RHIC Au-Au OPERATION AT 100 GeV IN RUN16*

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Abstract

In order to achieve higher instantaneous and integrated luminosities, the average Au bunch intensity in RHIC has been increased by 28% compared to the preceding Au run. This increase was accomplished in part by merging bunches in the RHIC injector AGS. Luminosity levelling for one of the two interaction points (IP) with collisions was realized by continuous control of the vertical beam separation. Parallel to RHIC physics operation, the electron beam commissioning of a novel cooling technique with potential application in eRHIC, Coherent electron Cooling as a proof of principle (CeCPoP), was carried out. In addition, a 56 MHz superconducting RF cavity was commissioned and made operational. In this paper we will focus on the RHIC performance during the 2016 Au-Au run.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is a circular collider that has been operated successfully for more than a decade. It has provided heavy ion collisions of several species at different energies. In 2016, at the beginning of the FY16 physics run, RHIC provided Au-Au beam collisions at 100 GeV/n beam energy for 10 weeks, followed by 6 weeks of d-Au (Deuteron-gold) energy scan physics running. The last week of the run, which was originally devoted to the CeC PoP experiment, was eventually re-used for the 100 GeV Au-Au physics run.

INJECTION CHAIN

The Au injection chain of RHIC includes EBIS/Tandem as an injector, followed by Linac, Booster and AGS. At the beginning of Run16, eight bunches in the AGS were merged into two bunches using a bunch merge scheme of 8→4→2.

To shorten the filling time, the merge scheme of 12→6→2 (Figure 1) was tested and adopted for RHIC operation after reaching the maximum intensity (2.1×10^9) in the AGS with the 8→4→2 merge scheme. To make this scheme work, EBIS also needs to provide 12 pulses per cycle reliably; additionally the Booster merge energy has to be raised to meet the power limit from the local power grid.

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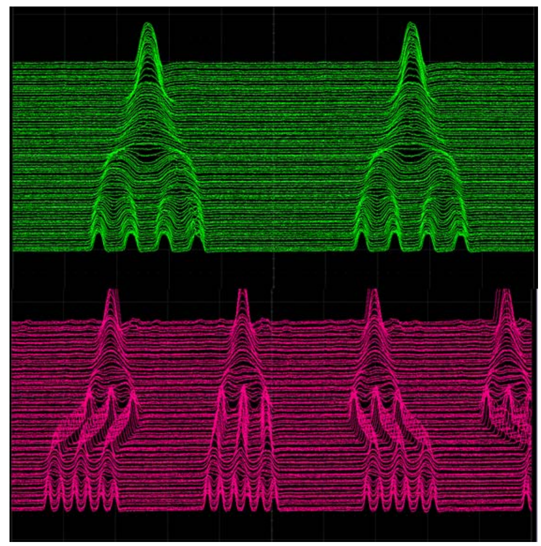

Figure 1: Merge scheme in the AGS for 8→4→2 (top) and 12→6→2 (bottom).

With the merging scheme of 12→6→2, the peak bunch intensity at AGS extraction has reached 3.15×10^9. However, the AGS injection intensity was limited to $2.4\sim2.5\times10^9$, which was imposed by the amplifier of the RHIC Landau cavity.

With the upgrade of the Booster low-level RF, the satellite bunch intensity was only 2% of the Au intensity in Run 14, while it is around 4~5% in Run 16 because of the larger number of bunches merged. The longitudinal emittance in the AGS was about 0.7eVs, which is similar to Run 14. The normalized transverse rms emittance in the AGS was about 1.7-1.8μm. The duty cycle was also extended from 5.4 seconds to 6.4 seconds, although was reduced to 6 seconds later. Because of the longer cycle time, the filling time of RHIC was extended. The increase emittance growth during the extended filling time resulted in about 5% smaller ramp efficiency that Run 14.

The Tandem also achieved a record Au intensity of 2.5×10^9 and met the limited RHIC intensity requirement during EBIS outages.

RHIC LATTICE AND BEAM LOSS

The 100 GeV Au-Au lattice for Run 16 was similar to the configuration used in Run14 [1, 2]. The integer tunes were (28, 29), and the lattice had a better off-momentum dynamic aperture. The initial beta* for collisions at IP6 and IP8 was 0.7 m, while the beta* for IP2 and IP12 was set to 5 m.

The protection bumps [2], which were designed during Run 14 to protect the STAR and the PHENIX detectors from abort kicker pre-fires, were also adopted in Run16. The amplitude of the bumps was 20 mm. Besides the acute beam loss from pre-fires, the protection bump area also experienced continuous chronic beam losses, which was dominated by Au^{78} generated by bound-free pair production in collisions.

