CERN
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

CENTRO DE INVESTIGACION Y ESTUDIOS AVANZADOS DEL I.P.N – MERIDA CAMPUS

High Energy Physics Latin American – European Network

# "Electron Clouds Effects in the LHC"

Georfrey Humberto Israel Maury Cuna

## Abstract

*In the LHC beam pipe, photoemission and secondary emission give rise to a quasi-stationary electron cloud, which is established after a few bunch passages. In addition, beam-induced multipacting of the electrons may lead to an enhanced gas desorption and an associated pressure increase. In addition, the energetic electrons heat the surfaces that they impact. Only a limited cooling capacity is available for the additional heat load due to the electron cloud. If it is exceeded, a quench of the superconducting magnets would result. This work gives results of the dependence of the heat load on several parameters: bunch spacing, numbers of protons per bunch, secondary emission yields and bunch profiles.*

Geneva, Switzerland
September 15, 2008

# Electron Cloud Effects in the LHC

## Introduction

The synchrotron radiation in the LHC creates a continuous flow of photo-electrons. The critical energy of synchrotron radiation at collision energy is 44 eV, a value for which the photoemission yield from the copper surface of the beam pipe is about maximum. These electrons are accelerated by the electric field of the bunch, to energies of ~100 – 1000 eV, and hit the vacuum chamber on the opposite side of the beam pipe where they create secondary electrons. The secondary electrons typically have ~ eV initial energies and they are still inside the beam screen when the next proton bunch passes, so they are again accelerated by the field of the next bunch [1, 3]. The avalanche-like build up finally reaches a dynamic equilibrium due to the electrons' electric space-charge field. In this way, photoemission, (plus, residual gas ionization) and secondary emission give rise to a quasi-stationary electron cloud inside the beam pipe through a beam-induced multipacting process [4]. It is schematically illustrated in Fig. 1.

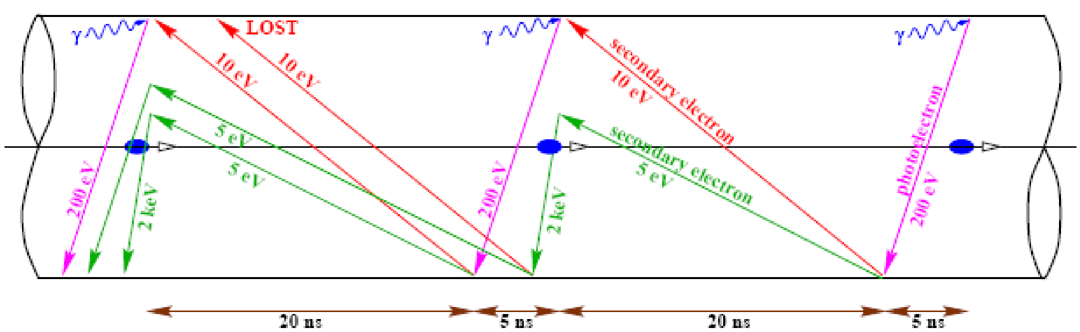


Figure 1. Schematic of electron cloud build up in the LHC beam pipe.

The electron cloud has several bad effects on collider operation. First, it desorbs gases from the walls of the beam screen, as a result of which the vacuum pressure may increase by several orders of magnitude. Second, it can cause beam instabilities that lead to emittance growth and even beam loss. The electrons near the center of the vacuum chamber are attracted by the electric field of the beam and accumulated inside the proton beam during a bunch passage. Because of this the protons at the tail of a bunch suffer additional (nonlinear) focusing. These electrons can cause instabilities of the single proton motion and thereby also a slow growth of the proton beam size [4, 5]. Lastly, the energetic electrons heat the surfaces that they impact. Only a limited cooling capacity is available for the additional heat load due to the electron cloud. If it is exceeded, a quench of the superconducting magnets would result [2, 6].

