

ANALYSIS OF POLARIZATION DECAY AT RHIC STORE *

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Abstract

Beam polarization is a critical parameter for the cold QCD program at the Relativistic Heavy Ion Collider (RHIC). There are polarization losses during the RHIC store due to various sources, such as emittance growth and higher order spin resonances. The beam polarization was measured several times over a store by p-carbon polarimeters in both rings, which provide information on polarization decay and polarization profile development over time. A polarized atomic hydrogen gas target (jet) was also used to monitor the polarization continuously through store, though with limited accuracy. These polarization measurements and the emittance measurements from the Ionization Profile Monitor (IPM) are analyzed and the polarization loss from different sources are reviewed.

INTRODUCTION

In each of the RHIC rings (blue ring or yellow ring), there are two Siberian Snakes to maintain polarization on the energy ramp and at store [1]. The stable spin direction is nearly vertical in both rings. When experiments require longitudinal polarization at the Interaction points (IP), local spin rotators are used to give local longitudinal polarization at the IPs. It has been observed that there are several sources causing polarization loss in RHIC. With Siberian Snakes in the ring, the snake resonances [2] still exist. The resonance strength increases with larger transverse emittance. Since there are spin tune and betatron tune spreads, some particles can experience the resonance condition and result in lower polarization. The polarization loss due to imperfection resonance is independent of the betatron amplitude. The polarization loss due to intrinsic and snake resonances is higher with large betatron amplitude. Such a polarization loss across the beam profile causes a polarization profile. It has been shown by measurements in RHIC that transverse beam profiles and polarization profiles can both be approximated by Gaussian distributions. The polarization profile and beam profile ratio R is defined as [3]

$$R = \left(\frac{\sigma_b}{\sigma_p}\right)^2 \quad (1)$$

where σ_b is the rms beam size, and σ_p is the corresponding polarization rms value. For beams with depolarizing schemes in both x and y planes, there are two different R values for the two planes. They can be different in general, but the observation is that both are about the same in RHIC.

The RHIC polarization was measured with two sets of polarimeters. A polarized jet at an IP gives absolute polar-

ization measurement for both beams [4]. It provides absolute beam polarization but the typical statistical error for an eight hour store is $\pm 3\%$. By combining many stores together, the polarization decay at store can be derived. The fast p-carbon polarimeters are relative polarimeters which can be calibrated with the jet polarimeter [5]. They provide a $\pm 2\%$ statistical error for a 30 sec. measurement. The p-carbon polarimeter target is a thin carbon ribbon of $10\mu\text{m}$ wide. The polarization measurement was done by scanning the target through a beam. Such a thin target makes it possible to obtain the beam polarization profile. Since both vertical and horizontal polarization profiles are needed for the polarization analysis, two polarimeters were built next to each other and each one uses vertical and horizontal aligned targets, respectively. The measurements with the two polarimeters were taken at 0, 3, 6, and 8 hours from the start of the store. By combining measurements from many stores at different times, the polarization decay and polarization profile growth information can be derived.

The RHIC transverse emittance was measured periodically at store by IPM throughout the length of the store. There is a slow but steady growth in both planes. Large emittance means larger depolarizing resonance strength, so contribution of polarization loss due to emittance growth is expected. Since we have both the polarization decay rate and emittance growth rate, it is possible to estimate the contribution of polarization losses from emittance growth and lattice effect.

POLARIZATION DECAY AND PROFILES

Polarized proton collisions were used in 2015 at 100 GeV and 2017 at 255 GeV, respectively. For the 100 GeV operation, the e-lens [6] was first used successfully and the bunch intensity was increased. Special lattice design for the ramp has been carried out to mitigate the polarization loss on the energy ramp. At store, the polarization life time is worse in the blue ring than in the yellow ring as shown in Fig. 1. The slope is much stronger in blue, which results in lower overall polarization. Nevertheless, the agreement between vertical and horizontal targets is within error bars. The jet polarization from many stores was also analyzed with 2 hour segments. The derived polarization decay was similar to the results of Fig. 1.

Similar to the beam polarization, the polarization profiles as function of store time can also be derived from the averaged polarization profiles. Figure 2 shows the polarization profile ratios. The overall trend for R is getting larger over time in store, indicating polarization losses are associated with the betatron amplitude (steeper polarization profiles).

The similar data analysis was also done for 255 GeV operation in 2017. The polarization decay and polarization

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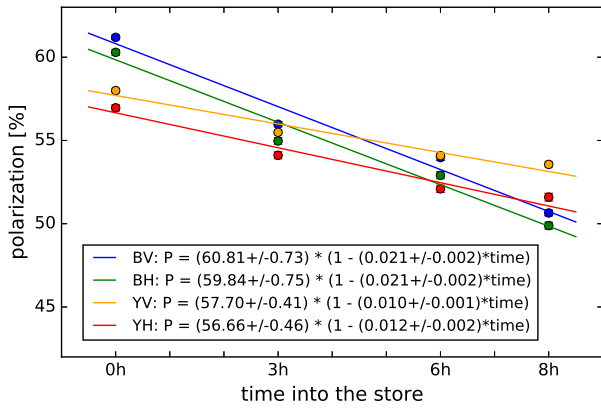


Figure 1: Polarization as function of time in both rings at 100 GeV from vertical and horizontal targets.

