HIGH LUMINOSITY β^*=0.5m RHIC INSERTIONS*

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Abstract

An increase in RHIC collision luminosity is possible by reducing the beam size at the interaction point (IP). We present a method for reducing the IP beta function, β^*, from the design minimum of $1m$ to $0.5m$. We demonstrate that this β^*=$0.5m$ configuration is achievable with existing RHIC power supplies for $100GeV$ protons. We discuss the correction of the higher order IR multi-poles and the second order chromaticity.

INTRODUCTION

RHIC consists two rings, each ring has 6 interaction regions (IRs). At the center of each IR is the IP, where collisions can occur. Each IR consists of 9 quadrupoles on each side of the IP organized anti-symmetrically. These quadrupoles can be further subdivided into a dispersion suppressor and telescope. Our goal is to reduce the beam size at the IP. This is achieved by reducing the beta function and dispersion at the IP. A schematic is shown in Fig. 4. In the next section, we discuss the β^* squeeze.

β^* SQUEEZE

We will find the quadrupole strengths shown in Fig. 4 to produce a lattice with a given β^* at the IP. With this design we have 12 parameters to vary. The procedure used requires meeting these 14 constraints:

- $\beta_x^* = \beta_y^* = \beta^*$ (2 constraints).
- $\eta^* = 0$ and $\alpha_x^* = \alpha_y^* = 0$ (3 constraints).
- $\beta_{max_x} = \beta_{max_y}$ in the triplets (1 constraint).
- Matching the Insertion to the arcs (6 constraints).
- Getting the correct tunes (2 constraints).

Using the MAD program [1], the optics were fit from $\beta^* = 1m$ to $\beta^* = 0.5m$. Additionally, the strengths for the quadrupoles are calculated from the power supply currents by using a 5th order polynomial fit to the measured transfer function (averaged over all quadrupoles of the same type). Fig. 1 gives the resulting penalty function. Fig. 2 gives the final power supply currents for $100GeV$ protons. This is after some additional smoothing with the ends fixed. Fig. 3 shows the beta function plot for a RHIC insertion at $\beta^* = 0.5m$.

Shunt and Trim Supplies

Each half of the insertion is controlled by 3 trim power supplies for the trim quadrupoles next to Q4, Q5 and Q6.

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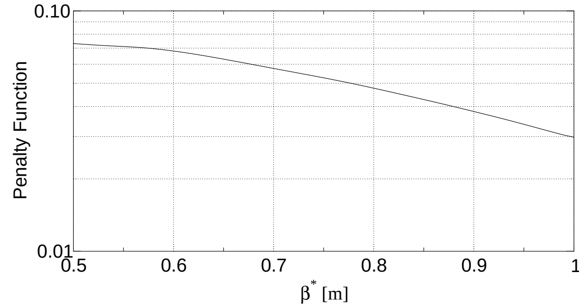

Figure 1: The final penalty function vs β^*

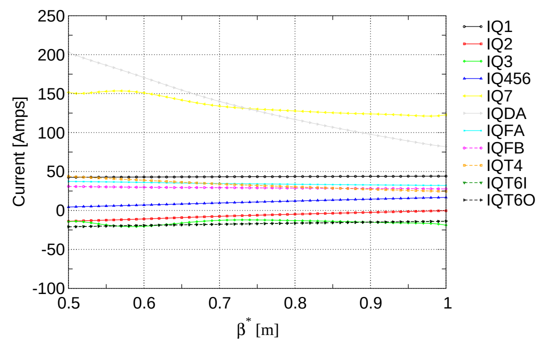

Figure 2: The shunt and trim supplies for the RHIC insertion as a function of β^*. Note, IQT4 = IQT4I = IQT4O = -IQT5I = -IQT5O and IQ456 is fixed to a function of β^*.

Furthermore, the inner and outer trim supplies can be independently controlled. On the QF main bus there are 5 shunt supplies for the main quadrupoles from Q1 through Q7. The QD bus has two shunt supplies per half insertion for controlling QFA(B) and the QDA quadrupoles. One is common between inner and outer, while two others can be independently controlled. The following tables gives the limits on these power supplies:

A comparison of the required currents given in Fig. 2

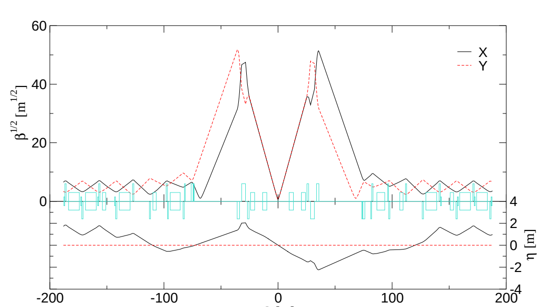

Figure 3: The RHIC insertion optics with $\beta^* = 0.5m$.

