SUMMARY OF THE RHIC PERFORMANCE DURING THE FY07 HEAVY ION RUN*

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Abstract

After the last successful RHIC Au-Au run in 2004 (Run-4), RHIC experiments now require significantly enhanced luminosity to study very rare events in heavy ion collisions. RHIC has demonstrated its capability to operate routinely above its design average luminosity per store of 2x10^{26}cm^{-2}s^{-1}. In Run-4 we already achieved 2.5 times the design luminosity in RHIC. This luminosity was achieved with only 40% of the total possible number of bunches filled, and with $\beta*$ = 1 m. However, the goal is to reach 4 times the design luminosity, an average of 8x10^{26}cm^{-2}s^{-1}, by reducing the $\beta*$ value and increasing the number of bunches to the accelerator maximum of 111. In addition, the average time at store was expected to be increased by a factor of 1.1 to about 60% of calendar time. We present an overview of the changes that increased the instantaneous luminosity, luminosity lifetime and integrated luminosity of RHIC Au-Au operations during Run-7 even though the goal of 60% time at store could not be reached.

OVERVIEW

Since the pilot run in 1999 and up to the end of 2006 RHIC had 3 operating periods (runs) with Au-Au collisions in the fiscal years of 2000, 2001-02 and 2004 [1]. The Au-Au runs alternated with a d-Au run in 2003 [2], a Cu-Cu run in 2005 [3] and two consecutive polarized proton runs in 2005 and 2006 [4, 5]. RHIC has two small β* interaction regions (IR) for high luminosity experiments, STAR and PHENIX, and four large β* interaction regions. To this date, two of the latter were occupied and used by more than one experimental setup each. HI collisions at energies below 100 GeV/nucleon were also provided during the various runs. This year, 4.6 GeV/nucleon beams were collided during a dedicated machine study period within less than 24 hours including setup [6]. This report summarizes the most recent 100 GeV/nucleon Au-Au run from 2007. An overview of the Au-Au runs to date, including the most recent run, is shown in the table . The gold luminosity enhanced design goals were achieved or even exceeded in Run-7. However, some goals, such as $\mathcal{L}_{week}$ and ions/bunch were not met routinely for the entire run but only for some parts of it. In 2007, RHIC ran for physics for 13 weeks. Fig. 1 shows the integrated delivered Au-Au luminosity for the two small beta* IRs (STAR and PHENIX), IR10 (LARP) and IR2 (MONOp) together with the most conservative (Lmin) and the most optimistic predictions (Lmax) during Run-7 as a function of days after physics declaration. The predictions are based on a β* value of 0.9 m and an up-time of 60%. While the minimum is a continuation of the best week from Run-4, the maximum considers stores with 111 bunches and a bunch intensity of 1.1x10^{9}.

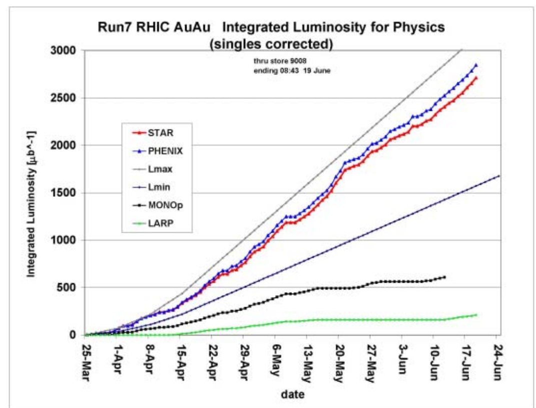

Figure 1: *Integrated delivered luminosity for the four IRs with the minimum and maximum predictions up to June 19, 2007.*

MACHINE SETUP

It took a total of 5 weeks from the first beam in RHIC at injection (with only one ring cold) to declaration of physics but only 2 weeks from both rings being cold and stable. In fact, 2 weeks of set-up were lost to a cryogenic problem caused by turbine oil contamination of a heat exchanger and one week was spent working on beam in one ring only while the other ring was still in the process of cooling down. The heat exchanger problem was the first of a series of hardware problems within the RHIC complex that would diminish the RHIC up-time and considerably lower its performance this year.

After an effective setup period of three weeks, including initial luminosity ramp-up with periods of over-night collisions for the experiments, the beginning of physics operations was declared on Mar 26th. By then the ramp transmission efficiency was consistently above 90% in both rings. To reach this efficiency took less than 4 days from the first ramping attempts. The first official physics store

* Work performed under Contract Number DE-AC02-98CH10886 under the auspices of the US Department of Energy.

