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Luminosity issues in 2009 100 GeV polarized proton run

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Abstract

Several luminosity issues are reviewed. Questions remain, which are stated for further investigation. Some suggestions are made for possible luminosity improvement.

1 Introduction

There are several factors affecting the luminosity in 2009 100 GeV polarized proton run.

1. The highest bunch intensity at RHIC early store (1.5 hour after accramp in this note) in 2009 is 1.25×10^{11} protons. In 2008 run, it was 1.42×10^{11} protons, which gives rise to 30% higher luminosity if other conditions are the same. Yellow ramp efficiency is identified as one of the main problem. Meanwhile, the beam-beam induced loss in about 1 hour into collision accounts actually no less than the ramp.

2. The typical transverse emittance at early store is 13 $\pi\mu m$ for bunch intensity of 10^{11} protons, but it is 17 $\pi\mu m$ for 1.25×10^{11} protons. The increase of the emittance implies a 30% difference in luminosity if other conditions are the same. The emittance growth with electron cloud below instability threshold may be partially responsible. Meanwhile, the Booster scraping may also be relevant.

3. The luminosity lifetime in 2009 run is significantly lower than that in 2005, 2006, and 2008 runs. At the beam-beam parameter of 0.01, the typical average luminosity lifetime in early store is 10 hours in 2009, and it is 15 hours in previous runs. Given 8 hours of store time, this implies more than 20% of the difference in integrated luminosity. The 0.7 m betastar adopted in 2009 might be relevant, but the evidence is not fully convincing. On the other hand, the continuing RF voltage ramp in store may be of concern.

4. In the last month of the run, the polarization at RHIC early store is declined from 60% to 55%, a 30% reduction in p^4 factor. It is noted that the Booster scraping is reduced in order to increase bunch intensity at RHIC, and the source polarization is also declined at the same time.

Questions regarding these issues are discussed, and some suggestions are made.

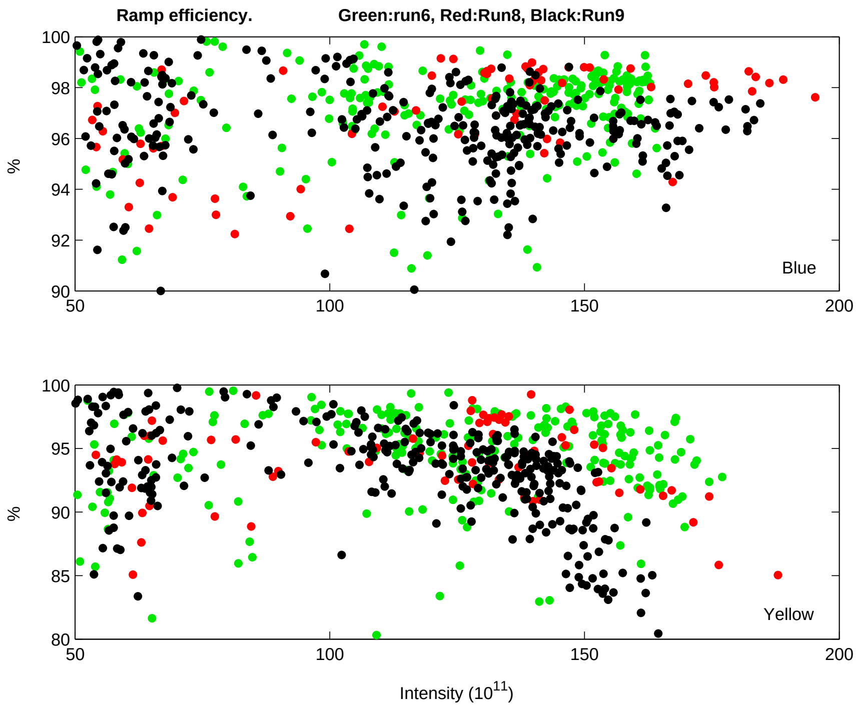

Figure 1: Blue and Yellow ramp efficiency vs. intensity in Run6, Run8, and Run9. The 6 Yellow ramps with the highest intensity in Run9 are short fills.

2 Intensity

2.1 Yellow ramp efficiency

In Fig.1, both Blue and Yellow ramp efficiency is shown for Run6, Run8, and Run9.

At high intensity, the Yellow is in general not as good as Blue, and the Run9 is worse than Run6 and Run8. The sharp decline of the Run9 Yellow efficiency at around 160×10^{11} protons is worth a closer look. The 6 fills with the highest Yellow intensity, $> 160 \times 10^{11}$, are not long fills. There are total 10 physics fills with lower intensity, but larger than 153×10^{11}. For these 16 fills, average ramp efficiency and the loss in the early 40 seconds of the ramp are shown in Table 1.

