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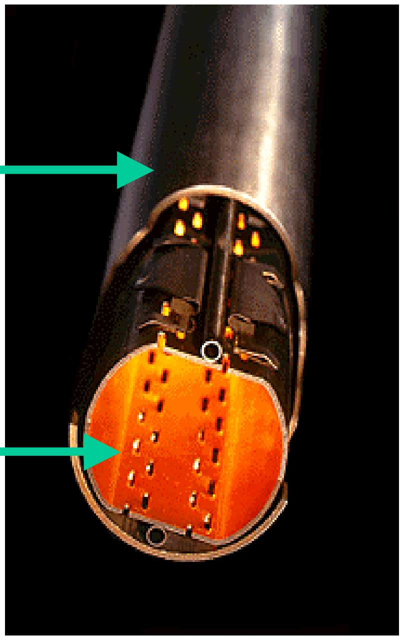
# SPS Electron Cloud Heat Load Measurements with WAMPAC and Simulations

V. Baglin and B. Jenninger

CERN LHC-VAC

# Contents

# 1. LHC E-Cloud Heat load



## 1.1 LHC vacuum chamber

- Cold bore at 1.9 K
- Beam screen (5-20 K) to intercept heat load

## 1.2 Heat load budget

- Total heat load budget per apperture : 0.72 W/m
- Dipole region : 28 % allocated to electron cloud *i.e.* 0.22 W/m
- Field free region : 22 % allocated to electron cloud *i.e.* 1.9 W/m

