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# *Lattice design for head-on beam-beam compensation at RHIC*

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# DISCLAIMER

# LATTICE DESIGN FOR HEAD-ON BEAM-BEAM COMPENSATION AT RHIC [*]

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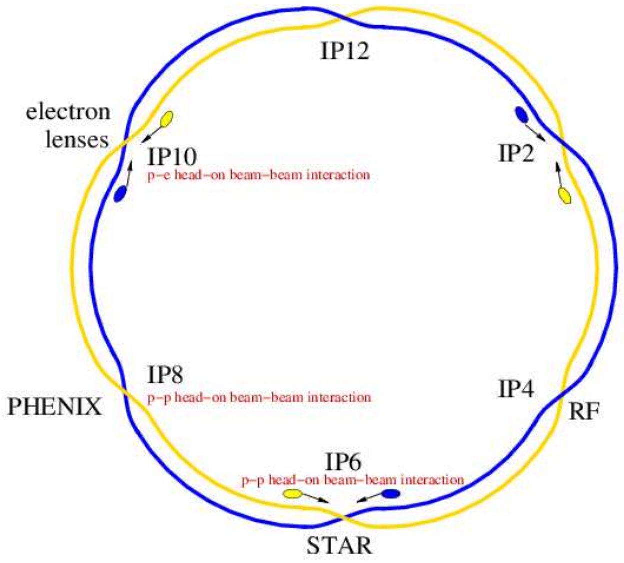

Figure 1: Schematic view of RHIC.

## *Abstract*

Electron lenses for head-on beam-beam compensation will be installed in IP 10 at RHIC. Compensation of the beam-beam effect experienced at IP 8 requires betatron phase advances of $\Delta\psi = k \cdot \pi$ between the proton-proton interaction point at IP 8, and the electron lens at IP 10. This paper describes the lattice solutions for both the BLUE and the YELLOW ring to achieve this goal.

## INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two superconducting storage rings that intersect at six equidistantly spaced locations around the circumference of the machine. Beams collide in interaction points (IPs) 6 and 8, which are equipped with the detectors STAR and PHENIX, respectively (see Figure 1). To increase the tolerable beam-beam parameter and therefore the luminosity in proton-proton collisions, head-on beam-beam compensation by means of electron lenses in IP 10 is foreseen.

## LATTICE DESIGN

In a linear lattice, complete compensation of the nonlinear beam-beam effect can be achieved by placing an electron lens with the same strength but opposite sign of the beam-beam kick at a betatron phase of $\Delta\psi = k \cdot \pi$ from the interaction point. With the RHIC electron lenses, which will be installed in interaction region (IR) 10, aiming at compensating the head-on beam-beam effect the beams experience at IP 8, this requires a betatron phase advance of $k \cdot \pi$ over the sextant between IP 8 and the electron lenses. Since the two electron lenses will be shifted longitudinally by roughly 2 m from the nominal IP 10, the additional phase advance of $\Delta\psi_{\mathrm{shift}} = \pm 2 \cdot \pi \cdot 0.035$ resulting from this shift has to be taken into account. Adjusting the phase advance will be achieved by additional shunt power supplies for the main quadrupoles QF and QD in this arc. However, at the regular RHIC proton working point of $(Q_x, Q_y) = (28.69, 29.68)$, the unmodified betatron phase advance over this arc is close to 90 degrees. Adjusting this to the desired value by means of the arc shunt supplies results in huge lattice distortions that cannot be corrected with the existing IR power supplies. To get a more favorable baseline phase advance, the working point therefore needs to be changed to $(Q_x, Q_y) = (27.69, 29.68)$ in the BLUE ring, and $(Q_x, Q_y) = (29.69, 30.68)$ in YELLOW. This results in betatron phase advances within less than 20 degrees of the target value, and adjusting them by means of the arc shunt power supplies leads to manageable lattice distortions that are subsequently eliminated by re-fitting the interaction regions 8 and 10.

The baseline lattices with these new working points for both rings are generated using the OpticsDesigner code [1], aiming at $\beta_{\mathrm{IP6}} = \beta_{\mathrm{IP8}} = 0.5\,\mathrm{m}$, and $\beta_{\mathrm{IP2}} = \beta_{\mathrm{IP4}} = \beta_{\mathrm{IP10}} = \beta_{\mathrm{IP12}} = 9.0\,\mathrm{m}$. After several iterations the solutions converged on $\beta$-functions of 0.58 m and 9.0 m, respectively, limited by power supply and lead current limits at 250 GeV. Table 1 lists the baseline parameters for the lattices in the BLUE and YELLOW ring.

