

MOMENTUM APERTURE FOR THE LOW β^* LATTICES IN THE RHIC Au-Au RUNS*

Y. Luo, K. Brown, W. Fischer, G. Marr, G. Robert-Demolaize, T. Roser, V. Schoefer,
S. Tepikian, D. Trobjevic, Brookhaven National Laboratory, Upton, NY USA

Abstract

In this article we calculate the momentum apertures with the low β^* lattices for the 100 GeV RHIC Au-Au runs. With RF re-bucketing, the maximum off-momentum spread of the beam reaches the Bucket height. To improve the momentum aperture, we perform chromatic correction with the chromatic sextupoles in the arcs. The methods to correct second order chromaticities in RHIC rings are presented. We also scan beta* at IP6 and IP8 and working point. The challenges to further reduce beta* in the RHIC Au-Au operation are discussed.

INTRODUCTION

In the 2010 RHIC 100 GeV Au-Au run [1], to reduce the big beam loss with the RF re-bucketing at store, two measures were made to improve the dynamic apertures of particles with large momentum deviation. First, we moved the working points of the Yellow ring down along the diagonal to (23.10, 22.05) from the nominal working point around (23.23, 22.22). Secondly, we released the β^* s at the two colliding interaction points (IPs) IP6 and IP8 from the design 0.6 m to 0.7 m. With the RF re-bucketing, the bunch length is reduced from 20 ns to 5 ns. However, the beam's relative momentum spread is increased from 1.1×10^{-3} to 1.7×10^{-3} . 1.7×10^{-3} is very close to the RF bucket height.

In the 2011 RHIC 100 GeV Au-Au run [2], the same lattice from the 2010 Au-Au run was used. In this run, the beam loss with the RF re-bucketing was much smaller than that from the previous run. One reason was that the longitudinal bunch area is about half of the previous run. There was less longitudinal emittance blow-up during the energy acceleration. Another reason is that the RF re-bucketing voltage was also smaller. In the 2010 run, the typical total RF voltage is about 4.0 MV. In the 2011 run, this value was about 3 MV or less. With a dedicated tune scan along the diagonal in the tune space, we found that the optimum working point for the Yellow ring was around the nominal working point (31.23, 32.22), instead of (23.10, 22.05) found and used in 2010.

In this article, we will carry out simulation studies to understand and to improve the momentum apertures in the 2010 and 2011 RHIC Au-Au and future RHIC heavy ion runs. The reductions in the momentum apertures due to the low β^* lattices and the RF re-bucketing are checked. To

improve the momentum aperture with RF re-bucketing, we will perform non-linear chromatic correction in the coming heavy ion runs. The dynamic aperture without and with second order chromaticity correction are presented. In this article, we focus on the Blue ring lattices. More work, such as, to understand the beam loss at store, to connect the operation observations and simulation results, and to apply non-linear chromaticity correction with multi-families and so on, is on going.

MOMENTUM SPREAD

First we calculate the bucket height and bunch height without and with RF re-bucketing. The bucket area and bunch height are defined as the maximum phase space and the maximum (dp/p_0) given by the RF bucket. For the heavy ion run, we use the bucket area and bucket height per nucleon. The unit of bucket area is given in eV.s. We also define the full bunch length as $6\sigma_l$.

Before re-bucketing, the RF harmonic number is 360, the total RF voltage is about 300 kV. With re-bucketing, the RF harmonic number is 2520 and the total RF voltage is about 4.0 MV. Without re-bucketing, the RF bucket area and the bucket height are about 5.4 eV.s and 1.2×10^{-3} . Considering that the actual bunch area is about 1.0 eV.s, the maximum momentum spread of the bunch is 0.6×10^{-3} . With RF re-bucketing, the bucket area is reduced to about 1.1 eV.s and the bucket height is about 1.7×10^{-3} . With the same bunch area 1.0 eV.s, the bunch's maximum momentum spread is very close to the bucket height.