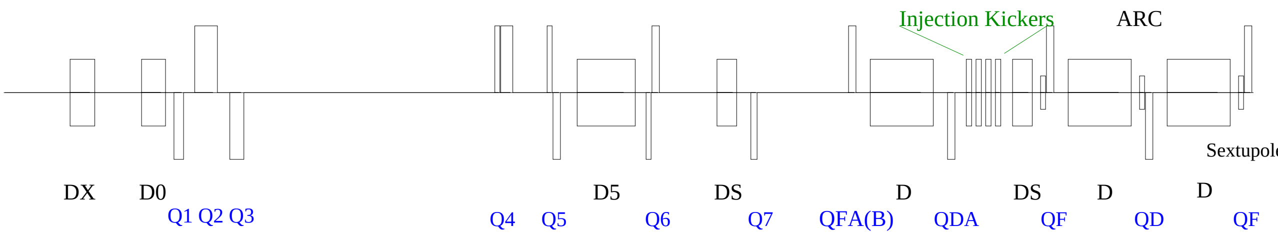

Figure 4: A schematic for half of the RHIC insertion. The quadrupoles Q4, Q5 and Q6 have associated trim quadrupoles. Q4 and Q5 trims are set to the same, but opposite strengths. Antisymmetry is broken for the trim quadrupole at Q6 and the quadrupoles at QFA(B). This leads to 12 adjustable parameters (including QF and QD).

Table 1: Shunt and Trim power supplies

Supply	Minimum [Amps]	Maximum [Amps]
Trim	-150	150
IQFA(B)	1	200
IQDA	-300	300
IQ7	1	600
IQ456	1	450
IQ3	1	300
IQ2	-150	150
IQ1	1	200

with the power supply limits given in Table 1 shows that the required currents are within the power supply limits.

Matching to Existing Squeeze

RHIC squeezes from β^* of $10m$ to $1m$ with an existing solution. A lot of effort went into optimizing the tunes, chromaticity, orbit, coupling, etc. with this squeeze. A smooth transition in the power supply currents from the new squeeze of $1m$ to $0.5m$ to the existing squeeze is required. To create a ramp with a β^* squeeze, a function $\beta^*(time[sec])$ must be carefully chosen so that the changes to the power supply currents remain smooth throughout the squeeze. This is accomplished with the quadrupole strength values $K(\beta^*)$ (see Fig. 5) for each quadrupole, along with the values of $dK(\beta^*)/d\beta^*$. Furthermore, some smoothing may be necessary to achieve the final goal. Finally, modeling from MAD does not necessarily agree with the machine model due to differences in the MAD description and the real machine. One example: all focusing quadrupoles do not have the same strength even when connected to the same current bus due to differences in the integrated strengths of these magnets.

NONLINEAR CORRECTION

The large $\beta_{max} = 2.66km$ in the triplets leads to some undesirable effects that must be corrected. Additionally, if the beams 95% normalized emittance is $20\pi mm\text{-}mrad$, the triplet's beam size is $\sigma = 9mm$ for $100GeV$ protons. Since the triplet aperture is $56.5mm$, this is quite tight. Furthermore, the dispersion in the triplets is $\pm 2m$, which is affected by the momentum spread. This creates aperture constraints in the triplets, high order chromatic effects, triplet multi-pole problems, etc. We start with the multi-poles effects and correction.

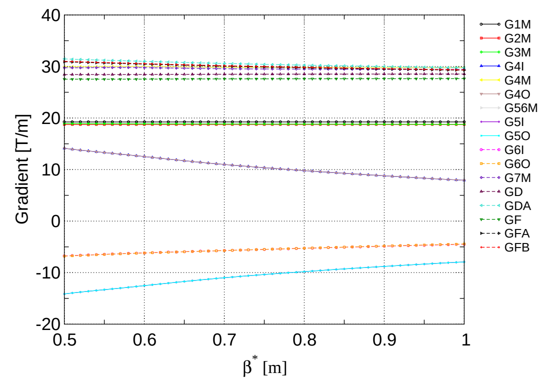

Figure 5: The gradient strengths for protons at $100GeV$ vs. β^*.

IR Multi-Pole Correction

In two of the IR's, we have high order correctors to improve dynamic aperture for the low β^* insertions. There is an operational tool [2] to measure the effect of the triplet multi-poles on the tune spread and calculate the corresponding corrector strengths. An orbit bump is applied through the triplets and the tune variations is measured with the PLL tune-meter [3]. We obtain a data set of the tune versus orbit bump amplitude. This data is then fit to polynomial. From the polynomial coefficients, the multi-pole correction strengths can be determined. Furthermore, the bump can be horizontal or vertical so that the skew multi-poles can be corrected as well. Next we discuss chromatic effects.

