Electron Clouds Thresholds with 75 ns Bunch Spacing

Ubaldo Iriso*

CELLS - ALBA

Ctra BP-1413, Cerdanyola, 08193 - Barcelona, SPAIN

(Dated: February 11, 2011)

This note explores the thresholds at which electron clouds are predicted using the code ECLOUD for nominal LHC conditions, but using a bunch spacing of 75 ns.

I. INTRODUCTION

In November 2010 electron cloud hallmarks appeared at the LHC when running beams with bunch spacings of 50ns. These hallmarks were pressure rise in the warm sections, heat loads in the cold regions, and emittance blow-up for last bunches in later batches [1].

Using a bunch spacing of 75 ns, pressure rises were detected in the machine as well, but at much more tolerable values (see Fig. 1). For next year operation, scrubbing is foreseen to reduce the maximum SEY and so reduce the electron cloud activity. The scrubbing will be performed with beams of 50 ns bunch spacing, the goal being to achieve an SEY such that no electron clouds appear with 75 ns bunch spacing.

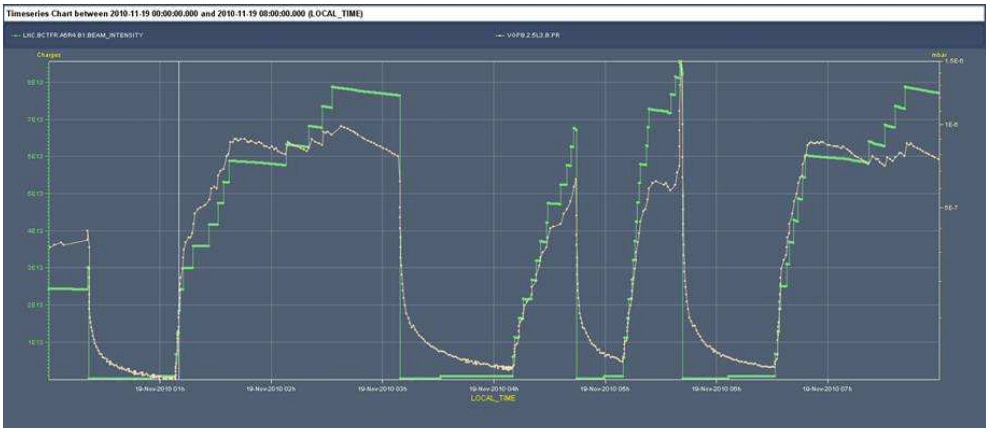

FIG. 1: Observations at IR3 with 75ns.

This note explores the SEY limits that shall be achieved during the scrubbing process such that the machine is not limited by electrons clouds during the operation with 75 ns bunch spacing.

These limits are predicted using the code ECLOUD, and we are focused on two regions with significant interest: the warm secion "IR3" (where the largest pressure rises have been measured in Nov. 2010), and the cold bending magnet (since ∼70% of the machine is covered by these elements).

Table I summarizes the ECLOUD parameters used in the simulation. In all cases (IR3 and bending), primary electrons are created from gas ionization, plus 10% created randomly around the vacuum chamber.

*Electronic address: ubaldo.iriso@cells.es

TABLE I: ECLOUD input parameters. The fill pattern was fixed to 4 batches of 24 bunches, with a batch spacing of 225ns. Emittance is fixed to $\epsilon = 2.3\mu m$rad.

Parameter	symbol [unit]	IR3	Dipole
# pe-macroparticles/bunch	npepb	2000	2000
# of bunches	nbunch	128	128
# interm. steps/bunch	nbsteps	150	150
# interm. steps/interbunch drift	nisteps	300	5000
# particles per bunch	protons	1.1e11	1.1e11
bunch spacing	sb [m]	22.49	22.49
bunch length	σ_l [m]	0.118	0.118
Hor beam size	σ_x [mm]	1.50	1.51
Ver beam size	σ_y [mm]	1.13	6.58
particle energy	E [GeV]	450	450
circumference	C[m]	27000	2700
primary ph-e emission yield	peeff	0.001	0.001
bunch # until ph-e are emitted	nbini	128	128
max slice # until ph-e are emitted	nsini	150	150
angle cut for the emitted photons	...	.041	.041
energy ph-e, position of peak	epemax [eV]	7.	7.
energy ph-e (sigma distrb.)	epesig [eV]	5.	5.
energy sec. e- (sigma distrb.)	semax [eV]	1.8	1.8
secondary emission yield (yim)	SEY	[1.7 - 2.7]	[1.7 - 2.7]
secondary emission yield for $E \to 0$	R	[0.3 - 0.7	[0.3 - 0.7]
energy for max SEY (yemax)	E_{max} (eV)	230.	230.
Hor Aperture Limitation	xbound [m]	0.03	0.022
Ver Aperture Limitation	ybound [m]	0.03	0.018
Bending field	bfield [T]	1e-7	0.535 / 4.16
initial pressure	P [nTorr]	320.	320.

