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Experimental Background Due To Particle Induced Gas Desorption In RHIC

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Abstract. Beam-gas collision created experimental background, i.e., singles, has affected heavy ion and polarized proton operations in Relativistic Heavy Ion Collider at Brookhaven National Laboratory. The gas molecules in interaction region are mainly caused by the electron induced gas desorption, and the electrons are produced from the beam induced electron multipacting, or called electron cloud. The background has a dependence on the usual electron cloud related parameters, such as the bunch intensity, bunch spacing, and the solenoid field. With the RHIC upgrade plan, the experimental background may become a luminosity limiting factor. Mitigations are discussed.

Keywords: background; pressure rise; electron cloud; beam-gas; gas-desorption.
PACS: 29.20.Dh; 29.27.Bd; 29.27.-a

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) has a circumference of 3.8 km, with two rings (Blue and Yellow), and six interaction regions (IR). Since 2001, RHIC has been providing collisions of Au-Au, Cu-Cu, d-Au, for energy ranged from 4.6 GeV/u to 100 GeV/u. RHIC is also the first collider to provide polarized proton collisions, at 100 GeV and 250 GeV, with the polarization around 65%.

The main experiments at RHIC include PHENIX, STAR, PHOBOS, and BRAHMS. The luminosity is monitored by the Zero Degree Calorimeter (ZDC), which is installed at the forward direction of each side of the experiments. The coincidence of the ZDC indicates true hadron collision, whereas the singles are called the background.

In Fig.1, the Blue and Yellow beam intensity, the ZDC coincident rate of the experiments PHENIX and STAR, and their background are shown for the recent polarized proton run 2008. With the typical ZDC coincident rate of around 10 kHz, the typical background is around 100 kHz.

The experimental background mainly comes from:

1. Beam-beam. This is due to the single Coulomb dissociation, and it is inherent.
2. Beam-chamber interaction. The interaction results in neutrons and other particles.
3. Beam-gas. The imperfect vacuum includes the static vacuum and the dynamic pressure rise at IRs.

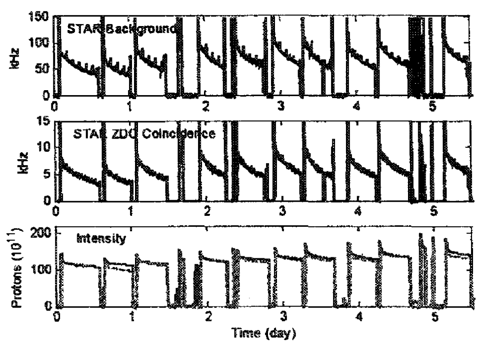

FIGURE 1. Polarized proton run 2008. Shown here are the Blue and Yellow beam intensity, the ZDC coincident rate of the experiment STAR, and the background.

The main countermeasure to the beam-chamber interaction include the beam collimation, shielding, and IR chamber surface improvement. A significant progress has been made on this aspect since 2001. On the other hand, the beam-gas created background remains a problem. Furthermore, with the RHIC upgrade plan, we expect that the dynamic pressure rise at IRs will be more prominent, and the experimental background may become a luminosity limiting factor.

In this article, we review the RHIC experimental background due to the particle induced gas desorption, and discuss the plans for cures.

BEAM-GAS CREATED EXPERIMENTAL BACKGROUND

The beam-gas created background may hamper the experimental data taking. In Fig.2, the background problem at the PHOBOS in the Au-Au operation 2004, and the Cu-Cu operation 2005 are shown. With the dynamic pressure rise around 0.3 nTorr at the IR, the beam-gas background can be clearly identified, and indeed the operation is affected. Because of the concern, in 2004 Au-Au run the bunch number was limited to 45, and in 2005 Cu-Cu run the number of bunches was limited to 37. Nevertheless, PHOBOS could not take data during the period of high pressure and hence high background, which lasted from half to one hour, or longer.

