

A SIMULATION STUDY OF THE ELECTRON CLOUD IN THE EXPERIMENTAL REGIONS OF THE LHC

A. Rossi, G. Rumolo and F. Zimmermann, CERN, Geneva, Switzerland

Abstract

The LHC experimental regions (ATLAS, ALICE, CMS and LHCb) are characterised by having a variable geometry, non-uniform magnetic field, and the presence of two beams that will collide at the Interaction Point (IP). A detailed study of electron multipacting in the experimental chambers is needed to establish the pressure increase due to electron stimulated desorption, especially critical in the experimental regions. Furthermore, knowledge of the predicted electron cloud density all along the experimental regions will allow for an estimation of its possible effects on the beam stability.

1 INTRODUCTION

Photoemission and/or ionisation of the residual gas inside the beam pipe causes production of electrons, which then move under the action of the beam field forces and their own space charge. These primary electrons can initiate a build up of a quasi-stationary electron cloud. In the interaction regions of the LHC the maximum acceptable residual gas density is limited by the background noise induced to the detectors. Electrons accelerated by the beam space charge and impinging on the walls can desorb molecules and contribute to the residual gas density. Moreover, the electron cloud may affect the beam stability and luminosity in collision. The aim of this study is to evaluate electron cloud build up in the LHC experimental areas and its effects on the residual gas pressure.

2 ELECTRON CLOUD BUILD-UP

The experimental chambers differ from the standard arc chambers mainly for their variable geometry, the non-uniform magnetic fields, and the two beams travelling in opposite directions. Practically all the experimental chambers are at room temperature and coated with low activation sputtered TiZrV Non-Evaporable Getters (NEG's) [1]. The TiZrV NEG has been chosen, among other reasons, because it can limit electron multipacting due to its low Secondary Emission Yield (SEY). It was found that, after only 200°C activation, the maximum SEY, δ_{\max} , becomes about 1.1 for incident electron energies between 300 and 400 eV [2], [3]. However, after a few air venting/activation cycles, the maximum SEY can increase up to ~ 1.4 [4].

2.1 Electron cloud simulation parameters

As the experiments are supposed to run independently of one another, we cannot rely on the experimental solenoid field (in the central sections of ATLAS and

CMS) to prevent multipacting. Therefore, the simulations have been carried out assuming field free regions.

The study of multipacting in the experimental regions has been conducted using E-CLOUD [5] and considering the following set of parameters and/or assumptions:

1. The maximum SEY is 1.1 or 1.4.
2. We have assumed the elastic reflection to occur as on the copper samples recently measured [6]. Elastic reflection is anyway strongly dependent on the surface roughness more than on the material on which the electrons impinge.
3. The photon flux to the wall for the LHC geometry has been evaluated using the code developed by F. Zimmermann [7]. We expect the photon flux in the straight experimental areas to be sensibly smaller than the one in the arcs.
4. Bunch transverse sizes have been taken at injection and at top energy, both at the interaction points and up to 20m downstream. The study shows, that there is no strong dependence of the electron multipacting on this parameter. This was predictable since for the cases considered, the beam was much smaller than the pipe cross section.
5. The two cases of two beams reaching a selected location simultaneously (25ns bunch spacing and double bunch intensity) and two beams at half distance (12.5ns bunch spacing and single bunch nominal intensity) have been simulated.
6. Geometry variable in steps for experimental regions.
7. The effects of RF traps in enlarged sections of the chambers have not been taken into account.

Table 1. LHC parameters assumed in the electron cloud simulations

	symbol	value
bunch proton population	N_b	1.05×10^{11}
bunch spacing		7.48 m
r.m.s. bunch length		7.5 cm
proton energy		7 TeV
primary ph-e rate per photon		2.98×10^{-7}
reflectivity		10%
max secondary emission yield	SEY	1.1 and 1.4
energy of max SEY		300 eV
energy distr. for sec. electrons		Gaussian
r.m.s. H and V beam size		15.86 - 444 μ m
radial half aperture		22 to 200 mm

2.2 Simulation results

The time evolutions of electron flux to the wall ($e^-/s/m$), for different radii are displayed in Fig. 1. It can be observed that, despite the low value of SEY, there is an electron cloud build up. Both the rise time and saturation values depend on the chamber radius.

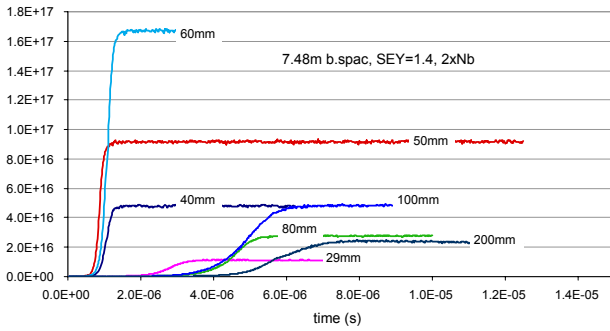


Figure 1: Time evolution of the electron flux to the wall ($e^-/s/m$) for different chamber radii, for nominal bunch spacing and double bunch current.

