RHIC STATUS AND PLANS*

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Abstract

RHIC ended successfully its second year of operation in January 2002 after a six month run with gold ions and two months of polarized proton collisions. I will review the machine performance and accomplishments, that include reaching design energy (100 GeV/u) and design luminosity during the gold run, and the first high energy (100 GeV) polarized proton collisions. I will also discuss the machine development strategy and the main performance milestones. The goals and plans for the shutdown and the next run, scheduled to start in November 2002 have been the focus of a RHIC Retreat in March 2002. I will summarize findings and plans for the upcoming run and outline a vision for the next few years of RHIC operation and upgrades.

1 INTRODUCTION

Run 2001 at RHIC started in late May 2001. The first 6 months were dedicated to gold-gold set-up and collisions at 100 GeV/u, followed by 2 months of polarized proton operations at 100 GeV, ended in January 2002. Sections 2 and 3 discuss run 2001 performance respectively for gold and protons with a discussion of new developments as well as performance limitations. Section 4 presents the main objectives and results of the beam experiment activity in run 2001. Planning for next year operations, that started at the RHIC Retreat in March 2002 and is presently continuing during the shutdown, is summarized in Section 5 together with the foreseen operation scenarios for run 2003. A path for RHIC upgrade throughout this decade, focused on luminosity increase and added physics capabilities, is presented in Section 6.

2. RHIC RUN 2001 - GOLD

The 2001 gold run has been RHIC's third one, following an engineering run in 1999, and the commissioning run in 2000, when RHIC achieved its first collisions at 70 GeV/u and the first physics results. In 2001 RHIC reached the design energy of 100 GeV/u and the design luminosity of 2×10^{26} cm^{-2} s^{-1}.

Table 1. Gold parameters run 2001: planned and achieved

energy flattop	100 GeV/u	yes
number of bunches	55 / ring	yes
bunch intensity -injection	1×10^9 Au/bunch	yes
bunch intensity - flattop	7.5×10^8 Au/bunch	no
longitudinal emittance	0.5 eVs/u/bunch	yes
transverse emittance	15 $\pi\mu$m (norm,95%)	yes
β^* injection	10m all IP	yes
β^* flattop	1m IP8- 2m other IP's	yes
bunch length	5 nsec (200MHz)	yes
peak luminosity	5 x 10^{26} cm-2 s-1	yes

*Work performed under the auspices of the US Department of Energy

2.1 Performance

All goal parameters for gold in 2001, listed in Table 1, were achieved during the run with the exception of bunch intensity at flattop, discussed later. The gold run had 12 weeks of physics production time following set-up and system commissioning time. The gold run integrated luminosity, compared to the 2000 performance, is shown in Figure 1.

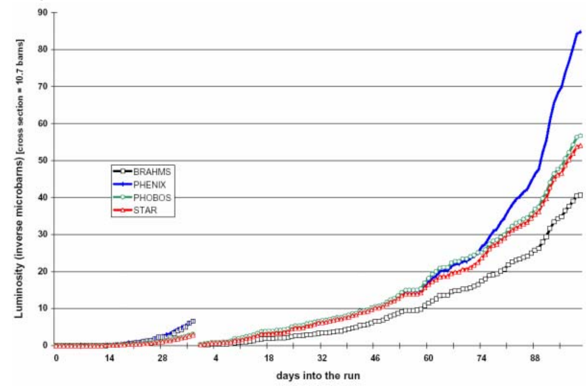

Figure 1. Gold run integrated luminosity

The increase in PHENIX luminosity in the last few weeks reflects the β^* squeeze to 1 m in IR8, while the other IR's were operated at the original design value of 2 m.

A good gold store (see Figure 2) typically lasted 4-5 hour.

