CARE-HHH-APD Mini-Workshop on

Electron-Cloud Mitigation “ECM’08”

CERN, 20-21 November 2008

electron-cloud simulation tools at CERN

Frank Zimmermann

CERN, Geneva, 21 November 2008

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395)

Outline

CERN programs
code repository
model uncertainties
benchmarking:

- code vs code
- code vs beam

CERN programs

ECLOUD *1997

e- build up, heat-load, multi-bunch wake field;
2-D space charge, 3-D *B* fields, simple geometries
G. Bellodi, O. Brüning, G. Rumolo, D. Schulte,
F. Zimmermann, X.L. Zhang

HEADTAIL *~2001

single-bunch instability, emittance growth
E. Benedetto, G. Rumolo, R. Tomas, F. Zimmermann

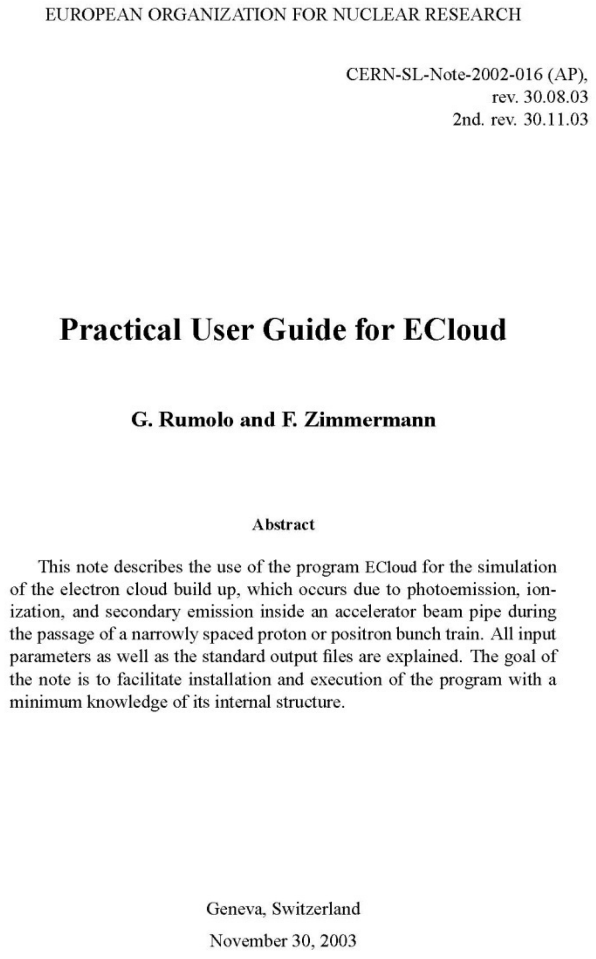
Faktor2 *~2006

e- and ion build up, arbitrary geometries, 2D & 3D space charge W. Bruns; “custodian”: G. Rumolo

IECP *2007 incoherent effect in e+ beams, F.Z.

documentation available on LHC electron-cloud web site:
http://ab-abp-rlc.web.cern.ch/ab-abp-rlc-ecloud/

ECLOUD manual 2003



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SL-Note-2002-016 (AP),
rev. 30.08.03
2nd. rev. 30.11.03

Practical User Guide for ECloud

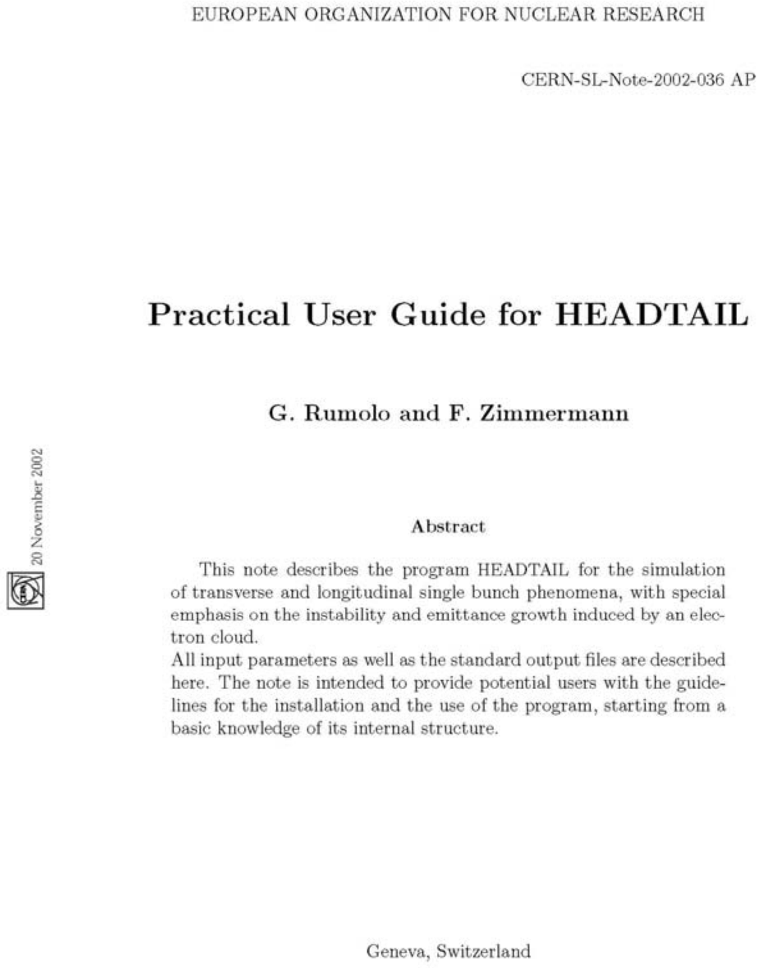
G. Rumolo and F. Zimmermann

Abstract

This note describes the use of the program ECloud for the simulation of the electron cloud build up, which occurs due to photoemission, ionization, and secondary emission inside an accelerator beam pipe during the passage of a narrowly spaced proton or positron bunch train. All input parameters as well as the standard output files are explained. The goal of the note is to facilitate installation and execution of the program with a minimum knowledge of its internal structure.

Geneva, Switzerland
November 30, 2003

HEADTAIL manual 2002



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SL-Note-2002-036 AP

20 November 2002

Practical User Guide for HEADTAIL

G. Rumolo and F. Zimmermann

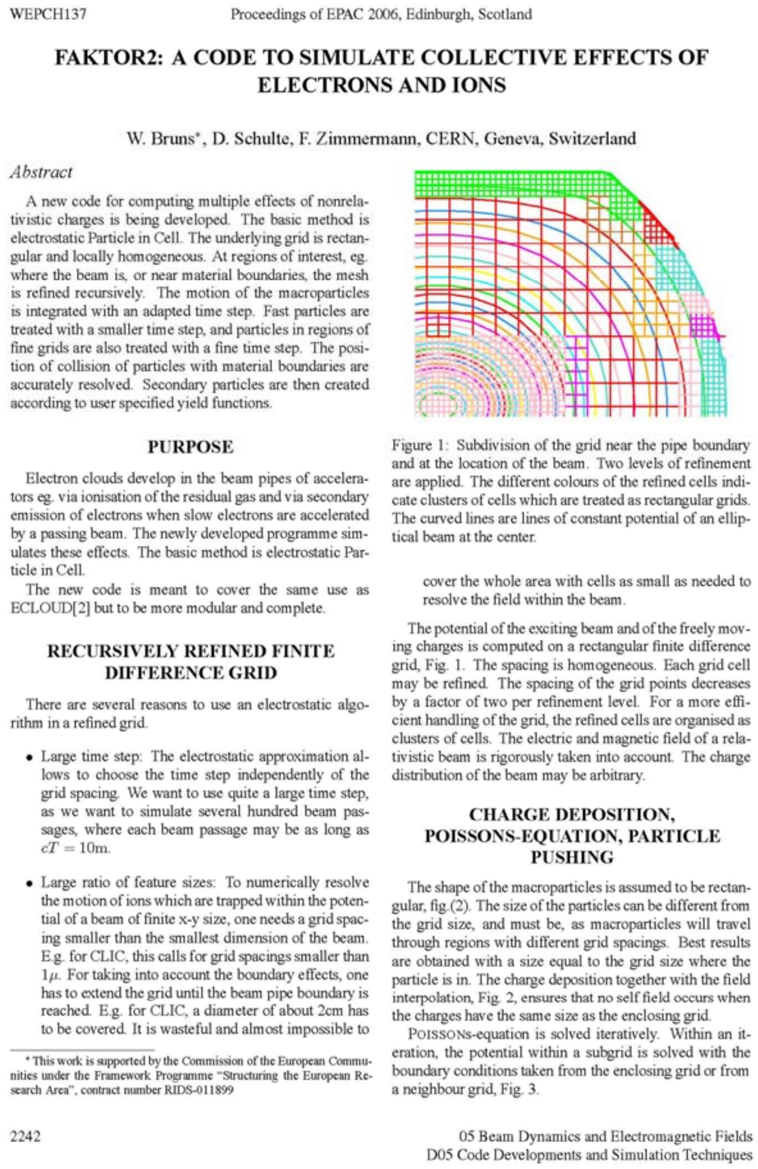
Abstract

This note describes the program HEADTAIL for the simulation of transverse and longitudinal single bunch phenomena, with special emphasis on the instability and emittance growth induced by an electron cloud.
All input parameters as well as the standard output files are described here. The note is intended to provide potential users with the guidelines for the installation and the use of the program, starting from a basic knowledge of its internal structure.

Geneva, Switzerland

documentation available on LHC electron-cloud web site:
http://ab-abp-rlc.web.cern.ch/ab-abp-rlc-ecloud/

FAKTOR 2 description 2006



WEPCH137 Proceedings of EPAC 2006, Edinburgh, Scotland

FAKTOR2: A CODE TO SIMULATE COLLECTIVE EFFECTS OF ELECTRONS AND IONS

W. Bruns*, D. Schulte, F. Zimmermann, CERN, Geneva, Switzerland

Abstract

A new code for computing multiple effects of nonrelativistic charges is being developed. The basic method is electrostatic Particle in Cell. The underlying grid is rectangular and locally homogeneous. At regions of interest, eg. where the beam is, or near material boundaries, the mesh is refined recursively. The motion of the macroparticles is integrated with an adapted time step. Fast particles are treated with a smaller time step, and particles in regions of fine grids are also treated with a fine time step. The position of collision of particles with material boundaries are accurately resolved. Secondary particles are then created according to user specified yield functions.

PURPOSE

Electron clouds develop in the beam pipes of accelerators eg. via ionisation of the residual gas and via secondary emission of electrons when slow electrons are accelerated by a passing beam. The newly developed programme simulates these effects. The basic method is electrostatic Particle in Cell.

The new code is meant to cover the same use as ECLOUD[2] but to be more modular and complete.

RECURSIVELY REFINED FINITE DIFFERENCE GRID

There are several reasons to use an electrostatic algorithm in a refined grid.

- Large time step: The electrostatic approximation allows to choose the time step independently of the grid spacing. We want to use quite a large time step, as we want to simulate several hundred beam passages, where each beam passage may be as long as $cT = 10$m.
- Large ratio of feature sizes: To numerically resolve the motion of ions which are trapped within the potential of a beam of finite x-y size, one needs a grid spacing smaller than the smallest dimension of the beam. E.g. for CLIC, this calls for grid spacings smaller than 1μ. For taking into account the boundary effects, one has to extend the grid until the beam pipe boundary is reached. E.g. for CLIC, a diameter of about 2cm has to be covered. It is wasteful and almost impossible to cover the whole area with cells as small as needed to resolve the field within the beam.

Figure 1: Subdivision of the grid near the pipe boundary and at the location of the beam. Two levels of refinement are applied. The different colours of the refined cells indicate clusters of cells which are treated as rectangular grids. The curved lines are lines of constant potential of an elliptical beam at the center.

The potential of the exciting beam and of the freely moving charges is computed on a rectangular finite difference grid, Fig. 1. The spacing is homogeneous. Each grid cell may be refined. The spacing of the grid points decreases by a factor of two per refinement level. For a more efficient handling of the grid, the refined cells are organised as clusters of cells. The electric and magnetic field of a relativistic beam is rigorously taken into account. The charge distribution of the beam may be arbitrary.

CHARGE DEPOSITION, POISSONS-EQUATION, PARTICLE PUSHING

The shape of the macroparticles is assumed to be rectangular, fig.(2). The size of the particles can be different from the grid size, and must be, as macroparticles will travel through regions with different grid spacings. Best results are obtained with a size equal to the grid size where the particle is in. The charge deposition together with the field interpolation, Fig. 2, ensures that no self field occurs when the charges have the same size as the enclosing grid.

POISSONs-equation is solved iteratively. Within an iteration, the potential within a subgrid is solved with the boundary conditions taken from the enclosing grid or from a neighbour grid, Fig. 3.

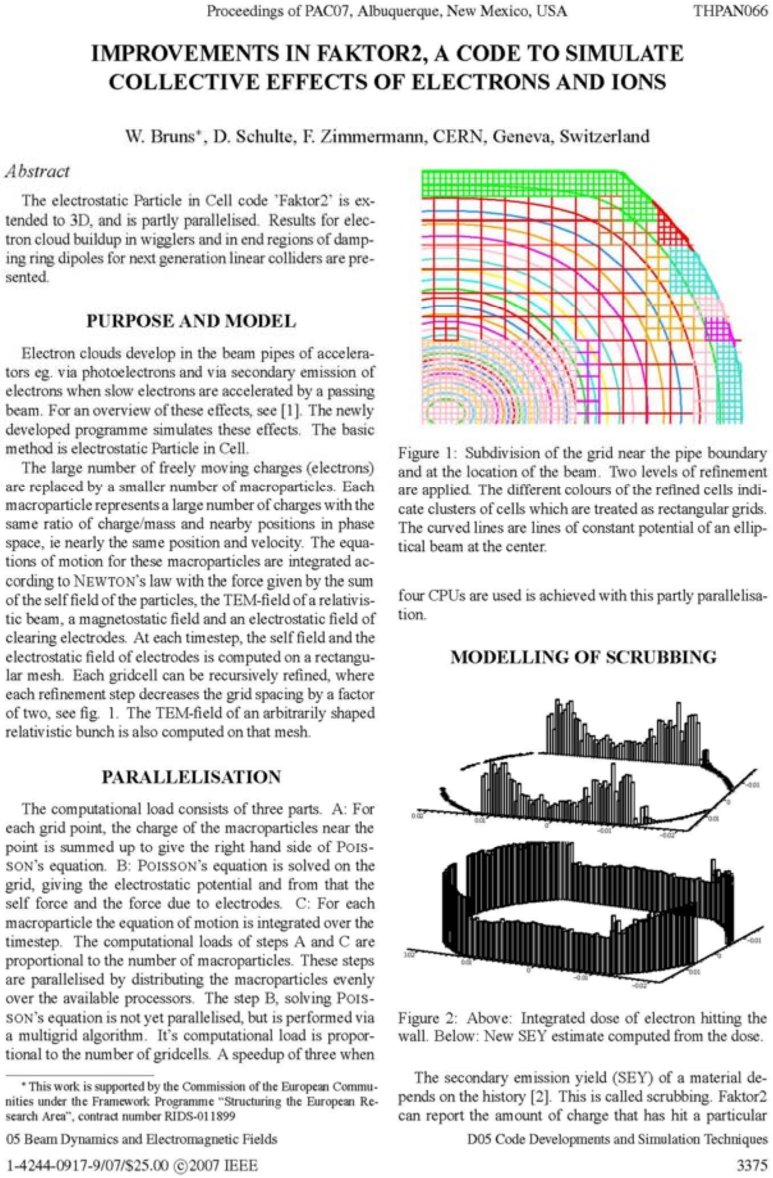
---

[*] This work is supported by the Commission of the European Communities under the Framework Programme "Structuring the European Research Area", contract number RIDS-011899

2242

05 Beam Dynamics and Electromagnetic Fields
D05 Code Developments and Simulation Techniques

FAKTOR 2 description 2007



Proceedings of PAC07, Albuquerque, New Mexico, USA THPAN066

IMPROVEMENTS IN FAKTOR2, A CODE TO SIMULATE COLLECTIVE EFFECTS OF ELECTRONS AND IONS

W. Bruns*, D. Schulte, F. Zimmermann, CERN, Geneva, Switzerland

Abstract

The electrostatic Particle in Cell code 'Faktor2' is extended to 3D, and is partly parallelised. Results for electron cloud buildup in wigglers and in end regions of damping ring dipoles for next generation linear colliders are presented.