## Simulation model and beam parameters

The ECLOUD program simulates the build up of the electron cloud. The ECLOUD simulation takes into account the electric field of the beam, arbitrary magnetic fields, the electron space charge field, and image charges for both beam and electrons. As input numbers, the code requires various beam parameters (bunch population, r.m.s. bunch

length, bunch spacing, etc.), surface properties (secondary emission yield, photoemission creation rate, photon reflectivity, etc.), the vacuum chamber geometry and the type of magnetic field [7]. The parameters explored and varied in this project were: emission yield, number of particles per bunch and bunch spacing.
In, almost, all simulations we assume a Gaussian longitudinal bunch distribution and cut the bunch into 50 slices. Electrons close to the beam will oscillate in the beam potential and cutting the bunch into slices allows a proper modeling of the electron motion during the bunch passage. In the simulation program the electrons are represented by macro-particles which initially all carry the same charge. In the simulations the program generates between 1000 and 5000 macro-particles per bunch. The initial macro-particle charge of about 4 x $10^7$ *e* is chosen such that the total photoelectron charge is equal to the real one. The number of macro-particles generated per beam slice is proportional to the number of protons inside the slice. For each slice the program first generates the new photo-electrons and then evaluates the force of the beam slice on the electrons. Thus, newly generated photo-electrons experience only a fraction of the full beam kick, depending on whether they are generated near the head or the end of the bunch. When an electron hits the beam screen, the program launches one or more secondary electrons at the point of impact. The total charge of the emitted secondaries depends on the energy and on the incident angle of the lost electron. The energy distribution of the emitted particle is determined by a Monte Carlo algorithm.

On the other hand, secondary electrons surviving from a previous bunch will always experience the full beam kick. For a non-circular beam pipe the image charges of the beam on the vacuum chamber are included in the calculated beam kick on the electrons. An additional option allows the generation of image charges which lead to the correct equipotential surface at the vacuum chamber [2]. Figure 2, shows a schematic of this simulation recipe.

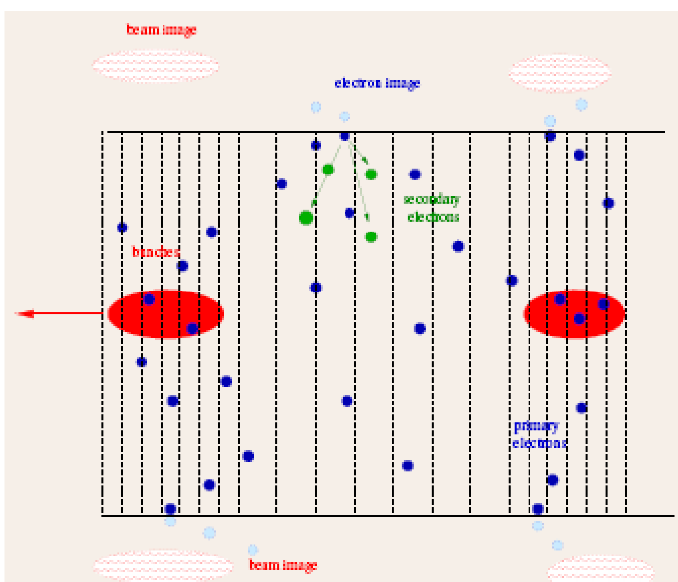

Figure 2. Schematic of simulation recipe.

In order to limit the growth of the electron cloud, as in reality, the electric space-charge field of the electrons is included in the simulation as well.

## Methodology

Four sets of simulations were performed: set A, set B, set C and set D, corresponding to a nominal LHC scenario, a 50-ns alternative LHC scenario, one upgrade LHC scenario and another upgrade with new bunch profile LHC, respectively.

| Set A "nominal" | |
|---|---|
| Yield | Bunch spacing |
| 1.1 - 1.7 | 25 ns |
| Nb | |
| $2 \times 10^{10} - 18 \times 10^{10}$ | |

| Set B "50-ns alternative" | |
|---|---|
| Yield | Bunch spacing |
| 1.1 - 1.7 | 50 ns |
| Nb | |
| $2 \times 10^{10} - 18 \times 10^{10}$ | |

| Set C "upgrade" | |
|---|---|
| Yield | Bunch spacing |
| 1.1 - 1.7 | 50 ns |
| Nb | |
| $20 \times 10^{10} - 60 \times 10^{10}$ | |

| Set D "upgrade new bunch profle" | |
|---|---|
| Yield | Bunch spacing |
| 1.1 - 1.7 | 50 ns |
| Nb | |
| $1 \times 10^{10} - 50 \times 10^{10}$ | |

Table 1. Summary of the parameters for each set of simulations.

