SETUP AND PERFORMANCE OF RHIC FOR THE 2008 RUN WITH DEUTERON-GOLD COLLISIONS*

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Abstract

This year (2008) deuterons and gold ions were collided in the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) for the first time since 2003. The setup and performance of the collider for the 2008 run is reviewed with a focus on improvements that have led to an order of magnitude increase in luminosity over that achieved in the 2003 run.

INTRODUCTION AND OVERVIEW

Since the 2003 operating period (Run 3) with d-Au collisions [1], there have been two runs with Au-Au collisions (Runs 4 and 7) in 2004 and 2007 [2], a run with Cu-Cu collisions (Run 5) in 2005 and two consecutive polarized proton runs (Runs 5 and 6) in 2005 and 2006. Over this period the luminosity in RHIC has steadily increased, providing impetus for another run with d-Au collisions. This report summarizes the d-Au portion of Run 8, the FY2008 operating period. During this run, there were 9 weeks of physics operations with d-Au collisions at 100 GeV/nucleon. This was followed by a four-week run with polarized proton collisions and a two day run with low-energy Au-Au collisions. Throughout the run, Accelerator Physics Beam Experiments (APEX) occurred every Wednesday and scheduled maintenance occurred every other Wednesday.

The "yellow" and "blue" rings of RHIC have two low beta-star interaction regions (IRs), IR6 and IR8, for high-luminosity experiments, and four larger beta-star interaction regions (IRs 2, 4, 10, and 12). d-Au collisions were provided in IR6 and IR8, for the STAR and PHENIX experiments respectively. Gold ions were accelerated to 100 GeV/nucleon in the yellow ring and deuterons to 101.957 GeV/nucleon in the blue ring. These energies give equal revolution frequencies in the two rings. Fig. 1 shows the d-Au integrated luminosity (in units of nb^{-1}) delivered to STAR and PHENIX during Run 8 together with the most conservative (Lmin) and optimistic (Lmax) pre-run projections as a function of time. The lowest curve in the figure gives the integrated luminosity delivered during Run 3. Fig. 2 shows the integrated luminosity by week. Here alternate weeks with lower integrated luminosity are the weeks during which there was a scheduled maintenance period. The fraction of calendar time at d-Au store was 58%.

The chronology of the d-Au run is summarized in Table 1. Note that having kept the RHIC rings at liquid nitrogen temperature during the shut-down period prior to Run 8, the cool-down to liquid Helium temperature pro-

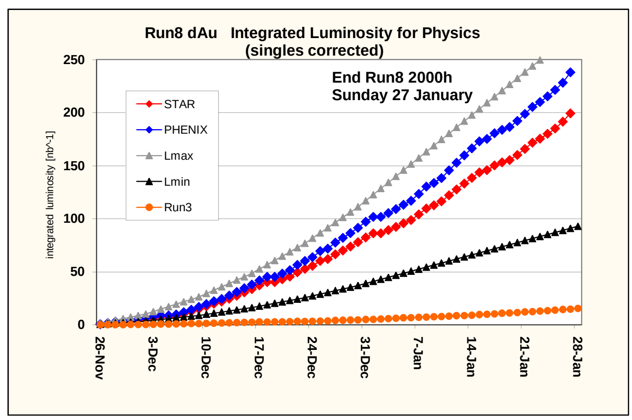

Figure 1: Run 8 d-Au Integrated Luminosity.

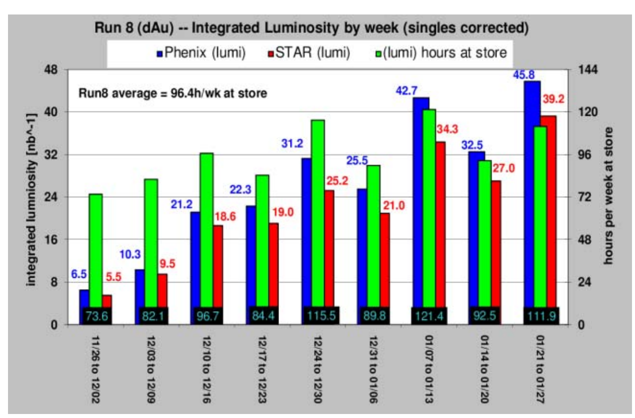

Figure 2: Run 8 d-Au Integrated Luminosity by Week.

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ceeded quickly and without incident. The collision rates given in the table and throughout the text are the measured rates of neutron pair production in the d-Au collisions. These are the recorded raw counts and are not singles corrected. For the 195 kHz rates recorded near the end of the run, the singles correction reduces the rate by 16%. Dividing the singles corrected rate by the measured cross section for neutron pair production (0.47 ± 0.05 b at STAR and 0.53 ± 0.05 b at PHENIX) gives the instantaneous luminosity.

