STUDY OF ELECTRON CLOUD FOR MEIC*

S. Ahmed[1†], B. Yunn[1], J. Dolph[2], T. Satogata[1,3], G.A. Krafft[1,3]
[1]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[2]Bridgewater College, 402 East College Street, Bridgewater, VA 22812, USA
[3]Center for Accelerator Science, Old Dominion University, Norfolk, VA 23529, USA

Abstract

In this paper, we report the first study of beam induced multipacting called electron cloud (EC) formation for the future medium energy electron ion collider (MEIC) beyond the 12 GeV upgrade of the existing continuous electron beam accelerator facility (CEBAF) at Jefferson Laboratory (JLab). For the assumed peak value of secondary emission yield δ_{max} = 1.6, we observe the build-up of cloud density of saturation level of 0.7 nC/m for 1500 consecutive bunches separated by 40 cm. This results in the tune shift per unit length of the order of 2.6×10^{-5} m^{-1}. Possible dynamical effects from the EC on the beam such as emittance growth and instabilities have yet to be investigated.

INTRODUCTION

High luminosity is required for MEIC and can be achieved with small beam size and closely spaced bunches. However, the narrow spacing between bunches can lead to an instability that blows up the beam size and limits achievable luminosity [1]. The MEIC at JLab has been envisioned as a future high energy particle accelerator beyond the 12 GeV upgrade of the existing CEBAF. The conceptual layout is shown in Fig. 1 and the basic parameters are illustrated in Table 1. The high luminosity $\sim 6\times10^{33}$ cm^{-2} s^{-1} in the machine is expected to be achieved by small bunches with low charge and small spacing (40 cm). There are several beam dynamics challenges involved in an accelerator design [2] – electron cloud (EC) is one of the important effects caused by beam induced multipacting. In general, the build up of EC is seeded by primary electrons from three main sources: photoelectrons, ionization of residual gas, and electrons produced by stray beam particles striking the chamber wall. The photoelectron effect is negligibly small in the case of protons and heavy ions at low energy. In this paper, we have examined the build-up of electron cloud via computer simulations by exploring the possible parameters. This report is a first comprehensive study towards the detailed understanding of the dynamical effects on beam from the EC such as emittance growth and instabilities. The computer code called ECLOUD [3] has been used in this study.

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† sahmed@jlab.org

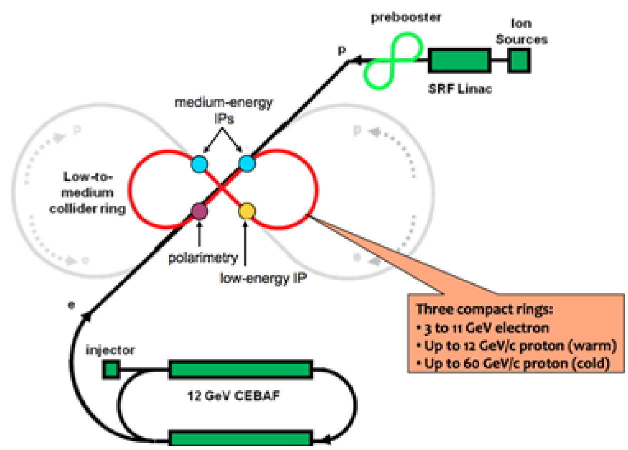

Figure 1: Conceptual layout of MEIC at JLab.

RESULTS AND DISCUSSION

We are in the early stage of design phase and hence many details like the material properties of beam pipe, peak sec-

Table 1: MEIC design parameters for EC simulations

Parameters	Symbol (Unit)	Value
Beam energy	E_b (GeV)	60
Relativistic beam factor	γ_b	64
Collision frequency	f_c (MHz)	750
Circumference	C (m)	1000
Revolution period	$T_0 (\mu s)$	3.34
Beam pipe cross-section	—-	Circular
Beam pipe radius	r_b (mm)	30
Harmonic number	h	2500
Number of bunches	K_B	2500
Bunch spacing	s_b (cm)	40
Bunch population	N_e (10^{10})	0.416
Bunch length	σ_l (mm)	10
Bunch profile	—-	Gaussian
Total beam current	I (A)	0.5
Energy spread	σ_E (10^{-4})	3
Normalized horizontal emittance	ϵ_x^n (μm-rad)	0.35
Normalized vertical emittance	ϵ_y^n (μm-rad)	0.07
Horizontal beta function at IP	β_x^* (cm)	10
Vertical beta function at IP	β_y^* (cm)	2
Residual gas pressure	P (nTorr)	5
Temperature	T (K)	300
Ionization cross-section	σ_i (Mbarns)	2
Peak SEY	$\delta_{max} \equiv \delta(E_{max})$	1.6
Energy at peak SEY	E_{max} (eV)	230
Simulation section	—-	Dipole magnet
Length of simulated region	L (m)	1.0
Dipole magnetic field	B (T)	1.7

ondary yields (SEY) etc. are not yet finalized and hence taken from other reports [4]. It is important to note that these parameters may change in the final design resulting in the change in final result. In this study, we have explored the parameter space affecting the electron cloud development.

