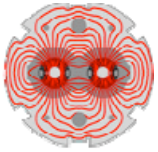


Electron-Cloud Crash Programme and US-LARP

Miguel Furman

LBNL

BEAM'07-CARE-HHH-APD Workshop

CERN, 1-5 October 2007

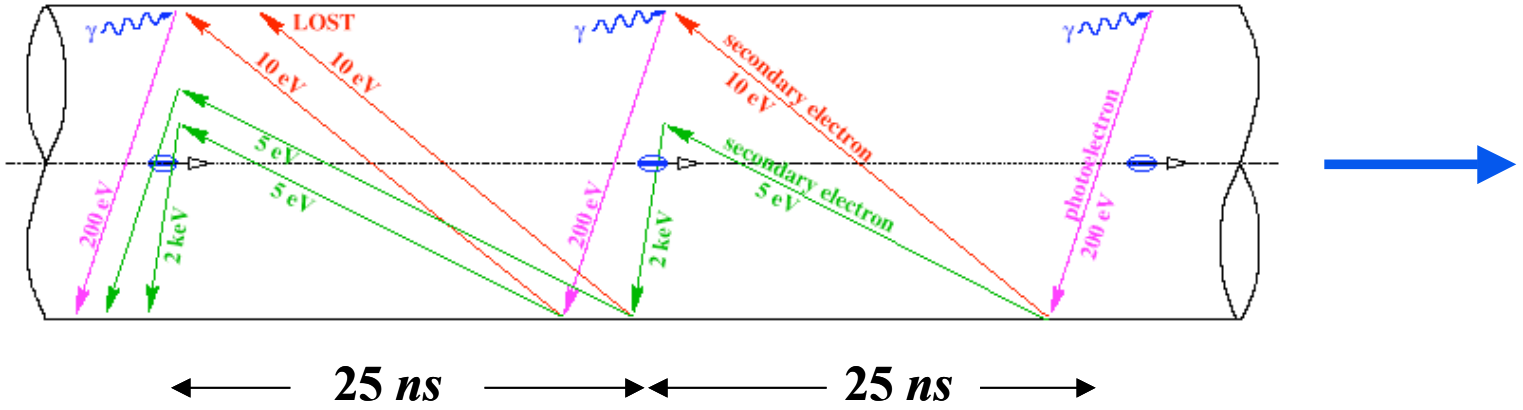
Francesco Ruggiero Memorial Symposium

Francesco Ruggiero, 1957-2007

I met Francesco on many occasions during my career in accelerator physics. I feel honored to have met him and grateful for what I learned from him. I am indebted for his strong and steady support of the LARP program, especially on electron-cloud physics.

What is the electron-cloud effect (ECE)?

LHC cartoon by F. Ruggiero



- Photoelectron density is amplified by secondary electron emission
  - Residual gas ionization may also contribute
- Typical e^- densities: $n_e = 10^{11}$–10^{13} m^{-3} (~a few nC/m)
- Possible adverse consequences: fast pressure rise, multibunch instability, emittance growth, gas pressure rise by desorption, excessive heat load on the chamber walls, particle losses, interference with diagnostics,…
- The ECE is a consequence of the interplay between the beam and the vacuum chamber
  - Beam intensity, bunch shape, fill pattern, geometry and electronic properties of the vacuum chamber
  - Particularly intense for positively-charge beams

Brief history: BCE and CE

- **BCE: effect first seen many years ago in proton storage rings:**
  - — two-stream instabilities (in space-charge compensated coasting beams)
    - BINP, mid 60's: G. I. Budker, V. G. Dudnikov, …
    - ISR, early 70's: E. Keil, B. Zotter, H. G. Hereward,…
    - Bevatron (LBL), early 70's: H. Grunder, G. Lambertson…
  - — beam-induced multipacting (ISR, mid 70's, bunched beams)
    - O. Gröbner, ICHEA 1977
    - multibunch effect; pressure rise instability
  - — trailing-edge multipacting (PSR (LANL), since mid 80's)
    - single-long-bunch effect
      - – beam loss and instability

- **CE: started in early 90's, KEK Photon Factory:**
  - — First observation of an electron-cloud effect in a lepton ring
  - — M. Izawa, Y. Sato and T. Toyomasu, PRL **74**, 5044 (1995)

ECE at KEK Photon Factory

- **Izawa, Sato & Toyomasu PRL 74 (1995):**
  - qualitative difference in coherent spectrum of e^+ vs. e^- multibunch beams under otherwise identical conditions:

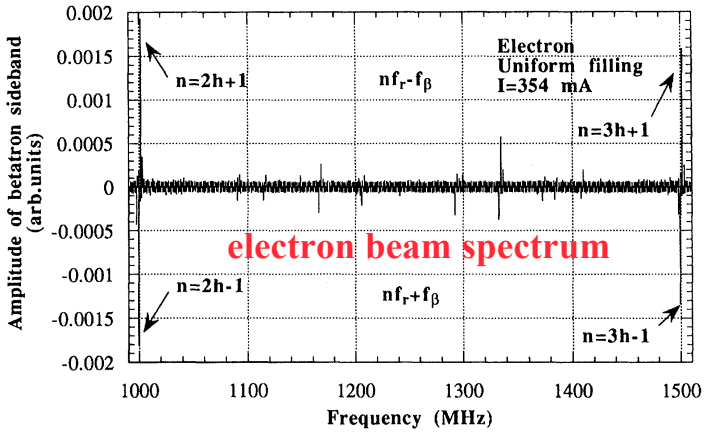


FIG. 1. Distribution of the betatron sidebands observed during electron multibunch operation with uniform filling.

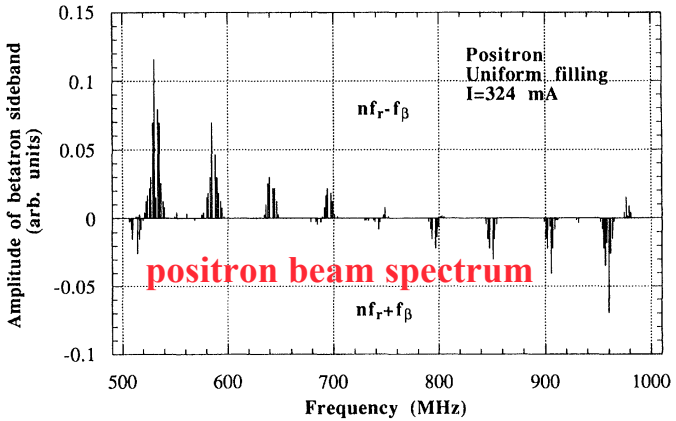
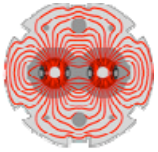


FIG. 2. Distribution of the betatron sidebands observed during positron multibunch operation with uniform filling.

Fast multibunch instability for e^+ beam:

- insensitive to "clearing gap"
- sensitive to bunch spacing
- electrons in the chamber were immediately suspected
- first simulations: K. Ohmi, PRL **75**, 1526 (1995)
- immediate concern for the B factories



More history: EC in the LHC

- 1995-96: concerns from the EC on vacuum by O. Gröbner based on ISR experience
- Early 1997: first simulations by F. Zimmermann that included photoelectrons showed a significant ECE; concern about electron energy deposition

- LHC is the 1st proton machine in which synchrotron radiation is significant:

  critical energy of photon spectrum: $E_{\rm crit} = \frac{3\hbar c}{2\rho}\gamma^3 = 44.1 \text{ eV}$ at 7 TeV

  intensity: $N_{\gamma/p,\rm tot} = \frac{5\alpha\gamma}{2\sqrt{3}}\Delta\theta = 0.4$ photons/proton/bend

  $\Rightarrow$ lots of photoelectrons!

- My involvement: at that time I was simulating the ECE for PEP-II
  - —dominated by secondary electron emission, not by the photoelectrons; secondary emission yield (SEY) of Al is ~2-3
  - —I became involved in the LHC EC studies after talking to O. Gröbner in ~1996

EC in the LHC (contd.)

- Later in 1997 it became apparent, both from CERN and LBNL simulations, that the main concern for the LHC is the energy deposition by the electrons on the vacuum chamber screen

- LHC is first storage ring ever in which this is a potential problem

- Initial estimates for heat load were ~several W/m
  - Exceeds the available cooling capacity of the LHC cryogenic system.
  - Cryogenic system was designed before the effect was discovered
  - At face value, would have to cut N_b or increase s_b by factors of ~a few to accommodate heat load

    ⇒ **operational limitation!**

- This was the motivation of the "Electron-Cloud Crash Program" at CERN

- And of the LARP involvement in LHC EC research

LHC EC crash program (1997)

Large Hadron Collider Project **LHC Project Report 166**

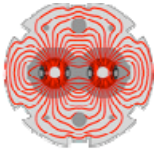
Electron Cloud in the LHC

Francesco Ruggiero*

Abstract

A theoretical and experimental crash program has been set up at CERN to investigate electron cloud effects in the LHC. In particular, I report about recent estimates of the critical secondary-emission yield, versus bunch population and bunch spacing, and ongoing multipacting tests with a coaxial resonator in a strong magnetic field.

ICFA mtg. on e^+e^- factories, Frascati, Oct. 1997.



