COMMISSIONING OF RHIC AT 100 GEV/NUCLEON*

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Abstract

This report describes commissioning of the Relativistic Heavy Ion Collider (RHIC) for 100 GeV/nucleon collisions at designed luminosity. To achieve these goals new systems had to be commissioned: Gamma-t transition crossing jump quadrupoles, rebucketing with the new RF storage cavities, phase lock loop feedback, betatron and crystal collimation, beta squeeze along the ramp, *Siberian* snake magnets for the proton polarization run, AC dipole system, chromaticity measurements along the acceleration ramp, orbit correction, new ramp management system, upgraded sequencer, new data instrumentation and logger acquisition system etc.

1 INTRODUCTION

The last running period of RHIC was performed with two modes: the fist one was to provide collisions to four experiments of the fully-stripped gold ions at design luminosities and the second to commission the polarized proton *Siberian* snake magnets providing collisions to five experiments of protons at energy of 100 GeV. The super-conducting RHIC rings successfully produced a goal of the run: the design luminosity. The gold on gold collisions at energies of 100 GeV/nucleon were performed in the summer and fall 2001 while the polarized proton collisions with spin physics during the beginning of this year. In a limited space we will describe major steps towards achieving the goal and show some of the results. Details of many commissioning step will be referenced to other presentations at this conference.

2 MAJOR STEPS

A start of the previous run was dominated first by methodical check of many systems. The regular as well as special fast γ_t quadrupole polarities were measured with a special made software. New excellent tools and programs like: ramp and wave form generator *(wfg)* managers to control all magnet currents during all part of the cycles, sequencer [1]– to control every step from the injection up to the top energy of continuous sequences including initialization of almost every instruments at the same time with the power supplies, quench detection and protection system, Post-mortem system to recover data at the beam abort, power-supply comparison (*ps*-compare) to compare the power supplies ramps of different cycles, logging system – to record measured data from many instrumentation systems at the same time. All these data are saved together with the measured currents in all power supplies, the injection program – to record at the same time the transverse and longitudinal matching from the transfer line to both blue and yellow rings, orbit correction with feed forward correction through the ramp, etc., had been commissioned.

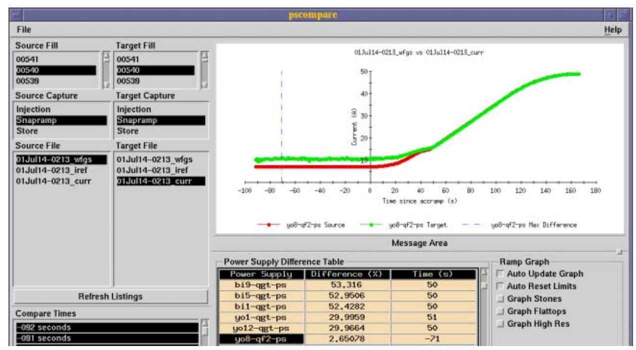

Figure 1. An example of disagreement between required (source) and measured current in the power supply.

2.1 Injection measurements

The measured lattice was compared to the model predictions at the injection. Series of measurements using two correction dipoles around the ring produced convincing agreement with a model [2]. Either changing the injection dipole field or the radial loop convincing results for the dispersion measurements were obtained.

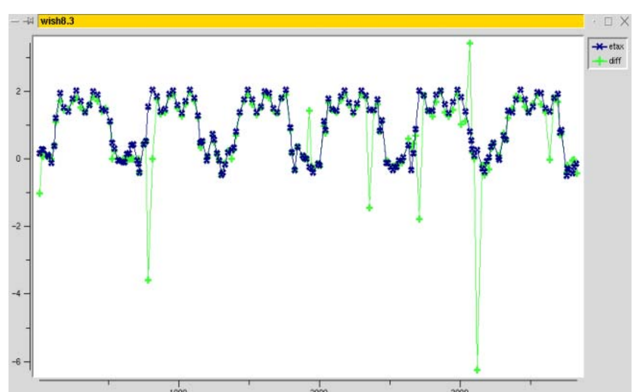

Figure 2. Dispersion measurement results at injection. Blue color is the model, green is measured units [m].

Unexpected betatron oscillations of the orbit within the unperturbed plane showed that the roll of the interaction region (IP) quadrupole was a major source of coupling. Decoupling of the ring was very important step [3].

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The chromaticity and tunes needed to be adjusted very well to remove the beam loss at the beginning of the acceleration due to persistent currents decay.

One of the major problems in both gold and proton runs were tune modulations induced by the beam-beam interactions at injection before the start of a ramp [4]. Introducing vertical orbit bumps to separate two beams at injection and during the first part of the ramp solved this problem.

