RHIC PERFORMANCE AS A 100 GEV POLARIZED PROTON COLLIDER IN RUN-9 *

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Abstract

During the second half of Run-9, the Relativisitc Heavy Ion Collider (RHIC) provided polarized proton collisions at two interaction points. The spin orientation of both beams at these collision points was controlled by helical spin rotators, and physics data were taken with different orientations of the beam polarization. Recent developments and improvements will be presented, as well as luminosity and polarization performance achieved during Run-9.

INTRODUCTION

The polarized proton run at 100 GeV beam energy in FY09 lasted from April 15 to June 30. After the 250 GeV polarized proton run ended on April 13, RHIC was prepared for the lower energy during two maintenance days. Since the injection configuration was inherited from the 250 GeV run, ramp development started immediately. Thanks largely to the now well-established tune feedback system [1], both beams reached top energy after only 36 hours of machine development, and the start of the physics data taking run was declared five days after the beginning of the 100 GeV development.

MACHINE CONFIGURATION AND SET-UP

To increase the luminosity compared to previous years, the beams were focused to $\beta^* = 0.7\,\mathrm{m}$ at the two collider experiments PHENIX and STAR, vs. $\beta^* = 1.0\,\mathrm{m}$ in Run-8 [2]. Proton bunch intensities remained at the same levels as in Run-8, around $1.5 \cdot 10^{11}$ protons/bunch. The peak luminosity was therefore expected to increase by roughly 50 percent compared to Run-8. However, the smaller β^* resulted in a significant hourglass effect, which reduced the luminosity as the bunch length grew during stores. To counteract this, the RF voltage was slowly increased during stores in an attempt to slow down the bunch lengthening.

Table 1: RHIC Parameters during Run-9

Beam energy [GeV]	100
No. of bunches/beam	109
No. of protons/bunch [10^{11}]	1.5
No. of collision points	2
emittance [μm]	15
β^* [m]	0.7
L_{peak} [$10^{30}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	50
$L_{\mathrm{store\ avg.}}$ [$10^{30}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	28
Spin orientation at PHENIX	longitudinal
Spin orientation at STAR	longitudinal

Modifications of the low energy beam transport (LEBT) line between the polarized proton source and the linac resulted in a transverse emittance reduction from 20π mm mrad to 15π mm mrad [3].
As both STAR and PHENIX had requested longitudinally polarized beams, the spin rotators around these two detectors were used to manipulate the spin direction accordingly. Table 1 lists the RHIC parameters during the run.

PERFORMANCE

With the β-functions reduced to $\beta^* = 0.7\,\mathrm{m}$ at both PHENIX and STAR, the peak luminosity reached $50 \cdot 10^{30}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$, vs. $35 \cdot 10^{30}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ with $\beta^* = 1.0\,\mathrm{m}$ in Run-8. However, since the luminosity lifetime reached only about 6 h instead of 10 h, Figures 1 and 2, the average store luminosity increased only marginally.

To investigate the root cause of this phenomenon, a number of parasitic studies were performed:

- lowering the number of bunches from 109 to 84 only improved the ramp efficiency but not the luminosity lifetime;
- turning off the slow RF voltage ramp at store resulted in the same poor luminosity lifetime due to fast bunch lengthening;
- low intensity stores with $1.0 \cdot 10^{11}$ protons/bunch and

* Work performed under Contract Number DE-AC02-98CH10886 with the auspices of the US Department of Energy.
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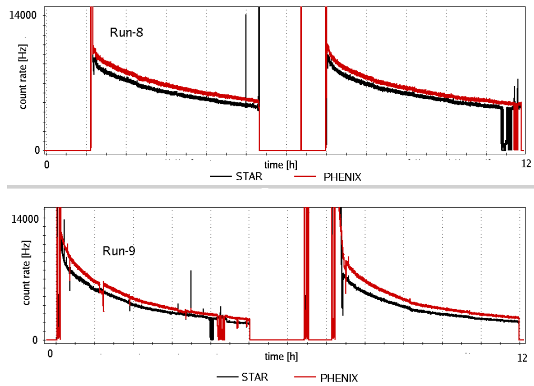

Figure 1: Luminosity evolution during two typical stores in Run-8 (top) and Run-9 (bottom).

