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RHIC Low Energy Beam Loss Projections

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1 Introduction

For RHIC low-energy operations, we plan to collide Au beams with energies of $E = 2.5$-10 GeV/u in RHIC. Beams are injected into collision optics, and RHIC runs as a storage ring with no acceleration. At these low energies, observed beam lifetimes are minutes, with measured beam lifetimes of 3.5 min (fast) and 50 min (slow) at E=4.6 GeV/u in the March 2008 test run. With these lifetimes we can operate RHIC as a storage ring to produce reasonable integrated luminosity. This note estimates beam losses and collimator/dump energy deposition in normal injection modes of low energy operation.

The main question is whether a normal injection run is feasible for an FY10 10-15 week operations run from a radiation safety perspective. A peripheral question is whether continuous injection operations is feasible from a radiation safety perspective. In continuous injection mode, we fill both rings, then continuously extract and reinject the oldest bunches that have suffered the most beam loss to increase the overall integrated luminosity. We expect to gain a factor of 2-3 in integrated luminosity from continuous injection at lowest energies if implemented[1]. Continuous injection is feasible by FY11 from an engineering perspective given enough effort, but the required extra safety controls and hardware dose risk make it unappealing for the projected luminosity improvement. Low-energy electron cooling will reduce beam losses by at least an order of magnitude vs normal low-energy operations, but low energy cooling is only feasible in the FY13 timescale and therefore beyond the scope of this note.

2 2008 Low Energy Run AtR Losses

Injection and limited operations were established during a test run from Mar 10-12 2008, starting with fill number 10003. AGS Au beam was established at about 06:50 Mon Mar 10 2008 and AGS/AtR work proceeded during a RHIC access to swap defocusing sextupole power supply polarities. The switching magnet was powered at 15:00 Mon Mar 10 2008. For the purposes of AtR dump loss accounting, I have counted time before the switching magnet turn-on as AGS/AtR setup time, and time after the switching magnet turn-on as RHIC setup time.

Beam intensity is recorded on the AtR current transformers, integrated over each AGS cycle:

- uxf1: In the AGS tunnel, upstream of quadruole uq1
- uxf3: At the start of the 20 degree bend, about 1m upstream of the upstream end of dipole wd1
- wxf1: About 13m upstream of the upstream end of the switching magnet swm. One quadrupole is between wxf1 and swm.
- xxf1/yxf1: About 17m upstream of the upstream end of each injection Lambertson. No quads are between xxf1/yxf1 and the injection Lambetsons.

For this low energy test period, the integrated losses and integrated intensities at each current transformer are given in Table 1. Beam intensities at current transformers were cut at 5×10^7 Au ions; all values below this are treated as zero. The integrated beam intensities at xxf1 and yxf1 are the total of all beam entering the RHIC tunnel. This does not immediately translate to circulating beam efficiency since there are Lambertson and other injection losses.

The AtR transmission efficiency from uxf1 to xxf1/yxf1 was about 95% for E=4.6 GeV/u Au, so we should expect chronic losses in AtR for this energy of about 5% of total beam delivered to RHIC. Extrapolations to lower energies and uxf1 to circulating beam efficiency are under study.

Table 1: RHIC Run-8 E=4.6 GeV/u Au AtR current integrated transformer losses and beam intensities, Mar 10-12 2008. Beam losses in the U and W lines are successive differences between uxf1, uxf3, and wxf1 integrated intensities.

Location	Integrated beam loss ($\times 10^9$ Au)
after uxf1, before uxf3	1595.9
after uxf3, before wxf1	896.8
in dump during tuneup	7191.3
in dump after tuneup	1168.8
in xarc	21.1
in yarc	119.5

Location	Integrated beam intensity ($\times 10^9$ Au)
uxf1	12876.8
uxf3	11280.8
wxf1	10384.0
xxf1	876.0
yxf1	1030.6

3 Projection Assumptions

For normal injection low energy estimates we assume the following:

- RHIC beam total energies are E=2.5-10 GeV/u. (Continuous injection mode is probably unnecessary above total energies of E=7-8 GeV/u.)
- RHIC operates only as a storage ring, with no acceleration.
- 110 bunches of about 0.5-1.0$\times 10^9$ initial bunch intensities (50-100% injection efficiency, likely conservative)
- 90% collimation efficiency, with 10% of beam losses elsewhere. This is considered mildly conservative [2].
- Beam lifetimes range from about 1 minute (E=2.5 GeV/u) to 20 minutes (E=7-8 GeV/u)
- The primary beam loss mechanism is space charge/IBS blowup of transverse emittance. This implies that most beam is lost at transverse apertures, particularly abort kickers and collimators. Mar 11 2008 test run data also shows some mild chronic losses around the other IR triplets. We were not using collimators during this test run. (See Fig. 1.)
- The RHIC ASE states that the "maximum number of heavy ions in each ring (is) to be less than the equivalent of 2.4$\times 10^{11}$ Au ions at 100 GeV/u" [3]. The total stored beam energy of this beam is 9.5$\times 10^{15}$ GeV-u.