Set A "nominal" - this group of simulations includes nominal parameters of LHC. Set B "50-ns alternative" - this set of simulations has the same characteristics as set A except for the changing of the "bunch spacing" of 25 ns to 50 ns. The Set C is an upgraded scenario for the LHC, where the number of protons per bunch was increased from $20 \times 10^{10}$ to $60 \times 10^{10}$. And, finally, the set D is an upgraded scenario with a new bunch profile. Sets A, B, C were simulated using a Gaussian bunch profile and set D correspond to a long flat bunch profile.

## Results

Figures 3 and 4 present the average heat load for the $1^{st}$ and $2^{nd}$ batch, corresponding to set A. We can see the heat load is very similar for the $1^{st}$ and the $2^{nd}$ batch. Figures 5 and 6 show the average heat load for the $1^{st}$ and $2^{nd}$ batch in case of the 50-ns alternative LHC scenario. Again, we can see that in, both cases, the heat load is very similar. Finally, Figures 7 and 8 show plots for the third set of simulation (upgrade LHC scenario) along with those for the set B. Overall, we observe that the heat load exceeds the cooling capacity lines for some (high) values of secondary emission yields (SEY) and for some (high) numbers of protons per bunch (Nb). Finally, Figures 9 and 10 show the equivalent plots for the $1^{st}$ and $2^{nd}$ batch of the ES/FCC upgrade scenario, with a Gaussian bunch profile. Figures 9 and 10 show plots of the new long flat bunch profile for the so-called LPA upgrade scenario.

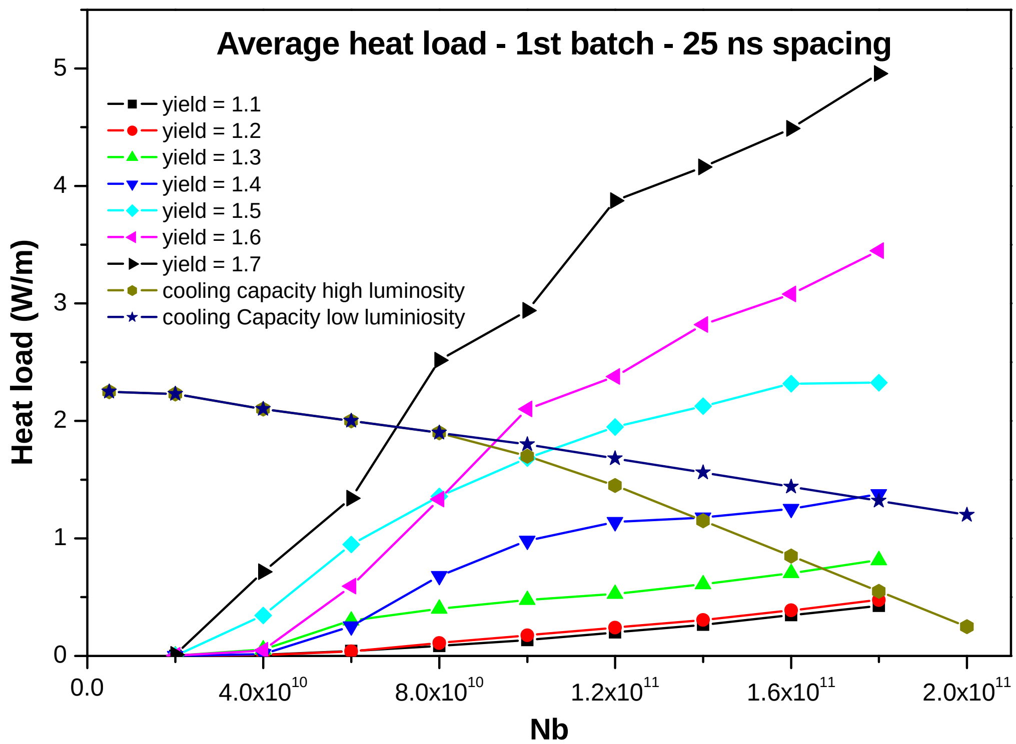


Figure 3. Plots of the average heat load for 1st batch of the set A.