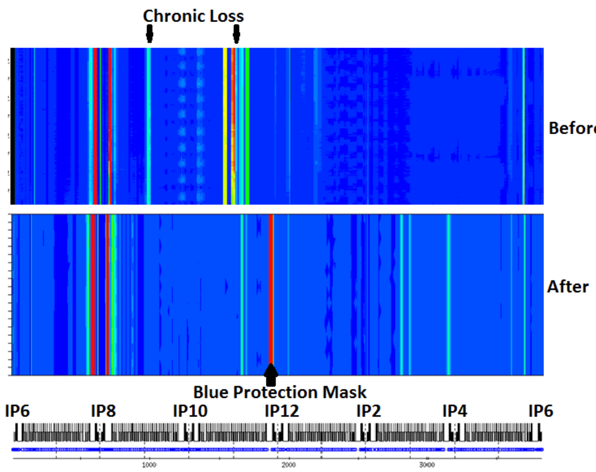

Figure 2: The chronic beam loss nearby protection bumps area before and after modification.

These chronic beam losses have caused electronics upsets and store aborts, and are considered one reason for the diode failure when one blue dipole magnet quenched during Run 16 operation. The total time for the dipole replacement was completed in 2.8 weeks, including identification, warm up, replacement, cooling down and resuming physics.

To replace the protection bumps and eliminate the chronic beam loss, two protection masks (at IP12 for blue and IP8 for yellow) were installed in both rings during Run15 [3]. These are movable beam masks located one arc downstream of the IR 10 abort kickers, so that they can intercept beam kicked during an abort kicker pre-fire event before the kicked beam reaches the detector. The betatron phase advances between protection mask and detectors have been optimized for Run 16.

During Run 16, from one dedicated blue pre-fire test and nominal operation, it was concluded that these masks are not adequate to prevent experimental triplet quenches as well as detector, even after optimizing the phase advance between pre-fire kicker and protection mask. It is also not advisable to place a mask immediately upstream of an experimental detector because of radiation shower, as is the case in the yellow ring.

Therefore, to reduce these chronic beam losses, some improvements of the protection bumps had been made, as illustrated in Figure 3. The yellow protection bump was moved by 2 FODO cells, and the direction of the maximum amplitude was flipped towards the outside of the RHIC ring, to reduce beam loss onto the protection diode. The blue protection bump and compensation bump were moved to a different arc. The blue closed orbit was also moved closer to the blue mask. After these changes, the total beam loss in the cold magnets was reduced, as well as the frequency of store aborts caused by electronics upset. There was increased beam loss observed on the blue protection mask (Figure 2), as intended. No chronic beam loss and radiation were detected at IP2 where the radiation sensitive wiggler of CeC PoP is located.

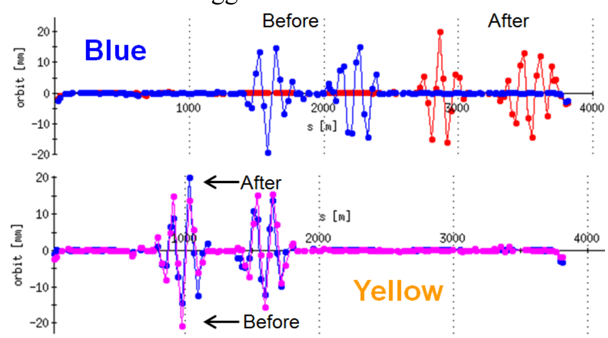

Figure 3: Closed orbit before and after protection bumps change.

SYSTEMS

A 56MHz passive superconducting RF (SRF) storage cavity [4] without Higher Order Mode (HOM) damper was commissioned during Run16. To find a way to make the cavity operational, the Fundamental Mode Damper (FMD) was used as HOM damper and FMD. With the help of the cavity tuner, a safe tuning path which avoided exciting several monopole modes was found, and the cavity voltage could be ramped up to 1MV. The cavity was operated in several stores during this 100 GeV Au-Au run. With 0.5 MV cavity voltage, the 10 cm PHENIX vertex cut detector signal increased about 17%.

Coherent electron Cooling [5] is a strong cooling method that is needed to achieve the ultimate luminosity of eRHIC. The CeC proof-of-principle (PoP) experiment aims at demonstrating this novel cooling technique. Installation of CeC-PoP in IP 2 was almost finished at the beginning of Run16, and electron beam commissioning started during RHIC operation. The compressed electron beam was accelerated to about 8 MeV and propagated through the interaction region to the high power beam dump [6]. The ion beam loss at IP2 was improved and eliminated after reducing the separation bump amplitude, better vacuum pipe alignment and orbit control at injection.

PERFORMANCE

The 100 GeV Au-Au operations started with ramping up the bunch intensity to 1.8×10^9 and the bunch number to 111, because of high vacuum pressure around IR2 area during start-up. Thereafter, 3D Stochastic Cooling (SC) with longitudinal gated cooling was configured, and machine setup was finished. On Feb. 22, the bunch merge scheme for RHIC fill switched from 8->4->2 to 12->6->2 beginning with fill 19587. Then, the injection beam intensity was increased up until reaching its limit of 2.4×10^9. Subsequently it was kept at 2.3×10^9.

