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RHIC 100 GeV Polarized Proton Luminosity

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Abstract

A big problem in RHIC 100 GeV proton run 2009 was the significantly lower luminosity lifetime than all previous runs. It is shown in this note that the beam intensity decay in run 2009 is caused by the RF voltage ramping in store. It is also shown that the beam decay is not clearly related to the beam momentum spread, therefore, not directly due to the 0.7m β^*. Furthermore, the most important factor regarding the low luminosity lifetime is the faster transverse emittance growth in store, which is also much worse than the previous runs, and is also related to the RF ramping. In 100 GeV proton run 2012a, the RF ramping was abandoned, but the β^* was increased to 0.85m, with more than 20% loss of luminosity, which is not necessary. It is strongly suggested to use smaller β^* in 100 GeV polarized proton run 2015/2016.

1 Introduction

There are several problems affecting the luminosity and polarization in 100 GeV proton run 2009.

Since the LINAC tank 9 pulse width is limited to 300 μs, from 400 μs used before, the Booster input intensity is limited to 4×10^{11} protons in run 2009. When the RHIC bunch intensity is pushed from 1.3×10^{11} to 1.6×10^{11}, the Booster scraping ratio has to be reduced from 2.1 to 1.4. As the result, the RHIC polarization is reduced from $> 60\%$ at low intensity to 50% at high intensity, and the RHIC transverse emittance is increased from 13 $\pi\mu m$ to 18 $\pi\mu m$, at the same time.

These problems have been reported in [1], but not yet fully resolved. For example, the LINAC tank 9 pulse is still limited at 300 μs in run 2013.

This is why a more complete discussion, including the RHIC polarization and transverse emittance problems in run 2013, is reported in [2]. As a brief summary of the significant

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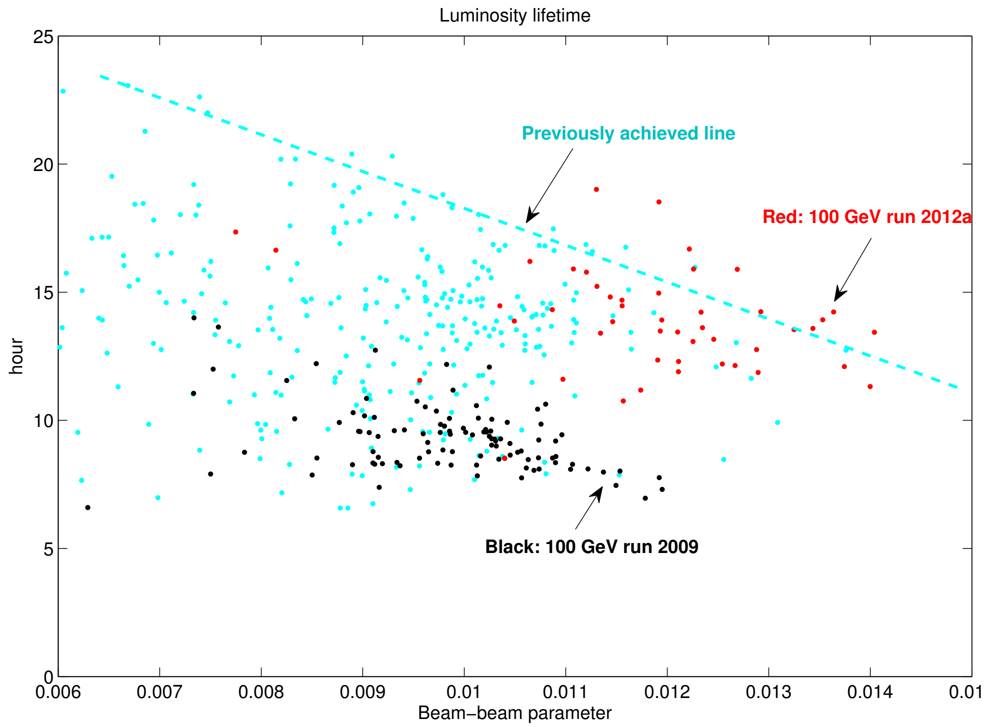

Figure 1: Luminosity lifetime vs. initial beam-beam parameter. The luminosity lifetime in 100 GeV run 2009 is much lower than the all previous runs. It is also much lower than run 2012a.

effect of the Booster scraping on RHIC polarization and luminosity in run 2009, Figure 4 and Figure 8 in [2] are plotted for comparisons with the better run 2006.

