

OPERATIONS AND PERFORMANCE OF RHIC AS A CU-CU COLLIDER*

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Abstract

The 5th year of RHIC operations, started in November 2004 and expected to last till June 2005, consists of a physics run with Cu-Cu collisions at 100 GeV/u followed by one with polarized protons (pp) at 100 GeV [1]. We will address here the overall performance of the RHIC complex used for the first time as a Cu-Cu collider, and compare it with previous operational experience with Au, PP and asymmetric d-Au collisions. We will also discuss operational improvements, such as a β^* squeeze to 85cm in the high luminosity interaction regions from the design value of 1m, system improvements, machine performance and limitations, and address reliability and uptime issues.

INTRODUCTION

In its 5th year of physics running, RHIC has been for the first time operated as a Cu-Cu collider: 8 weeks of physics at the high energy (HE) of 100 GeV/u, followed by 2 weeks at lower energy (LE) of 31.2 GeV/u and 1 day of collision at injection energy of 11 GeV/u.

The ion injector chain [2] (Tandem, Booster and AGS) was set-up for Cu delivery in only 1 week, produced reliably the $4.5\text{-}5 \times 10^9$ Cu ions/bunch with $10 \pi\text{-mm-mrad}$ transverse emittance required for luminosity production. Intensities of 7×10^9 were delivered for beam studies. Operations in the RHIC blue ring were established very rapidly, with a record of only 54 minutes from the first shot in the transfer lines to circulating beam. A short-to-ground and a bus-to-bus short that developed in the 80 to 4K cool-down made warm-up, repairs, and re-cooling in 3 cryo-sectors necessary. After the discovery, diagnosis and fix of an aperture obstruction, set-up with both beams finally started and progressed rapidly. Overnight collisions for experiments were set-up in 5 days and physics declared in 2 1/2 weeks, faster than the 4 weeks originally planned.

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In the next sections we will address the machine performance as a Cu-Cu collider, reliability and uptime, and new operations and diagnostics developments.

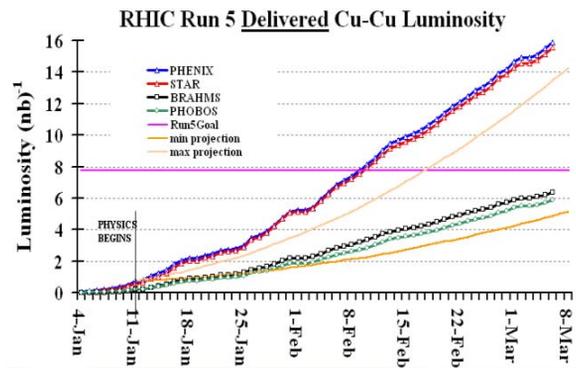


Figure 1: Luminosity for the Cu-Cu run at 100GeV/c

PERFORMANCE AND LIMITATIONS

Figure 1 summarizes RHIC performance in the Cu-Cu high energy run. Measured integrated luminosity at the 4 experiments (beams collided at Star and Phenix with $\beta^*=0.90$, at Brahms with $\beta^*=2.6$ m and at Phobos with $\beta^*=3$ m) is compared to the minimum and maximum luminosity projections [3] used for run planning. Minimum projections were based on RHIC performance in Run-4 with Au and assuming the same charge per bunch with Cu ions. RHIC as a Cu-Cu collider exceeded the maximum projection by integrating 15 nb^{-1} at the low- β^* experiments, more than a factor 2 over the initial goal for the run of 7 nb^{-1} . The cross section for n-pair production of Cu-Cu ions was measured to be 2.6 barn [4] The initial physics production store of 28 bunches of 4.5×10^9 evolved into the final configuration of 37 bunches with 5×10^9 Cu ions/bunch.

The main factors for exceeding predictions are: β^* squeeze down to 0.9m from 1.1m, optimisation of intensity and number of bunches, start-up and ramp-up of luminosity faster than the luminosity development model. Once the latter is factored in, the model predicts the luminosity slope accurately. The 3 major plateaus in the integrated luminosity curve correspond respectively to a major snowstorm, a massive power dip and a clustered series of equipment failures.

