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J. Wei, et. al.

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Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

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OBSERVATION OF ELECTRON-ION EFFECTS AT RHIC TRANSITION *

J. Wei†, U. Iriso, M. Bai, M. Blaskiewicz, P. Cameron, R. Connolly, A. Della Penna, W. Fischer
H. Huang, R. Lee, R. Michnoff, V. Ptitsin, T. Roser, T. Satogata, S. Tepikian, L. Wang, S.Y. Zhang
Brookhaven National Laboratory, New York, USA

Abstract

Electron cloud is found to be a serious obstacle on the upgrade path of the Relativistic Heavy Ion Collider (RHIC). At twice the design number of bunches, electron-ion interactions cause significant instability, emittance growth, and beam loss along with vacuum pressure rises when the beam is accelerated across the transition.

INTRODUCTION

Electron cloud effects previously observed in RHIC mainly include vacuum pressure rise, experimental background rise, and instrumentation interferences [1]-[4]. Beam-induced electron multipacting is expected to be the leading mechanism producing the cloud (Fig. 1).

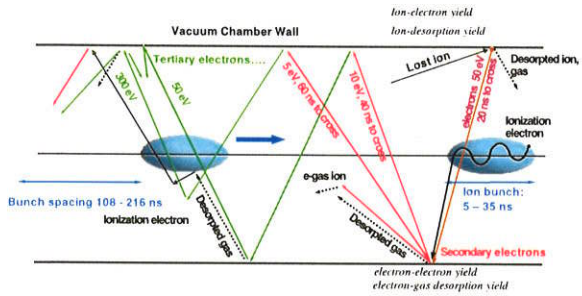

Figure 1: Electron build-up at RHIC shown as a result of beam-induced electron multipacting.

Table 1: RHIC parameters during year 2005 e-I study.

Ring revolution period	12.79	μs
Aperture, IR (2/6/8/10, 4/12)	7, 12	cm
Aperture (arc, triplet)	7, 13	cm
Beam species	Cu^{29+}	
Energy, injection - top	9.8 - 100	GeV/u
Transition energy, γ_T	22.9	
Bunch intensity	5×10^9	
Bunch center spacing	108	ns
Bunch length at transition, full	~ 5	ns
Electron bounce frequency	~ 400	MHz
Peak bunch potential	~ 1.6	kV
e^- energy gain upon acceleration	~ 300	V

Near transition (γ_T), most of the undesired effects (chromatic nonlinearity, self-field mismatch, and impedance-induced instabilities) on a nominal beam of 216 ns bunch spacing are mitigated by the γ_T-jump scheme during about 50 ms around the transition [5, 6]. Dedicated studies are planned and performed in 2005 with Cu bunches of half of the nominal spacing (108 ns) crossing γ_T (Table 1). For simplicity, only one (blue) of the two rings is populated with 40 bunches in 1/3 of the circumference. In addition to the e-cloud effects (pressure rise, electron flux) occurring during a time of seconds as the beam peak intensity increases when the beam approaches γ_T (Fig. 2), strong electron-ion (e-I) interactions (instabilities, emittance growth, beam loss) are observed during a time of tens of ms after transition when the ion motion is non-adiabatic.

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† jwei@bnl.gov

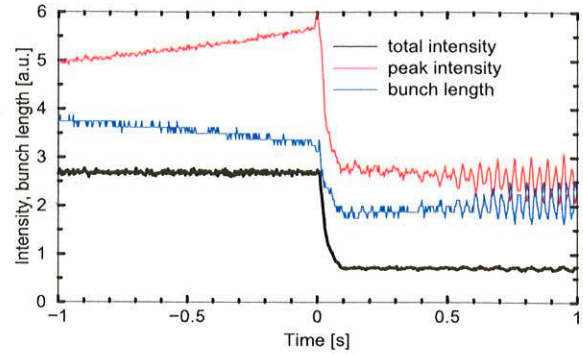

Figure 2: Beam loss and bunch size variation of bunch #40 at γ_T with V_{rf} = 300 kV.

OBSERVATIONS

This section lists e-cloud observations of year 2005.

