COMPARISON BETWEEN THE PREDICTIONS AND MEASUREMENTS FOR THE BEAM GAS INTERACTIONS DURING THE LAST GOLD AND PROTON RUNS IN RHIC *

D. Trbojevic, H.C. Hseuh, W. Fischer, S.Y. Zhang, and W. W. MacKay
BNL, Upton, NY 11973, USA

Abstract

The last gold-gold and polarized proton-proton collision runs were performed at energies of 100 GeV/nucleon. The beam gas interactions in RHIC are very important for the beam lifetime in RHIC. In this report the lifetime predicted by pressure data differences between the beams ON and beams OFF, at the energies of 100 GeV/nucleon, are compared to the predictions for the beam gas interaction and beam lifetimes.

1 INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) has successfully provided design luminosities in the production gold on gold run. The fully stripped gold ion collision run lasted until the end of November in 2001. The successful polarized proton collision run, where the new RHIC cryogenic snake magnets were commissioned ended at the end of January 2002. Serious vacuum problems and pressure rise occurred when the gold ion currents produced collisions above the RHIC design luminosities. This is presented in other publications at this conference [1] and [2]. As reported earlier [3] most of the RHIC beam pipe (80%) is at very low temperature of ~4K with extremely good vacuum conditions due to "cryogenic" pumping of the super-conducting magnets. About 20% of the RHIC beam pipes are at room temperature. It has been previously shown that the expected lifetime of the stored fully stripped gold ions $^{197}Au^{+79}$ would mostly depend on intra-beam-scattering (IBS), if the vacuum conditions in the RHIC warm sections provide residual gas pressures of the order of ~10^{-10} Torr. The dynamical aperture, at 100 GeV/nucleon was predicted to be +-6 σ. The polarized proton beam lifetime depends much less on the IBS and beam-gas interactions. The injection lattice during the polarized proton run was unfortunately set up to be the same as the collision lattice, which limited the available aperture at the injection. This limitation was clearly seen by the vacuum gauges signals due to unavoidable beam loss. The collision lattice had β^*= 3 m at each interaction collision point (IP), making the available aperture at the high focusing quadrupoles of the order of $+/-7\sigma$. The ion beam currents together with the vacuum pressure measurements from the warm beam pipes during a typical "store", are presented in the next section. Analysis of the predicted beam lifetimes and measured lifetimes are presented in the section 3, while concluding remarks follow in the last section.

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2 BEAM LIFETIME AND VACUUM MEASUREMENTS

We present the two RHIC runs: gold-gold collisions and polarized protons separately. There is a very clear distinction between beam-ON and beam-OFF vacuum measurements between gold-gold collisions and polarized proton signals. Clear differences in the vacuum signals corresponding to beam-ON and OFF during the gold stores are attributed to the beam gas interactions. A set of the vacuum data for three "warm" areas of the "blue" ring is presented in Figure 1.

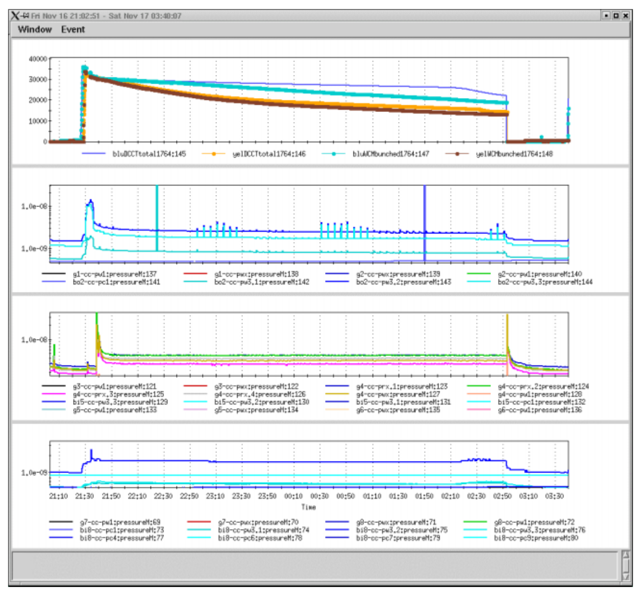

Figure 1. The vacuum signals from three of six warm sectors are shown together with the two "blue" and "yellow" beam signals, during the typical gold store.

The beam lifetime τ was slightly worse in the yellow (τ_{yellow}=5.8 hours) than in the blue ring (τ_{blue}=12.9 hours). The average pressure in the yellow ring was slightly higher in few warm regions, especially at the abort area (8 o'clock) where there was a vacuum leak at the abort kickers. A difference in the beam lifetime could not easily be attributed to the average vacuum pressure differences.