2.2 Ramping to full energy with β^*-squeeze

The RHIC is the first superconducting accelerator to unfortunately cross the transition energy during acceleration in the case of gold and other heavy ions. The beams are accelerated with a frequency of ~28.15 MHz with a harmonic number *h*=360. After successful quench training of 24 beam separation DX magnets, and commissioning of the fast γ_t quadrupole [5] system, regular ramps to the top energy of 100 GeV/nucleon were established [6].

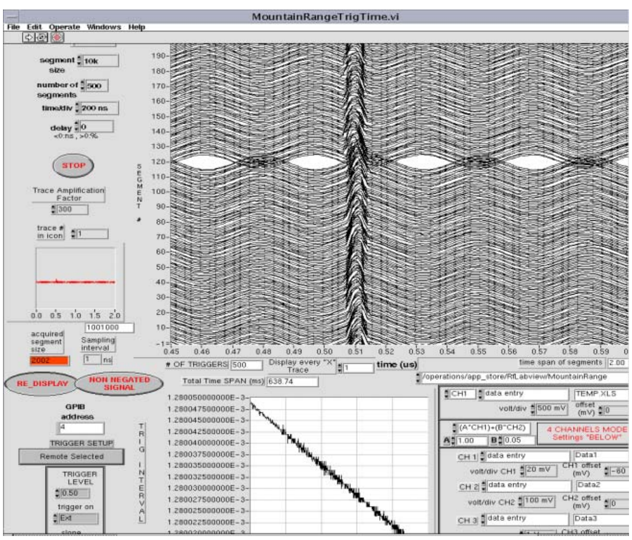

Figure 5. Transition crossing with the γ_t jump.

The collisions at all experiments were established at three different conditions during the gold-gold running period: first part of the ramp had to provide the "beta" squeeze from β^*=10 m at injection to β^*=5 m at transition. This is to allow better value of α_1, the second order of the momentum compaction at transition. As the ramp continues [7] and the currents and the magnetic fields in the interaction quadrupoles raise, the β^* at each IP reaches at the top energy first value of β^*=3 m, then β^*=2 m. At the last part of the run at "PHENIX" one of the experiments the beam was squeezed with β^*=1 m, while at the rest of the IP remained with the β^*=2m. [11]

A crossing of the transition energy became a serious problem when the beam intensities were approaching the design value of $1x10^9$ ions per bunch. Transition crossing time of the jump was adjusted for the best results as presented in figure 5. The polarized proton run did not have to deal with transition problems but the beam was injected from the Alternating Gradient Synchtrotron (AGS) very close to the transition value. Precise frequency matching between the AGS and RHIC was required for the RF capture. The orbit variations, horizontal and betatron tunes [8], chromaticity settings [9], decoupling [3], along the ramp had to be adjusted within a very small range. Coherent oscillations would immediately occur if the chromaticity values were not large enough or too close to zero. Precise adjustments of the injection tunes and chromaticities removed the persistent current decay induced beam loss. Very often the chromaticity needed [9] adjustments along the ramp as it is shown in an example in fig. 6.

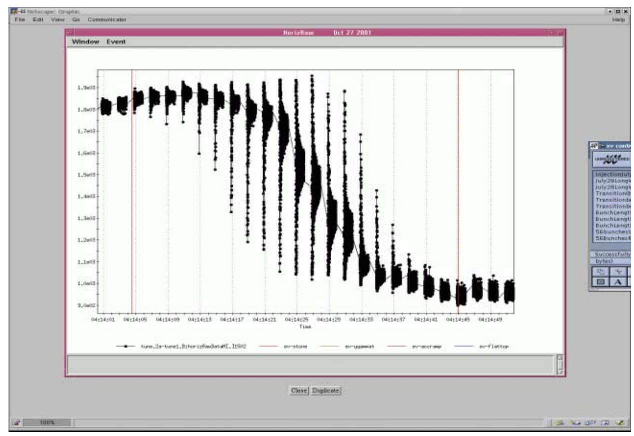

Figure 6. Coherent oscillations seen by the tune meter in the middle of the ramp.

The ramp manager [1]controlled the lattice parameters (tunes by the quadrupole currents, chromaticities – sextupole currents, etc.) along the ramp through the settings in time "stones" (as shown in fig. 6 by the vertical lines).

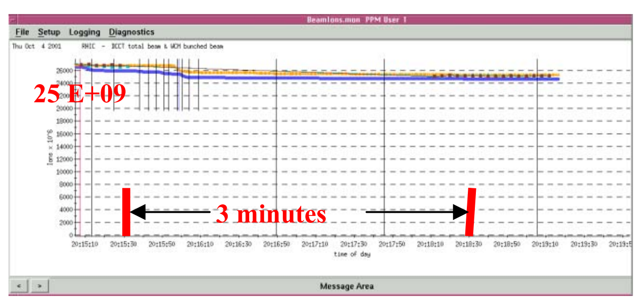

Figure 6. One of the typical ramp in the gold-gold collision run.

