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In the preparation for the 2011 RHIC 250 GeV polarized proton (pp) run, both experiment and simulation were carried out to investigate the possibility to accelerate the proton beam with a vertical tune near $2/3$. It had been found experimentally in Run-9 that accelerating the proton beam with a vertical tune close to $2/3$ will greatly benefit the transmission of the proton polarization ^[1].

In this note, we report the calculated dynamic apertures with the 100 GeV Au run and 250 GeV proton run lattices with vertical tunes close to the third order resonance. We will compare the third order resonance band width between the beam experiment and the simulation with the 100 GeV Au lattices. And we also will compare the calculated resonance band width between the 100 GeV Au and 250 GeV proton run lattices.

1. Introduction

To investigate how close the proton beam can be accelerated to $2/3$, a dedicated beam experiment was carried out to ramp the Au ion beam near $1/3$ in the beam experiment in the 2010 Au-Au run ^[2]. The plan was to ramp the Au ion beam in the Blue ring with a vertical tune above $1/3$ and to ramp the Au ion beam in the Yellow ring with vertical tune below $1/3$. However, limited by the beam experiment time the effort was focused on the Yellow ring ramp development because of large beam loss during transition in the Blue ring. In the Yellow ring ramp development, 4 successive ramps were demonstrated with vertical tune 32.328 ^[3], which is about 0.005 away from $1/3$ resonance line. The horizontal tune is 31.31 .

To explain the observations in the above Yellow ramp development, we will calculate the dynamic aperture with the 2010 Au-Au 100 GeV run Yellow lattice in the scan of vertical tune from 32.27 to 32.39 with a step size of 0.0005 . The horizontal tune is kept to 31.31 . After that, we will also calculate the dynamic aperture with the 2011 polarized proton run ramp blue lattice in the scan of the vertical tune from 29.60 to 29.72 . The horizontal tune will be kept to 28.68 .

In the simulation study, the β^* at IP6 and IP8 are 2.0 m, which is the same as that in the beam experiment. We included the interaction region multipole field errors in the lattice models. Table 1 lists the lattice and beam parameters in this study.

For every tune spots, the dynamic apertures were calculated with five angles in the $x/\sigma_x - y/\sigma_y$ plane. In this study, particles are tracked up to 10^6 turns. For the 2010 Au-Au run lattice, we only calculate the dynamic aperture for particles with relative off-momentum $dp/p_0=0.0009$ which is close to the maximum energy deviation of the RF bucket. For the 2011 polarized proton lattice, we used $dp/p_0=0.0005$ which is about 3.5 times the rms dp/p_0 (0.0001414).

Fig. 1 is one example of dynamic aperture for one tune spot. Most of the time, we compare the minimum dynamic apertures among these 5 angles between different working points. The unit of dynamic aperture the rms beam size σ .

Table1 Parameters Used for Beam Tracking

Parameters	100GeV Au-Au	250GeV PP
Qx (Fixed)	31.31	28.68
Qy (Scaned)	32.27-32.39	29.60-29.72
β^* (m)	2.0	2.0
Chromaticity	(1,1)	(1,1)
RF Voltage (keV)	300	300
Energy (GeV/nucleon)	100	250
Gamma	106	266
Beam-Beam	No	No
Multipole Field	Included	Included
$\delta p/p_0$	0.0009	0.0005

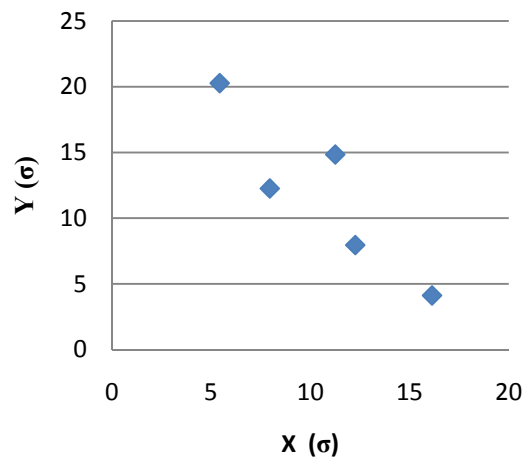


Fig 1 Dynamic Aperture for (28.68, 29.63) 250GeV PP lattice

2. 100 GeV Au-Au lattice Dynamic Aperture

Fig 2 is the result of dynamic aperture scan for the 100 GeV Au lattice. In this 2010 run lattice experiment, we achieved successful ramps in the Yellow ring with a vertical tune 32.328, 0.005 away from 1/3 resonance line. According to our simulation Fig 2, its dynamic aperture is about 4σ at this run.

