Simulating Electron Cloud Instability with POSINST

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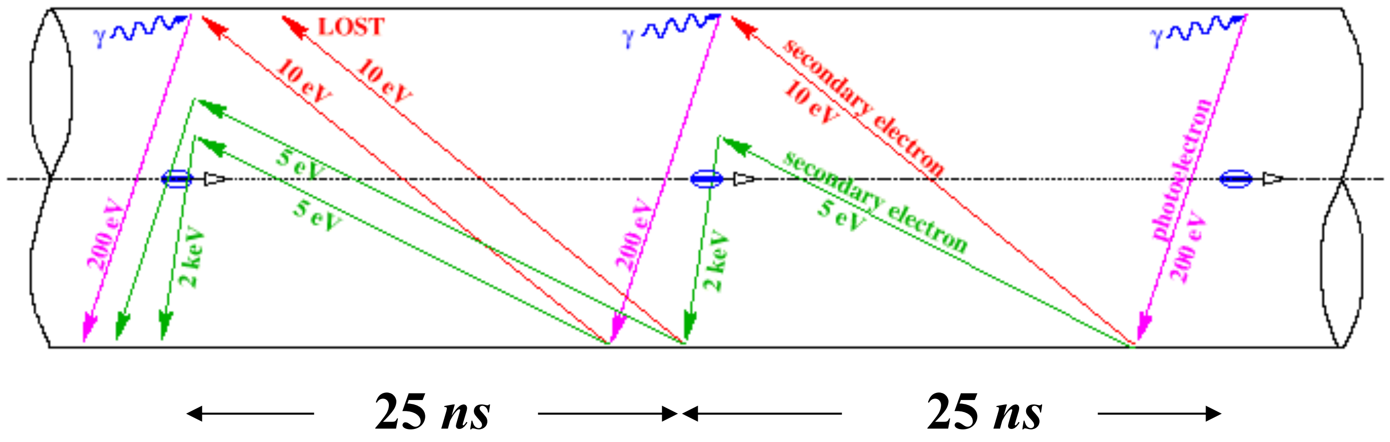
many of the slides are based on Miguel's PAC03 talk

Electron Cloud Instability

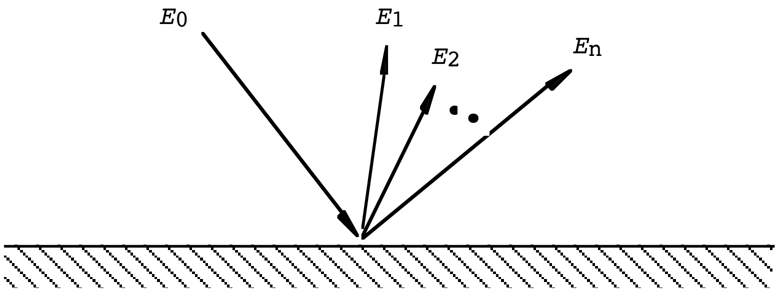
- Unwanted electrons in the vacuum chamber perturb the beam
  - coasting beams: 2-stream instability (BINP, early 60's)
  - bunched beams: beam-induced multipacting (ISR, mid 70's)
  - seen at PF, PEP-II, KEKB, BEPC, PS, SPS, APS, PSR, RHIC
  - expected at LHC, SNS, NLC DRs
  - surface physics effect compounded by beam structure and intensity
  - possible consequences: instability, emittance dilution, vacuum pressure rise, interference with diagnostic instrumentation, excessive power deposition
  - LBNL is an early pioneer in the field of EC simulations and analysis
  - our code POSINST incorporates a detailed model for secondary e^- emission
- Our main focus:
  - simulations for LHC, SPS, and NLC damping rings
  - identify important ingredients; mitigating mechanisms
  - code calibration: APS, PSR and SPS (lots of dedicated measurements)
- LBNL was the lead organizer of the "ECLOUD04" ICFA workshop
  - Napa, April 19-23, 2004
  - co-sponsored by ICFA, LBNL, CERN, ORNL and SNS
  - http://www.cern.ch/icfa-ecloud04

Cartoon of EC formation (LHC Case)



- Proton beam radiates
- Radiated photons release photoelectrons
- Photoelectrons are kicked by the beam and yield secondary electrons
- In general, ionization of residual gas are additional sources of electrons

Secondary e⁻ emission



Three main components of emitted electrons:

elastics: $\delta_e = \frac{I_e}{I_0}$,

rediffused: $\delta_r = \frac{I_r}{I_0}$,

true secondaries: $\delta_{ts} = \frac{I_{ts}}{I_0}$

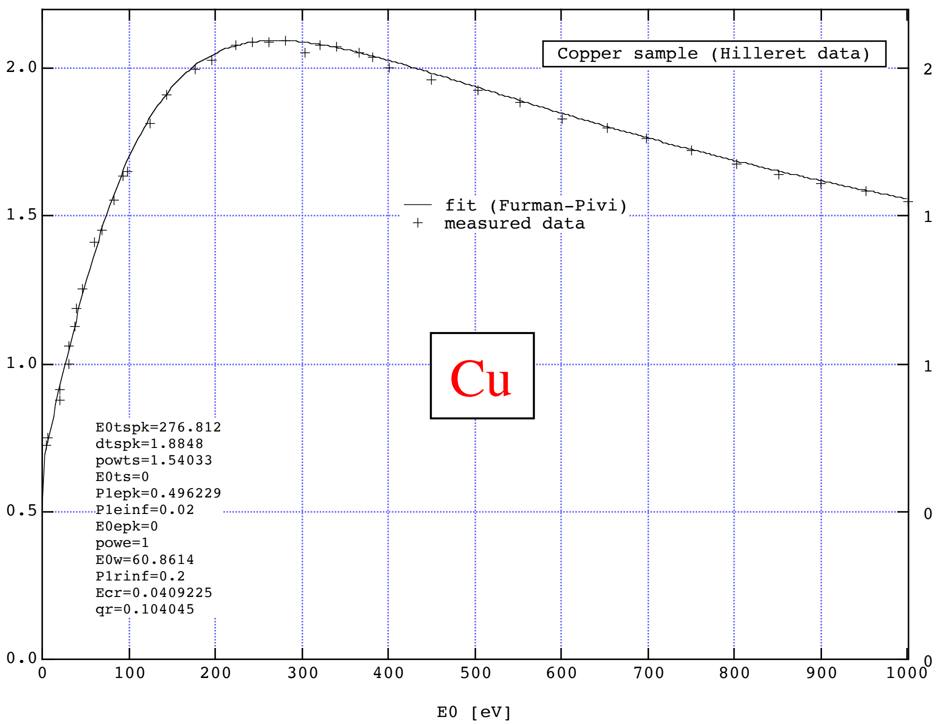
NB: $d\delta/dE$ is different for e, r and ts!!!