Another big problem in run 2009 is the much lower luminosity lifetime, only about a half of the previous 100 GeV proton runs, which then become a luminosity limiting factor.

In 100 GeV proton run 2012a, the luminosity lifetime is no longer a problem, shown in Fig.1.

There are two major changes in run 2012a. The first is that the RF voltage ramping used in run 2009 is abandoned. The second is the 0.7m β^* used in run 2009 is relaxed to 0.85m, with more than 20% luminosity sacrificed.

In this note, it is shown that the beam intensity decay in run 2009 is closely related to the RF voltage ramping in store.

It is also shown that the beam decay is not related to the beam momentum spread defined as usual. Since the beam momentum spread is one of the most important parameter in defining dynamic aperture, it is argued that the dynamic aperture of 0.7m β^* in run 2009 played very little role in the beam loss.

Perhaps even more importantly, the beam loss is not the most important factor leading to the much lower luminosity lifetime in run 2009. The faster transverse emittance growth in store is actually the dominant factor for the low luminosity lifetime. Moreover, the transverse emittance growth in run 2009 is also much worse than the previous runs, and it is also related to the RF voltage ramping.

In section 2, the beam intensity decay in run 2009 is shown to be related to the RF voltage ramping.

In section 3, it is shown that the beam loss is not related to the beam momentum spread. Since the multiple RF harmonics is used, a closer look is needed to fully address this issue.

In section 4, the details of the faster transverse emittance growth in run 2009 is discussed.

It is important to clarify the situation in run 2009 for the machine performance problems, in order to prepare for the 100 GeV polarized protons runs 2015/2016.

As a conclusion, in 100 GeV polarized proton run 2015/2016, a smaller β^* can be used for luminosity improvement.

2 Beam decay in run 2009 is related to RF voltage ramping

In Fig.2, the beam decay of the fills 10696, 10712, and 10781 in 100 GeV run 2009, compared with the RF voltage in store, is shown.

In run 2009, for total 28 long fills from 10689 to 10782, 3-hour RF voltage ramping is used. Later from 10783 to 11006, for total 61 long fills, 9-hour RF ramping is used.

As shown in Fig.2, the beam decay is clearly related to the RF voltage ramping. In fact, in the RF ramping from 150 kV to 400 kV, after about one hour, the decay rate is somewhat settled. Then once again, after the RF voltage staying in flat, it also takes about one hour for the decay rate to settle. The difference is, this time, the decay rate is settled at about a half of that in the RF ramping.

Once the RF bucket is suddenly changed, the beam particle needs to relocate in the longitudinal phase space. Due to the synchrotron motion, it would always reach a peak momentum deviation, and if the deviation is large, i.e., with large dp/p, then the particle may get lost due to the dynamic aperture limit. Note that this limit itself is very complicated in nature.

For some particles, this process may take a long time. As we learned from the RHIC operation in many years, an hour seems to be an acceptable time for this settlement. This explains the large beam loss during about one hour into the beam collision with β^* squeezing, which happens for each RHIC fill. In the case shown in Fig.2, this process happens twice, the first is at the early collision, and the second is at the RF voltage stopped ramping.

The later decay of about 2% per hour, at the flat RF voltage, is about a half of the best decay reached in the RF voltage ramping. This can be seen an evidence that the beam decay is related to RF ramping.