We define tune width as the distance between the first peak value and the first bottom value around 1/3. If we approach the 1/3 resonance line from left to right, just like experiment did, then the tune width is about 0.026; and the peak value is about 10.25σ .

There is one plateau in Fig 2, and it ranges from 32.3425 to 32.3545. To explain this, the tune diagram Fig 3 was plotted. The red line in Fig 3 is the vertical tune line that was scanned. More reasonable explain can be given by phase space tracking in this range.

3. 250GeV PP lattice Dynamic Aperture

Fig 4 is the dynamic aperture scan for 250Gev PP lattice. For this lattice, we want to approach the 2/3 resonance line from right to left. Its tune width is about 0.028 (only calculated from right side of 29.666). The peak value is about 18.65σ .

For the 2011 polarized proton run lattice, the new work point will be $0.672^{[3]}$. From Fig 4, its dynamic aperture is about 11.42σ . The lattice should run very well with this dynamic aperture. And maybe we have a little more room to reduce the vertical tune and get more polarization transmission efficiency.

The tune diagram for this lattice was plotted in Fig 5. There is a point (28.68, 29.66) on the red line, and this corresponds to the minimum value point in Fig 4. Another point (28.68, 29.666) is on the 2/3 resonance line.

At last, we also calculated the 2011 polarized proton 250GeV run yellow and blue lattice dynamic apertures with 28.69 horizontal tune. In Fig. 6, the red and green lines are yellow and blue lattice dynamic aperture with 28.68 horizontal tune. The blue and pink lines are yellow and blue lattice dynamic aperture with 28.69 horizontal tune.

From Fig. 6, it seems that yellow lattice with 28.69 horizontal tune has larger dynamic aperture than 28.68 horizontal tune.

4. Discussion

If we put Fig 2 and Fig 4 together and change horizontal axis to relative tune (i.e. the distance to the 3rd order resonance 32.333 and 29.666), we can get Fig 7.

From Fig 7, the 2011 polarized proton 250GeV run lattice has almost twice dynamic aperture as the 2010 Au-Au 100GeV run lattice. And its dynamic aperture is more sensitive to vertical tune change

around its resonance line. If we use our definition for tune width, the two lattice tune widths are almost similar.

5. Acknowledgments

The authors would like to thank Mei Bai and Haixin Huang for their helpful discussions.