PURPOSE AND MODEL

Electron clouds develop in the beam pipes of accelerators eg. via photoelectrons and via secondary emission of electrons when slow electrons are accelerated by a passing beam. For an overview of these effects, see [1]. The newly developed programme simulates these effects. The basic method is electrostatic Particle in Cell.

The large number of freely moving charges (electrons) are replaced by a smaller number of macroparticles. Each macroparticle represents a large number of charges with the same ratio of charge/mass and nearby positions in phase space, ie nearly the same position and velocity. The equations of motion for these macroparticles are integrated according to NEWTON's law with the force given by the sum of the self field of the particles, the TEM-field of a relativistic beam, a magnetostatic field and an electrostatic field of clearing electrodes. At each timestep, the self field and the electrostatic field of electrodes is computed on a rectangular mesh. Each gridcell can be recursively refined, where each refinement step decreases the grid spacing by a factor of two, see fig. 1. The TEM-field of an arbitrarily shaped relativistic bunch is also computed on that mesh.

PARALLELISATION

The computational load consists of three parts. A: For each grid point, the charge of the macroparticles near the point is summed up to give the right hand side of POISSON's equation. B: POISSON's equation is solved on the grid, giving the electrostatic potential and from that the self force and the force due to electrodes. C: For each macroparticle the equation of motion is integrated over the timestep. The computational loads of steps A and C are proportional to the number of macroparticles. These steps are parallelised by distributing the macroparticles evenly over the available processors. The step B, solving POISSON's equation is not yet parallelised, but is performed via a multigrid algorithm. It's computational load is proportional to the number of gridcells. A speedup of three when four CPUs are used is achieved with this partly parallelisation.

Figure 1: Subdivision of the grid near the pipe boundary and at the location of the beam. Two levels of refinement are applied. The different colours of the refined cells indicate clusters of cells which are treated as rectangular grids. The curved lines are lines of constant potential of an elliptical beam at the center.

MODELLING OF SCRUBBING

Figure 2: Above: Integrated dose of electron hitting the wall. Below: New SEY estimate computed from the dose.

The secondary emission yield (SEY) of a material depends on the history [2]. This is called scrubbing. Faktor2 can report the amount of charge that has hit a particular

---

[*] This work is supported by the Commission of the European Communities under the Framework Programme "Structuring the European Research Area", contract number RIDS-011899

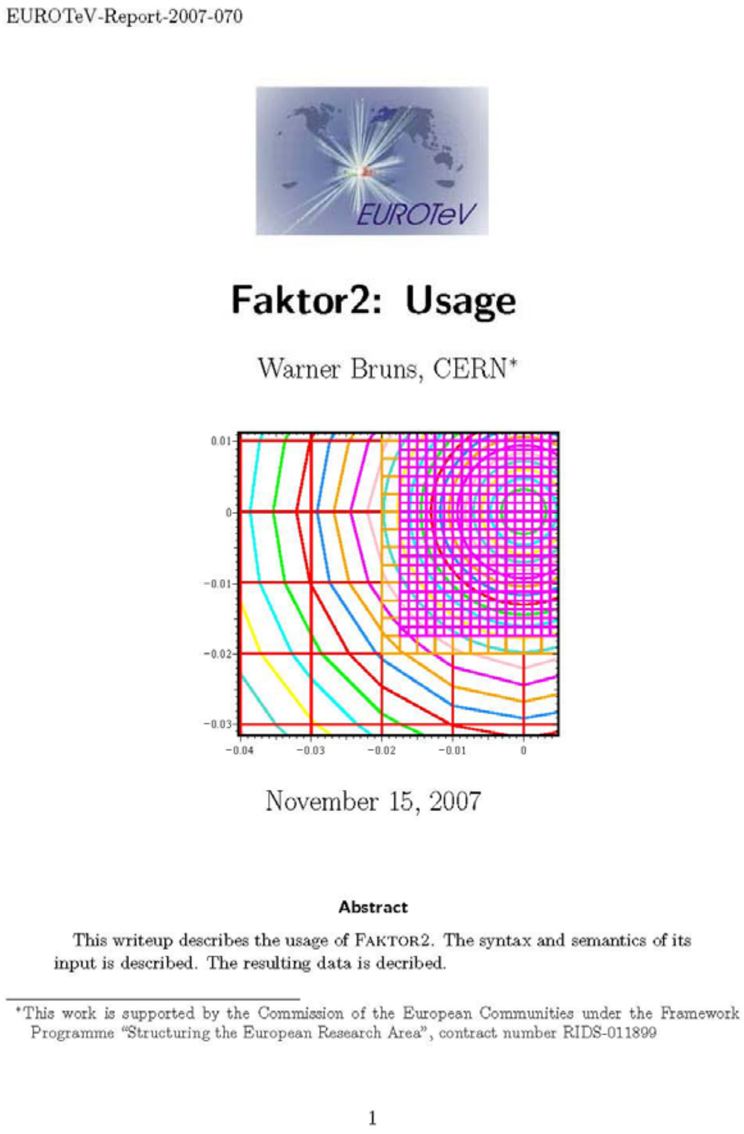
05 Beam Dynamics and Electromagnetic Fields

1-4244-0917-9/07/$25.00 ©2007 IEEE

D05 Code Developments and Simulation Techniques

3375

FAKTOR2 Usage and Rationale – EUROTeV reports published in 2007



EUROTeV-Report-2007-070

Faktor2: Usage

Warner Bruns, CERN*

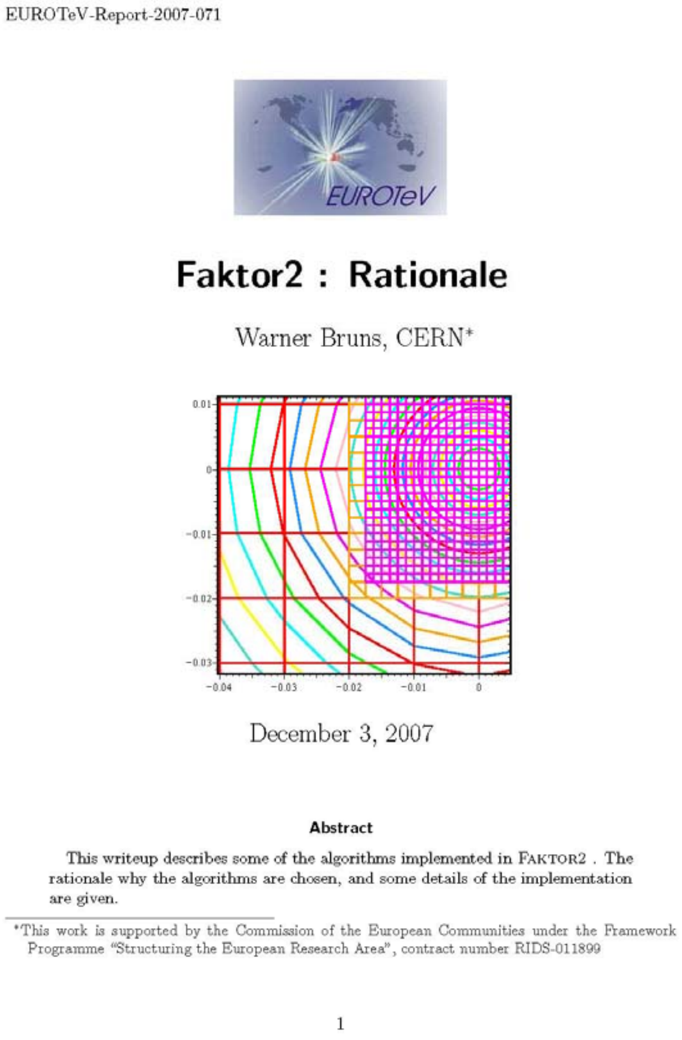
November 15, 2007

Abstract

This writeup describes the usage of FAKTOR2. The syntax and semantics of its input is described. The resulting data is decribed.

---

[*] This work is supported by the Commission of the European Communities under the Framework Programme "Structuring the European Research Area", contract number RIDS-011899



EUROTeV-Report-2007-071

Faktor2 : Rationale

Warner Bruns, CERN*

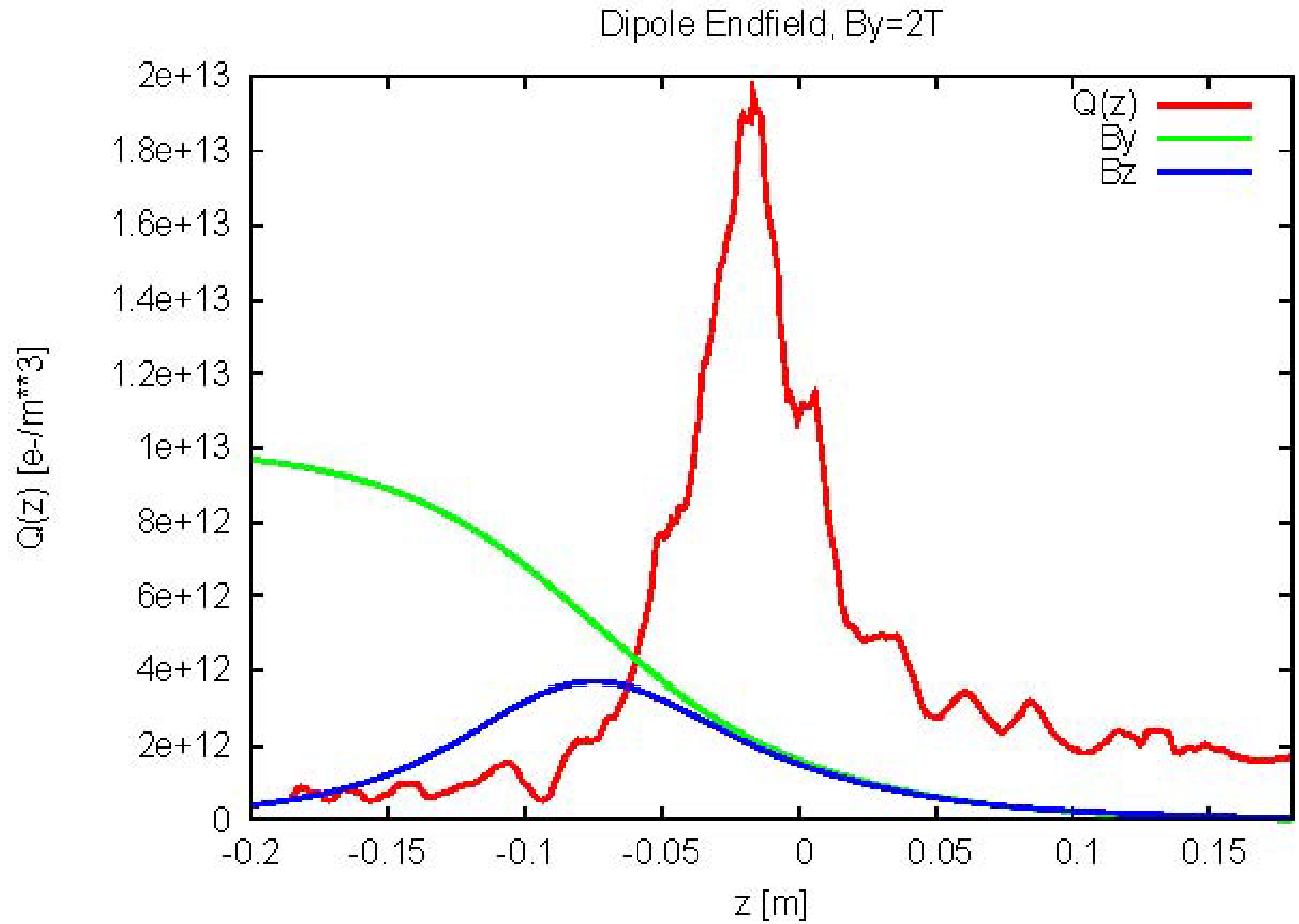
December 3, 2007

Abstract

This writeup describes some of the algorithms implemented in FAKTOR2 . The rationale why the algorithms are chosen, and some details of the implementation are given.

---

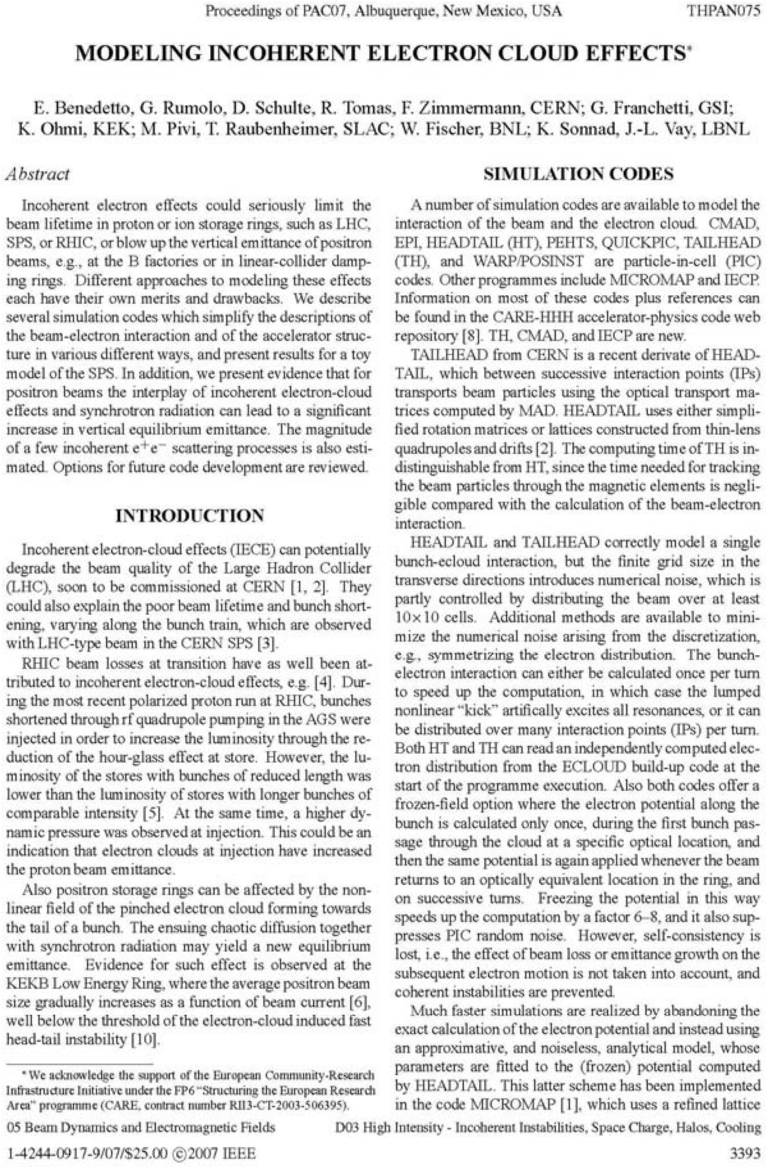
[*] This work is supported by the Commission of the European Communities under the Framework Programme "Structuring the European Research Area", contract number RIDS-011899



electron cloud in a dipole end field, simulated by 3D code FAKTOR2; W. Bruns, PAC'07

documentation available on LHC electron-cloud web site: http://ab-abp-rlc.web.cern.ch/ab-abp-rlc-ecloud/

IECP description 2007



Proceedings of PAC07, Albuquerque, New Mexico, USA THPAN075

MODELING INCOHERENT ELECTRON CLOUD EFFECTS*

E. Benedetto, G. Rumolo, D. Schulte, R. Tomas, F. Zimmermann, CERN; G. Franchetti, GSI;
K. Ohmi, KEK; M. Pivi, T. Raubenheimer, SLAC; W. Fischer, BNL; K. Sonnad, J.-L. Vay, LBNL

Abstract

Incoherent electron effects could seriously limit the beam lifetime in proton or ion storage rings, such as LHC, SPS, or RHIC, or blow up the vertical emittance of positron beams, e.g., at the B factories or in linear-collider damping rings. Different approaches to modeling these effects each have their own merits and drawbacks. We describe several simulation codes which simplify the descriptions of the beam-electron interaction and of the accelerator structure in various different ways, and present results for a toy model of the SPS. In addition, we present evidence that for positron beams the interplay of incoherent electron-cloud effects and synchrotron radiation can lead to a significant increase in vertical equilibrium emittance. The magnitude of a few incoherent e^+e^- scattering processes is also estimated. Options for future code development are reviewed.