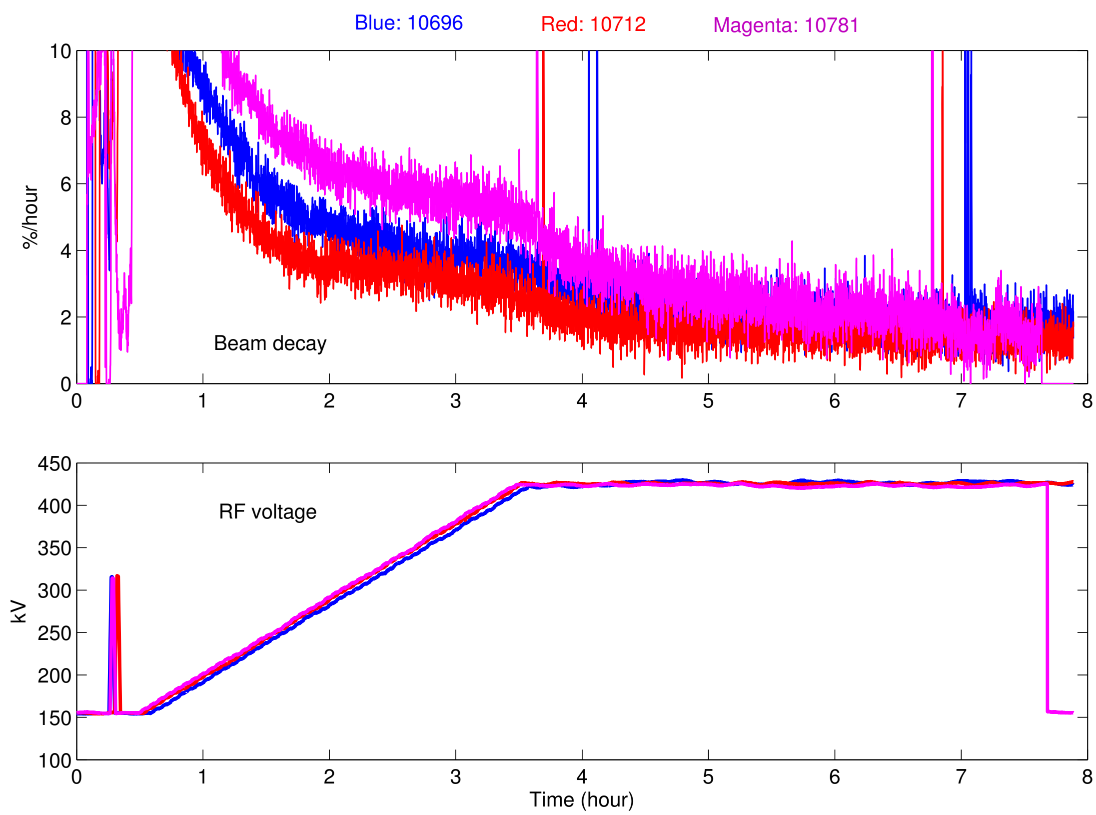

Figure 2: Beam decay of 10696, 10712, 10781 in run 2009 vs. RF voltage in store. The beam decay is closely related to the RF voltage ramping.

