Joint DESY and University of Hamburg
Accelerator Physics Seminar

Simulation of Electron-Cloud Heat Load for the Cold arcs of the LHC

Thanks to F. Zimmermann, G. Contreras, G. Iadarola and S. Roubatel

Humberto Maury Cuna

CINVESTAV/CERN

23 October 2012

Outline

- Introduction:
  - What an electron cloud is?
  - Electron cloud effects
- Electron Cloud Simulations
  - Simulation tools
  - Methodology
- Results
  - What information can we obtain from the simulations?
  - What is the utility of such information?

Introduction

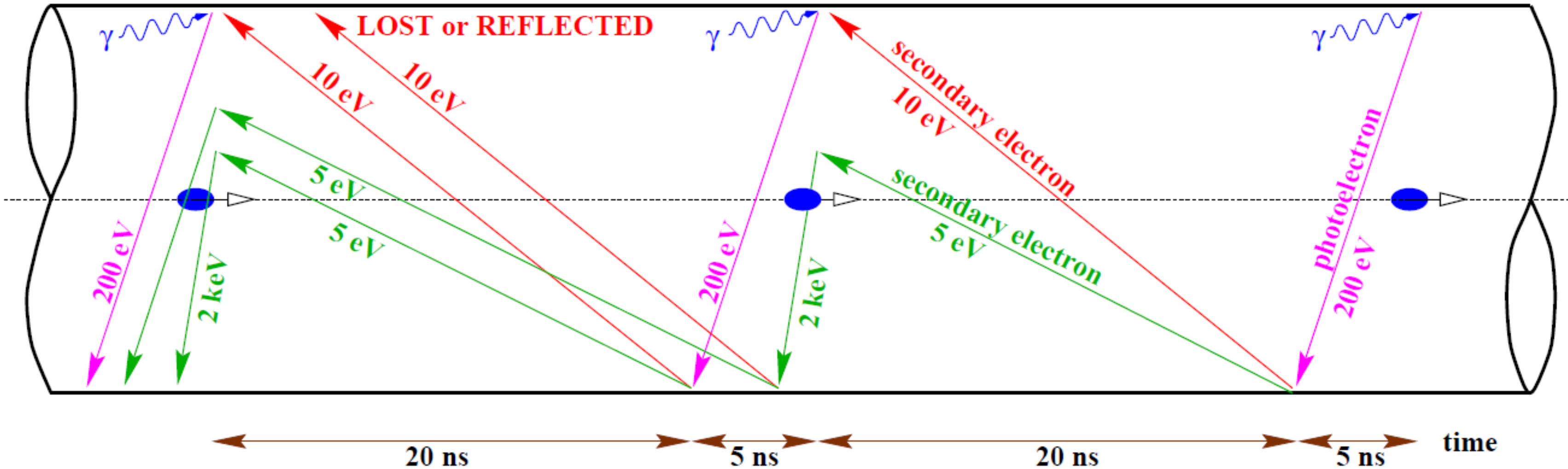
The electron cloud (EC) is a set of electrons produced inside the beam pipe of a particle accelerator that reduce the quality of the beam or can have bad effects on the machine performance.

What are the seeds of the electron cloud?

- Residual gas ionization.
- Photoemission when the beam-induced synchrotron radiation hits the surface of the beam pipe.

Schematic of the EC build-up

How is produced the EC build-up?



Key elements:

- **Seed electrons (either residual gas ionization or photoemission).**
- **Secondary emission process**
- **Multipacting**

What is the problem?

Electron cloud effects:

Due to e- induced gas desorption from the walls of the beam screen the vacuum pressure is increased by several orders of magnitude.

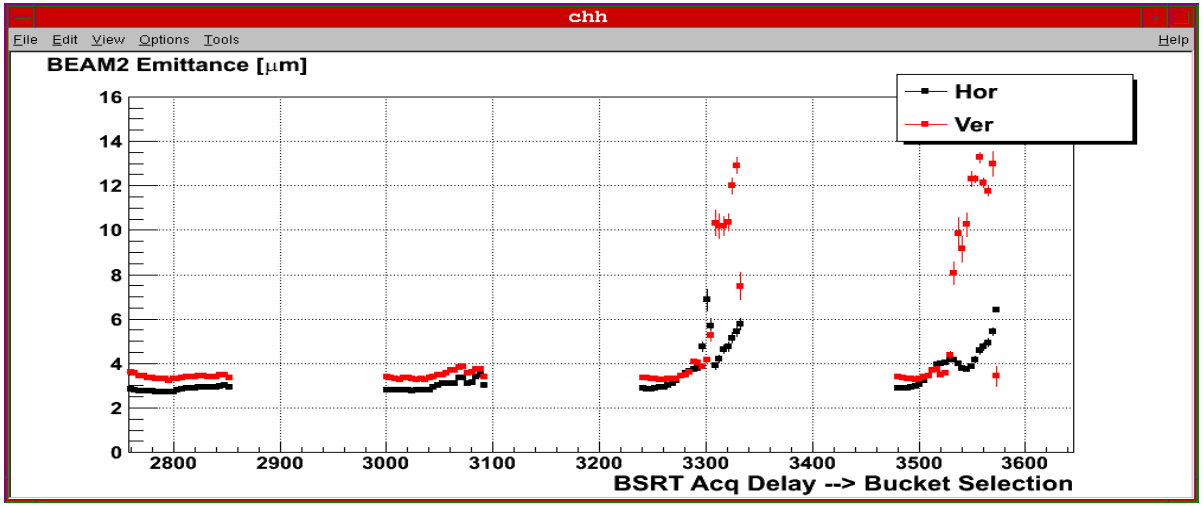
The electrons near the center of the vacuum chamber are attracted by the electric field of the beam and accumulate ("pinch") inside the proton beam during a bunch passage. They can cause beam instabilities, emittance growth, even beam loss, and poor lifetime.

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.

Introduction

- In 1999, EC effects have been observed with LHC-type beams first in the SPS, then in the PS.

- Since 2010, as predicted, EC effects were observed in the LHC: pressure rise, cryogenic heat load, beam instabilities, beam loss and emittance growth.



emittance growth observation
F. Roncarolo

What can we do?

Mitigation techniques

- A sawtooth pattern on the horizontally outer side of the beam screen inside the cold arcs.