Table 1: d-Au Run8 Abbreviated Chronology (2007-8)

26 Oct	Start RHIC cool-down from 77 to 50K
1 Nov	Start cool-down to 4K
6 Nov	Both rings at 4K
16 Nov	First collisions at IP6 and IP8
26 Nov	Start of physics declared
2 Dec	Initial collision rates reach 60 kHz
11 Dec	Initial collision rates reach 90 kHz
15 Dec	Initial collision rates reach 100 kHz
19 Dec	Beta-star reduced to 0.7 m in yellow ring
26 Dec	Beta-star reduced to 0.7 m in blue ring
26 Dec	Initial collision rates reach 135 kHz
8 Jan	Initial collision rates reach 160 kHz
26 Jan	Initial collision rates reach 195 kHz
27 Jan	End of d-Au physics run

MACHINE SETUP AND PERFORMANCE

Setup of the Tandem, Booster, and AGS, which serve as the chain of injectors for RHIC, began in late October 2007 with deuterons and gold ions available for injection into RHIC by 3 November. The injector setup for Run 8 was essentially the same as that for Runs 3 and 7 [3, 4] except for two notable differences. First, the nominal magnetic rigidity of Au^{79+} ions at RHIC injection was reduced from 90 to 86 Tm to reduce stress on the injection kicker in the yellow ring. The corresponding magnetic rigidity (69.48 Tm) of deuterons at RHIC injection is dictated by the requirement that the revolution frequency of deuterons in the blue ring be the same as that of gold ions in the yellow ring. (In Run 3 we found that having equal revolution frequencies at injection and during acceleration is necessary in order to eliminate harmful modulation of long-range beam-beam forces in the IRs.) The second difference is that a merge of eight to four deuteron bunches was done on the AGS injection porch in place of the adiabatic de-bunch and re-bunch scheme employed in Run 3. The corresponding merge of 24 to four gold bunches was already developed and implemented in Run 7 [4].

For Run 8, the standard RHIC lattice based on FODO cells with a phase advance of 82 degrees was used in the blue ring (for deuterons), while in the yellow ring a new lattice with a FODO cell phase advance of 92 degrees was used. This is the so-called Intra-Beam Scattering (IBS) suppression lattice [5], which, with the increased phase advance, gives a smaller average dispersion in the yellow ring arcs. This leads to reduced emittance growth rates from IBS and improved luminosity lifetime. An additional advantage of the IBS suppression lattice is that it relaxes the quadrupole currents required to squeeze the beta functions in the IRs.

Injection in both rings was performed with a beta-star of 10 m at all interaction points (IPs). In the first part of the acceleration ramp, beta-star was squeezed to 5 m at all IPs to optimize optics for the transition jump in each ring. (The jump occurs at slightly different times in the two rings due to the different lattices.) During the last part of the ramp, beta-star was squeezed to the value desired for collision optics. Initially this was 1 m at IP6 and IP8, and 10 m at the non-experimental IPs. Later in the run, beta-star was reduced to 0.7 m at IP6 and IP8. Beams were vertically separated with ± 5 mm bumps at all IPs through the acceleration ramp to avoid all but long-range beam-beam effects.

As soon as the RHIC rings were declared cold on 6 November, a three-week setup and intensity ramp-up period began. Setup of injection and capture of deuterons in the blue ring and gold ions in the yellow ring was completed by 11 November and first collisions at IP6 and IP8 were observed on 16 November. Tune feedback [6] and replay, used to keep the betatron tunes constant during the ramp, were operational in the blue ring on 18 November. (In the yellow ring, this feature was not used routinely until later in the run.) By 20 November, 37 bunches in each ring were being ramped to top energy with transmission efficiencies of 85% to 95% and initial collision rates of 18 kHz at IP6 and 21 kHz at IP8. The 197 MHz storage system [7] into which the bunches are transfered from the 28 MHz system was set up and operational by 21 November. Landau damping cavities, which are brought on after transition to enhance synchrotron frequency spread and stabilize high intensity bunches, were set up in the blue ring on 24 November. Several days later the Landau damping was also set up in the yellow ring. The start of physics was declared on 26 November with 54 bunches in each ring and initial collision rates of 26 kHz and 33 kHz at STAR and PHENIX respectively.

Longitudinal stochastic cooling, which had been commissioned [2, 8] in the yellow ring during Run 7 (significantly increasing the lifetime of gold ions), was operational for Run 8 by 30 November. By 2 December, 59 bunches in each ring were being ramped to top energy with transmission efficiencies of 94% and initial collision rates of 48 kHz at IP6 and 60 kHz at IP8.