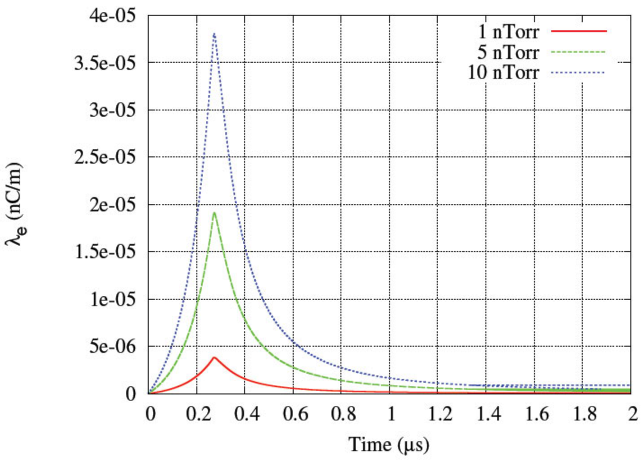

Figure 2: Evolution of electron cloud density with time for 200 consecutive bunches at residual gas pressure 1, 5 and 10 nTorr.

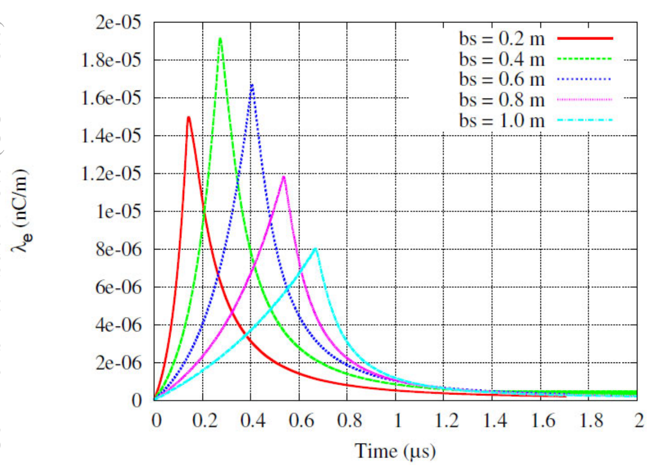

Figure 3: Time variation of electron cloud build-up (line density) for different bunch spacing. Simulations have been run for 200 consecutive bunches.

Fig. 2 shows the effect of variation in the residual gas pressure. We see that the rise in pressure raises the cloud density linearly. This result is consistent with the generation of primary electrons due to ionization which follows linearly with gas pressure [5]. Fig. 3 illustrates the evolution of cloud build-up for different bunch spacing. Density is maximum for the spacing of 40 cm. Increasing the bunch increases the density of the cloud because the increase of the ionization which is indeed seen in the simulations – see Fig. 4. The effects of bunch population and the pipe radius are shown in Figs. 5 and 6. As expected, increasing the bunch population increase the density of cloud build-up,

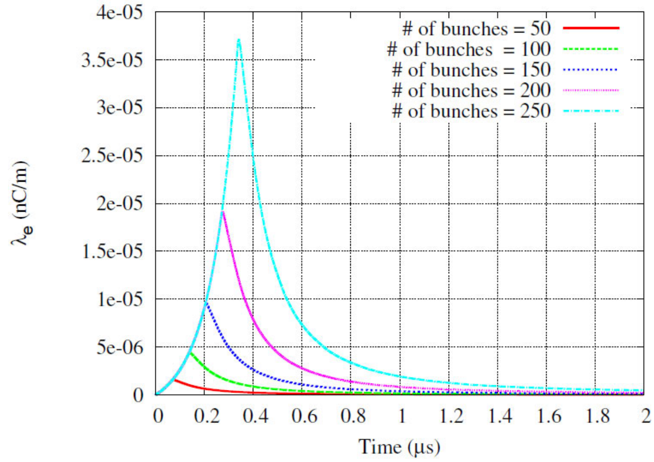

Figure 4: Time evolution of cloud density for different consecutive bunches.

however, decreases with pipe radii.

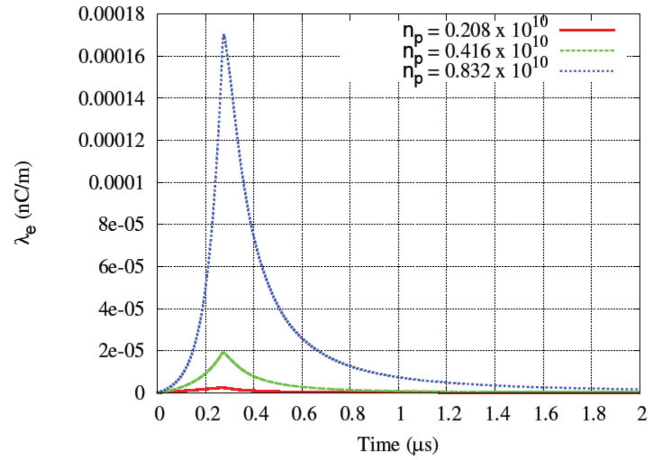

Figure 5: Time evolution of electron cloud linear density for different bunch population. Simulations are run for 200 consecutive bunches.

