RHIC PERFORMANCE FOR FY2012 HEAVY ION RUN*

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Abstract

In the 2012 RHIC heavy ion run, we collided uranium-uranium (U-U) ions at 96.4 GeV/nucleon and copper-gold (Cu-Au) ions at 100 GeV/nucleon for the first time in RHIC. The new Electron-Beam Ion Source (EBIS) was used for the first time to provide ions for the RHIC physics program. After adding the horizontal cooling, 3-D stochastic cooling became operational in RHIC for the first time, which greatly enhanced the luminosity. With a double bunch merging technique in the Booster and AGS, the bunch intensities of Cu and Au ions in RHIC surpassed their projections. Both PHENIX and STAR detectors reached their integrated luminosity goals for both U-U and Cu-Au collisions. In this article we review the machine improvements and performances in this run.

INTRODUCTION

In the previous gold-gold (Au-Au) runs in RHIC, thanks to decreased β^* at IPs, increased bunch intensities, the installation of stochastic cooling [1], and the high precision beam control feedback systems, the integrated luminosity had been doubled from Run-7 to Run-10, and from Run-10 to Run-11 [2]. In the 2011 RHIC Au-Au run, we achieved $\beta^* = 0.7$ m at the collision points, a maximum Au ion bunch intensity of 1.3×10^9 at the beginning of a store, and a maximum peak luminosity of $52.6 \times 10^{26}\text{cm}^{-2}\text{sec}^{-1}$ [3].

In 2012, we collided uranium-uranium (U-U) ions at 96.4 GeV/nucleon and copper-gold (Cu-Au) ions at 100 GeV/nucleon for the first time in RHIC. RHIC is capable of circulating and colliding two completely different beams. The football-shaped U ion collision offers opportunities to study the 'tip-tip' collision besides the 'body-body' collision. In the Cu-Au ion collision, the smaller Cu ion can be completely buried in the Au ion, which provides new insight into the mechanism by which quarks and gluons lose energy as they traverse the quark-gluon plasma.

* This work was supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.

IMPROVEMENTS

The first high energy U-U collisions were enabled by the versatile new Electron-Beam Ion Source (EBIS) [4]. EBIS can produce beams of essentially any ion species, and can switch rapidly between two different species. It was used for the first time to provide ions for the RHIC physics program.

To counter the intra-beam scattering (IBS) emittance growth in the RHIC heavy ion runs, stochastic cooling was implemented in RHIC in the past few years. The longitudinal system was implemented in 2007, and the vertical stochastic cooling in 2011. In 2012, by adding cooling in the horizontal plane, full 3-D stochastic cooling became operational for the first time in both RHIC rings.

In the 2010 and 2011 Au-Au runs, we observed large beam loss with rebucketing and during store with the vertical cooling on. These losses were from particles with large off-momentum deviation. In the 2012 ion run, we chose a lattice with integer tunes (28, 29), which are 3 units lower than what was used in the previous ion runs. With this lattice, simulation shows that the off-momentum dynamic aperture increased from 2 σ to 5 σ at the maximum relative off-momentum deviation $\Delta p/p_0 = 0.0018$ [5].

The EBIS preinjector operated with good reliability and stability, but an intensity from the preinjector that was lower than the optimum design performance, along with lower than expected foil stripping and ion transfer efficiencies, caused the Uranium ion intensity in RHIC to fall short. To increase the bunch intensity, double bunch merging was implemented in both Booster and AGS. This technique eventually became operational two days before the end of the U-U run. In principle, double bunch merging in Booster and AGS could increase the bunch intensity in RHIC by a factor of 4.

The RHIC orbit feedback system became operational for the first time in the 2011 proton run. In the 2012 ion run, with numerous improvements in the control software and hardware, the orbit feedback became more robust [6]. Together with tune/coupling feedback, the RHIC beam control feedback systems greatly reduces the beam time necessary for machine start-up and store tuning.

PERFORMANCES

U-U Run

The 2012 RHIC U-U run began on April 19, 2012 and ended on May 15, 2012. The first over-night store for the detector setup was delivered on April 22 as scheduled. The physics running mode was declared on April 23. During the 5-day start-up, one day was dedicated to tuning-up of the 197 MHz RF cavities and rebucketing at the top energy. One day was lost due to a Booster main magnet power supply failure and an EBIS vacuum leak. The physics mode lasted for 22 days in the 2012 RHIC U-U run.