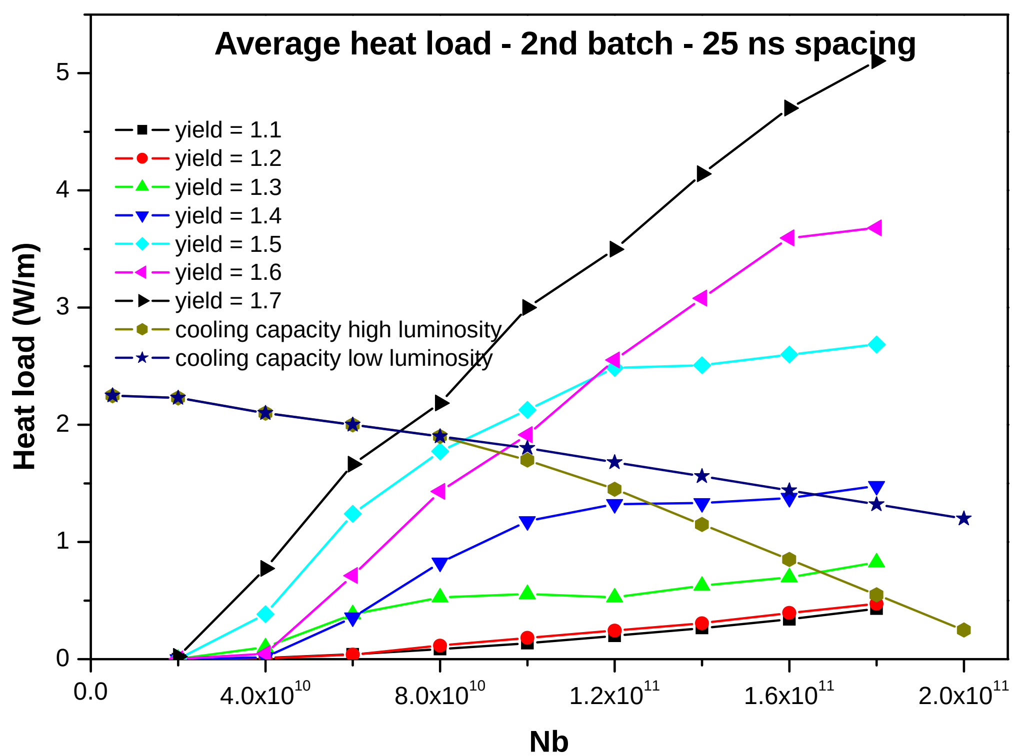


Figure 4. Plots of the average heat load for 2nd batch of the set A.