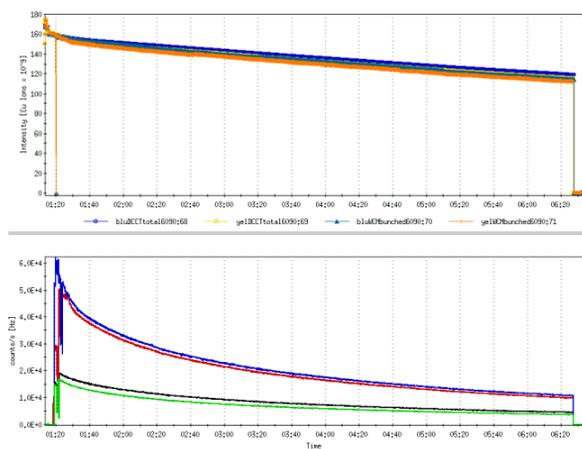


Figure 2: Typical Cu-Cu high-energy store

Figure 2 shows the total intensities and correlated collision rates of a typical HE store. The beam-beam interaction and intra-beam scattering limit the luminosity lifetime. It can be fitted to a double exponential decay, with 25% of the luminosity decaying with a time constant of about 1/2 hour, and the remainder with about 4.5 hours, resulting in a practical optimal store length time of 5 hours.

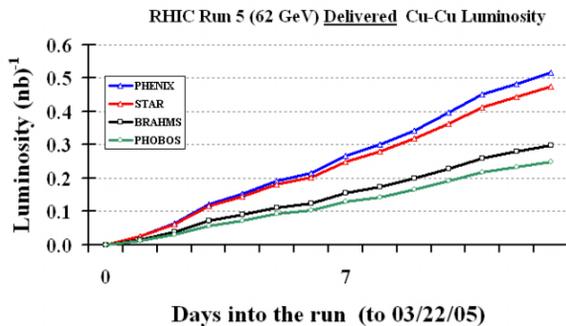


Figure 3: Luminosity for the Cu-Cu run at 31.2 GeV/c

Two weeks of collisions at 31.2 GeV/u followed the HE run after a 3 days set-up for the new operations mode. LE performance is summarized by the integrated luminosity in Figure 3. At the lower energy, the available aperture in the final focusing triples limited the β^* to 3m and 5m respectively in the low and high β^* experimental interaction regions. The production physics run was 42 bunches of 3.7×10^9 ions/bunch, with a luminosity lifetime of ~6 h.

Performance limitations

The main factors that limited bunch intensity in operations are the following:

- *fast transverse instabilities* on the ramp near transition. The signature is a 50% transverse emittance blow-up that causes a decrease in the beam lifetime and collision rates, and an increase in experimental background. Instabilities on the ramp were counteracted with chromatic tune spread, and around transition by octupoles and by shifting the chromaticity zero crossing point before γ_T .
 - *beam-beam*, causing emittance growth and consequent decrease of luminosity lifetime. This was counteracted by optimisation of the working point [5].
 - *intra-beam scattering*, causing decrease in bunched beam lifetime. This was counteracted by more RF voltage from extra storage cavities (common cavities). Continuous abort gap cleaning was in place to get rid of un-bunched beam during the store.
 - *yellow beam lifetime after re-bucketing*, requiring to keep chromaticity close to zero during the store. It was exacerbated by as yet un-explained closed orbit shifts with an approximate periodicity of 24 h [6].
- The main factors limiting the number of bunches in operations are:

- *pressure rise the Phobos experiment* warm pipe caused by electron clouds. In some HE stores the pressure rose beyond 10^{-10} Torr leading to unacceptable background in the detector. Operations was limited to not more than 42 bunches with 5×10^9 [7].
- *transition pressure rise at IR4*, that appears with 45 bunches and similar bunch intensity.
- *long-range beam-beam interaction* on the ramp as a result of phase slippage in the ring-to-ring frequency phase near transition. This was resolved with an increased loop gain. Vertical separation bumps of 5mm are in place during the early part of the ramp and they are gradually brought down to 0 during the β^* squeeze to avoid aperture losses in the IR triplets.