- A shield mounted on top of the LHC beam-screen pumping slots blocking the electrons.

- NEG coating.

- The ultimate mitigation technique:

  Beam Scrubbing

Reduction of the secondary emission yield with increasing electron dose hitting the surface, i.e., as a result of the EC itself.

Outline

- Introduction:
  - What an electron cloud is?
  - Electron cloud effects
- Electron Cloud Simulations
  - Simulation tools
  - Methodology
- Results
  - What information can we obtain from the simulations?
  - What is the utility of such information?

Electron Cloud Simulations

Simulation Codes:

- ECLOUD (F. Zimmermann et al.)
- PyECLOUD (G. Iadarola)

Input numbers:

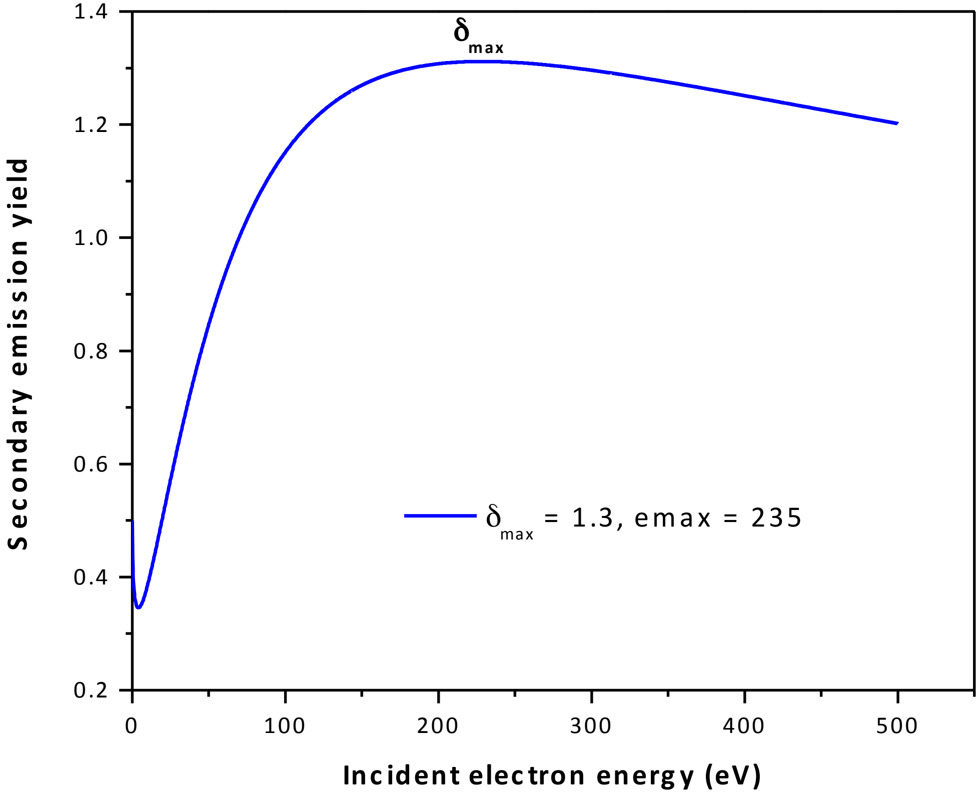
- Machine parameters
- Beam parameters
- Surface properties

- The EC simulation includes the electric field of the beam, arbitrary magnetic fields, the electron space charge field, and image charges.

Electron Cloud Simulations

Secondary emission yield:

$$\frac{\text{Number of secondary electrons}}{\text{Incident electron}}$$

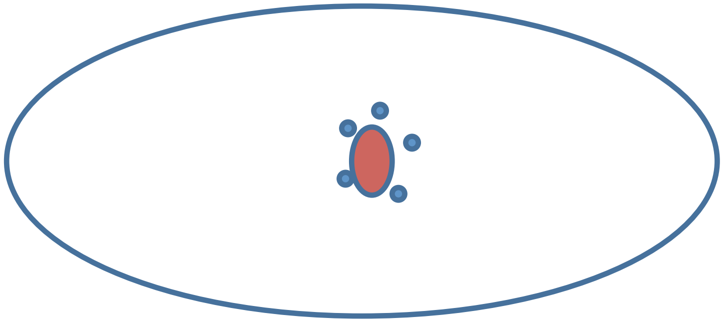


Low-energy electron reflectivity (R):

it designates the probability for an elastic reflection of an electron hitting the wall in the limit of zero primary energy.

Ingredients for e-cloud build-up simulation

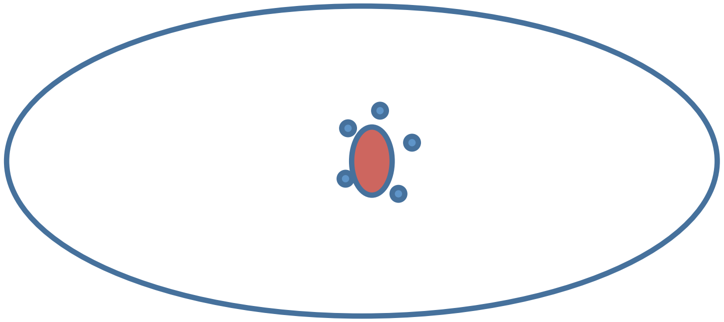
1. Seed electrons generation
(gas ionization, photoemission)



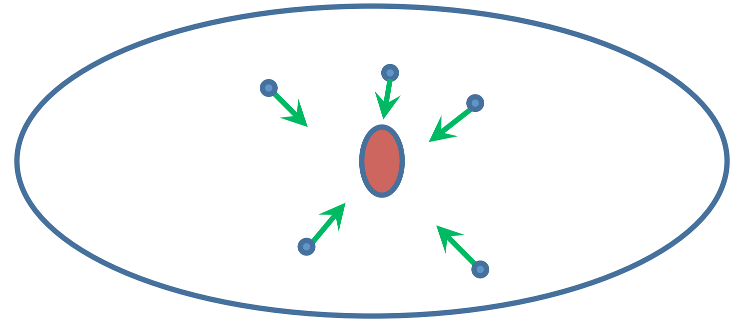
Slides taken from G. Iadarola ECLOUD meeting presentation on 28th November 2011