Yellow 09	Intensity	Ramp efficiency	40-second loss
	10^{11}	%	%
6 short fills	161.4 - 164.7	84.2	9.7
10 physics fills	153.3 -159.3	86.8	7.1

Table 1. Average ramp efficiency and the loss in early 40 seconds of the ramp for high intensity Yellow fills

The 40-second loss is also shown in Run6 and Run8, but in less degrees. For Golden fills 7909 in Run6 and 9989 in Run8, both with intensity $> 170 \times 10^{11}$, the 40-second loss is 3.5% and 8.0%, respectively.

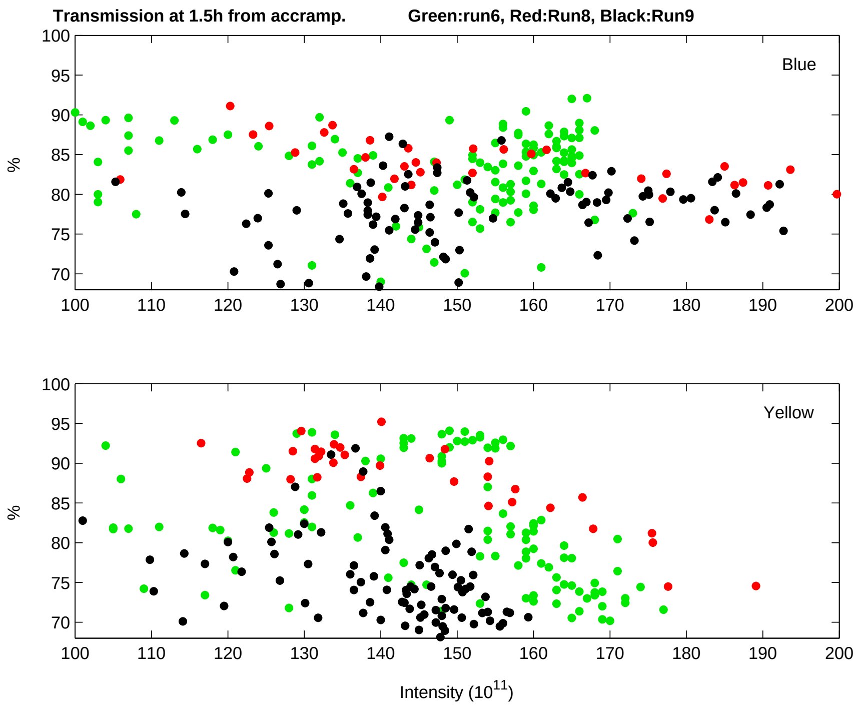

Figure 2: Blue and Yellow transmission at 1.5 hour from accramp (mainly the combined ramp efficiency and beam-beam effect at early store) in Run6, Run8, and Run9. Run8 and Run9 have same working point in store, the Blue transmission is similar, but not Yellow.