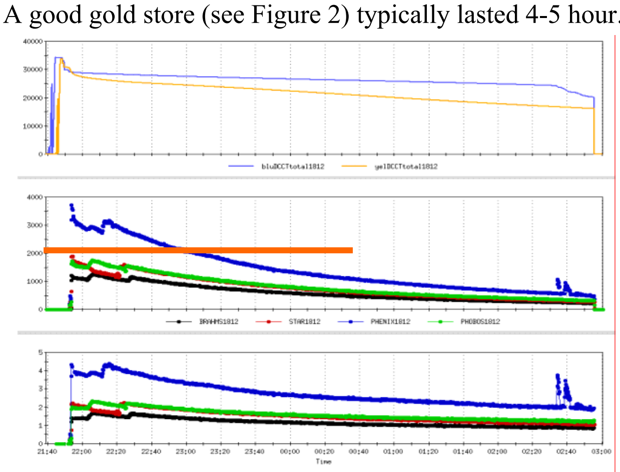

Figure 2. Au store: beam current ($\times 10^6$ ions), collision rates (Hz) compared to design (horizontal line), specific luminosity (Hz/10^{18}) (expected: 5 for Phenix, 2.5 others)

2.2 Developments

New systems were brought on line in 2001 together with several operational developments, that made the performance increase possible [1][2]. The γ_T jump quadrupole system was commissioned, as well as the 200 MHz storage RF system, resulting respectively in better transmission on the ramp and shorter bunch lengths at flattop. System upgrades included beam abort [3], position [4] and loss[5] monitors, collimators [6], with particularly promising results on crystal collimation [7].

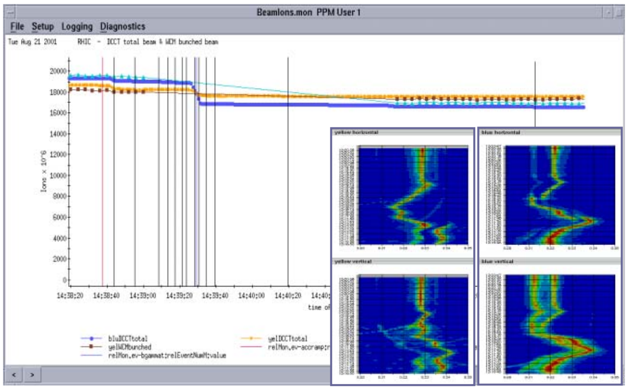

Figure 3. A RHIC ramp (DCCT beam intensity) and tune measurements on the ramp [14] .

Substantial dividends in luminosity were paid by the beta squeeze. The strategy for 2001 has been to squeeze on the ramp, first from the injection β*=10m to 5m at transition (at all IP's). Another stage of beta squeeze was successfully done on the last part of the ramp, from 5m to 2m at all IP's. IP8 only was further squeezed to 1 m [8]. Better understanding of the linear optics [9], together with improved measurement and feed-forward correction of orbit [10], tunes, coupling[11] and chromaticity on the ramp have been essential for maximization of ramp transmission. Ultimate ramp performance requires feedback of tunes and eventually chromaticity. Commissioning of a phase lock loop (PLL) tune measuring system started during gold operations, and tune feedback on the ramp was successfully demonstrated during proton operations. [12][13] The PLL opened also the possibility of real time chromaticity measurement on the ramp with a small (0.2mm) radial modulation[15].

Machine operation was improved during run 2001 by a more extensive use of the Sequencer [16], the new electronic logbook [17], and by making new procedures available in main control room. [18]

2.3 Limitations

Overall machine performance limitations in 2001 came from system reliability and beam dynamics effects. Machine availability over the production run was limited to ~40%, and this, although typical for an accelerator, had a direct impact to the integrated luminosity. The main beam dynamics challenges we had to confront in 2001 were a fast instability around transition, vacuum breaks at injection limiting the overall beam intensity, a lifetime decrease in the yellow ring at flattop, beam-beam effects and emittance growth due to intra-beam scattering.

A fast instability in RHIC causing beam loss has been controlled by chromaticity everywhere but in the vicinity of transition, where the chromaticity must change sign. The necessary tune spread around transition was first achieved by beam-beam tune spread (by keeping the beams in collision), but eventually and more effectively by powering 2 families of arc octupoles around transition.