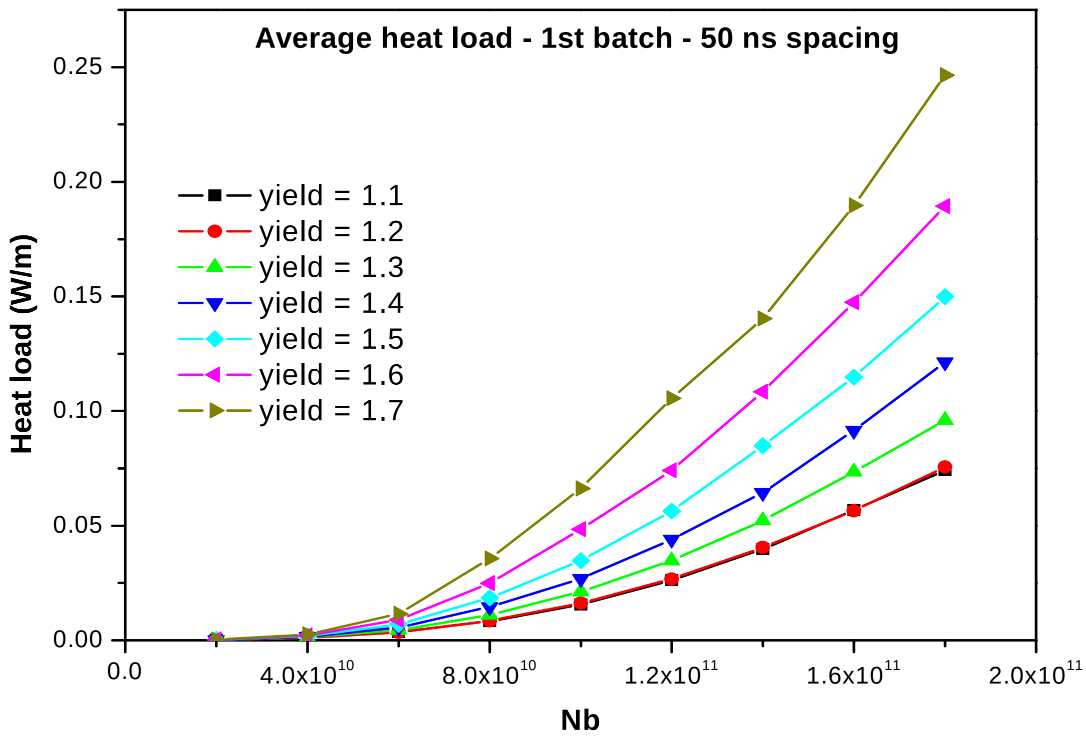


Figure 5. Plots of the average heat load for 1st batch of the set B.

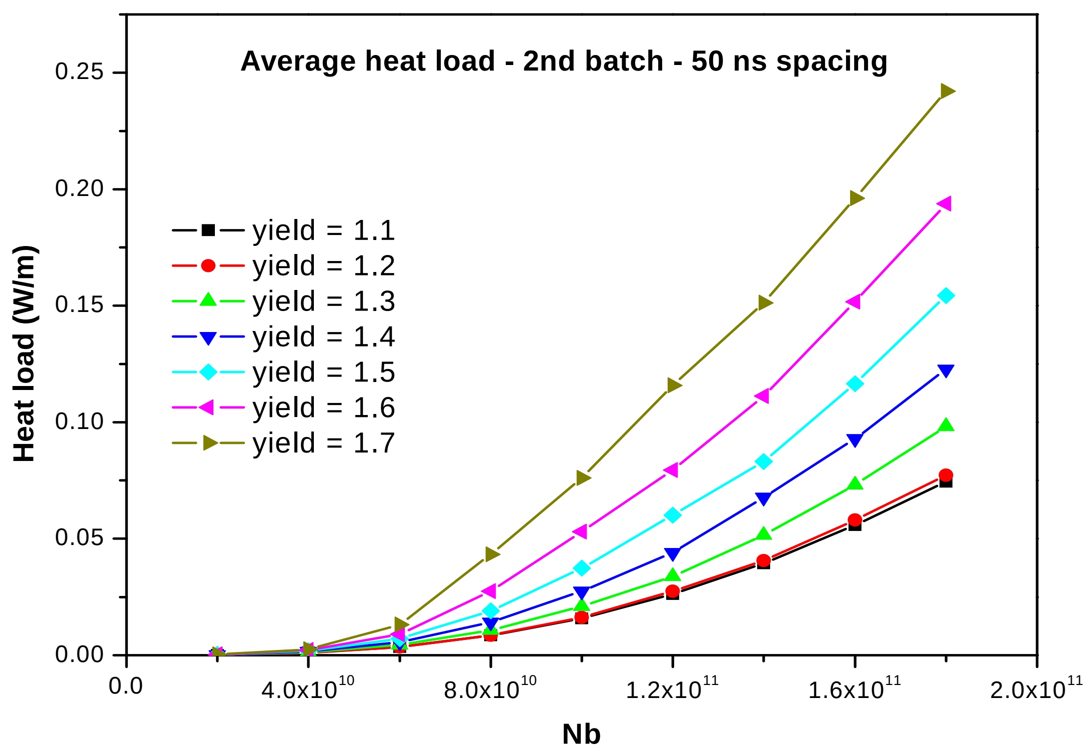


Figure 6. Plots of the average heat load for 2nd batch of the set B.

