ELECTRON CLOUD IN THE SPS: INTRODUCTION AND MOTIVATION

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Abstract

A short introduction to some key concepts relevant to the discussion of electron cloud effects and their implications for PS, SPS and LHC operation is provided, together with the motivation for experimental and theoretical studies.

1 INTRODUCTION

In the LHC, photoelectrons created at the pipe wall are accelerated by proton bunches up to 200 eV and cross the pipe in about 5 ns. Slow secondary electrons with energies below 10 eV have a time-of-flight longer than 20 ns and survive until the next bunch (see Fig. **??**). This may lead to an electron cloud build-up with implications for beam stability, emittance growth, and heat load on the LHC beam screen [**?**]. An effective solution is to condition the screen surface, either by synchrotron radiation photons or using electrons accelerated by a special proton beam, with increased bunch spacing or weak satellite bunches, thus clearing slow secondary electrons [**?**].

The critical energy of synchrotron radiation photons in the LHC at 7 TeV is $\varepsilon_{\rm cr} = 3/2\,\gamma^3\hbar c/\rho \simeq 45$ eV, i.e., well above the work function for copper. Even at top energy, however, the critical photon energy in the SPS is not sufficient to create photoelectrons. Moreover, it was reasonable to expect a substantial surface conditioning of the SPS vacuum chamber after so many years of operation, especially with leptons (photon scrubbing); infact last year it was planned to search for localized electron cloud effects during SPS MD's, with dedicated diagnostics in a vacuum chamber with high Secondary Electron Yield (SEY).

However the SPS vacuum chamber is often vented and this may create an oxide layer with high SEY. In addition, synchrotron radiation masks reduce or prevent photon scrubbing. Finally, the residual gas pressure in the SPS is higher than in the LHC and the proton beam generates a few ionization electrons.

These primary ionization electrons perform several transverse oscillations within the proton bunches and finally hit the vacuum chamber with energies up to several keV. For a sufficiently high SEY, they may trigger an avalanche process leading to the build-up of an electron cloud. These considerations indicate that electron cloud effects are indeed possible in the SPS. The purpose of the presentations and discussions in this session is therefore to:

- discuss experimental evidence for electron cloud effects in the SPS with LHC type beams
- compare SPS observations and simulations:
  - validate simulation ingredients and results
  - draw conclusions for the LHC
- discuss further experimental and theoretical studies required:
  - have we included all important physical mechanisms?
  - what are the key parameters?
  - what are the observables to measure in future MD's?
- review potential remedies and identify realistic solutions
- discuss implications for PS, SPS and LHC operation

2 SOME KEY CONCEPTS

The electron cloud build-up in the SPS (and LHC) is *not* a resonant phenomenon like multipacting in RF cavities. Moreover electrons are *not* trapped in the beam potential, but form a time-dependent cloud extending up to the pipe wall: in field-free regions this cloud is almost uniform, while in the dipoles electrons spiral along the magnetic field lines and tend to form two stripes at about 1 cm away from the beam axis.