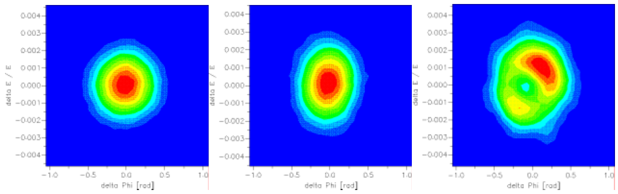

Figure 4. Tomographic reconstruction of bunch density before, at and after instability (10 msec growth rate)[19]

A vacuum breakdown in the RHIC warm sections limited the overall beam intensity to ~40x10^{9} ion/ring. The effect depends on intensity, bunch spacing and species. When a gold fill with 110 bunches (55 bunches nominal) was attempted, the pressure spiked during injection of the second beam (see Figure 5). Likely causes for the pressure rise are ion induced desorption, beam loss induced desorption and electon desorption possibly enhanced by electron cloud. The problem is being actively studied by simulation and data analysis [20][21].

The yellow beam lifetime deteriorated at flattop after the β* squeeze to 1 in IP8 and could not be operationally cured by re-tuning at flattop, leading us to suspect local errors in the yellow IR8 triplets.

Beam-beam effects were measured at injection, on the ramp and at flattop [35]. The beams had to be vertically separated at injection and through the ramp to minimize beam-beam effects.

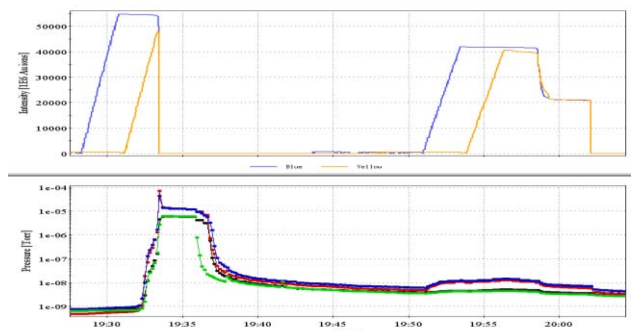

Figure 5 – Vacuum breakdown induced a beam abort during filling of the second ring with 110 bunches.

The ultimate limitation for RHIC is emittance growth from intra-beam scattering. Measurements of IBS and comparison with predictions can be found in [22]. Emittance growth is also affected by beam-beam interactions, and possibly enhanced by beam-beam modulation due to triplet mechanical vibrations. [23]. Ultimately, counteracting emittance growth is only possibly by active cooling as discussed in Section 6.

3. RHIC RUN 2001 – POLARIZED PROTONS

The 2 months of polarized proton operations in 2001 continued the 2 weeks of polarized proton (PP) development in run 2000, when PP were injected into RHIC, and one Siberian snake was commissioned. In run 2001, PP beams were accelerated to 100 GeV with the full complement of 2 Siberian snakes per ring [24].

3.1 Performance

The overall luminosity delivered to the experiments in run 2001 is shown in Figure 6. STAR in the last 20 days accumulated 290 nb^{-1}/week , with an average luminosity per week of $0.5\ 10^{30}$ $cm^{-2}\ s^{-1}$.

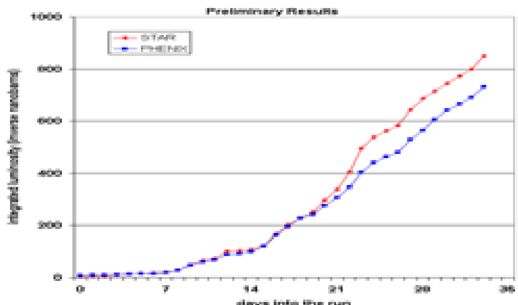

Figure 6. Polarized protons – integrated luminosity

Beam was delivered from the AGS in 2001 with a polarization of ~25% [25][26], injected into RHIC and accelerated to 100 GeV without significant polarization losses, which demonstrate that the snakes indeed work.

3.2 Developments

The Siberian snakes, helical dipole assemblies, installed in RHIC for run 2001 were successfully commissioned and operated [27]. The systems are shown in Figure 7.