6. Figure List:

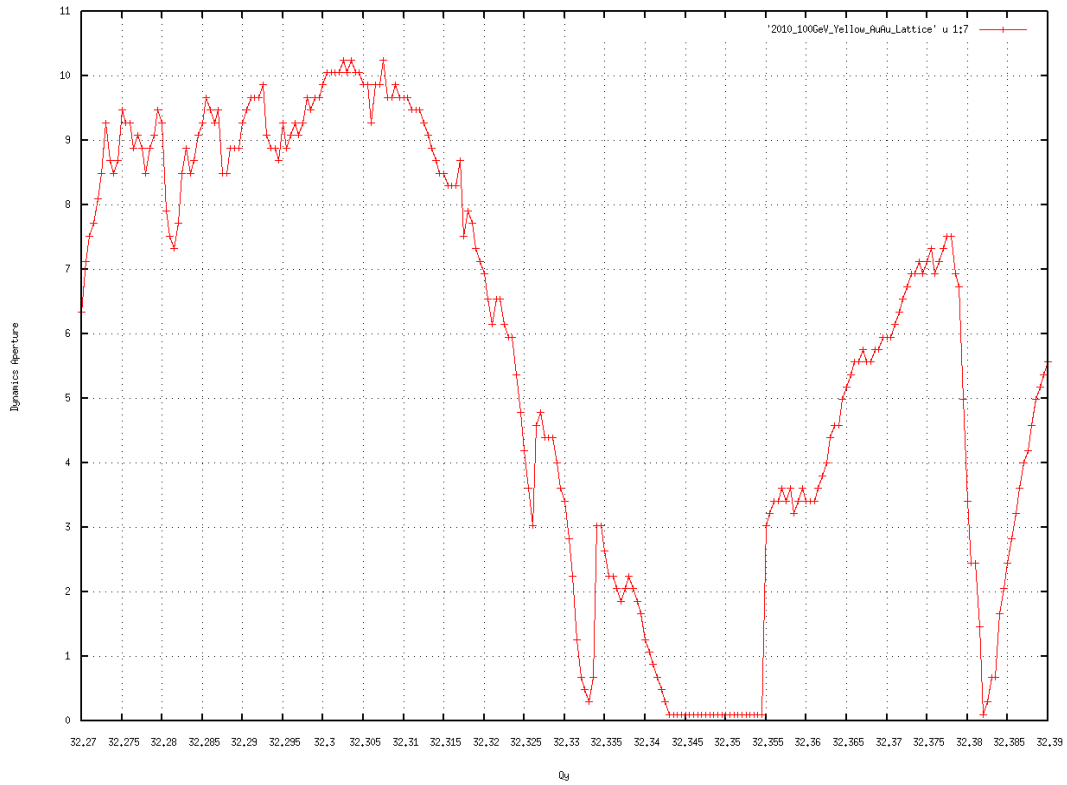


Fig 2 Dynamic Aperture Scan for 100GeV Au-Au Lattice

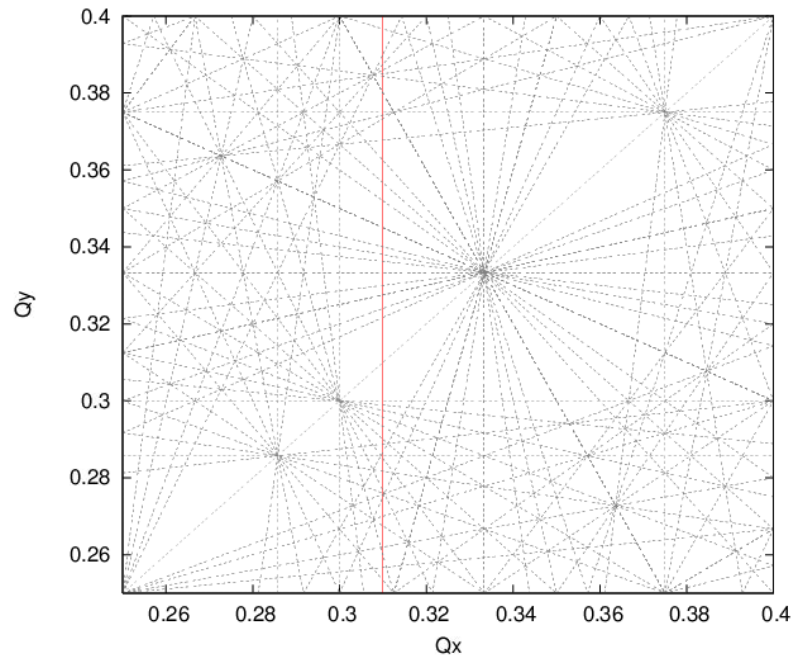


Fig 3 Tune Diagram for 100GeV Au-Au Lattice

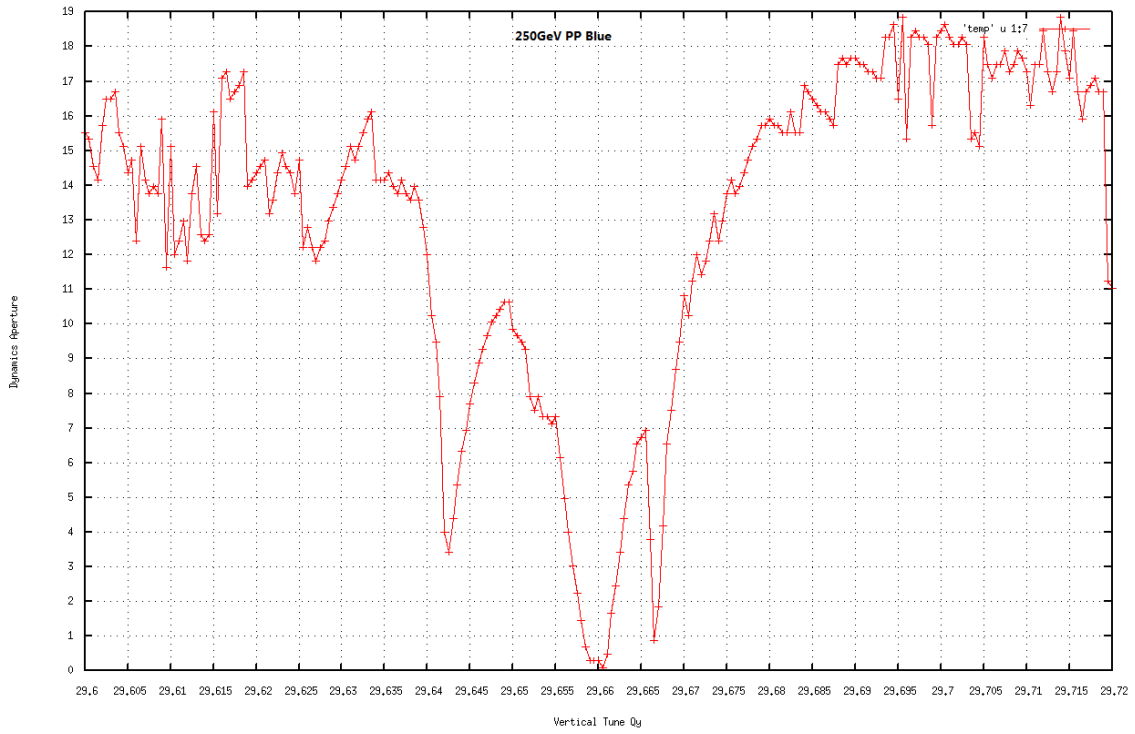