II. SIMULATIONS AT IR3

The beam pipe geometry in IR3 changes along its length. However, previous studies showed that the most critical part is where the transverse beam pipe is round with a chamber radius of 30mm [2].

Due to a misunderstanding, we ran the first simulations assuming a beam pipe radius of 15mm, which lead to confusing results because the observations in Fig. 1 were not at all reproduced: simulations showed no electron cloud. This is explained by the reduction of chamber radius, which translates into a smaller time of flight and so to a smaller electron survival between bunches.

So, results (with chamber radius of 30mm) are shown in the next plots.

A. Simulations at IR3: linear and volume density

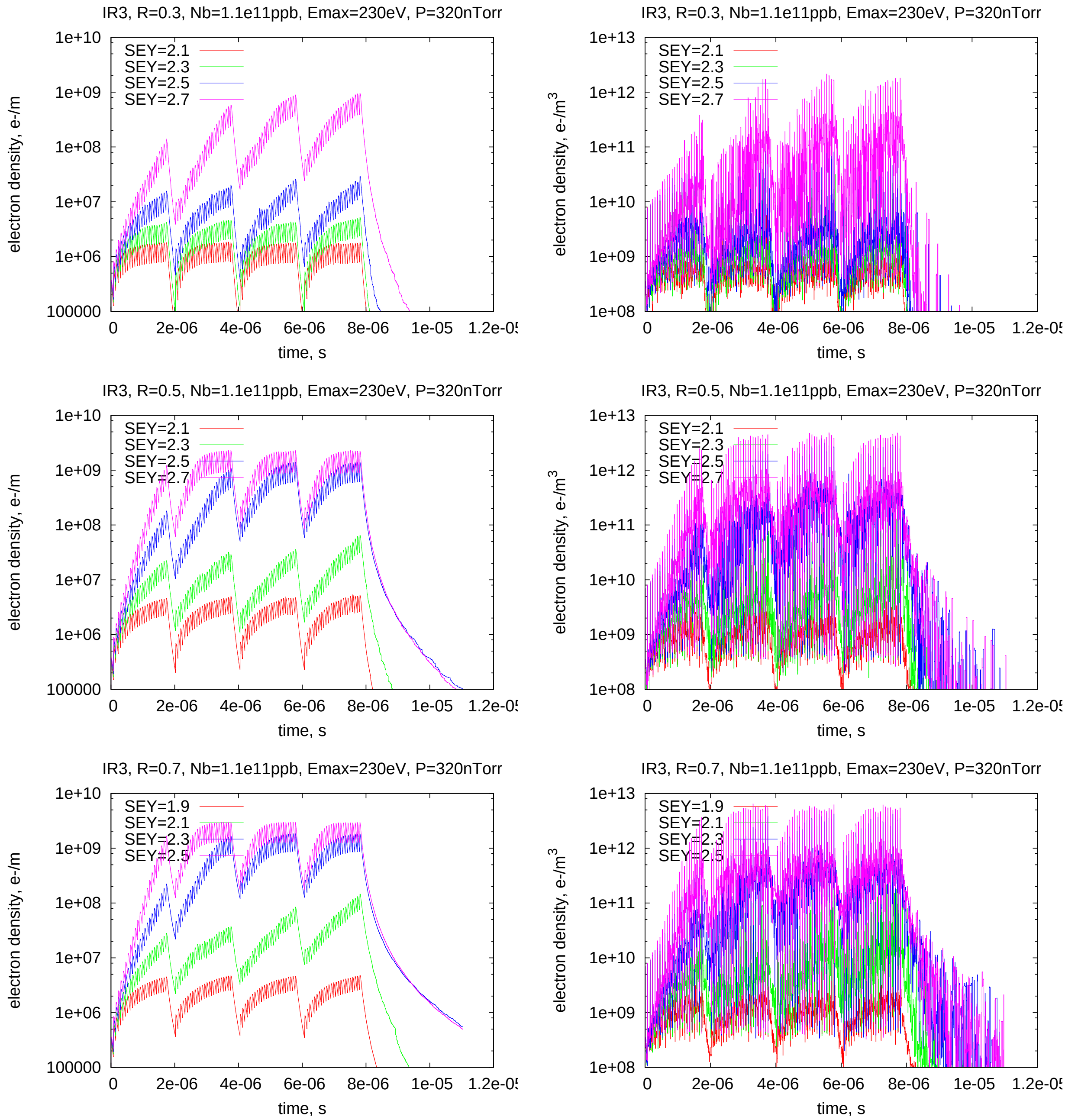

FIG. 2: Simulations for IR3: line and volume density.