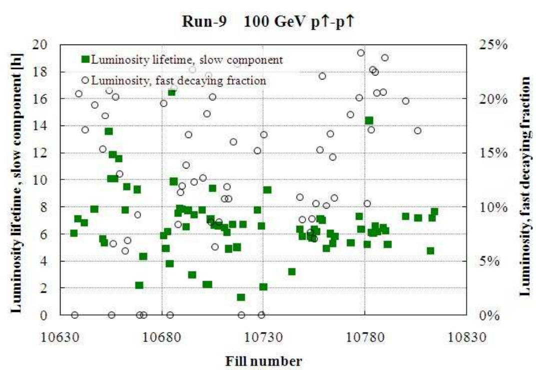

Figure 2: Luminosity lifetime vs. fill number during Run-9, as obtained from double-exponential fits $L = L_1 \exp(-t/t_1) + L_2 \exp(-t/t_2)$.

an RF voltage ramp to 200 kV/cavity in 3 h still resulted in only 6 h luminosity lifetime;

- slowing down the RF voltage ramp for regular intensity stores to 200 kV/cavity in 9 h improved the luminosity lifetime to 9 h, but only for about 80 percent of the total luminosity;
- reducing the RF voltage ramp to 150 kV/cavity in 9 hours resulted in 7 – 8 h luminosity lifetime, for 75 – 90 percent of the total luminosity.

When all these changes did not improve the luminosity lifetime, the machine lattice itself was suspected to be the culprit. Because the only major change since Run-8 had been the smaller β^*-value, the focusing at the two collision points was relaxed in two steps. First, the existing lattice was modified to result in a larger β^*-value of $0.8\,\mathrm{m}$. When no significant luminosity lifetime improvement was observed, the Run-8 lattice was re-loaded. After some machine tuning, the luminosity lifetime improved significantly, to similar values as in Run-8. This was therefore the final proof that the poor luminosity lifetime performance

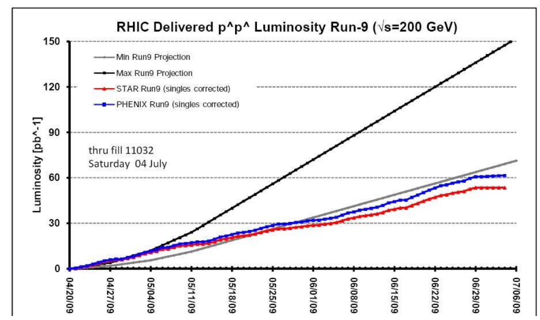

Figure 3: Integrated luminosity delivered to PHENIX and STAR during the course of the run.

was a result of the tighter β-squeeze, and not of some sort of new, unknown noise source.

As Figure 3 indicates, the integrated luminosity grew almost linearly during the entire run, because RHIC reached its peak performance from the beginning. Due to the aforementioned efforts to determine the cause of the poor luminosity lifetime, luminosity performance suffered somewhat for a couple of weeks during the middle of the run. After it had become clear that the poor luminosity lifetime is an inherent feature of the $\beta^* = 0.7\,\mathrm{m}$ optics, efforts focused on maximizing the integrated luminosity under these circumstances. However, due to the reduced luminosity lifetime the resulting integrated luminosity did not exceed the minimum projected performance, which is based on performance levels achieved in previous runs.

The property to maximize in polarized proton collisions with longitudinal spin direction of both beams is the figure-of-merit $L \cdot P_{\mathrm{Blue}}^2 \cdot P_{\mathrm{Yellow}}^2$, where L, P_{Blue}, and P_{Yellow} are the luminosity, and the polarization of the "Blue" and the "Yellow" beam, respectively.

The intensity-dependent polarization P_{AGS} at AGS extraction has been found as

$$P_{\mathrm{AGS}}[\mathrm{percent}] = 75 - 8 \cdot I_{\mathrm{AGS}}[10^{11}], \qquad (1)$$

where I_{AGS} is the proton bunch intensity. Inserting this relation into the expression for the figure-of-merit yields a maximum at an AGS bunch intensity of $I_{\mathrm{AGS}} = 3 \cdot 10^{11}$, which is well beyond targeted bunch intensities in RHIC.

However, several effects occuring in RHIC also have to be taken into account in this optimization process. Especially in the "Yellow" ring, the ramp efficiency depends strongly on the bunch intensity, resulting in intensity losses between 10 and 15 percent during the ramp for bunch intensities around $1.5 \cdot 10^{11}$, as shown in Figure 4.