4 Normal Operations (possible FY10 scenario)

In this scenario we fill each RHIC ring, cog beams into collision, then dump and refill after 1–2 beam lifetimes. No modifications to the existing kickers are needed, and abort scenarios are the same as normal operations. This produces about 20-60 fills per day. Other projected beam parameters are listed in Table 2 for several energies of interest.

During the 2008 test, we had 1 hour stores that lost about 10^{10} Au ions of total energy $E = 4.6$ GeV/u in each ring per hour in the reasonably-tuned blue ring. (See Fig. 2.) With these losses, total losses are about 1.8×10^{13} GeV-u/hr.

The lowest energy desired FY10 scenario of $E = 3.6$ GeV/u raises this estimate by a factor of 4-10, from increasing intensity and loss rates by factors of 2-3 each. This scenario then has $7.2 - 18 \times 10^{13}$ GeV-u/hr total projected losses, or $7.2-18\times 10^{12}$ GeV-u/hr losses that escape collimation, and $6.5-16\times 10^{13}$ GeV-u/hr losses in the collimators. These ranges are consistent with estimates listed in Table 2.

The uncollimated loss rates are rather small. For example, $7.2 - 18 \times 10^{12}$ GeV-u/hr integrated over 320-530 hours of operation is equal to the ASE stored beam limit of 9.5$\times 10^{15}$ GeV-u for a single loss event that stops operations for one hour.

Can the collimators handle the heat load? 10^{13} GeV/hr is 0.4 Watts, so this mode puts about 2.6-6.4 Watts of head load on the collimators, and one tenth of this is lost elsewhere. This is comfortably below

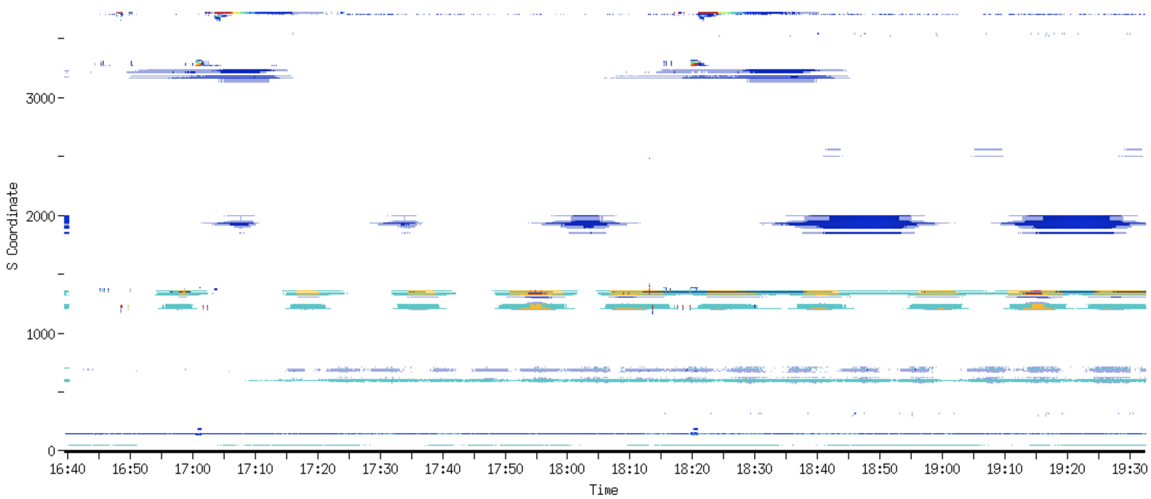

Figure 1: Beam losses during physics stores from fill 10005, Mar 11 2008 during E-4.6 GeV/u RHIC low energy tests. The vertical axis is s coordinate; chronic losses can be seen at IR6, IR8 (s=600m), IR12 (s=1800m), and IR4 (s=3200m). Large chronic losses are apparent at the abort kicker apertures in IR10 (s=1200m). Losses near s=3700m at 17:05 and 18:25 are yellow injection losses. The times correspond to those of Fig. 2.

