BNL-96528-2011-IR

C-A/AP/#437
Nov. 2011

Comments on momentum aperture of 100 GeV/n Au runs in RHIC

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1 Introduction

In RHIC 2010 100 GeV/n Au run, the momentum aperture has been an issue in the re-bucketing and the beam intensity lifetime in store. Both Blue and Yellow beams with comparable storage RF voltage and peak current have suffered more beam loss than in Run 2007 [1]. In this note, some comments are made for the momentum aperture of the lattices used from the Au runs in 2007, 2008 and 2010. From the wigglings and the beam decays of each lattice, information regarding the machine momentum aperture is presented. Several directions in further improvement are discussed.

2 Wigglings

Since chromaticity measurement with wigglings is a necessary step before a new lattice put into operation, it is possible to compare the momentum aperture in recent Au runs. With a radial shift of around 1 mm in the wigglings, a momentum deviation of around 0.001 can be used for a chromaticity measurement and corrections at store. Usual lattice commissioning makes this measurement not too difficult, which is often accompanied with small beam losses, such as that in Au run 2007 with Au72. In case that a large beam loss occurs, one needs to further correct the orbit, the tune, and the non-linearities as well. The effort could be significant if the results were less than satisfactory, such as the case in Au run 2010, with Au102 and Au104.

It is always possible that optimum machine tuning was missed out, and therefore the machine could have been better tuned. However, with the best wigglings performed for each lattice, some information regarding the machine momentum aperture can be learned, which is shown in Table 1.

Starting from 2008 dAu run with the Yellow ring for Au, the IBS (intra-beam scattering) suppression lattice with 90 degree phase advance per FODO cell is used. With stronger focusing, the tune, and the transition γ as well, are increased by 3 units. The dispersion in arcs is decreased and hence the H-function is reduced in achieving the smaller transverse emittance growth due to IBS [2].

Year	2007	2008	2008	2010	2010
Lattice	Au72	dAu80	dAu81,82	Au102	Au104
Ring	B&Y	Y	Y	B&Y	B&Y
β^*, m	0.8	1	0.7	0.6	0.7
γ_{tr}	23.2	26.5	26.5	26.3	26.3
Radial shift, mm	1.5	1.5	0.5	0.5	0.5
dp/p, %	0.135	0.175	0.058	0.058	0.058
Beam decay, $\%/hour$	20	500	100	100	100
Fill	8367	9157	9420	11372	11561,2

Table 1: Wiggling results with beam losses for Au lattices in store, from run 2007 to run 2010. The beam decay rates are close to the best achieved for each lattice with the corresponding radial shift.

Larger beam loss for given wigglings has been observed starting in dAu80 in 2008, but only in 2010 with Au102, a significant effort is applied trying to get smaller beam loss: it was suspected then the limited momentum aperture might be responsible to the shorter beam intensity lifetime in store, and hence the shorter luminosity lifetime. Along with this effort, Au104 with the relaxed β^* from 0.6 m to 0.7 m is developed.

Finally, in Fill 11615, with Au104, the yellow fractional tune is moved from 0.235 to 0.215, away from the quarter tune. This allowed for the 1 mm wiggling with the beam decay from DCCT down to less than 40% per hour. In Figure 1, the wiggling, the beam decay from DCCT, and the normalized DCCT and WCM intensity is shown for a comparison of Fill 8367 of Au72, and Fill 11615 of Au104.

After 11615, to the end of run, the new working point is adopted for the yellow beam, which improved the re-bucketing, but did not change too much for the beam intensity lifetime in store. Fill 11615 is the last, and also the best, wiggling in the 2010 Au run. The associated beam loss is improved from Fill 11561,2 (shown in Table 1), but it is still not as good as the one in Au72, Fill 8367. Moreover, the large bunched beam decay is not understood, and hence of concern.

3 Beam decay

The beam intensity decay is one of the most important parameter, since it directly affects the luminosity lifetime. Many factors are related with the beam decay:

1. With the upgrade of the RHIC performance, the burn-off is now an important factor in the beam intensity decay. In this article, we take a ratio of 20 for Au-Au collision, and 6 for dAu collision, for the burn-off cross section over the ZDC (zero degree calorimeter) cross section.