Fig 4 Dynamic Aperture Scan for 250GeV PP Lattice

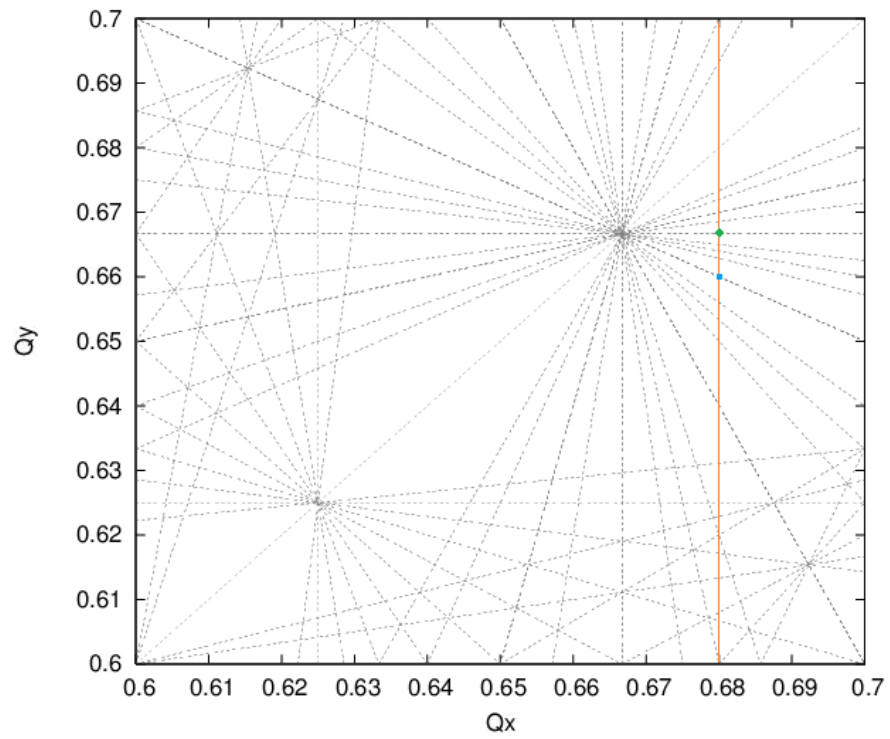


Fig 5 Tune Diagram for 250GeV PP Lattice

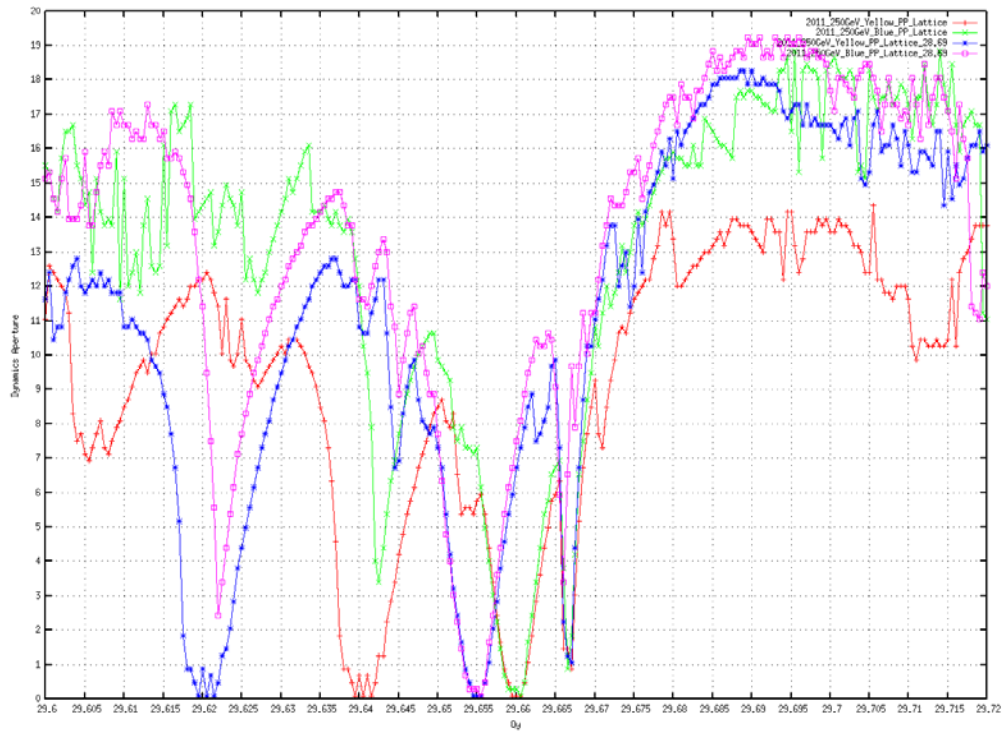


Fig 6 DA Comparison Calculation for Different Vertical Tune