INTRODUCTION

Incoherent electron-cloud effects (IECE) can potentially degrade the beam quality of the Large Hadron Collider (LHC), soon to be commissioned at CERN [1, 2]. They could also explain the poor beam lifetime and bunch shortening, varying along the bunch train, which are observed with LHC-type beam in the CERN SPS [3].

RHIC beam losses at transition have as well been attributed to incoherent electron-cloud effects, e.g. [4]. During the most recent polarized proton run at RHIC, bunches shortened through rf quadrupole pumping in the AGS were injected in order to increase the luminosity through the reduction of the hour-glass effect at store. However, the luminosity of the stores with bunches of reduced length was lower than the luminosity of stores with longer bunches of comparable intensity [5]. At the same time, a higher dynamic pressure was observed at injection. This could be an indication that electron clouds at injection have increased the proton beam emittance.

Also positron storage rings can be affected by the nonlinear field of the pinched electron cloud forming towards the tail of a bunch. The ensuing chaotic diffusion together with synchrotron radiation may yield a new equilibrium emittance. Evidence for such effect is observed at the KEKB Low Energy Ring, where the average positron beam size gradually increases as a function of beam current [6], well below the threshold of the electron-cloud induced fast head-tail instability [10].

SIMULATION CODES

A number of simulation codes are available to model the interaction of the beam and the electron cloud. CMAD, EPI, HEADTAIL (HT), PEHTS, QUICKPIC, TAILHEAD (TH), and WARP/POSINST are particle-in-cell (PIC) codes. Other programmes include MICROMAP and IECP. Information on most of these codes plus references can be found in the CARE-HHH accelerator-physics code web repository [8]. TH, CMAD, and IECP are new.

TAILHEAD from CERN is a recent derivate of HEADTAIL, which between successive interaction points (IPs) transports beam particles using the optical transport matrices computed by MAD. HEADTAIL uses either simplified rotation matrices or lattices constructed from thin-lens quadrupoles and drifts [2]. The computing time of TH is indistinguishable from HT, since the time needed for tracking the beam particles through the magnetic elements is negligible compared with the calculation of the beam-electron interaction.

HEADTAIL and TAILHEAD correctly model a single bunch-ecloud interaction, but the finite grid size in the transverse directions introduces numerical noise, which is partly controlled by distributing the beam over at least 10×10 cells. Additional methods are available to minimize the numerical noise arising from the discretization, e.g., symmetrizing the electron distribution. The bunch-electron interaction can either be calculated once per turn to speed up the computation, in which case the lumped nonlinear "kick" artifically excites all resonances, or it can be distributed over many interaction points (IPs) per turn. Both HT and TH can read an independently computed electron distribution from the ECLOUD build-up code at the start of the programme execution. Also both codes offer a frozen-field option where the electron potential along the bunch is calculated only once, during the first bunch passage through the cloud at a specific optical location, and then the same potential is again applied whenever the beam returns to an optically equivalent location in the ring, and on successive turns. Freezing the potential in this way speeds up the computation by a factor 6–8, and it also suppresses PIC random noise. However, self-consistency is lost, i.e., the effect of beam loss or emittance growth on the subsequent electron motion is not taken into account, and coherent instabilities are prevented.

Much faster simulations are realized by abandoning the exact calculation of the electron potential and instead using an approximative, and noiseless, analytical model, whose parameters are fitted to the (frozen) potential computed by HEADTAIL. This latter scheme has been implemented in the code MICROMAP [1], which uses a refined lattice

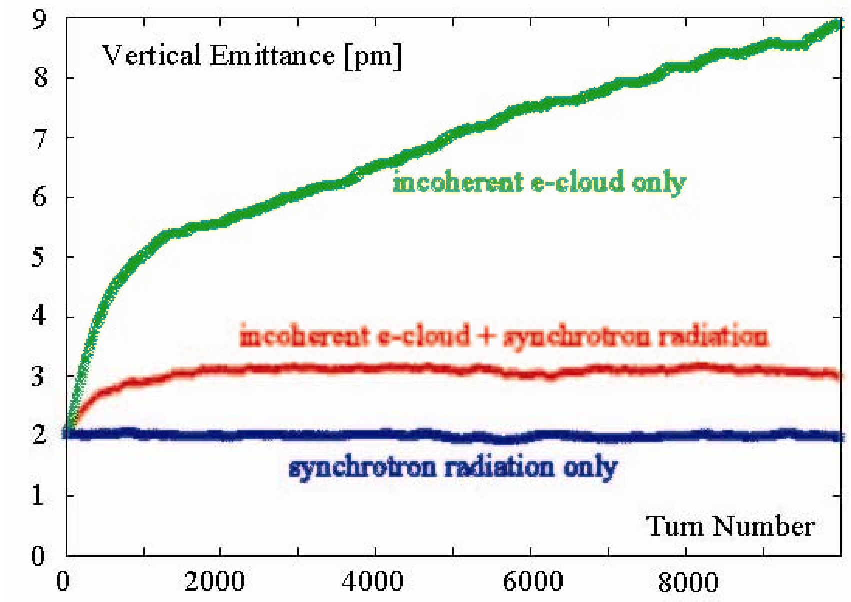
---

[*] We acknowledge the support of the European Community-Research Infrastructure Initiative under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395).

05 Beam Dynamics and Electromagnetic Fields D03 High Intensity - Incoherent Instabilities, Space Charge, Halos, Cooling

1-4244-0917-9/07/$25.00 ©2007 IEEE 3393

incoherent blow up in e+ storage ring



Vertical emittance in the ILC 6-km damping ring (OCS) as a function of turn number, with synchrotron radiation only, with a frozen electron-cloud pinch only, and with the combined effect, simulated by IECP using a single beam-electron IP per turn and an initial tune shift, at the head of the bunch, of $\Delta Q \approx$ *0.01, corresponding to an* electron density of 2×*1011 m−3. The incoherent tune shift* is taken to increase 140 times during the bunch passage

code repository (CARE-HHH)

http://oraweb.cern.ch/pls/hhh/code_website.disp_category?cat_name=Electron%20Cloud

Build-Up Simulations

- CMAD
- CSEC
- ECLOUD
- Faktor2
- POSINST

Incoherent

- CMAD
- HEADTAIL
- MICROMAP

Multi-Bunch Instability Simulations

- PEI-M

Multipacting

- ESA ESTEC

Self-Consistent Simulations

- CMAD
- Faktor2
- ORBIT
- QUICKPIC
- WARP

Single-Bunch Instability Simulations

- CMAD
- HEADTAIL

Synchrotron Radiation

- PHOTON

Benchmark Table

model uncertainties

secondary emission:

maximum emission yield

energy at which yield is maximum

elastic reflection at low energy;

dependence on impact angle;

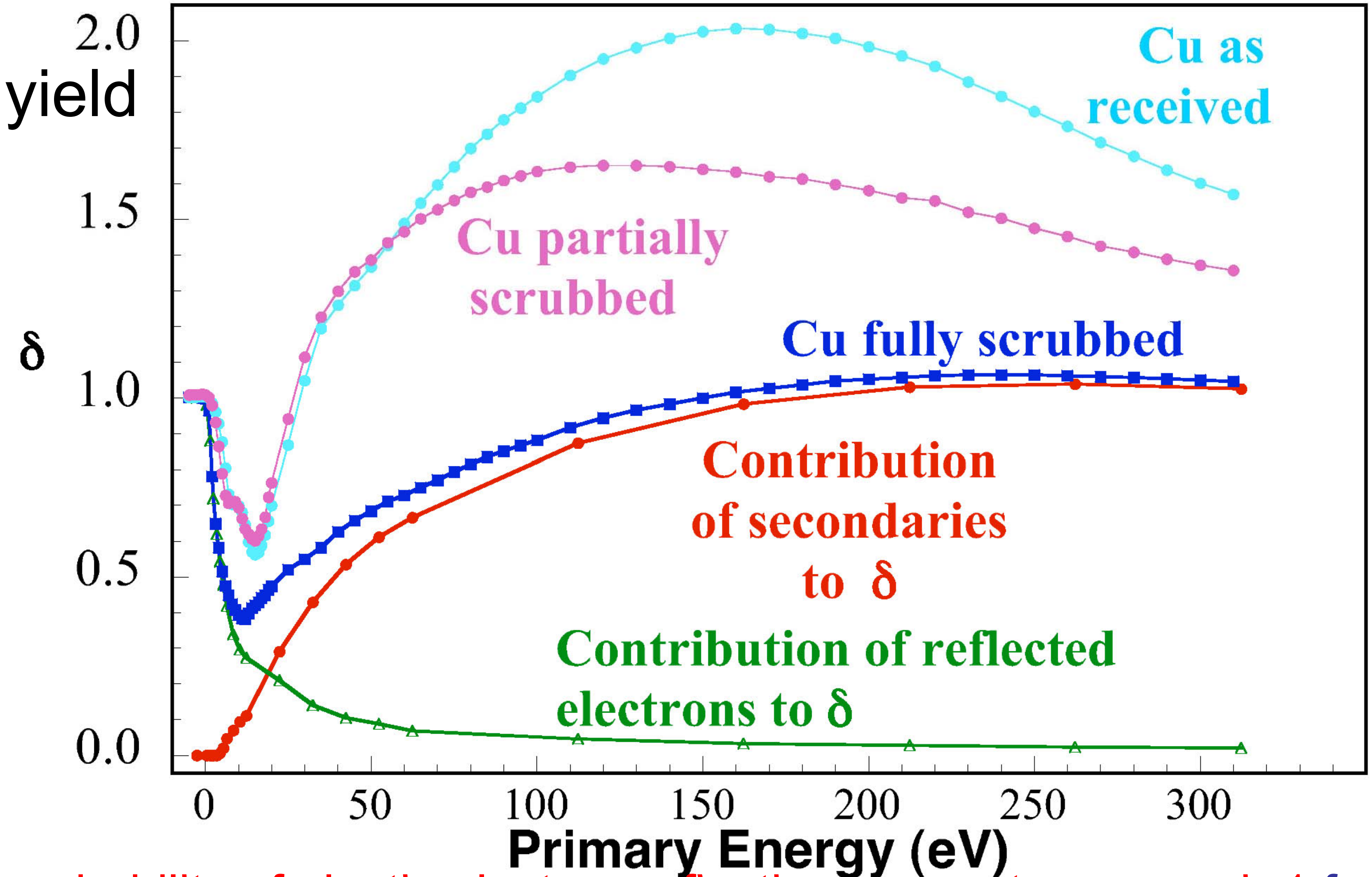
initial energy distribution;

model & role of rediffused e-?

photo-emission:

initial energy distribution, yield,...

R. Cimino, I. Collins, et al, Phys.Rev.Lett.93:014801,2004.



probability of elastic electron reflection seems to approach 1 for zero incident energy and is independent of δ^*_{max}

dependence of secondary emission yield on impact angle θ

data from SLAC: R.E. Kirby, F.K. King, “Secondary Emission Yields from PEP-II Accelerator Materials”, NIM A 469, 2001

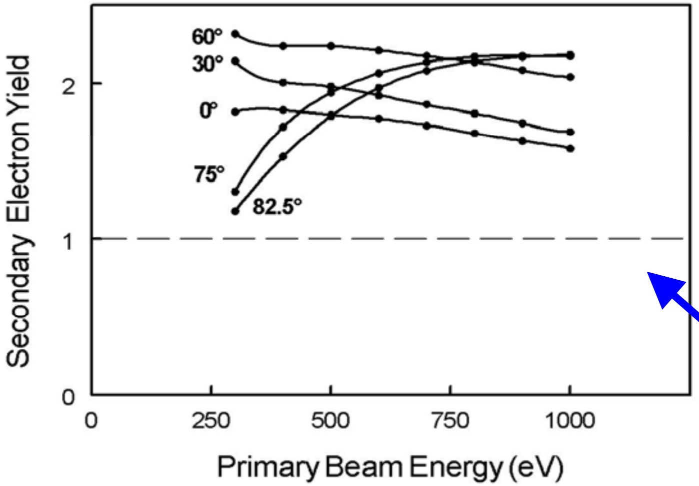


Figure 10. SEY of HER copper extrusion material, prior to electron dosing.

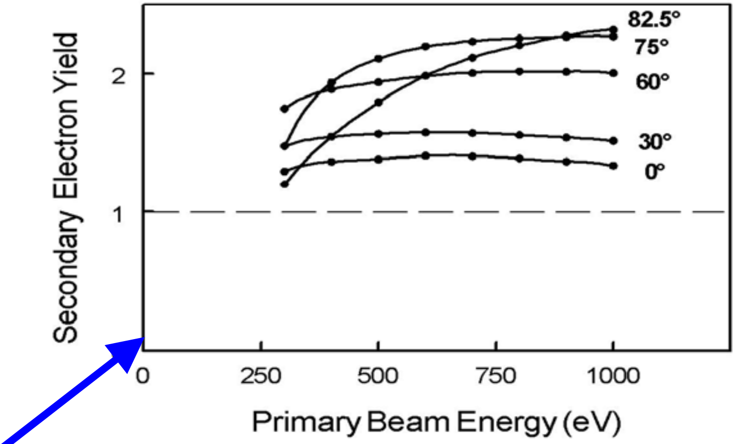


Figure 12. SEY of mechanically polished and degreased copper, for w-band acceleration applications.