Figure 1 shows the integrated luminosities for the two physics detectors PHENIX and STAR, together with their minimum and maximum projected luminosities. The minimum projected luminosity was based on the bunch intensity 0.6×10^9. The typical bunch intensity at the beginning of store was 0.3×10^9 in the 2012 RHIC U-U run.

The luminosity in the U-U run was greatly enhanced with 3-D stochastic cooling. With 3-D cooling, the normalized 95% transverse beam emittance was cooled down to 2.5π mm mrad in 2 hours from 13π mm mrad at the beginning of store. Figure 2 shows the luminosity with and without stochastic cooling. With 3-D cooling, the peak luminosity was 3 times the initial one, which was observed for the first time in a collider. The integrated luminosity per store is about 5 times that without any cooling. Despite the lower bunch intensity the integrated luminosity goals of both detectors were reached.

Figure 3 shows an example of the Zero Degree Calorimeter (ZDC) coincidence rates from the two detectors S TAR and PHENIX, the actual beam loss rates, and the burn-off contributions to the total beam loss in one store (fill number 16830). As mentioned above, this year we adopted a lattice which provides a large off-momentum dynamic aperture. The particle loss due to the momentum aperture limitation was essentially eliminated. Together with stochastic cooling, the beam loss was nearly due to burn-off [7], which is also the first time observed in a collider.

Cu-Au Run

The 2012 RHIC Cu-Au run began on May 15 and ended on June 25. The first over-night store for detector set-up was delivered on May 17 as scheduled. The physics mode was declared on May 18. The machine start-up took only 3.5 days. Physics mode ran for 38 days. 3-D stochastic cooling was operational on May 23.

Figure 4 shows the integrated luminosities for PHENIX and STAR. The achieved integrated luminosities for both detectors were above the maximum projection. We also reached PHENIX's narrow vertex integrated luminosity goal. Narrow vertex luminosity only counts the collisions within ± 10 cm of the IP.

Figure 5 shows the averaged bunch intensities at the beginning of store. Double bunch merging in the Booster

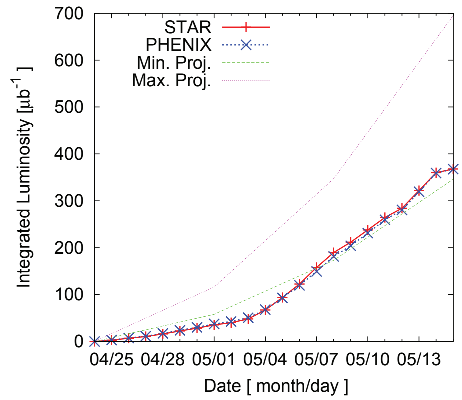

Figure 1: Integrated luminosities in 2012 RHIC U-U run. The minimum and maximum projections are shown.

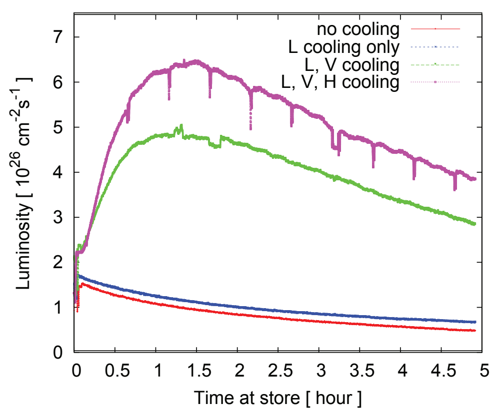

Figure 2: Luminosity without and with stochastic cooling in the 2012 RHIC U-U run. The rate drops every half an hour with 3-D cooling were caused by the automatic store orbit corrections and interaction re-steerings after them.

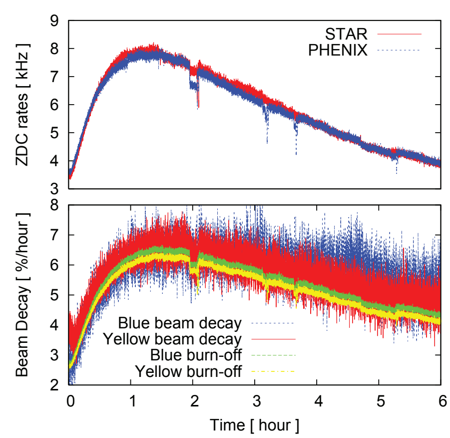

Figure 3: One example of the ZDC rates, beam decays, and burn-off contribution to the beam loss in 2012 RHIC U-U run. The burn-off is calculated based on the analytical cross section of 487.3 b.