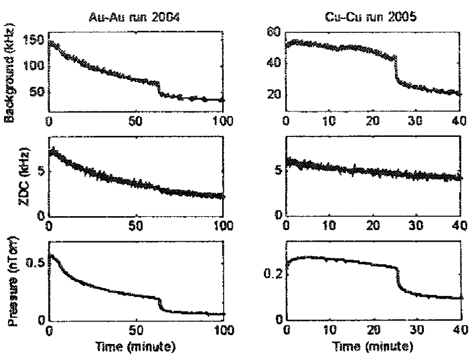

FIGURE 2. The pressure rise at the interation region of PHOBOS, together with the ZDC rate and background for Au-Au run 2004 and Cu-Cu run 2005.

The dynamic pressure rise at IRs is usually caused by

1. The beam halo scraping on chamber wall.
2. The electron desorption due to the electron cloud.

The former is the shallow angle incidents between the beam particle and the chamber surface, and hence it can be improved by either the beam collimation or to reduce the chamber ion desorption rate. Usually both efforts are made. The latter cause of the dynamic pressure rise, i.e., the electron desorption, is associated with the normal incident of the electrons expelled by the beam to the wall. The cures are to reduce the electrons, and the electron desorption rate as well.

In early RHIC runs, both types of the dynamic pressure rise were presented. Over the years, however, the beam halo scraping created pressure rise becomes less concerned because of the better collimation and chamber surface upgrade. Meanwhile, with more bunches and higher bunch intensities, the electron cloud induced dynamic pressure rise, and hence the beam-gas created background, becomes increasingly concerned.

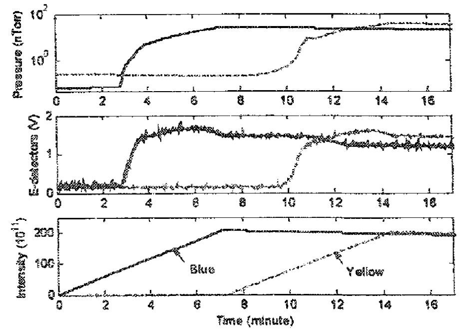

FIGURE 3. Typical proton beam injection with the Blue and Yellow intensities, the signal of electron detectors at Blue and Yellow section 1, and the pressure rise there.

In Fig.3, a RHIC proton beam injection with the electron detector signals and the dynamic pressure rise at Blue section 1 and Yellow section 1 are shown. Once the beam reaches an intensity threshold at the injection, the electron multipacting is started, and the significant increase is observed by the electron detectors in both rings. Associated with the electron cloud, the dynamic pressure rise of more than 3 orders of magnitudes, from around 0.1 nTorr to around 100 nTorr, takes place.

For normal RHIC beam pipes, with the average pumping speed of 17 ℓ $s^{-1}m^{-1}$ and the electron desorption rate of 0.005 molecule per electron, the electron density of about 10^{11} m^{-3} gives rise to pressure rise of 100 nTorr. In many machines, such as the CERN SPS, the B-factories at KEK and SLAC, the electron density is in a range of 10^{11} m^{-3} to 10^{12} m^{-3} when a strong electron multipacting is observed [1].

BACKGROUND AND ELECTRON CLOUD

In Fig.4, a proton beam induced electron multipacting is shown for Blue ring at RHIC. The average bunch intensity is $\sim 1.6\times10^{11}$ protons, and the bunch spacing is 108 ns. The multipacting is started from around 15 bunches in the bunch train, and the reset of the multipacting signals after the two bunch gaps can be identified.

The usual relevant factors in the electron multipacting are,

1. The secondary electron yield (SEY) of the chamber surface.
2. The solenoid field in the region.
3. The beam properties, such as the bunch intensity and the bunch spacing.

The problem of SEY can be improved by baking or using NEG coatings. At RHIC, the baking has reduced SEY from > 2 to about 1.5, and the NEG coating has drastically reduced electron multipacting wherever it is applied [2,3]. From 2004 to 2008, the total NEG pipes of 530 meters has been gradually applied in the rings. The NEG coatings also have been applied at the IRs to reduce the electron activities, but the conditions there are very restrictive, and the application is limited.

