RHIC PERFORMANCE FOR FY'10 200 GeV Au+Au HEAVY ION RUN *

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Abstract

Since the last successful RHIC Au+Au run in 2007 (Run-7), the RHIC experiments have made numerous detector improvements and upgrades. In order to benefit from the enhanced detector capabilities and to increase the yield of rare events in the acquired heavy ion data a significant increase in luminosity is essential. In Run-7 RHIC achieved an average store luminosity of $< L >= 12 \times 10^{26}$ cm^{-2} s^{-1} by operating with 103 bunches (out of 111 possible), and by squeezing to $\beta^* = 0.85$ m. This year, Run-10, we achieved $< L >= 20 \times 10^{26}$ cm^{-2} s^{-1}, which put us an order of magnitude above the RHIC design luminosity. To reach these luminosity levels we decreased β^* to 0.75 m, operated with 111 bunches per ring, and reduced longitudinal and transverse emittances by means of bunched-beam stochastic cooling. In addition we introduced a lattice to suppress intra-beam scattering (IBS) in both RHIC rings, upgraded the RF control system, and separated transition crossing times in the two rings. We present an overview of the changes and the results of Run-10 performance.

INTRODUCTION

Since the pilot run in 1999 and through to 2010, RHIC has had 4 operating periods (runs) with Au+Au collisions; in the years of 2000, 2001-02, 2004 [1], and 2007 [2]. The Au+Au runs alternated with a d+Au run in 2003 [3], a Cu+Cu run in 2005 [4], and another d-Au run in 2007/08 [7]. We also have run polarized protons, with the first run in 2001. Every year, with the exception of 2007 and 2010 we have run a polarized proton program [5, 6]. RHIC has two interaction points and four other interaction regions (IR) with beams separated transversely. Collisions at energies below $\sqrt{s}_{NN} = 200$ GeV/nucleon were also provided during the various runs [8]. This year we ran at $\sqrt{s}_{NN}$ of 62.4, 39, 11.5, 7.7, and 5 GeV/nucleon after an 11 week 200 GeV/nucleon run. An overview of the Au+Au runs to date is shown in the Table 1. The enhanced luminosity design goals for Au+Au were achieved in Run-7. In Run-10 we exceeded all these goals by factors of up to 2.5. Figure 1 shows the integrated delivered Au+Au luminosity together with the most conservative (L_{min}) and the most optimistic predictions (L_{max}) for Run-10 as a function of days after physics declaration. The L_{max} prediction was based on a β^* of 0.65 m, an up-time of 55%, and a ramping up of luminosity as stochastic cooling became operational. The minimum assumes a continuation of the performance from Run-7. The figure also shows the luminosity achieved at PHENIX from Run-7.

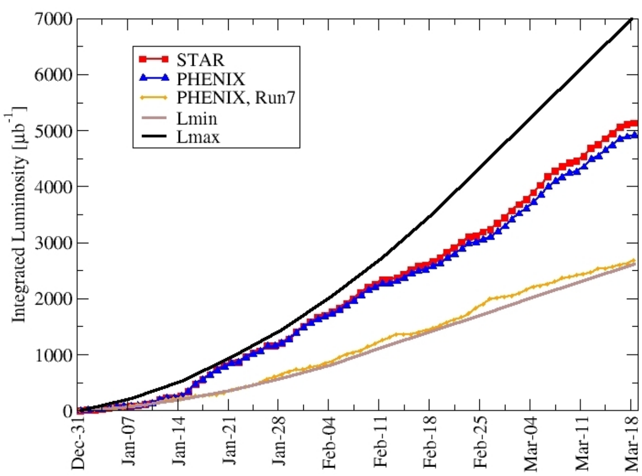

Figure 1: Integrated luminosity for $\sqrt{s}_{NN} = 200$ Au+Au.

RUN-10 SUMMARY

There were two major systems commissioned this year. The RHIC low level RF controls (LLRF) were completely replaced and both RHIC rings had longitudinal and vertical transverse stochastic cooling systems installed [9].