ISBN 978-3-95450-122-9

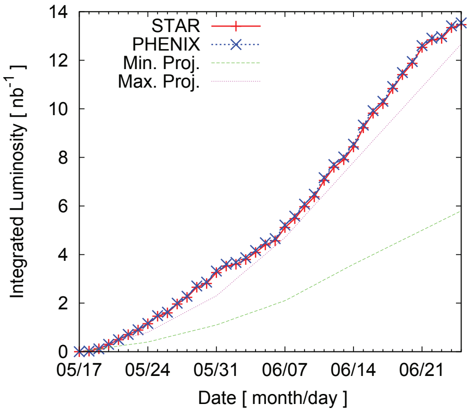

Figure 4: Integrated luminosities in 2012 RHIC Cu-Au run. The minimum and maximum projections are shown.

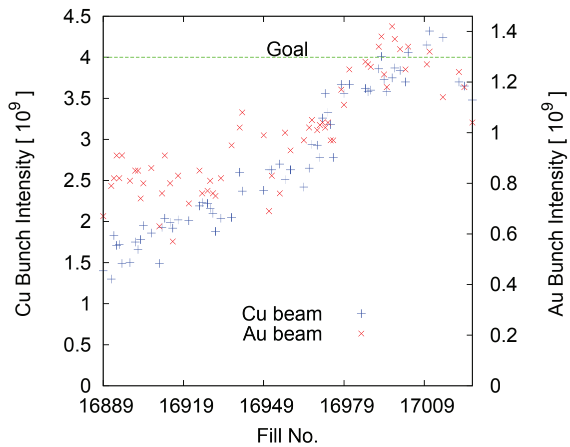

Figure 5: Averaged bunch intensities at the beginning of each individual store in the 2012 RHIC Cu-Au run.

and AGS was operational for the whole Cu-Au run and it greatly increased the bunch intensity in the RHIC. Since double bunch merging increased the ion beams transverse and longitudinal emittances, careful tuning of the Booster, AGS, and AGS-to-RHIC transfer lines was required. Continuous efforts were also made to improve the transmission efficiency from RHIC injection to store by fine tuning the working points, chromaticities, and transition loss. The Cu bunch intensity was doubled and the Au bunch intensity increased by 50% through the course of Cu-Au run. We achieved the most intense ion bunch intensity in RHIC up to date.

The IBS growth rate is proportional to $N_i Z^4/A^2$ while the stochastic cooling rate is proportional to $1/N_i$, where N_i is bunch intensity, Z and A are the ion charge state and atom number. In the Cu-Au run, Cu bunch intensity was more than 3 times the Au bunch intensity. Therefore, the IBS emittance growth rate of the Cu beam is half of that of the Au ion beam, while the stochastic cooling rate of the Cu beam is one third of the Au ion beam. In the beginning of this run, we observed large Cu beam loss through beam-beam interaction with unbalanced beam sizes. To maintain the Cu beam bunch intensity and to maximize the integrated luminosity, we intentionally reduced the Au beam's cooling rate in the first several hours of each store. The store length in the Cu-Au run was 14 hours. Figure 6 shows an example of the ZDC rates and beam emittances in one physics store, fill number 16988.

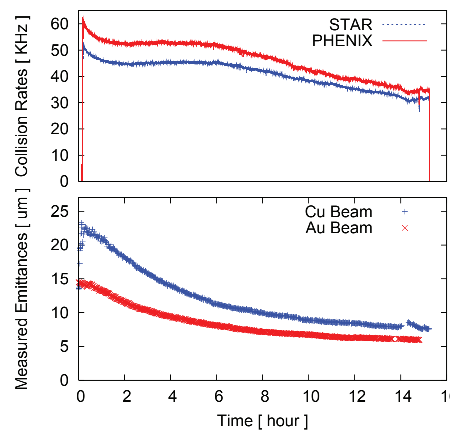

Figure 6: Experimental rates and beam transverse emittances in one physics store in 2012 RHIC Cu-Au run.

SUMMARY

The 2012 RHIC heavy ion run was a great success. It marked the first collisions of high energy U-U and Cu-Au ions in RHIC. With a versatile EBIS, powerful 3-D stochastic cooling, and double bunch merging in the injectors, high precision beam feedback systems, and many efforts of machine fine tunning, we achieved both detectors' integrated luminosity goals. During the 2012 RHIC heavy ion run, the machine down time due to hardware failures was much lower than previous runs. The physics store time were 72% and 65% of the calendar time in the U-U and Cu-Au runs.

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