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# RHIC PERFORMANCE FOR FY2014 HEAVY ION RUN*

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*Abstract*

After running uranium-uranium and copper-gold collisions in 2012, the high energy heavy ion run of the Relativistic Heavy Ion Collider (RHIC) for Fiscal Year 14 (Run14) is back to gold-gold (Au-Au) collisions at 100 GeV/nucleon. Following the level of performance achieved in Run12, RHIC is still looking to push both instantaneous and integrated luminosity goals. To that end, a new 56 MHz superconducting RF cavity was installed and commissioned, designed to keep ions in one RF bucket and improve luminosity by allowing a smaller beta function at the interaction point (IP) due to a reduced hourglass effect. The following presents an overview of these changes and reviews the performance of the collider.

## INTRODUCTION

After a short run of collisions at 7.3 GeV/nucleon beam energy [1], also used for (re)commissioning of the newly installed STAR Heavy Flavor Tracker (HFT) and PHENIX Vertex Detector (VTX), RHIC and its injectors were set up for the 18 cryo weeks of Run14 Au-Au operations at 100 GeV/nucleon. Later in the Run, considering the integrated luminosity delivered to STAR and PHENIX, and in agreement with both experiments, as of the time of this report He3-Au operations are foreseen for the last 3 weeks of Run14 at 100 GeV/nucleon. New subsystems - a 56 MHz superconducting RF cavity and an electron lens for beam-beam compensation - were also commissioned in parallel to RHIC operations.

## MACHINE SETUP

Based on the performance during Run12 and in order to minimize the commissioning period, the initial setup for the collider was based on the lattice design of the U-U high-energy run and adjusted for Au-Au collisions. Various subsystems were also upgraded during the summer shutdown period.

*Injectors*

The Au beam out of EBIS was injected and captured into four bunches in the AGS Booster. The beam was then accelerated to an intermediate energy porch where it was merged twice (4->2->1) into one bunch. Eight Booster cycles were transferred into the AGS then merged into two bunches which are then put into two of the 12 buckets used for acceleration. After this process, some beam is typically found in the other remaining buckets. For Run14 these 'satellite bunches' are significantly smaller than in Run 12 (during which the Booster and AGS configurations were similar). Their size is sensitive to the longitudinal emittance of the beam coming into the AGS merge, about 25-30% smaller than in Run12. This difference is due to the upgrade of the Booster low-level RF, now able to capture and merge the bunches in the Booster with less emittance growth. This reduced incoming emittance accounts for the reduction in the amount of beam in the satellite bunches from 8% in Run 12 to about 2% this run. Longitudinal losses from the main buckets were also reduced resulting in an overall improvement in the maximum intensity per bunch at AGS extraction to around 2.1x$10^9$, which is about 30% higher than in Run12.

Table 1: RHIC parameters for Run11 Au-Au and Run14 Au-Au (achieved).

| | Run11 Au-Au | Run14 Au-Au |
|---|---|---|
| No. of bunches | 111 | 111 |
| Ions/bunch [$10^9$] | 1.3 | 1.8 |
| $\beta^*$ at IP's [m] | 0.75 | 0.7 → 0.5 |
| Peak luminosity [$10^{26}$cm$^{-2}$s−1] | 50 | 90 |
| Avg. store luminosity [$10^{26}$cm$^{-2}$s−1] | 30 | 50 |
| Luminosity per week [$\mu$b$^{-1}$/week] | 1000 | 2000 |
| Run length [weeks in physics] | 6.4 | 13.3 |
| Time in store [% of calendar time] | 59 | 68 |

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### *RHIC Lattice*

Table 1 shows the collider parameters for Run11, the last Au-Au run, and Run14. The decision to use a configuration similar to what was used in Run12 was supported by the significant increase in delivered luminosity, a consequence of full 3D stochastic cooling (SC) and an increased off-momentum dynamic aperture (2 $\sigma$ to 5 $\sigma$ at $\Delta p/p_0$ = 0.0018) by running the lattice at integer tunes (28,29) [2].