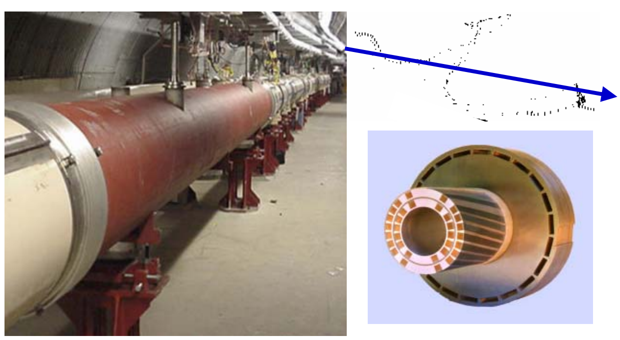

Figure 7. Siberian snakes, the spin trajectory inside and the end windings of the helical dipoles.

Other essential components for the polarized proton program are the polarized source, the polarimeters, and the spin flipping system. The OPPIS source performed very well, with routine polarization levels of 70%, and $15x10^{11}$ proton at the source output. The polarimeters in RHIC worked reliably allowing fast (~1 min) polarization measurements [28] at injection and flattop, with minimal perturbation of beam characteristics. The spin flipping system was also commissioned for the Blue ring [29]. The spin flipper, a vertical AC dipole can also be used for linear and non-linear beam dynamics measurements if operated at a frequency near to the betatron tune; initial testing for linear optics measures was promising [30].

Other than the snakes, to prevent spin resonances, polarization preservation on the ramp requires excellent control of orbits and tunes. Alignment data for the quadrupoles were used to correct the vertical orbit not to the ideal zero at the BPM's but to the real flat plane, and orbit corrections were applied to all step-stones on the ramp. In order to limit tune excursions on the ramp, the strategy for proton operation has been to keep a fixed optics from injection to flattop. A fixed β^* of 3m in all IP provided a good compromise between having sufficient aperture at injection and sufficient luminosity for the experiments at flattop. A careful choice of tunes at flattop was also necessary, primarily keeping the vertical tune away from 0.23, a strong spin resonance. Precise tune control on the ramp requires tune feedback and the RHIC tune feedback system was tested with 3 successful ramps during polarized proton operations. (see Figure 8) [12][13].

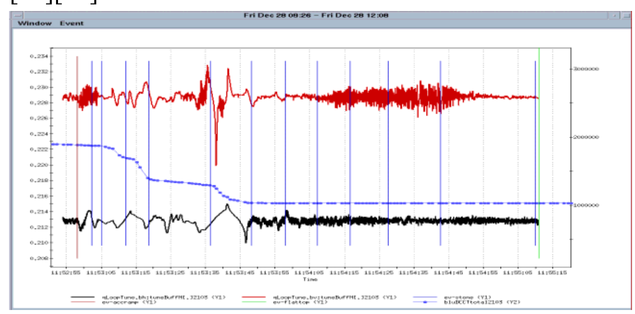

Figure 8. Tunes on the first ramp with tune feedback on.

On the very last day of the PP run a successful attempt of detuning the β^* at flattop to 10m was done that allowed elastic scattering physics data taking for the pp2pp experiment located in IR2.

3.3 Limitations

The polarization delivered from the AGS to RHIC during 2001 was limited to 25-30%, lower than the 40-50% polarization levels in 2000. The largest factor to account for the polarization loss in the AGS has been the unavailability of the Siemens AGS main power supply in 2001. The backup solution (Westinghouse generator) lowered the AGS ramp rate by a factor 2, aggravating resonance depolarizing effects.

4. BEAM EXPERIMENTS IN 2001

In addition to physics production running and machine development, RHIC evolved a program for beam experiments, that started during run 2000 [31]. The goal of dedicated beam studies is to test new beam techniques and idea, that, if successful, are then integrated into machine operations. The beam experiment program for 2001 was planned ahead of time and evolved during the run, with collaborations from CERN, FNAL and other institutions. 70 and 20 hours of beam time were respectively dedicated to beam studies during the gold and PP runs. The main experimental results were obtained in the following areas: IR local corrections [32][33], beam-beam studies [34][35], longitudinal [36] and transverse [37] impedance measurements, resonance compensation [38], spin manipulations, testing of new coupling techniques [39], pressure rise investigations, beam dynamics studies [40].

