LUMINOSITY INCREASES IN GOLD-GOLD OPERATION IN RHIC*

W. Fischer†, L. Ahrens, J. Alessi, M. Bai, D. Barton, J. Beebe-Wang, M. Blaskiewicz, J.M. Brennan, D. Bruno, J. Butler, R. Calaga, P. Cameron, R. Connolly, J. Delong, T. D'Ottavio, A. Drees, W. Fu, G. Ganetis, W. Glenn, T. Hayes, P. He, H. Huang, H.C. Hseuh, P. Ingrassia, U. Iriso, R. Lee, Y. Luo, G.Marr, W.W. MacKay, A. Marusic, R. Michnoff, C. Montag, J. Morris, T. Nicoletti, B. Oerter, S. Peggs, A. Pendzick, C. Pearson, F. Pilat, V. Ptitsyn, T. Roser, J. Sandberg, T. Satogata, C. Schultheiss, A. Sidi-Yekhlef, L. Smart, S. Tepikian, R. Tomas, N. Tsoupas, D. Trbojevic, J. Tuozzolo, K. Vetter, K. Yip, A. Zaltsman, A. Zhang, S.Y. Zhang, J. van Zeijts, and the RHIC Operations Team
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

After an exploratory phase, during which a number of beam parameters were varied, the RHIC experiments now demand higher luminosity to study heavy ion collisions in detail. In gold-gold operation, RHIC delivers now twice the design luminosity. During the last gold-gold operating period (Run-4) the machine delivered 15 times more integrated luminosity than during the previous gold-gold operating period (Run-2), two years ago. We give an overview of the changes that increased the instantaneous luminosity and luminosity lifetime, raised the reliability, and improved the operational efficiency.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) was commissioned in 1999. Since then it had 3 operating periods with gold-gold collisions (Run-1, Run-2, Run-4), and one operating period with deuteron-gold collisions (Run-3). A run lasts typically about half a year. In all past runs RHIC also operated with polarized protons for a few weeks [1].

RHIC serves 2 high luminosity experiments (PHENIX, STAR), and 2 lower luminosity experiments (BRAHMS, PHOBOS). In gold-gold operation, the machine collided beams at 4 different energies: 10, 31, 65, and 100 GeV/u. For these collisions, the β-function at the interaction points varied from 10 m down to 1 m.

In its most recent operating period (Run-4) the machine ran for physics for 12 weeks at 100 GeV/u with gold-gold collision. It took 4 weeks of machine set-up, and luminosity ramp-up before the physics run started. This was about 1 week less than anticipated. After a set-up time of less than 2 days, RHIC also ran gold-gold collisions at 31.4 GeV/u for 9 days, followed by a 6 week development run for polarized protons. We report on the luminosity increases in gold-gold operation in Run-4.

Fig. 1 shows, in comparison, the delivered luminosities for the 3 gold-gold runs. Tab. 1 shows the main parameters of these runs along with the design and enhanced design parameters. While the design goal for the average store luminosity was exceeded by a factor 2, another factor of 2 is needed for the enhanced luminosity goal.

* Work performed under the auspices of the US Department of Energy.
† Wolfram.Fischer@bnl.gov

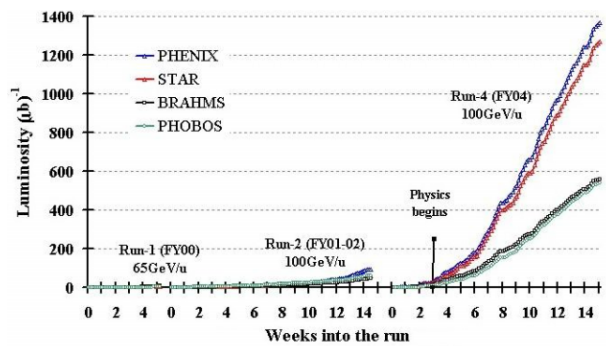

Figure 1: Integrated gold-gold luminosity delivered to the 4 RHIC experiments during Run-1, Run-2, and Run-4.