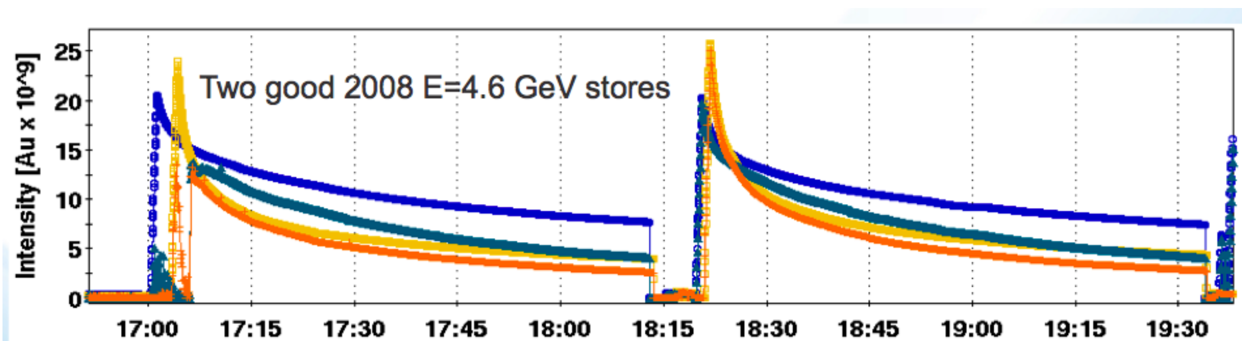

Figure 2: Two good beam physics stores from fill 10005, Mar 11 2008 during E=4.6 GeV/u RHIC low energy tests. Blue and yellow correspond to the two RHIC rings, and separate traces correspond to total and bunched beam intensities. The times correspond to those of Fig. 1.

the cryo heat load threshold of 1 W/m even if the non-collimator losses are confined to a small region. The collimators are water-cooled copper blocks and should be able to comfortably dissipate this heat load [2].

5 FY10 Scenarios

The nominal RHIC run plan for Run 10 (FY11) contains options for 25- and 30-cryoweeks due to budget uncertainty. It mostly consists of operations above RHIC injection energy. There are, however, three energies below RHIC injection energy planned, as listed in Table 3[4]. Each operational time listed in this table includes some startup time, so physics conditions listed in Table 2 are appropriate for about 75-80% of the time listed, and very conservative during the remainder of the startup time that consists of single bunch injection with lower intensity bunches.

References

[1] E. Pozdeyev, private communication.

[2] A. Drees, private communication.

Table 2: Nominal RHIC low energy operations chronic beam loss scenarios. Here we inject into each ring, then keep stored beams in collision before dumping both and refilling again, so "/fill" and "/hour" numbers are for fills of both rings. RHIC Au beam lifetime and luminosity lifetime have not been measured below $\sqrt{s_{NN}} = 9.2$ GeV. ATR losses are from 5% transport inefficiency, including stripping losses. RHIC injection losses are based on the quoted injection efficiency, and are distributed between injection septum losses and aperture losses in the RHIC rings.

CM energy $\sqrt{s_{NN}}$ [GeV]	5	7.7	8.3	9.2	11.5	18
Beam energy E [GeV]	2.5	3.85	4.15	4.6	5.75	9
Fills/hr	4	3	2	1	0.5	0.3
# bunches	110	110	110	110	110	110
AGS bunch intensity [10^9]	1	1	1	1	1	1
Injection efficiency	0.3	0.4	0.5	0.6	0.7	0.8
Total RHIC intensity [10^9]	66	88	110	132	154	176
ATR loss/fill [10^9]	11	11	11	11	11	11
ATR loss/hr [10^9]	44	33	22	11	5.5	3.3
ATR loss/hr [10^{13} GeV-n]	2.17	2.50	1.80	1.00	0.62	0.59
RHIC inj loss/fill [10^9]	154	132	110	88	66	44
RHIC inj loss/hr [10^9]	616	396	220	88	33	13.20
RHIC inj loss/hr [10^{13} GeV-n]	30.34	30.03	17.99	7.97	3.74	2.34
RHIC store loss/fill [10^9]	41.72	55.63	69.53	83.44	97.35	111.25
RHIC store loss/hr [10^9]	166.88	166.88	139.07	83.44	48.67	33.38
RHIC store loss/hr [10^{13} GeV-n]	8.22	12.66	11.37	7.56	5.51	5.92
Collimator efficiency	0.9	0.9	0.9	0.9	0.9	0.9
Collimator loss/hr [10^{13} GeV-n]	7.40	11.39	10.23	6.81	4.96	5.33
<Collimator loss rate>/ring [W]	1.65	2.53	2.28	1.51	1.10	1.19
Excess loss/hr [10^{12} GeV-n]	8.22	12.66	11.37	7.56	5.51	5.92
<Excess loss rate> [W]	0.37	0.56	0.51	0.34	0.25	0.26
Excess loss/s [10^6 Au]	4.64	4.64	3.86	2.32	1.35	0.93

Table 3: RHIC Run 10 (FY11) energies and operational times, per [4].

$\sqrt{s_{NN}}$ [GeV]	Total Beam Energy E [GeV/u]	25 week scenario [weeks]	30 week scenario [weeks]
18	9	0	1.5
11.5	5.75	1.5	2.5
7.7	3.85	1.0	1.0

[3] C-AD Operations Procedures Manual 2.5.2, "RHIC Accelerator Safety Envelope Parameters", Section 5.1.1.

[4] S. Vigdor, "RHIC Run 10 Plan", RHIC News, Aug 11 2009, retrieved from web location `http://www.bnl.gov/rhic/news/081109/story1.asp`.