To reduce power supply cost and minimize cold penetrations, the interaction region quadrupoles are connected in series with the main quadrupole circuits [2]. While quadrupoles Q1 to Q7 are powered by the QF main buss, Q8 and Q9 are connected to the QD circuit. The current through individual IR quadrupoles is varied by an elaborate system of nested shunt power supplies. Figures 2 and 3 show the quadrupole insertion schematics. Beginning at IR 4, the main current flows through the defocusing main quadrupoles (QD) and the insertion quads Q8 and Q9. This

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| | | |
|---|---|---|
| BLUE | | |
| | $Q_x, Q_y$ | 27.69, 29.68 |
| | $\Delta Q_x, \Delta Q_y$ between e-lens and PHENIX | 4.035, 5.535 |
| | $\beta_x, \beta_y$ at IPs 6 and 8 | 0.59 m, 0.58 m |
| | $\beta_x, \beta_y$ at IPs 2, 4, 10, and 12 | 9.0 m, 9.0 m |
| YELLOW | | |
| | $Q_x, Q_y$ | 29.69, 30.68 |
| | $\Delta Q_x, \Delta Q_y$ between e-lens and PHENIX | 5.465, 4.465 |
| | $\beta_x, \beta_y$ at IPs 6 and 8 | 0.58 m, 0.58 m |
| | $\beta_x, \beta_y$ at IPs 2, 4, 10, and 12 | 9.0 m, 9.0 m |

Table 1: Key parameters of the modified RHIC lattices.

pattern repeats until IR 10 is reached half way around the ring, from where the main current returns through the focusing main quadrupoles (QF) and the IR quadrupoles Q1 to Q7 in a repeating fashion until IR 4 is reached again. In the regular RHIC lattice configuration, the quadrupole currents at Q6, Q7, and Q9 are close enough to their respective counterparts on the other side of IR 8 that they can share a single power supply that bridges the IP. Three individually powered trim quadrupoles QT4, QT5, and QT6 on each side of each IP allow tuning of the interaction regions. Since the main quadrupole buss returns at IR 10, the two sides of IR 10 are completely independent.

To completely decouple the quadrupole strengths on the two sides of IR 8, and therefore increase the lattice flexibility to the level required for re-matching after adjusting the betatron phase advance between IRs 8 and 10, additional power supplies need to be introduced for Q6, Q7, and Q9, as indicated in Figure 4. In the YELLOW ring, the Q9 power supplies on both sides of IR 10 have to be upgraded from $\pm 300\,\mathrm{A}$ to $\pm 450\,A$ to account for the larger main quadrupole current through these magnets, introduced by the larger integer tunes. In addition, the H/V trim power supply in IR 10, which offsets the main magnet currents through the focusing quads (QF) from that through the defocusing ones (QD) to enable independent tune adjustments in the two planes, has to be upgraded from the current 300 A limit to 450 A in the BLUE ring, as a consequence of the two-integer tune split between the two planes.

## CONCLUSION

Modified lattices for head-on beam-beam compensation have been developed for RHIC polarized proton operations at 250 GeV. The main modification with respect to standard RHIC lattices is the choice of different integer tunes, namely $Q_x, Q_y = 27.69, 29.68$ in BLUE, and $Q_x, Q_y = 29.69, 30.68$ in YELLOW, which results in a more favorable betatron phase advance between IP8 and IP10.

The higher integer tune in the YELLOW ring will increase $\gamma_t$ by approximately one unit throughout the entire ramp. Since protons are injected just above transition energy, additional means will be necessary to counteract this increase at injection, for instance by further increasing the current in the $\gamma_t$ power supplies already used for this purpose [3]. The maximum achievable reduction of $\gamma_t$ is currently being studied during APEX studies in the FY11 polarized proton run [4].

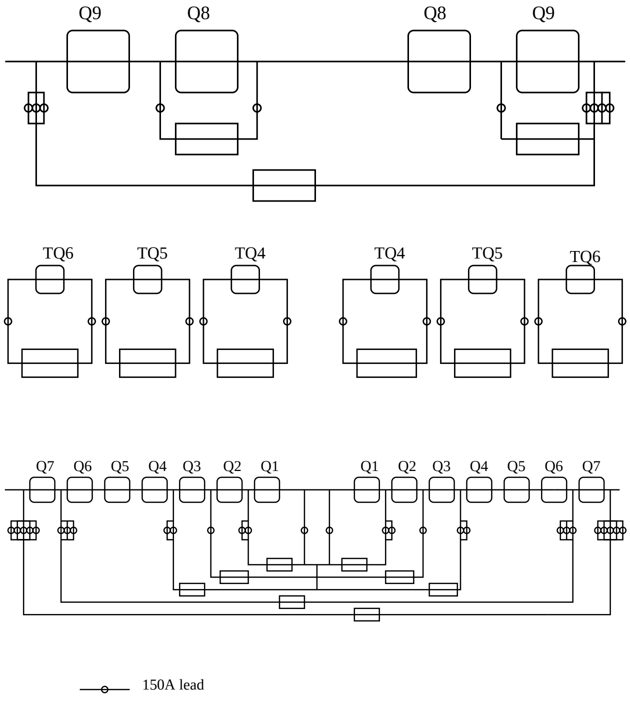

Figure 2: RHIC power supply scheme in IR 8.