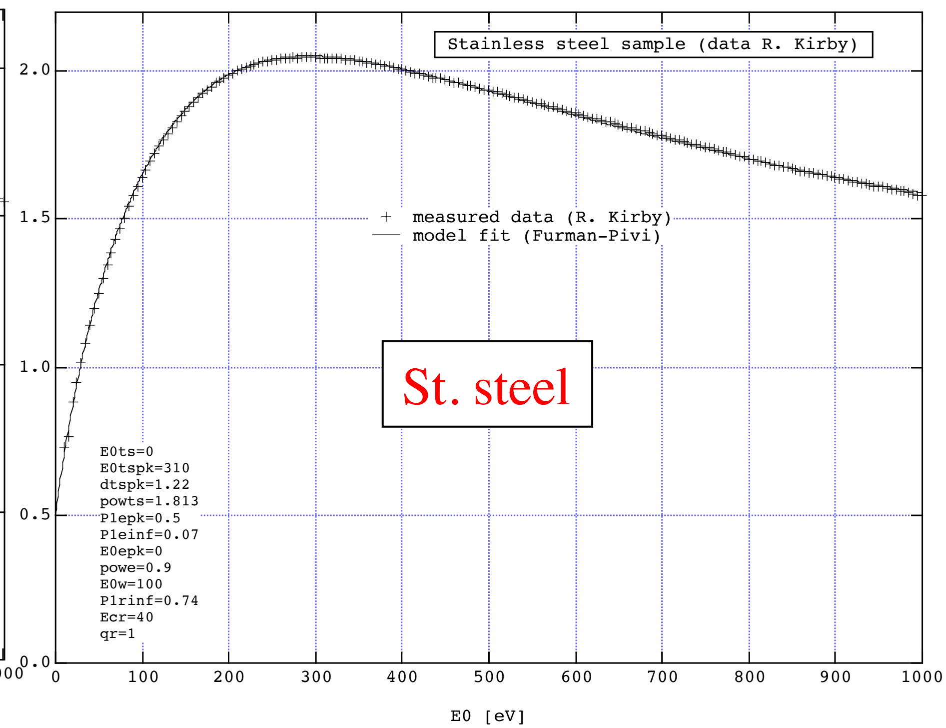
Monte Carlo code, with kicks from beam and space charge from cloud itself; beam is fixed

Simulation (Furman-Pivi, PRSTAB **5**, 124404):

- event=one electron-wall collision
- instantaneous generation of n secondaries (or absorption)
- include E_0 and θ_0 dependence
- detailed phenomenological model for δ and $d\delta/dE$

Two sample measurements of the SEY





- caveat: samples not fully conditioned!

(N. Hilleret; R. Kirby)

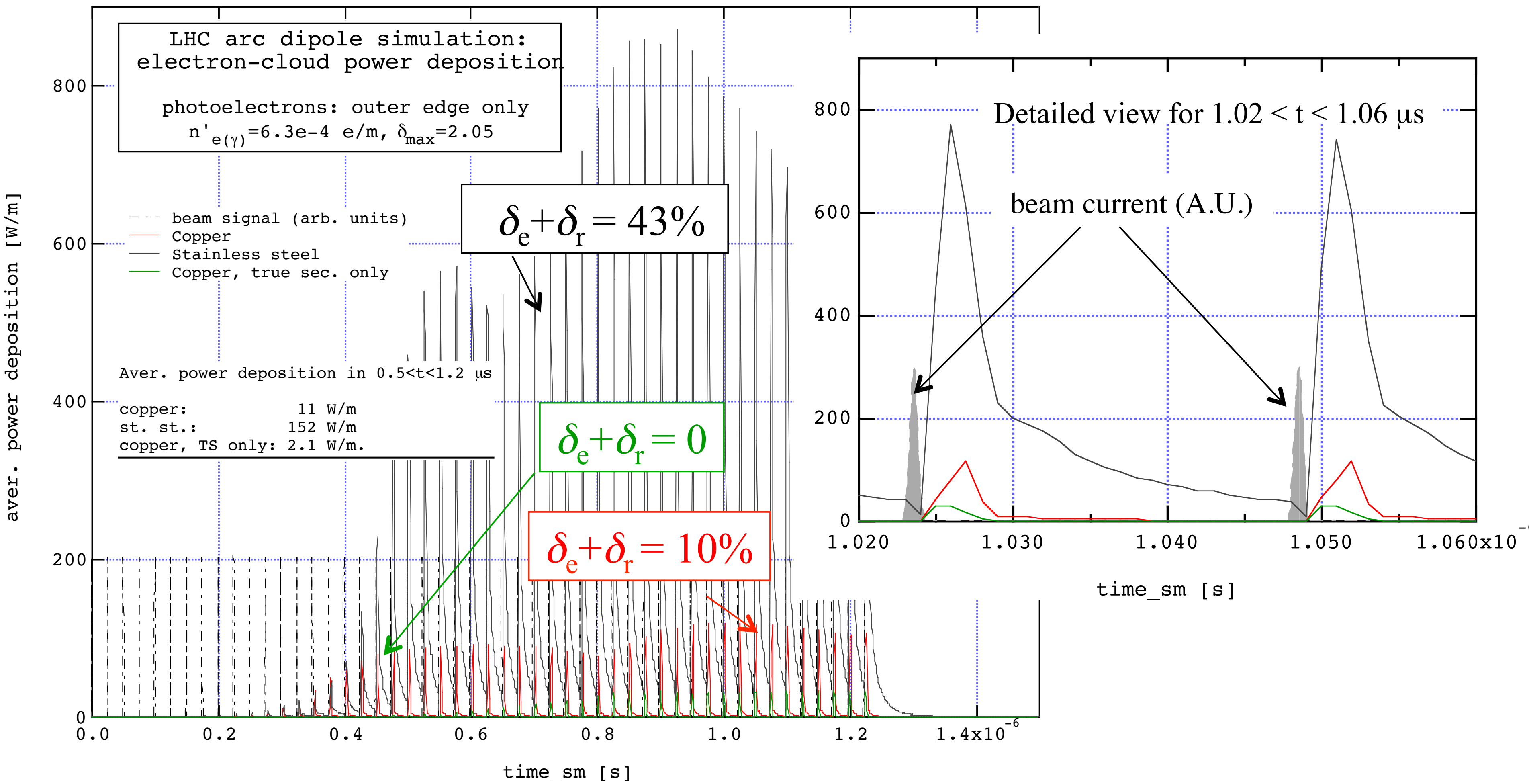
Example: electron-cloud simulations for the LHC