In Fig. 2, the saturation values of the electron flux to the wall per unit wall area ($e^-/s/cm^2$), with $SEY = 1.1$ and $SEY = 1.4$ are compared. The saturation levels appear to be more sensitive to a variation of SEY for radii > 70 mm. For the calculations of the residual gas density it was assumed that the electron flux to the wall is a step function, given the shape of the curves and that the two cases considered (simultaneous arrival and half bunch spacing) should correspond to the extreme cases.

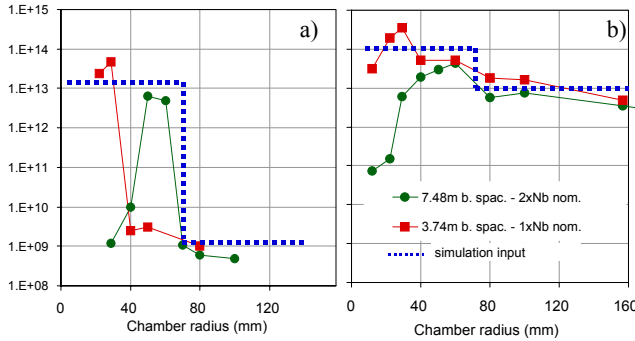


Figure 3: Saturation values of the electron flux to the wall ($e^-/s/cm^2$) as a function of the radius. a) $SEY = 1.1$; b) $SEY = 1.4$. Dotted line : values used for the density estimations.

The maximum impact energy varies between 2.5 keV for the half bunch spacing case and 4.5 keV for simultaneous beams (which corresponds to twice the bunch current). It is found that a non negligible fraction of the electrons impinge on the walls with an energy larger than 10 eV, that is larger than the threshold energy for stimulated gas desorption [8].

3 MOLECULAR DENSITY ESTIMATION IN THE EXPERIMENTAL REGIONS

3.1 Molecular density estimation parameters

As mentioned in the previous section, a large fraction of the electrons impinging on the wall will cause gas desorption. The Electron Stimulated Desorption yield (ESD) depends on the impact energy [8]. The values for ESD used for the estimates of the residual gas density are listed in Table 2 for TiZrV coating [9]. Since the ESD varies by a factor of ~ 2 between 100 and 300 eV, and

given the spread of measured data in the literature, a constant value for all energies was assumed. Photon Stimulated Gas Desorption (PSD) from TiZrV NEG coating and its sticking coefficients are also listed in Table 2. It should be noted that the desorption yields from NEG coating are reached with other materials after a long conditioning (about 1 year LHC beam time).

Table 2. LHC parameters for the TiZrV NEG coating

Desorption Yield	H ₂	CH ₄	CO	CO ₂
PSD ⁱ	2.5×10^{-7}	2.5×10^{-9}	1.25×10^{-8}	1.25×10^{-8}
ESD ⁱⁱ [9]	2.0×10^{-4}	5.0×10^{-6}	1.0×10^{-4}	1.0×10^{-4}
Sticking Coefficient				
Freshly activated NEG ⁱⁱⁱ [1]	5.0×10^{-3}	0	1.0×10^{-1}	1.0×10^{-1}
Cycled NEG ^{iv} [1]	5.0×10^{-4}	0	1.0×10^{-2}	1.0×10^{-2}

ⁱ Corrected for grazing incidence ([10], [11]) and considering the expected 12eV critical energy at the LHC interaction regions [12].

ⁱⁱ ~ 500 eV incident energy.

ⁱⁱⁱ Corresponding to $SEY = 1.1$.

^{iv} Cycled = exposed to air at atmospheric pressure and reactivated several (~ 10) times. $SEY = 1.4$.

3.2 Results

As an example, the density profiles for the CMS (with TOTEM) experimental beam pipe are presented in Fig. 3. The density corresponding to $SEY = 1.1$ (Fig. 3.a) is estimated for a freshly activated NEG coating. The major contribution to the gas density is given by electron induced desorption, and the main gas species is methane (not pumped by the NEG coating). After the NEG coating has been exposed to air at atmospheric pressure and reactivated for about 10 times, the δ_{max} increases to ~ 1.4 with a consequent increase of the electron cloud activity, as detailed in section 2. At the same time, the sticking coefficients, is reduced to about one tenth of the initial value. Both phenomena lead to a further increase in the molecular density as shown in Fig. 3.b. The hydrogen density is now comparable to that of methane, since the distributed pumping speed for hydrogen is low, while the pumping of methane is not affected by the NEG deterioration.

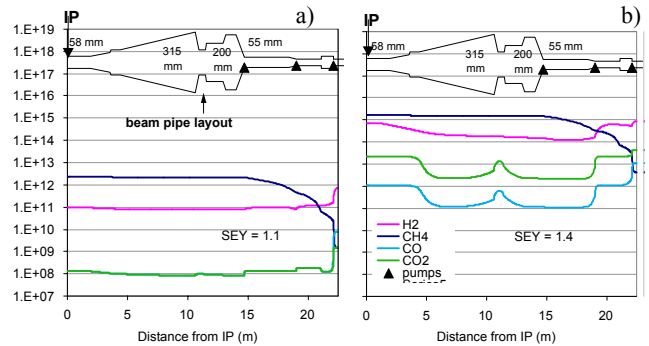


Figure 3 : CMS experiment. Molecular density profile (molecules/ m^3) a) freshly activated TiZrV NEG coating with a $SEY = 1.1$. b) $SEY = 1.4$ and 1/10 of the initial NEG pumping.