RELIABILITY AND UPTIME

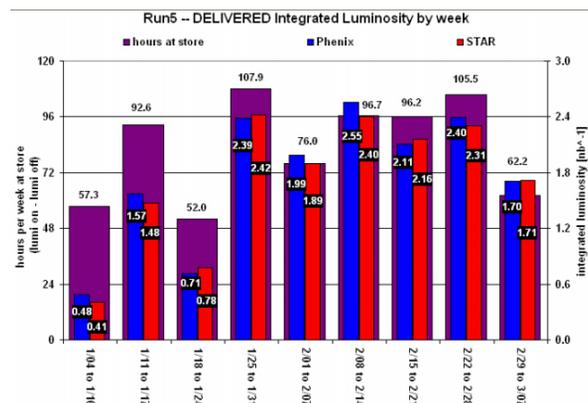


Figure 4: Luminosity delivered/week and time at store for the high-energy Cu run

Figure 4 summarizes the integrated luminosity delivered to the low- β^* experiments per week and the time at store measured from lumi-on (beams clogged into collisions) to lumi-off (when beams are prepared for dumping), for the high-energy run. Figure 5 plots the time at store for the 2 weeks of low-energy running, measured again from lumi-on to lumi-off.

Time in collisions at store for the HE run was 52% of calendar time, and increased to 74% of calendar time for the LE run.

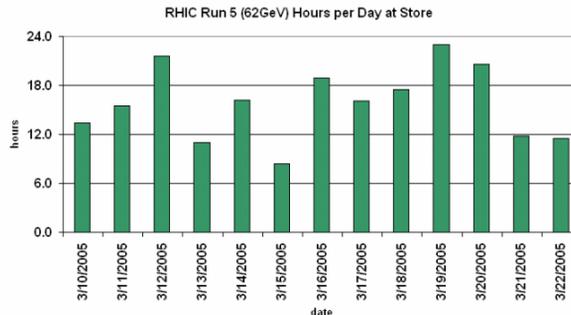


Figure 5: Hours at store / day for the low energy Cu run.

The significant difference in uptime for the 2 operational modes can be attributed to an increased quench margin and to the more relaxed beam parameters used for the LE run, most relevantly a 30% lower bunch intensity and 3 times larger β^* at the low- β^* interactions.

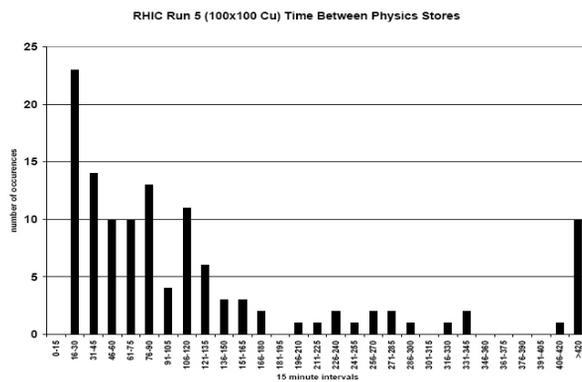


Figure 6: Distribution of time between stores in the high-energy run, in 15 minutes bins.

This in turns means a lower incidence of ramp losses and lost ramps, less tuning for lifetime at store and much faster turn around time between stores as compared to the high-energy run, described in Figure 6.

NEW DEVELOPMENTS

Several new developments were planned during the summer '04 shutdown and implemented for Run-5, ranging from operation improvements to instrumentation re-works and updates. The following is a non-exhaustive list of developments that resulted in improved machine performance or procedures.

As already discussed, improvements in ramp software matching capability [8] and experience with non-linear IR correction [9] made possible a β^* decrease by 15%, that was successfully tested in beam studies during Run-4.

Coupling correction on the ramp with the novel technique of skew quadrupole modulation [10] was commissioned and used, and resulted in faster ramp development.

Injection set-up for the RHIC rings was automated resulting in faster store-to-store turn-around times. A low intensity bunch interlock was included as well as an automatic AGS extraction field correction to match the RHIC energy.

The development of stochastic cooling for the RHIC bunched beams [11] progressed with the first successful tests of the kicker cavities at store that can operate without interfering with normal RHIC operations.

Instrumentation improvements included a major re-work of the beam position monitor electronics [12], which together with a novel application for beam-based alignment [13] improved performance of the orbit system. The ionisation profile monitor [14] and the Shottky system underwent as well a major rework that provided more reliable emittance measurements respectively on the ramp and at store.

The vacuum system [15] was improved by adding more than 200 m of NEG coated pipes this year. Evaluation is still in progress but tests with beam confirmed the viability of this vacuum upgrade to reduce electron cloud. The corrector power supplies continuous improvements (number of necessary PS swaps/run reduced in 2 years from 60 to 6), together with the realignment of magnets in IR12 resulted in better orbit control and reliability.

Last but not least, operations and controls software were improved, and new operations tools like configuration control WEB pages and database driven ramp analysis software were routinely used, resulting in improved operational efficiency.

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