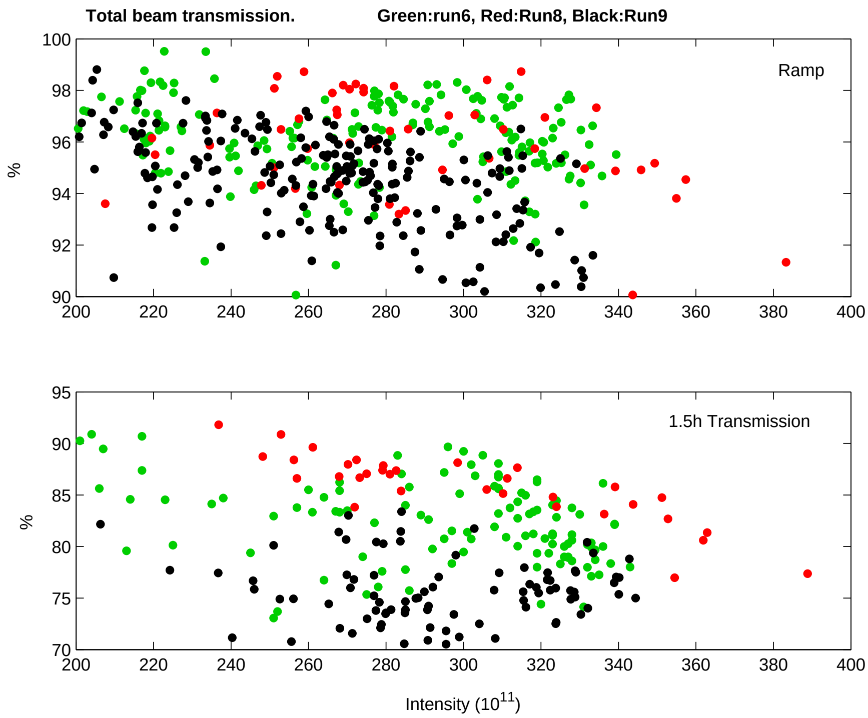

Figure 3: Total beam ramp efficiency and the 1.5 hour transmission in Run6, Run8, and Run9. Both are similar for Run6 and Run8, but Run9 is not as good. Intensity for ramp efficiency is taken at accramp, and for 1.5 hour transmission is at the end of injection.

It is also shown in Fig.1 that in Run6, the Yellow ramp efficiency could be better than 95% for 170×10^{11} protons, and the tuning of the RF voltage during the early ramp has been proven relevant [1].

2.2 Beam-beam caused loss

Once beam is put in collision, the beam-beam induced loss is high in about an hour. In Table 2, the average beam-beam loss, estimated from the 1.5 hour transmission and the ramp efficiency, is shown for the 10 physics fills with highest Yellow intensity.

Yellow 09	Intensity	Ramp efficiency	1.5h transmission	beam-beam
	10^{11}	%	%	%
10 physics fills	153.3 -159.3	86.8	70.3	81.0

Table 2. Estimated efficiency due to beam-beam interaction (column 5) in early store once beam in collision

In Fig.2, both Blue and Yellow transmission at 1.5 hour is shown for Run6, Run8, and Run9 physics fills. Compared with Fig.1 of the ramp efficiency, the beam-beam induced loss can be estimated.

In Run6, the effect of the horizontal 2/3 resonance on the beam-beam induced loss has been clearly demonstrated. In the early Run6, the Yellow had the working point of (H/V=0.693/0.686), which is away from the 2/3 resonance, but the Blue is above the diagonal in the tune space and close to the resonance. In the later run (from Fill 7823), the working point is swapped for Yellow and Blue. This effect can be clearly identified from Fig.2, where the big change of Blue and Yellow 1.5 hour transmission around the intensity of 155×10^{11} is because of this working point swap (most later fills have higher intensity).

In Run8, setting both Blue and Yellow at the working point of (0.695/0.685) has been successful, and the large difference of Blue and Yellow transmission is disappeared, shown in Fig.2. The evaluation of the total beam (Blue + Yellow) shows that, however, the beam-beam induced loss in Run8 is about the same as Run6. This is shown in Fig.3, where the total beam ramp efficiency from FDAView and the 1.5 hour transmission are shown. It seems that both the ramp efficiency and the 1.5 hour transmission of the total beam in Run6 and Run8 are very similar. It is possible that the coherent beam-beam mode (π-mode) due to similar tune in Run8 is taking effect. This mode has been clearly observed in Run9, however, it is only shown in vertical, not in horizontal.

The same working point as Run8 is adopted in Run9. From Fig.2, one may observe that the Blue beam 1.5 hour transmission is the same as that in Run8, but the Yellow beam-beam induced loss is apparently worse. An interesting question is why the Yellow suffered both in the ramp and the beam-beam effect in Run9, and Blue is not.

Fig.4 shows that in the entire run9, 3 fills are above the line of the 1.5 hour transmission achieved by all other fills. The beam transmission of 10689, 690, and 781 can be compared with Run6 and Run8 in this regard. The working point of 10689 is (BH/BV=0.695/0.688) and (YH/YV=0.691/0.677) at early store. However, many other fills seem to have similar working point, and the transmission are not as good.