Table 1: *Evolution of RHIC performance parameters for the various 100 GeV RHIC HI runs including the preliminary 2007 results.The design values and the "enhanced design" goals for the current run are also listed. The $\beta*$ value of 0.8 m in Run-7 could not yet be confirmed, the data is still being analyzed. Run-7 is still in progress at this time.*

run	year	E_{store} (GeV)	$\beta*$ (m)	no. of bunches	ions/bunch 10^9	$\epsilon^{norm.}_{x,y}$ (π mm mrad)	$\mathcal{L}_{peak}$ (10^{26}cm^{-2}s^{-1})	$\mathcal{L}_{avg.}$	$\mathcal{L}_{week}$ (μb^{-1})
design		100	2	55	1.0	15-40	9	2	50
enhanced design		100	1	111	1.0	15-40	30	8	300
Run-2	FY2001/02	100	1	55	0.5	15-40	3.7	1.5	24
Run-4	FY2004	100	1	45	1.1	15-40	15	5	160
Run-7	**FY2007**	**100**	**0.8 (1.1?)**	**111**	**1.1**	**15-40**	**30**	**10-14**	**200-400**

totaled about 48x10^9 ions per ring, distributed over 51 bunches each, and achieved a peak luminosity of about 14x10^{26}cm^{-2}s^{-1}. At this point RHIC's performance was higher than during the last week of Run-4 with typically 45 bunches and a peak luminosity of approximately 11x10^{26}cm^{-2}s^{-1}. Over the course of the following two weeks the number of bunches was increased in several steps to the maximum of 111 per ring which we reached on April 12^{th}. In order to increase the number of bunches per ring beyond the previously achieved 45 bunches we spent about 2 hours on scrubbing [7]. Fig. 1 summarizes the effect of the scrubbing on the pressure in IR4 and IR12, areas known to be the 'bottleneck' due to the presence of equipment such as cavities and polarimeters. The initial slow decay

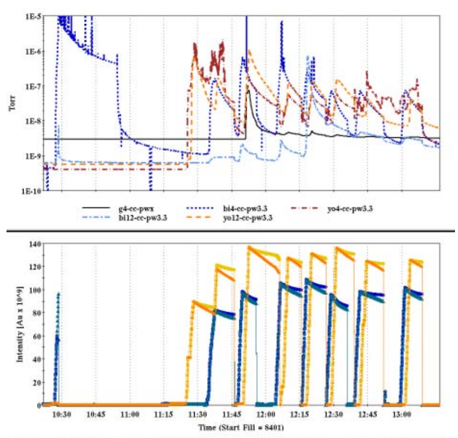

Figure 2: *Pressure readings in IR4 and IR12 (top) and injected total beam current (bottom) during the scrubbing procedure.*

of the pressure bump in bi4 (blue ring, sector 4) is due to an ion-pump failure. During the procedure the peak pressure rise moves from sector 4 to sector 12. In both sectors it shows a significant reduction after the 4^{th} injection of 111 bunches. The spikes in the readings of yo4-cc-pw3.3 are artificial and due to a noisy pressure gauge. A pressure bump in a common beam pipe (g4-cc-pwx) is only present for the very first injection of more than 130x10^9 ions total and diminishes after that. About 2 weeks after begin of physics the bunch intensity that could be injected into RHIC reached a saturation of about 1.15x10^9/bunch for both rings. Nevertheless, there was a number of successful ramps with intensities of up to 1.3x10^9/bunch.

LUMINOSITY LIMITATIONS

The instantaneous luminosity that can be reached in RHIC is limited by a variety of effects such as electron cloud driven pressure rises, intra beam scattering (IBS) and instabilities. Our most restrictive luminosity limit right now is the instabilities at or near transition. After a bunch merge in the AGS the injectors consistently provided 1.3x10^9 ion/bunch for RHIC. However, it turned out that for most of the run an upper limit of about 1.2x10^9 applied below which the transmission efficiency could be kept above 90% while above this limit the ramps either failed or the transmission efficiency dropped to around 80% or less. On average, taking into account all stores with more than 6 bunches that lasted longer than 2 hours, the transmission efficiency for the blue ring was 94% and for the yellow ring 91%. The transmission efficiency, as well as the local pressure in the beam pipe, turned out to be quite dependent on the magnet field orientation of the experimental magnets. With the PHOBOS experiment in IR10 being replaced by NEG coated beam pipes, the limiting pressure bumps moved to the straight section of IR6 (STAR) and, depending on field orientation, to IR8 (PHENIX).