- Main issue: power deposition on vacuum chamber.
  - could overwhelm the cryogenics system if not mitigated
  - main goal of simulations: detailed understanding of effects from the secondary electron emission process off the vacuum chamber surfaces
  - work in close contact with LHC personnel (LHC Vacuum Group and AP)
  - simulation benchmarking against measurements at SPS
  - EC is a likely performance-limiting issue

- Current conclusion:
  - power deposition is sensitive to details of the secondary e^- emission process
  - not completely understood
  - more work is critically needed:
    - improved simulations
    - better input data for the simulations

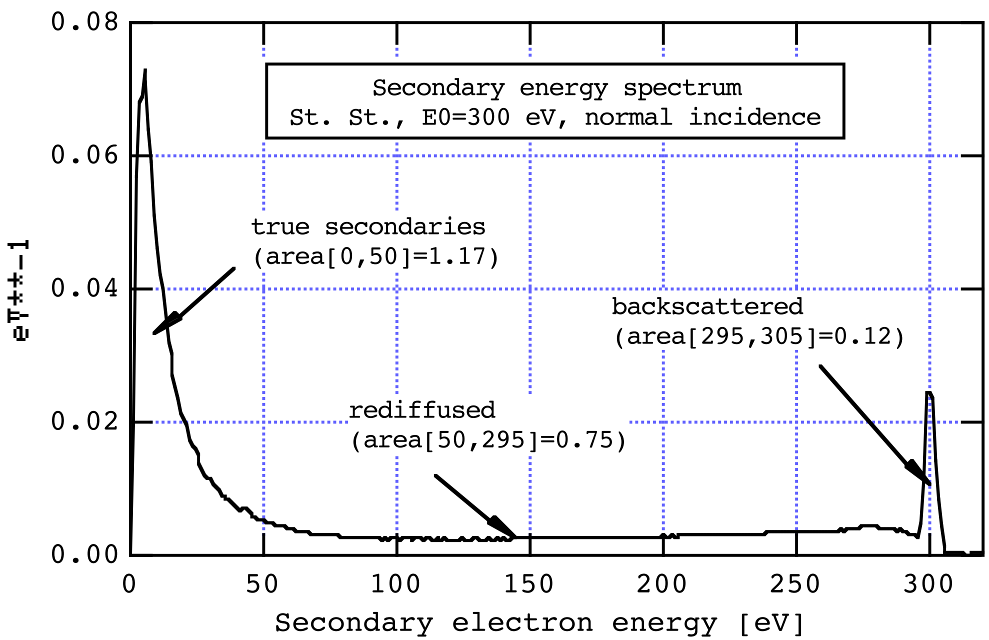
Example: sensitivity to details of secondary emission

POSINST: Simulated power deposition (W/m) vs. time in an LHC arc dipole
(for peak SEY=2.05, on the “pessimistic” side)



Sample spectrum: $d\delta/dE$

- Depends on material and state of conditioning
  - St. St. sample, E_0=300 eV, normal incidence, (Kirby-King, NIMPR A469, 1 (2001))



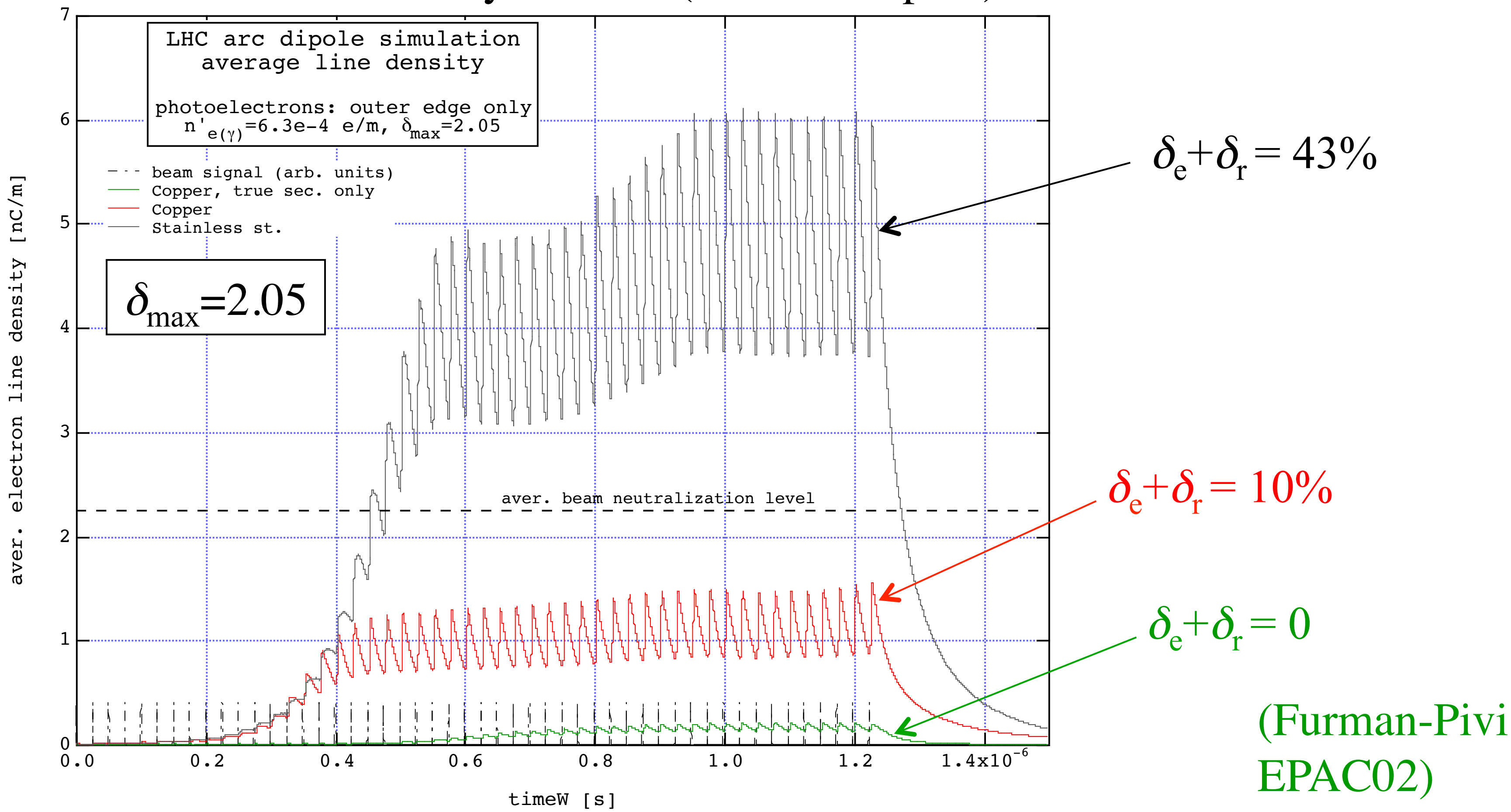
st. steel sample	Cu sample
$\delta = 2.04$	$\delta = 2.05$
$\delta_e = 6\%$	$\delta_e = 1\%$
$\delta_r = 37\%$	$\delta_r = 9\%$
$\delta_{ts} = 57\%$	$\delta_{ts} = 90\%$
$\delta_e + \delta_r = 43\%$	$\delta_e + \delta_r = 10\%$