## 1.3 Electron cloud heat load estimation

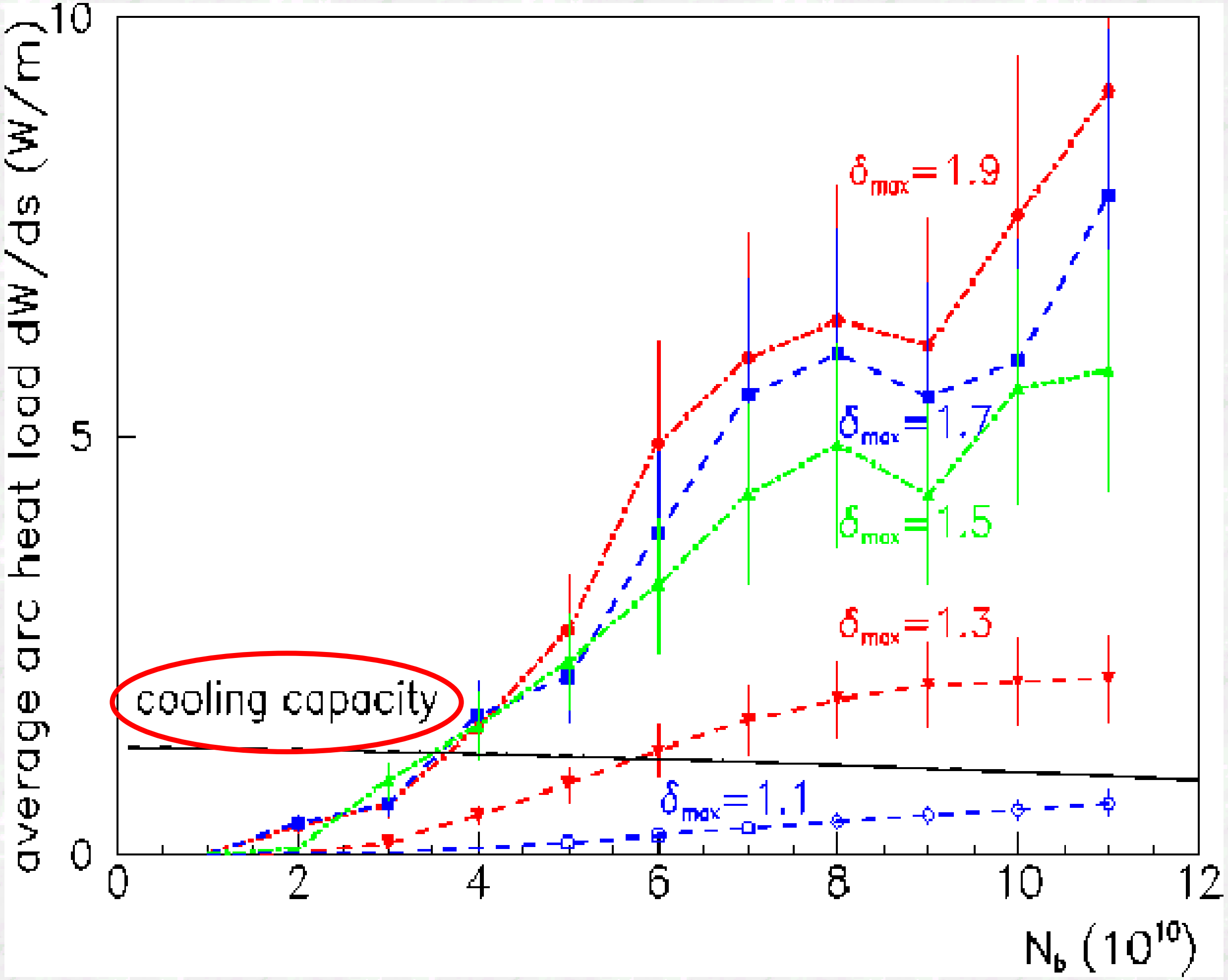
- Cooling capacity

## 1.4 SPS

- Observation of electron cloud with LHC type beams
- Use as an experimental test bench for LHC to measure heat load and benchmark simulations

# Electron cloud heat load and cooling capacity

**Electron Cloud in the LHC: Simulations for LHC**




Heat load is by far too high for LHC !

The figure shows the weighted average LHC arc heat load and the available cooling capacity as a function of bunch population for various values of the maximum secondary emission yield, assuming a photo-electron yield of 5%, photon reflectivity 5% and epsilon_max = 240 eV. Included in the simulation is a large component of elastically scattered electrons, as measured on LHC prototype vacuum chambers in EPA (V. Baglin, I. Collins)

08/02/2001 Frank.Zimmermann@cern.ch

# 2. SPS WAMPAC Calorimeter

(WArm MultiPActing Calorimeter)