Ingredients for e-cloud build-up simulation

1. Seed electrons generation
(gas ionization, photoemission)



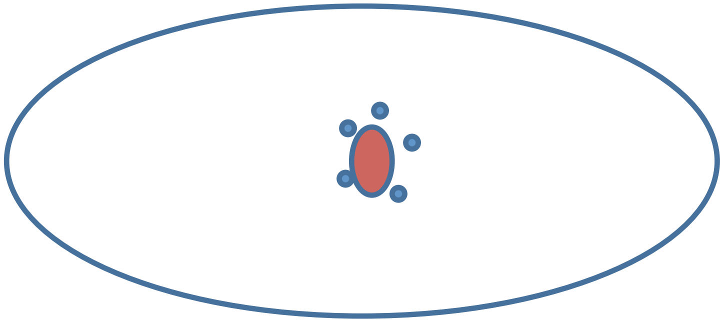
2. Force exerted by the beam on e^-



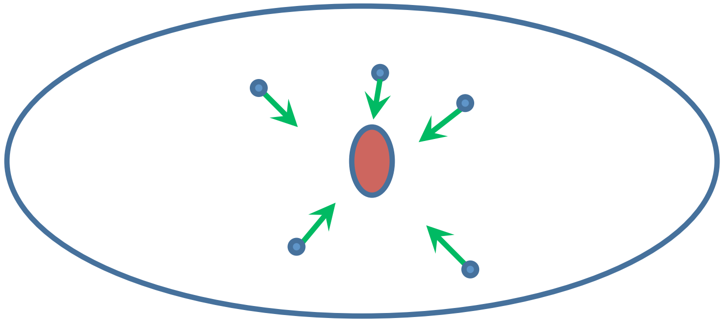
Slides taken from G. Iadarola ECLOUD meeting presentation on 28 – Nov - 2001

Ingredients for e-cloud build-up simulation

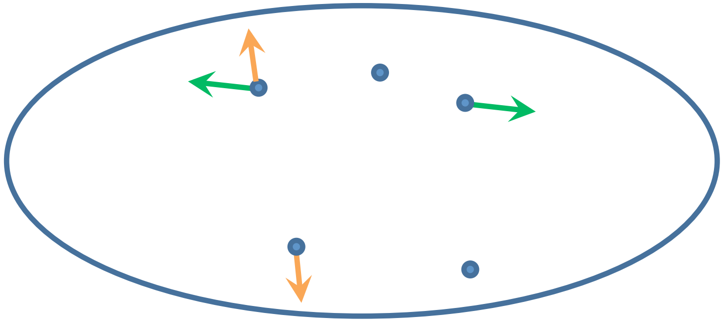
1. Seed electrons generation
(gas ionization, photoemission)



2. Force exerted by the beam on e$^-$



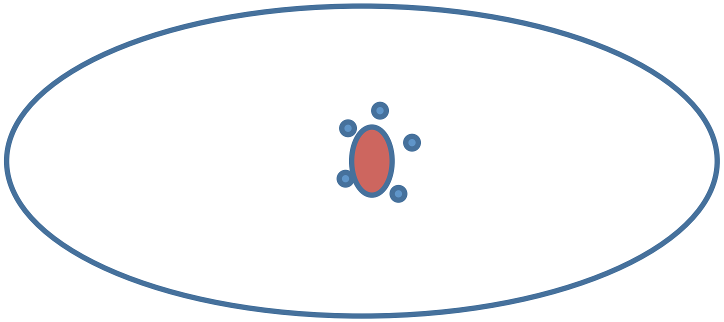
3. Force exerted by the e$^-$ on each other
(space charge)



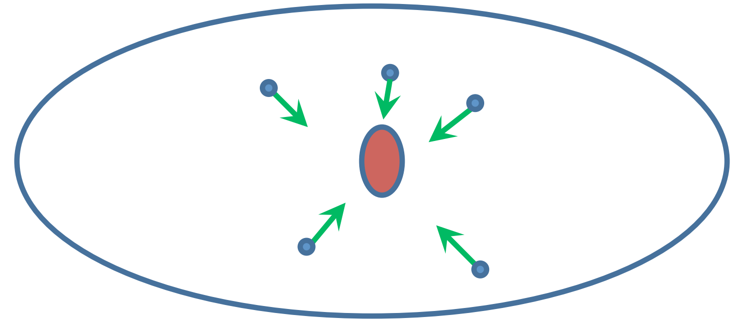
Slides taken from G. Iadarola ECLOUD meeting presentation on 28 – Nov - 2001

Ingredients for e-cloud build-up simulation

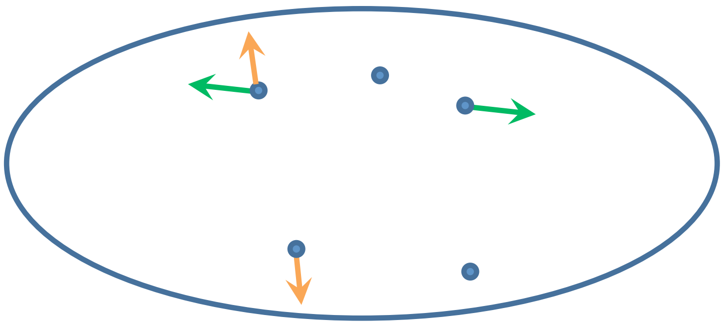
1. Seed electrons generation
(gas ionization, photoemission)



