It is also necessary to make changes to some of the power supplies. The greatest change is the power supply that shunts the current from Q4 to Q3 which must be increased to 2000A and power leads capable of handling this current. Depending on the transfer function of the trim quadrupoles, one or two may need to have a larger power supply. Finally, the shunt supply from QD to QDA must be increased by about 60*A* and the shunt supply from QF to Q7 must be increased about 34*A* for the even insertion and 24*A* for the odd insertion.

References

[1] E. D. Courant and H. S. Snyder, Annals of Physics: **3**, 1-48 (1958)
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Figure Captions

Fig. 1 The root beta and dispersion functions along the insertion for the 4, 8 and 12 o'clock insertions (even).

Fig. 2 For a scattering angle of 70μ*rad* and a beam of 5π *mm-mrad* at 250*Gev* the scattered particles position is compared with the beam size along the even insertion.

Fig. 3 The root beta and dispersion functions along the insertion for the 2, 6 and 10 o'clock insertions (odd).

Fig. 4 For a scattering angle of 70μ*rad* and a beam of 5π *mm-mrad* at 250*Gev* the scattered particles position is compared with the beam size along the odd insertion.

Similarly, the odd insertion will also have two Roman Pots, but these will be placed at positions different relative to the even insertion. The first Roman Pot will be 72*m* from the crossing point, between Q3 and Q4, with an L_{eff} of 36*m*. The second Roman Pot will be at 144*m* from the crossing point with an L_{eff} of 87*m*. Fig 3 gives the twiss beta functions and dispersion as a function of position along the insertion. Note, β^* is 195*m* for this solution. Fig. 4 gives $L_{eff}y'$ along the insertion and Table 2 gives the quadrupole strengths, gradients at top energy and the current requirements.

Table 2: Quadrupole strengths, 2, 6 and 10 o'clock insertion (odd)

Quadrupoles	Strength [m^{-2}]	Gradient [*T/m*]	Current [*A*]
Q1	0.0428970	36.012	3765
Q2	0.0436961	36.683	3835
Q3	0.0420354	35.289	3689
Q4, trim	0.0408204	-34.268	143
Q5, trim	0.0454000	38.113	159
Q6, trim	0.0363980	30.556	127
Q7	0.0924858	77.642	5151
Q4, Q5, Q6, main	0.1000000	83.950	5600
QFA (Q9I, Q8O)	0.0742885	62.365	4111
QDA (Q8I, Q9O)	0.0753824	63.284	4172
QF	0.0817048	68.591	4527
QD	0.0844124	70.864	4682

Since, there is no adiabatic path from the standard $\beta^* = 10m$ injection optics to either of the above large β^* optics, we must inject with these optics when an elastic scattering experiment is carried out. These optics will remain unchanged throughout the entire run which may have implications for other experiments. Examining the beta functions given in Figures 1 and 3 shows large beta functions of less than 160*m* at Q4 where the beam pipe is standard 7.2*cm* diameter. Fortunately, the dispersion is small in this region. Additionally, scraping will be needed to reduce the emittance of the beam. These constraints give an acceptance criteria which could affect other experiments going on else where in the ring.

Conclusion

The RHIC insertion is tunable for elastic scattering experiments, with a resulting L_{eff} of about 58*m* or 87*m* depending on the insertion. Since, this is a perturbation of normal operations at RHIC, we had to forgo the large margins on the field strengths of Q4, Q5 and Q6 insertion quadrupoles and there corresponding trims.

becomes rather poor.

Placing limits on the trim quadrupoles determines the maximum β^* that can be achieved. This can be helped by adjusting the current through Q4, Q5 and Q6. Additionally, the limits on the shunt supplies between Q3 to Q2 and Q2 to Q1 play a role.

There are two kinds of insertions in RHIC, which differ due to the anti-symmetry of the lattice. Interchanging the x and y twiss functions of one kind of insertion gives the twiss functions of the other kind (this is not true for the dispersion functions). Thus, we have two solutions for the two kinds of insertions, one for either the 4, 8 or 12 o'clock insertions (referred to as even) and a different solution for either the 2, 6 or 10 o'clock insertions (referred to as odd).

For the even insertion, there are places for two Roman Pots. The first place is in the long warm drift space (between Q3 and Q4) with a moderate L_{eff} of 27*m* at about 54*m* from the crossing point. The second will be placed between Q9 and Q10 at about 149*m* from the crossing point for a larger L_{eff} of 58*m*. The β^* is about 155*m* as shown in Fig. 1. Furthermore, the α^* is not zero since the Roman Pots are not at the $\pi(n + 1/2)$ phase positions where *n* is an integer. This was necessary in order to find free space to place the Roman Pots. Fig. 2 shows the $L_{eff}y'$ as a function of position along the insertion, and Table 1 gives the quadrupole strengths, gradients at top energy ($B\rho$ is 839.5 *Tm*) and the currents required. Note, the trim quadrupoles assume that the transfer function is 0.24 Tm^{-1}/A, however, the RHIC design manual quotes 0.283 Tm^{-1}/A. If we constrained the solution with the former number, then, β^* drops to 80*m*.