B. Simulations at IR3: flux and energy

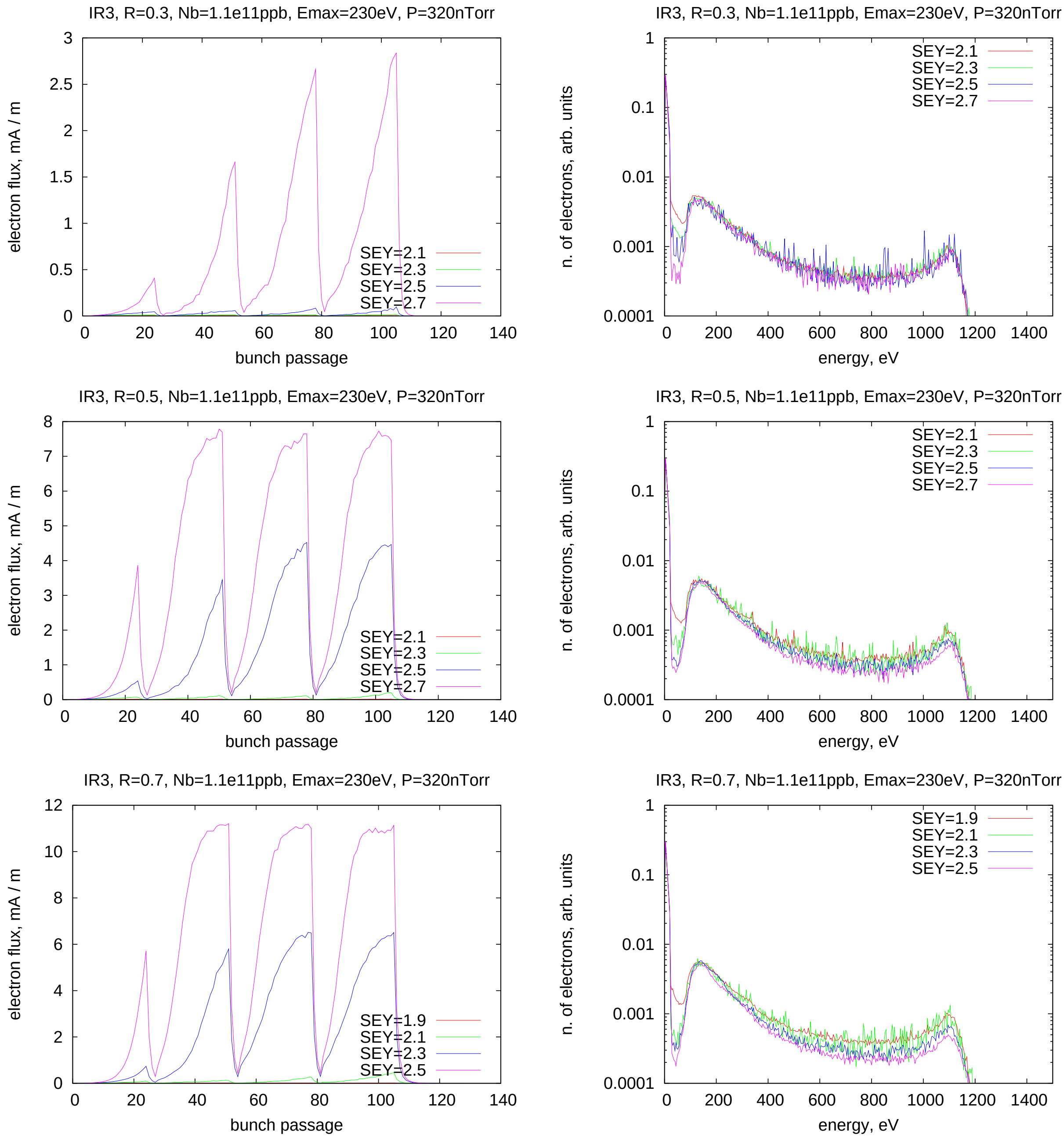

FIG. 3: Simulations for IR3: flux and energy spectrum.

C. SEY thresholds at IR3 for different Reflectivities

The code gives the "electron volume density" in several input files (centerdensity.data – file 43, cdbunch.data — file 42, cd.data – file 61). The differences among them are unclear, the definition of "volumetric electron density" is unclear. .

We are looking for an electron volume density lower than 1e11e-/m^3, which is supposed to be the onset for beam instabilities [3]. This limit is found using the HEADTAIL code, whose input is the volumetric electron density at $\pm(10 \times \sigma_{x,y})$ before the bunch arrival.

Since the volumetric electron density changes significantly during the bunch passage (see zoom at Fig. 4), we decided to infer the volumetric density as the linear density divided by the transverse chamber area (see Fig. 5).

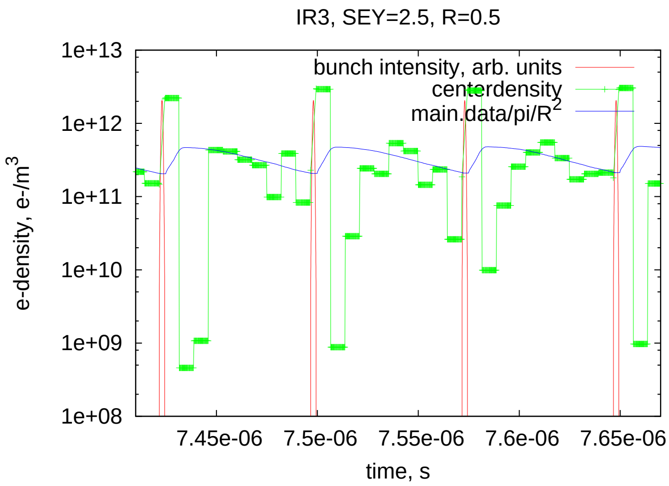

FIG. 4: Volumetric density (as given in file "centerdensity.data"), density inferred by the linear density (as given in file "main.data") divided by πb^2, and bunch intensity during the last 4 bunch passages for SEY=2.5, R=0.5.