## 2.1 Heat equations and measurement

Heat load to the screen

Screen warm-up

$$\dot{Q} - R \cdot \Delta T - C\,\Delta\dot{T} = 0$$

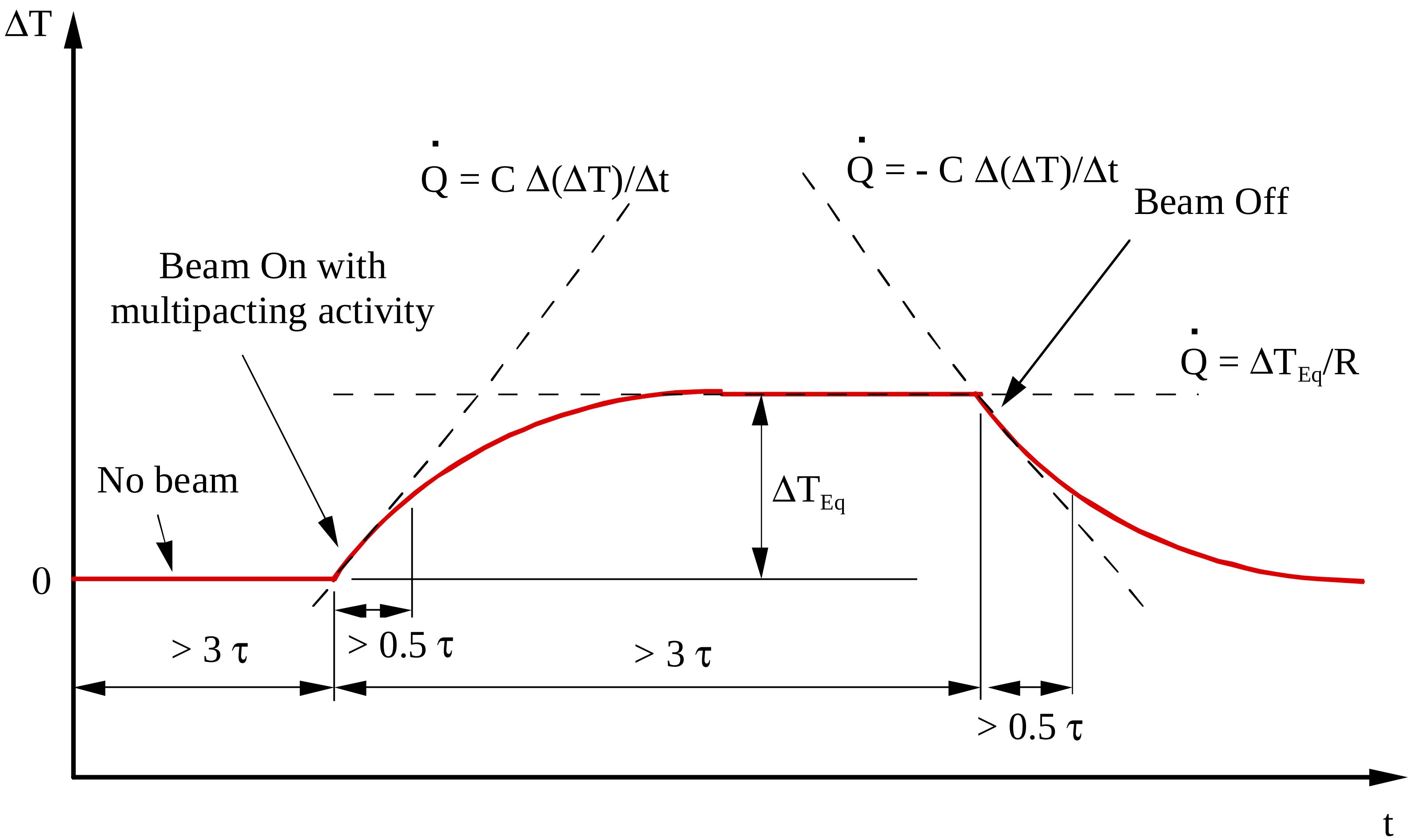
Radiative and contact heat loss

$\Delta T$, temperature difference between screen and vacuum chamber
Thermal resistance, R = 6 K/W
Thermal capacitance, C = 1200 J/K

$$\Delta T(t) = \dot{Q} \cdot R \cdot \left(1 - e^{-\frac{t}{RC}}\right)$$

With $\tau$ = RC = 2 hours

# Ideal measurement cycle




Initial and final slope :

