RHIC Performance with Polarized Protons in Run-6*

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Abstract. The RHIC polarized proton run (Run-6) in 2006 started on February 1 and continued for 21 weeks. The Run-6 included the machine operation at different beam energies and with different orientation of beam polarization at the collision points. The machine operation at 100GeV and 31.2 GeV provided physics data of polarized proton collisions to the STAR, PHENIX and BRAHMS experiments. Record levels of the luminosity (up to $3.5 \cdot 10^{31}$ cm^{-2} s^{-1} peak) and proton beam polarization (up to 65%) were achieved during the 100GeV operation. The beam polarization was preserved during the acceleration by using Siberian Snakes, based on helical magnets. The polarization orientation at STAR and PHENIX experiments was controlled with helical spin rotators. During different stages of the run the physics data were provided with longitudinal, vertical and horizontal orientations of the beam polarization at the collision points. Total luminosity integrals of 45 pb^{-1} at 100 GeV and 0.35 pb^{-1} at 31.2 GeV were delivered to the experiments.

Keywords: polarized protons, acceleration, luminosity
PACS: 29.27.-a, 29.27.Hj, 29.20.-c

INTRODUCTION

The RHIC Run-6 was first RHIC run dedicated to the operation with polarized proton beams only. The run started on February 1, 2006, and continued for 21 weeks. Main part of the Run-6 was the operation at beam energy of 100 GeV (c.m. energy of 200 GeV). Two weeks were devoted to the operation at the beam energy of 31.2 GeV. There were also two short machine development runs at beam energies of 11 GeV and 250 GeV. The later run achieved remarkable success demonstrating, for the first time, the 45% polarization of proton beam at 250 GeV. The details of the RHIC machine

* Work performed under Contract No. DE-AC02-98CH1-886 with the auspices of the DOE of United States, and with support of RIKEN (Japan) and Renaissance Technologies Corp. (USA)

CP915, *Proceedings of the 17th International Spin Physics Symposium*, edited by K. Imai, T. Murakami, N. Saito, and K. Tanida

configuration for the polarized proton beams and the results of the 250 GeV run can be found in Ref.[1].

LUMINOSITY AND POLARIZATION DURING 100 GEV RUN

The operation at 100 GeV beam energy was the main part of Run-6, including 12 weeks of the operation for physics. Two experiments, STAR and PHENIX, participated in collecting data from polarized proton-proton collisions at 100 GeV. Total integrated luminosity of 45 pb^{-1} was delivered to each experiment.

During the run record levels of collision luminosities and beam polarization were achieved. Table 1 shows main parameters of polarized proton beams and RHIC lattice during the 2006 and in two previous runs. The 3.5-fold increase in the peak and average luminosities during the 2006 run came from the improved beam emittance and the increased bunch intensity. The increase in the bunch intensity became possible by improvements in AGS pre-accelerator, where the application of dual snake scheme eliminated the beam polarization dependence on the proton bunch intensity, observed in previous runs [2]. Also, the reduction of participating experiments and corresponding collision points from three in 2005 to two in 2006, allowed the increase in the bunch intensity and reduction in the beam emittance without exceeding the beam-beam limit. Before the run additional NEG coated beam pipes were installed in the warm RHIC regions, bringing the total length of NEG coated pipes to 430 m. Together with vacuum upgrade in cold bore sections, this improvement reduced the harmful effects of electron clouds and associated pressure rises on the transverse beam emittance. As the result, the Run-6 achieved significantly smaller transverse emittance for the operation with more than 100 bunches, compared with the previous run. Still, a strong correlation was observed between bunch length shortening and the growth of transverse emittance. The most probable explanation of this correlation is the enhancement of electron cloud formation by shorter bunches. Hence, the control of the bunch length was important operational factor during the run.

The beam emittance control was improved in both AGS and RHIC. Emittances were measured on regular basis using multiple techniques. New emittance measurement technique, using the CNI polarimeter target scan through the circulating beam, was successfully developed and used during the run providing the emittance of individual bunches.

TABLE 1. Beam parameters, luminosities and polarization at Run-6 and previous two runs.