LUMINOSITY AND BACKGROUND

The RHIC luminosity in gold-gold operation is limited by intra-beam scattering (IBS), vacuum break downs with intense beams, and instabilities; it is affected but not limited by the beam-beam effect. The total beam-beam induced tune spread reaches 0.01.

Increases in the bunch intensity therefore yielded the largest gains in the instantaneous luminosity (see Tab. 1). After replacement of the Booster injection septum, bunches of 10^9 or more Au ions could be reliably prepared for

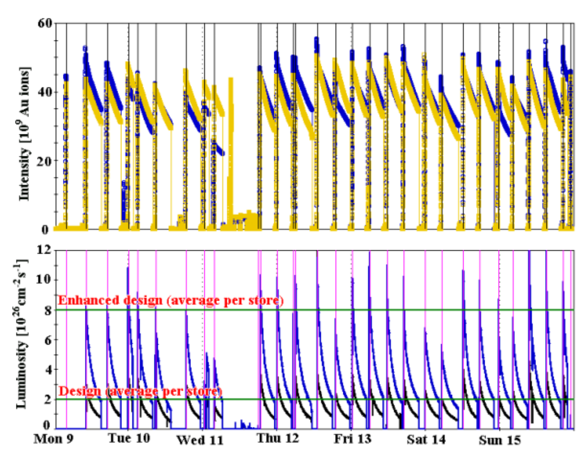

Figure 2: A week in February 2004. The upper part shows the beam intensities. The lower part depicts the instantaneous luminosities of a high luminosity (PHENIX), and a lower luminosity experiment (BRAHMS). The gap on Wednesday is due to 12 h of beam experiments.

Table 1: RHIC performance evolution in gold-gold operation. Shown are the beam parameters that lead to the highest luminosities at the PHENIX experiment. RHIC serves 2 high- and 2 lower luminosity experiments.

	max energy [GeV/u]	no of bunches	ions/bunch $[10^9]$	β^* [m]	emittance [mm mrad]	$\mathcal{L}_{peak}$	$\mathcal{L}_{store,ave}$ $[10^{26}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	L_{week} $[\mu\mathrm{b}^{-1}]$
Run-1 (FY2000)	65	55	0.3	3	15-40	0.3	0.2	4
Run-2 (FY2001/2002)	100	55	0.5	1	15-40	3.7	1.5	24
Run-4 (FY2004)	100	45	1.1	1	15-40	15	4	160
Design	100	55	1.0	2	15-40	9	2	50
Enhanced design	100	112	1.0	1	15-40	30	8	300

RHIC. A bunch preparation technique was tested that could lead to even larger bunch intensities. This technique involved an additional merging of bunches in the Booster [2].

Vacuum. The RHIC luminosity is limited by vacuum break-down, driven by electron clouds and ion desorption [3, 4, 5]. Over the last few shut-downs, various upgrades to the vacuum system were made. These involved careful baking of all bakeable elements, and the installation of electron detectors, solenoids, and NEG coated beam pipes for test purposes. However, in both rings a newly installed element (collimators in Blue, stochastic cooling kicker in Yellow) remained unbaked due to scheduling conflicts. These elements limited the beam intensity. An even more severe limit for the luminosity came from pressure rises seen in PHOBOS at store [6]. All pressure rises were alleviated by a reduction in bunch numbers and the use of optimized bunch patterns [7].

Intrabeam scattering. Due to IBS particles leave the rf buckets and continuous gap cleaning is needed to keep the abort gap free of particles [8]. This effect dominates the beam lifetime (Fig. 2). IBS also leads to increases in the transverse emittance during stores. Both these effects lead to a luminosity lifetime of only about 2.5 h, and frequent refills are needed to achieve a high average luminosity. The store length (4 h) was optimized using the luminosity lifetime, the average refill time (2 h), and additional considerations from the experiments.

Instabilities. The beam is vulnerable to instabilities near transition as the bunches become short and the peak intensity large. Transition crossing is done with a γ-jump [9]. Transverse instabilities are suppressed by octupoles [10] and a careful setting of the chromaticity. The chromaticity along the ramp can be measured using a phase-locked loop tune meter and radius modulations; instabilities can be observed with a coherence monitor. Newly installed dedicated Landau-damping cavities, running at a harmonic of the revolution but not bunch frequency, provide additional synchrotron tune spread [2].