Differences between vacuum pressures with beam ON and OFF for the yellow ring for a few gold on gold stores, are presented in Figure 2. The large peak injection corresponds to the beam loss injection and beginning of acceleration, as the DCCT monitor shows. The vacuum pressure signals decay to the background level after both beams were dumped at the end of the store.

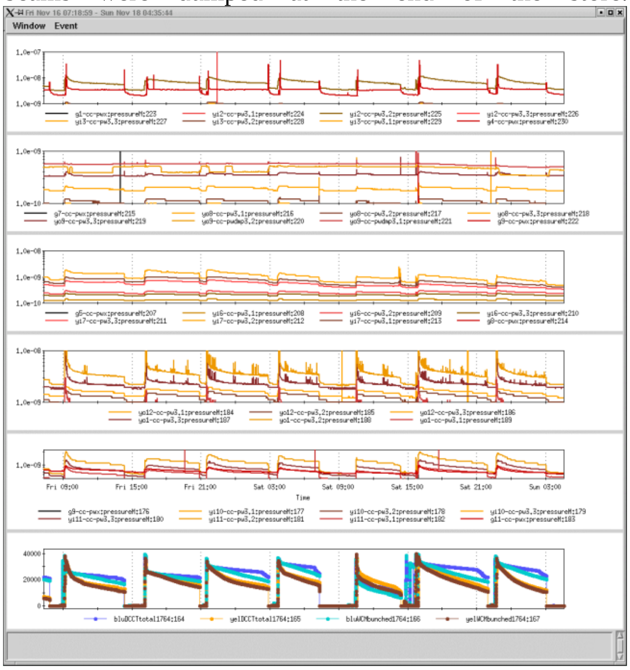

Figure 2. Pressure gauges in five "warm" yellow ring areas are presented for seven gold beam stores.

The residual gas analyzers (RGA) around the ring had also measured the vacuum signals presented in figures above. One of the typical RGA's signals is presented in figure 3.

Figure 3. Residual gas analyzers data in three areas of RHIC during the gold-gold run. The largest signals are from the hydrogen molecules.

Estimated lifetimes from the residual gas pressure measurements show clearly large differences between the measured lifetimes. The residual gas pressure differences between ion beam OFF-ON conditions during the polarized proton run were not distinguishable. This is more clearly presented in figure 4.

The initial pressure peaks occurred during the injection and acceleration, were not taken into consideration for explaining the beam lifetime vs. beam-gas interaction correspondence.

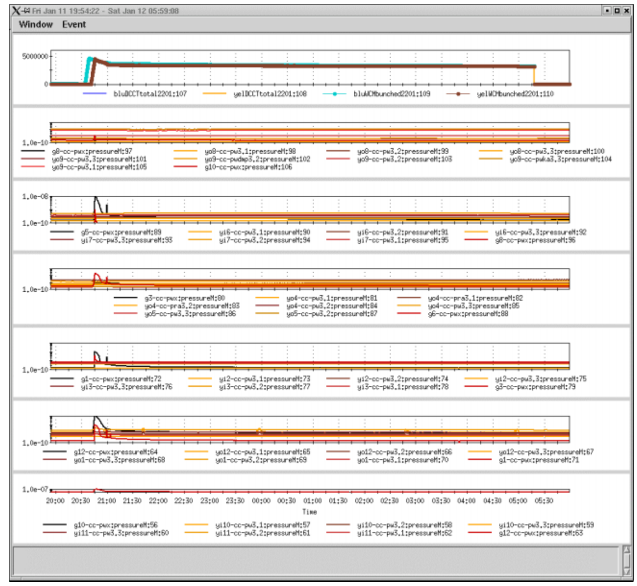

Figure 4. The two proton stored beams are presented at the top of the figure, while the vacuum gauge signals in the yellow "warm" regions follow bellow.

One of the typical proton stores, as presented in figure 4, shows that at the injection there was a very clear vacuum rise corresponding to a beam loss shown as a drop of the beam signal.