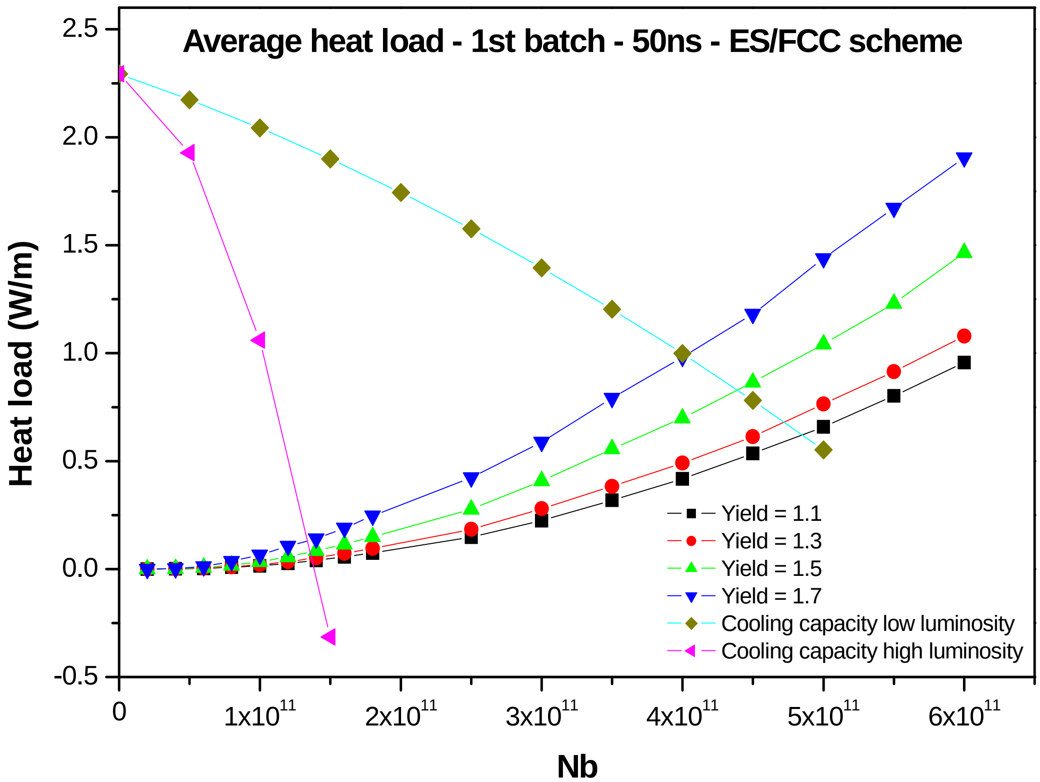


Figure 7. Plots of the average heat load for 1st batch of the set C.