Fig. 1 shows the bunch's maximum momentum spread $(dp/p_0)_{max}$ with re-bucketing versus the bunch area. Here we use the total RF voltage 4 MV. Clearly, the smaller the bunch area, the smaller the beam's momentum spread. In the 2010 run, there was longitudinal emittance blow-up, while in the 2011 run there was less emittance blow-up. The reason for the longitudinal emittance blow-up is under investigation.

LOW β^* LATTICES

To further increase the peak luminosity in the RHIC heavy ion runs, we could further squeeze the β^* s at the collision points. However, with a smaller β^* , the uncorrected linear and non-linear chromaticities will be bigger and therefore the dynamic aperture will be reduced. Also with a smaller β^* , the β function will be bigger in the interaction region and therefore there may be not enough physical aperture there.

As an example, Fig. 2 shows the Blue ring horizontal

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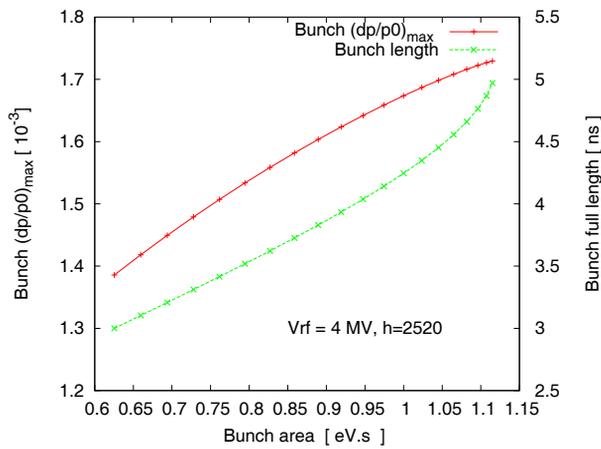


Figure 1: Bunch's $(dp/p_0)_{max}$ and full length versus the bunch area. Here $V_{rf}=4$ MV and $h=2520$.

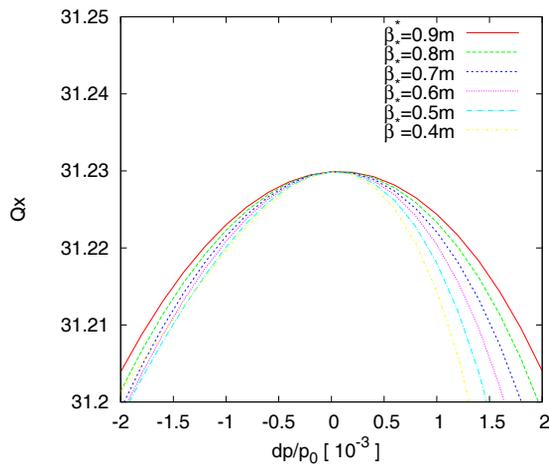


Figure 2: The Blue ring horizontal off-momentum tunes for the Blue ring lattices. Second order chromaticities are not corrected.

off-momentum tunes with different β^* lattices versus the particle's relative momentum deviation dp/p_0 . Clearly, the second order chromaticity is dominant. For a lower β^* lattice, the bigger its absolute value is. For particles with $dp/p_0 > 1.5 \times 10^{-3}$, the horizontal tunes will touch or even close the strong fifth betatron resonance at 31.2.