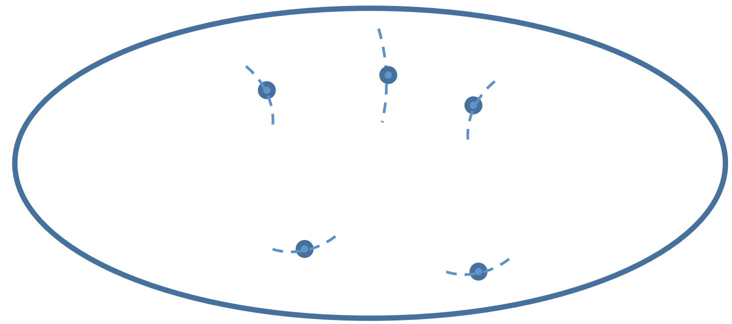
2. Force exerted by the beam on e^-



3. Force exerted by the e^- on each other
(space charge)



4. Equations of motion
(also in presence of an external magnetic field)

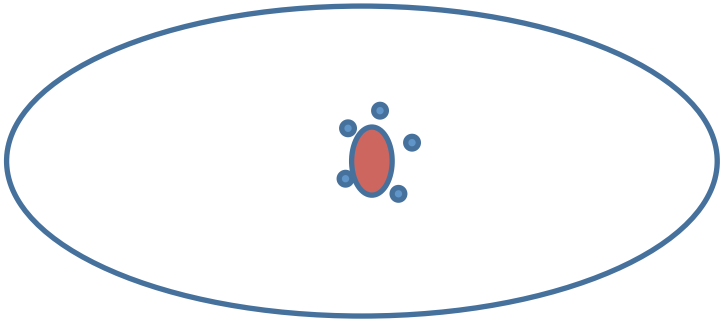


Slides taken from G. Iadarola ECLOUD meeting presentation on 28 – Nov - 2001

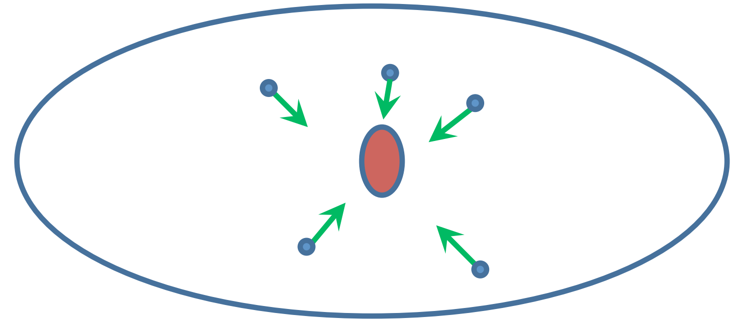
Ingredients for e-cloud build-up simulation

1. Seed electrons generation

(gas ionization, photoemission)

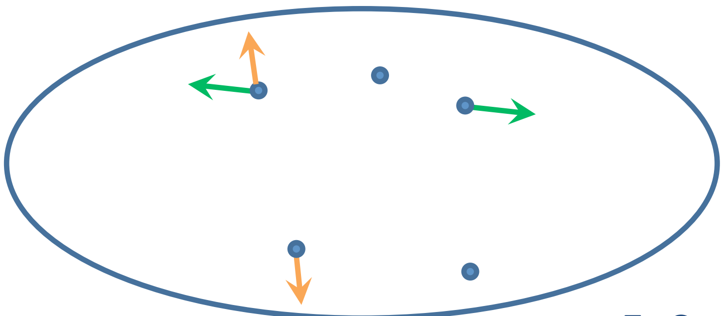


2. Force exerted by the beam on e^-



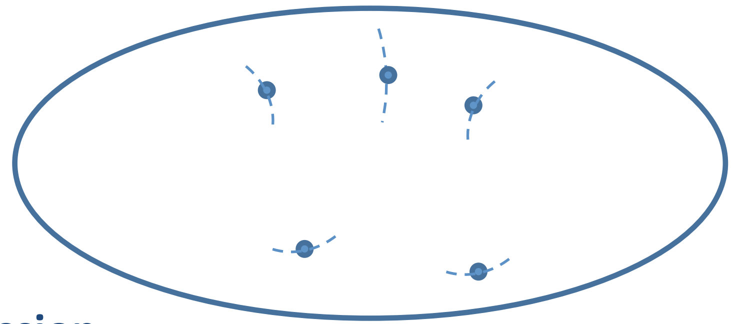
3. Force exerted by the e^- on each other

(space charge)

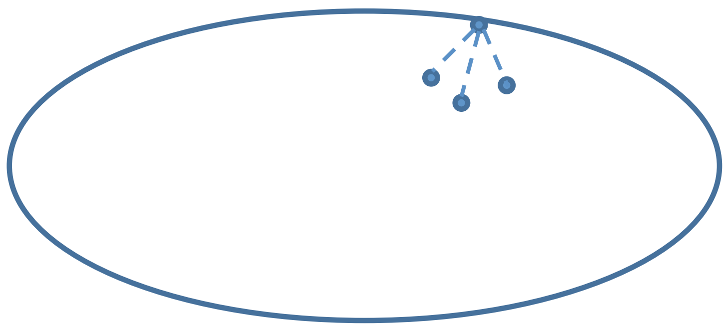


4. Equations of motion

(also in presence of an external magnetic field)