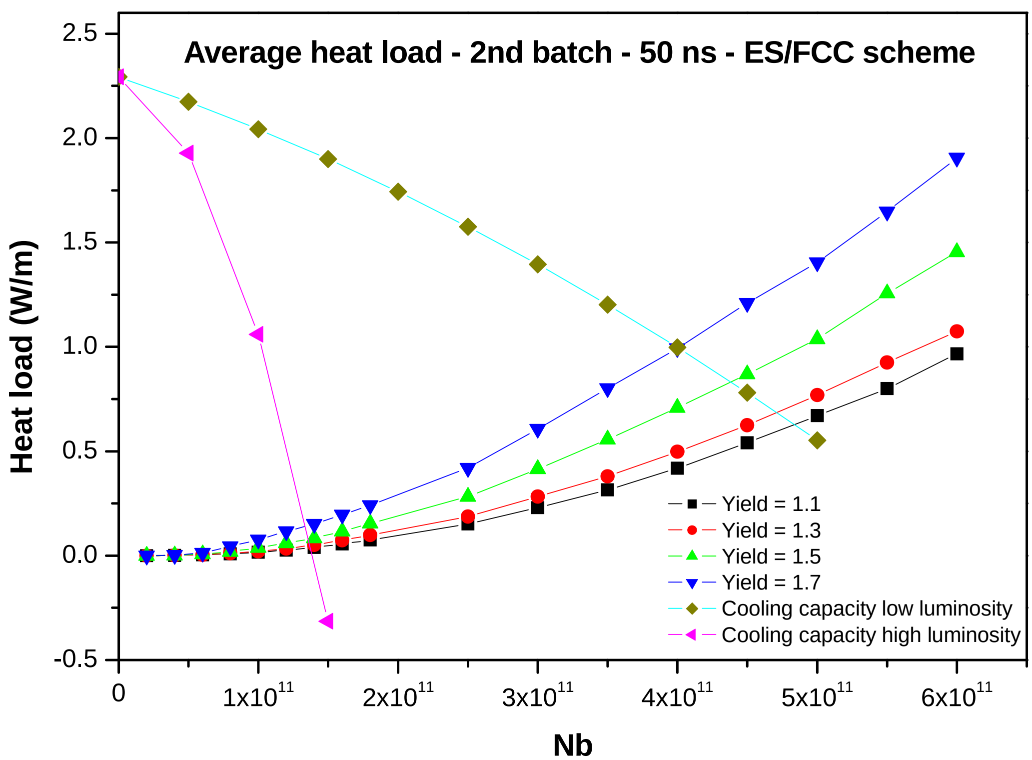


Figure 8. Plots of the average heat load for 2nd batch of the set C.

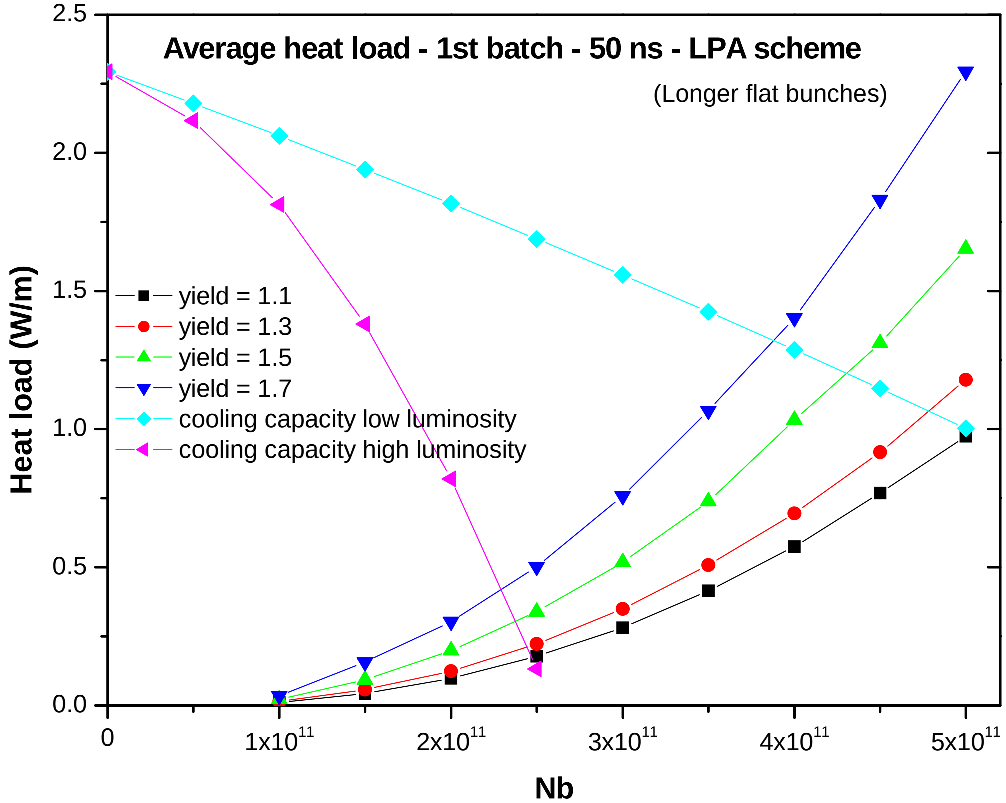


Figure 9. Plots of the average heat load for 1st batch of the set D.