Table 1: Quadrupole strengths, 4, 8 and 12 o'clock insertion (even)

Quadrupoles	Strength [m^{-2}]	Gradient [*T*/*m*]	Current [*A*]
Q1	0.0420471	35.299	3690
Q2	0.0437010	36.695	3836
Q3	0.0438937	36.849	3853
Q4, trim	-0.0434749	-36.497	-152
Q5, trim	0.0454000	38.113	159
Q6, trim	0.0300736	25.247	105
Q7	0.0928157	77.919	5171
Q4, Q5, Q6, main	0.1000000	83.950	5600
QFA (Q9I, Q8O)	0.0743917	62.452	4117
QDA (Q8I, Q9O)	0.0755708	63.442	4183
QF	0.0818697	68.730	4537
QD	0.0845650	70.992	4691

large as possible.

Tuning the insertion.

Tuning the RHIC insertion requires many constraints ranging from dynamical beam behavior to the hardware constraints for implementation. We consider the beam dynamics first. The RHIC insertion[2] uses an antisymmetric quadrupole arrangement about the interaction point. This implies that $\beta_x(s) = \beta_y(-s)$ and $\alpha_x(s) = -\alpha_y(-s)$ where s is the coordinate along the beam and $s = 0$ is at the crossing point. The strengths of the quadrupoles in the insertion are found such that: (1) the crossing point parameters needed for the experiment are realized and (2) beta and dispersion functions match the corresponding arc functions at the ends of the insertion.

There are 9 quadrupoles in each insertion and 2 quadrupoles in the arc that are available for tuning. The limits on the quadrupole strengths and power supplies are set by the standard operation of the ability to tune the insertion from $\beta^* = 1m$ to $\beta^* = 10m$. These limits are the determining factor on the maximum β^* that can be achieved in RHIC. To tune the insertion for elastic scattering, we impose the following conditions

$$\eta^* = 0$$

$$\nu_x = 28.187$$

$$\nu_y = 29.179$$

$$a_{11} = 0$$

and matching the functions to the arcs

where ν_x and ν_y are the operating tunes of RHIC and η^* is the horizontal dispersion at the crossing point.

Besides the above conditions, there are also the following constraints on the quadrupoles, power supplies and lead end currents that needs to be considered[3-4]:

(1) limits on the trim quadrupole strengths, determined by the 150*A* power supply, the given quench current and the transfer function[1];
(2) the shunt power supply and lead ends between Q3 to Q2 and Q2 to Q1 where the power supply and the leads limit current to 150*A*;
(3) the maximum current through the Q4, Q5 and Q6 main quadrupoles, limited by the quench current[2];
(4) the shunt power supply between QF to Q7;
(5) the shunt power supply between QD to QDA.

Without limits on the shunt supplies from QF to Q7 or QD to QDA leads to solutions requiring up to about 60*A* more current than is planned. If limits are imposed on these currents, the solution

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1. As of this writing, the trim quadrupoles transfer function has not been measured.
2. By adjusting the current in these three quadrupoles, we can reduce the current needed in their corresponding trim quadrupoles.

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Tuning the RHIC Insertion for Elastic Scattering

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Abstract

An elastic scattering experiment measures the angle of the outgoing particle after collision. This scattering angle is too small to be measured by conventional means since the particles never leave the beam pipe. To observe and measure the scattering angle, we use the optics of the insertion as a magnifier. This requires special tuning of the insertion leading to large β^* operation. We present a tuning scheme at RHIC for an elastic scattering experiment and discuss some of the hardware implications in the implementation.

Introduction

An elastic scattering experiment requires special tuning of the insertion. During a collision, the scattering angles are so small, the scattered particles remain in the beam pipe, perhaps within the beam itself. By using the optics of the insertion, the scattering angle can be magnified enough to be observed. Undesirable effects, such as magnification of the collision position and errors introduced by dispersion must be minimized. Since, the ideal RHIC lattice has no vertical dispersion, the dispersion effects can be minimized by measuring scattering in the vertical direction (denoted by *y*).

The two beams will collide at the interaction point in a local coordinate system at a vertical distance, *y'*, from the reference orbit and scatter with the slope, *y'*. These particles will then pass through the various magnetic lenses in the insertion until they reach a detector (Roman Pot). The detector measures the positions of the scattered particles with respect to the reference orbit. This position can be determined from[1]

$$\begin{bmatrix} y \\ y' \end{bmatrix}_{RP} = \begin{bmatrix} \sqrt{\frac{\beta_{RP}}{\beta^*}}(\cos\Psi + \alpha^*\sin\Psi) & \sqrt{\beta^*\beta_{RP}}\sin\Psi \\ -\frac{(1+\alpha^*\alpha_{RP})\sin\Psi + (\alpha^* - \alpha_{RP})\cos\Psi}{\sqrt{\beta^*\beta_{RP}}} & \sqrt{\frac{\beta^*}{\beta_{RP}}}(\cos\Psi - \alpha_{RP}\sin\psi) \end{bmatrix} \begin{bmatrix} y \\ y' \end{bmatrix}^*$$

where β^* and α^* are the twiss parameters at the interaction point, Ψ is the phase advance from the interaction point to the Roman Pot and β_{RP} and α_{RP} are the twiss parameters at the Roman Pot.

Since, the Roman Pots can only measure y_{RP}, the above equation can be reduced to $y_{RP} = a_{11}y^* + L_{eff}y'^*$ where $a_{11} = \sqrt{\beta_{RP}/\beta^*}(\cos\Psi + \alpha^*\sin\Psi)$ and the magnification is $L_{eff} = \sqrt{\beta^*\beta_{RP}}\sin\psi$. The goal in tuning the RHIC insertion is to set a_{11} to zero and make L_{eff} as