CHROMATIC CORRECTION

RHIC second order chromaticities can be corrected in the RHIC online model using an implementation of the MAD8 HARMON module. However, the RHIC online model is not accurate enough with a low β^* lattices. Here we focused on the 4-knob method [3]. In this method, we sort 24 sub-chromatic sextupoles into 4 sub-families, or 4 knobs, according to sextupoles' contributions to the half-integer resonance driving terms. There are two knobs for the horizontal and vertical second order chromaticity corrections respectively. This method does not change first or-

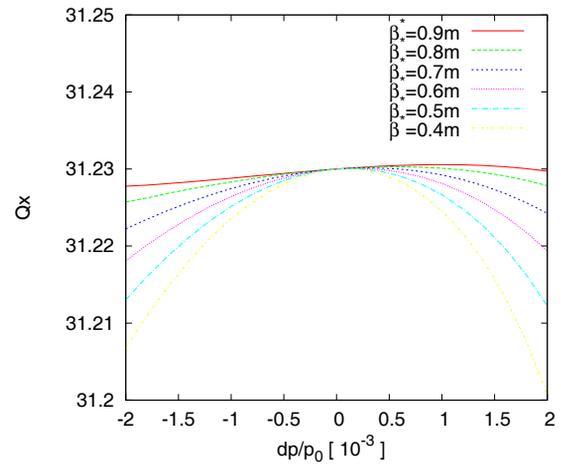


Figure 3: The Blue ring horizontal off-momentum tunes for the Blue ring lattices. Second order chromaticities are corrected.

der chromaticities, and works when the RHIC online model does not closely reproduce the machine.

As an example, Fig. 3 shows the horizontal off-momentum tunes with the second order chromaticity correction for the above Blue ring lattices. Comparing to Fig. 2, the horizontal second order chromaticities are largely reduced. Here the correction with 4-knobs is used. The correction with large β^* lattice give better results than that with lower β^* lattices. For the lattices with very small β^* m, more complicated correction methods are being investigated.

DYNAMIC APERTURES

In this section, we calculate the off-momentum particles' dynamic aperture without and with the above second order chromaticity correction. Dynamic aperture is defined as the maximum betatron amplitude within which particles are not lost after a certain number of tracking turns. It is given in the units of transverse rms beam size σ . In the following, the zero amplitude tunes are matched to (31.23, 32,22) and the linear chromaticities are set to (1,1) before tracking. The particles are tracked element-by-element up to 10^6 turns in 10 phase angles in the x-y phase space [4]. The weak-strong beam-beam interaction model is adopted. The Au bunch intensity is 1.5×10^9 .

Fig. 4 shows the dynamic apertures of the Blue ring with different β^* lattices. For a certain dp/p_0 , the dynamic aperture with larger β^* lattice is bigger than that with a smaller β^* lattice. For a certain β^* lattice, the dynamic aperture for the on-momentum particles is higher than that for the off-momentum particles. With $\beta^* = 0.7$ m lattice, the dynamic aperture for the on-momentum particles is about 4.8σ , which is about 2.5σ larger than that for the off-momentum particles with $(dp/p_0) = 1.5 \times 10^{-3}$. $(dp/p_0) = 1.5 \times 10^{-3}$ is about the bunch's maximum momentum spread and the RF

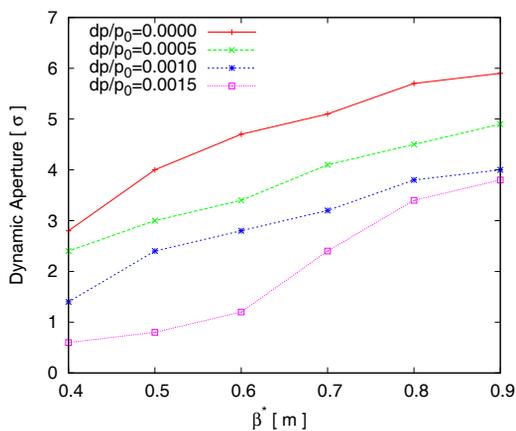


Figure 4: Dynamic aperture without second order chromaticity correction for the Blue ring with different β^* lattices. The RF re-bucketing and beam-beam are included.