Parameter	Unit	2004	2005	2006
No. of Bunches	--	56	106	111
Bunch Intensity	10^{11}	0.7	0.9	1.35
β^*	m	1	1	1
Transverse Emittance, normalized, 95%	mm mrad	18	28	18
Peak Luminosity	$10^{30}cm^{-2}s^{-1}$	6	10	35
Average Luminosity	$10^{30}cm^{-2}s^{-1}$	4	6	20
Collision Points	--	4	3	2
Time in Store	%	41	56	46
Average Polarization at Store	%	46	47	60-65

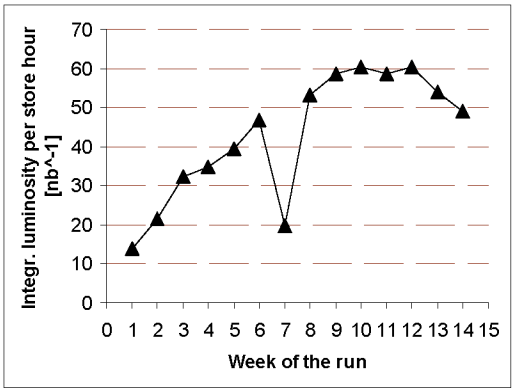

FIGURE 1. Integrated luminosity per store hour during 100 GeV run.

Careful selection of the working point at the store was necessary to provide the acceptable beam lifetime and, at the same time, to prevent the beam depolarization. Based on the experience from the previous runs, the working point was placed inside the (0.68,0.695) box on the Q_x-Q_y betatron tune plane. The choice kept the tunes sufficiently far from high order spin resonance $Q_{x,y}$=7/10. It was found that the major factor defining the beam lifetime at the store was Qx=2/3 resonance. The reduction of the resonance strength was attempted, but the process had not been completed.

Figure 1 shows the progress in the integrated luminosity per store hour during the run. The dip in the luminosity during 7th week corresponds to an interruption in the machine operation related to the investigation of an electric flash accident. Small droop in the luminosity at the end of the run was the result of several stores with longer than optimal store time.

Figure 2 shows the proton beam average polarization measured in every store by CNI polarimeter [3]. Another polarimeter, based on hydrogen jet, also made the absolute measurements of the beam polarization during the course of the run [4]. Remarkable progress is seen on the polarization, which was improved in the Run-6 to 60-65% level at the energy of 100 GeV. Most of the improvement was result of the dual snake scheme in AGS. Careful AGS retuning for the dual snake operation provided high and stable polarization level for the beam injected into RHIC [2]. The high intensity polarized ion source (OPPIS) routinely provided 10^{12} H^- ions/pulse with 82-86% polarization during the Run -6.

In RHIC, two Siberian Snakes per ring worked perfectly to preserve polarization preservation during the beam acceleration to 100 GeV. In order to prevent the depolarization the betatron tunes with fractional part 0.75 and 0.7, corresponding to high order spin resonances, were avoided. The depolarization effects from those resonances were clearly seen during the regular machine operation as well as during the dedicated beam studies [1,5]. A novel tune and decoupling feedback was successfully used at the machine setup stage to minimize the betatron tune excursion during the beam acceleration [6].

The polarization preservation in RHIC was also ameliorated by progress in reduction of vertical beam orbit excursions. First, the complete machine vertical realignment

was done before the run. Second, BPM system electronic upgrade, completed before the run, provided for more accurate beam orbit measurements. In addition, the vertical orbit variation with 24h period observed in previous runs was addressed by regular orbit corrections.

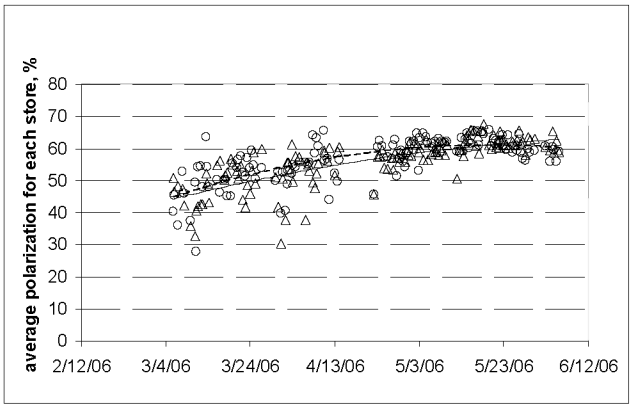

FIGURE 2. Average proton beam polarization for each store, measured by CNI polarimeter, in both Blue (circles) and Yellow (triangles) rings during 100 GeV run.

The spin rotators, based on helical magnets, were used during the course of the run to provide desirable polarization orientation at the experimental collision points. The rotator configuration included horizontal and longitudinal beam polarization in PHENIX and vertical and longitudinal beam polarization in STAR at different stages of the run.

LUMINOSITY AND POLARIZATION DURING 31.2 GEV RUN

For two weeks the machine operation was devoted to the experiments with polarized protons at 31.2 GeV energy. The total luminosity integral of 0.35 pb^{-1} was delivered to three participating experiments: PHENIX, STAR and BRAHMS. Beam polarization was at the same 60-65% level similarly to the 100 GeV run. The spin rotators at PHENIX were used to provide the longitudinal beam polarization at that experiment.

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