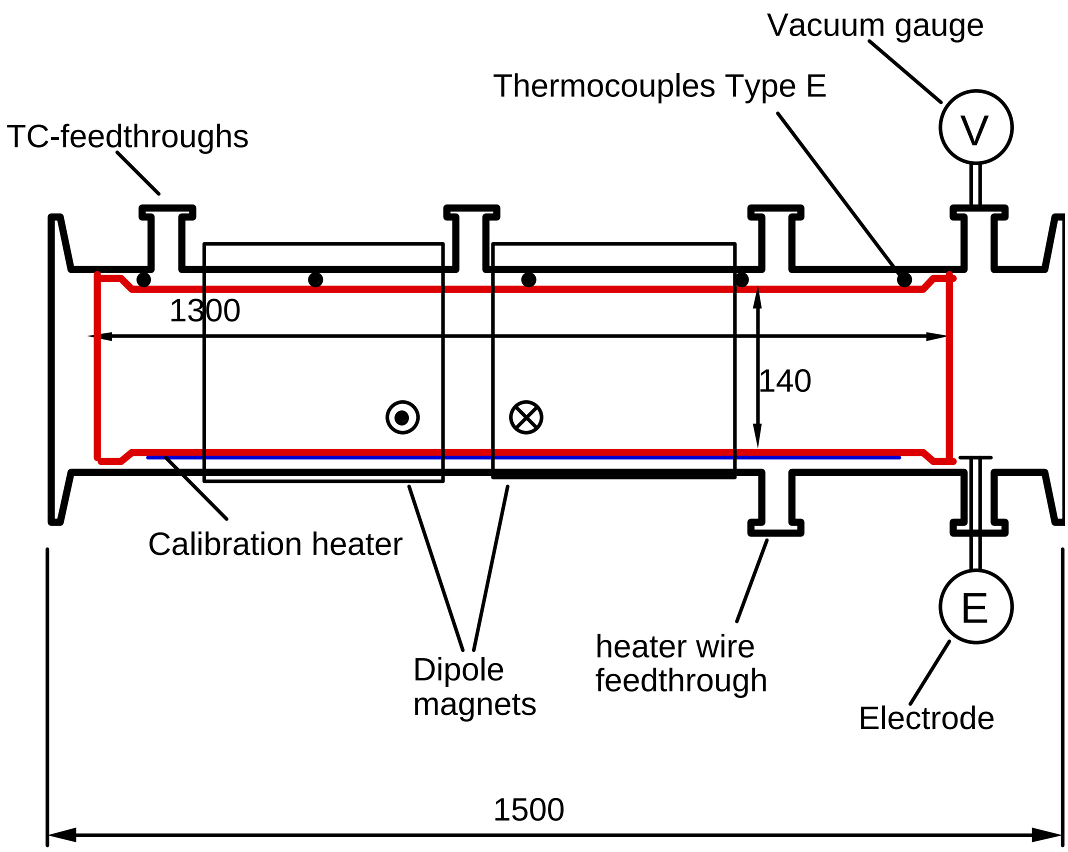
$$\dot{Q} = C\frac{\Delta(\Delta T)}{\Delta t}$$

Equilibrium :

$$\dot{Q} = \frac{\Delta T_{Eq}}{R}$$

## 2.2 Experimental set up in BA 4, 417

- Cu screen, 1.3 m long, ID 140 mm, 0.5 mm thickness
- Thermocouple, calibration heater
- 50 gauss dipole field over 0.7 m
- Pressure gauge, PU electrode