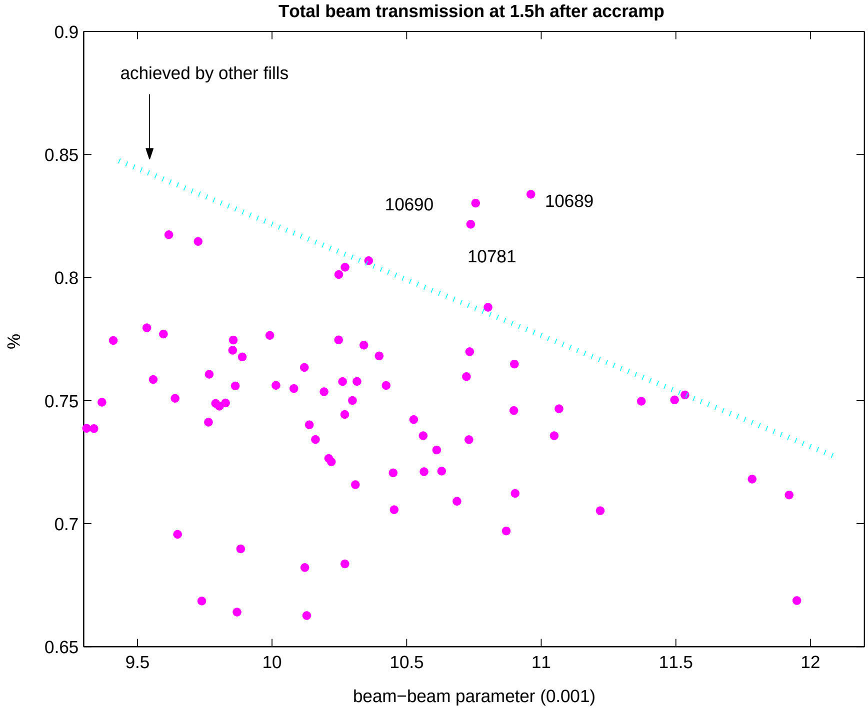

Figure 4: 3 fills are above the line of the 1.5 hour transmission vs. the beam-beam parameter achieved by all other fills in Run9.

3 Emittance

3.1 Dependence on bunch intensity

The beam emittance growth with respect to bunch intensity in Run9 is shown in Fig.5, where the emittance is calculated using the experiment PHENIX ZDC [2]. The typical normalized emittance at early store is 13 $\pi\mu m$ for bunch intensity of 10^{11} protons, but it is 17 $\pi\mu m$ for 1.25×10^{11} protons. The emittance growth threshold looks like at 10^{11} protons per bunch.

It is interesting to note that Fill 10864, with 64 bunches, has lower emittance than the line achieved by all 109-bunch fills in Run9. This seems to indicate that the electron cloud below the instability threshold has played a role in the emittance growth with high intensity. It has been observed in RHIC proton runs that with the average electron density of 10^{10} $/m^3$ in the rings, the beam emittance can grow as much as 20 $\pi\mu m$ in an hour [2]. At highest intensity physics fills in Run6, Run8, and Run9, the average electron density is in the order of 10^9 $/m^3$ in the rings. The emittance growth with high intensity in these runs has been observed in a similar pattern as that shown in Fig.5.

3.2 Booster scraping effect

It was observed that the Booster vertical scraping has an effect on the beam emittance at RHIC in Run6 and Run8 [3,4].

In the last month of Run9, the RHIC bunch intensity is increased from 0.9×10^{11} to 1.25×10^{11} protons, which is achieved mainly by reducing the Booster scraping. In Fig.6,

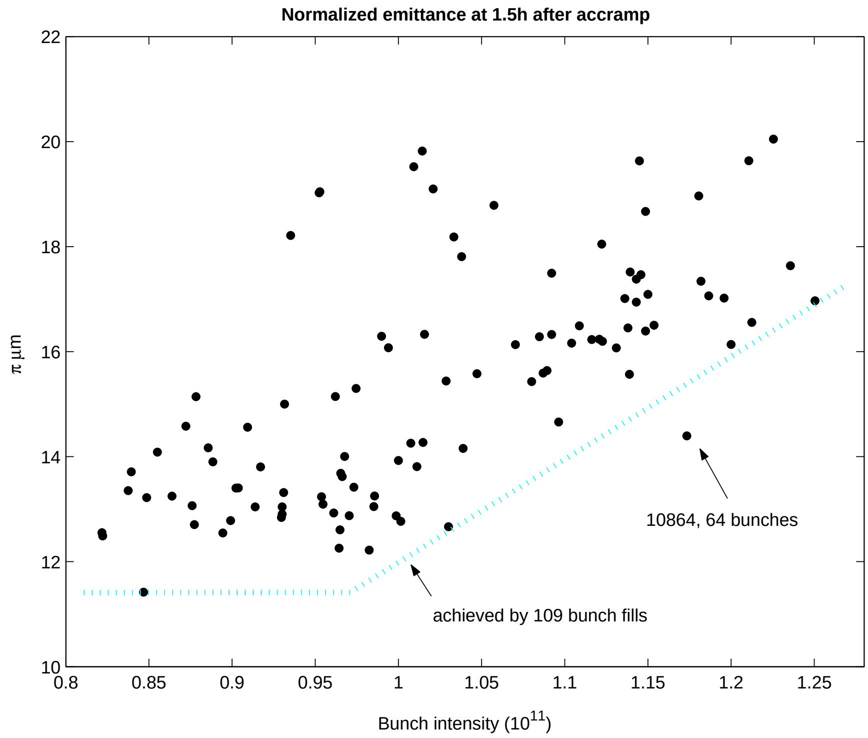

Figure 5: The beam normalized emittance at early RHIC store in Run9. There is a dependence on bunch intensity.