Beam loss

With the harmonic 360 RF system at 200 kV voltage (V_{rf}), beam losses are measured with the wall current monitor (WCM) across γ_T varying from 13% for the first to 42% for the last bunch (Fig. 3). In comparison, at the nominal 216 ns spacing the loss is less than 5%. The loss increases significantly with the RF voltage as the peak beam

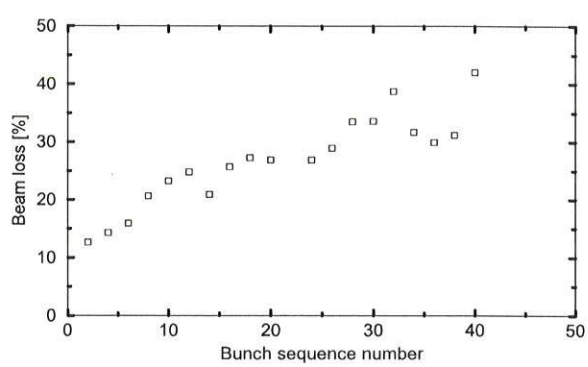

Figure 3: Beam loss at transition as a function of bunch sequence number with V_{rf}=200 kV and $b_{oct} = -3$ unit.

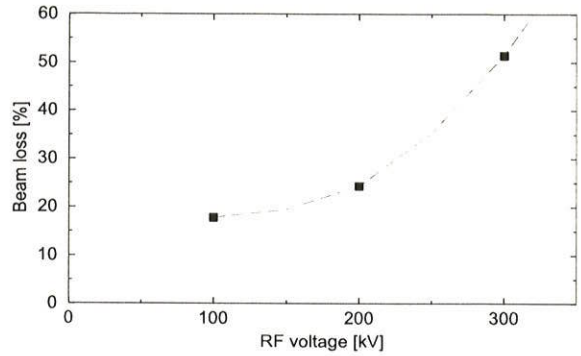

Figure 4: Average beam loss at γ_T as a function of the RF voltage with $b_{oct} = -3$ unit.

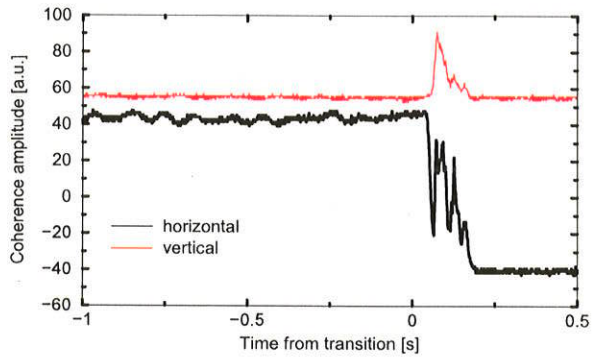

Figure 5: Coherence signal of bunch #40 from the turn-by-turn BPM data. The horizontal instability signal is within a step caused by the orbit shift due to γ_T-jump.

intensity, electron energy gain, and e-multipacting all increase (Fig. 4). Fig. 2 shows about 73% loss of bunch #40 within 0.1 s after γ_T.

Transverse fast instability

Fig. 5 shows the transverse coherence signal defined as the transverse centroid displacement measured from the turn-by-turn beam position monitor (BPM). A transverse instability occurs immediately after transition for about 0.1 s, leading to beam loss and emittance growth that are increasingly severe for later bunches of the bunch train. Fig. 6 shows the mean square of difference signal measured by a "button" BPM at 0.5 ns sampling rate. Again, the horizontal signal is complicated by the γ_T-jump induced orbit shift. The instability as well as the beam loss is reduced by the damping effect of octupole families (Fig. 7).

Transverse emittance growth

Bunch-train dependent transverse emittance growth at γ_T is observed when the beam loss is moderate (Fig. 8). With a larger beam loss (e.g., $V_{rf} \geq$200 kV cases), the dependence becomes not obvious, presumably because particles of larger emittance are lost. An accurate measurement is difficult with the ionization profile monitor when the loss-related pressure rise is excessive.