Since RHIC is operating near the beam-beam limit, the luminosity L does not necessarily scale with the bunch intensities as $I_{\mathrm{Blue}} \cdot I_{\mathrm{Yellow}}$, but may rather begin to saturate at high intensities. As a result the optimum intensity to maximize the figure-of-merit is reduced. Figure 5 shows the measured figure-of-merit at the beginnig of each physics store, when the machine was handed over to the experi-

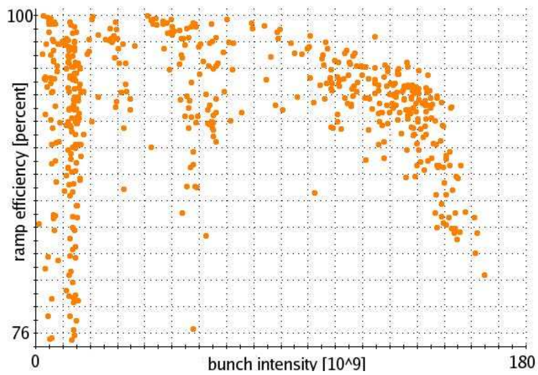

Figure 4: Ramp efficiency in the "Yellow" ring as function of injected bunch intensity.

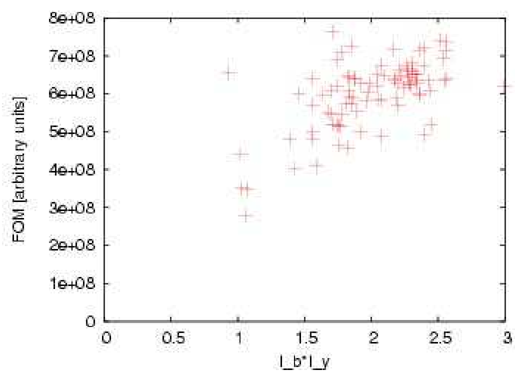

Figure 5: Measured figure-of-merit at the beginning of each physics store, as function of the bunch intensity product $I_{\mathrm{Blue}} \cdot I_{\mathrm{Yellow}}$.

ments after steering and collimation.

The resulting integrated figure-of-merit is depicted in Figure 6. Due to an average polarization level of 56 percent over the entire course of the run, the minimum projection was clearly exceeded despite the poor luminosity lifetime.

PP2PP

The final week of the run was devoted to the elastic scattering experiment pp2pp. This experiment uses Roman Pots installed in the warm section between Q3 and Q4 to measure elastic scattering events at high precision. To enable these high precision experiments, the angular spread σ' of the beams at the interaction point has to be minimized. This is accomplished by a large β-function of $\beta^* = 20\,\mathrm{m}$. In addition, the emittance of the beams is drastically reduced by collimator scraping. The optical properties of the transport channel from the IP through the triplet to the detector was measured by different methods. In this configuration, an integrated luminosity of $0.6\,\mathrm{nb}^{-1}$ was delivered with an average store polarization of 63 percent.

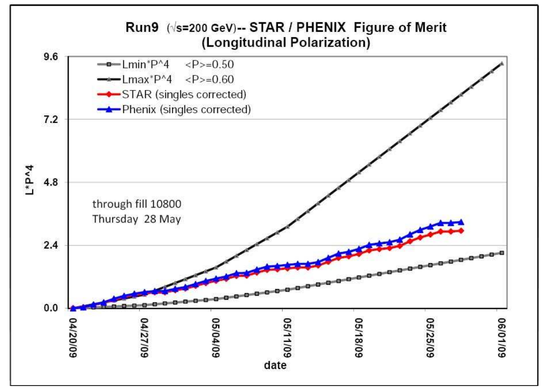

Figure 6: Integrated figure-of-merit $L \cdot P^2_{\mathrm{Blue}} \cdot P^2_{\mathrm{Yellow}}$ delivered to PHENIX and STAR during the course of the run.

SUMMARY

During the 100 GeV polarized proton run in FY09, RHIC performed at its present limit. After an extremely fast start-up phase peak luminosity and polarization performance was reached almost immediately. However, in spite of a 50 percent higher peak luminosity the integrated luminosity fell short of expectations due to a reduced luminosity lifetime. A considerable amount of time was spent during the run to study the root cause of this reduction, until it was finally determined that this is an inherent feature of the new $\beta^* = 0.7\,\mathrm{m}$ lattice in conjunction with the beam-beam interaction.

To increase the integrated luminosity in future runs, relaxing the low-β focusing to $\beta^* = 0.85\,\mathrm{m}$ while increasing the beam emittance and intensity is expected to be beneficial. With a new fast orbit feedback system currently being implemented, a near-integer working point could be feasible, expected to provide larger dynamic aperture than the current one [4]. In the long term, installation of electron lenses for head-on beam-beam compensation will allow for larger beam-beam parameters and therefore higher luminosities [5].

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