Note that, beyond 22 m from the IP, the surface is supposed to be at cryogenic temperature. Here, the distributed pumping is effective for methane, but lower than the NEG pumping for the other gas species. The profile of the CO and CO₂ gas density in the CMS geometry results from a larger electron flux to the wall in the smaller cross sections and a reduced NEG pumping (which is proportional to the pipe surface area).

4. BENCHMARKING

If the quantitative results of the electron cloud simulations are correct, the main contribution to the residual gas density comes from electron induced gas desorption, as it was explained in the previous section. Since these values are used to assess the validity of the experimental beam chambers design, benchmarking of the simulation results against experimental data is urgently needed.

In this section, preliminary results of the electron cloud code benchmarking are presented. The time evolution curves of the electron build-up signal [13] (negative voltage) during experiments in the CERN SPS with LHC type proton beam (25 ns bunch spacing) are compared with the simulation results. The data cannot be converted into number of electrons collected by the pick-up per second, because the instrument was not calibrated prior to the run.

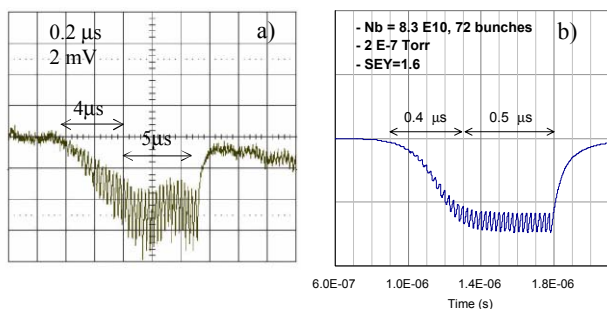


Figure 4 : Time evolution with a train of 72 bunches. The experimental data [13] (electron flux to the wall, a) are compared to simulation results (electron line density, b).

In Fig. 4.a) the electron build-up was measured with a train of 72 bunches, 8.3×10^{10} protons/bunch. The pressure was about 2×10^{-7} Torr. The input data for the simulations that best reproduce the experimental data are listed in Table 3.

Table 3. LHC parameters assumed in the electron cloud simulations for the benchmarking

	Value
bunch proton population	8.3×10^{10}
bunch spacing	7.48 m
r.m.s. bunch length	30 cm
proton energy	26 GeV
residual gas pressure	2×10^{-7} Torr
gas ionisation cross section	2 MBarn
max secondary emission yield	1.6
energy of max SEY	300 eV
energy distr. for sec. Electrons	Gaussian

r.m.s. H and V beam size	444 μm
radial half H and V aperture	H=76 and V=17.5 mm

It was assumed that the primary electrons are created by ionisation of the residual gas by the proton beam, as it should be in the SPS. The beam structure and the values assumed for the gas pressure were the same as recorded during the experiments. The time evolution of the experimental data are well reproduced by the simulations.

5 CONCLUSIONS AND FUTURE WORK

The variation of the electron cloud activity with radius (as for the LHC experimental beam pipe geometry) and SEY characteristic of TiZrV NEG coating have been simulated using ECLOUD. The results of the simulations have been used as input to estimate the residual gas density in the interaction regions during proton beam running. It was found that, despite the low SEY of the TiZrV NEG coating after activation, the levels of electron flux to the wall at saturation can induce a gas desorption which will dominate the residual gas density.

Benchmarking of the simulation results are promising. Further effort should be put to validate quantitatively the code results so as to use it as a design tool.

6 REFERENCES

- [1] C. Benvenuti et al., Vacuum 60 (2001) 57-65.
- [2] C. Scheuerlein et al., CERN EST/2000-07 (SM).
- [3] B. Henrist et al., CERN Vac. Tech. Note 98-08.
- [4] B. Henrist et al., CERN Vac. Tech. Note 98-20.
- [5] G. Rumolo and F. Zimmermann, same proceedings.
- [6] N. Hilleret et al., CERN LHC-Project-Report-472.
- [7] F. Zimmermann, CERN, LHC Project Report 237 (2000).
- [8] G. Vorlaufer et al., CERN Vac. Tech. Note 00-32.
- [9] C. Benvenuti et al., Vacuum 50 N. 1-2 (1998) 57-63.
- [10] O. Gröbner et al., Vacuum 33, N. 7 (1983) 397-406
- [11] V. Baglin et al., presented at IVC 15, San Francisco, Nov 2001.
- [12] J. Gómez-Goñi et al., J. Vac. Sci. Technol. A 12(4) Jul/Aug 1994.
- [13] M. Jimenez et al., proc. 11th Chamonix workshop, 2001.