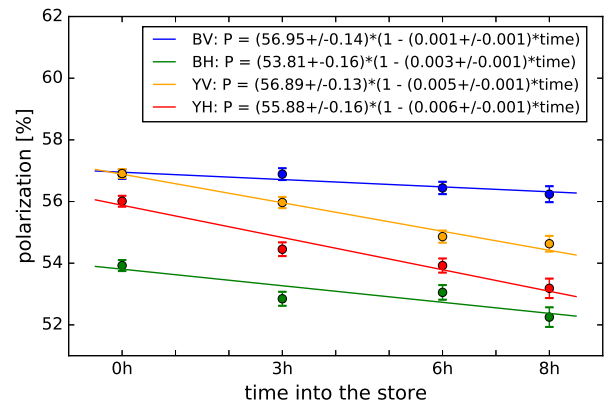


Figure 3: Polarization as function of time in both rings at 255 GeV from vertical and horizontal targets.

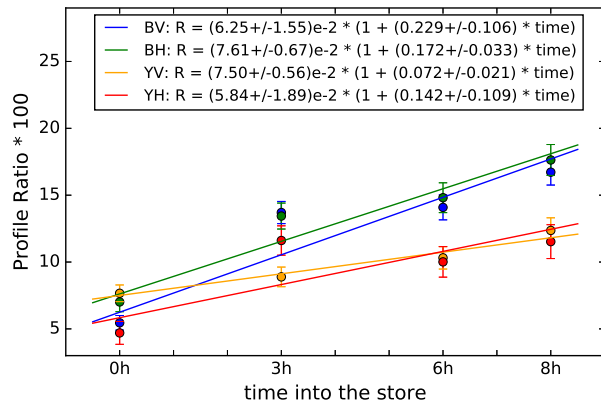


Figure 2: Profile ratios from vertical and horizontal targets at 100 GeV.

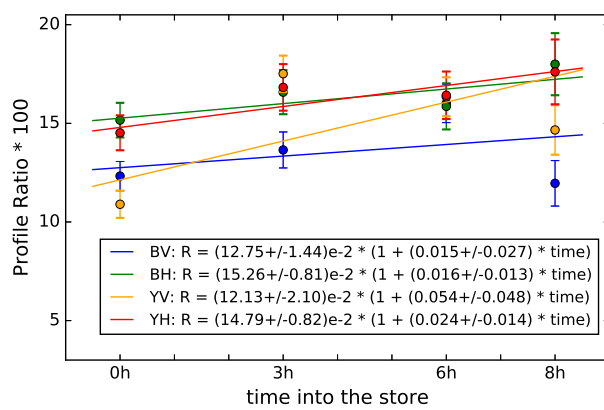


Figure 4: Profile ratios from vertical and horizontal targets at 255 GeV.

profile evolution are in Figs. 3-4. Since both e-lens and spin rotators were not used in 2017, the lattices at store were different from 2015. The jet polarization from many stores was also analyzed with 2 hour segments. The derived polarization decay was similar to the above analyses, consistent with a much smaller slope than that of 2015. Although the depolarizing resonance strength goes up with energy, the lattice design can reduce these resonance strengths at store. The smaller polarization loss at store is a result of careful lattice design.

Errors shown in Figs. 1-4 include a correction $\sqrt{\chi^2/NDF}$ to account for nonlinearity of the polarization and profile dependence on time. Such a correction may be attributed to the systematic errors.

POLARIZATION DECAY AND LATTICES

For round polarization profiles in both planes, the whole beam polarization P_{ave} is given by [3]

$$P_{ave} = \frac{P_0}{(1 + R)^2} \quad (2)$$

where P_0 is the polarization with zero emittance. As Figs. 2 and 4 show, the R values are linearly growing as function

of time in the RHIC store. This means that the polarization of the whole beam is going down with time (Eq. 2). The polarization profiles are developed in the AGS and RHIC during acceleration. At the beginning of the store, R is non-zero. Due to additional polarization losses between 100 GeV and 255 GeV, the polarization profile is stronger (larger R) at 255 GeV. The polarization loss at store could have several sources. There are still snake resonances at stores, so that the working point needs to be away from the resonance lines. Due to finite sizes in the tune spread, some particles with larger amplitude experience stronger resonance strength and more polarization loss. Consequently, the polarization profile parameter R gets larger during a store. As Eq.(1) shows, the whole beam polarization loss can come from two sources: either the particles move to a larger betatron amplitude and encounter a stronger resonance strength, or additional polarization loss at the same betatron amplitude. The second one is due to stronger high order depolarizing resonances at store energy, which is a measure for the lattice quality. Since the emittance dependence on time can be derived from the RHIC IPM measurement, the dependence of the polarization profile on time can be estimated.