Two independent methods were used to measure the local linear errors in the IR triplets: The beam-based results were found in good agreement with roll alignment measurements on selected cold masses. Linear IR correction are now an operational procedure. The IR bumps technique was applied to the measurement and correction of non-linear errors in the IR triplets. The tune shift as a function of amplitude was locally compensated with octupole and sextupole correctors. The technique demonstrated the potential of measuring multipoles up to 12-pole (see Figure 9).

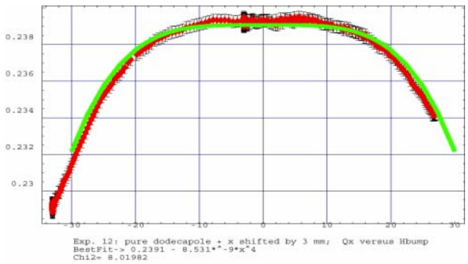

Figure 9. Measured dodecapole effect: tune shift (left) as a function of bump amplitude (right).

RHIC operates in the strong-strong beam-beam regime. Coherent tune shifts were accurately measured with the PLL and a controlled experiment provided possible the first signature (in a hadron collider) of coherent beam-beam modes. (see Figure 10) [35] [41].

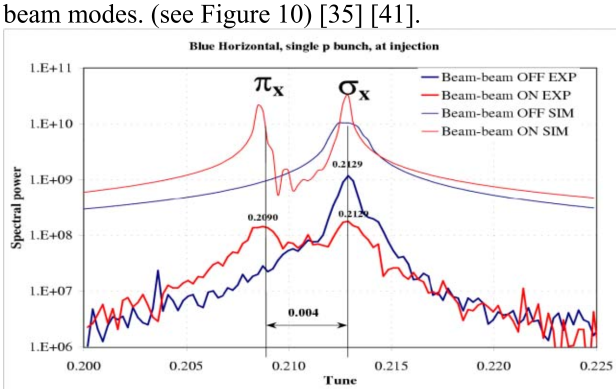

Figure 10. Coherent beam-beam modes in RHIC.

5. PREPARATION AND PLANS FOR RHIC RUN 2003

Run 2001 ended in January 2002, RHIC is in a shutdown right now, busily preparing for the upcoming run 2003 scheduled to start this November. I will review the planning and the most likely running scenarios for 2003.

5.1 The RHIC Retreat

The first step toward run 2003 was taken at the RHIC retreat, held in March 2002. The goals were to start 2003 planning, by setting realistic goals for operation and experiments, to set priorities for the shutdown and to review the run 2001 experience. Discussion focused on machine performance, reliability, integration, diagnostics and beam experiments. [42]. The main output from the retreat has been a realistic projection on RHIC performance in 2003 as described in Tables 2 and 3 [43]. Table 3 summarizes the performance goals for 2003 for different running modes, gold, PP , d-Au and lighter ions.

Table 2. Run 2003 performance goals

mode	N_b	Ions/ bunch x10^9	β^* m	E πμm	L^{peak}	L^{ave} store	L^{ave} week
AuAu	56	1	1	15	14×10^{26}	3×10^{26}	70μb^{-1}
PP	112	100	1	25	16×10^{30}	10×10^{30}	2.8pb^{-1}
Au-d	56	1(Au) 100(d)	2	20	5×10^{28}	2×10^{28}	5 nb^{-1}
SiSi	56		1	20	5×10^{28}	2×10^{28}	5 nb^{-1}

Given 29 weeks of running time in 2003, subtracting 5 weeks for cryo-operation, and allowing 2 weeks of set-up time for each running mode, it is possible to estimate the integrated luminosity for different running scenario. Maximum expected performance, based on Table 2, are compared to minimum, based on last year end of the run figures.

