Proton Beam Emittance Growth at RHIC*

S.Y. Zhang and V. Ptitsyn, BNL, U.S.A

Abstract

With significant beam intensity improvement in RHIC polarized proton runs in 2005 and 2006, the emittance growth becomes a luminosity limiting factor. The beam emittance growth has a dependence on the dynamic pressure rise, which in RHIC proton runs is mainly caused by the electron cloud. The beam instability is usually absent, and the emittance growth rate is much slower than the ones caused by the head-tail instability. It is suspected that the emittance growth is caused by the electron cloud below the instability threshold.

INTRODUCTION

The application of 200 m non-evaporable getter (NEG) coated beam pipe in 2005 helped for reducing the highest dynamic pressure rise of RHIC Blue and Yellow long straight sections [1], allowing more bunches with higher bunch intensity in Run 2005. With much higher beam intensities, the emittance growth was observed. As a result, physics fills with highest beam intensities produced less than the highest luminosity. In 2006, additional 180 m NEG pipes were installed, and beam intensity was further increased. Peak luminosity in Runs 2005 and 2006 was increased from previous years by factors 2 and 3, respectively. This is shown in Table 1.

Table 1: RHIC proton runs in 2004, 2005 and 2006.

	2004	2005	2006
Peak luminosity, $10^{30}/cm^2s$	6	11	35
Bunch number	55	55 - 110	110
Bunch spacing, ns	216	216 - 108	108
Bunch intensity, 10^{11}	0.7	0.9	1.3
NEG pipes, m	50	250	430

In Fig.1, the 95% normalized emittance at RHIC early store, calculated using the ZDC (Zero degree calorimeter) coincident rates of the two major experiments, PHENIX and STAR, in Runs 2005 and 2006 verses the total beam intensity is shown.

The beam emittance growth has a dependence on the dynamic pressure rise. The RHIC dynamic pressure rise is peaked around the end of the beam injection and the early acceleration. After that it is subsided and becomes virtually non-existent at long stores.

* This work was supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy and by a sponsored research grant from Renaissance Technologies Corporation.

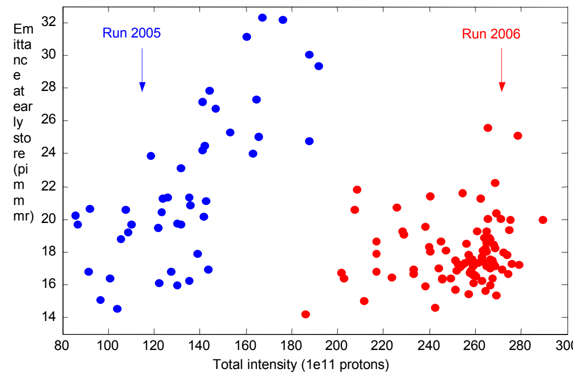

Fig. 1: Normalized beam emittance at early store verses total beam intensity in 2005 and 2006 100 GeV polarized proton runs.

The dynamic pressure rise in RHIC proton runs is mainly caused by the electron cloud, which is, therefore, suspected to be responsible to the emittance growth [2-4]. Indeed, the emittance growth has a dependence on the bunch spacing and other electron cloud related parameters. As comparison, without presence of electron cloud in RHIC store, the emittance growth there has no dependence on bunch spacing, and it has a dependence on the beam-beam parameter instead.

The emittance growth discussed in this article is usually not accompanied by the beam instability, and it has much slower growth rates than the ones caused by the beam instability. The typical emittance growth rate in the operations of 2006 is in the order of 2 πmmmr per hour. With much higher beam intensity in beam experiments, the emittance growth rate can be about 40 πmmmr per hour.

DEPENDENCE ON PRESSURE RISE

The dependence of the beam emittance growth at RHIC on dynamic pressure rise was observed in the polarized proton Run 2005 and Run 2006. All fills with small emittance growth have low pressure rise, and all fills with high pressure rise have large emittance growth.

Table 2 shows two fills in Run 2005, 7264 and 7327, and one fill in Run 2006, 7909. Fill 7327 has higher intensity, and hence larger emittance, than 7264. Fill 7909 has higher intensity, but smaller emittance than 7327.

Table 2: Comparison of Fiils 7264, 7327, and 7909

Fill	7264	7327	7909
Total beam intensity, 10^{11}	143.5	187.4	268.8
Emittance, πmmmr	16.9	24.8	15.4

1-4244-0917-9/07/$25.00

The vacuum chamber condition was the same for 7264 and 7327 in Run 2005, but it was improved for 7909 in Run 2006. The pressure rises at all long straight sections are shown in Fig.2. The overall pressure rise is the highest for Fill 7327, and the lowest for Fill 7909.