5. Secondary emission

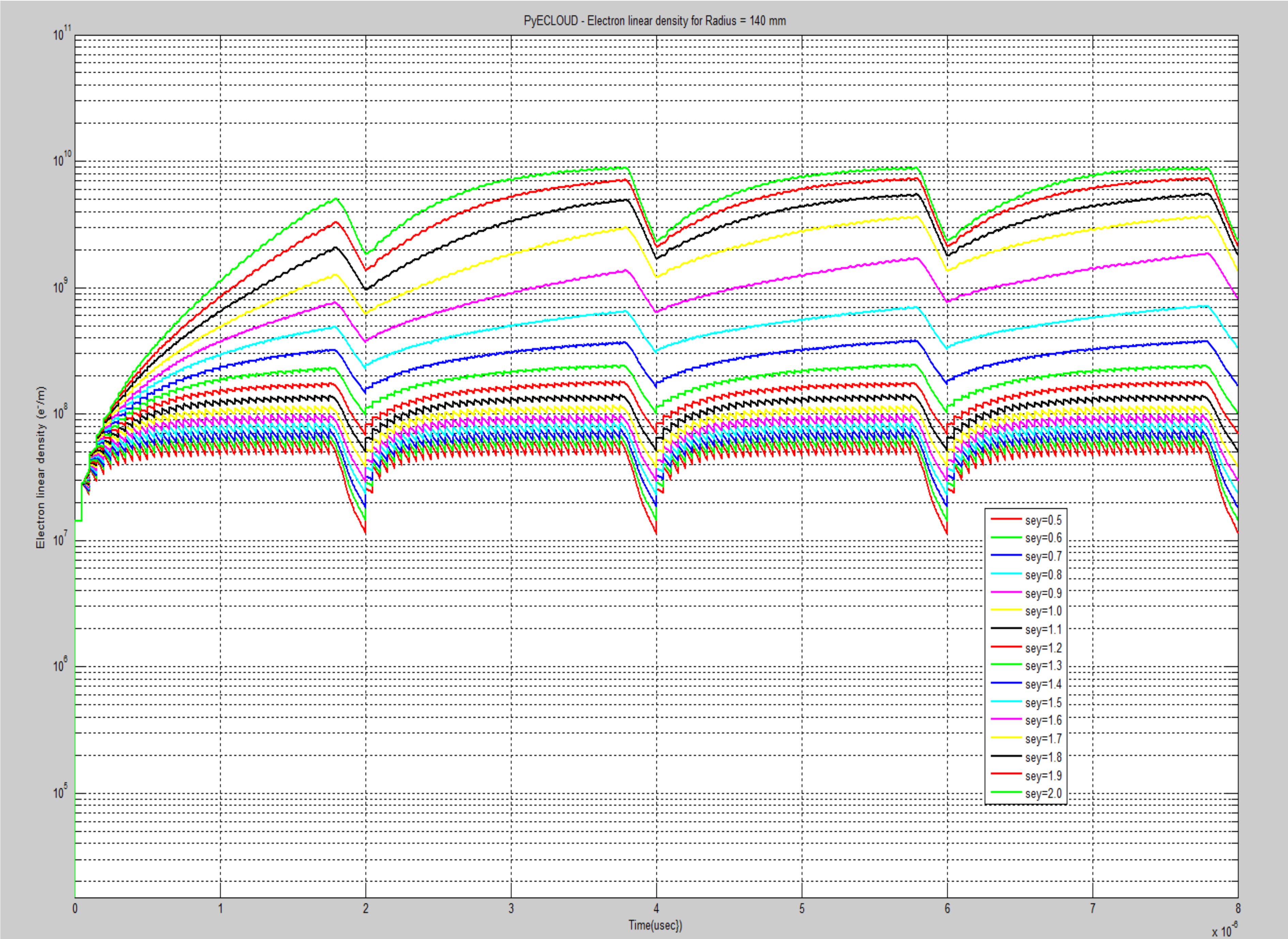


Slides taken from G. Iadarola ECLOUD meeting presentation on 28 – Nov - 2001

EC build-up evolution

Gas ionization movie sample

Photoemission movie sample


PyECLOUD - Electron linear density for Radius = 140 mm
Electron linear density (e⁻/m)
Time(usec))
x 10⁻⁶
sey=0.5
sey=0.6
sey=0.7
sey=0.8
sey=0.9
sey=1.0
sey=1.1
sey=1.2
sey=1.3
sey=1.4
sey=1.5
sey=1.6
sey=1.7
sey=1.8
sey=1.9
sey=2.0

Simulations Methodology

Parameter	450 GeV	3.5 TeV	7 TeV
Bunch intensity	$1.22x10^{11}$ p/b	$1.22x10^{11}$ p/b	$1.15x\ 10^{11}$ p/b
RMS bunch length	11.8 cm	9 cm	7.55 cm
Bunch spacing	50 ns	50 ns	25 ns
Transverse normalized emittance	2 μm rad	2.5 μm rad	3.75 μm rad
Pressure	32 nTorr	---	---

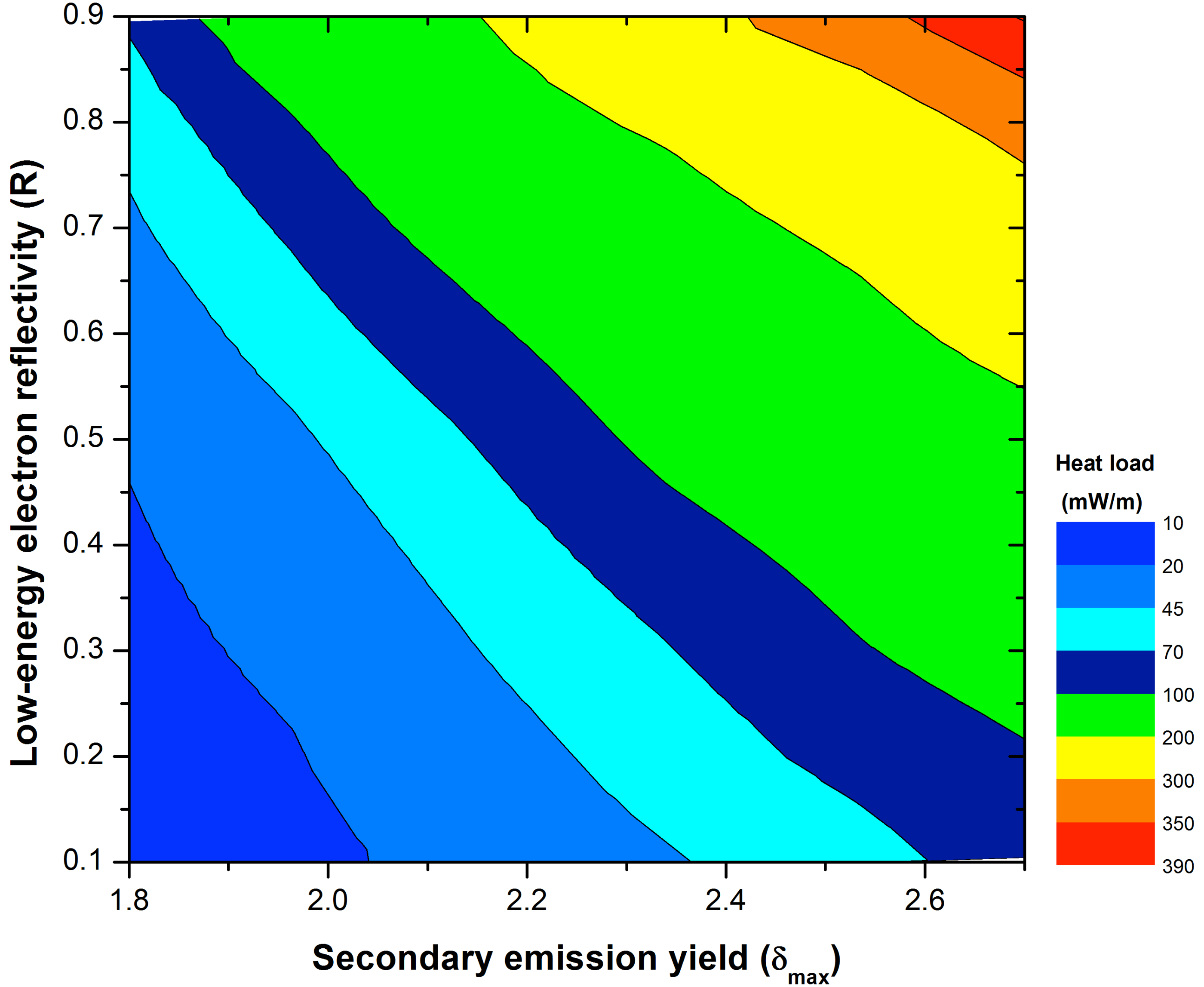
- All the simulations were performed for a bending section using ECLOUD version 4b.
- We assumed a Gaussian bunch profile.