We ran an aggressive startup with new lattices in each ring that included many improvements. The new lattices included IBS suppression optics for both rings [10], gamma transition jumps separated by 1.3 seconds, made feasible by distorting the optics around transition [11], and $\beta^* = 0.6$ m with 0 mrad crossing angles at the two small β^* IR's. To reduce the magnet training time we ran with 2 mrad

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Table 1: Evolution of RHIC performance parameters $\sqrt{s}_{NN}$ = 200 GeV/nucleon RHIC Au+Au runs including the preliminary 2010 results.The enhanced design goals were defined in 2006. In Run-7 the set β^* was 0.85m (the table gives the measured values). The β^* value of 0.75 m in Run-10 has not yet been confirmed. Transverse beam emittances for Runs 2, 4, and 7 ranged from 17 to 35 $\pi\mu$m during a store. In Run 10 they ranged from 17 to 20 $\pi\mu$m. The reason for the improvement was the use of bunched beam transverse stochastic cooling.

Run	Year	β^* [m]	no. of bunches	ions/bunch [$\times 10^9$]	L_{peak} [10^{26} cm^{-2}sec^{-1}]	$L_{ave.}$	L_{week} [μ b^{-1}]	Physics Weeks	$L_{Delivered}$ [n b^{-1}]
design		2	55	1.0	9	2	50		
enhanced design		1	111	1.0	30	8	300		
Run-2	2001	1	55	0.6	4	1.5	24	15.9	0.26
Run-4	2004	1	45	1.1	15	5	160	12	3.53
Run-7	2007	0.83 (PHENIX) 0.77 (STAR)	103	1.1	30	12	380	12.8	7.25
Run-10	2010	0.75	111	1.1	40	20	650	10.9	10.0

crossing angles at all the other IR's.

One important improvement for this run was to have an operational tune and coupling feedback system ready for the very first ramp [12]. This greatly decreased the number of energy ramps to get beam to full energy. During the run orbit feedback was commissioned, which significantly helped with ramp development for beam studies and medium energy physics store setups [13]. Chromaticity feedback was also commissioned during accelerator physics studies periods [14]. For the $\sqrt{s}_{NN} = 62.4$ GeV/nucleon run we setup the ramp using tune, coupling, and orbit feedback. For the $\sqrt{s}_{NN} = 39$ GeV/nucleon run we setup with all four systems, getting to full store energy and intensity in just four ramps [15].

Another accelerator modification that had some impact on the startup was modification to the venting of the valve boxes in RHIC to reduce the oxygen deficiency hazard in certain areas. This affected the power supply checkout, since to make these modifications many power supply connections had to be opened. This required additional effort to check polarities and integrity of the connections.

Being aggressive in our choice of parameters had the benefit of allowing us to explore the limits of the RHIC lattice and various RHIC systems. Early in the run it became clear that we would have to relax on the β^* at the two experiments. Beam losses were too high when we started to squeeze the bunch lengths to meet the requirements of one experiment. We moved to a $\beta^* = 0.75$ m and ran the physics program at that value.

We were also aggressive in getting bunched beam stochastic cooling systems installed and commissioned. Even though we ran into problems and were only able to operate the stochastic cooling systems in non-optimal modes, the commissioning of the stochastic cooling systems was successful. We proved that we could cool bunched beams at high energy, both longitudinally and transversely, and simultaneously. In addition, with beam coupled transversely at store, we cooled both transverse planes with just the vertical cooling systems.

MOMENTUM APERTURE LIMITS

To get the short bunch lengths required by one of the experiments we rebucket the beam from the 28 MHz accelerating systems into 200 MHz storage RF buckets by phase shifting the 28 MHz RF to put the beam on the unstable fixed point, lengthening the bunches. Then we phase rotate the beam and capture it in the 200 MHz buckets. This (ideally) doesn't increase longitudinal emittance, but it does increase the momentum spread of the beam by over a factor of 2. At the 0.65 m β^* this was enough to cause the beam to abort on losses. Therefore we decided to relax on β^*. But in moving to the larger β^* we still had high losses. As shown in Figure 2 the Blue ring has maximum dynamic aperture between the fractional tunes of 0.215 and 0.23 while the Yellow ring has maximum dynamic aperture between 0.2075 and 0.225. The nominal working point for both rings is around 31.23 and 32.22 (note: vertical tunes are nominally 1 unit higher, for coupling correction). Lowering the yellow fractional tune down to 0.21 brought the losses under control.

NEW RHIC LLRF

The new RHIC LLRF was designed to be a stand alone, generic, modular digital controlled [16]. The new systems include improved bunch to bunch phase control during the transfer from the AGS to RHIC, stable cogging during acceleration (in the past the beams in the two rings would not remain cogged during acceleration), improved control over setting the store target frequency before switching to open loop mode, and improved radial and phase control during the transition phase jump. Because the system was a complete replacement of the old RF control system, commissioning this new system took place during the machine startup period.