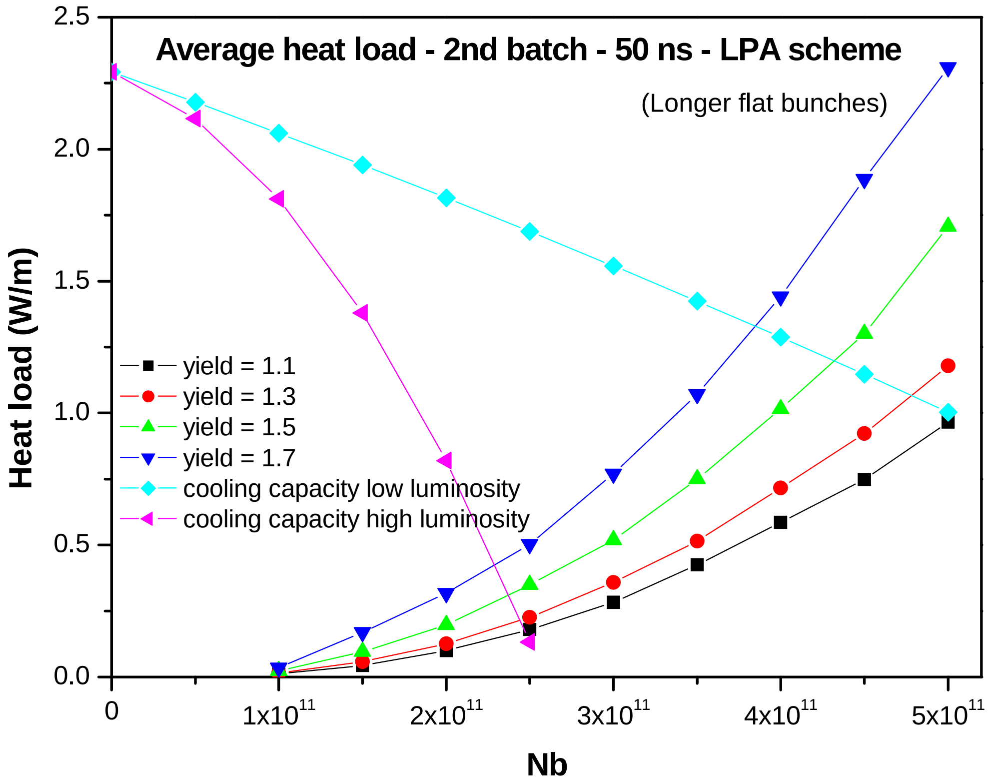


Figure 10. Plots of the average heat load for 2nd batch of the set D.

## Conclusions

- The heat load for the 1st & 2nd batch is almost the same for all cases.
- *25 ns spacing:*
  for SEY < 1.3 ultimate parameters,
  for SEY < 1.4 nominal LHC,
  for SEY < 1.5 up to $N_b = 9 \times 10^{10}$
- *50 ns spacing:*
  for nominal $\beta^* = 0.55$ m up to $N_b > 2\text{x}10^{11}$
  High-luminosity upgrade requires separate cooling for IRs; then
  ES/FCC ($\beta^* = 0.08$ m) up to $N_b \sim 4.5\text{x}10^{11}$
  LPA ($\beta^* = 0.25$ m) up to $N_b \sim 5.5\text{x}10^{11}$
- *50 ns spacing and new bunch profile:*
  The heat load depends on the bunch profile. At the same 50-ns bunch spacing, the heat load is higher is 20 - 40% higher for flat long bunches than for bunches with a Gaussian bunch.

## Acknowledgements

I would like to thank Frank Zimmermann for all his help and guidance during my summer work. Rainer Wanzenberg, Theo Demma, Giovanni Rumolo and Elena Benedetto deserve my warm thanks for their help with the simulations.

I also want to thank the AB/ABP group of the CERN, in particular Lauriane Bueno and Fanouria Antoniu for their help, hospitality and support.

Finally, I want to thank Guillermo Contreras for his help, and support to make possible my visit to CERN.

This work was partially supported by a HELEN grant.

## References

[1] F. Zimmermann, "A Simulation Study of Electron-Cloud Instability and Beam-Induced Multipacting in the LHC", LHC Project Report 95 (1997).
[2] O. Brüning, "Simulations for the Beam-Induced Electron Cloud in the LHC bean screen with Magnetic Field and Image Charges," LHC Project Report 158 (1997).
[3] N. Diaczenko *et al*., "Killing the electron cloud effect in the LHC arcs" Proceedings of the 2005 IEEE Particle Accelerator Conference (PAC 05). 16-20 May 2005
[4] G. Rumolo and F. Zimmermann, "Practical User Guide for ECloud" (2003).
[5] F. Zimmermann, private communication (2008).
[6] F. Zimmermann and E. Benedetto, "Electron-Cloud Effects in the LHC", ICFA Newsletter No. 32 , May/June 2004.
[7] G. Rumolo and F. Zimmermann, "Practical User Guide for ECLoud (2003).