Background. To improve the experimental background, shielding was installed in PHENIX and BRAHMS, and the collimator system upgraded from a one- to a two-stage system. At the beginning of stores, the bunches are transferred from the accelerating rf system into the storage rf system (to shorten the bunches and increase the longitudinal focusing) [2], beams are steered to maximize the luminosity [11], and the collimators are set to minimize the background. All these activities were performed automatically and reliably, thus increasing the useful time in store significantly.

Improvements to the the luminosity lifetime were made through the use of low noise rf sources [12], and the nonlinear correction of the interaction regions magnets [13].

TIME IN STORE

An increase in the time in store not only leads to a larger integrated luminosity, it is also a sign of a more reliable and reproducible machine. Fig. 3 shows the weekly time distribution for various activities. Every week about 11 h are dedicated to beam experiments, and about 8 h to maintenance. 35 h are needed for machine set-up, and 25 h are due to failures. Overall, the time in store increased to 53%, with steady improvements during the last runs (see Fig. 4).

A number of efforts saved at least one day per run:

Faster down ramps. The time to ramp the magnets from the flattop level back to the injection level was reduced from

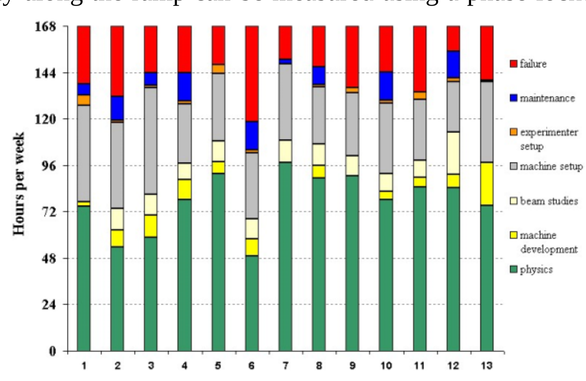

Figure 3: Weekly time distribution for various activities.

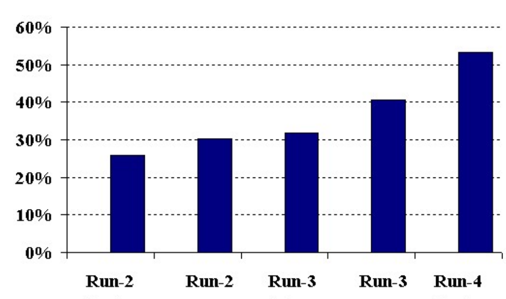

Figure 4: Evolution of the time in store for the operating modes of the last 3 runs. The time in store is given as a percentage of the calendar time that includes beam experiments and maintenance.

12 min to 5 min. About 300 ramps were made during the initial set-up period; the run had 274 physics stores, and a considerable number of ramps for development. Further improvements to the down ramp speed are possible.

Corrector power supply replacements. During Run-3 a total of 60 corrector power supplies were replaced, during Run-4 this number was cut in half (Fig. 5) due to implemented modifications. The power supplies are replaced at the earliest possible convenience, typically at the end of a store, in order to keep the overall machine configuration stable. A power supply replacement takes about 1.5 h.

Ice balls at current leads. In the past, ice balls formed at cold current leads from the humid air in the tunnel. This required a weekly maintenance shift to avoid mechanical and electrical malfunction of elements near the leads. The cold parts of the leads were insulated with a self-adhesive plastic foam layer, eliminating the maintenance need.

Quench link interlocks (QLIs). QLIs can be triggered by beam induced quenches, and for a number of other reasons. From Run-2 to Run-3 to Run-4 the number of QLIs was reduced from 395(46) to 270(69) to 240(54) where the numbers in brackets denote beam induced quenches. The beam induced quenches were primarily caused by ramp losses during β-squeeze, and abort kicker pre-fires. Abort kicker pre-fires have been almost eliminated [14]. Recovery from a QLI lasts 1 h or more.