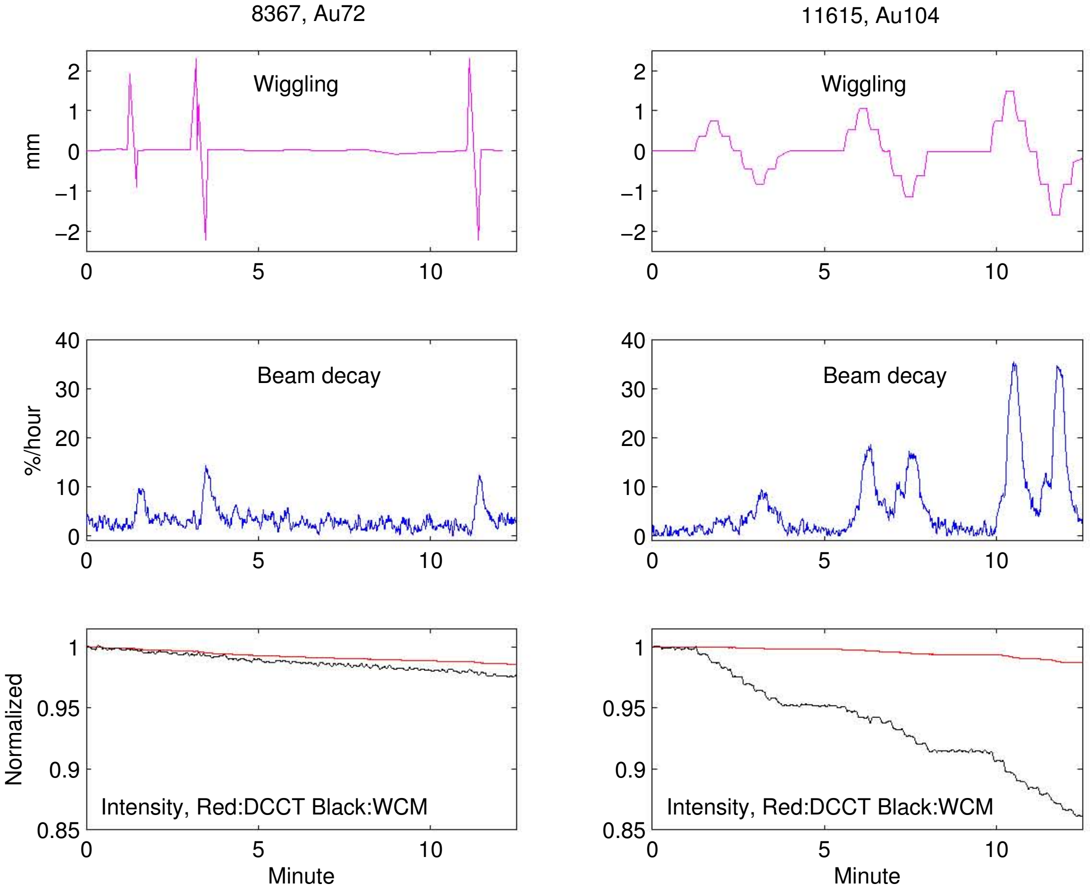

Figure 1: Fill 8367 in Au72 and Fill 11615 in Au104. Fill 11615 is not shown in Table 1, and its fractional tune is moved from the nominal 0.235 to 0.215. The largest radial shift is 1.5 mm and 1 mm, corresponding to the momentum deviation of 0.00135 and 0.00117 for 8367 and 11615, respectively. The beam decay is derived from DCCT, it is about 15%/hour and 35%/hour for 8367 and 11615, respectively. For 8367, the beam decay from the DCCT and WCM (monitoring the bunched beam intensity) is about the same, but for 11615 the WCM derived decay is bout 7 times larger than the decay from DCCT.

2. One of the most important beam loss mechanism is that the beam ions leak out from the RF bucket, and eventually get lost. However, it has been demonstrated in Au run 2007 and since, the beam loss due to this mechanism has been almost eliminated when the longitudinal stochastic cooling is applied.
3. On the transverse side, the orbit, the tune and chromaticity, and the nonlinearities are all relevant to the beam decay. Moreover, the machine physical and momentum apertures, together with the beam transverse emittance and the momentum spread, play important roles.

By taking off the contributions of the burn-off, and assuming a minimal loss due to the longitudinal effects when the longitudinal stochastic cooling is applied, the beam decay due to transverse effects can be singled out.

Once again, it is possible that optimum tuning could be missed out. However, with the best beam decay for each lattice, some information can be learned. The beam parameters of the fills with smallest beam loss in store for each lattice, all with the longitudinal stochastic cooling, are shown in Table 2 and the beam decay structure is shown in Figure 2.

