Vacuum limitations due to electron clouds during the Relativistic Heavy Ion Collider Run-4

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1 Introduction

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory consists of two superconducting rings, denoted Blue and Yellow. The machine can accelerate and store particles from protons to fully stripped gold ions[1]. The current operating period (Run-4) began in November 2003, and will last until May 2004. In Run-4 gold ions were accelerated to and stored at 100GeV/u and 31.2GeV/u. Later in the run the machine will also be operated with polarized protons.

The two most severe luminosity limitations in heavy ion operation are intrabeam scattering, and vacuum pressure rises with intense beams. Intrabeam scattering leads to luminosity lifetimes of about 2.5 hours, and fast refills are needed to achieve a high average luminosity. Ultimately beam cooling at full energy is required to overcome intrabeam scattering. Pressure increases with intense beams limit the luminosity in two ways. First, they limit the beam intensity that can be accelerated and stored. Second, they create backgrounds that are not acceptable to the experiments. Experimental observations indicate that the pressure increases are predominately caused by electron clouds.

2 Beam current limitations

Pressure increases with intense ion beams can be observed in various warm locations in the two RHIC rings. The pressure increases are especially pronounced at transition, and after rebucketing (see Figure 1). One location in each ring limits the intensity that can be accelerated and stored.

When the beams cross the transition energy, the bunch length is reduced to 4ns, from 18ns at injection, while the peak current and the momentum spread are increased. At rebucketing the bunches are transferred from the accelerating rf system, with 36ns bucket length, into the storage rf system, with 5ns bucket length. The shorter bunches have again a higher peak current and a larger momentum spread. Simulations show that shorter bunches with the same intensity are more likely to trigger an electron cloud formation[2,6].

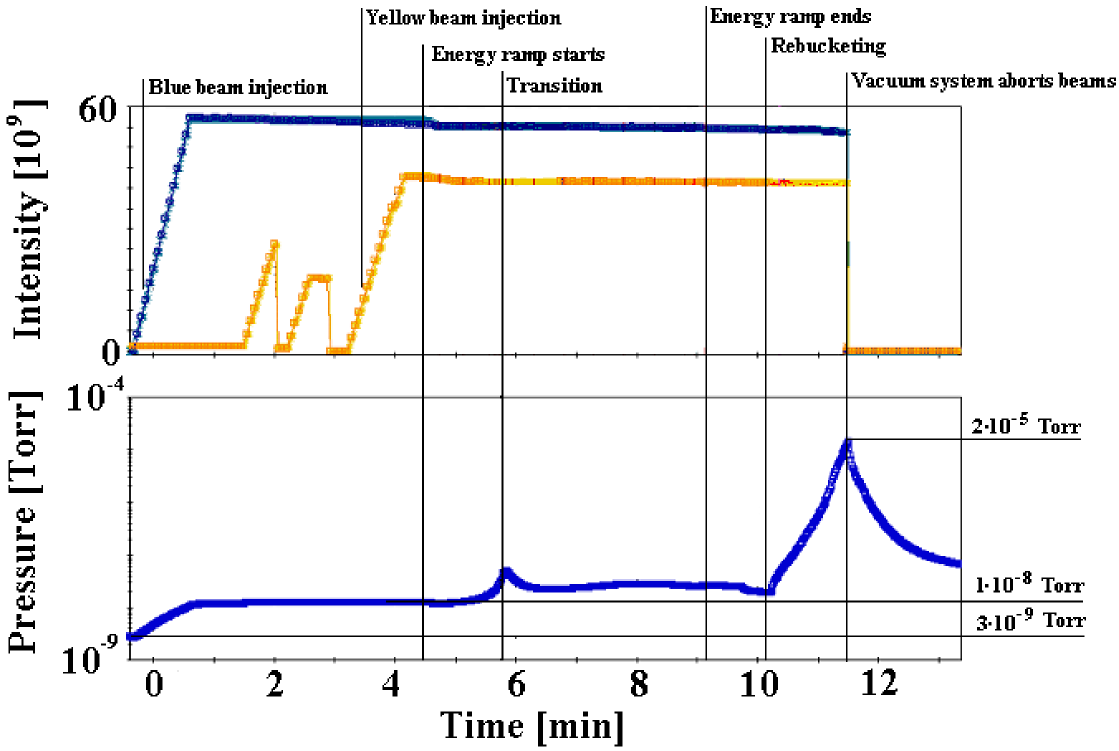

Figure 1 Vacuum instability in Blue sector 8 (unbaked collimators), with 56 bunches per ring. The upper part shows the beam intensities during injection, acceleration and rebucketing. The lower part shows the pressure changes during injection, transition crossing and after rebucketing.

In Run-4 the Blue beam intensity was limited by the vacuum in sector 8, at the location of a newly installed unbaked collimator. In the Yellow ring the intensity was limited by the vacuum in sector 4, at the location of a stochastic cooling kicker, also unbaked initially. Both devices had not been baked, since they were installed late during the last shutdown, and not enough time was available for a bake-out before operation began. The Yellow stochastic cooling kicker was baked later during the run, raising the intensity threshold by some 10%.