Accomplishments

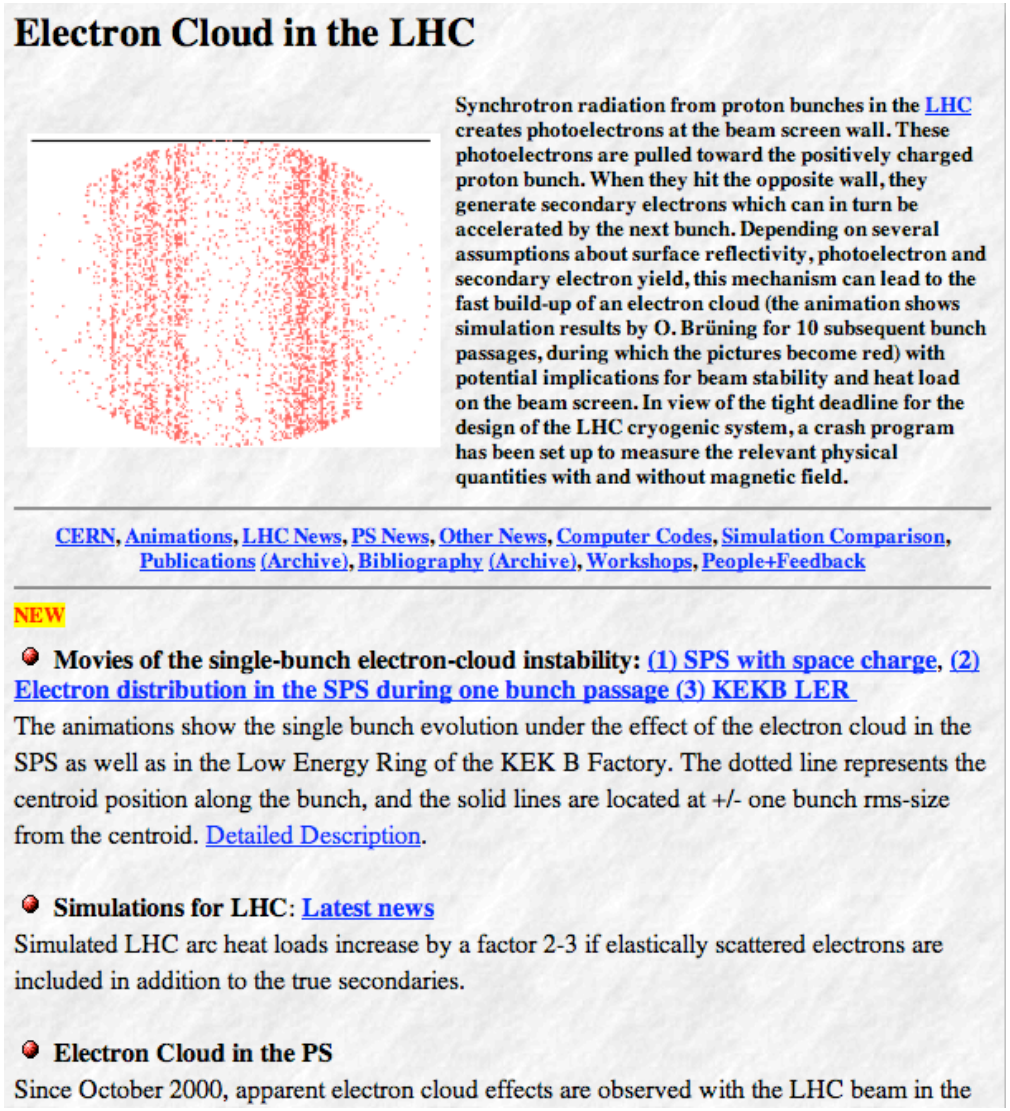
either directly from, or inspired by, the LHC crash program

- Careful measurements of quantum efficiency and SEY in technical materials
- Identification of TiZrV as a novel low-SEY coating
- Development and deployment of several types of in-situ electron detectors
- Measurement of correlation of vacuum pressure with electron activity
- Development of new mitigation mechanisms (eg., grooved surfaces, high chromaticity mode, multibunch feedback for SPS in x-plane,…)
- First observations of the EC with LHC beam in SPS (1999) and PS (2001)
- Practical demonstration of self-conditioning of the ECE at SPS (~few days)
- Measurement of EC flux and energy spectrum at SPS and RHIC with these detectors
- Development of careful secondary emission models
- Understanding via analytical models
- Great developments in simulation codes, validation, and benchmarking
- Prediction of ECE density and power deposition for LHC
- Investigation of ECEs in other types of machines (eg., heavy-ion linacs)
- Investigation of severity of ECE against fill pattern, bunch intensity, etc
- …