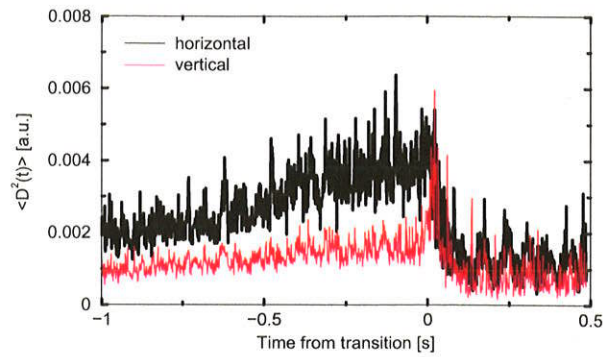

Figure 6: Mean square of the difference displacement measured by the "button" BPM sampling every 0.5 ns.

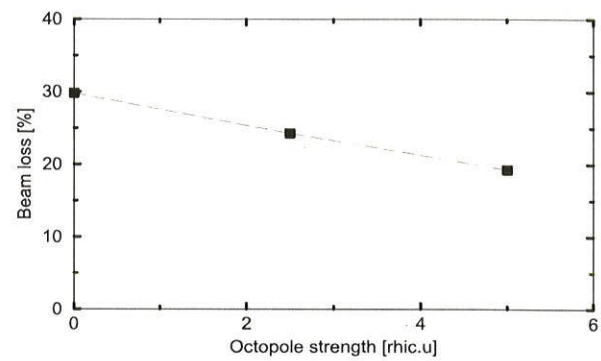

Figure 7: Average beam loss as a function of the octupole magnet strength $|b_{oct}|$ with $V_{rf} = 200$ kV.

Longitudinal profile variation

Fig. 9 shows that the beam loss occurs mostly at the trailing edge of the bunch matching the e-cloud mechanism. In the longitudinal direction, neither instability nor bunch-train dependent emittance growth are observed.

Electron flux and vacuum pressure rise

Fig. 10 shows the electron flux on the wall measured by a retarding-field electron detector [2]. The flux increases as

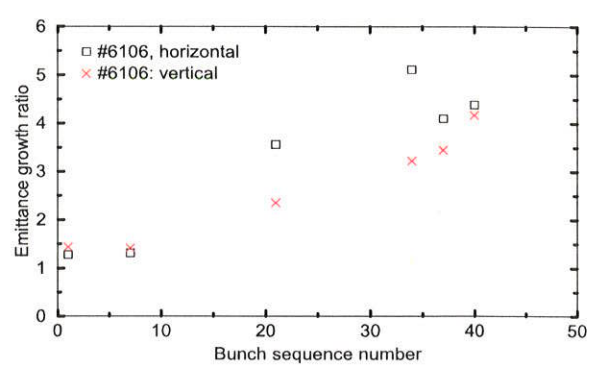

Figure 8: Bunch train dependence of the beam emittance growths at γ_T with V_{rf}=100 kV and $b_{oct} = -4$ unit.

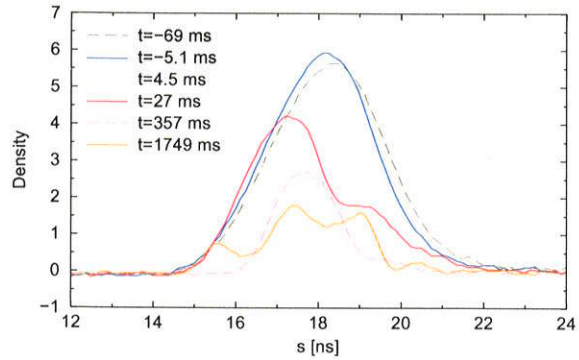

Figure 9: Evolution of the longitudinal profile upon the beam loss near γ_T with V_{rf}=300 kV and $b_{oct} = -4$ unit.