- Hilleret's group CERN: Baglin et al, CERN-LHC-PR 472.
- Other measurements: Cimino and Collins, 2003)

Sensitivity to relative ratios of δ_e, δ_r and δ_{ts}: LHC

- LHC simulation δ_{max} fixed at 2.05; $N = 1.05 \times 10^{11}$
- dominated by photoelectrons; $n'_{e(\gamma)} = Y^* n'_\gamma = 6.3 \times 10^{-4}$ e/m

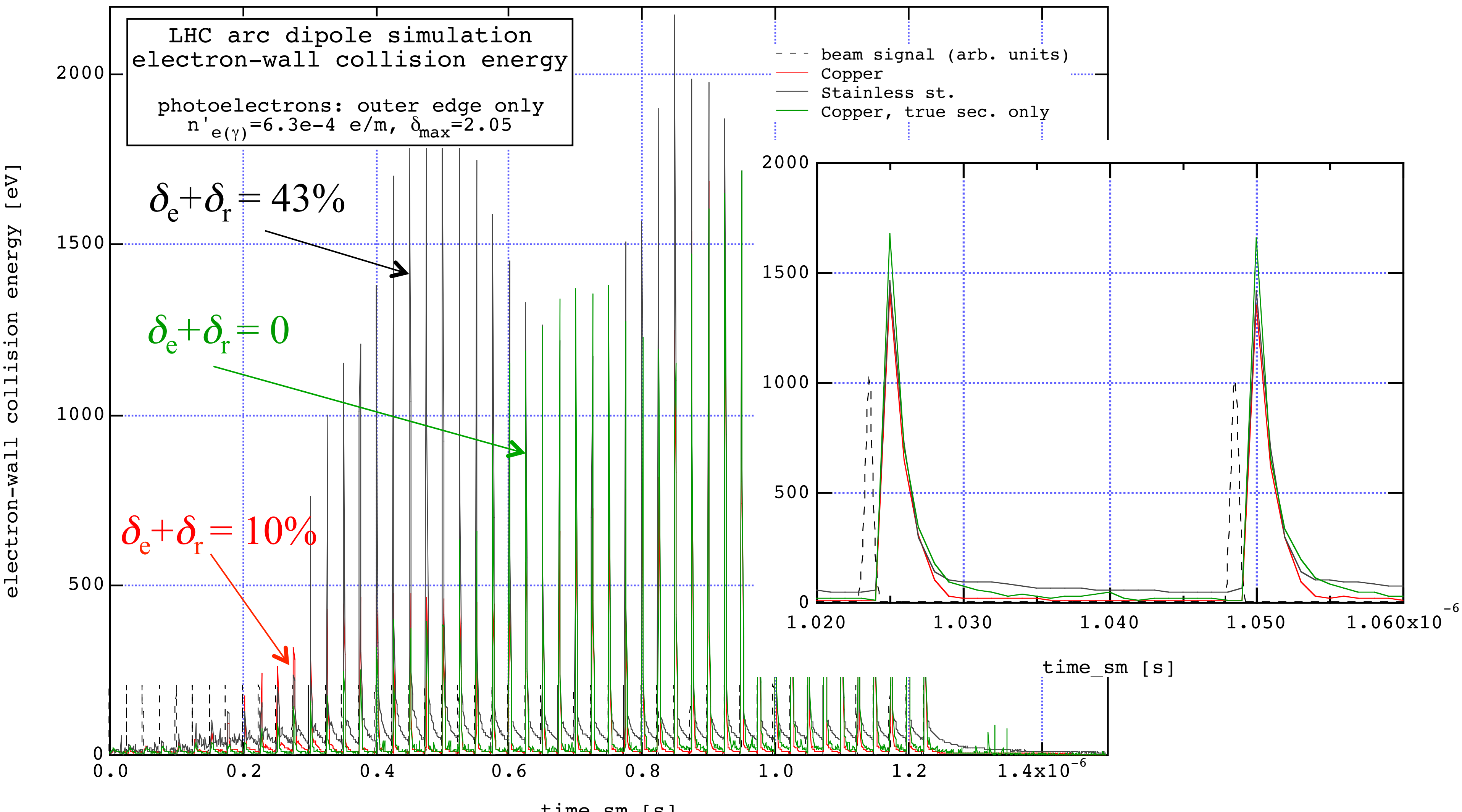
electron line density vs. time (LHC arc dipole)