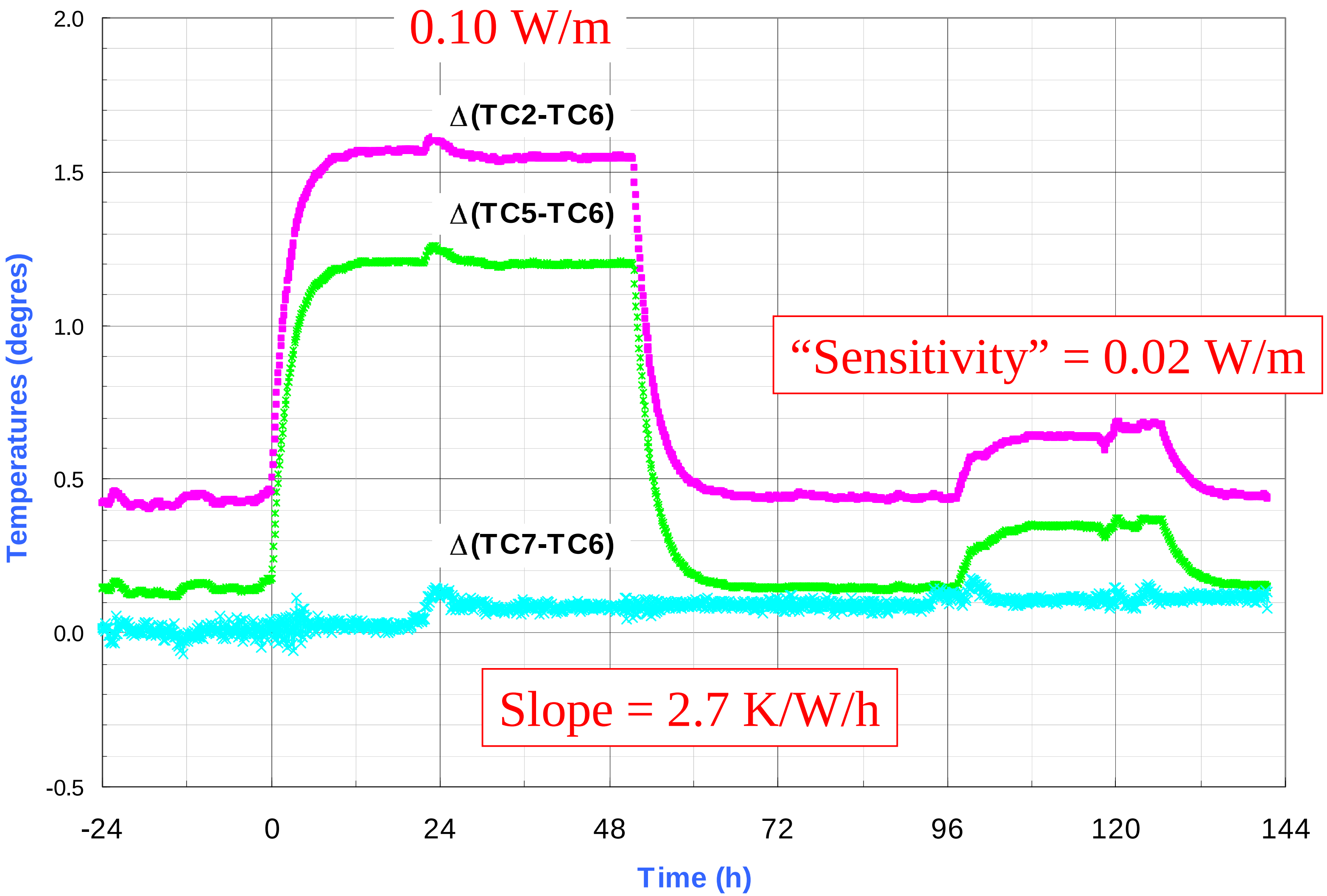


## 2.3 Calibration and sensitivity

- By applying a known heating power the thermal capacitance and resistance are deduced :

C = 1330 J/K,
R= 7 K/W,
τ= 2.6 hours

(Image current ~ 2 mW/m)