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In Run14, because the high collision rates have caused triggering issues for the STAR HFT, the STAR ZDC rates were levelled to 50 kHz after 2.5 hours into the store. From the beginning of Run16, after several store tests of levelling to 60 kHz, the STAR ZDC rates were kept constant at 70 kHz (Figure 4, top plot) from the beginning of each store via a vertical separation bump. To preserve intensity and allow longer levelled stores for STAR, the initial SC cooling power was reduced and controlled throughout the store (Figure 4, bottom plot). This resulted in 4~5% more integrated luminosity for STAR.

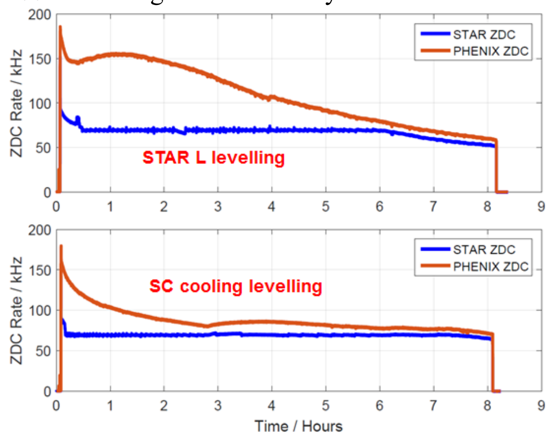

Figure 4: STAR luminosity levelling with 70 kHz ZDC rate (top); SC cooling levelling was used for higher integrated luminosity for STAR.

With the higher intensity provided by the AGS, the average bunch intensity in RHIC before physics collision was 1.85×10^9, while it was about 1.4×10^9 in Run 14. The 100 GeV Au-Au peak luminosity of RHIC in Run 16 has increased about 85% compared to Run 14 (Figure 5), based on the 10 best stores in each of the two runs; while the store integrated luminosity has increased about 75% even with SC cooling levelling. The delivered integrated luminosities are shown in Figure 6.

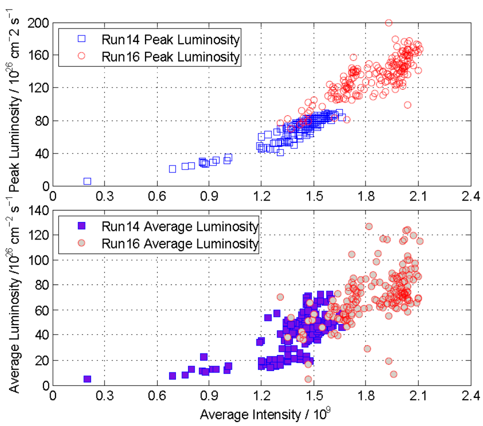

Figure 5: peak luminosity (top) and average luminosity (bottom).

SUMMARY AND PLANS

The RHIC 100 GeV Au-Au Run16 benefitted from record Au intensities from EBIS, the Booster and the AGS for RHIC. With the help of the merge scheme of 12→6→2 and the improvement of EBIS, the AGS achieved 50% more intensity than before. In RHIC, this resulted in 28% higher bunch intensities. About another 20% more intensity available in the AGS can be injected in to RHIC in the future, after increasing the power of Landau cavity amplifier.

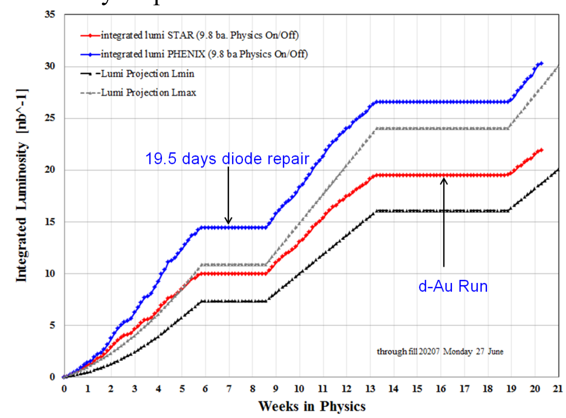

Figure 6: Delivered integrated luminosities for STAR and PHENIX during RHIC Au-Au 100 GeV Run16.

During Run 16, a quench protection diode needed to be replaced due to radiation and quench related damage. This repair was performed within just 19 days. With more intensity in the future, the machine protection needs to be carefully re-evaluated. A mechanical switch is also under consideration to eliminate abort kicker pre-fires [6].

The 56 MHz SRF has operated at 1 MV without any HOM dampers - the first operational SRF cavity in RHIC. To further achieve stable operation above 1MV up to 2 MV in the future, some modifications are being carried out now.

CeC beam has been delivered from the gun to the high power dump [7]. To achieve 20 MeV beam and demonstrate CeC as a viable cooling technique within the next two years, several improvements are under way.

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