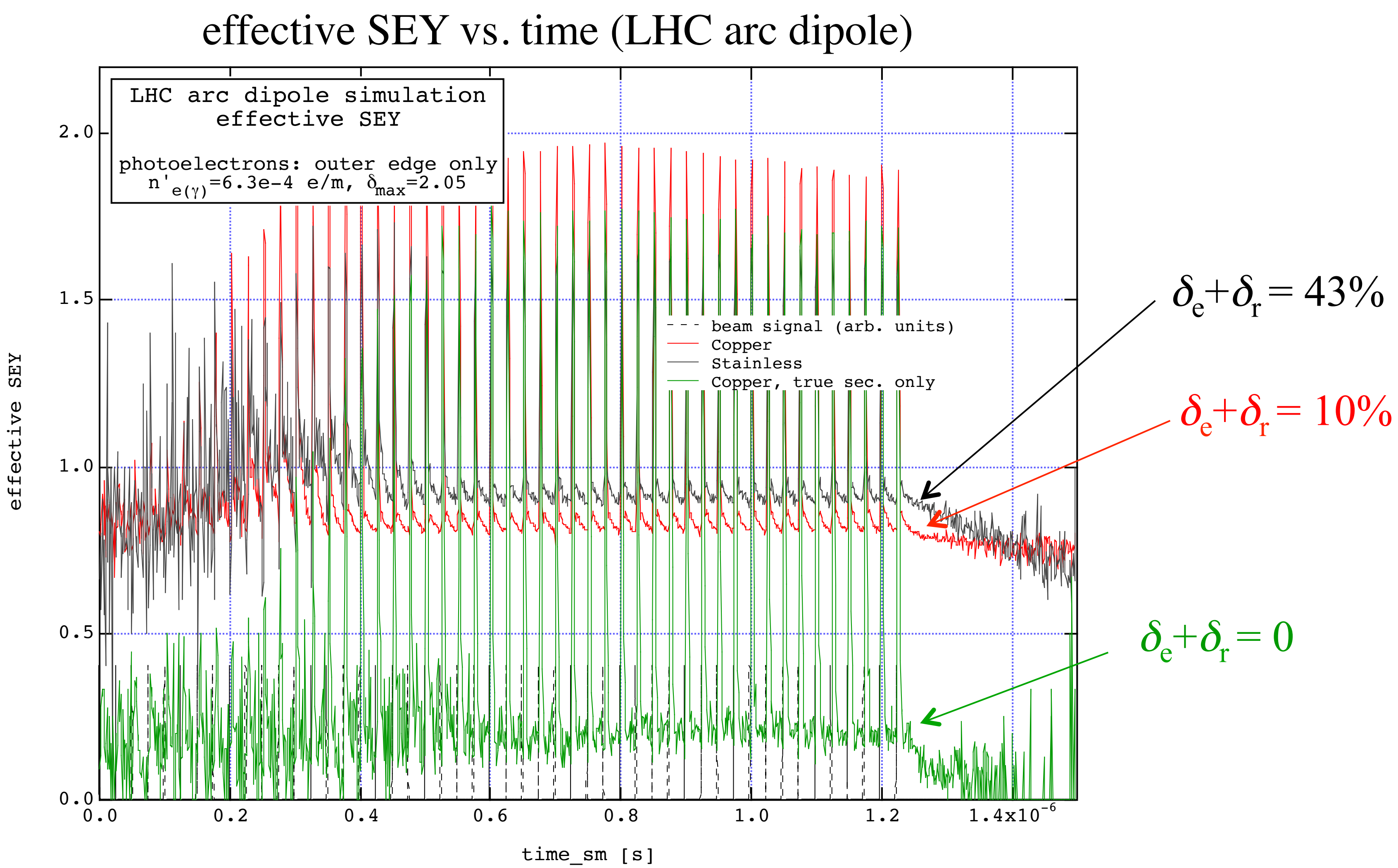
(Furman-Pivi EPAC02)

Sensitivity to relative ratios of δ_e, δ_r and δ_{ts}: LHC

e^--wall collision energy vs. time (LHC arc dipole)