Year Lattice	2007 Au72	2008 dAu80	2008 dAu82	2010 Au104
Ring	Y	Y	Y	B
β^*, m	0.8	1	0.7	0.7
Bunch number	103	87	87	111
Bunch intensity, 10^9 Au ions	1.03	0.90	1.06	1.12
RF voltage, MV	3.2	2.9	2.7	4.3
Fill	8825	9417	9500	11860

Table 2: Beam parameter of the fills with best beam decay in store for each lattice. For given momentum aperture, higher bunch intensity and/or higher RF voltage are considered not favorable for smaller beam decay.

Here are some details for each case.

1. For Au72, many fills with the yellow longitudinal stochastic cooling have shown that the beam loss is reduced to burn off, such as Fill 8825 has demonstrated in Figure 2.
2. There are more than 41 long fills used dAu80 in run 2008, which has a 1 m β^*. Fill 9417 is one with the smallest decay. In the later part of store, the beam loss is almost all from the burn-off, but the early loss in Yellow with dAu80 are larger than that in Au72.

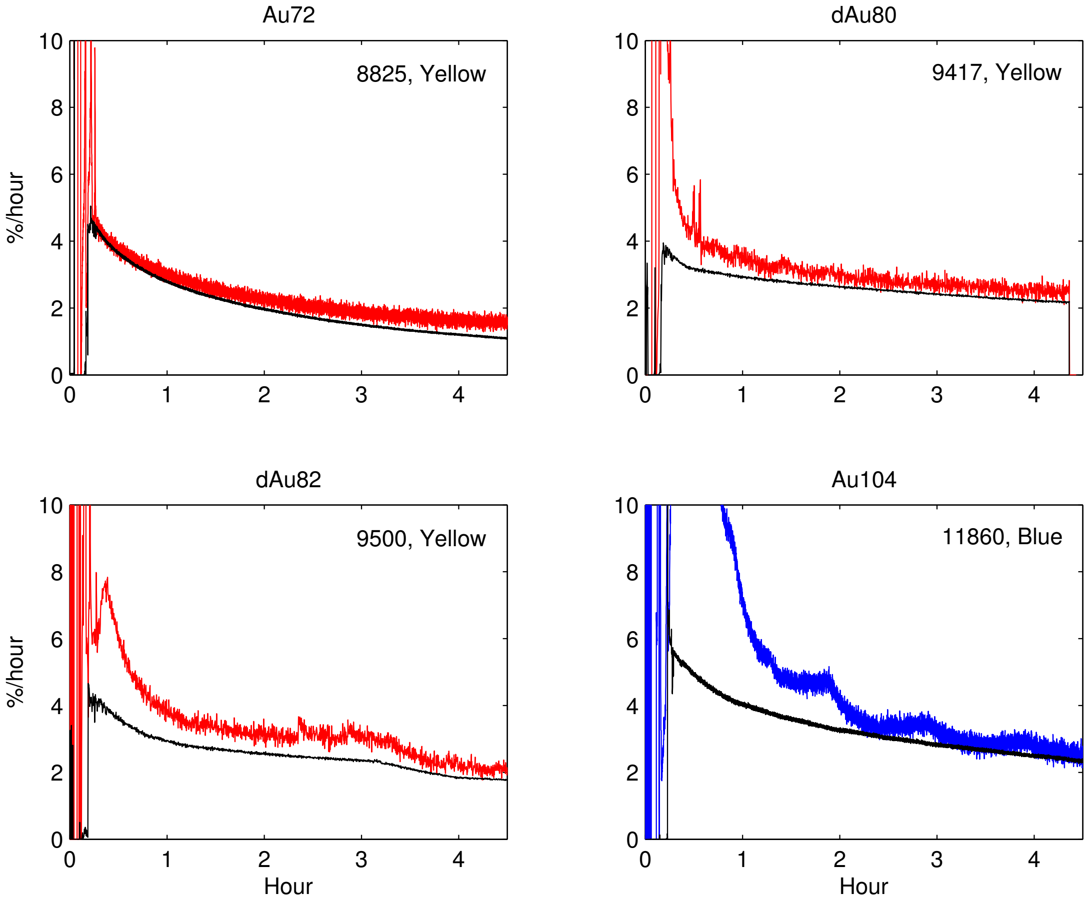

Figure 2: Fills with best beam decay in store for each lattice, all have the longitudinal stochastic cooling, which is applied to Yellow in 2007 and 2008, and applied to Blue in 2010. The black line is the decay due to the burn-off.

3. In later dAu2008 run, 0.7 m β^* is applied to Yellow (dAu81) and then to Blue also (dAu82), and there are more than 88 long fills in the operation. Fill 9500 has a best Yellow decay.

4. In Au run 2010, longitudinal stochastic cooling is applied to Blue, but not Yellow. Also, vertical cooling is applied in both rings. Fill 11860 is one of the fills with a best beam decay in Blue.

