COMMISSIONING OF RHIC DEUTERON-GOLD COLLISIONS

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Abstract

Deuteron and gold beams have been accelerated to a collision energy of $\sqrt{s}$ = 200 GeV/u in the Relativistic Heavy Ion Collider (RHIC), providing the first asymmetric-species collisions of this complex. Necessary changes for this mode of operation include new ramping software and asymmetric crossing angle geometries. This paper reviews machine performance, problems encountered and their solutions, and accomplishments during the 16 weeks of ramp-up and operations.

INTRODUCTION

After productive p-p and Au-Au collider physics runs in 2000–1 with collision energies of $\sqrt{s}$ =130–200 GeV/u, RHIC experiments reported early high-p_t jet quenching results [1]. To compare Au-Au results with cold nuclear matter probes, 16 weeks of operations time were spent commissioning and operating $\sqrt{s}$ = 200 GeV/u deuteron-gold (dAu) collisions in RHIC, from late November 2002 to late March 2003. This was the first operation of a asymmetric-species heavy hadron collider, and an important demonstration of RHIC's flexibility to probe hot and cold nuclear matter at the 200 GeV energy scale.

A summary of machine performance goals and achievements for this run are listed in Tables 1 and 2. Almost all run goals were either met or exceeded. The only unachieved primary goal was gold per-bunch beam intensity, limited by injector and injection performance.

Table 1: RHIC 2002–3 dAu Run Parameters

Machine Performance	goal	achieved
Setup/Ramp-up time [weeks]	2/3	2.5/3
Storage energy [GeV/u]	100	100
Number of bunches	55	110/55
$\beta^\star$ [m]	2	2/3/4
Diamond length σ [cm]	20	15
Peak luminosity [$\times 10^{28}$ cm^{-2} s^{-1}]	4.0	6.2
$\langle L\rangle$(store) [$\times 10^{28}$ cm^{-2} s^{-1}]	1.6	2.8
$\langle L\rangle$(week) [nb^{-1}/week]	4.0	4.6

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RUN PREPARATION

With limited run time, an early consensus among experiments was reached to focus on a single run configuration with deuterons in the blue ring and gold ions in the yellow ring. This setup required reversal of DX power supply shunts to maintain unipolar constraints on these power supplies at injection and through the acceleration ramp[2]. These machine constraints could also only be satisfied by including a 1 mrad crossing angle at injection and, more importantly, a 1 mrad common angle for head-on collisions at storage energy, as shown in Fig. 1. Zero-degree neutron calorimeters (ZDCs), used for luminosity monitoring, were moved by 10 mm in the appropriate direction to maintain necessary signal levels[3]. Power supply and ZDC work required two days of run-specific setup time.

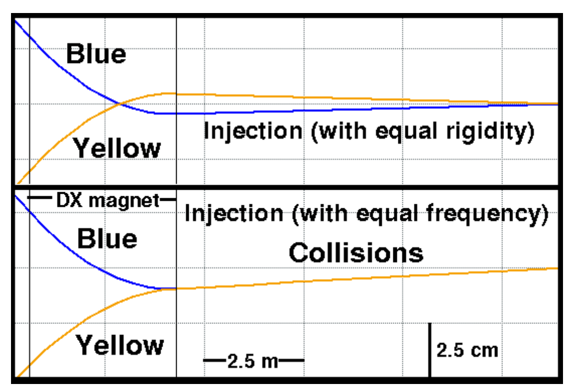

Figure 1: dAu collision geometries at injection and store

Both Tandems were used and had excellent uptime: Tandem MP7 supplied gold beam and MP6 supplied deuteron beam. All injectors (Tandems, Booster, AGS and transfer lines) were required to "mode-switch" between both species for every RHIC fill with a typical species change time of 3–5 minutes[4]. Production injection always started with deuterons, to minimize IBS-driven gold beam emittance dilution on the injection porch. Overall injector setup time and development were a concern throughout the run due to division of effort between setup of both species.

Run preparation also included demonstrations by controls and instrumentation to gracefully handle two beams of significantly different character and intensities. Logging, instrumentation, and control systems easily demonstrated the flexibility to handle separate species in each RHIC ring.

