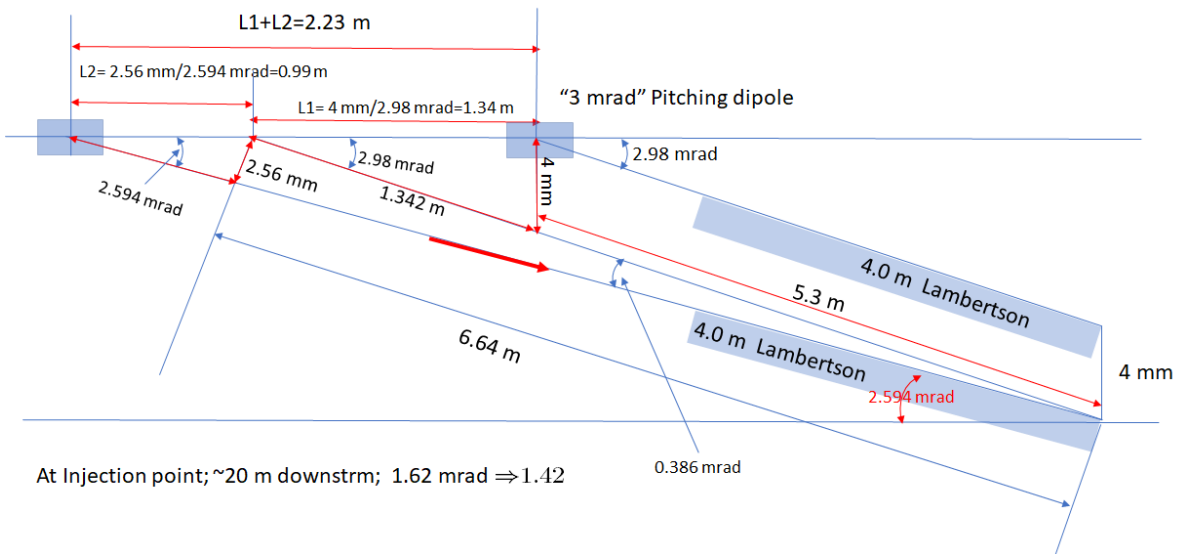


Figure 8. This figure assists for the calculation of the new location of the pitching dipole after the Lambertson magnet has been lowered by 4 mm.



The change of the magnetic field in the circulating beam region of the Lambertson magnet after the removal of the beam pipe which acts as a magnetic shield.

As was mentioned earlier the vacuum pipe of the circulating beam inside the Lambertson magnet acts as a magnetic shielding of this volume defined by the pipe. After the Lambertson magnet was built the magnetic field measurements performed on the magnet showed that the magnetic field inside the pipe of the circulating beam was below the earth's field.

To determine the magnetic field in the circulating field region after the removal of the pipe a 3D model of the Lambertson magnet was built as shown in Fig. 9 using the OPERA computer code. The magnetic field along the trajectory of the circulated beam is plotted in Fig. 10 for two cases, one with the magnet excited at the field to bend 100 Tm rigid beam and the other at 80 Tm. The integrated magnetic field along the trajectory of the circulating beam was calculated and the results appear in Fig. 10 and in Table 3.

The Lambertson magnet was build to bend beams with rigidity of 100 Tm but for other reasons the rigidity of the injected beams was lower to ~80 Tm.

Table 3. The angle of bend of the circulating beam when it passes through the Lambertson magnet which has the vacuum beam pipe removed.

Rigidity [Tm]	Inegrated By [Tm]	Angle of bend [mard]
100	0.0032	0.032
80	0.00061	0.008

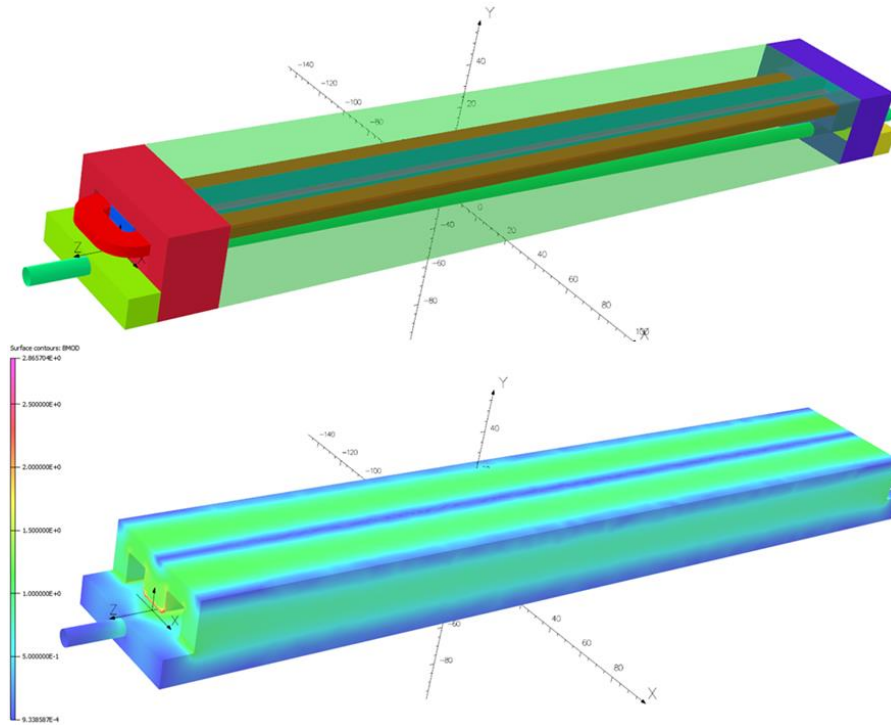


Figure 9. A 3D model of the Lambertson magnet as built using the Modeler module of the OPERA computer code.

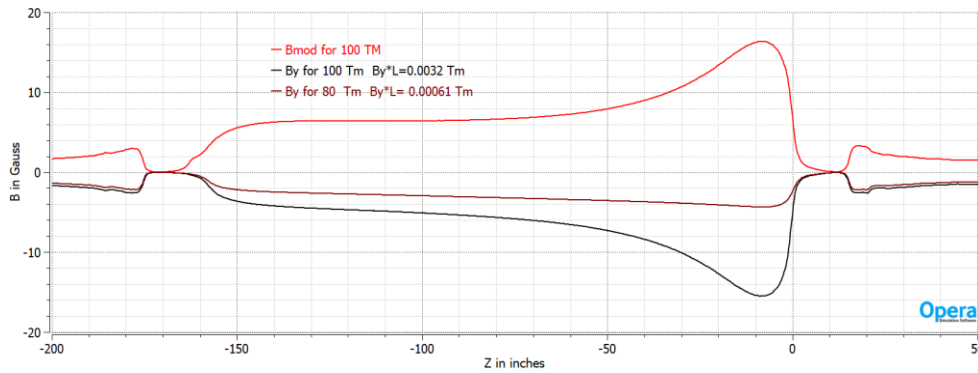


Figure 10. The  $B_{\text{mod}}$ , and  $B_y$  plotted along the reference orbit of the circulating beam with the magnet excited to bend beams with rigidity at 100 Tm and 80 Tm.

## Conclusions

By lowering the RHIC injection Lambertson magnet by 4 mm the require kick on the injected beam is lowered form 1.62 to 1.42 mrad. The removal of the vacuum beam pipe of the circulating beam presents no problem to the circulating beam.

## References

- [1] [Nuclear Inst. and Methods in Physics Research, A 973 \(2020\) 164167](#)