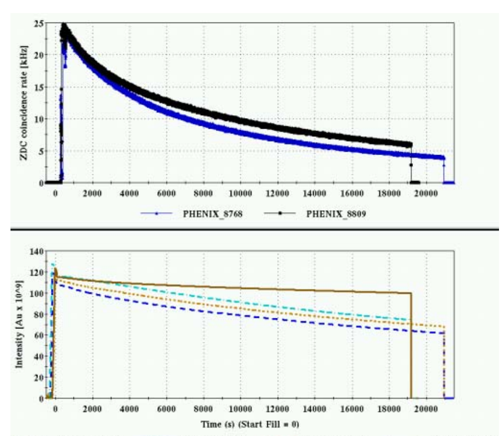

Figure 3: *Beam intensity (bottom) and collision rates (top) in 2 stores with (8768) and without (8809) yellow stochastic cooling.*

Beam debunching due to IBS is the main reason for beam losses at store. The continuous abort gap cleaning [8] was capable of keeping the amount of debunched beam in the ring even with 111 bunches and 1.2x10^9 ions/bunch well below the upper operational limit of 5x10^9. Stochastic Cooling [9], commissioned and made operational in the 2^{nd} half of Run-7 for the yellow ring only, eliminated the debunching and reduced the beam loss rate to the level of the burn-off rate from collisions. In Fig. 3, with two exemplary stores with and without stochastic cooling, the reduced beam decay for the yellow beam can be easily seen. The resulting increase in luminosity lifetime, as shown in Fig. 3 in the top graph, increased the integrated delivered luminosity by more than 10%, maybe even by as much as 20%, compared to uncooled stores. This result is preliminary and a complete analysis of the available data is still in progress.

UPTIME

The weekly integrated luminosity in Run-7 varied by up to 100% from week to week, from below 200 μb^{-1} up to almost 400 μb^{-1} per experiment. One of the good weeks is shown in Fig. 4. The collision rate as measured by the PHENIX ZDCs is corrected for accidental coincidences. Stores were scheduled to last 5 hours. The figure also demonstrates that a peak luminosity of 30x10^{26}cm^{-2}s^{-1} (assuming a cross section of approximately 10 b) could consistently be achieved as well as an average integrated luminosity of 8x10^{26}cm^{-2}s^{-1} per store. However, most

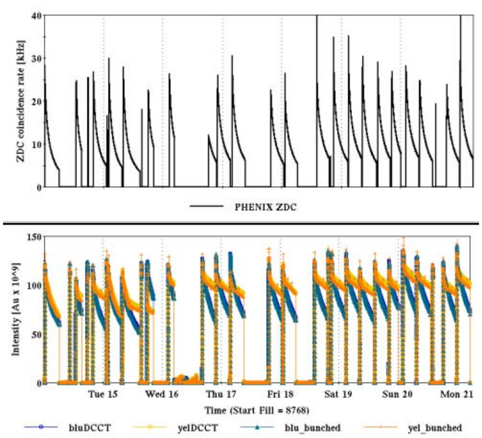

Figure 4: *The best week in Run-7. Collision rates (top) and total beam current (bottom). The integrated luminosity during this week reached 380 μb^{-1} per experiment.*

weeks were not as good as the one shown in Fig. 4. A number of failures plagued RHIC operations throughout the run. PS failures, partially due to bad weather conditions and high temperatures in late spring, were the main contributor together with RF problems some of which were initially caused by beam loading given the unprecedented total Au-intensity in RHIC. Reducing the number of bunches from 111 to 103 with two additional smaller gaps reduced the beam loading problem as well as electron-cloud driven vacuum issues considerably. The average time at store, as shown in Fig. 5, resulted in about 45%, not quite as good as in Run-4 nor close to our goal of 60% but similar to the polarized proton Run-6. Both runs were taking place in late spring/early summer and suffered from weather issues. However, the average time in store in Run-6 includes one week of DOE mandated stand down after an arc flash incident with a circuit breaker. The cryogenic system failure that caused a loss of almost 2 weeks in the beginning of Run-7 is not accounted for since it happened before physics was declared.

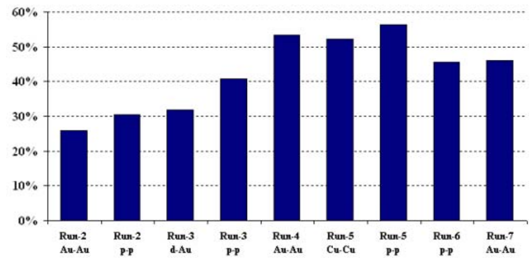

Figure 5: *Average time in store for all runs since 2001. Only days up to June 9^{th}, 2007, are included for Run-7.*

SUMMARY

During this year's Au-Au run RHIC delivered more than two times as much integrated luminosity than during Run-4 that had about the same duration. This could be achieved mainly due to the increased number of bunches (from 45 to 111), the mild increase in bunch intensity (1x10^9 to 1.1x10^9) and an improved luminosity lifetime due to stochastic cooling in the yellow ring. While all those improvements together should have resulted in a factor 3 increase over the previous run, only a factor 2 could be achieved. This 'reduced success' is due to the drop of the time in store from 53% (Run-4) to approximately 44% (Run-7, preliminary). It is apparent that the failure rate is connected to hardware limitations such as a significant growth of the number of power supply failures when RHIC is operated close to the current limit and under inclement weather conditions. An analysis of the underlying causes for the increased failure rates of most systems is still in progress.

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