The difference in beam decay is mainly in the first hour or two in store, and one possible reason of the larger loss in dAu80, dAu82 and Au104 at early store is the limited momentum aperture.

4 Discussion

From the wiggling results and the beam decay in store, it seems that the momentum aperture of the IBS suppression lattices is smaller than Au72, but the mechanism is not full understood, and the chance that the machine tuning did not reach optimum cannot be ruled out.

Directions of the machine improvement include the followings.

One mechanism is the strong quarter resonance of the IBS suppression lattice together with the chromatic aberrations. The beam decay improvement by moving the tune away from 0.25 seems to support this argument. It would be of interest to see what improvement can be achieved by making a similar move for the Blue ring. It is also of interest to try the new working point around 1/3, or 2/3.

Dynamic aperture simulation is a focus in the study. The non-linearity corrections, the β^*, the working point, the beam momentum spread (determined by the beam longitudinal emittance and the store RF voltage), and perhaps the intensity related issues are all relevant. Further relaxing β^* and reducing store RF voltage are not of much interest. This leaves a further non-linearity correction and to change the working point on the table.

The lattice dispersion may directly affect the machine momentum aperture. It has been noticed that all the IBS suppression lattices (with β^* 0.6 m to 1 m) have significantly larger horizontal dispersion at all IRs than Au72. The large dispersion at IR6 and IR8 with smaller β^* (Au102 and Au103, both with β^* of 0.6 m) might have more impact on beam momentum deviation associated loss.

In Figure 3, the comparison of the dispersion function of Au72 and Au104 is shown. Au104 is similar to all other IBS suppression lattices, with smaller dispersion in arcs, and larger dispersion in all IRs, than Au72.

In Figure 4, a closed look at IR8 is shown. Like that in IR6, the large dispersion is just sitting at the triplets, where the beta function is also the largest. This raises concerns of the non-linearities associated with the particles having large momentum deviations. For example, the momentum deviation related beta function distortion

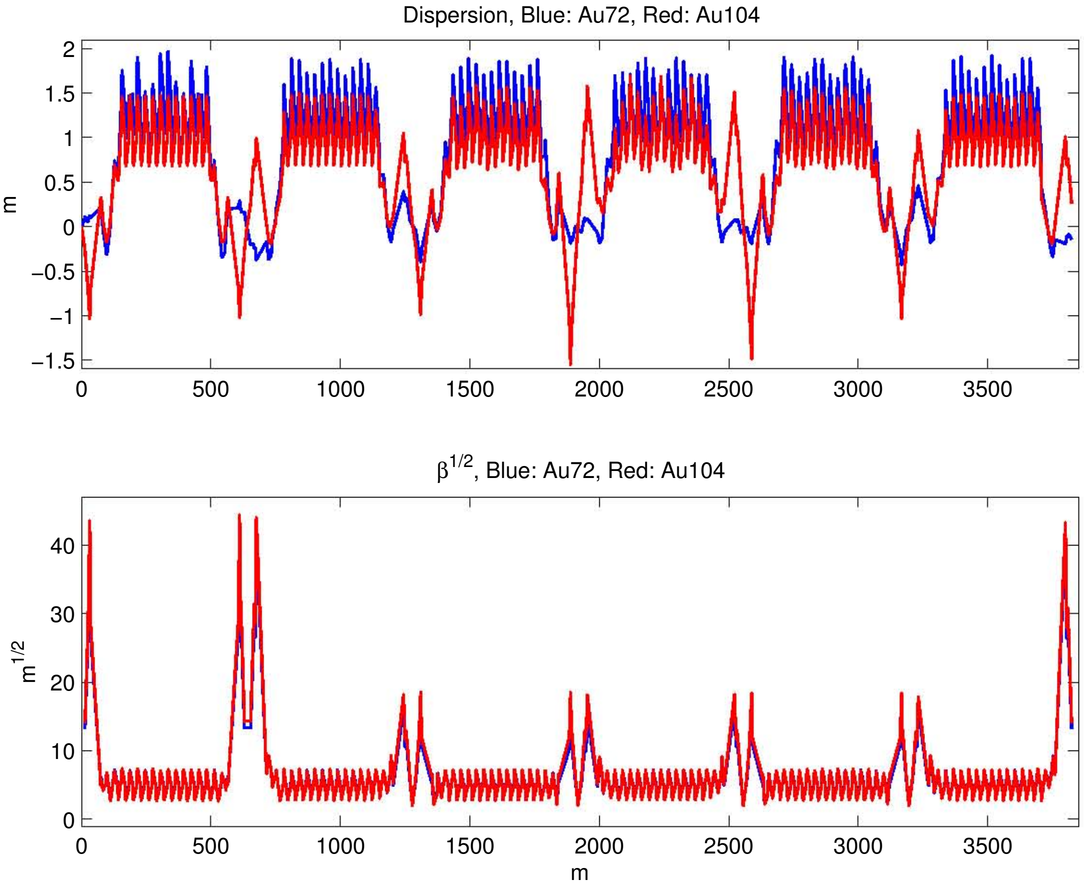

Figure 3: Dispersion and beta function of Au72 and Au104.