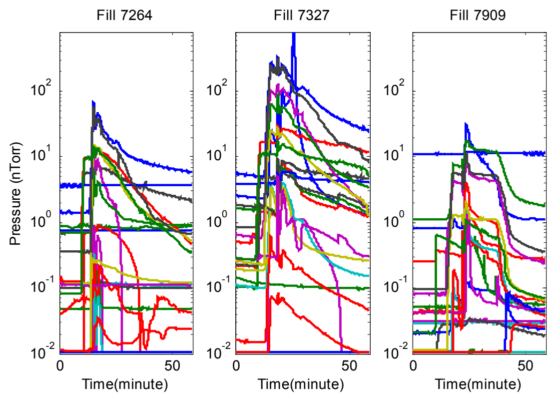

Fig. 2: Pressure rise at all long straight sections for Fills 7264 and 7327 in Run 2005, and Fill 7909 in Run 2006.

To watch directly the emittance growth dependence on the dynamic pressure rise, total 110 bunches with 1.9 $\times10^{11}$ protons per bunch (more than 50% higher than that in operations) were injected, then the RF voltage was increased from 160 kV to 300 kV to shorten the bunch.

In Fig.3, the Blue vertical and the Yellow horizontal emittances measured by IPM (ionization profile monitor) are compared with the pressure rises. The first peak of the pressure rise is at the end of the beam injection, and the second peak is at the rising of the RF voltages. Both peaks of the dynamic pressure rise are coincident with the faster emittance growth.

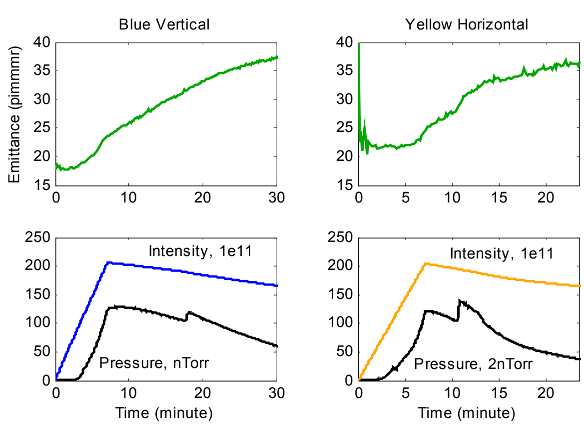

Fig.3: Beam emittance growth observed by IPM for high intensity beam injection, followed by increasing RF voltage.

The emittance measurement of the IPM was also verified by using polarimeter target for the Blue horizontal. Fig.4 shows the agreement.

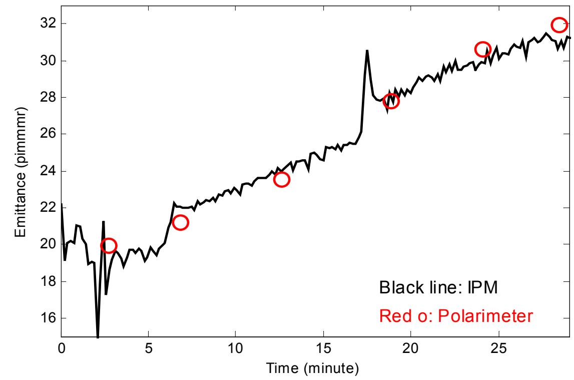

Fig. 4: Beam emittance growth observed by IPM for Blue horizontal agrees with the measurement using the polarimeter target.

DEPENDENCE ON BUNCH SPACING

During Run 2005, the bunches injected into RHIC was gradually increased from 55 to 110. The dependence of emittance growth on the bunch spacing is shown in Fig.5. For all fills with the bunch spacing of around 110 ns, the emittance growth is clearly the largest. The bunch intensities there are from 0.66×10^{11} to 0.86×10^{11}, not the highest, which was 0.91×10^{11} protons.

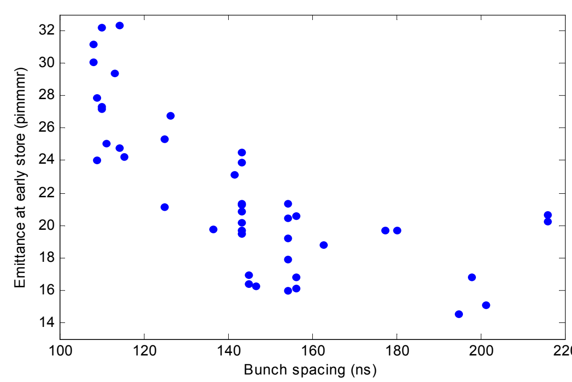

Fig. 5: Beam emittance at early store verses bunch spacing. The data are from Run 2005, with bunch numbers from 55 to 110.

The beam emittance growth in store has a dependence on the beam-beam parameter, which is independent from the bunch numbers, and hence the bunch spacing. In Fig.6, the emittance growth in store is plotted against the bunch intensity and the beam-beam parameter for Runs 2005 and 2006. The bunch intensity in 2006 is much higher than in 2005, but the collisions were reduced from 3 to 2, therefore, the largest beam-beam parameters are both at 0.012.