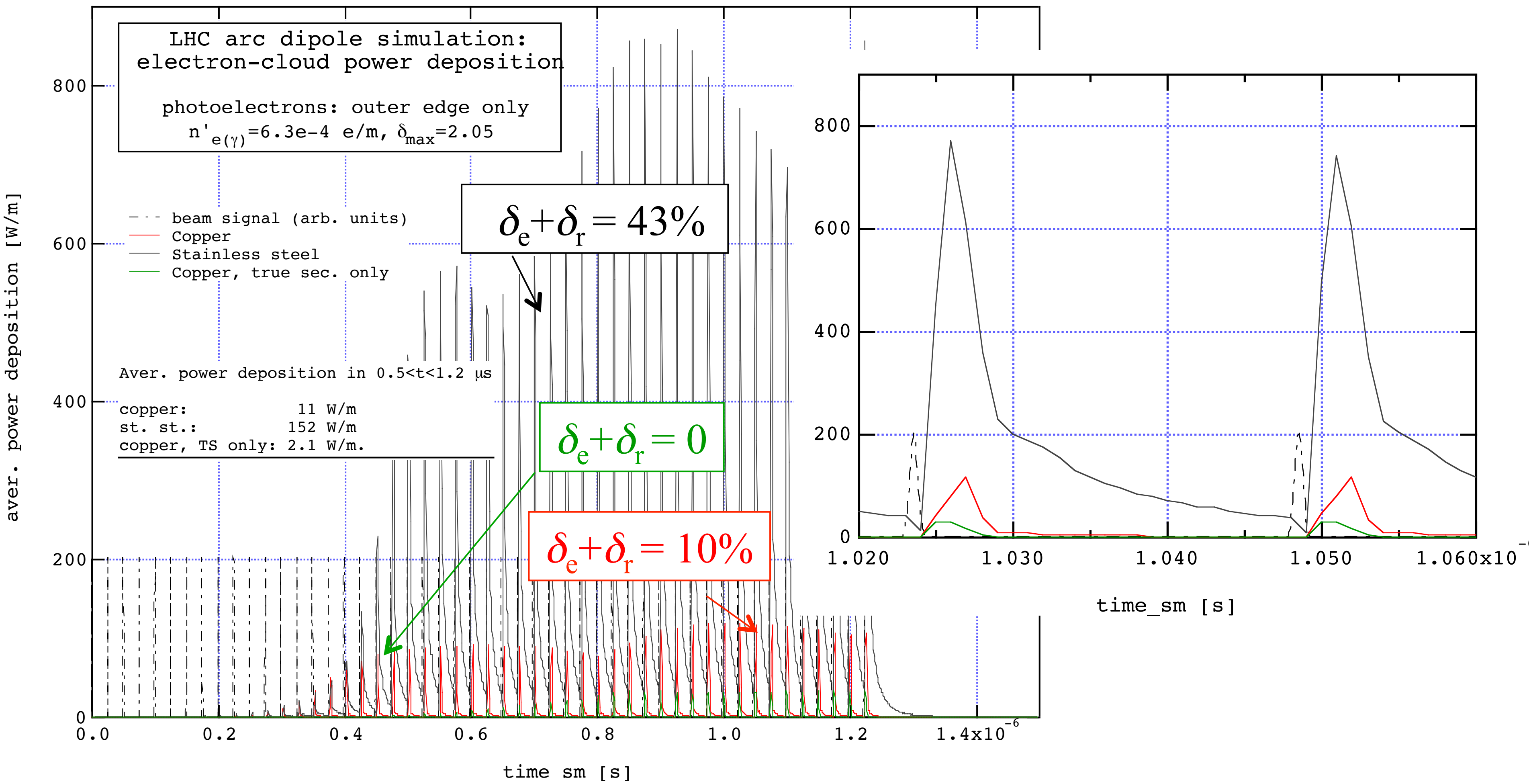


Sensitivity to relative ratios of δ_e, δ_r and δ_{ts}: LHC

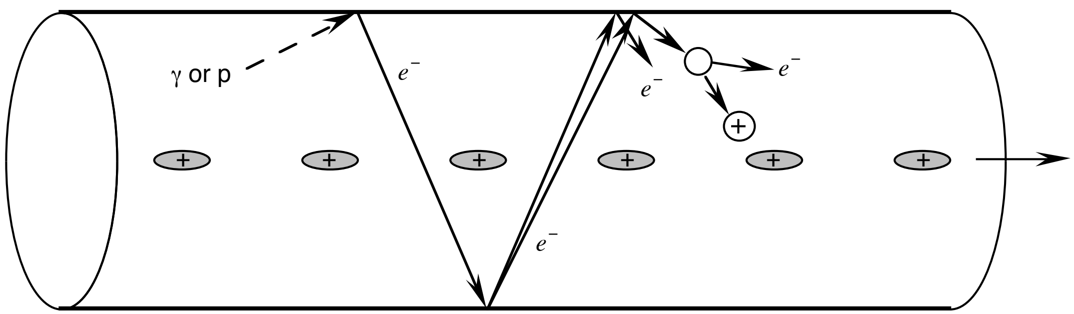


Sensitivity to relative ratios of δ_e, δ_r and δ_{ts}: LHC

power deposition vs. time (LHC arc dipole)



EC formation: beam-induced multipacting (BIM)



- train of short bunches, each of charge $Q=NZe$, separated by s_b
- Δt = e$^-$ chamber traversal time
- b = chamber radius (or half-height if rectangular)

The parameter $G = \dfrac{ZNr_e s_b}{b^2}$ defines 3 regimes:

$$\left(r_e = \frac{e^2}{mc^2} = 2.82 \times 10^{-15}\ \mathrm{m} \right)$$

$$G \begin{cases} < 1 & \text{short bunch spacing } (s_b/c < \Delta t) \\ = 1 & \text{resonant (BIM) } (s_b/c = \Delta t) \\ > 1 & \text{long bunch spacing } (s_b/c > \Delta t) \end{cases}$$

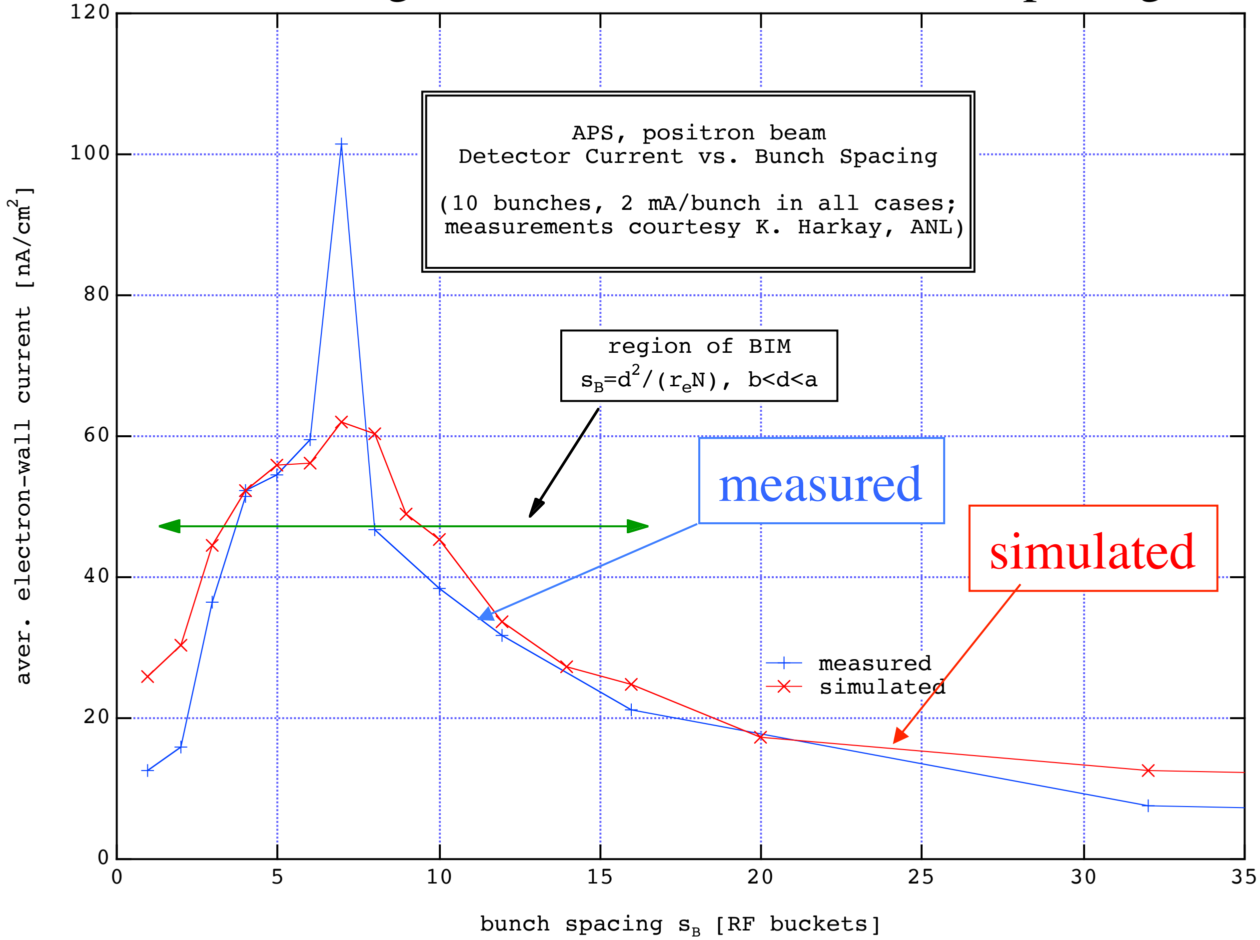
(also for solenoidal field if $T/2=s_b/c$)