TC1 to TC5 : Cu screen
TC6 : vacuum chamber
TC7 : tunnel air

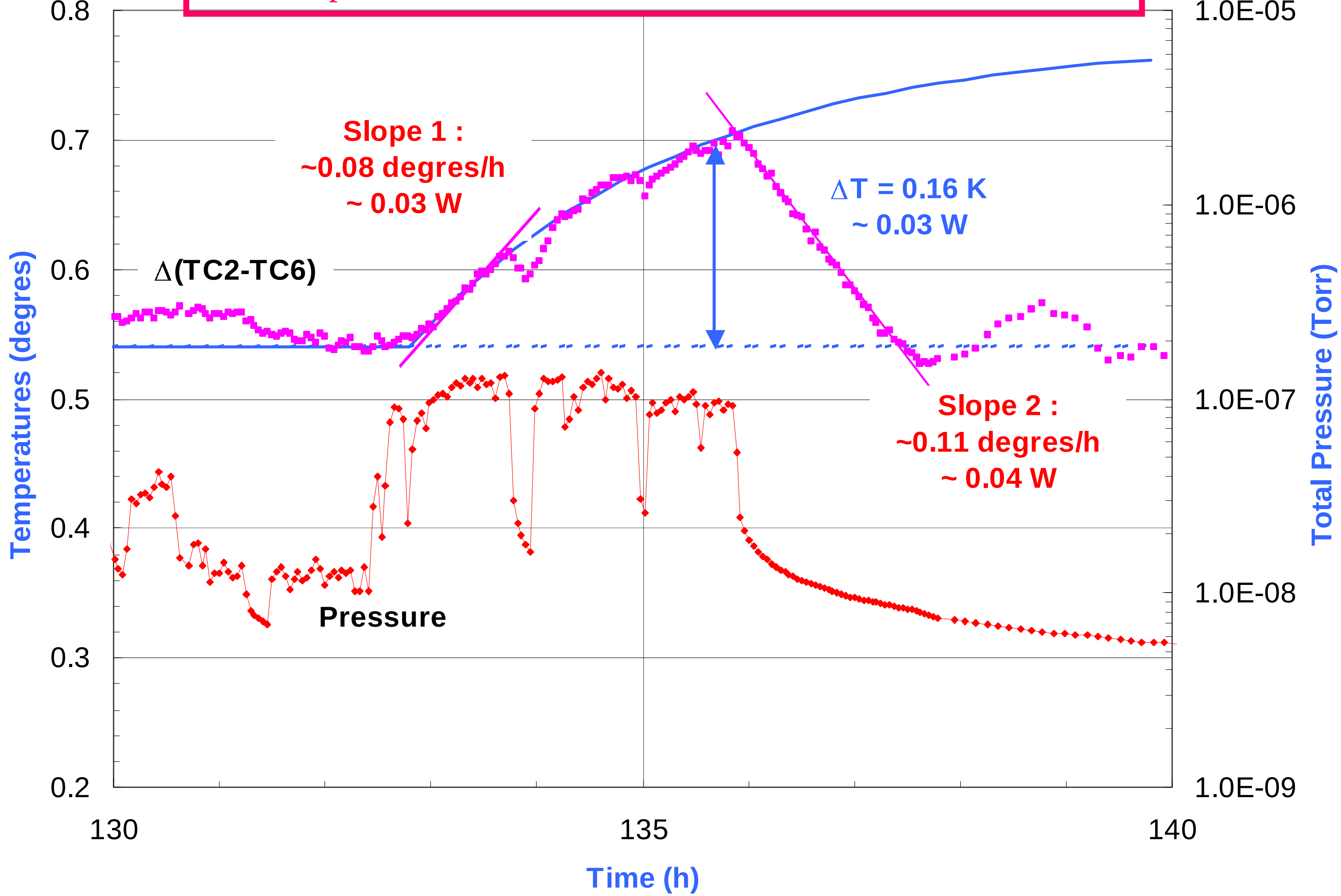
Slope : $\dot{Q} = C\frac{\Delta(\Delta T)}{\Delta t}$

Equilibrium : $\dot{Q} = \frac{\Delta T_{Eq}}{R}$

## 2.4 Results with LHC type beam

- 3 batches of 72 bunches ~ 5 $10^{10}$ protons/bunch, nominal spacing 225 ns

$P_{wampac}$ ~ 30 - 40 mW i.e ~ 40-60 mW/m




V. Baglin

## 2.5 Rough estimation of LHC heat loads

- Assumptions:
  - No scaling of power with radius
  - No scaling of power with magnetic field

- Parameters for previous observation:
  - 5 $10^{10}$ protons/bunch
  - $\delta_{max}$ ~ 1.9 – 1.95
  - Magnetic length, L = 0.7 m
  - Duty cycle, d ~ 56 % *i.e.* three batch are circulating during fifty six percent of the supercycle time.
  - One batch is required to trigger multipacting
  - Filling factor with multipacting, f = 2/11 *i.e.* three batch circulating and two batches with multipacting
  - Power in Wampac ~ 0.035 W

$$P_{\mathrm{LHC}} = \frac{1}{0.7 \times 2/11 \cdot 0.56} 0.035 \sim 0.5\ \mathrm{W/m}$$

With half of the nominal LHC beam current, before beam scrubbing, the dissipated electron cloud power is about 0.5 W/m

# 3. Benchmarking Simulations

## 3.1 Inputs

- 24/10/01 from 5:30 to 8:30
- 3 batches of 72 bunches, 5 $10^{10}$ protons/bunch
- Nominal spacing (225 ns)
- 3/11 filling factor, 56 % duty cycle
- $\delta_{max}$ ~ 1.9 – 1.95