Copper - different surface finish and surface chemistry - large variation in behavior, CERN data not available

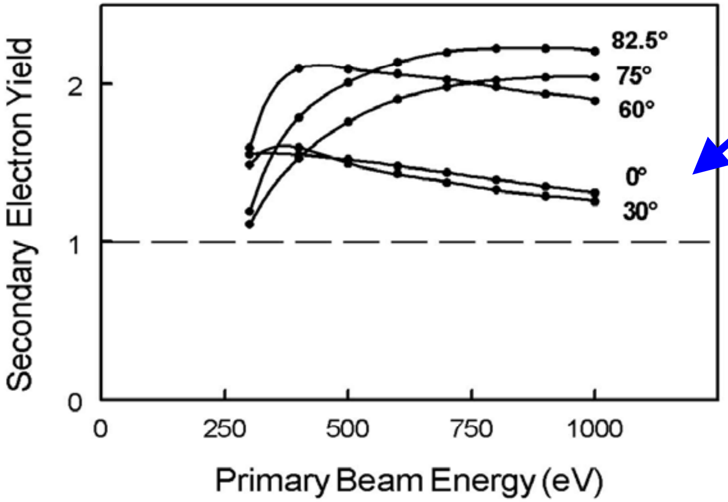
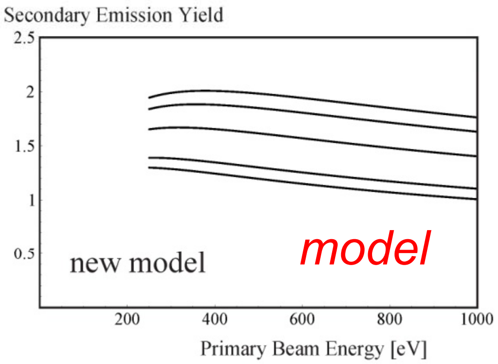
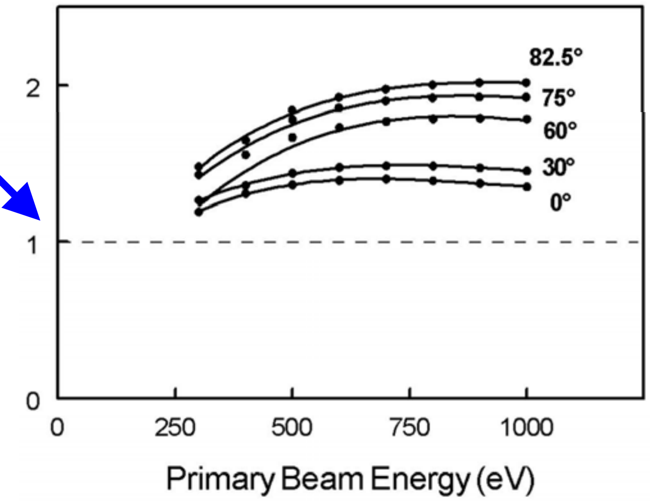


Figure 11. SEY of HER copper extrusion material, after electron dosing of 4.0x10^{18} electrons cm^{-2}.



model



re 13 . SEY of Ar ion-sputtered HER copper. Ion dose parameters: 3 keV, 1.2x10^{18} ions-cm^{-2}. GDC equivalent: 0.34 keV, 2x10^{19} ions-cm^{-2}.

Present Model of Secondary Emission Yield

$$\delta_{tot}(E_p,\theta)=\delta_{true}(E_p,\theta)+R\delta_{elastic}(E_p,\cancel{\theta})+\cancel{\delta_{rediffused}(E_p,\theta)}$$

secondary electrons consist of true secondaries and elastically reflected;
since 2003 we assume that elastic reflection is independent of Θ (no data)

true secondaries:

$$\delta_{true}(E_p,\theta)=\delta_{\max}(\theta)\frac{s\times(E_p/E_{\max}(\theta))}{s-1+(E_p/E_{\max}(\theta))^s}$$

[M. Furman, 1997]

$$\delta_{\max}(\theta)\approx\delta^*_{\max}\exp\left(\frac{1}{2}(1-\cos\theta)\right)$$

$$E_{\max}(\theta)\approx E^*_{\max}\times(1+0.7(1-\cos\theta))$$

[Kirby, 2001;
Henrist, 2002;
Furman, 1997]

elastic reflection:

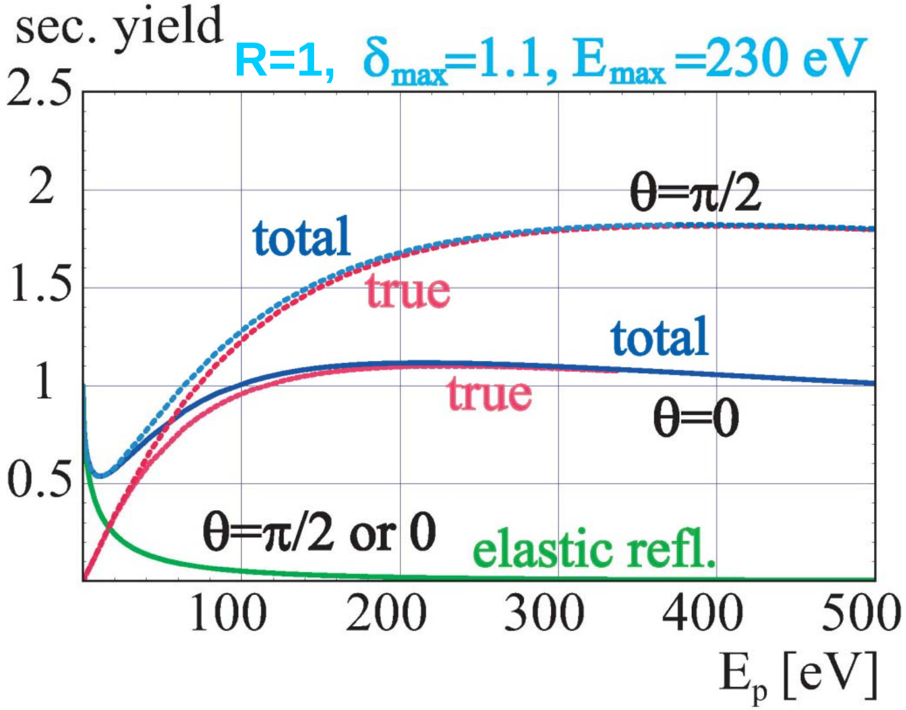
$$\delta_{elastic}(E)\approx\left(\frac{\sqrt{E}-\sqrt{E+E_0}}{\sqrt{E}+\sqrt{E+E_0}}\right)^2$$

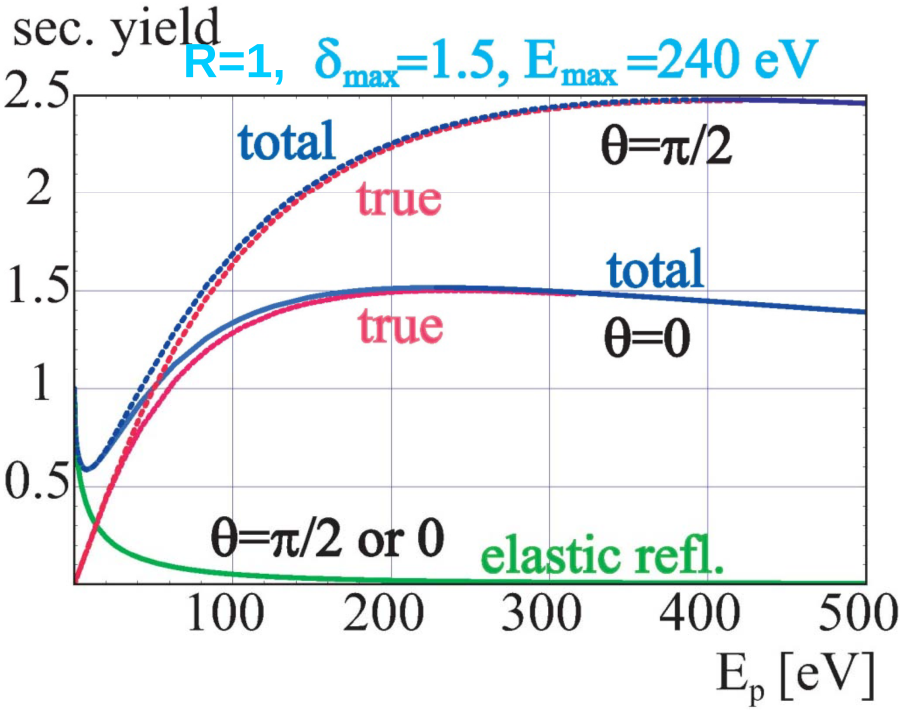
[Cimino, Collins, et al., 2003]

this *quantum-mechanical formula* fits *the data well for* E_0*~150 eV*

M. Furman includes rediffused electrons and finds that they increase the heat load by 100%

Illustration of present secondary-yield model





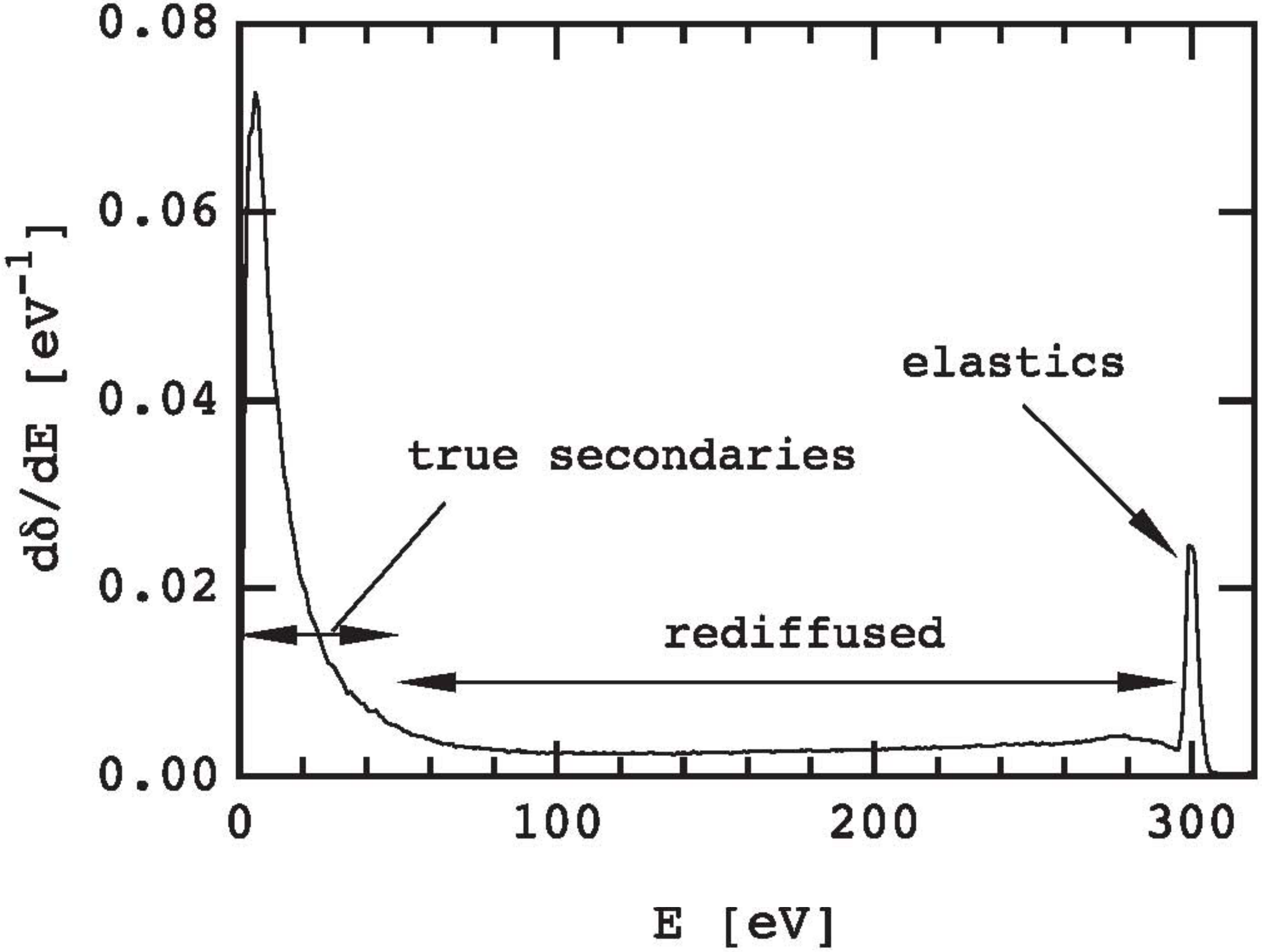


FIG. 1. Sample secondary emission spectrum for $E_0 = 300$ eV incident electron energy. For illustrative purposes, the rediffused component is here much larger [$\delta_r(E_0) \sim 0.75$, or ~37% of the total] than what we actually used in our simulations (~ 8.5%) for comparable values of E_0.

[M. Furman, V. Chaplin, **PRST-AB 9:034403, 2006**]

what do we mean by code "benchmarking"?

✓***debugging*** (code should calculate what it is supposed to calculate)

✓***validation*** (results should agree with established analytic result for specific cases)

✓***comparison*** (two codes should agree if the model is the same)

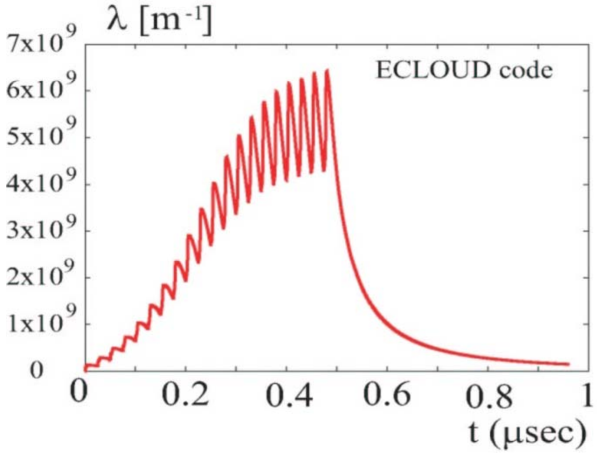
✓***verification*** (code should agree with measurement)

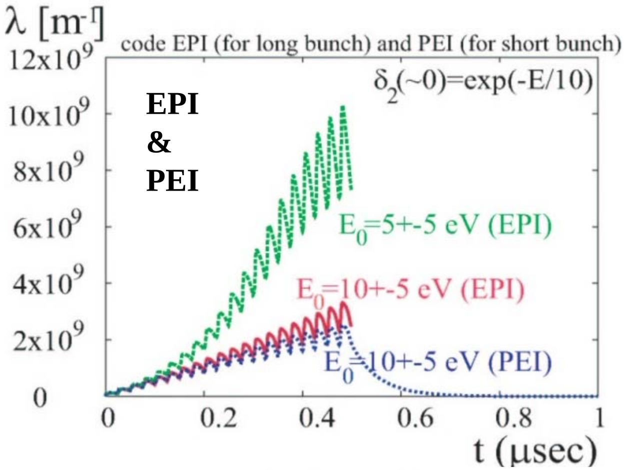
M.A. Furman, HHH-2004

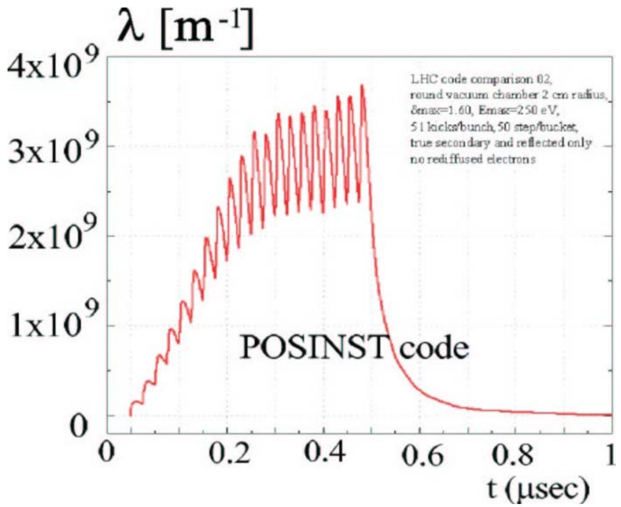
benchmarking

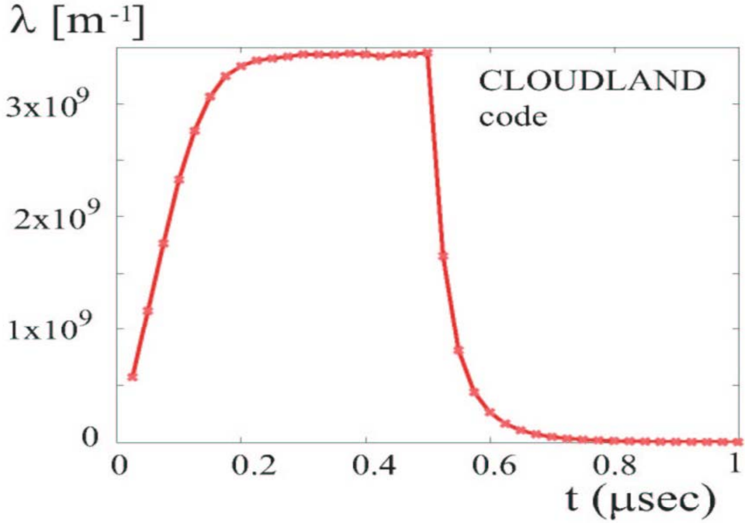
(1) code vs code

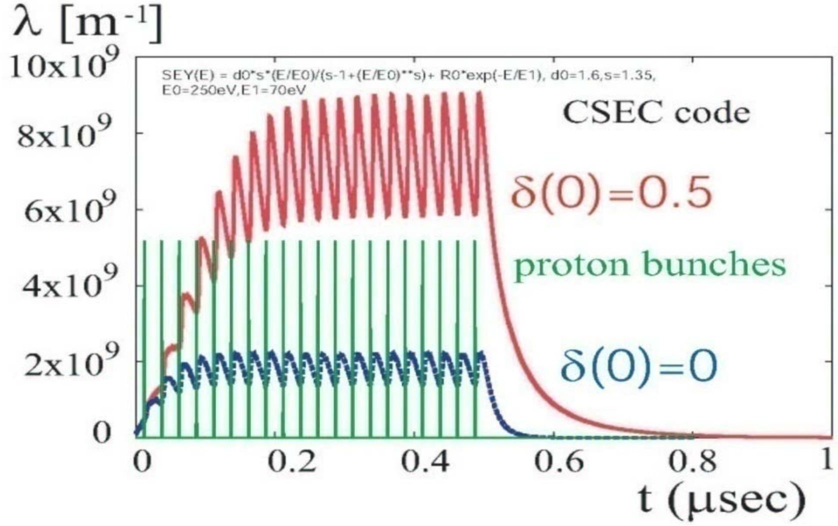
benchmarking of build-up simulation codes, EPAC 2004