In the above studies, we have noticed the exponential build-up followed by a decay of the cloud density but no saturation. This means that the number of bunches considered in these simulations are not enough to generate sufficient ionization of the level where the space charge due to EC stops further emission of secondaries from the wall. We do, however, observe saturation by employing 1500 consecutive bunches. Fig. 7 shows the time evolution of EC line density, which clearly demonstrates the exponential growth followed by the saturation and finally the decay.

The straightforward consequence of EC density is a tune shift owing to the focusing effect of the electrons on the beam. Assuming that the EC density distribution is round in the transverse plane, the tune shift per unit length of beam traversal through the cloud is given by [6]

$$\Delta\nu/L = \frac{r_p\bar{\beta}\rho_e}{2\gamma_b} \quad (1)$$

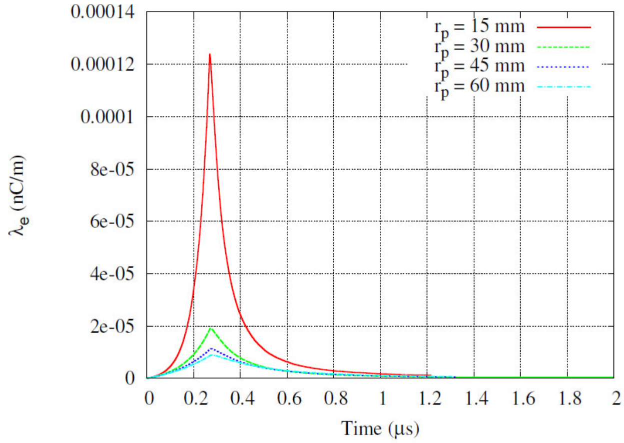

Figure 6: Time evolution of electron cloud for beam pipe with different radii. Simulations are run for 200 consecutive bunches.

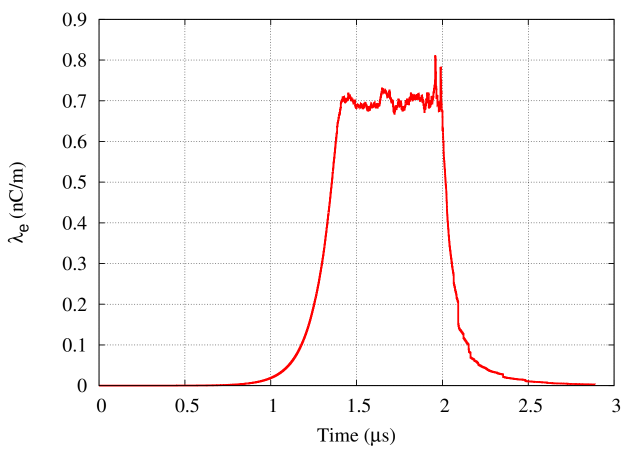

Figure 7: Time evolution of electron cloud for base MEIC parameters listed in Table 1. Simulations are run for 1500 consecutive bunches.

where the classical proton radius $r_p = 1.535 \times 10^{-18}$ m and $\rho_e = 1.55 \times 10^{12}$ m^{-3} is the EC density, $\bar{\beta}$ = 1400 m, γ_b = 64. We obtain $\Delta\nu/L = 2.6 \times 10^{-5}$ m^{-1}; taking $L = C$ gives an idea of the magnitude of $\Delta\nu$ = 0.026.

NEXT STEPS

The observed EC saturation density of $\rho_e = 1.55 \times 10^{12}$ m^{-3} in Fig. 7 is commensurate with transverse mode coupling instability threshold densities calculated for the SPS by Ohmi, Zimmermann, and Perevedentsev [7] of approximately $(3 \times 10^{11} + 5 \times 10^{11}\xi)$ m^{-3} for a typical hadron synchrotron chromaticity ξ of 2-3 units. These initial simulations do not rule out EC effects as important for MEIC hadron ring design.

EC tune shifts, instability thresholds, and growth times must therefore be carefully evaluated, particularly considering the additional complications of beam-beam tune spread and electron cooling. Further work will simulate the EC saturation density in various MEIC operations scenarios to calculate details of the EC-induced wakefield to establish more stringent bounds on instability thresholds and determine whether EC mitigation, such as NEG coatings or solenoid fields, should be considered in the MEIC/EIC design.

CONCLUSION

This paper reports the first study of EC density build-up mainly due to the ionization of the residual gas inside the beam-pipe chamber in the presence of dipole magnetic field. In these computer simulations, we have explored the effects of possible parameter space. The EC density build-up depends linearly on the gas pressure, however, the non-linear dependence on the other parameters such as bunch population, bunch separation, and the beam pipe radii is observed. The saturation of EC density is achieved by the fairly large number (1500) of consecutive bunches where the space charge force stops further emission of secondary electrons from the wall. The estimated tune shift per unit length due to EC density is 2.6×10^{-5} m^{-1}. The dynamic effects of EC on beam such as emittance growth and instabilities will be reported separately.

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