Table 3. Tun 2003 performance expectation range

mode	Lave/ week	ILumi 2-mode	ILumi 3-mode	Lave/ week	ILumi 2-mode	ILumi 3-mode
AuAu	24μb^{-1}	168μb^{-1}	72μb^{-1}	70μb^{-1}	490μb^{-1}	210μb^{-1}
PP	.3pb^{-1}	2.1pb^{-1}	.9pb^{-1}	3pb^{-1}	20pb^{-1}	8.4pb^{-1}
Au-d	-	-	-	5nb^{-1}	35 nb^{-1}	15 nb^{-1}
SiSi	-	-	-	5nb^{-1}	35 nb^{-1}	15 nb^{-1}

Prioritization of activities for the shutdown and next year operations were discussed at the retreat. A few concepts emerged, for instance: the necessity of evolving towards true weekly planning of machine activities, the importance of polarization development time for the AGS, the plan of re-starting machine operation with tune feedback from day one, and the desirability of integrating the experiment magnets into control room operations.

5.2 Operation scenarios for run 2003

The process of decision on next run operating scenario is going on and final decisions will be taken in Summer 2002. The following running modes for 2003 are being considered by the RHIC scientific community [44]:

1) d-Au at 100 GeV/amu
2) p-p at 100 GeV with polarized beams
3) Au-Au at 100 GeV/amu
4) Au-d at 100 GeV/amu (opposite d-direction)
5) p-p at ~250 GeV with polarized beams
6) Au-Au at several beam energies.

The most likely scenario for the next run is a period of deuteron-gold collision, with AGS polarization development in parallel, followed by polarized protons operations.

6. BEYOND 2003

A staged RHIC luminosity upgrade plan is in place that has the potential of vastly increasing the machine capability. Table 4 compares the design (RDM) parameters, to a first upgrade phase (RDM+) based on operational improvements, realistic on a 2003-4 timescale. An increase of a factor 10 and 35 respectively in peak and average luminosity will be possible (RHIC-II) with the addition of an e-cooling system, for which a preliminary design exists and development started. [45]. (see Figure 11).

Table 4: Scenario for the RHIC gold upgrade

	units	RDM	RDM+	RHIC II
Initial ε (95%)	πμm	15	15	15
Final ε (95%)	πμm	40	40	3
β* at IP	m	2	1	1→0.5
N bunches		56	112	112
N ions/bunch	10^9	1	1	1
b-b ξ	per IR	0.0016	0.0016	0.004
rms σ	μm	216	150	95
Angular σ	μrad	108	153	95
Peak L	$10^{26}cm^{-1}s^{-1}$	8	32	83
Average L	$10^{26}cm^{-1}s^{-1}$	0.2	0.8	70

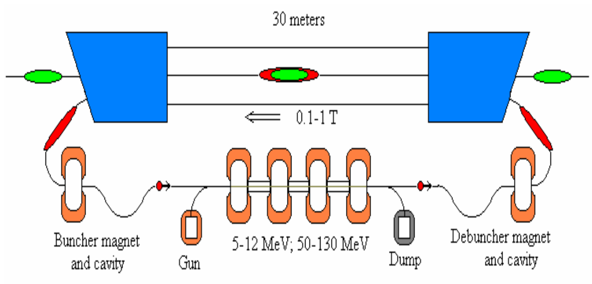

Figure 11. Schematics of the proposed electron cooling system based on an energy recovering linac.

Table 5. Scenario for RHIC polarized proton upgrade

	RHIC Spin	RHIC II	Future upgrade
ε (95%) [πμm]	20	12	12
β at IR [m]	1	1	0.3
N of bunches	112	112	336
P/bunch [10^{11}]	2	2	2
ξ per IR	0.007	0.012	0.012
Angular size at IR[μrad]	112	86	157
RMS beam size at IR [μm]	112	86	47
Luminosity [$10^{32}cm^{-2}s^{-1}$]	2.4	4	40

An upgrade scenario for polarized proton operation exists as well (see Table 5). A substantial increase in luminosity (Future uprade) is possible only by installation of new mini-beta IR quadrupole, tripling the number of bunches, and will require major detector upgrade.

Great interests exists in the scientific community to extend the physics reach of RHIC, by adding the capability for electron-ion collisions.. Different technical solutions, that include linac-ring and ring-ring options, are in an advanced stage of study [46].

In conclusion, on the basis of recent results, and medium and long term plans, RHIC is well positioned to play a major research role well into this and the next decade.

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