As a simple estimation, we assume round beam and polarization profiles. Furthermore, the time dependence of these

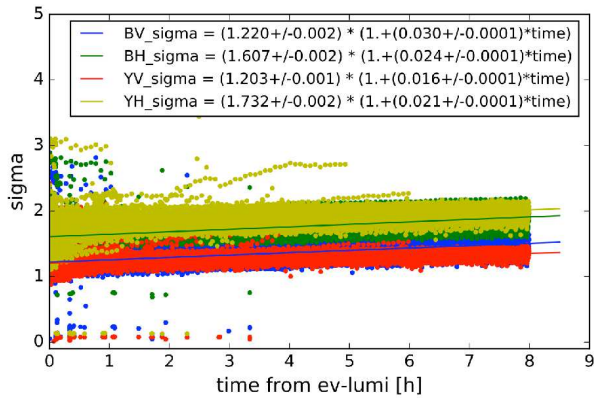


Figure 5: The beam sigmas from RHIC IPM in both rings for all physics stores in the run15 pp running period. The linear fits are for data points with store time up to 8 hours.

quantities are assumed to be linear. R values vs. time in store can be linearly fitted as function of time:

$$R \approx R_0(1 + a_r t) \approx \left[\frac{\sigma_{b0}(1 + a_b t)}{\sigma_{p0}(1 - a_p t)} \right]^2 \quad (3)$$

or

$$(1 - a_p t) = \frac{(1 + a_b t)}{\sqrt{(1 + a_r t)}} \approx 1 + (a_b - \frac{a_r}{2})t \quad (4)$$

In general, the emittance will grow over time and the polarization profile will be sharper over time. In the above equation, both a_b and a_p will be positive numbers. The polarization profile increase (reduction of σ_p) factor a_p is given by

$$a_p = -(a_b - \frac{a_r}{2}) \quad (5)$$

The beam sizes at IPM locations are different from the ones at the polarimeters due to the different beta functions. But the relative time dependence slope (a_b) should be the same. We can use the slopes derived at IPM locations for the analysis of beam profiles at the polarimeter locations. The beam sizes from IPM in both rings are plotted in Fig.5 for the 100 GeV operation. The initial beam sizes are similar in both rings for both planes. For the same ring, the slopes of both planes are similar, too, which justifies to average the two slopes for the analysis. With the averaged slopes for beam profiles derived from the IPM data, the slopes of polarization profiles are derived. They are listed in Table 1 together with 255 GeV data analyzed the same way. For 100 GeV data, the contributions for the yellow ring from beam emittance growth (a_b) and polarization profile decay (a_p) are similar. For the blue ring, the contribution from a_p is more than two times of that from a_b , which indicates a stronger effect from higher order depolarizing resonance effects in blue. For 255 GeV data, the contributions from stronger depolarizing

Table 1: Averaged decay parameters for blue (B) and yellow(Y) rings for 100 GeV and 255 GeV, respectively.

	a_r	$2a_b$	$2a_p$
B(100)	0.177 ± 0.031	0.054 ± 0.002	0.123 ± 0.031
Y(100)	0.074 ± 0.021	0.037 ± 0.002	0.037 ± 0.021
B(255)	0.016 ± 0.009	0.022 ± 0.005	-0.006 ± 0.010
Y(255)	0.026 ± 0.013	0.036 ± 0.002	-0.019 ± 0.014

resonance is consistent with zero within the statistical error. This implies that the effort to reduce the resonance strength for 2017 paid off. In addition, the 255 GeV run in 2017 was done without spin rotators as physics required transverse polarization, which also helped.

There are two sources for the polarization loss related to the beam betatron motion: emittance growth, and the polarization loss due to (high order) depolarizing resonances. The contributions from the two sources are quantified from this analysis. As the results for the blue ring at 100 GeV show, the fast blue polarization decay problem comes from two sources: somewhat faster emittance growth but mainly stronger effect from depolarizing resonances at stores. It is worthwhile to consider a spin simulation study with realistic lattices to compare with these results.

SUMMARY

The polarization decay and polarization profile development (R value) were analyzed by combining polarization measurements from many stores. The polarization decay and polarization evolution are consistent from vertical and horizontal targets. The time dependence of these quantities provides source information about the polarization loss. Although transverse emittance growth during store is an apparent factor, the additional polarization loss is related to the lattice and working point. The difference among various lattices implies that the effect can be mitigated by a careful selection of working point and lattice design. Further simulation with various realistic lattices can be compared with these results and lead to better polarization at RHIC store.

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