## ACKNOWLEDGMENTS

I would like to thank Steve Tepikian and Joerg Kewisch for help with the MAD program, and Don Bruno for double-checking the power supply and lead currents.

## REFERENCES

[1] S. Tepikian, unpublished

[2] RHIC Design Manual

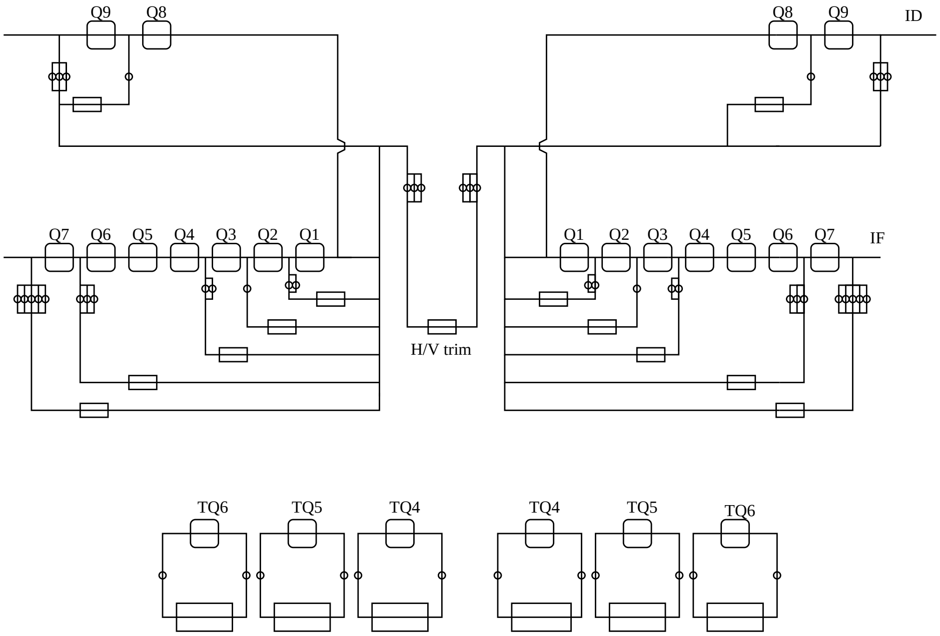

Figure 3: RHIC power supply scheme in IR 10.

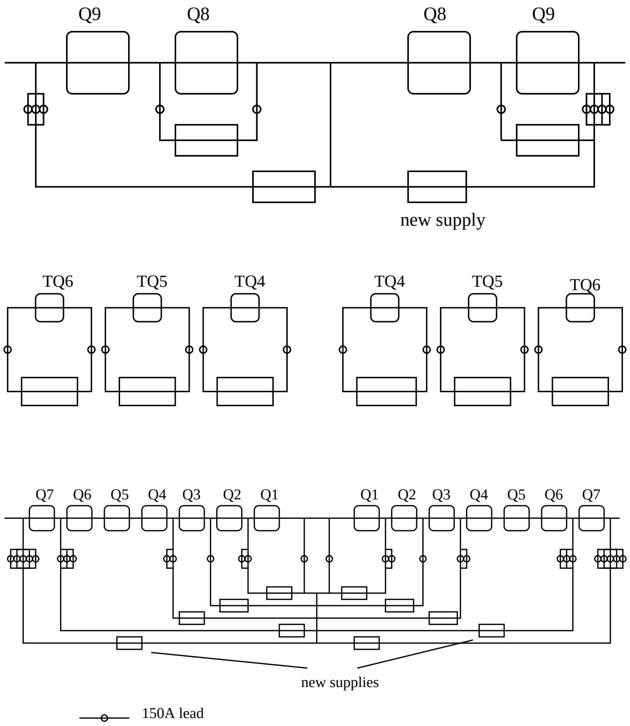

Figure 4: Modified power supply scheme in IR8 to completely decouple the two sides of the IR.

[3] C. Montag, "A Low $\gamma_t$ Injection Lattice for Polarized Protons in RHIC", Proc. PAC'07

[4] C. Montag et al., "Beam Experiments Related to the Head-on Beam-beam Compensation Project at RHIC", these Proc.