LHC ECE DATABASE

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

- Maintained by F. Zimmermann
  - —Simulation code repository
  - —Experimental data
  - —News, CERN meetings, workshop announcements and proceedings
  - —Publications archive
    - ~200 at last count



Electron Cloud in the LHC

Synchrotron radiation from proton bunches in the LHC creates photoelectrons at the beam screen wall. These photoelectrons are pulled toward the positively charged proton bunch. When they hit the opposite wall, they generate secondary electrons which can in turn be accelerated by the next bunch. Depending on several assumptions about surface reflectivity, photoelectron and secondary electron yield, this mechanism can lead to the fast build-up of an electron cloud (the animation shows simulation results by O. Brüning for 10 subsequent bunch passages, during which the pictures become red) with potential implications for beam stability and heat load on the beam screen. In view of the tight deadline for the design of the LHC cryogenic system, a crash program has been set up to measure the relevant physical quantities with and without magnetic field.

CERN, Animations, LHC News, PS News, Other News, Computer Codes, Simulation Comparison, Publications (Archive), Bibliography (Archive), Workshops, People+Feedback

NEW

Movies of the single-bunch electron-cloud instability: (1) SPS with space charge, (2) Electron distribution in the SPS during one bunch passage (3) KEKB LER

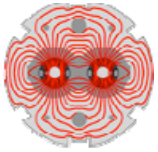
The animations show the single bunch evolution under the effect of the electron cloud in the SPS as well as in the Low Energy Ring of the KEK B Factory. The dotted line represents the centroid position along the bunch, and the solid lines are located at +/- one bunch rms-size from the centroid. Detailed Description.

Simulations for LHC: Latest news

Simulated LHC arc heat loads increase by a factor 2-3 if elastically scattered electrons are included in addition to the true secondaries.

Electron Cloud in the PS

Since October 2000, apparent electron cloud effects are observed with the LHC beam in the



Importance of the EC

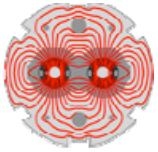
- ECE has been observed at many other machines:
  - — PEP-II, KEKB, BEPC, PS, SPS, APS, RHIC, Tevatron, MI, SNS, …
  - — diminished performance
    and/or
  - — dedicated experiments

- PEP-II and KEKB:
  - — controlling the EC was essential to achieve and exceed luminosity goals

- PSR: high-current instability, beam loss

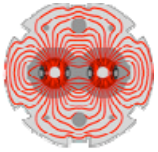
- RHIC: fast vacuum pressure rise instability at high current forces beam dump (in some fill patterns)

- Concern for future machines (LHC, ILC DR's, MI upgrade,…)



Status of EC R&D for LHC

- Current consensus: EC heat load will cease to be a problem for the LHC when the peak SEY falls below ~1.2–1.3
  - —Probably will be achieved after a relatively brief conditioning time
  - —But, no clear experimental demonstration yet of this conditioning effect for long, closed, cold Cu chamber
- Effect of EC on the beam: no conclusive answer yet
  - —Very difficult simulations; ongoing work
- Much R&D effort goes on for the proposed upgrade (both LHC and injectors)



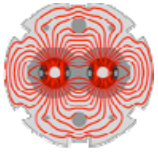
An army of people

A. Adelmann, G. Arduini, V. Baglin, S. Berg, M. Blaskiewicz, E. Blum, O. Brüning, Y. H. Cai, F. Caspers, C. Celata, A. Chao, R. Cimino, R. Cohen, I. Collins, F. J. Decker, A. Drees, W. Fischer, G. Franchetti, A. Friedman, O. Gröbner, K. Harkay, P. He, S. Heifets, N. Hilleret, U. Iriso, M. Izawa, J. M. Jiménez, R. Kirby, M. Kireef-Covo, T. Kroyer, G. Lambertson, J.-M. Laurent, R. Macek, A. Molvik, K. Ohmi, S. Peggs, E. Perevedentsev, M. Pivi, C. Prior, A. Rossi, F. Ruggiero, G. Rumolo, Y. Sato, D. Schulte, K. Sonnad, P. Stoltz, G. Stupakov, J.-L. Vay, M. Venturini, S. Y. Zhang, X. Zhang, A. Zholents, F. Zimmermann, R. Zwaska… (*)

(underlined: CERN affiliation)

I am grateful to all of them!

(*) I apologize for any omissions; please send me an email to fix this



Final words

- Much of the progress in EC R&D world-wide for the past ~10 yrs is owed to, or has significantly benefited from, the LHC "Electron-Cloud Crash Program"

- Francesco Ruggiero deserves much of the credit for his strong and steady leadership

- I am saddened by Francesco's untimely passing, but I find comfort in the fact that his expertise will keep providing guidance through his many publications