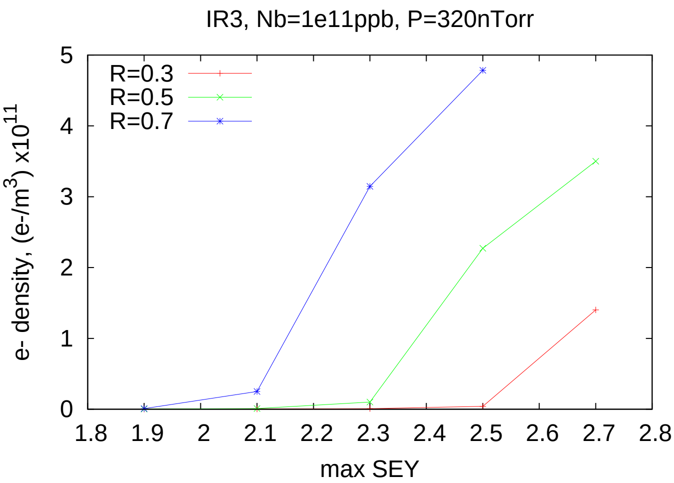

FIG. 5: Simulations for IR3. The value in the abscissa represents the average over 75 ns before the last bunch passage of the 4th batch.

III. SIMULATIONS AT DIPOLES

For the time being, only injection conditions (450GeV, B=0.535T).

Since the SEY limit using R=0.5 is 2.6, we consider that for R=0.3 the SEY limit would be unrealistically high and so we have not launched simulations with R=0.3.