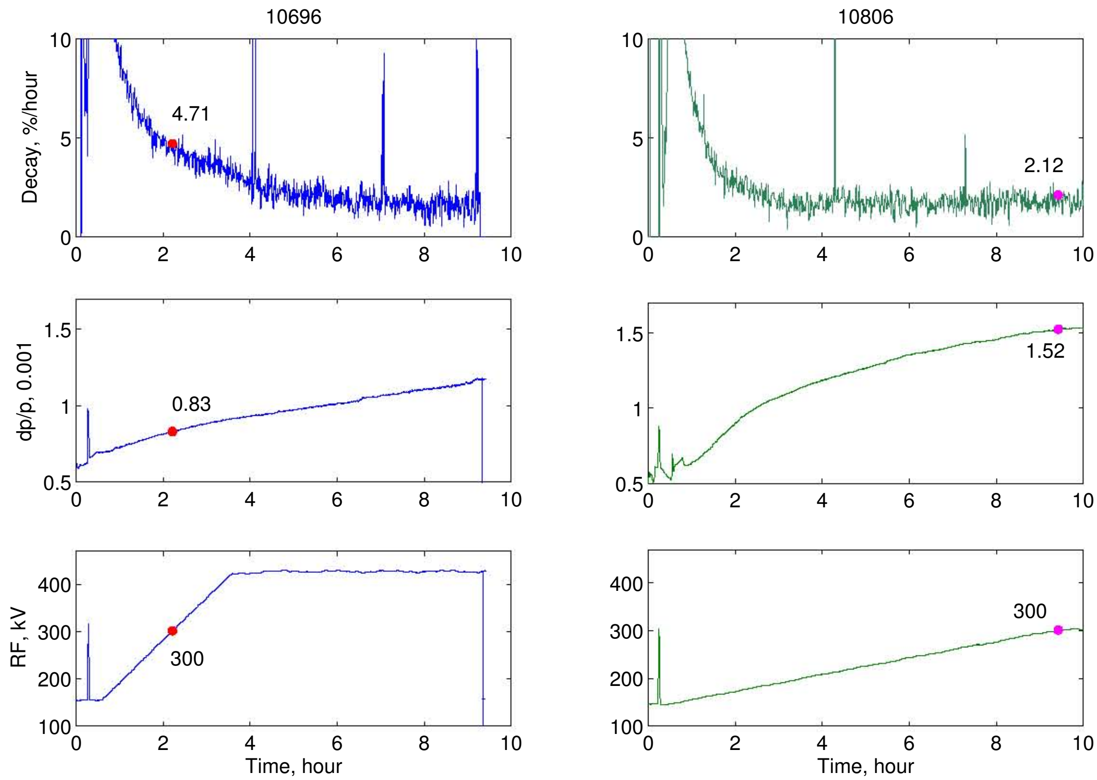

Figure 3: RF voltage, calculated beam momentum spread, and beam decay of 10696 with 3-hour ramping, and 10806 with 9-hour ramping. The points of 10696 and 10806 at 300 kV RF voltage are to compare. The beam loss is not related to the beam momentum spread.

In overall, both Blue and Yellow beam decay is the worst in run 2009, compared with the all previous runs. As the result, the RF voltage ramping in store is abandoned right after run 2009.

3 Beam decay in run 2009 is not related to momentum spread

In Fig.3, it is shown that the beam decay is not related to the beam momentum spread. Using 10696 of 3-hour RF ramping, together with 10806 of 9-hour RF ramping, this fact can be more clearly demonstrated.

The beam momentum spread, dp/p, is calculated using the RF voltage V_{rf} and the full bunch length τ_ℓ by

$$\frac{dp}{p} = \tau_\ell f_{rf} \sqrt{\frac{e\pi V_{rf}}{2h\,|\eta|\,\beta^2\gamma E_0}}$$