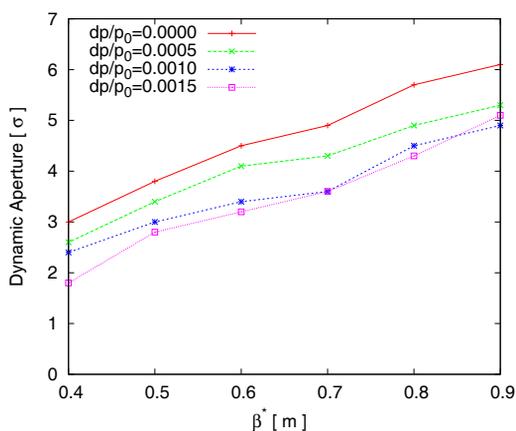


Figure 5: Dynamic aperture with second order chromaticity correction for the Blue ring with different β^* lattices. The RF re-bucketing and beam-beam are included.

bucket height.

Fig. 5 shows the dynamic apertures with the above second order chromaticity correction. With second order chromaticity correction, the dynamic aperture for the on-momentum particles do not change too much. However, compared to Fig. 7 without second order chromaticity correction, the dynamic apertures for the off-momentum particles are increased. For the $\beta^* = 0.7\text{m}$ lattice, the dynamic aperture for the particles with $(dp/p_0) = 1.5 \times 10^{-3}$ is improved by about 1σ to 3.5σ . Therefore, the second order chromaticity correction improves the momentum aperture.

The nominal working point for the heavy ion runs is about (31.23, 32.22) except in the Yellow ring in the 2010 Au-Au run. In that run, the Yellow working point was pushed down to (31.10, 32.05) to achieve less beam loss during RF re-bucketing. But in the 2011 run, we found the optimum working point in the Yellow back to the nominal tunes. In the following we calculate the dynamic aper-

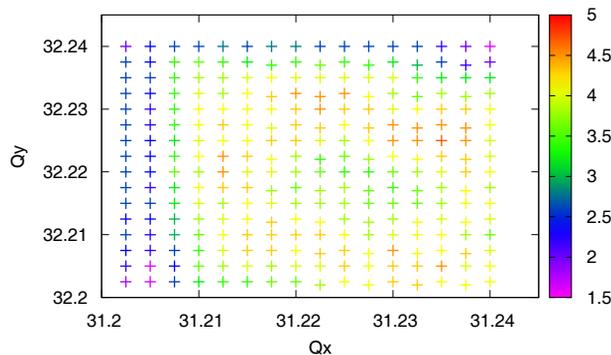


Figure 6: Dynamic aperture for $dp/p_0 = 1.5 \times 10^{-3}$ with $V_{rf} = 4$ MV. The Blue ring lattice with $\beta^* = 0.7$ m is used. The second order chromaticity correction is included.

ture for particles with $dp/p_0 = 1.5 \times 10^{-3}$ in a tune scan. The fractional horizontal and vertical tunes of the zero-amplitude particles are scanned from 0.2 to 0.24 with a step size 0.0025. The second order chromaticity correction are included. Here we present the results with the Blue ring lattice with the $\beta^* = 0.7$ m. The tune scan with the Yellow ring lattice is in progress.

Fig. 6 shows the dynamic aperture in the tune scan with the total RF voltage 4 MV. The tunes in the plot are the zero-amplitude tunes which are slightly different from the tunes measured on line with the phase lock loop (PLL). From Fig. 6, the dynamic aperture is higher with tunes below diagonal than that above diagonal. And the dynamic aperture is slightly bigger when the vertical zero-amplitude tune is close to 32.05 and 32.28 while the horizontal tune is above 31.21. The maximum dynamic aperture is close to (31.235, 32.225).

SUMMARY

In the article we verified that in the 2010 and 2011 Au-Au runs, the beam's momentum spread was close to the RF bucket height. To improve the dynamic aperture for the off-momentum particles, we investigate the effect of second order chromaticity correction and the total RF voltage. We also presented the results of tune scans. In the future we will improve the existing chromatic correction methods to yield bigger dynamic aperture for the smaller β^* lattices. The interpretation of the operation observations with simulation are in progress.

REFERENCES

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