A. Simulations at dipoles: linear and volume density

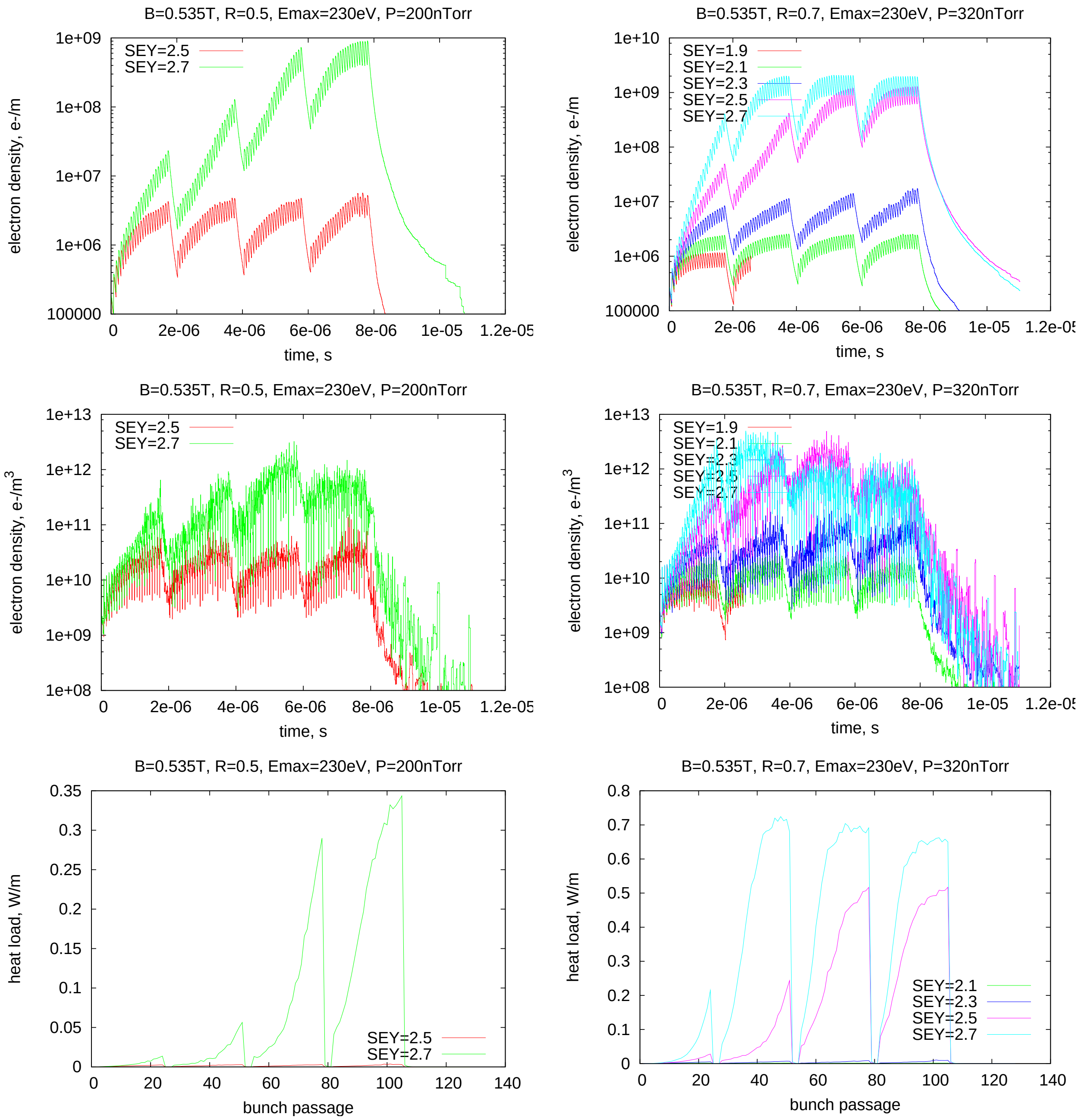

FIG. 6: Simulations for the dipole region: line and volume density. The behaviour at the midle plot rows is somehow puzzling.

B. Simulations at dipoles: electron distribution

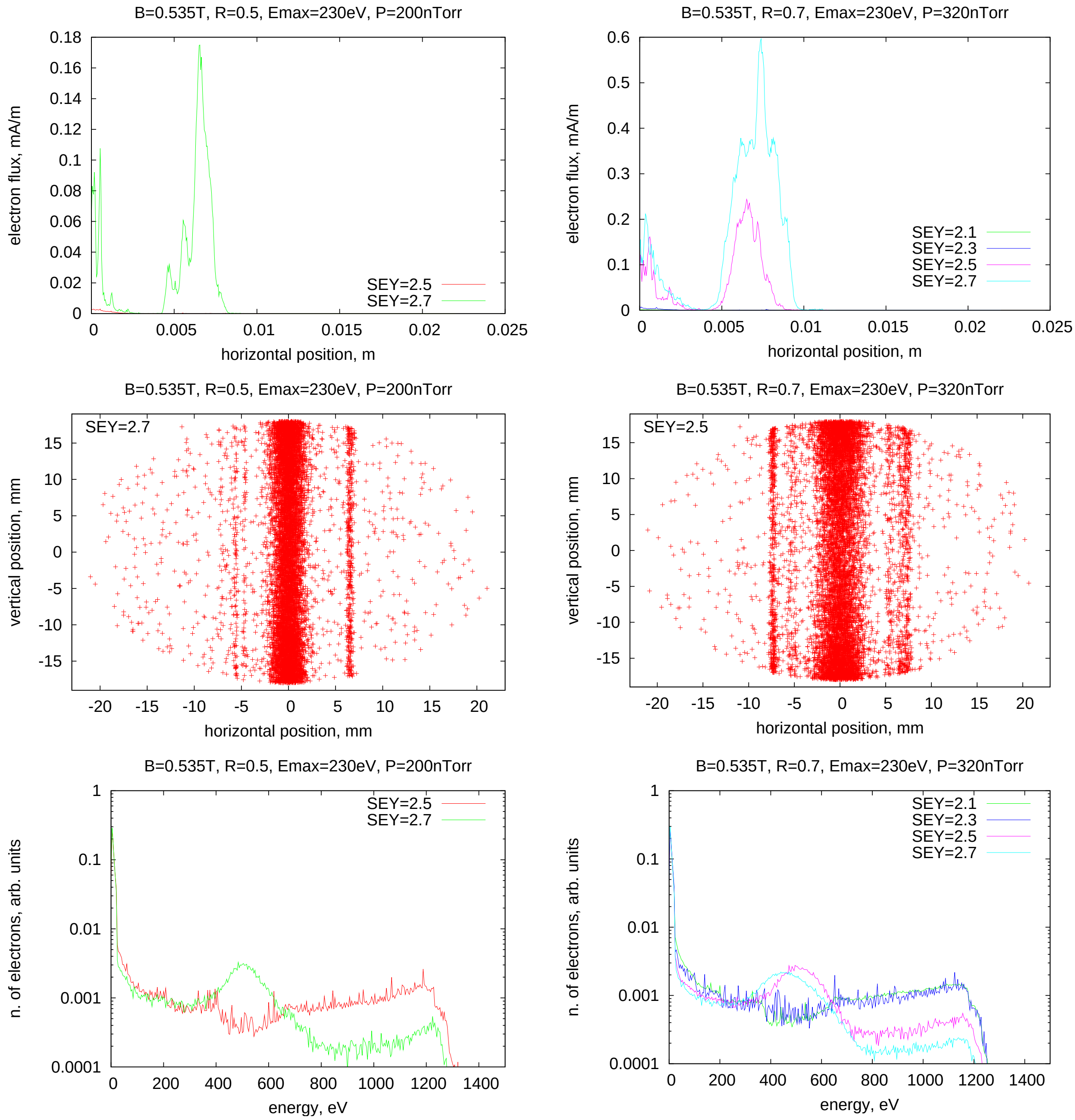

FIG. 7: Simulations for dipole: horizontal flux (top row), electron transverse distribution (middle row), and energy spectrum (bottom row). Note the small peak at around 500eV for the cases where multipacting is seen, while a small dip is found in cases where no multipacting occurs.