Table 2: RHIC 2002–3 dAu Stored Beam Parameters

Storage Parameter	Au, Yellow Ring		d, Blue Ring	
	goal	achieved	goal	achieved
Intensity/bunch	1.0×10^9	0.7×10^9	0.8×10^{11}	1.2×10^{11}✓
Total Intensity (55/110 bunches)	55×10^9	38 / 60×10^9✓	45×10^{11}	57 / 69×10^{11}✓
Transverse Emittance [95%, $\pi\mu$rad]	10–40	10–30✓	15	12 ✓
Bunch Length [ns] (200 MHz RF)	5	5✓	5	5✓

RUN CHRONOLOGY AND ISSUES

At the 2002 RHIC Retreat, a goal was set of 14 days of set-up time (time to initial collisions) and 21 days of ramp-up time (time to develop collisions and lifetime to physics production) for every new species configuration[5]. This run guidance, based on experience during gold and polarized proton commissioning, was reasonably close, with 18 days from first beam in the blue ring to first collisions. 20 days after first collisions, minimum goals were met for the start of dAu physics.

As in previous RHIC Au runs, injection was performed with $\beta^\star$=10 m at all interaction points (IPs). The initial acceleration ramp also squeezed to $\beta^\star$=5 m at all IPs to optimize optics for independent transition jumps, and then squeezed to final collision optics in the last half of the acceleration ramp. Collision optics were $\beta^\star$=10 m at non-experimental IPs, and $\beta^\star$=2–4 m at experimental IPs, depending on experiment background issues. Beams were vertically separated with $\pm$5 mm bumps at all IPs through the acceleration ramp to avoid all but long-range beam-beam effects.

Initial setup was injecting beams with equal rigidities, minimizing transfer line mode switching requirements and maintaining species symmetry between both rings for injection setup. However, collisions required equal frequencies between the two beams, and in this condition modulated long-range beam-beam forces created untunable beam loss during the acceleration ramp. On Jan 2 we changed ramp conditions to equal frequencies from injection to collision (see Fig. 1), minimizing beam-beam modulation, producing more efficient acceleration ramps, and enabling study of ring-to-ring RF locking during acceleration[6]. Ramp recommissioning took less than two days.

Table 3: Short RHIC 2002–3 dAu Run Chronology

11/1	Start of RHIC cooldown
12/13	Both rings at 4K
12/22	First ramps of d/Au to collision energies
12/24	First d/Au collisions at all experiments
12/27	Start of routine detector commissioning
1/2	Injection: equal rigidity to equal frequency
1/9	Routine 110 bunch ramping
1/12	Start of 2003 d/Au Physics Run
2/21	Low-noise storage RF driver
2/22	Deuteron transverse instability fixed
	First production store to hit goal levels
2/26	Return to 55 bunch operations
	Routine goal operations
3/24	End of 2003 d/Au Physics Run

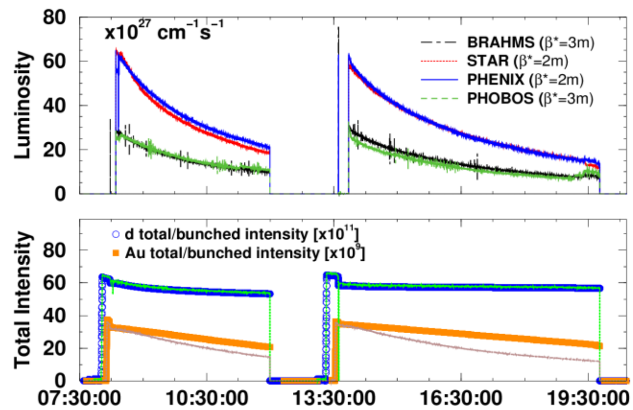

Figure 2: Two typical RHIC FY03 dAu stores, showing beam current ($\times10^{9/11}$ Au/p, total and bunched) and luminosity lifetime. Luminosity lifetime was dominated by gold beam lifetime and IBS-driven debunching and emittance growth. Time between stores was about 1 hour.

RUN PERFORMANCE DETAILS

Fig. 3 shows single-bunch and total beam intensity evolution through the course of the run, measured at the end of every acceleration ramp. To meet performance goals, the number of bunches in each ring was doubled from 55 to 110 at the beginning of January. Though this produced reasonable physics, pressure rises created intolerable backgrounds and beam lifetime issues[7], and required a return to 55 bunch stores on Feb 26. Single-bunch intensity development was limited by RHIC development time and mode switching, though deuteron intensities were improved in late Feb with RF bunch merging in the Booster[4]. RHIC ramp efficiencies averaged 95% after the startup period.

Fig. 4 shows the total integrated luminosity for the run, with final totals well above the minimum required for physics. This plot correlates only roughly with Fig. 3; on Feb 22 an emittance-diluting instability in the deuteron acceleration ramp was diagnosed and cured, improving emittance and raising luminosity by almost a factor of two.