Figure 1 show a vacuum instability in Blue sector 8. The static pressure before the beam is filled is 3×10^{-9} Torr. The pressure rises to 1×10^{-8} Torr after 56 bunches are injected. At transition the pressure rises to 5×10^{-8} Torr and drops back as the acceleration continues. After rebucketing the pressure increases exponentially over 1½ minutes until 2×10^{-5} Torr are reached. The vacuum system then aborts the beam.

With 61 bunches in both rings, 0.95×10^{9} Au^{97+} ions per bunch can be accelerated and stored in the Blue ring, and 0.80×10^{9} Au^{97+} ions per bunch in the Yellow ring. With 56 bunches in both rings, 1.00×10^{9} Au^{97+} ions per bunch can be accelerated and stored in the Blue ring, and 0.90×10^{9} Au^{97+} ions per bunch in the Yellow ring. With 45 bunches, the available bunch intensity is not sufficient to exceed the vacuum limit in either ring. 1.15×10^{9} Au^{97+} ions per bunch can be accelerated and stored in both rings.

The fact that shorter bunches raise the pressure, and longer bunch spacings can suppress the pressure rise, point to electron clouds as a driving mechanism for the pressure rise. Furthermore, in proton-proton operation during the RHIC Run-3, an electron cloud signal was observed directly in conjunction with a pressure rise, although at a different location[3,4].

There are two observations that are not fully understood. First, if the pressure increases were only the result of electrons bombarding the wall, one would expect a pressure increase linear in time, not exponential. Furthermore, in deuteron-gold operation during Run-3, the transition pressure rise appeared to be mainly dependent on the total intensity, not the bunch spacing[5].

3 Experimental background limitations

One of the four RHIC experiments, PHOBOS, has experienced high backgrounds from increased pressure in the experimental area. In some of the stores, the pressure rises after rebucketing by about an order of magnitude, and drops back after some time, typically an hour. During the time of increased pressure, experimental backgrounds are too high to allow for data taking.

In Figure 2 the history of the pressure rise problem in PHOBOS is shown. The machine was initially run with 56 bunches per ring, which was then increased to 61 bunches. At the same time the bunch intensity was continuously increased. After some time with 61 bunches, the pressure rise problem became visible for the first time. A reduction in the bunch number to 56 eliminated the problem, even with further increases in the bunch intensity. With 56 bunches, all bunches are spaced by 6 buckets, while with 61 bunches, some bunches are spaced by only 3 buckets. The short bunch spacing was found to trigger electron cloud formation much earlier in simulations[6].

After some running time with 56 bunches, the problem resurfaced, although the bunch intensity had not been increased. At the same time the static pressure had slightly increased from 20pTorr to 40pTorr. The bunch number was again reduced, to 45, accompanied by an increase in the bunch intensity to maintain the luminosity. In this configuration the bunch intensity available from the injectors became the luminosity limit. The bunch number was adjusted when not enough bunch intensity was available.

With 45 bunches the pressure rise problem was suppressed for a number of stores, but gradually the number of stores that exhibited a pressure rise problem increased, until almost all stores had high pressures during the early part of the store. The pressure rise problem was observed with beams of 100GeV/u and 31.2GeV/u.

The fact that the pressure rise is triggered after a bunch shortening, that an increase in the bunch spacing helps suppressing it, and that it is independent of the beam energy points again to electron clouds as the driving mechanism[7]. The PHOBOS experimental beam pipe is a 12m section of beryllium that has a high secondary emission yield. Detailed simulations indicate that the electron clouds are concentrated near the ends of the beryllium pipe[7].

Not all stores show a pressure rise problem. This suggests that a threshold in some parameter set must be crossed to trigger the pressure increase; a threshold is also crossed when the pressure drops back sharply after about an hour. From the data displayed in Figure 2 one cannot find, however, a narrow range in either the bunch intensity or initial pressure that would lead to a pressure rise upon rebucketing. Neither can one find a narrow range in either the bunch intensity or the pressure that are sufficiently low to switch off the effect after some time.