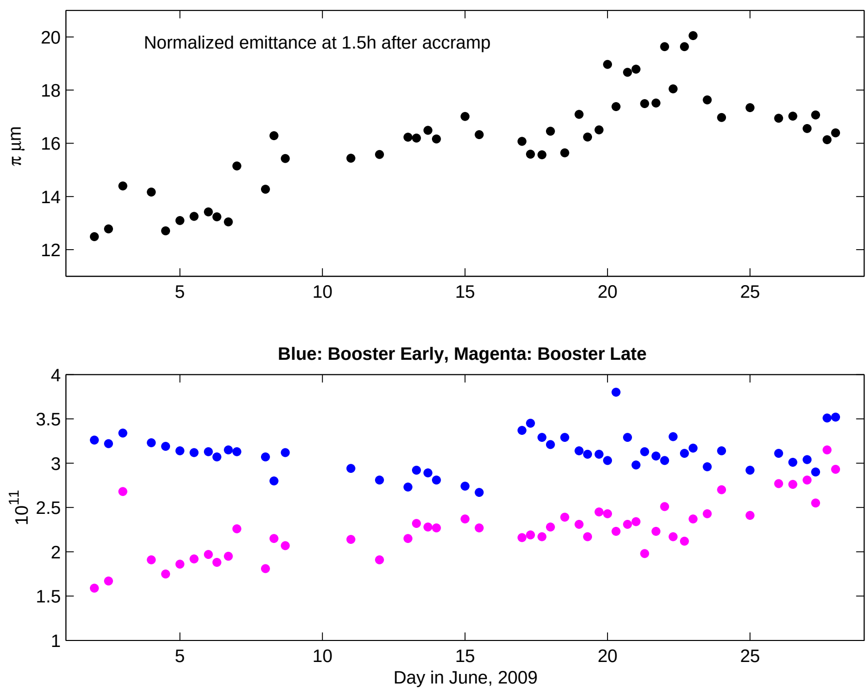

Figure 6: The beam emittance at RHIC and the Booster early and late intensities are shown for June, 2009. The Booster scraping is gradually reduced during the period.

the beam emittance at RHIC and the Booster early and late intensities are shown for June, 2009. The Booster scraping can be viewed as the ratio of Booster early/late. The higher the ratio, the larger the scraping. This ratio has been gradually reduced during June, and the emittance is on the rise.

It is not clear how much the emittance growth in RHIC is due to the reduced Booster scraping. One may argue that there are other mechanism to explain the emittance growth with higher intensity. However, in Run6, it has been demonstrated that the emittance growth can be kept small for RHIC injection bunch intensity from 1.3×10^{11} to 1.55×10^{11} protons (approximately the bunch intensity at early store of 1.05×10^{11} to 1.25×10^{11} protons) by increasing the Booster scraping [3, Figure 2].

4 Luminosity Lifetime

4.1 Luminosity lifetime

Beam-beam interaction has been a dominant factor in the luminosity lifetime, observed in the past proton runs in RHIC. From Run5, Run6, and Run8, the best achieved luminosity lifetime with respect to the beam-beam parameter is lined up, which is shown in Fig.7. Note that most fills are below this line, indicating complications in the machine tuning at store.

The luminosity lifetime in Run9 is significantly lower than previous runs. At the later run period, all Run6, Run8 and Run9 fills are clustered around the beam-beam parameter 0.01, and the typical luminosity lifetime is 15 hours for Run6 and Run8, but it is 10 hours for Run9.

The intensity lifetime (or beam loss) and the emittance growth are the two main factors in luminosity lifetime. Despite the aligned beam-beam dependent luminosity lifetime, the roles played by the beam loss and the emittance growth is not well understood. This is illustrated in Table 3, where for each run, 10 fills with highest bunch intensity in the later 20 physics fills are selected (including the Golden fills in each run), and the average bunch intensity, the beam-beam parameter, the Blue and Yellow lifetime, the emittance growth rate, and the luminosity lifetime are shown.