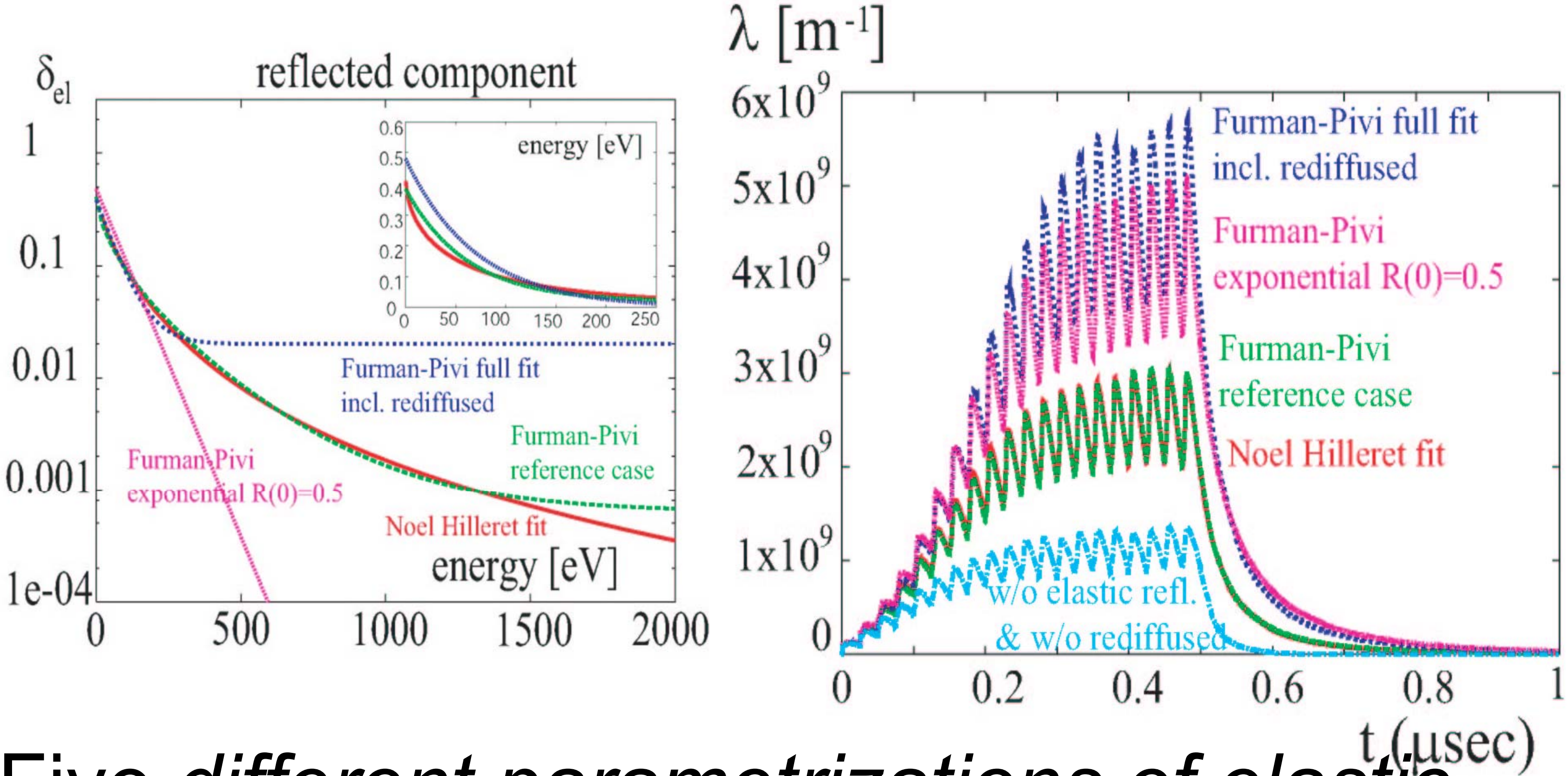






large variation in results

benchmarking of ECLOUD simulations, EPAC 2004

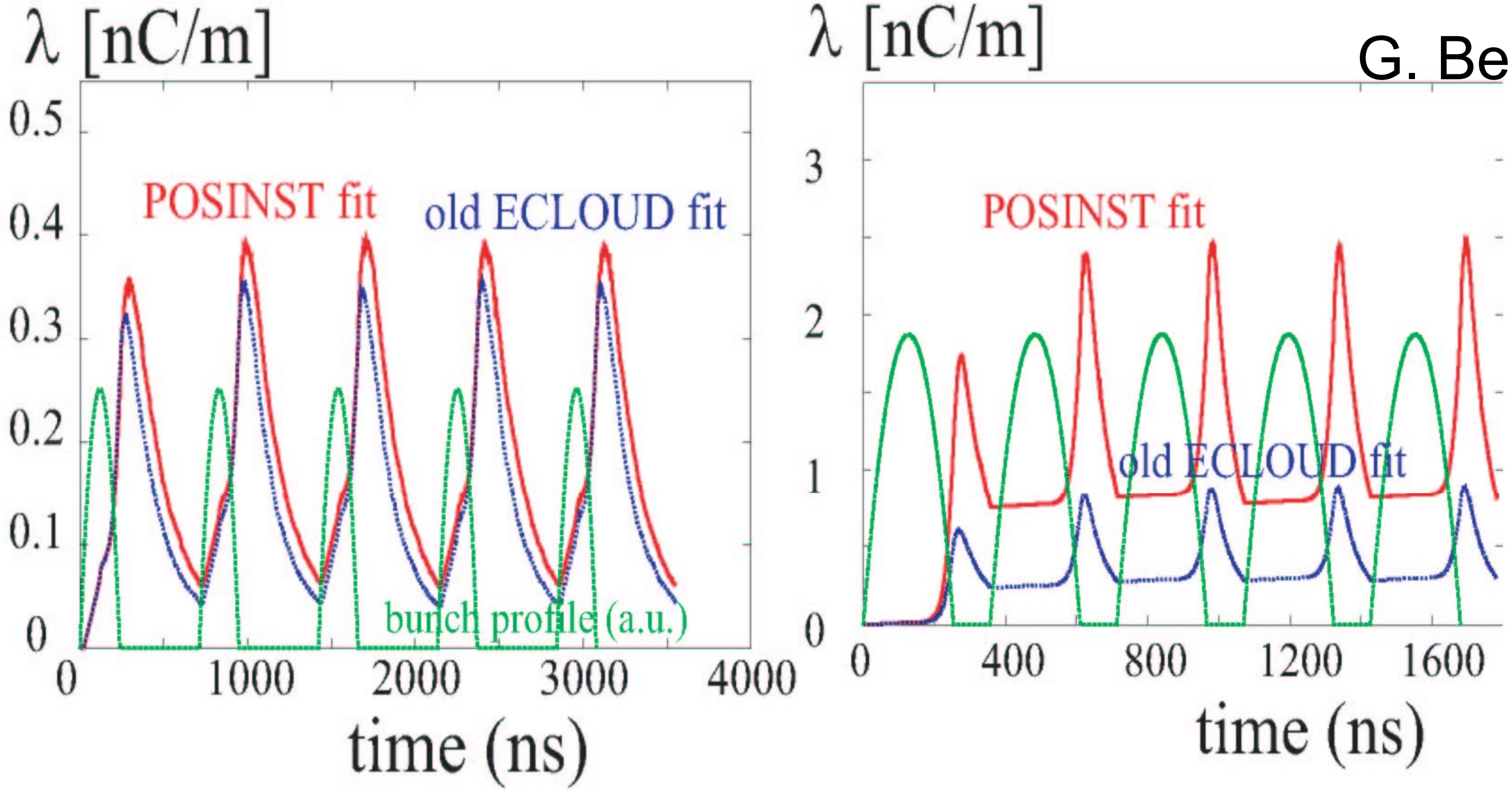


Five *different parametrizations of elastic electron reflection* (left) and the corresponding ECLOUD simulation results (right).

details of ***secondary emission yield*** → *large variation*

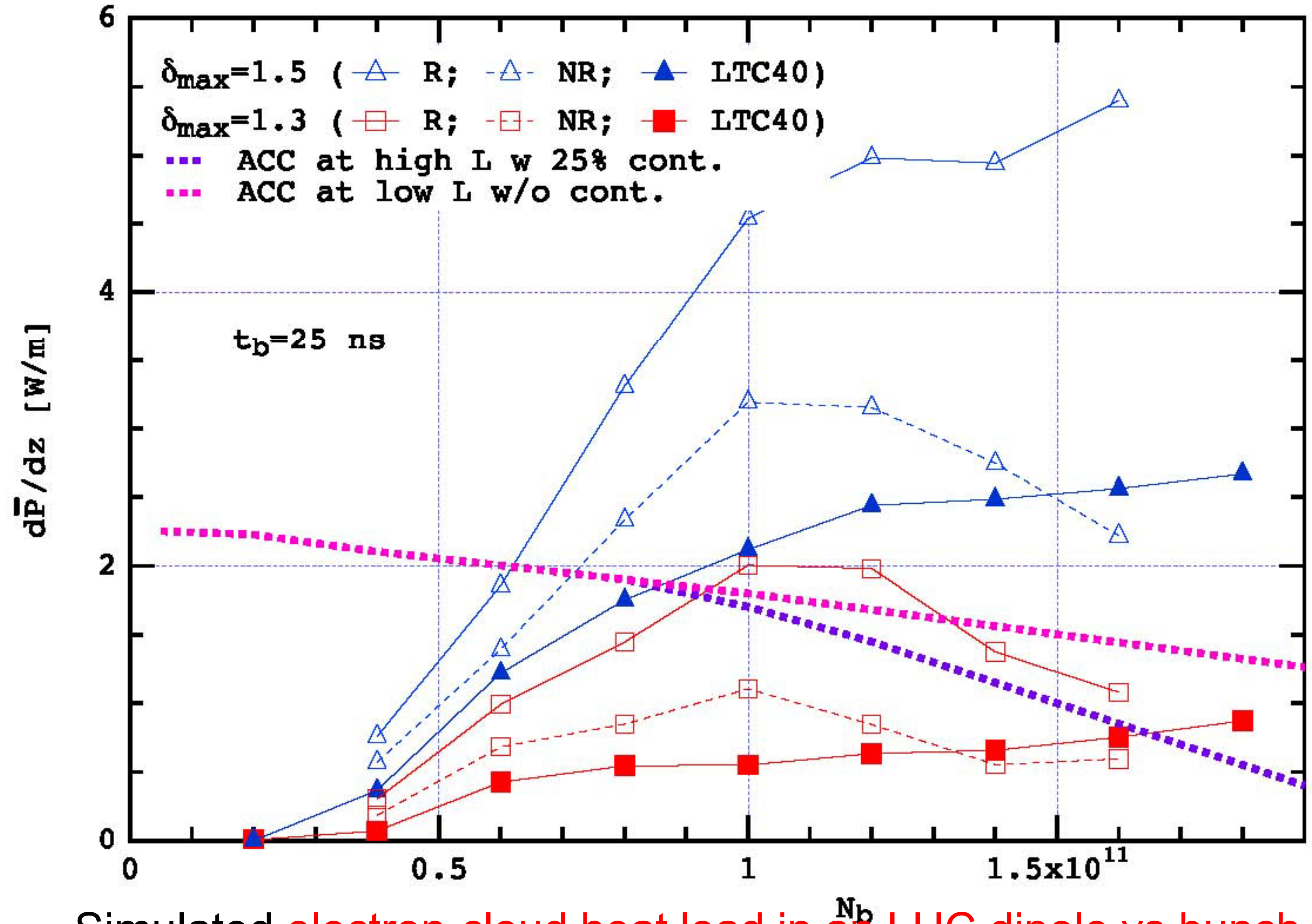
benchmarking of ECLOUD simulations, EPAC 2004

G. Bellodi



Comparison of build-up simulations with ECLOUD for ISIS (left) and PSR (right) using either the POSINST model of an alternative expression for **secondary energy spectrum**