Outline

- Introduction:
  - What an electron cloud is?
  - Electron cloud effects
- Electron Cloud Simulations
  - Simulation tools
  - Methodology
- Results
  - What information can we obtain from the simulations?
  - What is the utility of such information?

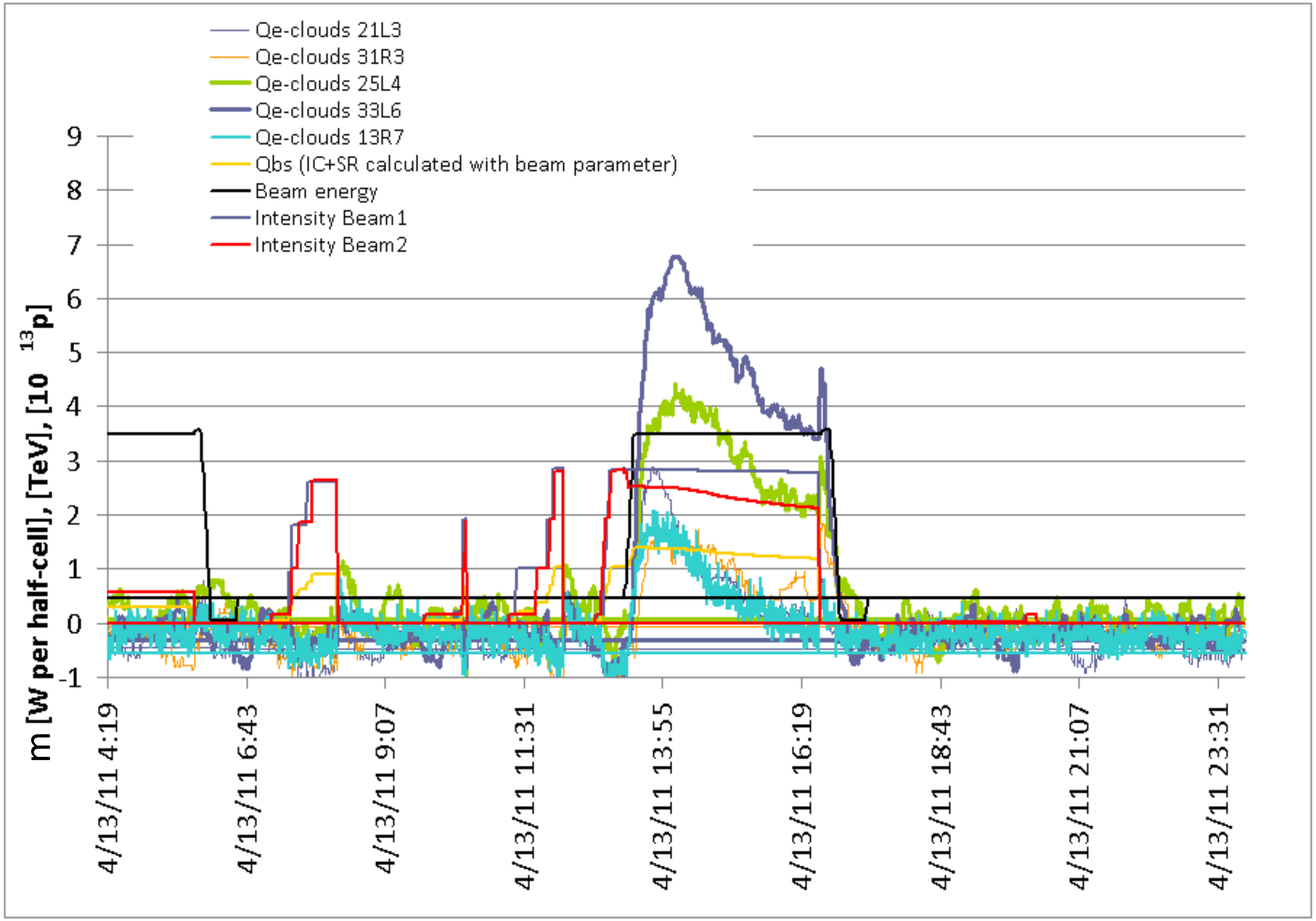
Results

Het load contour plot for 50-ns bunch spacing at 3.5 TeV



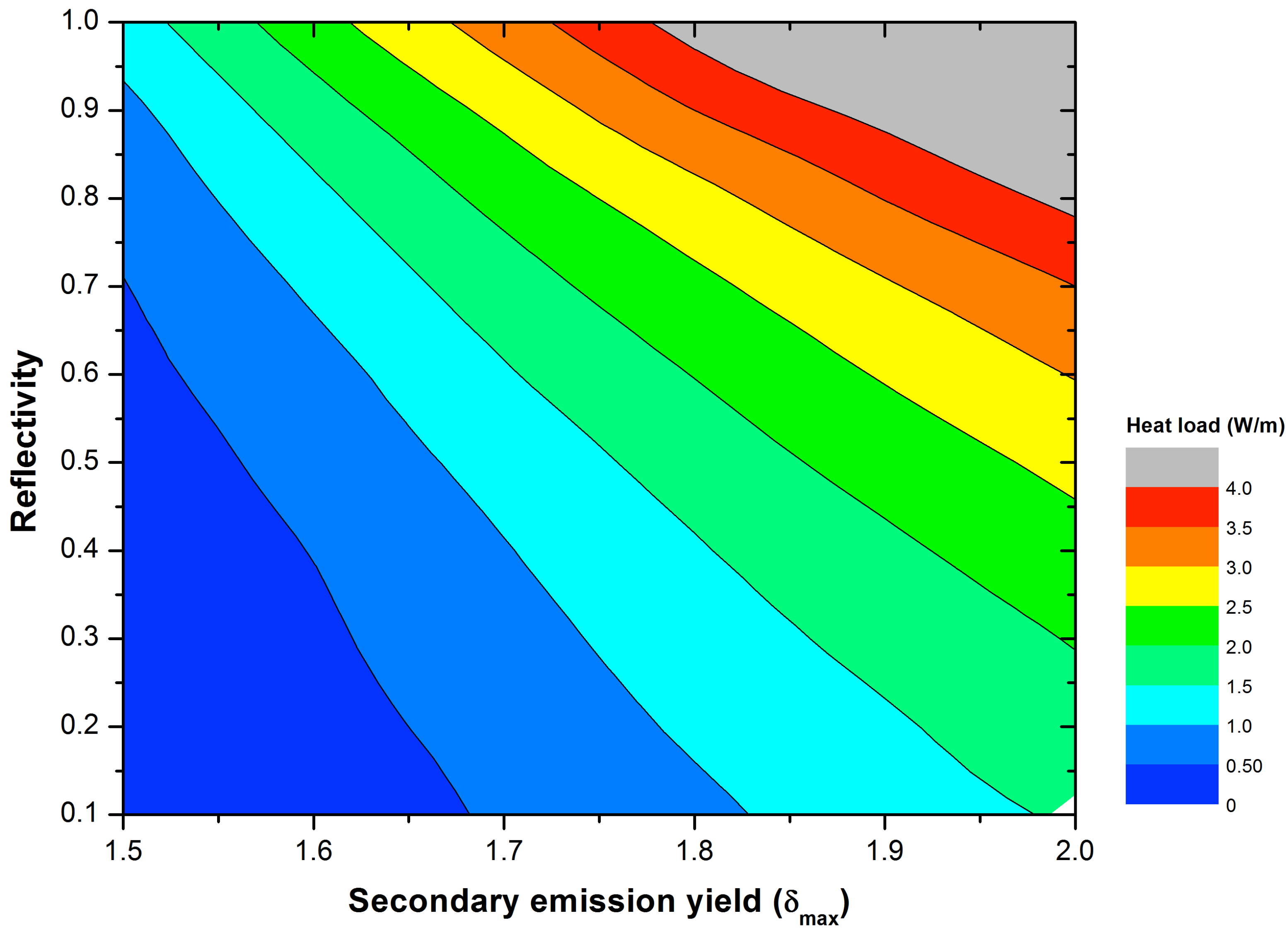
Results

Heat load benchmarking:

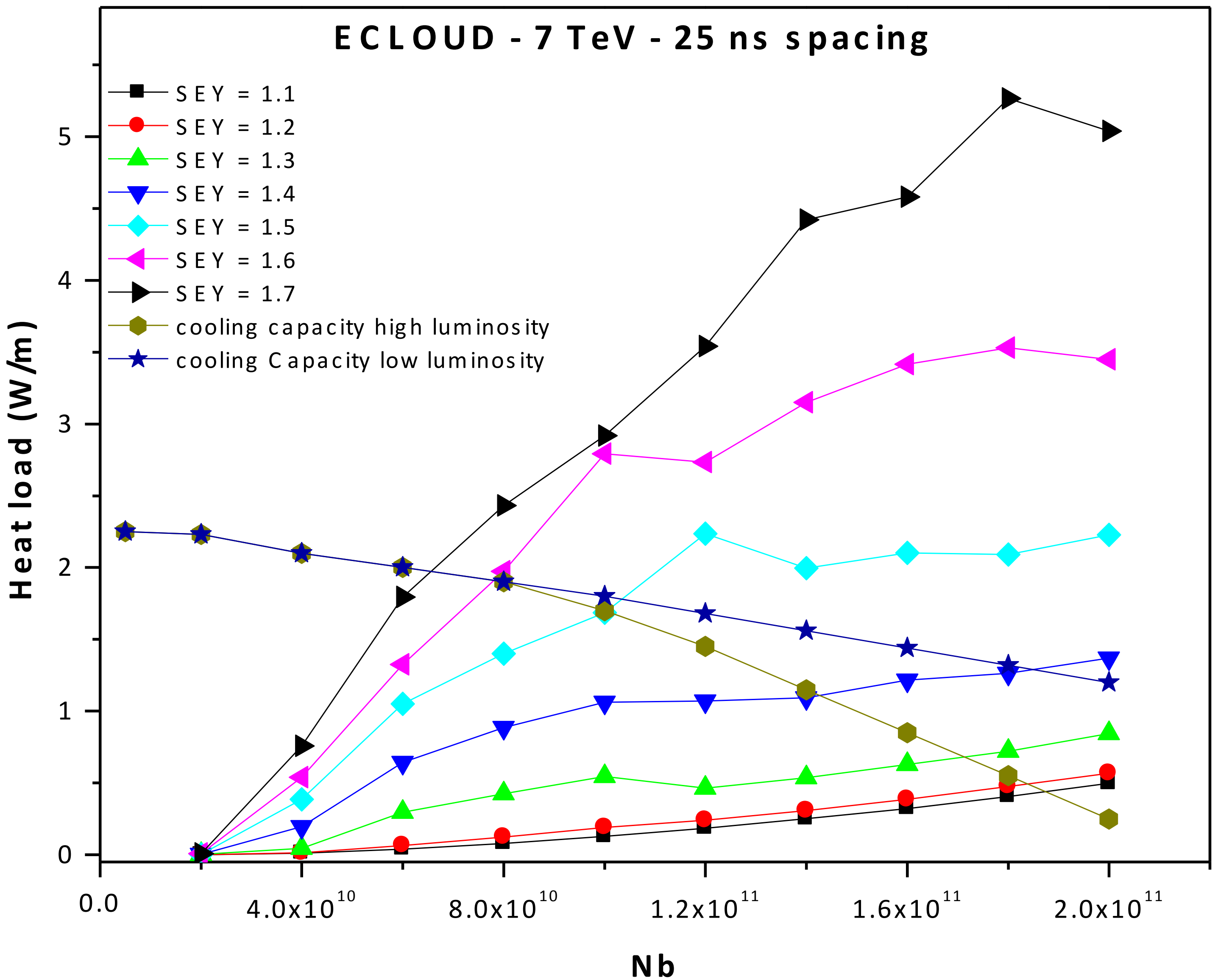


Results

Heat load contour plot for 25 ns bunch spacing at 450 GeV

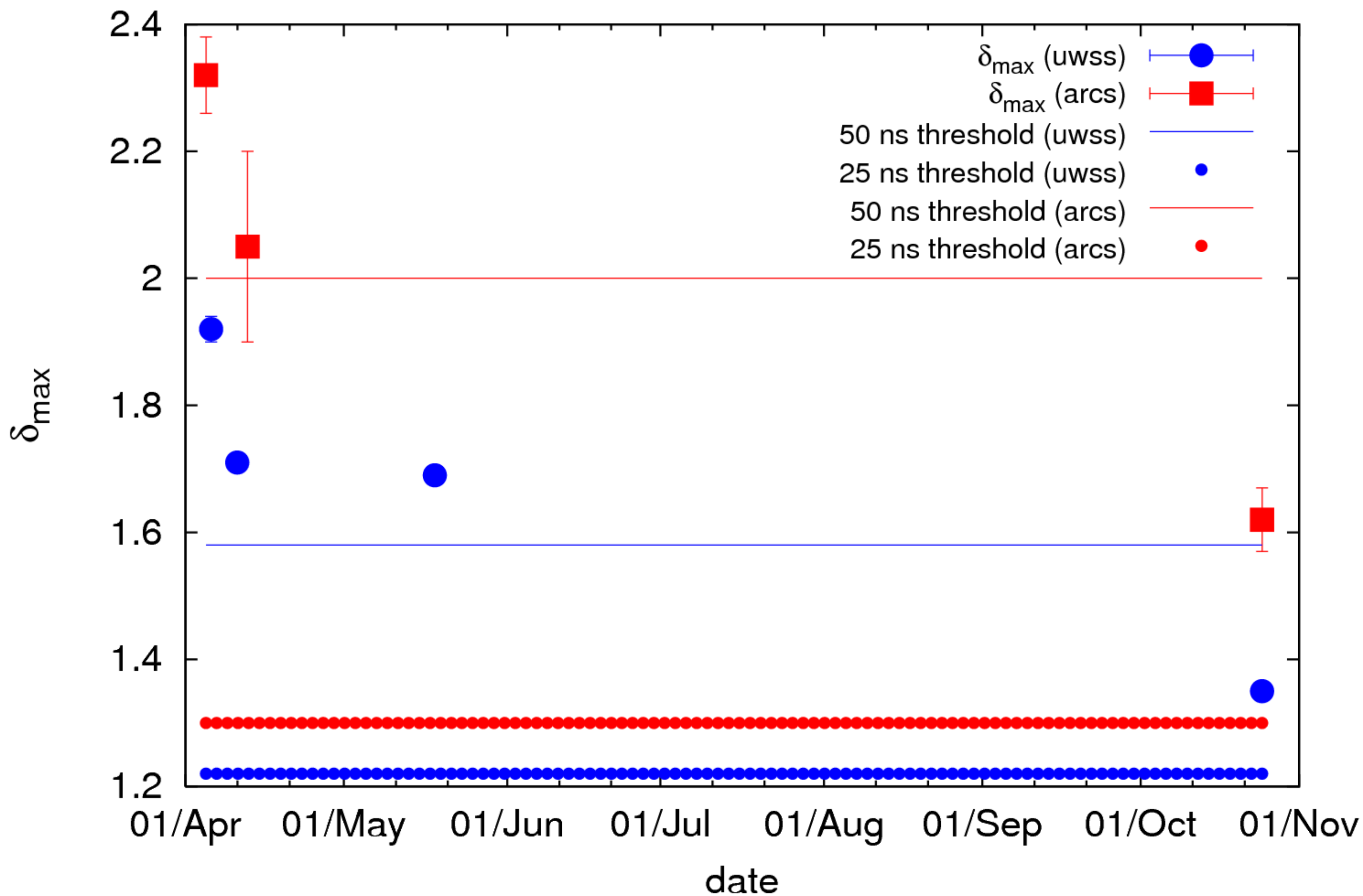


Results


ECLOUD - 7 TeV - 25 ns spacing
SEY = 1.1
SEY = 1.2
SEY = 1.3
SEY = 1.4
SEY = 1.5
SEY = 1.6
SEY = 1.7
cooling capacity high luminosity
cooling Capacity low luminosity
Heat load (W/m)
0
1
2
3
4
5
0.0
4.0x10^10
8.0x10^10
1.2x10^11
1.6x10^11
2.0x10^11
Nb

Results

Evolution of δmax for the LHC arc chamber during the 2011 LHC run as inferred from benchmarking heat-load simulations (ECLOUD) and measurements at 25-ns and 50-ns bunch spacing, assuming a low-energy electron reflectivity R = 0.5.



Conclusions

- For the nominal LHC operation scheme with 25-ns bunch spacing at top energy, the maximum secondary-emission yield should be below 1.4 in order to reach the nominal bunch intensity with acceptable heat load.
- For the current operational mode of the LHC the calculations at 50-ns bunch spacing show acceptable heat load values for all combinations of δ_{max} and R.
- The simulated heat-load values can be compared with measured heat-load data for 50-ns and 25-ns bunch spacing in order to estimate the actual surface parameters (especially δ_{max}) for the LHC and their evolution in time.
- $0.5 < R < 0.7$?

Future work

- Heat load benchmarking for the next scrubbing run at 25 ns.
- EC simulations for the HL-LHC.

Acknowledgements

- Frank Zimmermann
- Guillermo Contreras
- Giovanni Iadarola
- Giovanni Rumolo
- Octavio Dominguez
- Chandra Bhat
- Silvano Roubatel

Special thanks to J. Roßbach, M. Vogt and Rainer Wanzenberg.

This work has been cofunded by the Mexican National Council on Science and Technology (CONACYT), by the project EuCARD and by the EPlanet program.

Thank you for your attention

Questions???