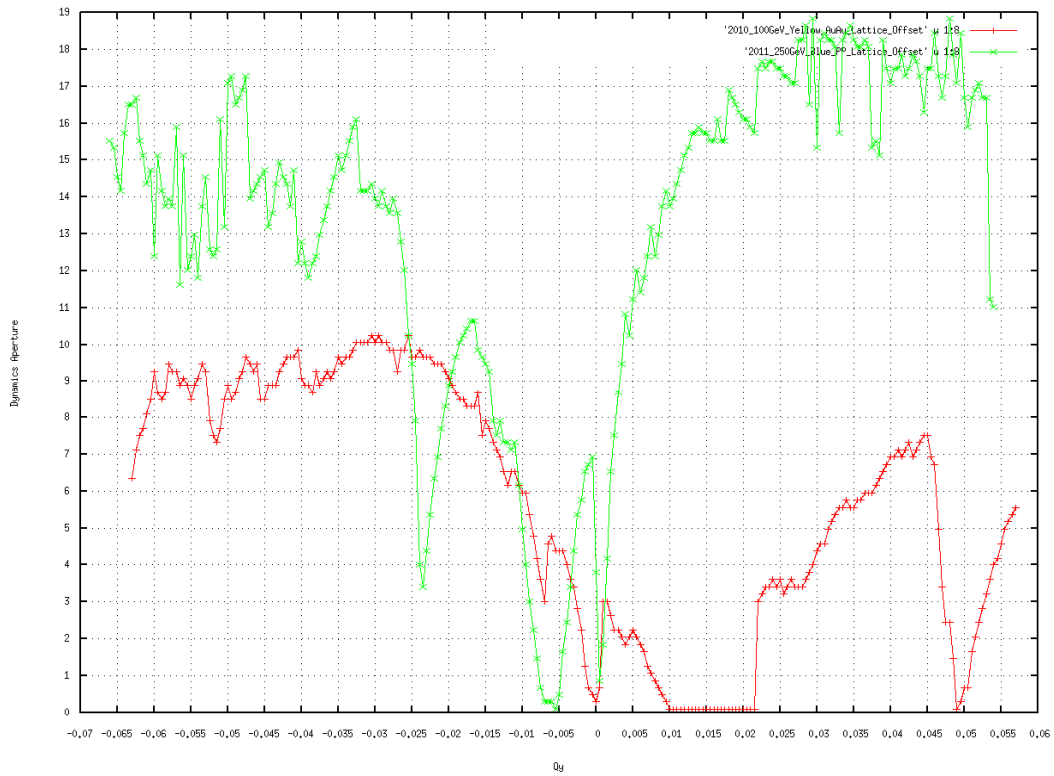


Fig 7 DA Comparison between Two Lattices

7. Reference

- [1] M. Bai, private communication (2009).
- [2] M. Bai, private communication (2010).
- [3] Haixin Huang. RHIC User 2010 Report