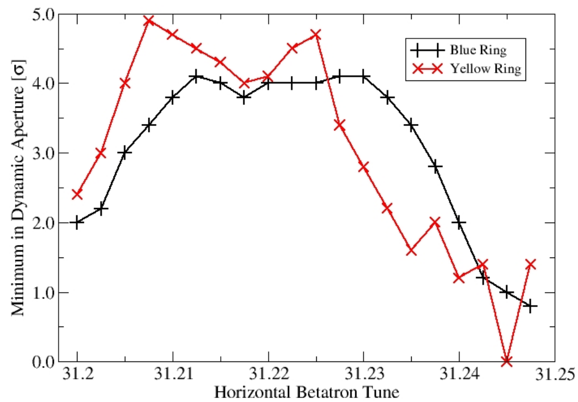

Figure 2: Simulation of dynamic aperture with the 0.75m β^* optics. Includes RF rebucketing and second order chromaticity. The single particle momentum deviation is 1.7×10^{-3}. Vertical tune is always 0.0025 units higher than Horizontal for this scan.

STOCHASTIC COOLING

This past summer shutdown the stochastic cooling group, with help from the Vacuum, Instrumentation, and other groups, installed 4 brand new systems in RHIC; two longitudinal systems and two transverse systems. As shown in figures 3 and 4 the systems performed as expected. This was the first demonstration of transverse stochastic cooling in RHIC. Unfortunately the various systems experienced multiple hardware issues that prevented routine operation. Cross coupling noise in the transverse systems prevented us from operating them simultaneously. We operated with them in a sequential mode, cooling with one for a short time and then the other. For physics stores we ran with one longitudinal system (in the Blue ring) and the two transverse systems in this less optimal mode. Without any stochastic cooling we had a ratio of average to peak luminosity of 33% (Run-4). With longitudinal cooling in Yellow (Run-7) it was 40%, with longitudinal and vertical cooling (Run-10, not yet fully optimized) it was 50%.

SUMMARY

RHIC Run-10 was a highly successful run. We commissioned a new LLRF system, new stochastic cooling systems, proving that we can effectively cool high energy bunched beams in all three dimensions simultaneously, and we succeeded in reaching new luminosity records, operating RHIC almost twice as high as the previous run and an order of magnitude beyond the original design goals for average luminosity.

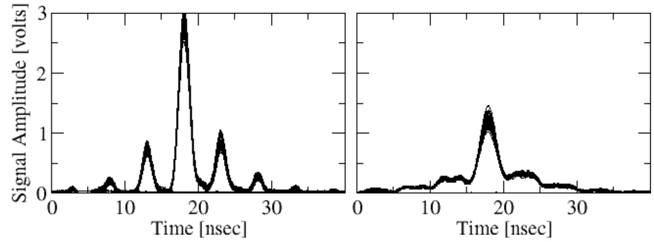

Figure 3: Longitudinal stochastic cooling (showing a single rebucketed bunch) in RHIC, as seen on the wall current monitor. The image on the left is a RHIC bunch that has been cooled for a few hours. The image on the right is a RHIC bunch without any cooling. The satellite bunches are a consequence of the longitudinal emittance being too large to fit in a single 200MHz bucket.

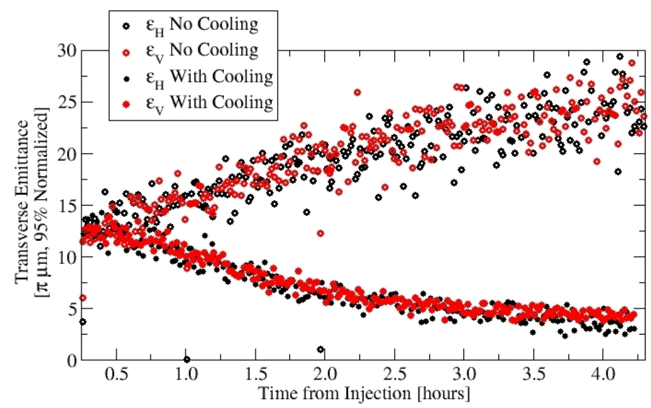

Figure 4: Horizontal and vertical emittances during two different physics stores. The open set of points show the normal increase due to IBS during a store. The solid points show decreasing emittances from transverse cooling. Measured using the RHIC IPM [17]

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