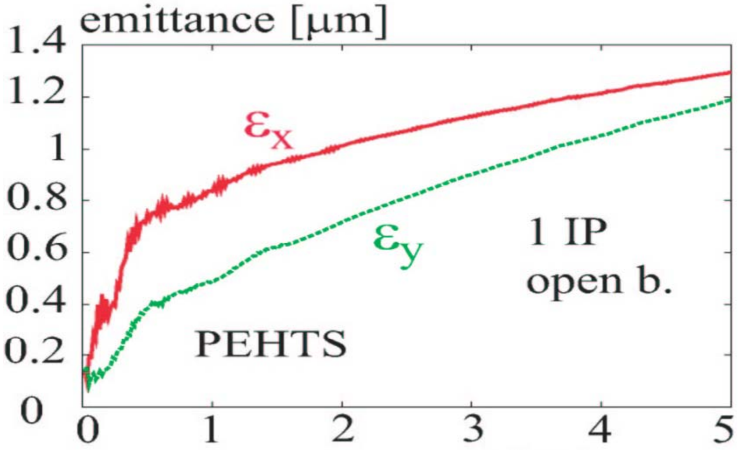
ECLOUD versus POSINST

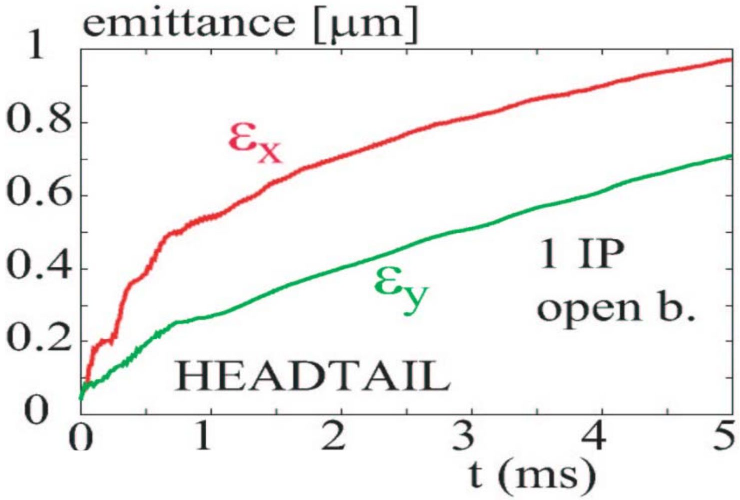


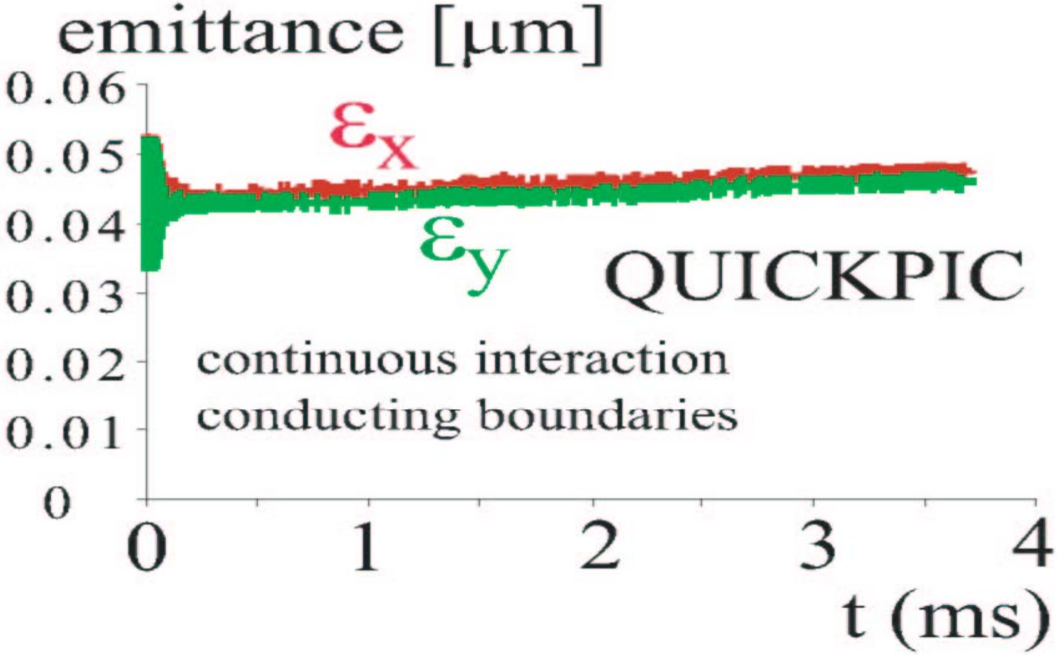
same secondary emission yield model gives about same result for different codes

Simulated electron-cloud heat load in an LHC dipole vs bunch population for two different value of δ_{max}. R: **POSINST code with full SEY model**, NR: **POSINST code with no-rediffused model**, LTC40 : result from **ECLOUD code without re-diffused electrons**. The available cooling capacity (ACC) under two different assumptions is also indicated [M. Furman, V. Chaplin, **PRST-AB 9:034403, 2006]**

benchmarking of instability codes, EPAC 2004

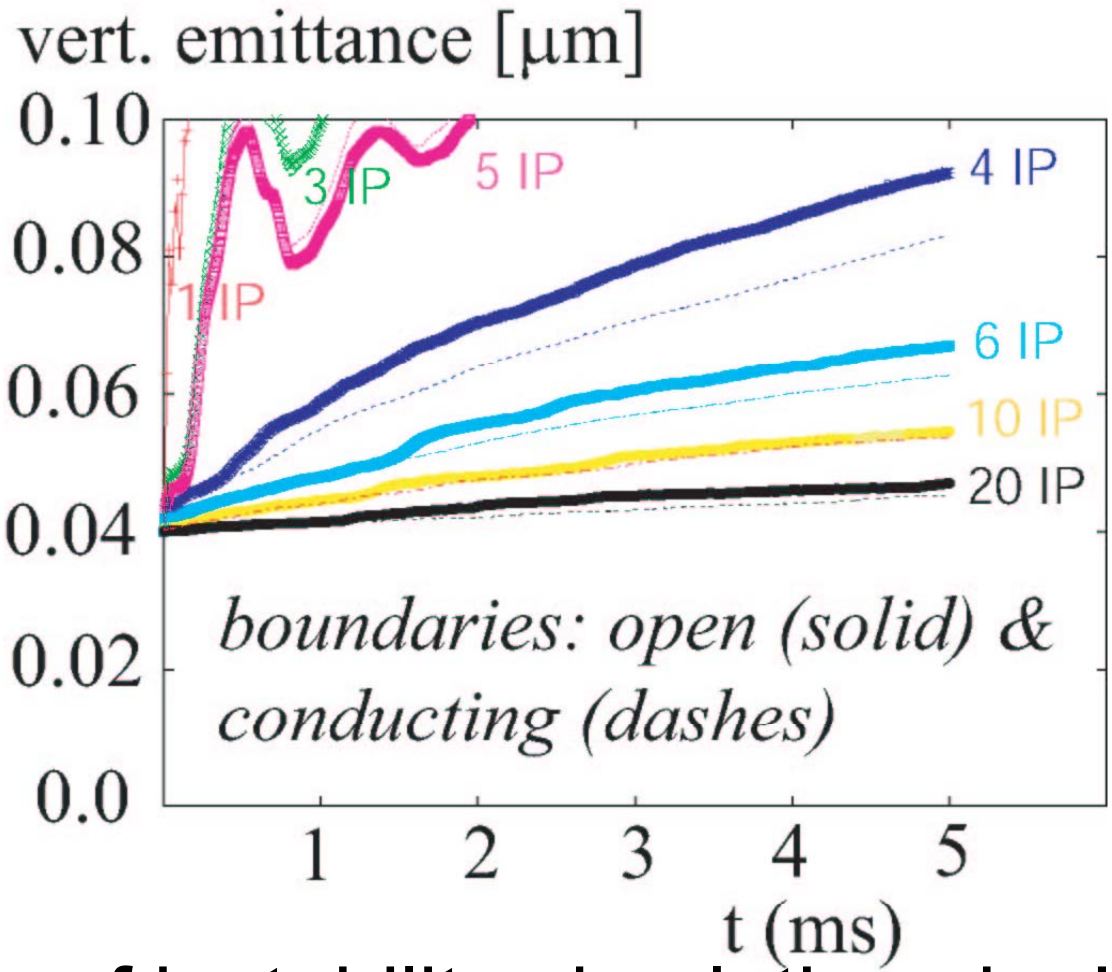






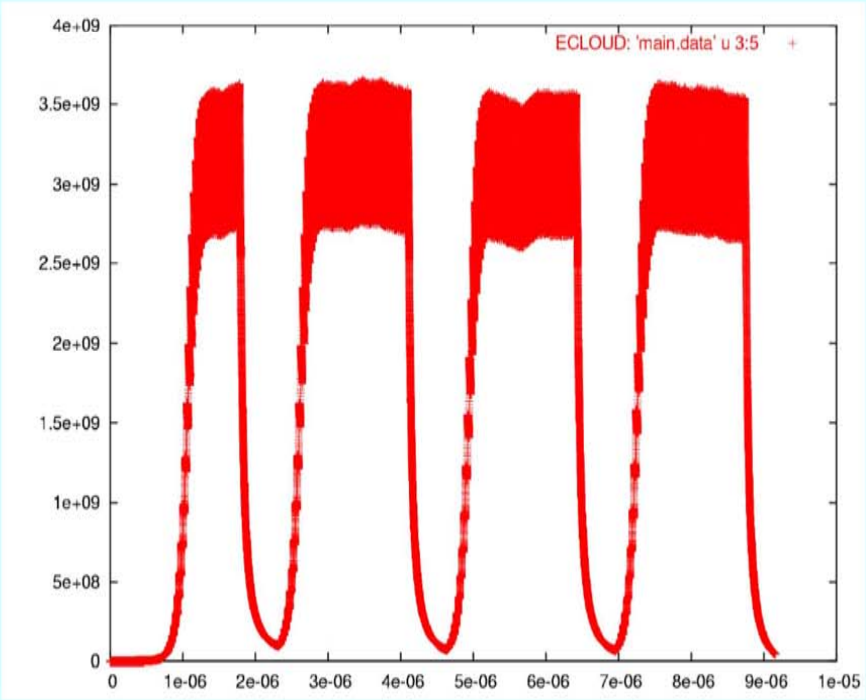
Results of instability simulations by various codes.

benchmarking of instability codes, EPAC 2004

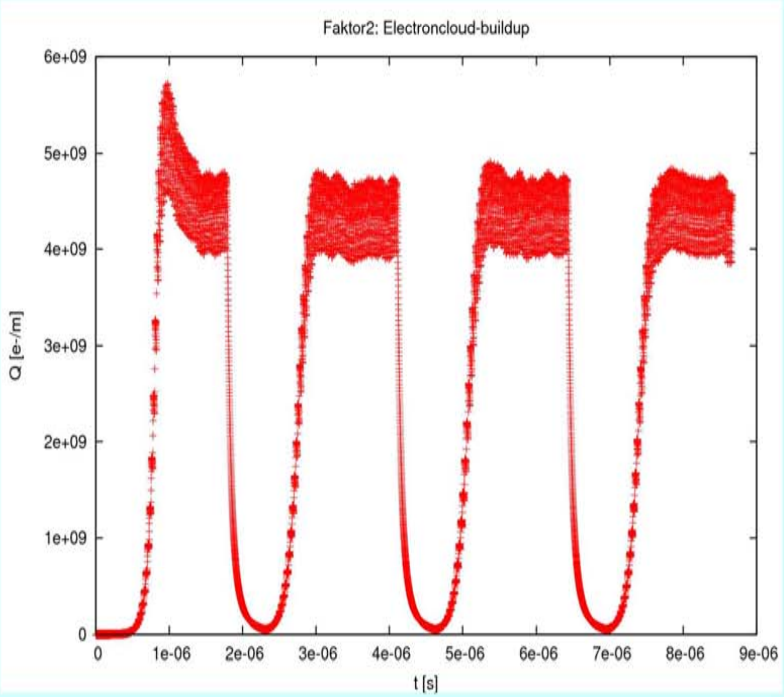


Results of instability simulations by HEADTAIL with various numbers of IPs for both open and conducting boundary conditions.

ECLOUD vs FAKTOR2, 2008



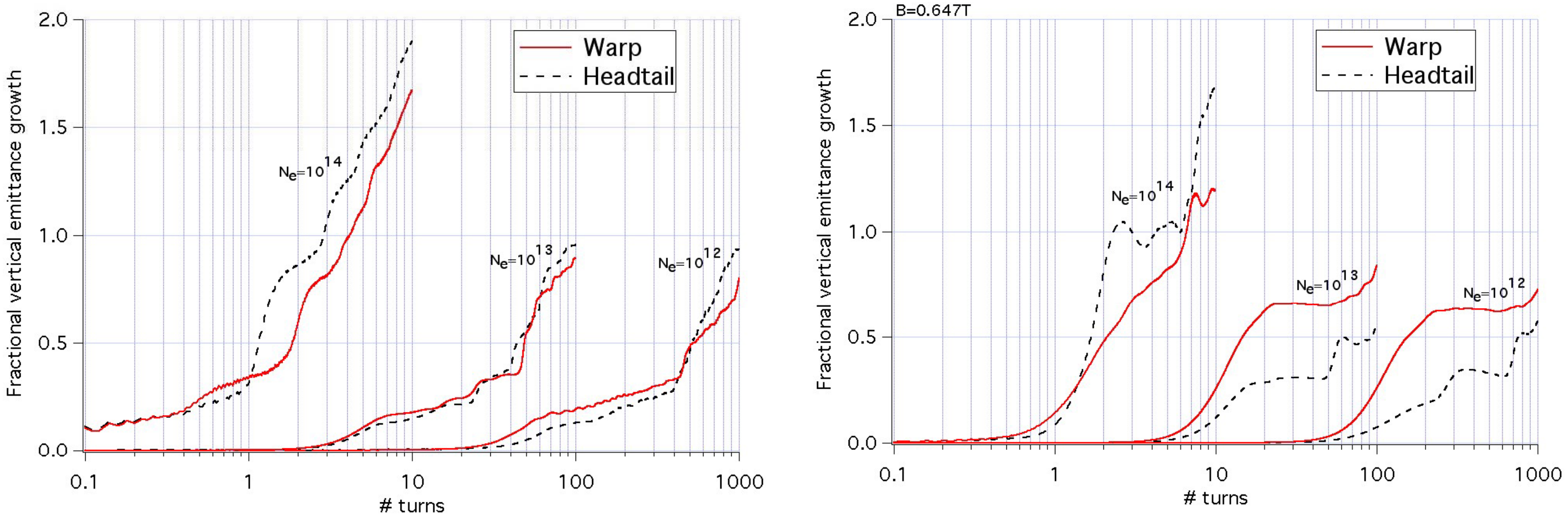
e-/m, computed by ECLOUD



e-/m, computed by Faktor2

W. Bruns

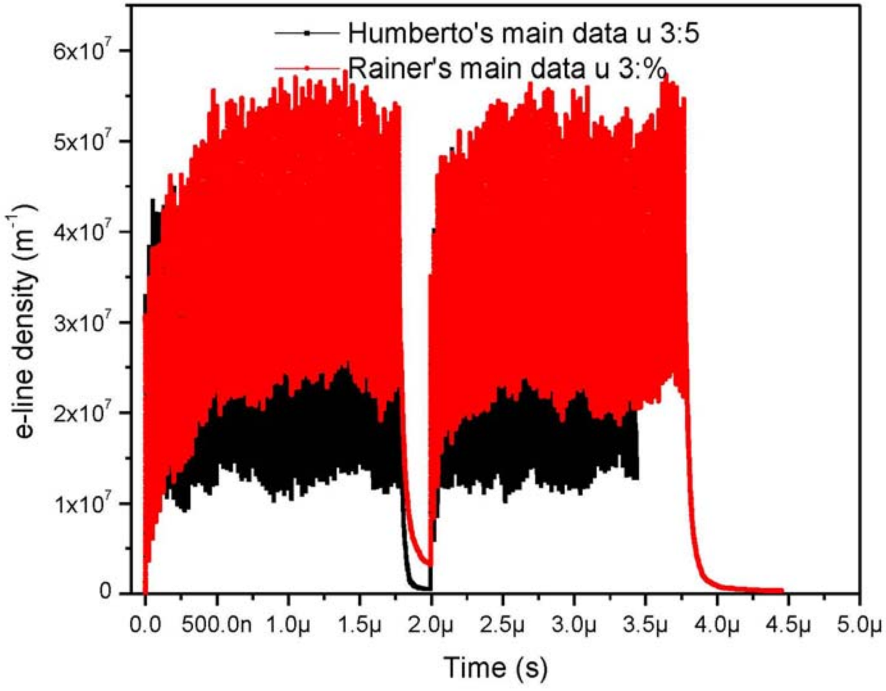
HEADTAIL versus WARP, 2008



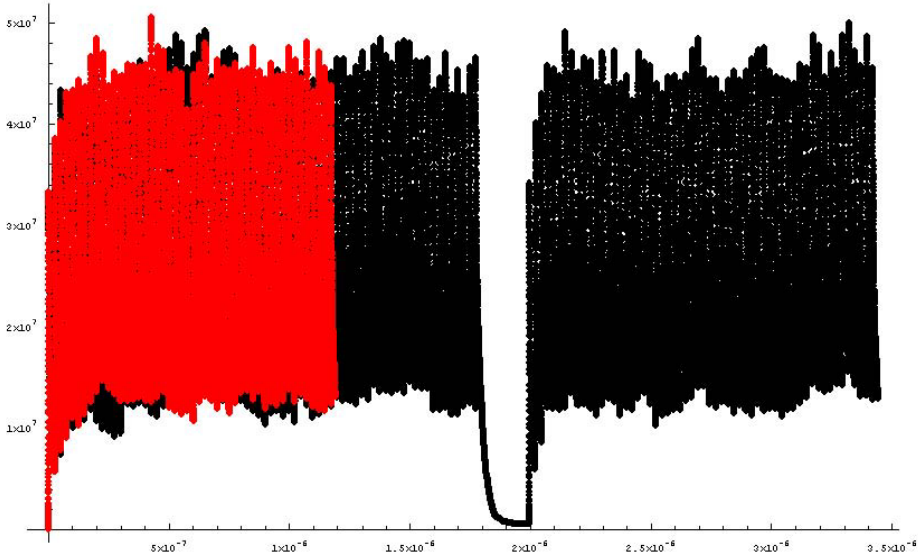
Benchmarking of "quasi-static" WARP/POSINST single-bunch instability simulations and HEADTAIL results in a field-free region and with 0.647 T dipole field using 10 ($\rho=10^{12}$ m^{-3}), or 100 ($\rho=10^{13}$ and 10^{14} m^{-3}) electron-beam interactions points per turn in both codes, for parameters similar to LHC at injection, without synchrotron motion [J.-L. Vay, K. Sonnad, 2008]