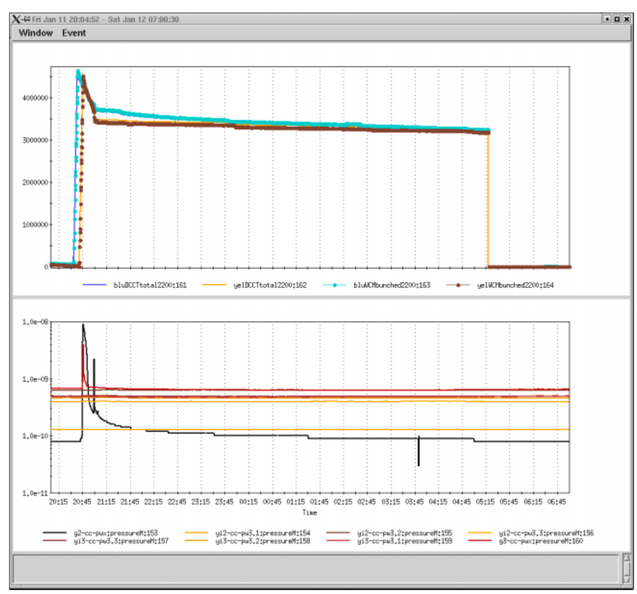

Figure 5. The polarized proton store is presented in details. At the top of the figure the DCCT signal of both blue and yellow beams are shown.

The vacuum pressure signals are from one of the "warm" sectors around the IP2 (2&3 sectors). The large peak at injection corresponds to the DX dipole gauge. The lifetimes of the "blue" and "yellow" proton beams in this store were calculated to be τ_b~80 and τ_y~130 hours, respectively.

3 ANALYSIS OF VACUUM DATA

At high gold beam ion intensities the pressure bump instabilities during injection had occasionally interrupted normal operation as presented at this conference in our other reports [1][2]. The ultra-relativistic fully stripped heavy ion calculations ($\gamma > 30$) for all inelastic processes had previously been very well analyzed [6]. Our calculations [3] of the cross-sections for the radiative, non-radiative, and "vacuum" electron captures showed that they are much smaller than elastic nuclear collisions cross-sections. The cross section for the γ=108 gold ions collisions with the residual gas molecules was estimated to be [3] ~2.5 10^{-24} cm^2.

The beam lifetime τ is given by:

$$\frac{1}{\tau} = \frac{1}{N}\frac{dN}{dt} = n\, l\, f\left(\sigma_N + \sigma_C\right) \qquad n = \frac{p}{kT}$$

$$n = 9.66 \cdot 10^{18}\, \frac{p(Torr)}{T}, \quad molecules / cm^3$$

where the circumference in RHIC is $l=3834$ *m*, *n* is the density of molecules, *f* is the revolution frequency, σ_N and σ_C are cross sections for the nuclear scattering and capture, respectively, and T is the absolute temperature in K. Measurement results are presented in Tables 1 and 2.

Table 1. Pressure differences in RHIC beam OFF and ON during the gold-gold run 2001

Sectors	ΔBlue (Torr)	τ(hour)	ΔYellow (Torr)	τ(hour)
12&1	2.0 10^{-09}	1705	4.0 10^{-09}	853
2&3	2.2 10^{-09}	1550	5.5 10^{-09}	620
4&5	1.5 10^{-09}	2274	4.5 10^{-09}	758
6&7	1.2 10^{-09}	2843	1.1 10^{-09}	3101
8&9	1.1 10^{-09}	3101	1.0 10^{-08}	341
10&11	1.0 10^{-09}	3411	1.0 10^{-09}	3411
τ_{vacuum}	1.5 10^{-09}	379	4.4 10^{-09}	131
$\tau_{measured}$		12.9		5.8

Table 2. Pressure measurements during the proton-proton stores in polarized proton run 2002

Sectors	Blue (Torr)	τ(hour)	Yellow (Torr)	τ(hour)
12&1	5.0 10^{-10}	63360	1.1 10^{-09}	28800
2&3	2.0 10^{-09}	15840	6.0 10^{-10}	52800
4&5	9.0 10^{-09}	3520	2.0 10^{-09}	15840
6&7	5.0 10^{-10}	63360	5.0 10^{-10}	63360
8&9	8.0 10^{-10}	39600	8.0 10^{-10}	39600
10&11	8.0 10^{-10}	39600	9.0 10^{-10}	35200
τ_{vacuum}	2.5 10^{-09}	2246	9.8 10^{-10}	5369
$\tau_{measured}$		80		130

4 SUMMARY

The residual gas pressure data in both the gold on gold and polarized proton on proton collision runs, could not explain gold and proton beam lifetimes in RHIC. The gradient, roll, and uncompensated nonlinearity errors in the high triplet quadrupoles, the IBS, fast emittance growth, beam-beam interactions, not optimized betatron tunes, etc. could be reasons for shorter than expected lifetimes.

5 REFERENCES

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