C. SEY thresholds at Dipoles for different Reflectivities

We follow the same approach to infer the "volumetric electron density": since the volumetric electron density changes significantly during the bunch passage (see Fig. 8), we decided to infer the volumetric density as the linear density divided by the transverse chamber surface (see Fig. 9).

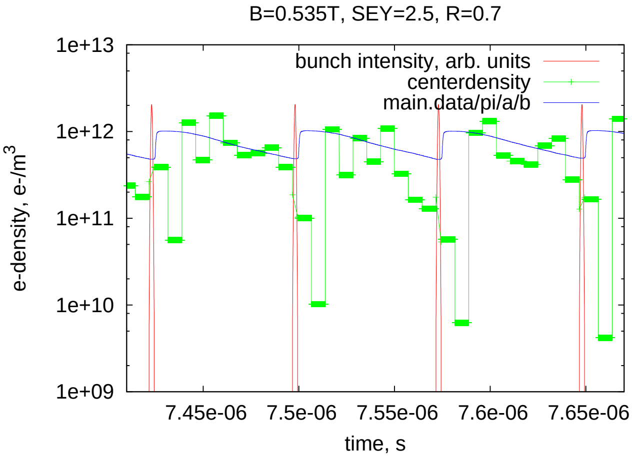

FIG. 8: Volumetric density (as given in file "centerdensity.data"), density inferred by the linear density (as given in file "main.data") divided by πab, and bunch intensity during the last 4 bunch passages for SEY=2.5, R=0.7.

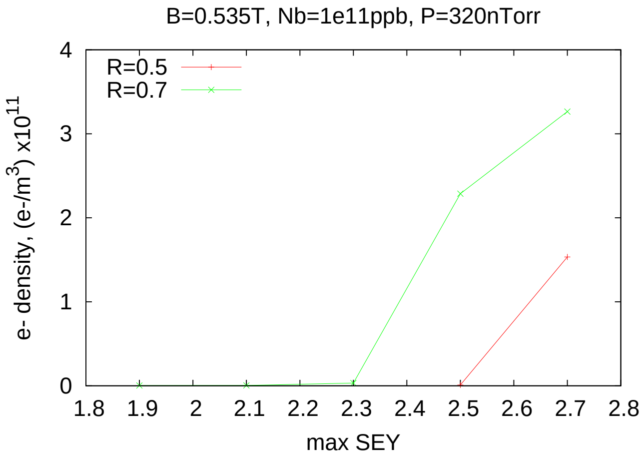

FIG. 9: Simulations for a dipole. The value in the abscissa represents the average over 75 ns before the last bunch passage of the 4th batch.

IV. SUMMARY

The SEY thresholds at which we predict the electron cloud to occur are summarized in Table II, which are based on Figs. 5 and 9, as well as the evolution of the electron density in Figs. 2 and 6.

TABLE II: SEY thresholds at IR3 and dipoles for an electron cloud formation that may lead to electron densities above the instability limit (1e11e-/m^3).

	SEY limit @IR3	SEY limit @Dipole
R=0.3	>2.5	>2.7
R=0.5	>2.3	>2.6
R=0.7	>2.1	>2.4

V. OUTLOOK

In the upcoming weeks, it will be interesting to study the scenario in which electron clouds thresholds can be avoided just by playing with beam parameters. Here are some candidates:

- Emittance: we used 2.3um, we can study 4, 8, and 16um. We expect a linear dependence with the transverse beam size, which translates into a $\sqrt{\epsilon}$.
- Longitudinal beam size: although Nov. 2010 observations with 50ns do not show a big dependence, it is worth to check if we have the same case for 75ns. In case of problems, we can play with the cavity voltage to increase the bunch length (which should decrease the e-cloud).
- Everything here has been done for Nb=1.1e11ppb. However, to increase luminosity it is desirable to increase Nb (as it scales as Nb^2). Would this case be interesting for the experiments? Worth studying it?
- Check e-cloud behaviour for storage conditions (at E=3.5TeV).
- What would be the freedom to inject with different batch spacings? Would it be worth to check a "map approach"?

Somethings worth trying, regarding the code and the observations benchmarking:

1. The current SEY parameterization in ECLOUD is neglecting the so-called "rediffused" electrons. In case the observations are difficult to reproduce with ECLOUD, introducing these electrons should not be too complicated.
2. It would be nice (CPU-time wise) to be able to start the ECLOUD code with an arbitrarily electron distribution (at rest, or even with a given (p_x, p_y, p_z)). This should be more complicated.
3. Get the data in Fig. 1 and plot pressure vs intensity, or bunch number. It should show an initial exponential growth (corresponding to the initial exponential e-flux growth), followed by a linear regime (corresponding to the saturation part). The code should then reproduce this behaviour.

VI. ACKNOWLEDGMENTS

Thank you...

