# RHIC PERFORMANCE AS POLARIZED PROTONS COLLIDER IN RUN-6*

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*Abstract*

The Relativistic Heavy Ion Collider in Run-6 was operating in polarized proton mode. Polarization was maintained with two Siberian Snakes per ring. Beams were colliding with 100 GeV and 31.2 GeV energies. The control of polarization orientation at STAR and PHENIX experiments was done using helical spin rotators. Physics data were taken with longitudinal, vertical and horizontal beam polarization at the collision points.

This paper presents the performance of RHIC as a polarized proton collider in the Run-6 with emphasis on beam polarization and luminosity issues.

## INTRODUCTION

The RHIC polarized proton run (Run-6) in 2006 year started on February 1 and continued for 21 weeks, until June 29. Run-6 was divided into several sub runs, corresponding to the operation at different beam energies. Table 1 presents those Run-6 sub runs (it does not include 2 weeks spent on ring cooldown and warmup, 3 weeks of the machine start up time, as well as one week of machine unscheduled shutdown in the middle of the run).

Table 1: Different energy sub runs during the Run-6

| Beam energy | 100 GeV | 11 GeV | 31.2 GeV | 250 GeV |
|---|---|---|---|---|
| Purpose | Physics operation | Machine test | Physics operation | Machine test |
| Time | 12 weeks | 1 day | 2 weeks | 1 week |
| Participating experiments | PHENIX, STAR | | PHENIX, STAR, BRAHMS | PHENIX, STAR |

## RUN PREPARATIONS

During the six months of RHIC shutdown in 2005 several important upgrades were made which resulted in improved machine performance in the Run-6.

Additional NEG coated beam pipes were installed in the warm RHIC regions, bringing the total to 430 m. That further reduced the harmful effects of electron clouds and associated pressure rises.

A complete vertical realignment of the machine was done. Magnet positions had drifted by several mm, especially in the interaction regions, on the scale of several years. The major purpose of the realignment was to reduce the depolarization effects which exist with non-planar beam orbit. For Run-6 the realignment was especially important because of the planned 250 GeV test with polarized beam.

Addressing the problems caused by limited momentum aperture in Run-5, the 100 GeV lattice had been optimized in order to considerably reduce the dispersion function in the IR6 and IR8 regions.

Additional shielding was added into the RHIC tunnel in order to protect the STAR detector, which seriously suffered from beam backgrounds during the previous run.

Upgrade of electronics in RHIC BPM system improved the system reliability and allowed for a more accurate beam orbit control, an important factor in the polarization preservation.

## 100 GeV RUN

The 100 GeV run was first and the main part of Run-6, with a total of 12 weeks of Physics operation. After 1.5 weeks of cooldown to liquid helium temperatures, the machine setup started and was accomplished in record time, three weeks. A crucial item in this achievement was a successful application of a combined tune and decoupling feedback [1]. The feedback application considerably decreased the time usually spent on the betatron tune adjustments along the ramp and addressed the problem of betatron coupling correction on the ramp which existed in previous runs.

On March 4 the start of the Physics run at 100GeV beam energy was announced. Figure 1 shows the progress in the gain of integrated luminosity delivered to the experiments during the run. A total of 45 $pb^{-1}$ integrated luminosity was delivered to each STAR and PHENIX. During the run the machine was off for one week to investigate arc flash accident.

Table 2 shows the beam polarization, luminosity, beam and lattice parameters achieved in the course of the run.

### *Luminosity*

Unlike previous polarized proton runs, this year only two experiments, STAR and PHENIX, have been participating in the physics program at 100 GeV energy.

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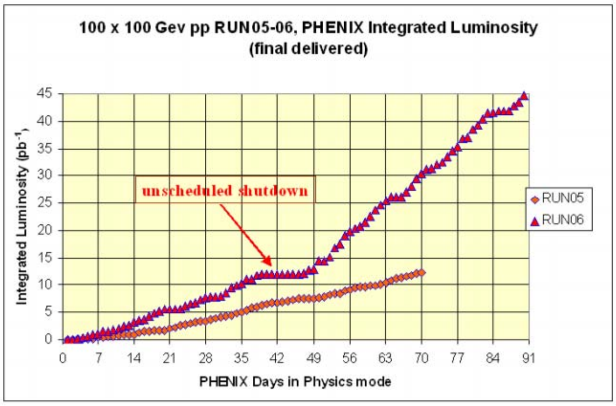


Figure 1: Integrated luminosity during the Run-6 and the previous year Run-5.