If G = 1 and $\delta_{\mathrm{eff}} > 1$, EC can grow dramatically (O. Gröbner, ISR; 1977)

BIM in the APS

- e$^+$ beam, 10-bunch train, field-free region

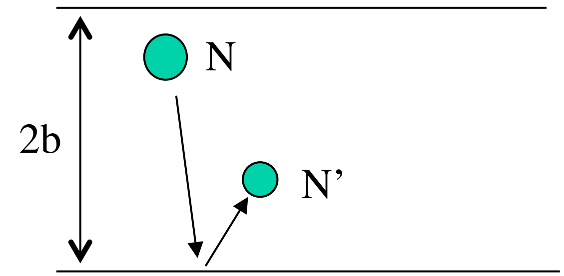
time-averaged e$^-$ flux at wall vs. bunch spacing



(Furman, Pivi, Harkay, Rosenberg, PAC01)

EC dissipation - simplest analysis

- beam has been extracted, or gap between bunches
- field-free region, or constant B field
- assume monoenergetic blob of electrons
- neglect space-charge forces



definition of δ_{eff}: $N' = \delta_{\text{eff}} N$

after n bounces: $N_n = N e^{-n\Delta t/\tau}$

therefore: $\delta_{\text{eff}} = N'/N = e^{-\Delta t/\tau}$

where $\Delta t =$ traversal time$= \dfrac{b}{c}\sqrt{\dfrac{2mc^2}{E}}$ and τ = dissipation time

therefore $\delta_{\text{eff}} = \exp\left\{-\dfrac{b}{c\tau}\sqrt{\dfrac{2mc^2}{E}}\right\}$

simulations show that this formula works to within ~20%

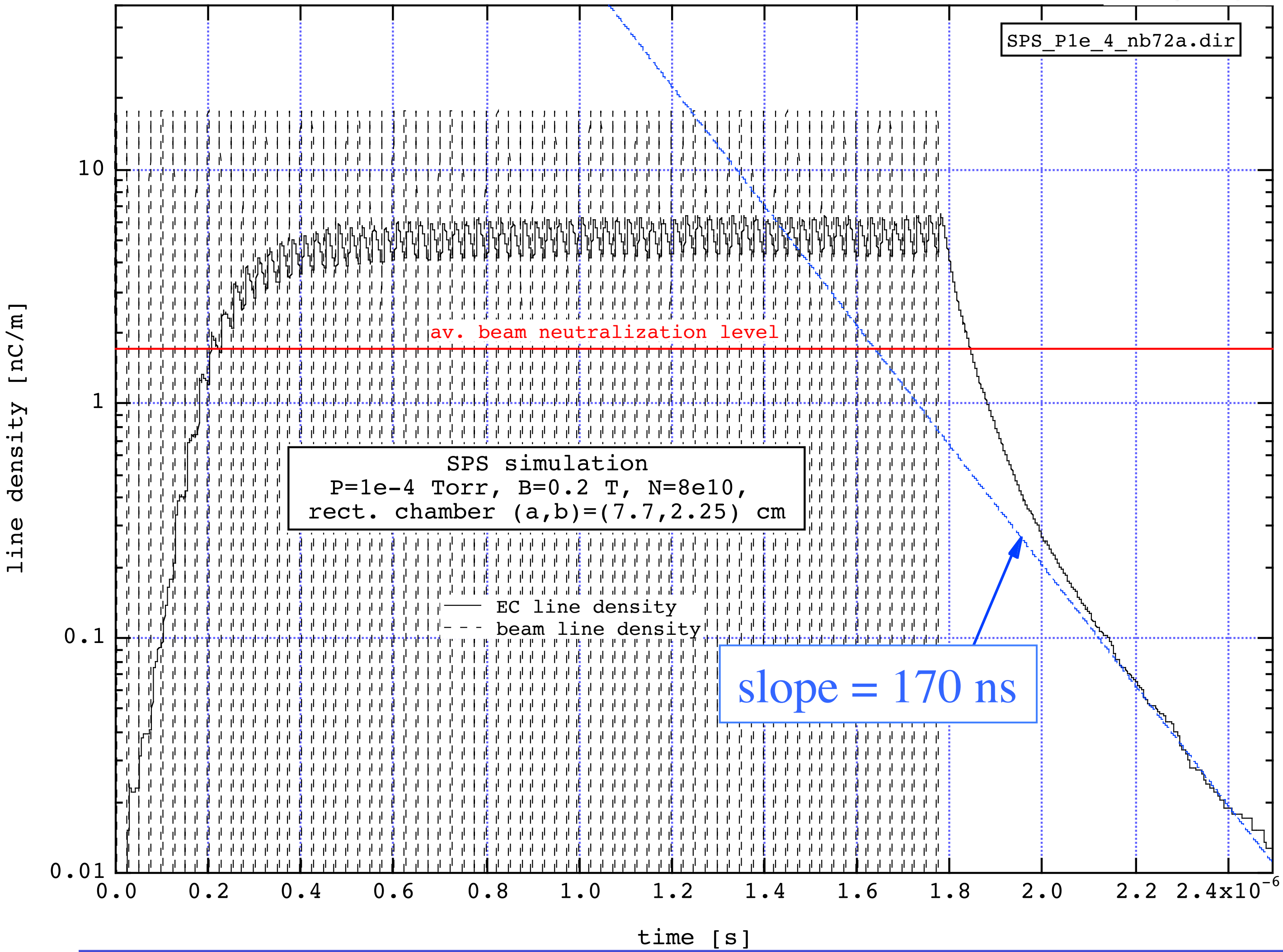
If not monoenergetic and not along a straight line, then

$$\delta_{\text{eff}} = K\int dE\,\rho_E(E)\delta_0(E) = \exp\left\{-\frac{b}{c\tau}\int dE\,\rho_E(E)\sqrt{\frac{2mc^2}{E}}\right\}$$