[1] G. Arduini, *Observations with 50ns (e-cloud, instabilities), very preliminary summary.*
[2] O. Domínguez, private communications.
[3] K. Li, *Presentation at e-cloud meeting, 17.1.2011.*
[4] , S. Turner, CAS on Vacuum Technology, CERN, 1999.
[5] J. Gomez-Goni and A.G. Mathewson, *Temperature dependence of the electron induced gas desorption yields on stainless steel, Copper and Aluminum*, J. Vac. Sci. Technol., 1997.
[6] F. Billard, N. Hilleret and G. Vorlaufer,*Some results on the electron induced desorption yield of OFHC Copper*, CERN, 2000, LHC/VAC/FB/NH/GV00-32.

Appendix A: Particles trajectories in a dipole

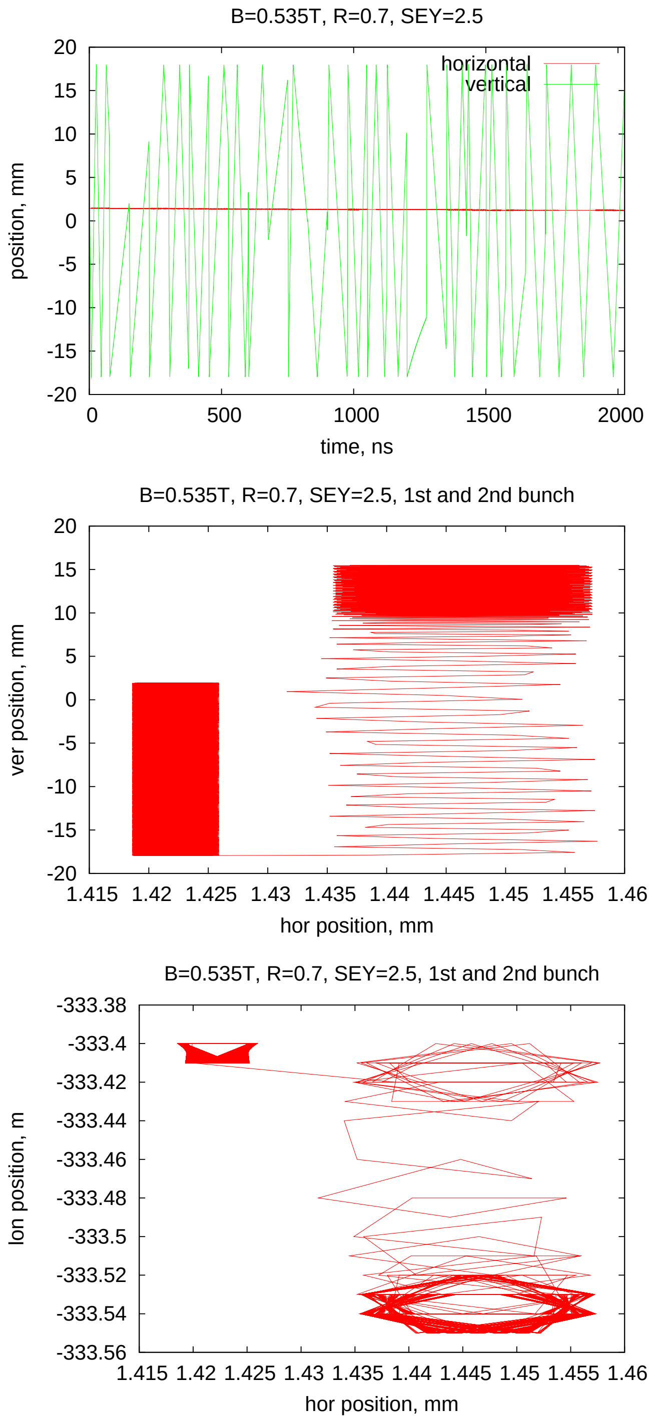

FIG. 10: Hor and Ver trajectories during the first batch passage (top). Ver vs Hor position evolution during the first two bunch passages (middle). Longitudinal vs Hor position evolution during the first two bunch passages (bottom).

Appendix A: Static pressure rise in presence of an electron cloud

Assuming the beam pipe is a periodic structure with vacuum pumps of pumping speed $2S$ spaced by the distance $2L$, the static pressure distribution along the longitudinal position z between two vacuum pumps is [4]:

$$P(z) = q\Big[\frac{2Lz - z^2}{2c} + \frac{L}{S}\Big] \quad , \quad \text{for } 0 \leq \text{z} \leq \text{2L}. \tag{A1}$$

Here the z origin is placed at one of the vacuum pumps, c is the specific molecular conductance of the vacuum chamber, and q is the specific linear outgassing rate.

Consider electron cloud situations in which the outgassing rate due to an electron flux dI/dl (in units of [A/m]) exceeds by a wide margin the thermal outgassing rate. In the absence of magnetic fields and assuming a regular and homogeneous chamber, one can further consider the electron flux to be constant throughout the beam pipe. The outgassing rate then does not depend on the longitudinal beam pipe position z, and it can be expressed by

$$q = \eta_e \frac{kT}{e}\frac{dI}{dl} \ , \tag{A2}$$

where e is the absolute value of the electron charge, k is Boltzman constant, T is the temperature, and η_e is the electron induced molecular desorption coefficient of the beam pipe wall, that is, the number of desorbed molecules per impinging electron.