Transfer line cooling. Microbes in the cooling system of the AGS-to-RHIC transfer line were feeding off corrosion products, and clogged the flow switches that monitor the proper flow of the cooling water. The flow switches would thus detect a problem and shut off the transfer line. During Run-3 this had caused more than a day of down-time. The problem was solved by filtering out the microbes' nutrients.

Automation. More and more tasks are driven by a sequencer. This applies to injector preparation, injection set-up, ramp preparation, store preparation, and automatic entries in the electronic log book. The efficiency of correction programs was increased by better machine models [15]. An automatic closed orbit correction after each ramp made the machine reproducible over the length of the run. In the past, the machine had to be retuned after a week to maintain performance. The PHOBOS experimental magnet, primarily a quadrupole, was fully integrated in the machine operation, giving the experimenters the option of arbitrary polarity settings.

A controls upgrade lead to 2 MW of power savings in the cryo operation, and 10% savings in the quench recovery time. Future improvements to the time in store can come from a further reduction of QLIs, and a reduction in the set-up time, possible through a better integration of the injector operation, and more convenient and more efficient computer control of RHIC.

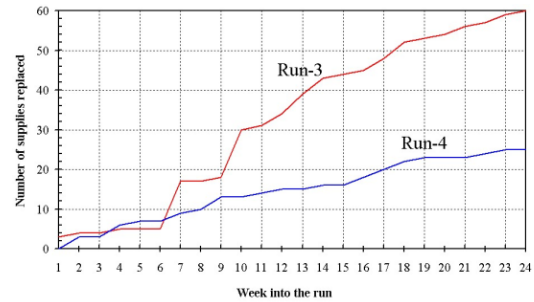

Figure 5: Power supply replacements in Run-3 and Run-4. Week 1 through 18 show gold-gold operation, 19 through 24 polarized proton operation.

SUMMARY

During the recent gold-gold operating period (Run-4), RHIC delivered 15 times more integrated luminosity than during the, slightly longer, previous gold-gold operating period 2 years ago (Run-2). Consistently higher bunch intensity from the injector, and an upgraded vacuum system lead to a higher peak luminosity. A number of measures increased the time in store to 53% of the calendar time. At store, bunches were reliably transferred from the accelerating into the storage rf system. Automatic steering [11] and collimation set-up reduced the store time during which some of the experiments cannot take data. The machine was set-up for operation at a lower energy within less than 2 days.

ACKNOWLEDGEMENTS

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REFERENCES

[1] T. Satogata, "RHIC performance and plans towards higher luminosity and higher polarization", these proceedings.

[2] J.M. Brennan et al., "RF techniques for improved luminosity at RHIC", these proceedings.

[3] W. Fischer et al., "Electron clouds and vacuum pressure rise in RHIC", ECLOUD'04, Napa, California (2004).

[4] U. Iriso et al., "Analysis of electron cloud at RHIC", these proceedings.

[5] S.Y. Zhang et al., "RHIC pressure rise", these proceedings.

[6] G. Rumolo and W. Fischer, "Observations on background in PHOBOS and related electron cloud simulations", BNL C-A/AP/146 (2004).

[7] W. Fischer and U. Iriso, "Bunch patterns and pressure rise in RHIC", these proceedings.

[8] A. Drees and R. Michnoff, "Continuous abort gap cleaning at RHIC", these proceedings.

[9] C. Montag and J. Kewisch, Phys. Rev. ST Accel. Beams 7, 011001 (2004).

[10] C. Montag et al., Phys. Rev. ST Accel. Beams 5, 084401 (2002).

[11] A. Drees and T. D'Ottavio, "Luminosity optimization using Automated IR Steering at RHIC", these proceedings.

[12] T. Hayes, "A low noise rf source for RHIC", these proceedings.

[13] F. Pilat et al., "Performance of the non-linear interaction region corrections in RHIC", these proceedings.

[14] J. Mi et al.,"Some modification of RHIC abort kicker power supply", these proceedings.

[15] J. van Zeijts, "Transverse optics improvements for RHIC Run-4", these proceedings.