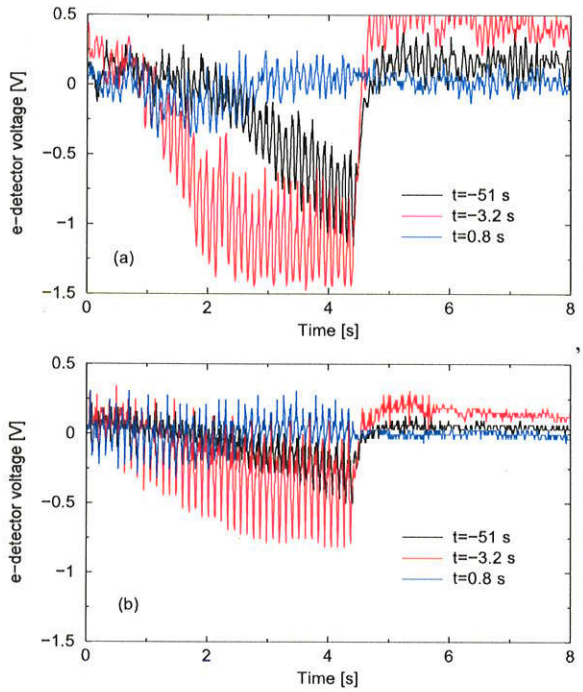

Figure 10: e-flux measured in the (a) horizontal and (b) vertical directions near γ_T. An ac-coupled amplifier is used with a low-frequency cut-off of about 300 kHz. The grid is not biased. The collector is biased at 50 - 100 V positive.

the beam approaches transition. Associated is the vacuum pressure rise both in the warm and cold region of the ring.

DISCUSSIONS AND SUMMARY

Electron cloud is found to be a serious obstacle on the RHIC upgrade path. At merely twice the design number of bunches, electron cloud and electron-ion interactions cause transverse instabilities and emittance growth, and beam loss, along with vacuum pressure rise and background increase. The effect is extremely strong at transition despite of the γ_T-jump.

e-cloud effects occur both in the warm (30% length) and cold (about 70%) regions. NEG coating and solenoid windings have been shown to effectively alleviate the effects in the warm section. A focusing-free transition with reduced

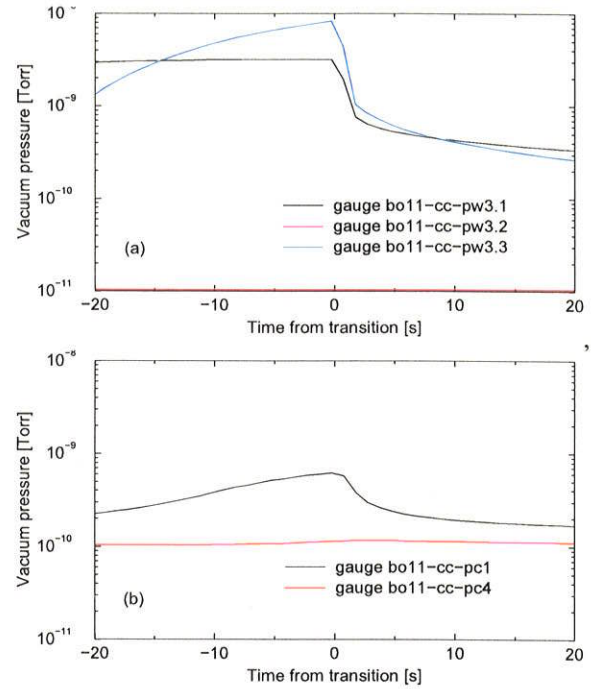

Figure 11: Vacuum pressure rise in the (a) warm and (b) cold region of the ring. Pressure on gauge bo11-cc-pw3.2 located between the two NEG-coated pipes does not rise.

peak intensity can possibly mitigate the problem [7].

Many questions remain to be answered. (1) It is not clear why the beam loss of the first bunch in the train is much higher than the nominal. More detailed logging of the vacuum pressure (every 0.1 s instead of 1 s) may clarify the gas scattering contribution. (2) It is not clear whether the instability alone causes more than 70% beam loss in 10 ms; what are the principle instability modes [8]; and why beam loss and the transverse instability occur only after but not before transition. A possible explanation yet to be verified is a sizable tune shift due to e-cloud coupled with a transition-jump lattice close to resonance. e-detector data needs to be logged in finer steps (1 ns instead of 10 ns) to explore e-cloud generation within each single bunch.

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