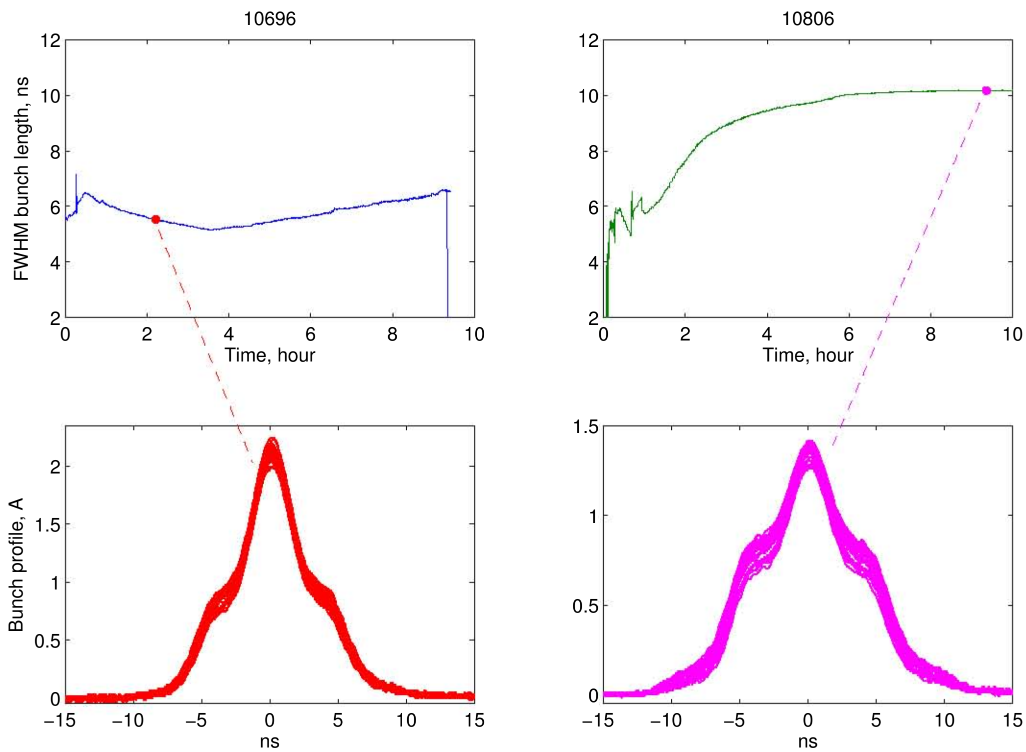

Figure 4: The FWHM bunch length of 10696 and 10806 are shown. Also, the bunch profiles at the two points with 300 kV RF voltage are shown. The bunch length of 10806 is much larger than 10696 at these points.

where h is the harmonic number, η is the slippage.

In run 2009, multiple RF harmonics is used in beam store. Here, only the dominant 28 MHz RF is used for calculation. Also, the full bunch length τ_ℓ is simply taken twice as much as the observed FWHM bunch length.

It is clear that in either 10696 and 10806, the beam momentum spread is growing all the time in store, which is not a surprise. On the other hand, the beam decay is always in decreasing.

The RF voltage at 300 kV in 10696 and 10806 is compared as an example. For 10696, the momentum spread of $dp/p = 0.83 \times 10^{-3}$ is with the decay of 4.71 %/hour, and for 10806, it is $dp/p = 1.52 \times 10^{-3}$ with the decay of 2.12 %/hour.

In Fig.4, the FWHM bunch length of 10696 and 10806, together with the bunch profile at the time, are shown. The FWHM bunch length is measured as the Full Width Half Magnitude, and therefore, it carries sometime large error. However, it is still a usable indicator of the full bunch length, and hence for the beam momentum spread calculation.

In Fig.5, the particle distribution in phase space, together with the line density, is used to match the two points of 10696 and 10806 discussed above. The line density can be, approximately, compared with the bunch profiles shown in Fig.4. From the particle