ECLOUD versus ECLOUD, 2008

DESY ECLOUD vs. **CERN ECLOUD**



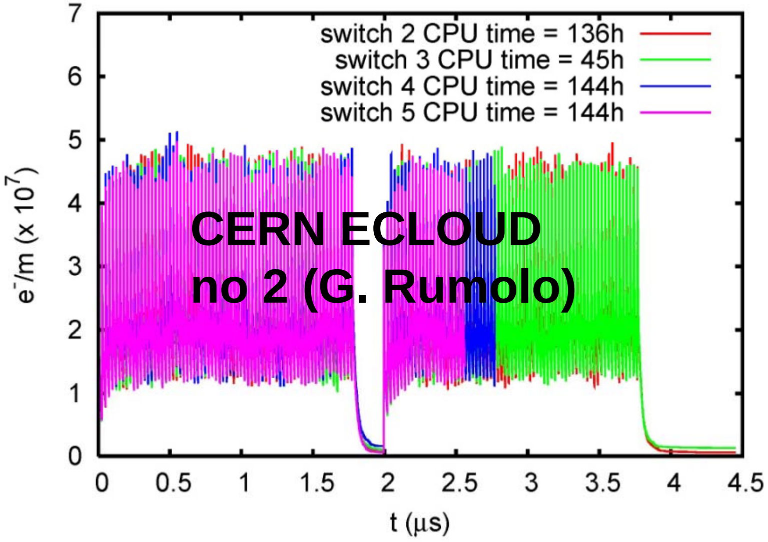
INFN ECLOUD vs. **CERN ECLOUD**



simulations for LHC quadrupole

Humberto Maury Cuna, CINVESTAV, Mexico & CERN summer student; Giovanni Rumolo, CERN; Rainer Wanzenberg, DESY; Theo Demma, INFN-LNF; summer/fall 2008;

for dipole and drift all versions agree

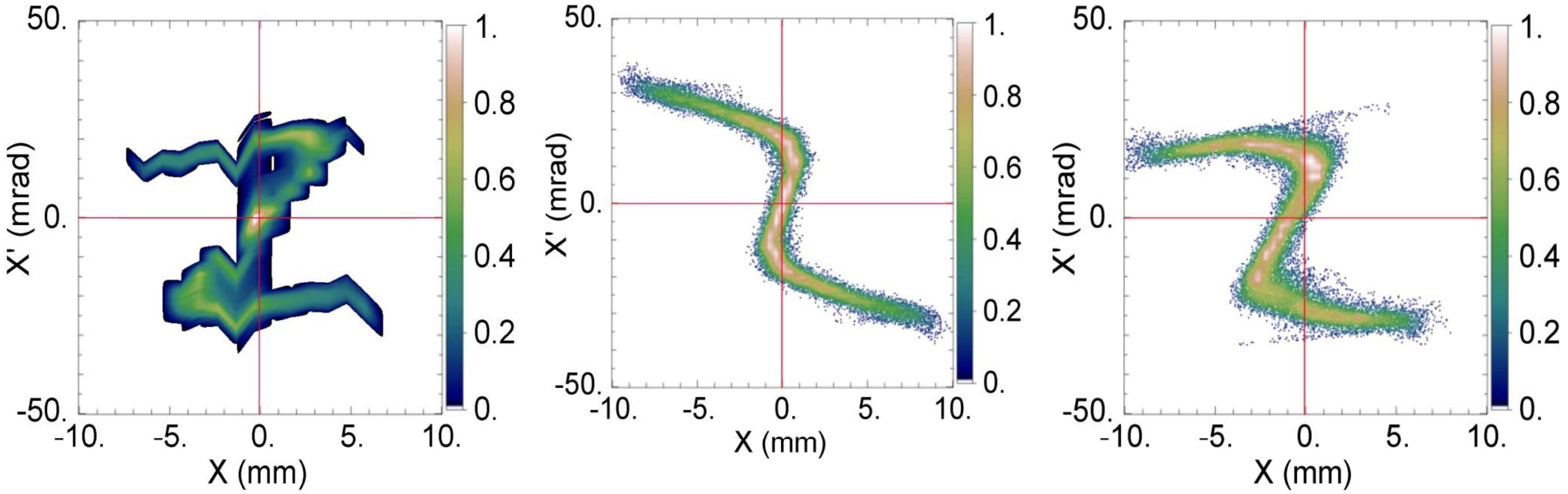


CERN ECLOUD no 2 (G. Rumolo)

benchmarking

(2) code vs beam

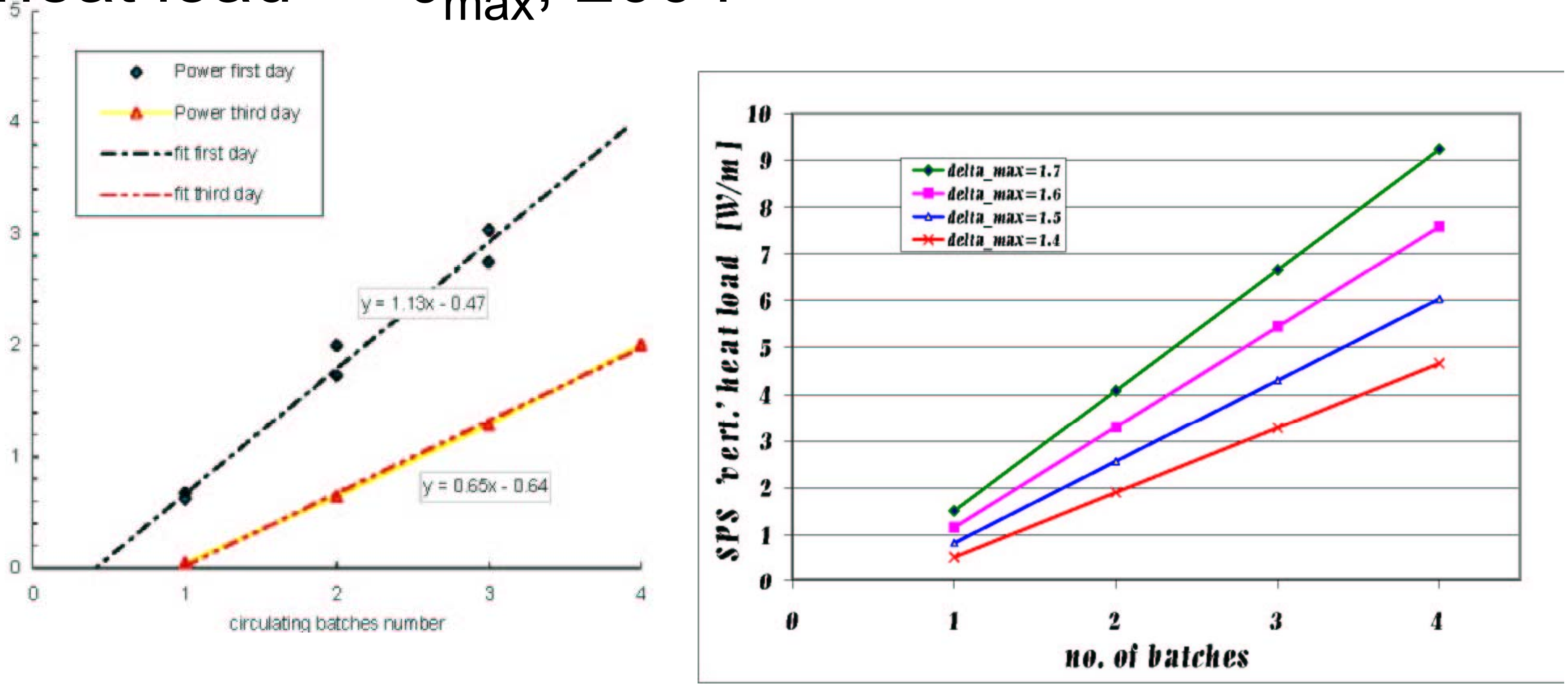
initial beam distribution



Transverse phase-space distribution at the exit of HCX quadrupole channel: **measured** (left) & **simulated** with the **WARP/POSINST** code **for a semi-Gaussian initial distribution** (center); simulated with the same code, but using **measured initial distribution** (right)

M. Furman,J. Qiang, G. L. Sabbi, P.A. Seidl, J.-L. Vay, LBNL, USA; A. Friedman, D.P. Grote, LLNL, 2006.

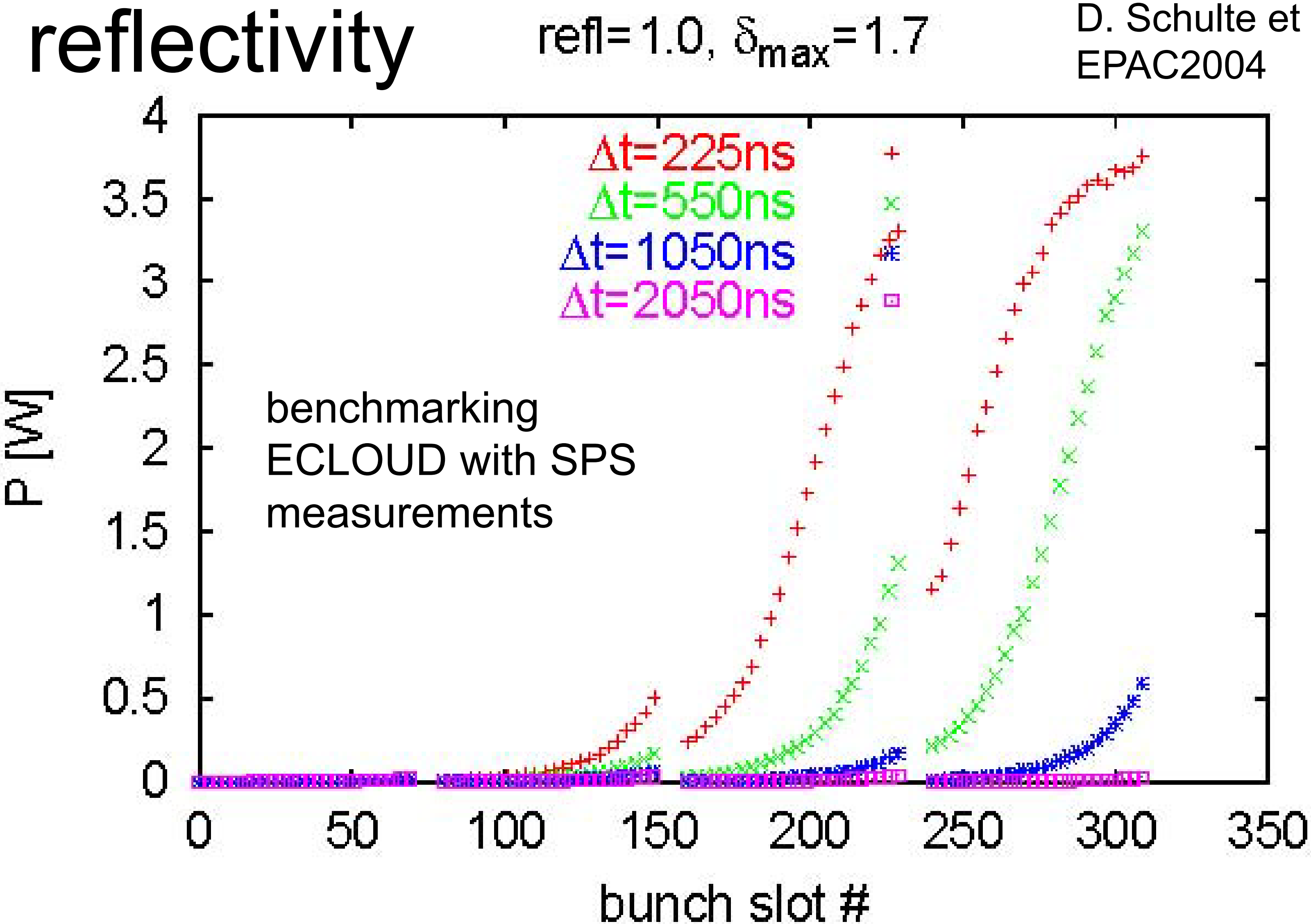
benchmarking ECLOUD with SPS measurements; heat load → δ_{max}, 2004



Left: evolution of the deposited power in W/m inferred from the vertical momentum spectrum measured during the 2003 scrubbing run with $N_b=10^{11}$ protons. Right: simulation of the same measurement [V. Baglin, F. Zimmermann et al, EPAC'04]

e- reflectivity

D. Schulte et al,
EPAC2004

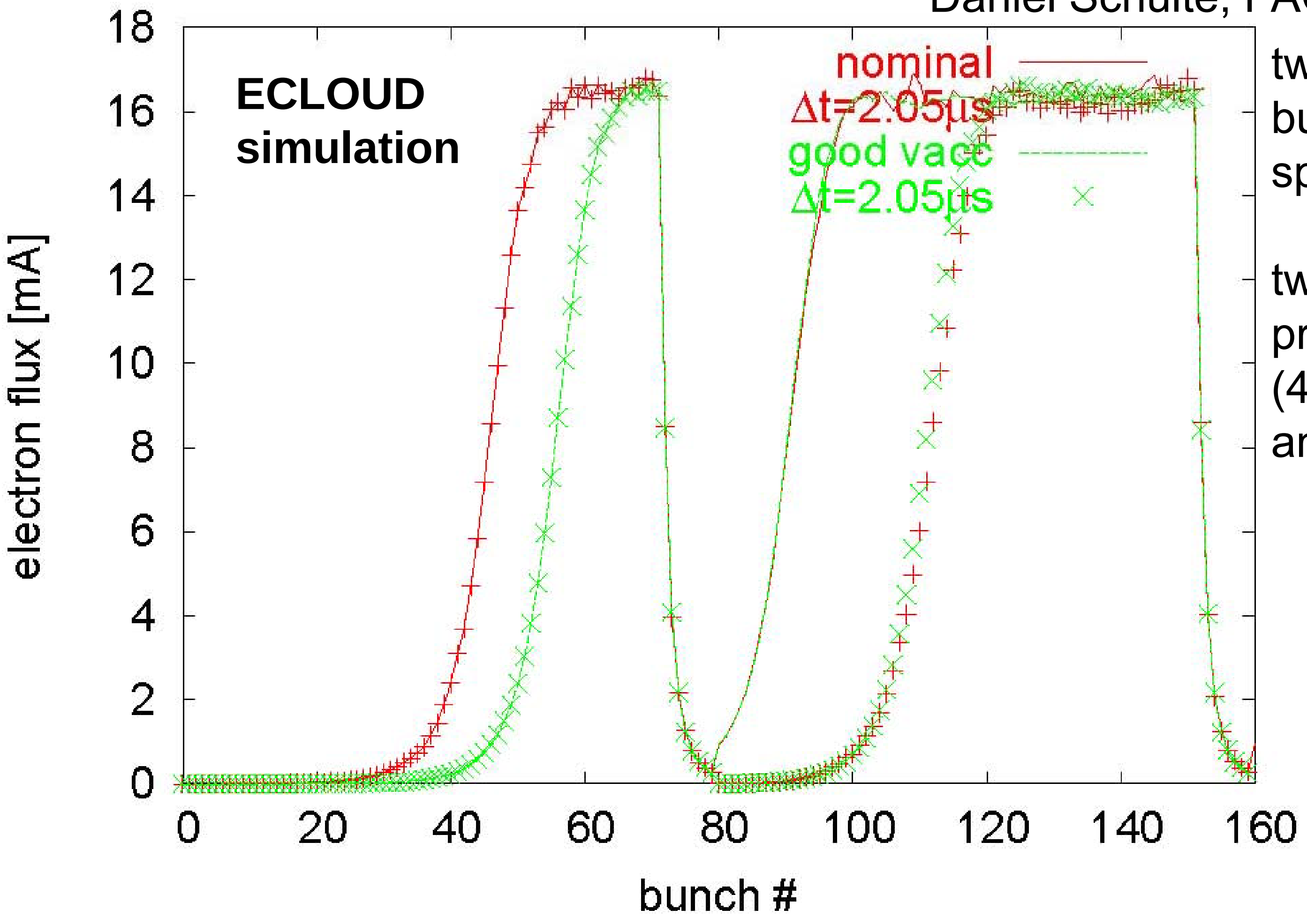


benchmarking
ECLOUD with SPS
measurements

For a bunch spacing 75 ns and intensity close to the nominal LHC value a significant electron flux existed for four bunch trains and the nominal train distance of 225 ns. Increasing the train distance to 550 ns reduced the activity strongly while at 1050 ns it was invisible. Simulations using δ_{max} = 1.7 (the value expected at this moment in time) & reflectivity = 1 could reproduce this behaviour