## 3.2 O. Gröbner code

- Average secondary electron yield and electron energy
- 68 mW/m

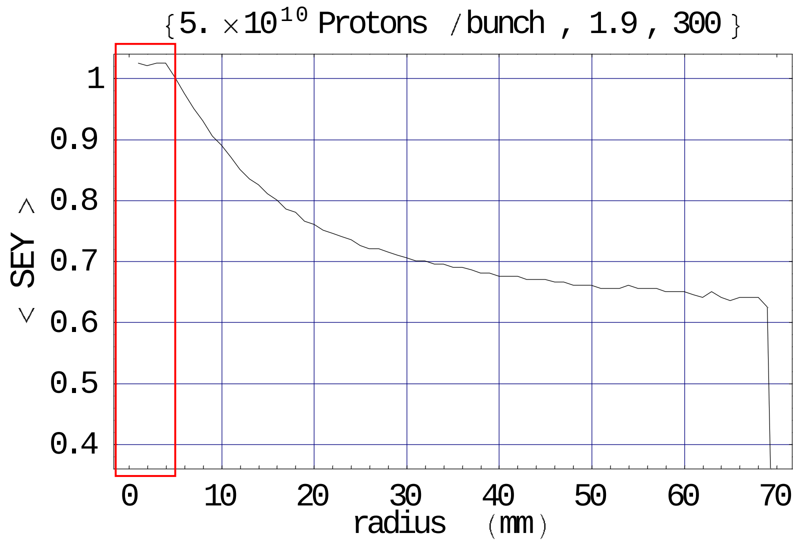
## 3.3 G. Rumolo & F. Zimmermann code

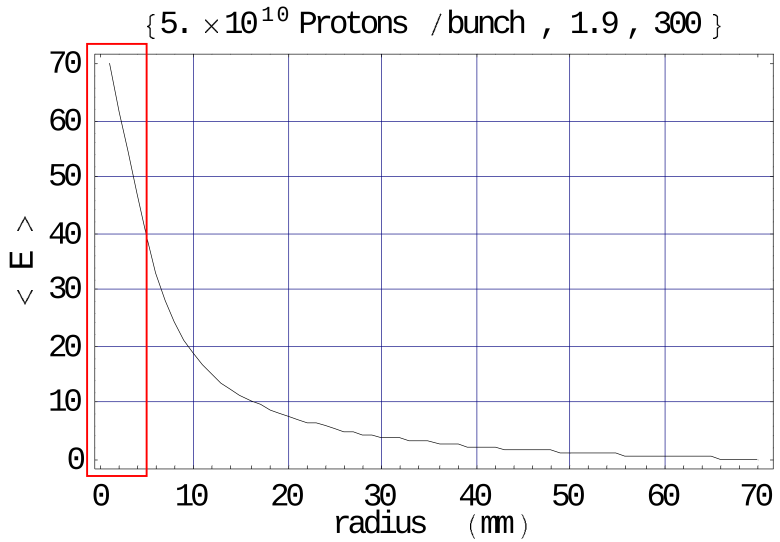
- Macroparticle tracking

| Pressure [Torr] | $\delta_{max}$ | <E> [eV] | Flux [e/m/s] | Sat. Power [W/m] | Wampac Power [mW/m] |
|---|---|---|---|---|---|
| $10^{-8}$ | 1.90 | 36.9 | 4.3 $10^{17}$ | 2.54 | 31 |
| $10^{-8}$ | 1.95 | 32.9 | 5.0 $10^{17}$ | 2.64 | 66 |
| $10^{-8}$ | 2.00 | 29.2 | 6.0 $10^{17}$ | 2.80 | 78 |

(No field)