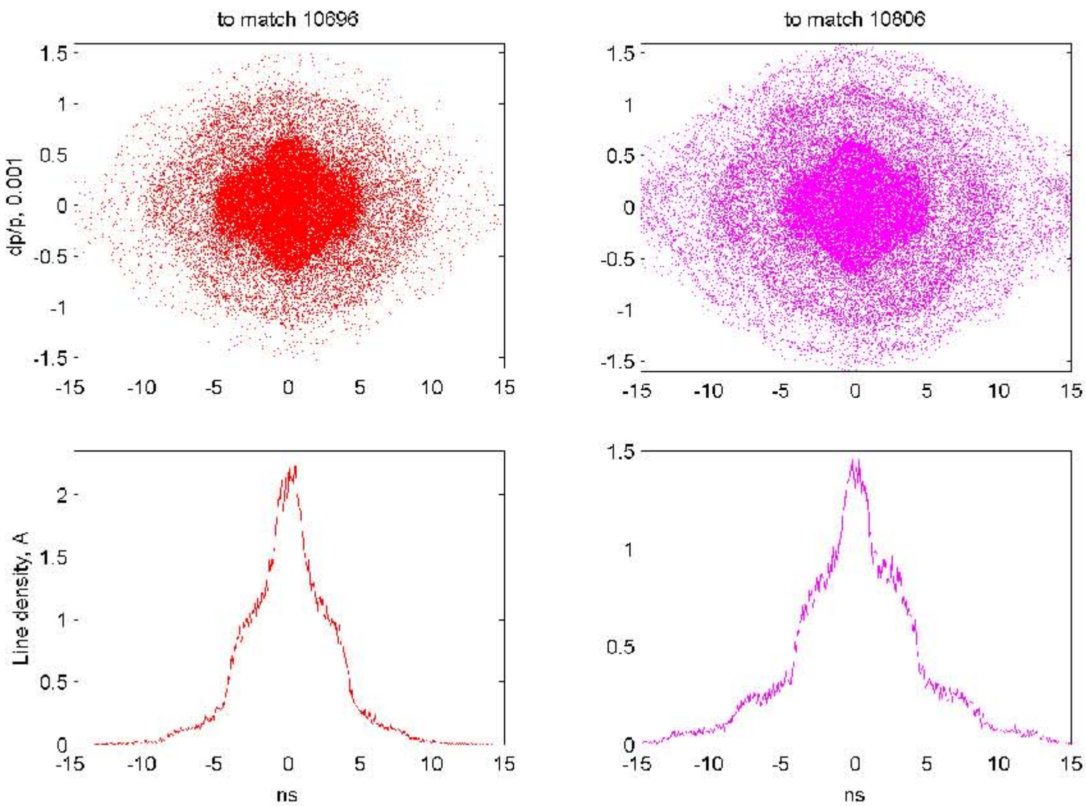

Figure 5: To match the bunch profile in Figure 4, particle distribution in the longitudinal phase space is created by a simulation, with 300 kV of 28 MHz and 150 kV of 197 MHz. It is shown that the momentum spread of 10806 is clearly larger than 10696.

distribution in phase space, it looks for 10696 the best estimate of the momentum spread is $dp/p \approx 1 \times 10^{-3}$, and for 10806, it would be larger than that.

Yet, the beam decay of 10696 at 300 kV is doubled of 10806, despite the fact that by any means the beam momentum spread of 10696 is quite smaller than 10806 at these points.

In defining the dynamic aperture, the β^* and the beam momentum spread are perhaps the two most important parameters. For example, in [3], Figure 2 is compared dynamic aperture with β^*, and Figure 4 is compared dynamic aperture with the beam momentum spread, dp/p.

The dynamic aperture limit in run 2009 cannot be clearly identified by the observation of the beam loss and the related beam momentum spread, as shown in Fig.3.

Nevertheless, one may conclude that the beam decay in run 2009 is not directly related to the beam momentum spread, and it seems not limited by the dynamic aperture at the momentum spread shown in Fig.3.

4 Transverse emittance growth and the RF ramping

Actually, a more important fact in run 2009 is that the dominant factor of the low luminosity lifetime is the faster transverse emittance growth in store, rather than the beam loss.

It is interesting to note that the transverse emittance growth in store in run 2009 is much worse than all the previous runs, and furthermore, it is also related to the RF voltage ramping.

In Fig.6, the transverse emittance growth in run 2009 is compared with run 2012a. The emittance growth is the average from 1.5 hour to 5.5 hour after the event of accramp, and it is calculated from the PHENIX ZDC rates.

For run 2009 fills with 3-hour RF ramping, 10689 - 10782, the average emittance growth rate is 8%/hour, and for that with 9-hour ramping, 10783 - 11006, it is 9%/hour. Both are much larger than that of run 2012a of 5%/hour. In fact, the typical transverse emittance growth in 100 GeV runs before 2009 is 4 to 5%/hour.

If the average emittance growth rate of the fills with 9-hour ramping in run 2009 is taken, then the 9%/hour emittance growth rate itself gives rise to the luminosity lifetime of only 11 hours. The beam intensity lifetime for these fills is about 30 hours. The observed average luminosity lifetime is around 9 hours.

As the comparison, 5%/hour emittance growth in run 2012a gives rise to 20 hours of the luminosity lifetime. The observed luminosity lifetime is about 15 hours.