benchmarking ECLOUD with SPS measurements

Daniel Schulte, PAC05



two different bunch train spacings

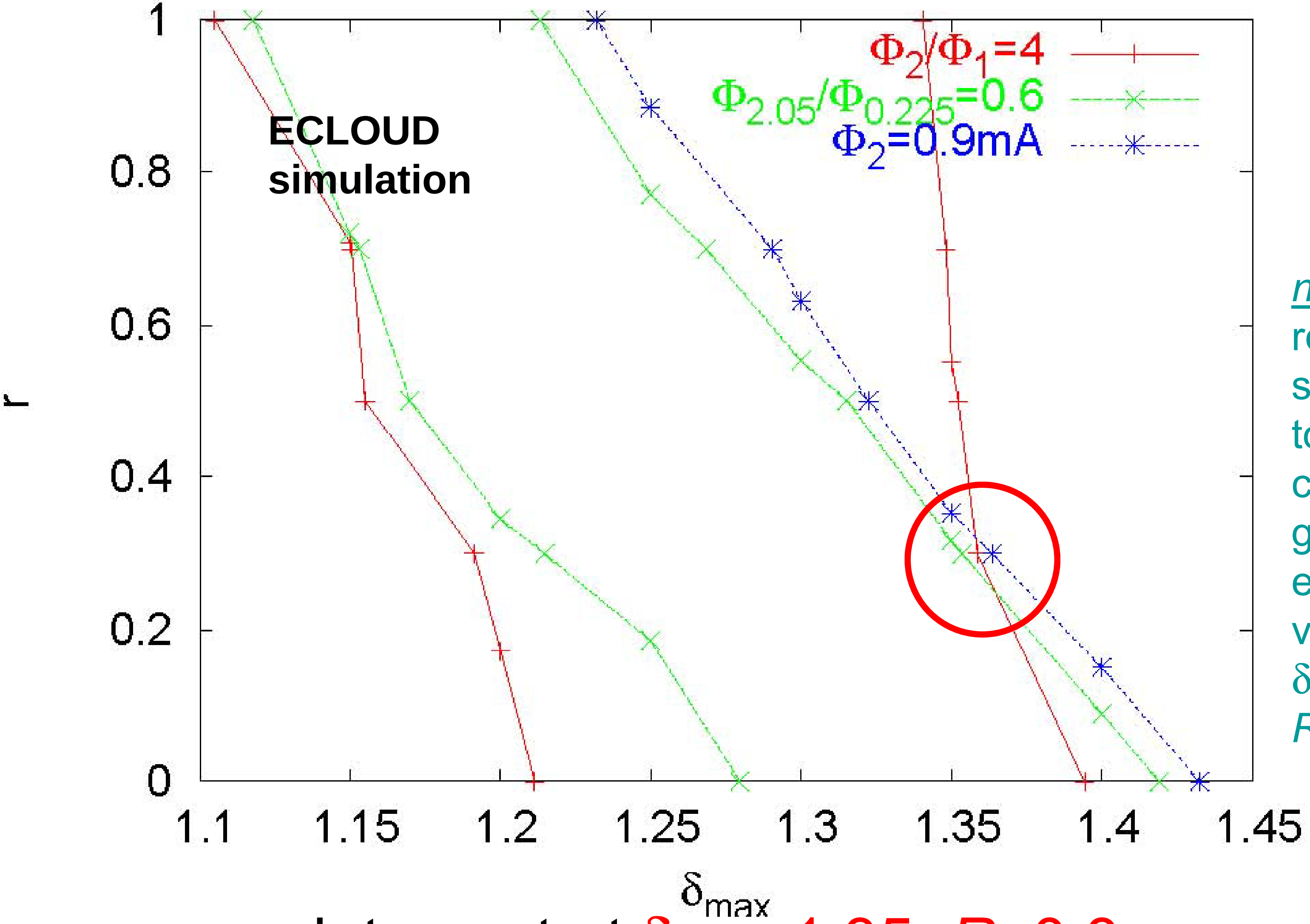
two different pressures (40 ntorr and 4 ntorr)

surface conditions (δ_{max}, *R*) and detector properties are uncertain

→ constrain parameters by **benchmarking multiple measurements**

→ change **distance between trains** & use **relative measurements**

flux: (1) ratio 1&2 trains, (2) two spacings, (3) absolute



Daniel Schulte, PAC'05

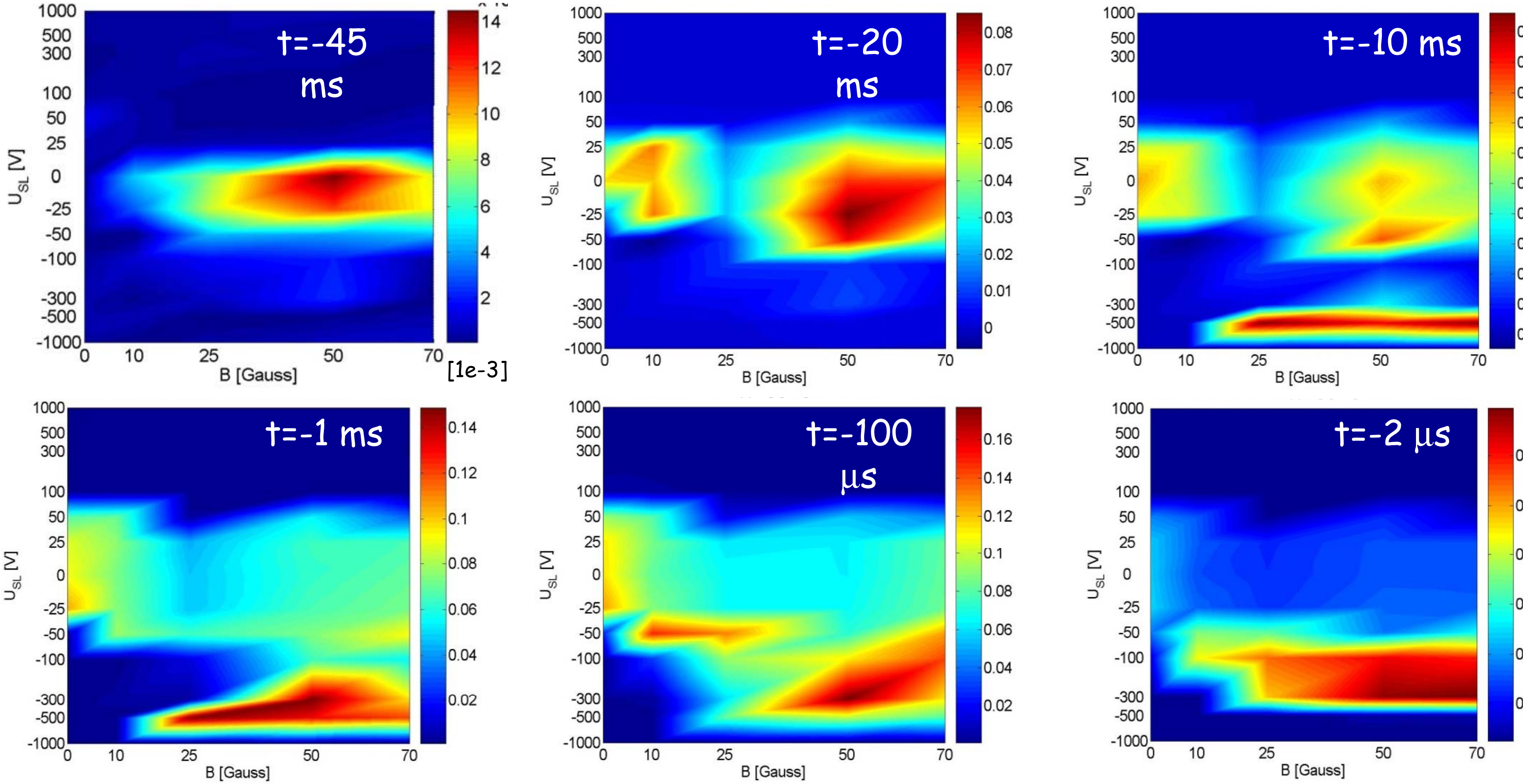
note:
results sensitive to pressure, chamber geometry, etc., variation:
δ_{max}~1.4-1.3
R~0.1-0.7

three curves intersect at δ_{max}=1.35, *R*=0.3;
flux at later times (Φ=0.3 mA) → δ_{max}=1.2 was reached

PS results: “islands” with surviving EC

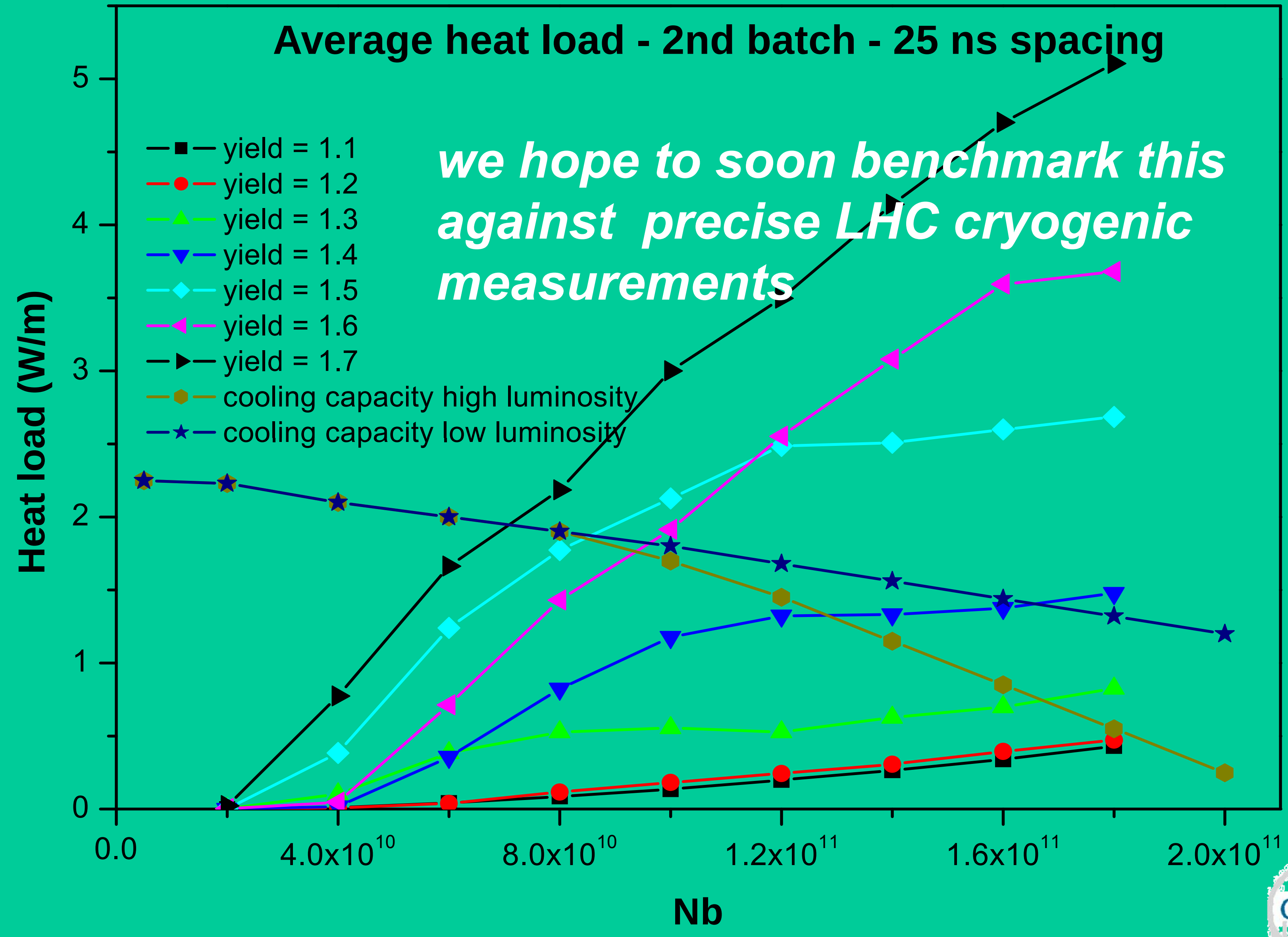
- e- signal plotted at different times before ejection
- e- build-up earlier with magnetic field; e- “islands”
- for large clearing voltages (|U|> 1 kV) e- are suppressed

what does simulation say?



T. Kroyer, E. Mahner, F. Caspers, CARE-HHH BEAM’07; and PRST-AB 11, 094401 (2008).

e- heat load simulated by ECLOUD code



we hope to soon benchmark this against precise LHC cryogenic measurements

Humberto Maury Cuna, CINVESTAV, Mexico, HELEN summer student 2008

Summary

There are **4 e-cloud codes** available **at CERN** and many more in the community

Benchmarking of electron-cloud codes has been ongoing at CERN since ~1997

Both build-up and instability simulation codes can produce **results that vary by factors 3-100**. The differences reflect a **strong sensitivity to modeling details** (elastic reflection, secondary energy spectrum, rediffused electrons, angular dependence)

what next?

model PS data (*B* & *E* fields)
study modulated magnetic fields
LHC heat load?
instability details for feedback

CINVESTAV
Mexico?

model microwaves (+ B field + beam + e-):

- as diagnostics tool
- as possible cure
- as e-cloud enhancer
- as “magnetron effect”

good topic for collaboration with ESA & co

useful links:

ECM'08 workshop

http://indico.cern.ch/conferenceDisplay.py?confId=42645

LHC electron cloud web site:

http://ab-abp-rlc.web.cern.ch/ab-abp-rlc-ecloud/

CARE-HHH web site

http://care-hhh.web.cern.ch/CARE-HHH/

CARE-HHH accelerator code web repository

http://oraweb.cern.ch/pls/hhh/code_website.startup