All experiments at RHIC usually have strong solenoid field around the IP (interaction point), typically ±3 meters. The total IR extends 17 meters, and the remnant solenoid field beyond ±7 meters from IP is in tens to just a few Gauss, which may not be sufficient to suppress the electron multipacting.

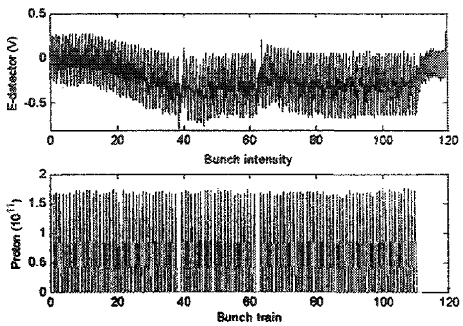

FIGURE 4. Blue bunches and the electron multipacting observed by the electron detector. The bunch intensity is about 1.6×10^{11} protons, and bunch spacing is 108 ns.

The luminosity improvement demands more bunches with higher bunch intensity. For example, the RHIC proton bunch intensity is planned to increase from 1.5×10^{11} to 2×10^{11} in upgrade. The electron cloud is expected to enhance. Furthermore, in addition to the bunch intensity, it is found that the bunch length could be an important factor in the electron multipacting. Given the same bunch intensity, the shorter the bunch length, the higher the peak beam current.

In Fig.5, the bunch length evolution during the beam acceleration in the recent polarized proton run at RHIC is shown. The electron multipacting is started at the later part of the injection for both rings, then the strength of the electron cloud inversely follows the bunch length. At the beam store, the FWHM (Full Width at Half Maximum) bunch length is reduced from about 7.5 ns to 6.5 ns (full length of 15 ns to 13 ns), when the RF voltage is raised from 150 kV to 300 kV. The electron multipacting in both Blue and Yellow rings is greatly enhanced.

To reduce the beam particle leakage from the RF bucket, and to improve the vertex for experiments, the RHIC upgrade plans call for shorter bunches at store. The bunch full length at the beginning of the store is 13 ns in 2008 polarized proton run. By using a 9 MHz RF cavity to longitudinally match the beam injected into RHIC, the longitudinal emittance growth at the injection and acceleration can be improved. With this scenario, the bunch length at store may be reduced to 7.7 ns. A further improvement using a 56 MHz superconducting cavity at store may reduce the bunch length to 4 ns.

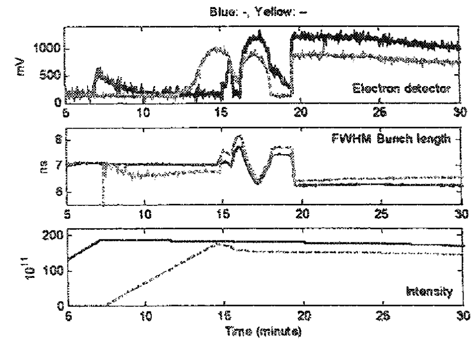

FIGURE 5. The Blue and Yellow beam intensity in the polarized proton run 2008, with the FWHM bunch length and the electron multipacting at Blue and Yellow section 1.

With the increase of the proton bunch intensity to 2×10^{11}, the peak current at early store will be increased from 3 A in the polarized proton run 2008 to 6.6 A for the 9 MHz scenario and 13 A for the 56 MHz scenario. The beam peak current increase is expected to be a challenge for the mitigations of the electron cloud at the IRs, and hence the beam-gas induced experimental background will be of concern in the RHIC upgrade. A simulation is underway for better understandings.

To prepare for the RHIC upgrade, several possible remedies for background concerns are under study, these include the further improvement of the chamber surface at the IRs, the possible leakage of solenoid field from the main experimental magnets into the regions farther away from IP, and the test of solenoid wires at the ends of IRs, noting where the remnant solenoid field may be too weak to suppress the electron multipacting.

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