In Fig.7, the hour-glass corrected transverse emittance of 10696, 10712, 10781 of 3-hour RF ramping in run 2009 is compared with the RF voltage. The transverse emittance growth rate during the RF voltage ramping is faster than that at the flat RF voltage.

This explains why the transverse emittance growth in run 2009 is much faster than all previous proton runs, and it is also much faster than run 2012a as well. Only in run 2009,

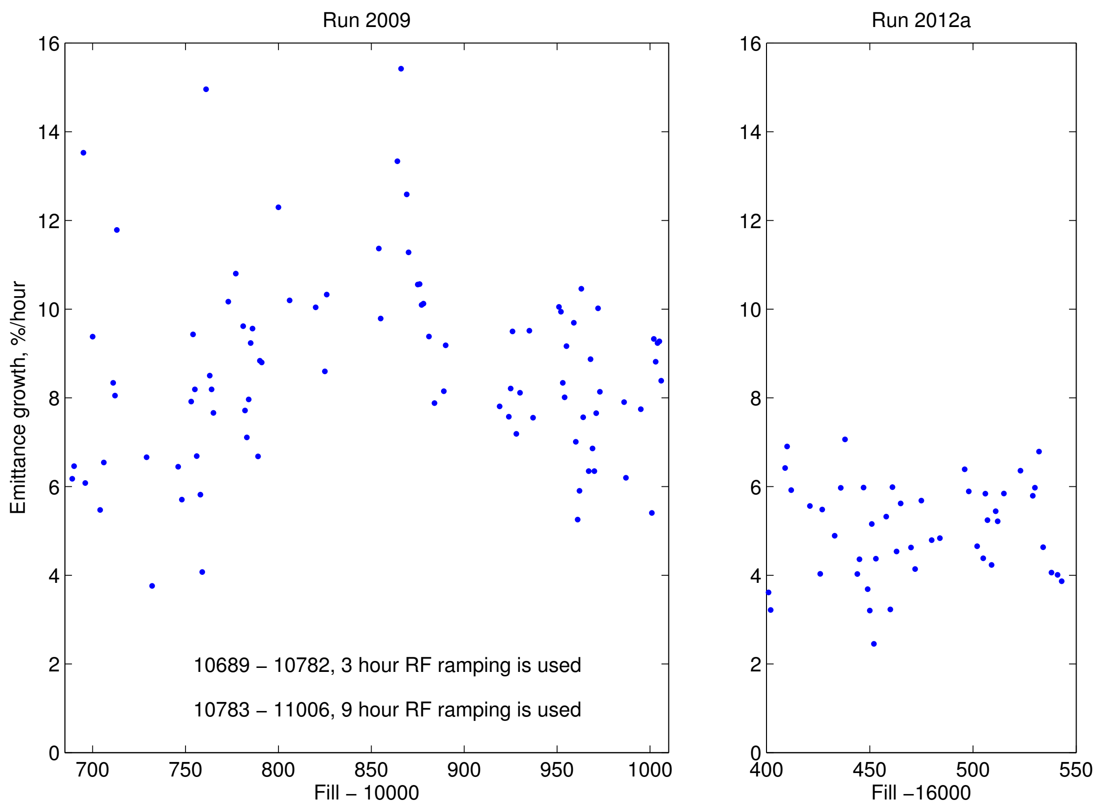

Figure 6: The transverse emittance growth rate of run 2009 is compared with run 2012a. The average emittance growth in run 2009 is 9% per hour, which itself contributes to luminosity lifetime of 11 hours. Therefore, the faster transverse emittance growth in store is the dominant factor in the low luminosity lifetime of run 2009.