Nonlinear Chromatic Correction

Besides transverse effects there are longitudinal effects as well. A beam with a momentum spread produces a tune spread from chromatic effects. The most significant contribution to chromatic effects are the triplets in RHIC. The large β_{max} exasperates the problem. Using the MAD

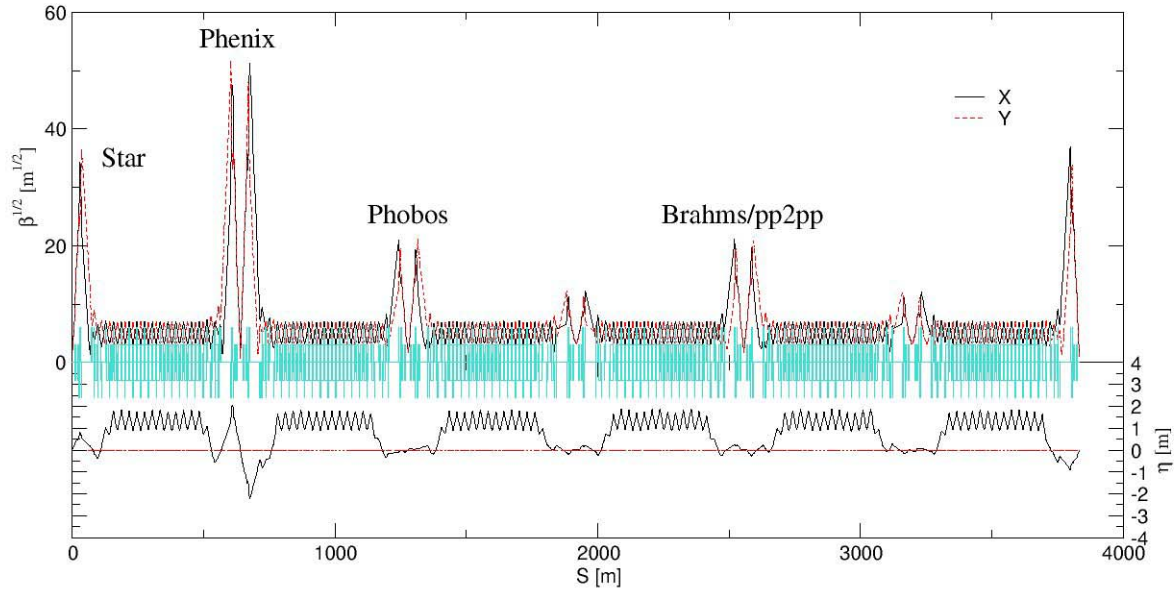

Figure 6: The RHIC optics parameters. The Star insertion is set to $\beta^* = 1m$, Phenix has $\beta^* = 0.5m$, Phobos and Brahms are at $\beta^* = 3m$ and the remaining insertions have $\beta^* = 10m$

model with the design optics Fig. 6, the amplitude and chromatic terms can be calculated as:

$$\nu_x = \nu_{x_0} - 644\epsilon_x - 1753\epsilon_y + 2\delta - 623\delta^2 - 211100\delta^3$$

$$\nu_y = \nu_{x_0} - 1753\epsilon_x + 390\epsilon_y + 2\delta + 1727\delta^2 + 80400\delta^3$$

Both the second and third order terms become significant when $\Delta p/p \simeq 0.003$ in the horizontal plane and the second order term becomes significant when $\Delta p/p \simeq 0.001$ Compare this with the chromatic terms if we set the Phenix insertion to $\beta^* = 1m$ (this is the current optics in RHIC for the Run 2003 polarized proton operation) instead:

$$\nu_x = \nu_{x_0} - 447\epsilon_x - 1203\epsilon_y + 2\delta + 209\delta^2 - 134000\delta^3$$

$$\nu_y = \nu_{x_0} - 1203\epsilon_x + 269\epsilon_y + 2\delta + 977\delta^2 - 31500\delta^3$$

A preliminary measurement of the second order chromaticity has produced numbers similar in magnitude to those above. A more detailed analysis of these results needs to be done.

The second order chromaticity can be corrected in RHIC by either using four families of sextupoles [4] or using four families of octupoles which are organized as two families in high dispersion regions and two families in low dispersion regions. The two families in the high dispersion regions correct the second order chromaticity while the two families in the low dispersion region are used to correct the tune spread from the first two families. Since, the octupoles are wired in this fashion, we would correct second order chromaticity by this method.

SUMMARY

We presented a design for the RHIC insertion that achieves a $\beta^* = 0.5m$ at the IP. This design works with the existing power supplies for protons at $100GeV$. We discuss how to implement this solution with the existing β^* squeeze ramp. Furthermore, correction of the triplet multipoles and second order chromaticity is discussed as well. Further studies for dynamic aperture should be done due to the tight space available in the triplets. We plan to have beam studies with this insertion in the future.

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