# O. Gröbner code

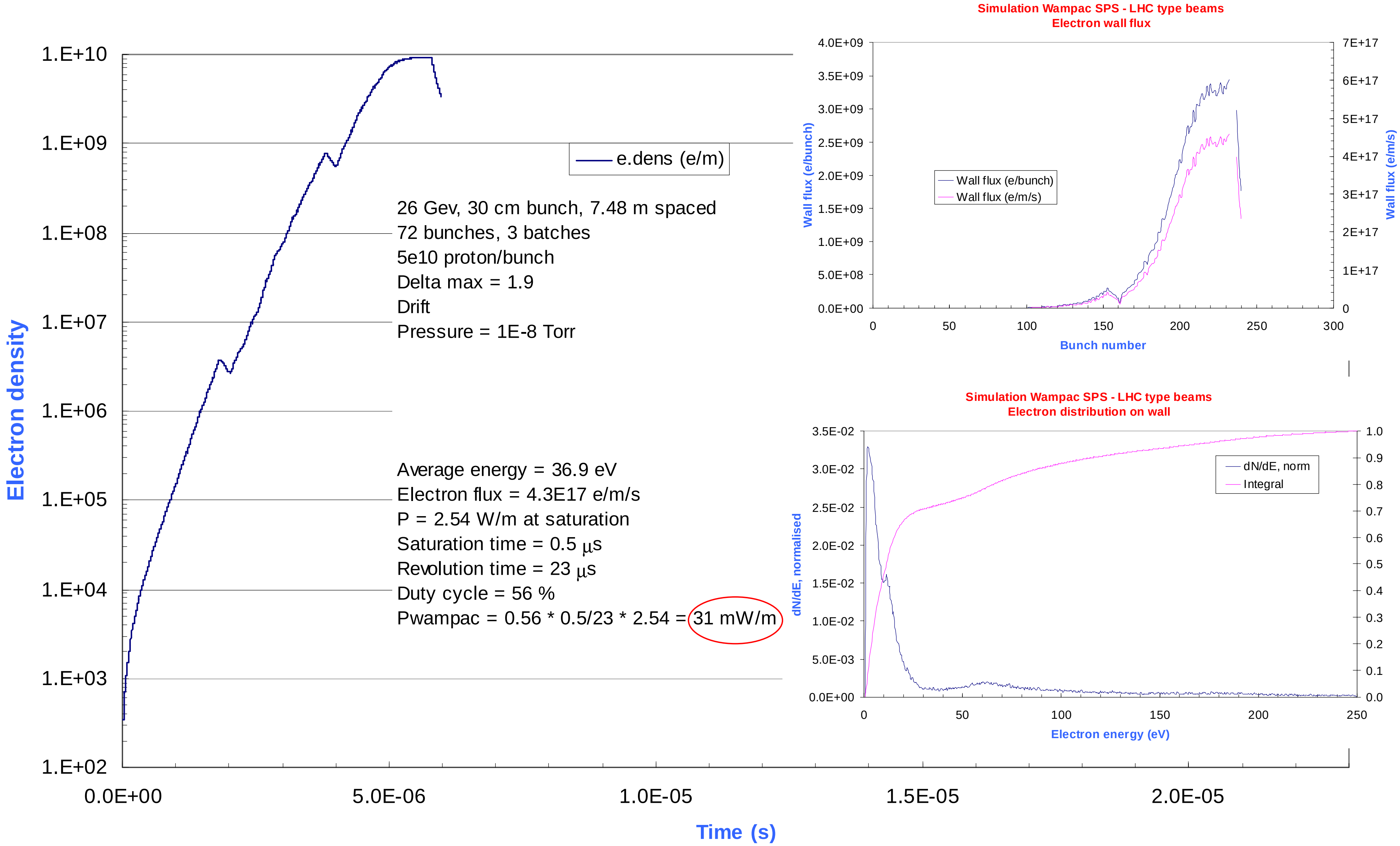



Average energy of the electron cloud : 8.3 eV
Average energy of the electron having a <SEY> above one : 43.7 eV
Electron density at saturation : $10^9$ electrons/m (L. Vos)

Power = 68 mW/m

# G. Rumolo & F. Zimmermann code



# 4. Conclusions and Future Work

## 4.1 Calorimeter

- Simple, room temperature
- $Q_{min}$ ~ 20 mW/m
- 40 to 60 mW/m measured with LHC type beams

## 4.2 Simulations

- "Analytical" approach is in a good agreement
- Macroparticle tracking is in agreement

## 4.3 Future work

- Measure the heat load in a dipole field with a vertical apperture of 40 mm close to LHC (WAMPAC II)
- Compare heat load measured at room temperature versus heat load measured in a cryogenic environment with COLDEX in SPS