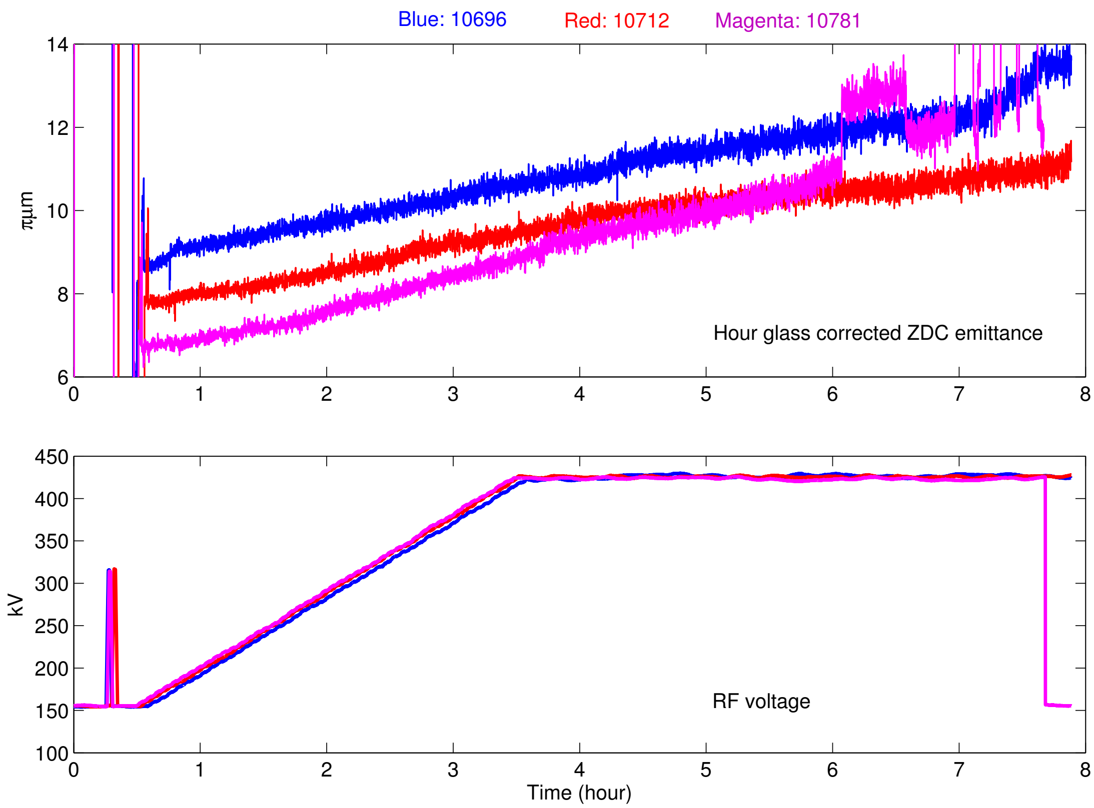

Figure 7: The hour-glass corrected transverse emittance of 10696, 10712, 10781 is compared with the RF voltage. It is clear that with the RF ramping, the transverse emittance grows faster.

the RF voltage ramping in store is used.

This also explains why only run 2009 had such low luminosity lifetime, at about a half of all other runs, compared with the same beam-beam parameter.

5 Conclusion

The beam decay in run 2009 is related to the RF voltage ramping, it is not related to the beam momentum spread, and hence not due to the dynamic aperture limit of 0.7m β^*.

More importantly, the dominant factor of the low luminosity lifetime in run 2009 is the faster transverse emittance growth in store, which is also related to the RF ramping.

In fact, there is no known mechanism that faster transverse emittance growth can be accounted to the dynamic aperture limit.

Therefore, it is strongly suggested to use a β^* smaller than 0.85m in 100 GeV polarized proton run 2015/2016.

References

[1] "Luminosity Issues in 2009 100 GeV Polarized Proton Run", S.Y. Zhang, C-A/AP/361, 8/1/2009

[2] "RHIC proton luminosity and polarization improvement", S.Y. Zhang, submitted for C-A/AP, 1/17/2014

[3] "Dynamic aperture calculations for the 2012 RHIC 100 GeV polarized proton run", Y. Luo, W. Fischer, X. Gu, S. Tepikian, V. Schoefer, C-A/AP/464, Sept., 2012