Since the time constant of the vacuum pumps is a few seconds, the pressure evolution cannot be followed within one turn. The pressure responds then to the time averaged flux over one turn,

$$\left\langle \frac{dI}{dl} \right\rangle_\tau = \frac{1}{\tau}\int_0^\tau \frac{dI(t)}{dl} dt \ , \tag{A3}$$

where τ is the revolution period, and $dI(t)/dl$ is the instantaneous electron flux. Using Eqs. A1 and A2, the pressure due to an electron cloud at a given position $z = 0$ is

$$P(z=0) = P_0 + \eta_e \frac{kT}{e} \left\langle \frac{dI}{dl} \right\rangle_\tau \frac{L}{S} \ . \tag{A4}$$

where P_0 is the static pressure.

The electron desorption coefficient, η_e, depends on the released gas molecule, the energy of the striking electron, the surface material, and the accumulated dose on the surface. For stainless steel, data for energies as low as 300 eV are found in Ref. [5]. For OFHC Copper and energies as low as 20 eV, data can be found in Ref. [6]. Just to get a VERY rough estimation of the order of magnitude, we consider CO at room temperature and use typical values found in literatures and shown in Table III. Assuming a $\langle \frac{dI}{dl} \rangle_\tau = 2$ mA/m (see Fig. 3), the static pressure due to an electron cloud would be: $P = 1 \times 10^{-6}$ mbar.

TABLE III: Parameters used to estimate the static pressure in presence of an electron cloud in IR3.

parameter	symbol	unit	value
distance between pumps	$2L$	m	4
CO pumping speed	$2S$	l/s	200
CO molecular desortpion yield	η_e	molecs/e-	0.1
temperature	T	K	300
beam pipe radius	b	mm	30

A more exact estimation can be done by using the actual values at IR3 for pumping speed and geometry (ask the Vacuum Group), and by taking into account the variation of η_e with the energy of the impinging electrons and for different gases. Some vacuum pumps also change their pumping speed depending on the pressure range, in which case it should also be taken into account.

All these effects are not considered in the code ECLOUD. However, we can compute the flux integral from the code. This magnitude has a crucial importance because, the pressure (which is the most available diagnostic in the machine) depends linearly with the flux integral (see Eqs. A3 and A4):

$$P(z) \propto \int_0^\tau \frac{dI(t)}{dl} dt \ , \tag{A5}$$

and it can be computed from ECLOUD. Figure 11 shows the pressure evolution as a function of the injected bunches. The lhs plot shows the difference between the instantenous and the integral flux, while the plot on the rhs shows the difference for different SEYs. One can distinguish the initially exponential growth followed by a linear regime once saturation is achieved.

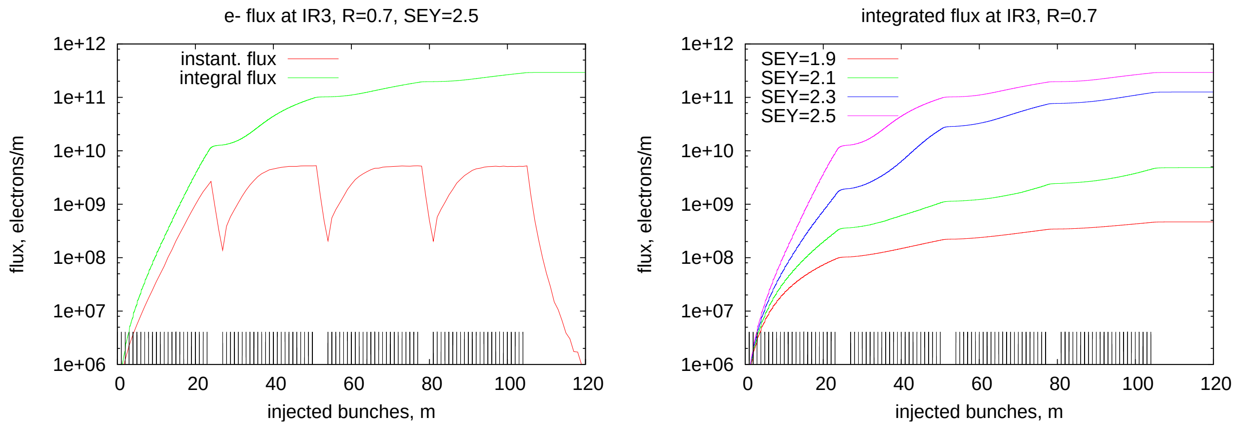

FIG. 11: Pressure evolution during the injection of 4 batches with 27 bunches/batch. The lhs shows the difference of the instantaneous vs the integrated flux for the case with R=0.7, SEY=2.5; while the rhs shows the integrated flux for different SEYs, which should be directly proportional to the pressure readings.