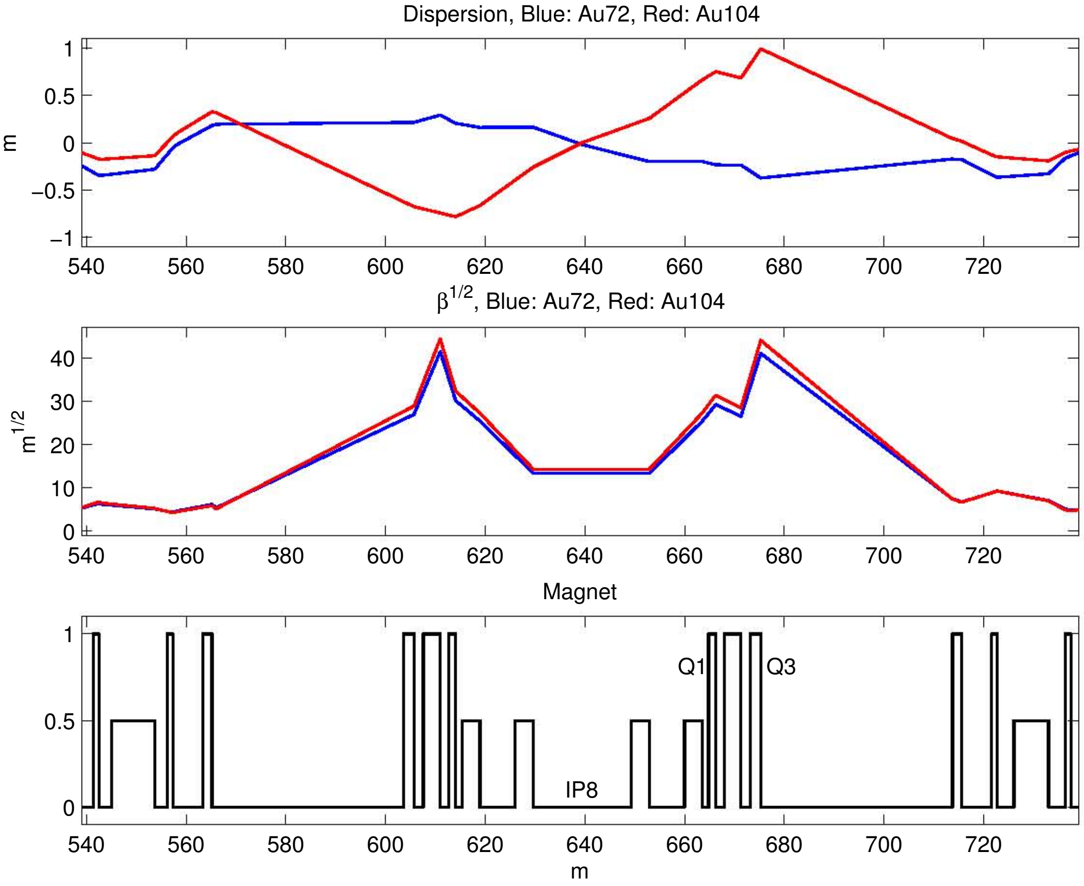

Figure 4: Dispersion and beta function of Au72 and Au104, and the magnets at IR8.

at the triplets could be large [3]. Also, the associated betatron-synchrotron coupling might be of concern.

It is of interest to see if the dispersion at least in IR6 and IR8 could be reduced from the current IBS suppression lattice design.

With the vertical stochastic cooling applied to both rings in Run 2011, the transverse emittance growth due to IBS can be put under control, and perhaps the advantage to use the IBS suppression lattice is its potential of the beta squeeze.

From both the wiggling results and the beam decay, the lattice Au72 with the β^* of 0.8 m did not show a sign of complications in the beam decay. It would be of interest to see what happens if the β^* of Au72 is reduced to 0.7 m.

5 Acknowledgment

I would like to thank W. Fischer, Y. Luo, V. Ptitsyn, T. Roser, S. Tepikian, and D. Trbojevic for helpful discussion.

References

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