One of the accelerations is shown in fig. 6. The last three vertical markers are already at the top energy.

2.3 Collisions at full energy – flat top

The collisions of each store at the top energy of 100 GeV/nucleon were recorded at each experiment by the "zero degree calorimeters" as shown for two stores in fig.7. They are established by the RF adjustments of the

56 bunches longitudinally the "cogging" process. The best conditions for the experiments in the longitudinal space are obtained, as shown in figures 8 and 9, before and after rebucketing, respectively.

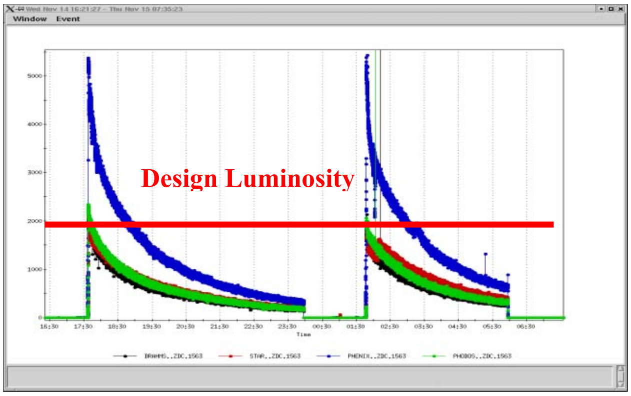

Figure 7. Luminosities at each experiment: the blue is for the "PHENIX" with β^*=1 m, the rest "STAR", "PHOBOS", and "BRAHMS" β^*= 2m.

The storage cavities shorten bunches are operated with a frequency of ~197 MHz with a harmonic number of *h* =7x360 = 2520.

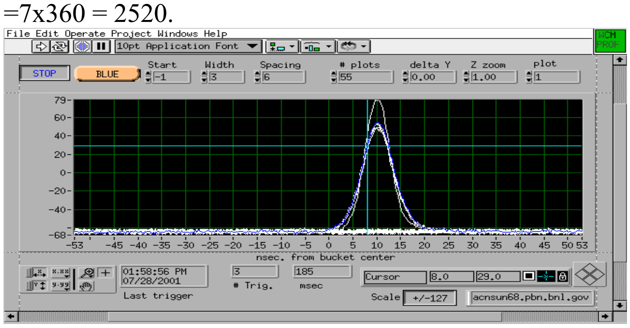

Figure 8. Longitudinal beam profile at storage in 28 MHz buckets 5 ns/div.

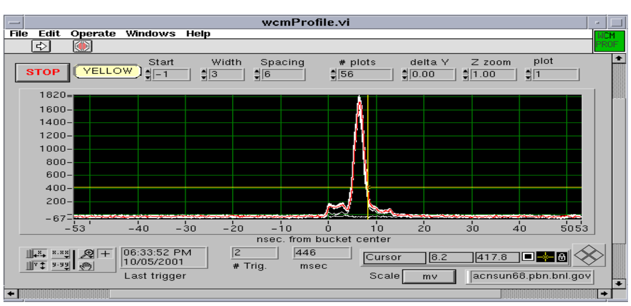

Figure 9. After rebucketing during gold-gold collisions

Many attempts to accelerate intensities above design values could not succeed due to vacuum and probably electron cloud instability problems [13]. Measurements of the betatron functions at the flat top had shown a clear gradient errors in the IP triplets due to differences in the quadrupoles transfer functions. This will be corrected in the next run. During the collisions beam profile, beam intensity, and luminosity measurements have shown that there is both longitudinal and transverse emittance blow up. The results will be compared to the expected emittance growth due to the intra beam scattering (IBS). A new AC dipole system was very successfully commissioned [10].

3 SUMMARY

The last gold on gold collisions and polarized proton collision runs were successfully preformed during the summer and fall 2001 and at the beginning of 2002, respectively. The design luminosities were established, many new systems were very successfully commissioned. In addition new unplanned improvements occurred like beam-gap cleaning, Landau cavity damping during acceleration, vertical beam separation, octupoles before transition, PLL chromaticity measurements, etc. A crystal channeling system has been used as a collimation system [12]. Problems with the vacuum and beam instabilities will be considered very seriously for the next RHIC run. Lattice measurements at the injection and at the top energy showed disagreements and large quad IP roll errors. These problems will be analyzed and corrected if possible

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