where K=f(angles)≈1.1–1.2

EC dissipation after beam extraction: SPS simulation

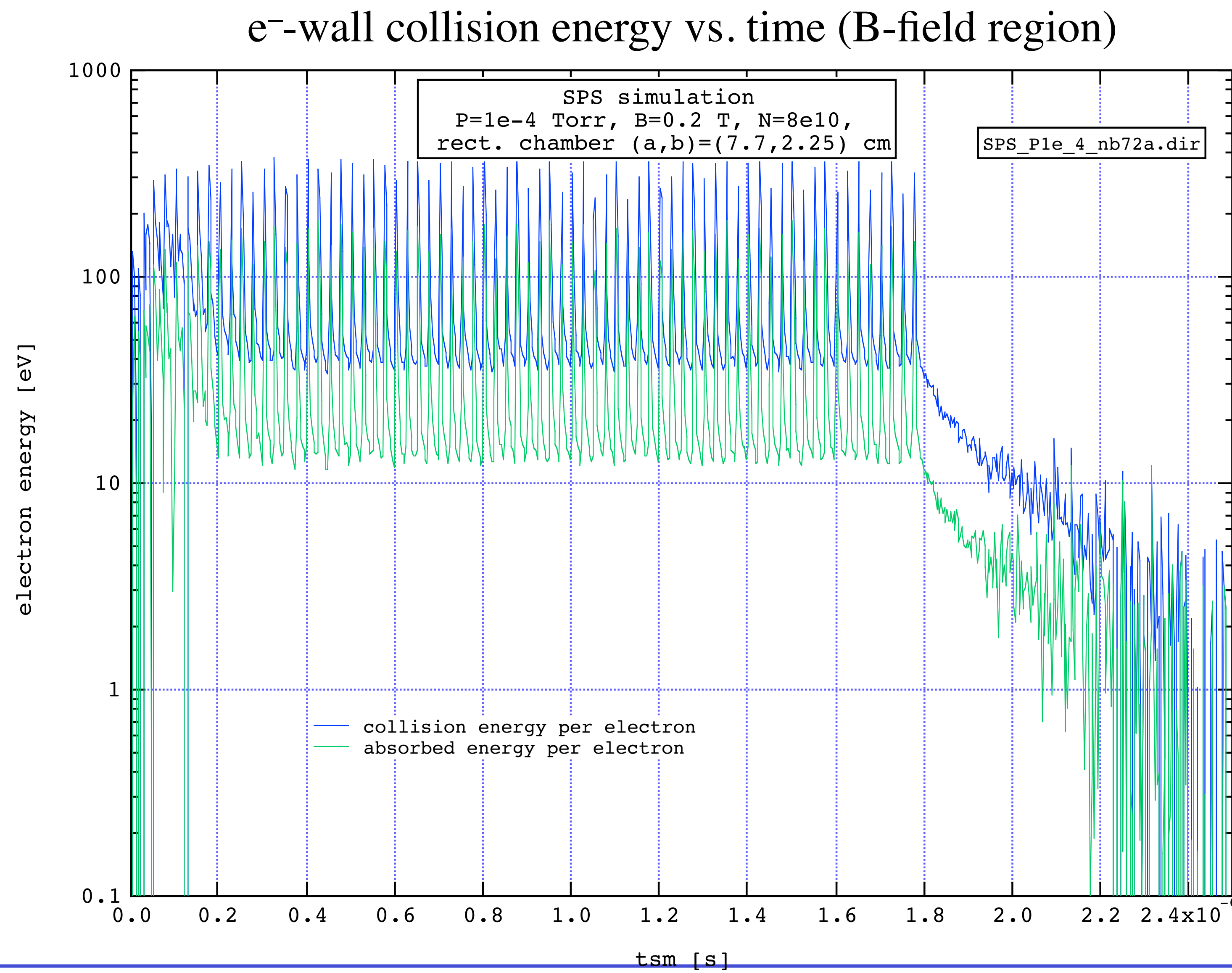
- stainless steel chamber, dipole magnet, $B = 0.2$ T, $N = 8 \times 10^{10}$
- dominant primary process: residual gas ionization; $n'_{e(ion)} = 6.6 \times 10^{-4}$ e/m



NB: p_{vac} is >> nominal

input SEY:
$\delta_{max} = 1.9$
$\delta(0) = 0.5$

EC dissipation after beam extraction: SPS simulation



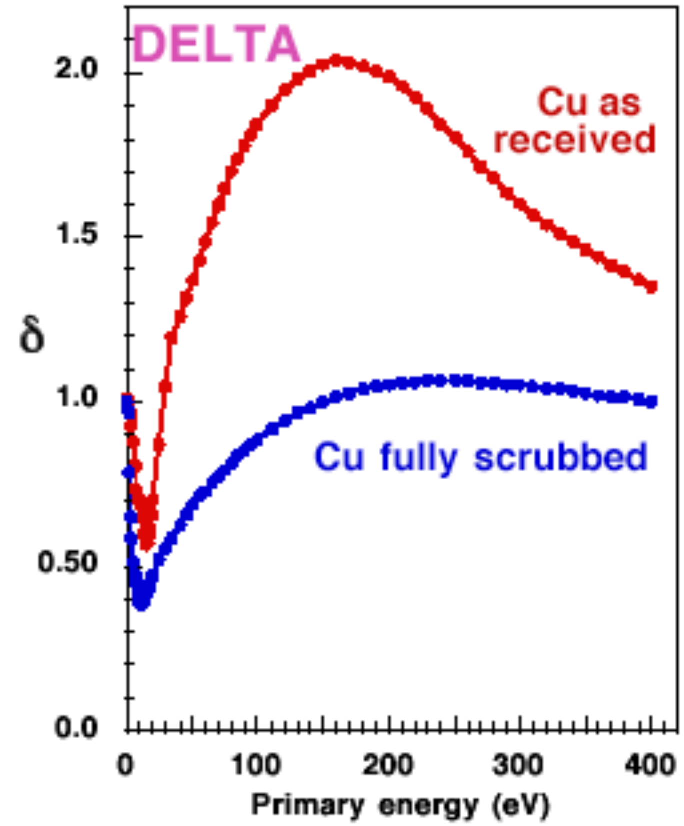
Conditioning effects: beam scrubbing

- Decrease of SEY by e^- bombardment
  - self-conditioning effect for a storage ring: "beam scrubbing"
- SPS EC studies (M. Jiménez; F. Zimmermann):
  - 3+ years of dedicated EC studies with dedicated instrumentation
  - scrubbing very efficient; favorable effects seen in:
    - vacuum pressure
    - in-situ SEY measurements
    - electron flux at wall
  - e^- energy distribution in good agreement with simulations above 30 eV
  - TiZrV coating fully suppresses multipacting after activation

Conditioning effects–contd.

- consistent with bench results for Cu found at CERN!
  - the result $\delta(0)\approx 1$ seems unconventional
  - if validated, it could have a significant unfavorable effect on the EC power deposition in the LHC
    - because electrons survive longer in between bunches

Copper SEY (CERN)



(R. Cimino and I. Collins, proc. ASTEC2003, Daresbury Jan. 03)