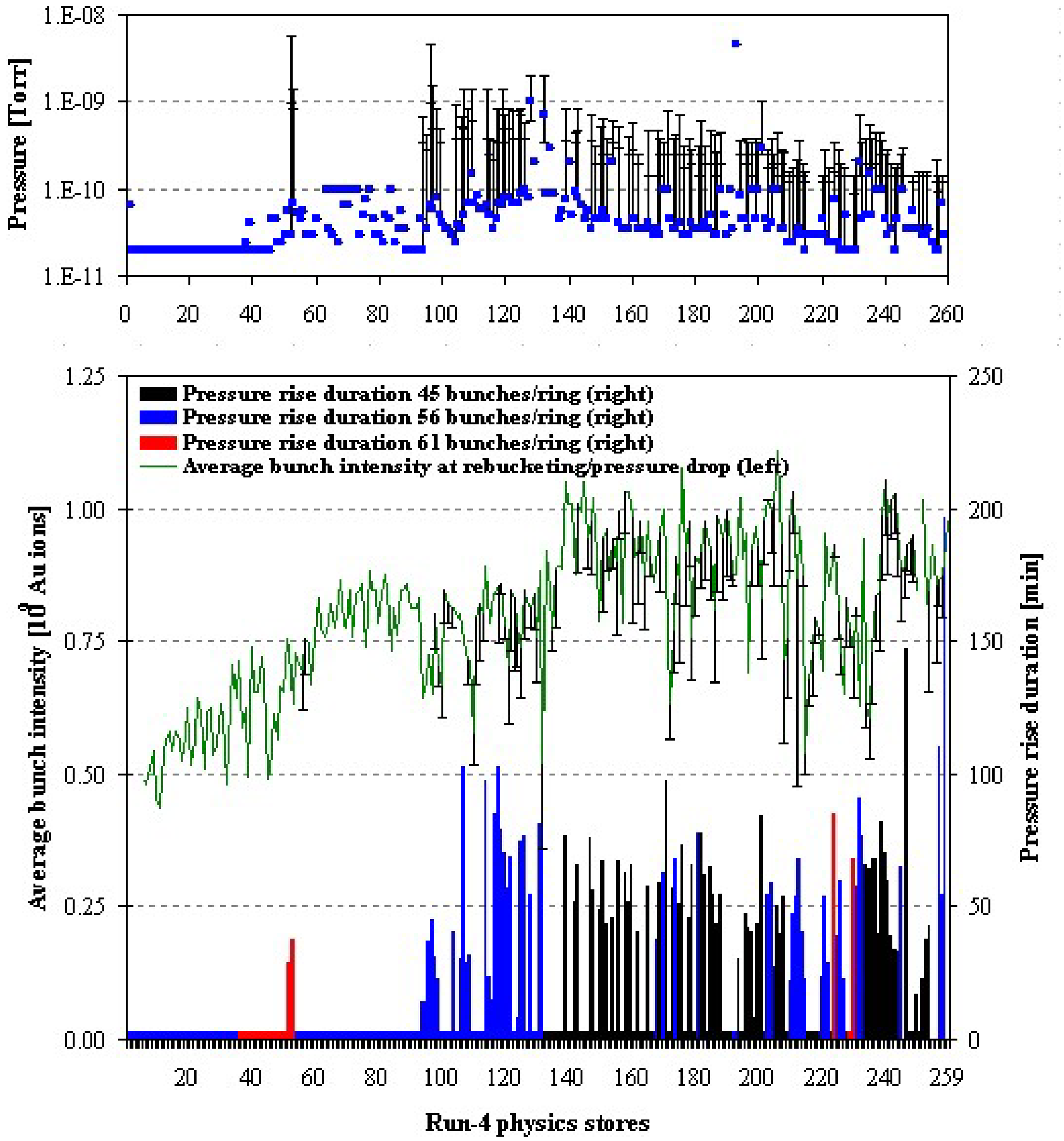

Figure 2 History of the PHOBOS pressure rise problem during the RHIC Run-4. In the upper part, the pressure at PHOBOS is shown at rebucketing for the physics stores of Run-4. For stores with a pressure rise after rebucketing, also shown are the maximum pressure and the pressure when it begins to drop sharply. In the lower part on the left hand scale the bunch intensity, averaged over all bunches in the Blue and Yellow rings, is depicted. Stores with a PHOBOS vacuum problem also show the average bunch intensity at the time when the pressure begins to drop sharply. In the lower part on the right hand scale, the duration of the pressure problem is shown, ordered into stores with 45, 56, and 61 bunches per ring. Note that the last 14 stores are with Au^{79+} beams at 31.2GeV/u, all other stores are with Au^{79+} beams of 100.0GeV/u.

A second experiment, STAR, has also seen, at times, higher backgrounds from pressure increases in the experimental area[8]. This pressure rise, however, is not likely to be caused by electron clouds. The STAR magnet provides a solenoidal field of 0.5T in the central part, and fringe fields of more than 5mT in all of the experimental area. The magnetic field should suppress electron clouds. The central part of the experimental beam pipes in STAR cannot be baked at temperatures above 100°C, and the pressure increase may be caused by a different effect.

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5 Summary

The RHIC luminosity is limited by pressure increases with intense ion beams. Observations point to electron clouds as the dominant source for most of the pressure increases. The increased pressure limits the intensity that can be injected, accelerated, and stored. Even lower intensity limits are set by the background requirements of some of the experiments. While electron clouds are the most likely source of the increased pressure, the mechanism leading to an exponential pressure increase is not understood. To increase the intensity thresholds that trigger vacuum problems, the replacement of warm beam pipes with NEG coated ones, especially in the experimental regions, is under consideration.

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