Average of 10 fills	Run6	Run8	Run9
Bunch intensity, 10^{11}	1.25	1.35	1.21
Beam-beam parameter, 0.001	10.3	9.7	10.0
Blue lifetime, hour	59.2	70.3	47.3
Yellow lifetime, hour	49.5	107.1	28.6
Intensity lifetime, hour	50.9	79.8	35.9
Emittance growth, %/hour	4.9	5.5	7.9
Luminosity lifetime, hour	13.8	15.7	10.1

Table 3. Averaged parameter of 10 physics fills with the highest bunch intensity in later Run6, Run8, and Run9.

Although Run6 and Run8 have similar luminosity lifetime, the intensity lifetime is significantly different, i.e., the intensity lifetime in Run8 is about 60% better than Run6.

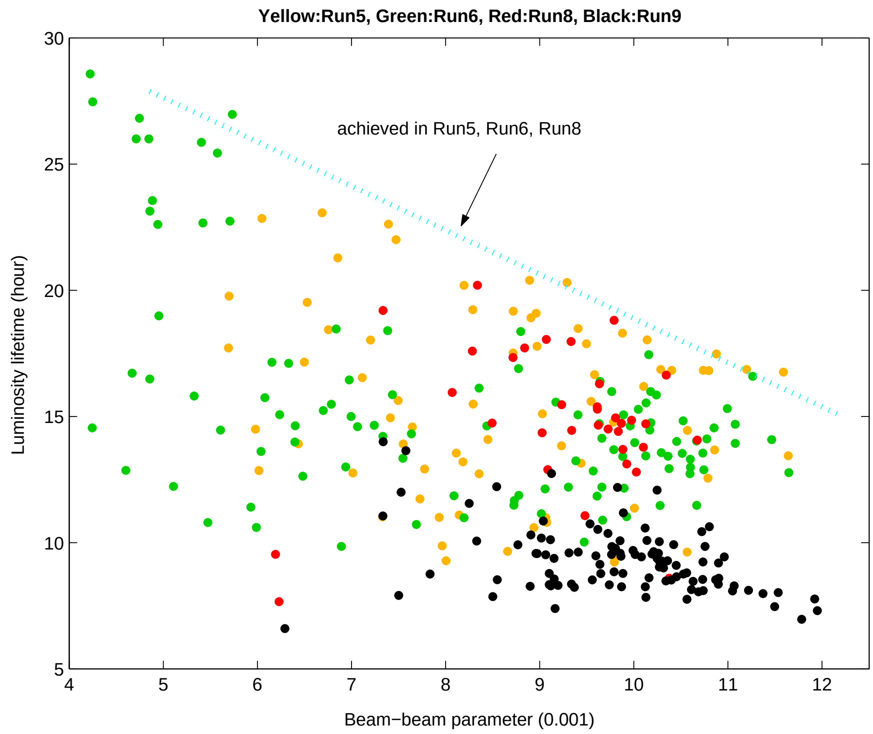

Figure 7: The luminosity lifetime with respect to the beam-beam parameter in Run5, Run6, Run8, and Run9. The Run9 luminosity lifetime is significantly lower than that achieved in previous runs.

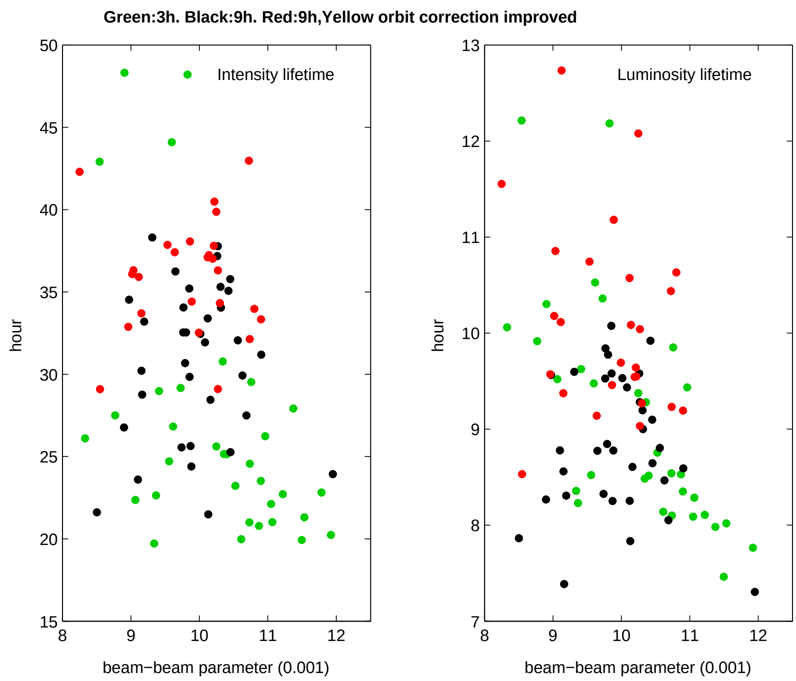

Figure 8: Intensity and luminosity lifetime in Run9, for 3 hour, 9 hour RF voltage ramp at store, and with 9 hour ramp and improved Yellow orbit correction.