Table 1: Beam parameters and luminosity in 100GeV run

| *Parameter* | |
|---|---|
| No. of bunches | 111 |
| Bunch intensity, $10^{11}$ | 1.3 |
| Store energy, GeV | 100 |
| $\beta^*$, m (in IR6 and IR8) | 1 |
| Norm.95% emittance, $10^{-6}$ | $20\pi$ |
| Peak luminosity, $10^{30}cm^{-2}s^{-1}$ | 35 |
| Aver. luminosity, $10^{30}cm^{-2}s^{-1}$ | 20 |
| No. of collision points | 2 |
| Aver. polarization in store, % | 65 |

Having collisions at only two interaction points, IR6 and IR8, instead of three or four collision points used in previous runs, opened the way to higher bunch intensities, allowed by beam-beam effects, and therefore to higher luminosities. Besides the bunch intensity increase a significant effort was put onto the beam transverse emittance control as an important factor to provide reproducible luminosity level for the operation close to the beam-beam limit. In addition to the ionization profile monitor as the main tool of the transverse emittance measurement, beam profile measurements using carbon targets of CNI polarimeter were developed and widely used during the run. This measurement provided us also with very useful information on the emittances of the individual bunches. The AGS IPM and ATR scintillation flags emittance measurements were used to control the emittance of the beam coming from the AGS. During the run, a novel technique for beam profile measurement using the scintillation light coming from the hydrogen jet, located in the IR12 region, has been developed [3]. Several consequent beam emittance improvements done during the course of the run contributed considerably into the luminosity gains. The smaller emittances (below $15\pi$ mm.mrad) were achieved for the beam coming from the AGS. In RHIC various sources of the emittance growth were addressed. The effect of parasitic beam-beam collision on the ramp was improved by better control of the orbit separation bumps and the relative longitudinal phase between the beams. The question still remains open about possible gradual emittance growth on the ramp, which was observed by IPM measurements and may come from noise or parasitic harmonic components in power supply currents.

It was also noted that shorter bunches led to larger transverse emittances. This effect may be caused by the harmful influence of electron clouds and further studies would be required to understand the mechanism of this emittance increase. Because of this connection between bunch length and transverse emittance we had to maintain large enough longitudinal emittance which led to unwanted increase in the experimental collision vertex.

A critical item for stable operation was to define the best conditions for the beam, luminosity and polarization lifetime in the store. Following the experience of previous runs the working points in the store were placed inside the (0.68,0.695) box in the Qx-Qy plane. Initially, in an attempt to keep the tune as far as possible from Qx=2/3 resonance, the working points of Yellow and Blue beams were placed quite close to each other. In this configuration clear additional peaks were seen in the vertical spectra of the Beam Transfer Function measurements, in both Blue and Yellow beams, which were attributed to the coherent beam-beam effects. Later, a clear improvement in beam and luminosity lifetime was observed after the working points had been separated and put on the opposite sides of the Qx=Qy diagonal.

As mentioned, it was found that the dominant factor, restricting available betatron tune space, was the Qx=2/3 resonance. In both rings the beam lifetime depended considerably on the distance from this resonance line. The resonance correction, using the interaction region sextupole correctors, had been developed, and attempted in both rings. For Yellow beam it resulted in some improvement of beam lifetime in the store.

It was noted in previous runs that the RHIC closed orbits, especially the vertical one, varied with a 24h period in sync with outside temperature. The orbit variation in the IR triplets due to this effect is on the scale of 2-3 mm. In Run-6 the store stability against this thermal variation was provided by the regular orbit correction done at the beginning of every store.

Another new tool against the harmful effect of beam-beam interactions, a 10Hz orbit feedback system has been under development during the run. The system attempts to compensate 10Hz jitter of the relative beam-to-beam orbit position at the interaction points. This system is not yet operational.

### *Beam Polarization*

The run showed remarkable improvement in the RHIC beam polarization which was due to an increase in AGS polarization transmission. In previous years strong polarization decrease was observed in the AGS for intensities above 1.e11 p/bunch. The problem of the polarization dependence on the bunch intensity was solved with the addition of cold partial snake (with compensating quadrupoles), installed in AGS in 2005.