On 10 December we discovered that the vertical tunes at store had wandered too close to one another, causing interaction with the beam in blue to significantly reduce the lifetime of the yellow beam. This was subsequently fixed and by the next day 87 bunches in each ring were being ramped to top energy with transmission efficiencies of 88% and initial collision rates of 70 kHz at IP6 and 90 kHz at IP8. We also found that the lifetime at store was significantly improved by placing the operating points of the two rings symmetrically on either side of the $Q_V - Q_H = 1$

resonance. By early 15 December the initial collision rates at IP8 had reached 100 kHz.

A store length of 6 hours was used throughout the run. This is close to the calculated optimum value of 5.5 hours obtained by fitting the observed luminosity versus time to a double exponential decay, and taking into account the average time from the end of one store to the beginning of the next and the time for the experimental detectors to be fully on at the beginning of a store.

Further increases in collision rates came with the reduction of beta-star at IP6 and IP8 from 1.0 to 0.7 m first in the yellow ring on 19 December and then in blue a week later. Additionally, tuning of chromaticity and octupoles around transition in both rings helped suppress instabilities [9] resulting in increased transmission through transition. By late 26 December the initial collision rates at IP8 were up to 135 kHz.

The known diurnal vertical orbit motion resulted in a change in the beam lifetimes and experimental background rates at store over the 6 h length of the stores. This was fixed by introducing automatic correction of the vertical orbit every 30 minutes in both rings at store (starting 28 December). On 4 January the number of bunches in each ring was increased from 87 to 93 and by 8 January initial collision rates at IP8 were up to 160 kHz. A final increase to 95 bunches per ring was done on 15 January.

Upon passing through transition, deuteron and gold ion bunches undergo significant quadrupole oscillations which increase the bunch length and make subsequent rebucketing less effective. During Run 8, a feedback system to damp the oscillations was built and became operational [10] in the yellow ring on 16 January.

By 23 January initial collision rates were up to 175 kHz at IP8 and by the 26th they were up to 195 kHz. The d-Au portion of Run 8 ended at 8 pm on 27 January. The circulating beam intensity and collision rates for two exemplary stores (from 9 pm on 26 January to 10 am on the 27th) are shown in Fig. 3. Here 95 bunches in each ring were ramped to top energy with transmission efficiencies of 95% and initial collision rates of 125 kHz at IP6 and 195 kHz at IP8. The intensities at injection were 1.2×10^{11} deuterons and 1.0×10^{9} gold ions per bunch.

The main limitation for the luminosity lifetime in RHIC is intra-beam scattering which increases beam emittance resulting in beam loss. This has been ameliorated by the IBS suppression lattice [5] introduced in the yellow ring. The instantaneous luminosity that can be reached is limited by transverse instabilities at transition driven by lattice impedances and electron clouds. To reduce electron cloud effects the length of NEG coated warm beam pipes was increased (again) during the last shut-down (from 476 m to 532 m). Although intensities of 1.4×10^{11} deuterons and 1.4×10^{9} gold ions per bunch were achieved in RHIC at injection, these had to be limited to 1.2×10^{11} deuterons and 1.0×10^{9} gold ions per bunch (with 95 bunches in each ring) in order to get through transition with low beam loss and no emittance blow-up [9].

The total d-Au integrated luminosity delivered during Run 8 was 437 nb^{-1} with 199 and 238 nb^{-1} going to STAR and PHENIX respectively. This is a factor of 10 increase over what was delivered during Run 3. A large part of this increase is due to the reduction of beta-star (from 2 m in Run 3 to 0.7 m in Run 8), the increase in the number of bunches per ring (from 55 in Run 3 to 95 in Run 8), and the increase in the time at store (about a factor of 2). The peak d-Au luminosity in Run 8 (reached near the end of the run) was $31 \times 10^{28}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ compared to 6.2×10^{28} $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ in Run 3.

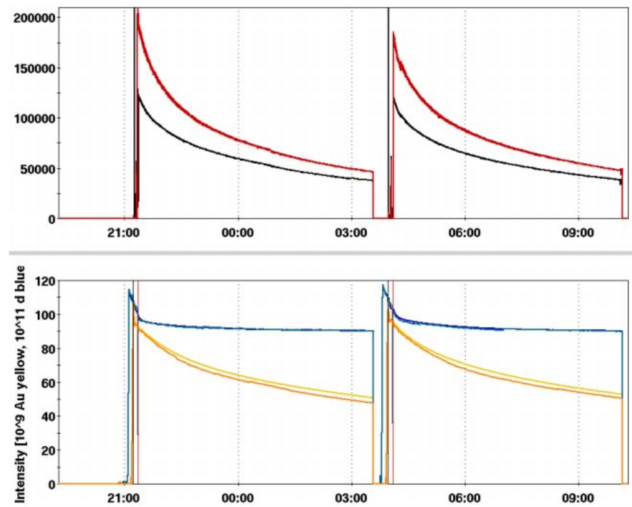

Figure 3: d-Au Run Stores 9652 and 9653.

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