New this run for the STAR experiment is the Heavy Flavor Tracker (HFT), a state-of-the-art micro-vertex detector utilizing active pixel sensors and silicon strip technology [3]. A review of accidental beam loss scenarios was conducted which showed that abort kicker prefires have the highest probability of driving the beam close to or into the cold aperture of the triplet quadrupoles of the STAR interaction region (IR6), inducing particle showers onto the HFT. An abort kicker prefire might expose up to 15 bunches to varying kick angles all not sufficient for a clean and controlled beam abort, meaning the affected bunches must be intercepted before they reach IR6. A specific closed orbit scheme was devised to send these bunches to the cold aperture in the arc immediately downstream of the abort kicker locations instead of the closest downstream triplet quadrupole of a low-beta IR (i.e. the STAR IR for the Blue beam). This scheme changes the regular path length of the beam, and an additional closed orbit bump had to be implemented to compensate for this change. Figure 1 shows the protection and compensation orbit bumps for both Blue and Yellow rings. During the FY14 high energy Au-Au run to date, 8 blue and 11 yellow abort kicker prefires occured, but no damage to the HFT was reported by the STAR collaboration.

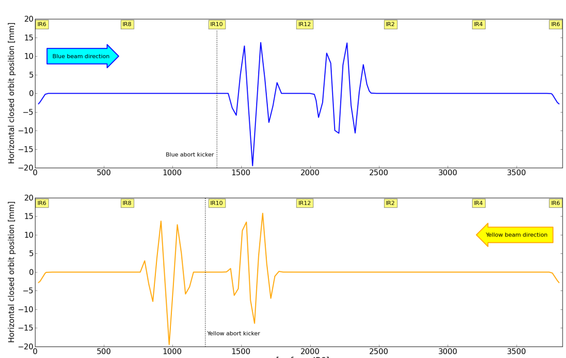


Figure 1: Closed orbit bump for the Blue (top) and Yellow (bottom) beam in RHIC for abort kicker prefire protection.

### *Systems*

For Run14, Stochastic Cooling (SC) featured new longitudinal pickups with a keyhole design, reducing the vertical aperture and boosting the cutoff frequency for microwave propagation, subsequently improving the flatness of the response. New longitudinal kickers (6 cells per cavity) were also installed. These kickers employ waveguide coupling which eliminates the need for coaxial transmission lines in the vacuum chamber. Additionally, the kickers are designed to run at an elevated temperature. Incandescent lamps are used to warm the system through glass windows and reduce the illumination when the microwave drive is on, leading to a constant temperature without cooling water in the vacuum. With Au beam in both rings all cooling could be run at maximum gain for even better efficiency than what was achieved in Run12 with (already) full 3D cooling [4].

Two electron lenses were fully installed for Run-14, and have been commissioned with Au beams [5]. The lenses are designed for partial head-on beam-beam compensation of colliding proton beams in future runs. The beam-beam parameter with Au+Au collisions is only about half the value with p+p collisions, and beam losses of cooled Au beams are dominated by burn-off not beam-beam effects. During the run the magnetic structure was commissioned, and the electron beam current and profile needed for proton beam-beam compensation were demonstrated. Instrumentation was tested including a novel detector for backscattered electrons that measures the overlap of electron and hadron beams [6]. The effect of the electron beam on orbit, tune and tune distributions was measured. Pulsed and DC operation did not show any additional emittance growth (with a growth time resolution of about 1h).

A 56MHz 2MV passive superconducting RF (SRF) storage cavity was installed and commissioned in RHIC for the start of Run 14. The purpose of this cavity, common to both Blue and Yellow rings, is to provide a very large RF bucket, reducing longitudinal diffusion from IBS during Au stores and generating as much as a 30% improvement in integrated luminosity. Beam driven testing exposed what appears to be a ponderomotive instability which was not observed without beam. Investigation and data analysis is continuing, but a cavity mechanical resonance seems to be the source. For nominal RHIC store currents ( 330 mA DC), the cavity detuning frequency appears to be significantly higher than the detuning frequency at which the ponderomotive instability occurs though.

## PERFORMANCE

Commissioning started on March 11, 2014 with the first overnight store delivered for physics 4 days later with a beam intensity of $0.9 \times 10^9$ ions/bunch. Even though the RHIC injectors had higher bunch intensities available early on, it was decided to slowly ramp to $1.6 \times 10^9$ ions/bunch(design value for Run14) to prevent the vacuum pressure to rise to high levels in both STAR and PHENIX experimental insertions, as well as the e-lens area (IR10). From March 28 on, RHIC was running at or above its targeted bunch intensity and with all three SC planes active in both beamlines, helping reach new records in both peak and integrated luminosity for a RHIC Au-Au 100 GeV run. In previous years the bunch intensity was limited by a fast transverse instability during transition crossing in RHIC. During Run14 no instabilities