DEPENDENCE ON BUNCH LENGTH

In Run 2006, all the fills have the same bunch spacing of 108 ns, the bunch length effect on the beam emittance growth is observed. The shorter bunches can be

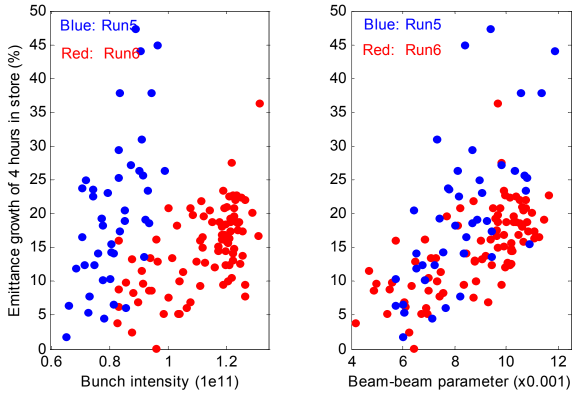

Fig. 6: The beam emittance growth of early 4 hours in store in Run 2005 and Run 2006 verses bunch intensity and beam-beam parameter.

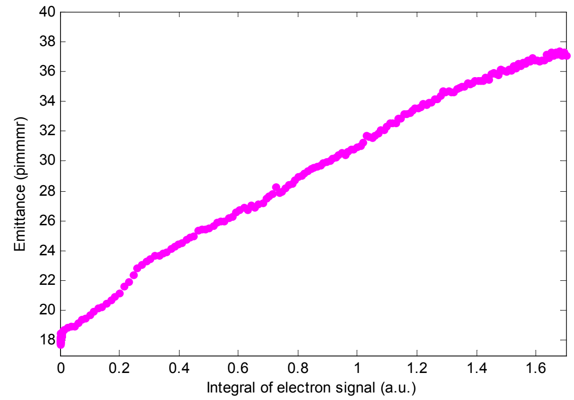

Fig. 8: Blue vertical beam emittance growth and the electron signal from the vertical electron detector at Blue section 1 in RHIC.

injected into RHIC using the longitudinal quad pumping at the AGS extraction. With same total intensity, the luminosity of the fills with quad pumping was reduced by 15%. In Fig.7, the normal fill 7856 and the one used quad pumping, 7860, are compared. The beam intensities are about the same, but the beam emittance of 7860 at early store is ~ 23 πmmmr, whereas 7856 is ~ 20 πmmmr.

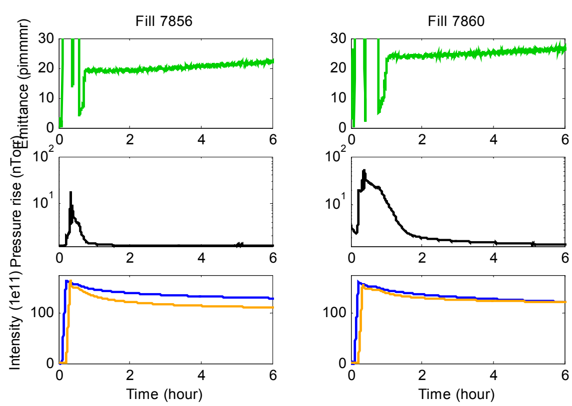

Fig. 7: Beam intensity, average pressure rise, and the emittance of normal Fill 7856, and the Fill 7860 using quad pumping.

DEPENDENCE ON ELECTRON SIGNAL

Due to the non-uniform distribution of electron cloud in RHIC, the 12 electron detectors in rings are mainly used to monitor local electron cloud activities. The pattern of the electron multipacting observed in these electron detectors are, however, very similar. Therefore, the correlation of the emittance growth and the electron signals of electron detectors may reveal qualitatively the emittance growth dependence on the electron cloud.

In Fig.8, the Blue vertical emittance growth in Fill 7935 is compared with the vertical electron detector signal at section 1 in RHIC. The correlation of the emittance growth and the integral of electron signal is appeared to be approximately linear. This may indicate that the overall accumulated electron kicks on the beams are linearly responsible to the beam emittance growth.

ELECTRON DENSITY

Electron cloud induced dynamic pressure rise is monitored around the ring by more than 100 vacuum gauges, typically 3 gauges in a long straight section, and 4 gauges in an interaction region. Together with the dynamic pumping speed, the species of the molecules, chamber surface properties and the related electron desorptions, the electrons in ring can be calculated.

In Table 3, electron densities at 5 warm sections with total length of about 150 m are shown for Fill 7935, which constitutes about 90% electrons in entire Yellow ring, relevant to the beam emittance growth at about 40 πmmmr per hour.

Table 3: Electron densities at 4 Yellow long straight sections and 1 interactions region, which constitutes about 90% electrons in entire Yellow ring for Fill 7935.

Location	Yo1	Yo4	Yi7	Yo9	IR4
e-density, $10^{10}/m^3$	15.8	17.3	20.9	27.4	37.2

REFERENCES

[1] S.Y. Zhang, H.C. Hseuh, W. Fischer, H. Huang, T. Roser, NEG Coating Application at RHIC, C-A/AP/220, Oct. 2005.
[2] H. Fukuma, ECLOUD'04, Napa, CA, 2004.
[3] F-J. Decker, ECLOUD'02, Geneva, Switzerland, 2002.
[4] E. Benedetto, G. Franchetti, and F. Zimmermann, Physical Review Letters, 97, 034801, July 2006.