Analytical and simulation studies before the run as well as the initial AGS machine setup with polarized beams had found that the highest polarization level was provided in a dual snakes scheme, where both the new cold snake and the older warm snake were used at the same time [2]. The application of the dual snake scheme in the AGS also led to a lower RHIC injection energy, to preserve the good spin matching between the AGS and RHIC. The injection energy was decreased by about 0.5 GeV (to $G\gamma$=45.5 instead of previously used 46.5). The injection lattice was modified, using a special set of quadrupoles, to move the transition energy further away from this lower injection energy.

The development for higher beam polarization in the AGS continued in parallel with the RHIC operation, eventually achieving the level of 60-65% beam polarization routinely provided to RHIC. With two Siberian Snakes in each of the RHIC rings the beam polarization is well preserved up to 100 GeV without noticeable loss. The fractional part of betatron tunes must be kept far enough from 0.7 and 0.75 in order to avoid the depolarization from high order spin resonances. Figure 2 shows the progress on beam polarization achieved during the course of the run, with the polarization measured by the CNI polarimeter at the store energy (100 GeV). In addition to the CNI polarimeter the H-Jet polarimeter has been collecting data for both beams during the course of the run. That data will verify and improve the knowledge of absolute beam polarization at 100 GeV energy.

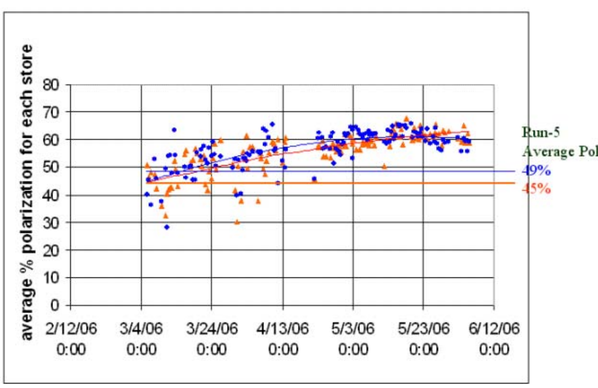


Figure 2: Beam polarization measured in the store in both RHIC rings (Blue and Yellow) during the course of the 100 GeV run.

In each RHIC rings there are two pairs of spin rotators, based on helical magnets, which allow to manipulate locally the polarization direction at the PHENIX and STAR experiments. During the 100 GeV run this capability to regulate the polarization direction was exploited greatly. The rotators were used in various configurations, providing horizontal and longitudinal beam polarization in PHENIX and vertical and longitudinal beam polarization in STAR at different stages of the run. The rotators were turned on after the beam acceleration to 100 GeV and beta-squeeze to 1m value in the collision points (IR6 and IR8) had been done.

The considerable role in providing RHIC with high intensity polarized proton beam with required small emittances belongs to the high intensity polarized ion source (OPPIS). The source provided routinely $10^{12}$ $H^-$ ions/pulse with 82-86% polarization.

## 31.2 GeV RUN

A two weeks long 31.2 GeV run took place in June. Three experiments participated in taking data, hence collisions were done in three interaction regions (IR2, IR6 and IR8). Because of that, a reduced bunch intensity was used to satisfy the beam-beam limit. Also, to satisfy aperture limits, in the interaction region quadrupoles, the $\beta^*$ in the collision points was increased to 3m. At those conditions a maximum peak luminosity of 1.5e30 $cm^{-2}s^{-1}$ was achieved. The integrated luminosity of 0.35 $pb^{-1}$ was delivered to the experiments. The beam and luminosity lifetime issues at the store were similar to those at 100GeV run. The spin rotators were used in the PHENIX region to provide longitudinal polarization for that experiment.

## MACHINE DEVELOPMENT RUNS

Two short runs during Run-6 were devoted to investigating machine configurations for possible future operations. One day of machine development run at 11GeV was quite successful and showed the principal possibility to operate the machine at such low energy, which is approximately half of the normal injection energy of 24 GeV. The interest in that energy area is driven mainly by heavy ion physics questions, namely by a search for the critical point of quark-gluon matter. The optics measurements done during the 11 GeV run should tell us about chances to go to even lower energy.

Another machine development run is the first test of polarized proton acceleration to the 250GeV energy. Main goal of the test is to verify that the beam polarization is preserved during the acceleration. The orbit tolerances as well as the tolerances of the betatron tune, required to minimize the polarization loss should be evaluated. An additional task would be to have a first look at the achievable luminosity level at 250 GeV beam energy. At the time of writing this paper the 250 GeV run is still underway.

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