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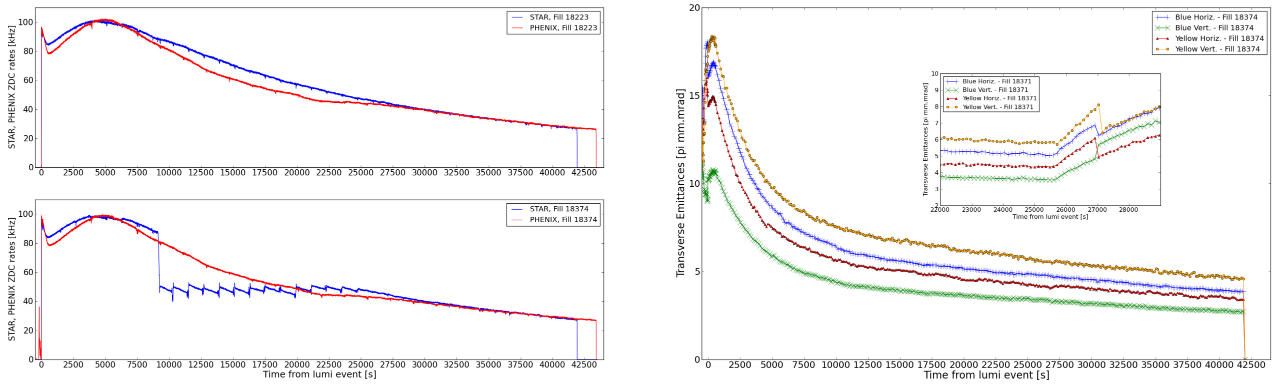


Figure 2: Left: collision rates (ZDC) for the STAR and PHENIX experiments for the two best 100 GeV Au-Au fills in regular (top) and target (bottom) mode. For the latter, the STAR ZDC rates are dropped to 50 kHz 3 hours (later re-optimized to 2.5 hours) into each store to maximize the integrated luminosity delivered to the HFT. - Right: horizontal and vertical transverse emittances of the Blue and Yellow beams for a typical RHIC 100 GeV Au-Au store with stochastic cooling on (main) and turned off at the end of a store (inclusion) during a dynamic $\beta^*$ squeeze experiment.

were observed, likely the result of beam scrubbing from the high intensity proton run in the previous year.

As the run progressed, it appeared that the high collision rates were causing triggering issues for the STAR HFT. To allow the experiment to reach both of its high and low luminosity goals, the ZDC rates were dropped to 50 kHz three hours into each store, which maximizes the usable integrated luiminosity for each physics fill. Figure 2 shows the STAR and PHENIX coincidence rates (ZDC) for the two best physics store for each "mode". The performance of the RHIC SC on the transverse beam emittances is also shown, where a reduction of a factor 2.5-3 from the beginning of store can be observed, down to about 5 $\pi$ after 11 hours. Also included is the effect of turning SC off during one of the dynamic beta* squeeze test, with rapidly growing emittances in all four planes. Figure 3 shows the cumulated delivered luminosity to each experiment over the time during which RHIC delivered physics.

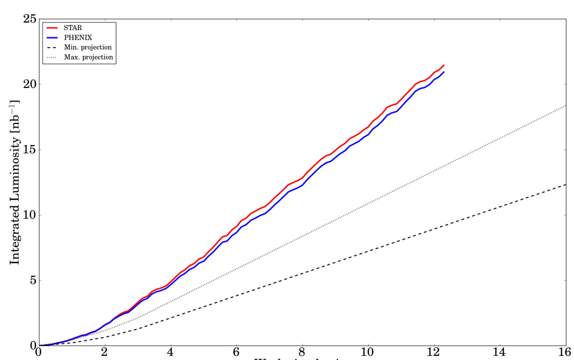


Figure 3: Delivered integrated luminosities for STAR and PHENIX during RHIC Au-Au 100 GeV Run14. The minimum and maximum projections are also shown.

## CONCLUSION

The RHIC 100 GeV Au-Au Run14 delivered record breaking bunch intensities and integrated luminosity to both STAR and PHENIX experiments. Integrated luminosities exceeded the initial design goals by nearly 50% by the end of the run in large part due to the high performance of the injectors and the Stochastic Cooling system. Two electron lenses and a 56 MHz superconducting RF cavity were also installed and commissioned to keep pushing achievable luminosity and optics even further, thus completing the RHIC-II upgrade.

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