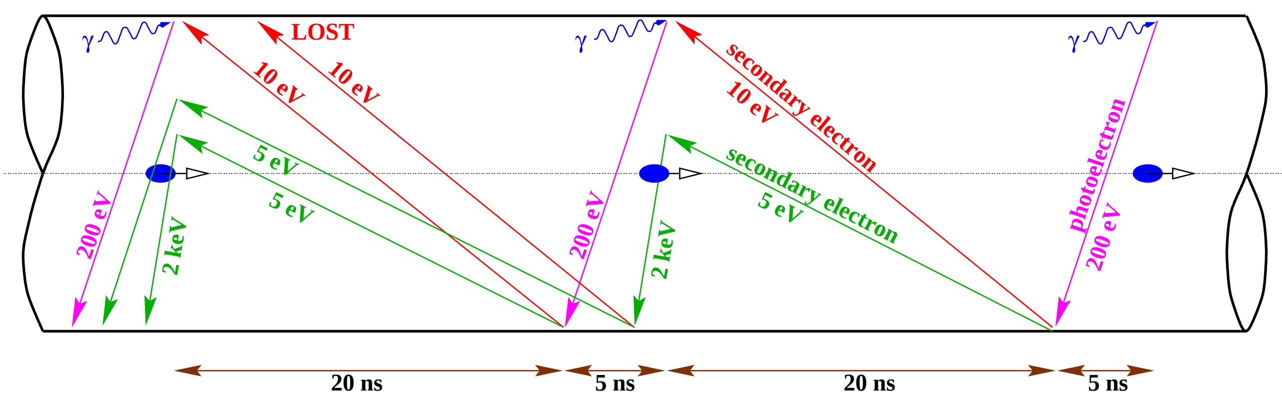

Figure 1: Sketch of the electron cloud build-up in the LHC.

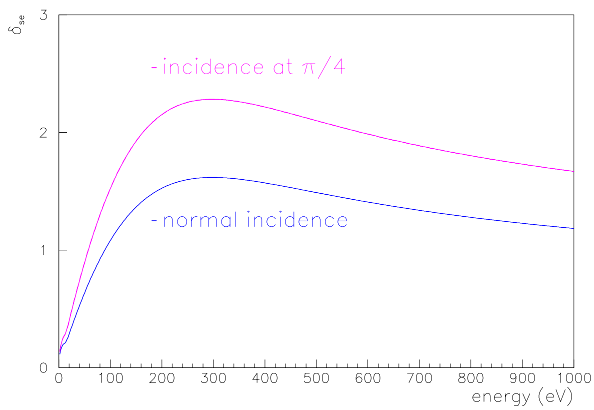

Figure 2: Secondary electron yield $\delta_{\rm SEY}(W,\theta) = \frac{\delta_{\max}}{\cos\theta}\, h\left(\frac{W}{W_o}\right)$, as a function of the primary electron energy W for normal incidence $\theta = 0$ (lower curve) and incidence at $\theta = \pi/4$ (upper curve). The maximum yield $\delta_{\max}$, corresponding to a primary electron energy W_o typically around 300 eV, is a characteristic of the metal, while h is a universal function having the phenomenological expression $h(\xi) = 1.11\, \xi^{-0.35} \left(1 - e^{-2.3\, \xi^{1.35}}\right)$.

Depending on the bunch spacing, a significant fraction of secondary electrons is lost in between two successive bunch passages. Each bunch passage can be considered as the amplification stage of a photomultiplier: a minimum gain is required to compensate for the electron losses and this corresponds to a *critical secondary electron yeld* $\delta_{\rm cr}$ (see Fig. **??**), typically around 1.3 for nominal LHC beams. When $\delta_{\max} > \delta_{\rm cr}$, the electron cloud is amplified at each bunch passage and reaches a saturation value, determined by space charge repulsion. As a rule-of-thumb, saturation occurs when the electron density approaches the average proton beam density (space charge neutralization).

The electron cloud build-up is a *single pass* effect. In addition to an increased heat load on the cold LHC beam screen, it may give rise to single and multi-bunch instabilities. The single bunch instability is a kind of beam break-up caused by the short range wakefield in the electron plasma; it can not be easily cured by the damper and may lead to a potentially fast emittance growth. The multi-bunch instability arises from the coupling between subsequent bunches induced by the long term memory of their transverse positions, affecting the electron cloud density. These effects have to be studied, understood and mastered for a successful operation of the LHC and of the SPS as its injector.

3 REFERENCES

[1] F. Ruggiero, World-wide web page on "Electron Cloud in the LHC", `http://wwwslap.cern.ch/collective/electron-cloud/`.

[2] O. Brüning, F. Caspers, I.R. Collins, O. Gröbner, B. Henrist, N. Hilleret, J.-M. Laurent, M. Morvillo, M. Pivi, F. Ruggiero, and X. Zhang, "Electron Cloud and Beam Scrubbing in the LHC", CERN LHC Project Report 290 (April 1999), in Proc. 1999 Particle Accelerator Conference (PAC99), New York, eds. A. Luccio and W. MacKay (IEEE, New York, 1999), pp. 2629-2631.