With the same lattice, one can only look for the difference in the machine tuning in store. Similarly, better understanding is needed for the difference between the Run9 and Run8.

4.2 Effect of RF voltage ramp and Yellow orbit correction

The RF voltage ramping in store is used for the entire Run9. In the early run, RF voltage is ramped from 150 kV to 400 kV in 3 hours at early store, and later it is ramped to 300 kV in 9 hours. With continually changed RF bucket, protons manage to settle down in phase space, with a long time constant. This might explain that the beam decay in Run9 never reached the level in Run6 and Run8, where both Blue and Yellow decay can be at 1% per hour. It is noticed that even with the steady bucket, the beam decay usually takes more than one hour to settle down. The machine tuning at store is difficult, with the ramping RF voltage it is harder.

Some difference of the intensity lifetime and the emittance growth have been observed for 3 hour and 9 hour ramp. Also, the Yellow orbit correction was not optimized for a large part of the run, which has also affected the intensity and therefore the luminosity lifetime. This is shown in Fig.8. The typical intensity lifetime at the beam-beam parameter of 0.01 is 25, 35, and 37 hour for the 3 hour, 9 hour, and 9 hour plus Yellow orbit correction improvement. The better orbit correction has increased luminosity lifetime by about an hour.

5 Polarization

5.1 Effect of intensity and source polarization

In Fig.9, the Blue polarization measured at RHIC early collision is shown for the entire Run9, and the RHIC bunch intensity and the source polarization are also shown for comparison. The effect of the source polarization on the RHIC has been observed in the entire Run9. The effect of the bunch intensity is more clearly demonstrated during the last month in the run. It has been shown in Fig.6 that during that period, the Booster scraping is reduced in order to increase the intensity. Since the source polarization is also declining at the same time, it is difficult to identify how much each mechanism is responsible for the decline of the RHIC polarization. Therefore, the Run6 and Run8 experience review might be helpful.

5.2 Review of Booster scraping effect

In Fig.10, the Blue beam polarization at RHIC early store and the Booster setting in the last month of Run6, Run8 and Run9 are shown. The Booster early and Booster late intensities show the degree of the scraping. Note that the source polarization is almost constant in the Run6, but it is not as flat in Run8 and Run9.

In Run6, for the increase of the RHIC intensity in the later run, the Booster injection and early intensity is increased, and the Booster scraping is not decreased, but increased. This seems to help the RHIC polarization improvement.

In both later Run8 and Run9, the reduced Booster scraping is used for the higher intensity in RHIC, the polarization is in general not improved, but declined.