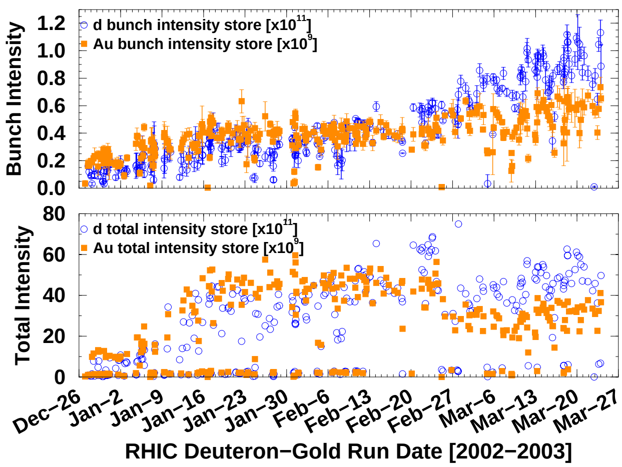

Figure 3: RHIC dAu run intensity evolution, as measured at the end of every acceleration ramp. Small total intensities are indicative of 6-bunch setup or beam study ramps. Error bars in the top plot are over all bunches in the store. Unsuccessful ramps are excluded.

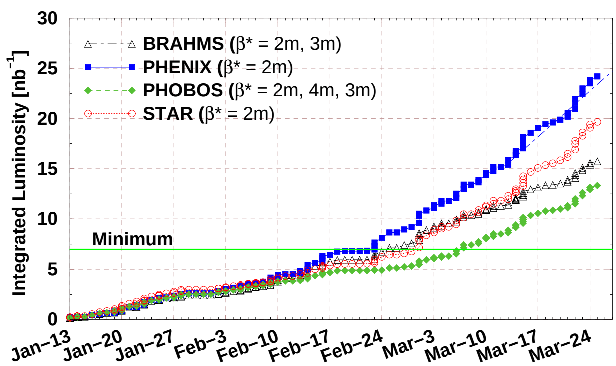

Figure 4: dAu run integrated luminosity. PHENIX integrated luminosity averaged 4.6 nb $^{-1}$/week near run end.

RUN HIGHLIGHTS

A new transverse injection damper system was commissioned[9] early in the run, successfully limiting emittance growth due to bunch-by-bunch injection variations. The addition of 720 Hz digitizers in February also added the capability of coherence monitoring to this system. Signals during production acceleration ramps showed a clear deuteron beam transverse instability (see Fig 5) near transition, leading to large emittance dilution and backgrounds. Using the coherence monitor, this instability was avoided by careful chromaticity adjustments[8].

The RHIC PLL tune system[10] was commissioned to routine use during this run, and there were several ramps with successful tune feedback that constrained limited tune variations to 10^{-3}, though with more beam loss than without tune feedback. Feed-forward ramp coupling corrections were also performed in both rings, using a new method for coupling correction based on N-turn maps[11].

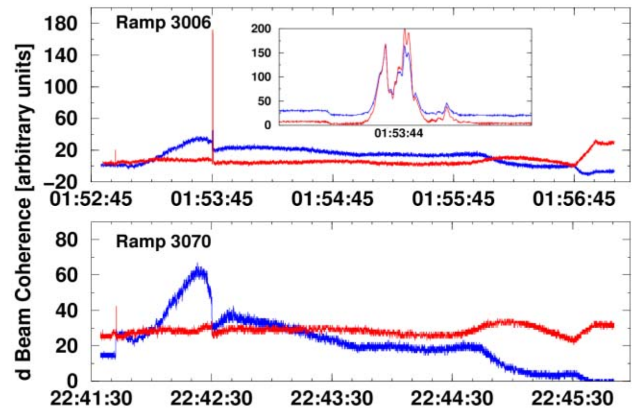

Figure 5: Blue transverse coherence monitor readings for ramps 3006 (Feb 16) and 3070 (Feb 27), showing the effects of chromatic instability correction. The inset shows details of the near-transition instability over one second.

With injection kicker improvements, this was the first RHIC run to demonstrate routine 110-bunch injection, part of the RHIC-II luminosity upgrade. 110-bunch ramping sometimes created pressure rise within the PHOBOS IR region, creating destructive radiation for an experiment that is dominated by radiation-sensitive Si detectors. Returning to 55-bunch operations eliminated these pressure rises[7].

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