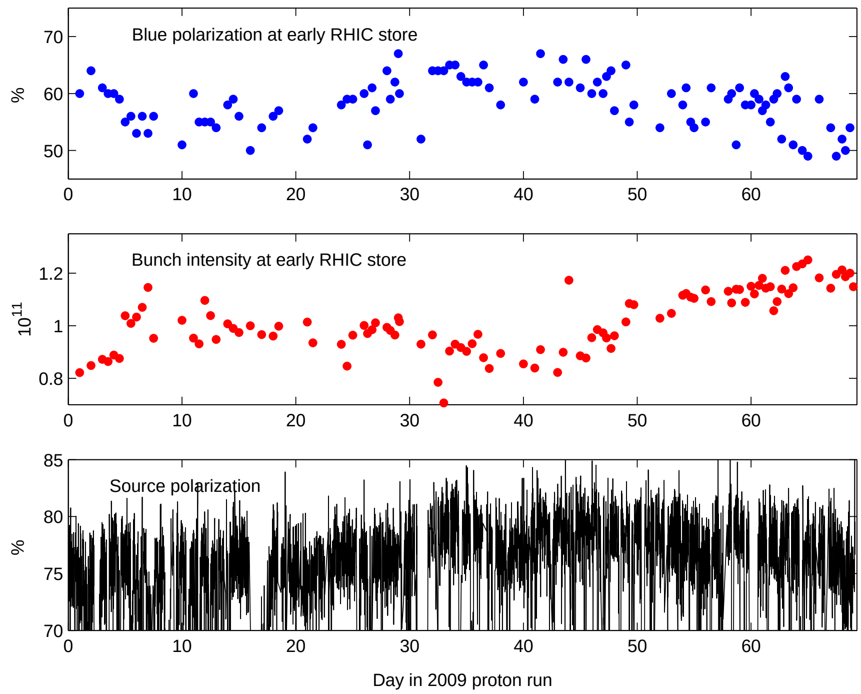

Figure 9: The Blue polarization at RHIC early collision, and the RHIC bunch intensity and the source polarization in Run9 for comparison.

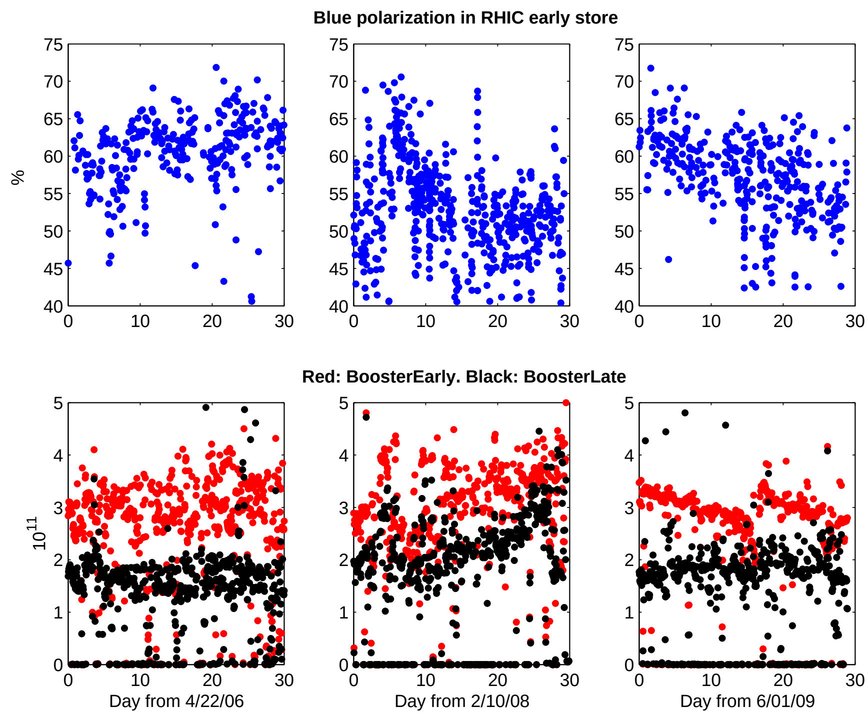

Figure 10: The Blue polarization at RHIC early store and the Booster setting in the last month of Run6, Run8 and Run9.

6 Questions and suggestions

The Yellow ramp efficiency is affected by the 40-second loss, which shows a dependence on intensity. This loss is also seen in Run6, and it was improved by the RF voltage tuning.

The Yellow loss at early store due to beam-beam interaction is also worse than in Run6 and Run8. However, Blue 1.5 hour transmission in Run9, which is a combined ramp efficiency and beam-beam effect in early store, is identical to Run8. So if dynamic aperture due to the 0.7 m betastar in Run9 is a limit, it is not for Blue. One may further ask: if the dynamic aperture is a problem for Yellow but not for Blue, then why Blue and Yellow decay are the same in the store in Run9?

The RHIC emittance growth happens in the later Run9, when the Blue intensity is pushed from 150×10^{11} to more than 200×10^{11} protons. A beam scrubbing could be applied to at least identify the relevance of the electron cloud on the emittance growth.

During the last month in Run9, the Booster vertical scraping is reduced for the intensity push. The Run6 experience shows that by increasing the scraping, the emittance could be kept almost constant for higher intensity, up to 1.55×10^{11} protons at the RHIC injection.

The luminosity lifetime is significantly lower than the previous proton runs. Study results for dynamic aperture limit due to beta squeeze are not fully convincing. The settling of decay at store has a long time constant, the continuing changed bucket only increase the difficulty in the store tuning. It is suggested to use the steady bucket at store, like that in Run6 and Run8.

The source polarization has been affecting the RHIC in the entire run. On the other hand, the Booster setting that used in Run6, i.e., not reducing the Booster scraping, may help to prevent the RHIC beam polarization from decline.

7 Acknowledgment

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