COMPARISON BETWEEN ELECTRON CLOUD BUILD-UP MEASUREMENTS AND SIMULATIONS AT THE CERN PS

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Abstract

The build up of an Electron Cloud (EC) has been observed at the CERN Proton Synchrotron (PS) during the last stages of the LHC high intensity beam preparation, especially after the bunch shortening before extraction. Two dedicated EC experiments, both equipped with two button pick-ups, a pressure gauge, a clearing electrode and a small dipole magnet, are available in two straight sections of the machine. A measurement campaign has been carried out, in order to scan the EC build-up of LHC-type beams with different bunch spacing, bunch intensity and bunch length. Such information, combined with the results from build up simulations, is of relevance for the characterization in terms of Secondary Emission Yield (SEY) of the chamber inner surface. The interest is twofold: this will enable us to predict the EC build up distribution in the PS for higher intensity beams in the frame of the upgrade program, and it will provide validation of the EC simulation models and codes.

INTRODUCTION

Indicators of the electron cloud were first observed in the CERN-PS in 2001 during the last part of the cycle for the production of the the so-called LHC-type beams, i.e. the beams of the type needed for the LHC filling. The production scheme of these beams in the PS is based on two or three steps of bunch splitting in order to obtain at the exit of the PS bunch trains with 50ns or 25ns spacing, respectively. In either case, the final stage of bunch splitting takes place at the flat top and is followed by adiabatic bunch shortening and fast bunch rotation shortly before extraction [1]. Therefore, these beams only circulate in the PS for few tens of msec with a structure prone to electron cloud formation (beam parameters are summarized in Table 1).

During this short time before extraction, an electron cloud was initially revealed in 2001 by the presence of a baseline drift in the signal from the pick up as well as beam transverse instabilities [2]. The transverse instabilities made a new appearance with 25ns beams in 2006, when the bunches were accidentally shortened to 10ns or below (instead of the nominal 12ns) during the phase of adiabatic shortening prior to the fast rotation. This again suggested that the short bunches could initiate the electron cloud build up earlier in the cycle and produce enough electron cloud for a sufficiently long time as to render the beam visibly unstable. In March 2007, an experiment for dedicated electron cloud measurements was set up at the PS to be able to directly measure the electron signal by using a shielded biased pick up [3] and confirm its presence in the machine in the last phase of the LHC beams production. The experimental setup was designed, fabricated, and mounted in straight section (SS) 98 during the accelerator shutdown 2006/2007. All the details of the setup can be found in Ref. [3]. These studies confirmed that the electron cloud develops during the last 40 to 50 ms before ejection, i.e. when the bunches are shortened by the RF gymnastics. Besides, they also showed that the electron cloud can be suppressed by putting a sufficiently large voltage of either polarity onto a clearing electrode, even if the clearing efficiency depends on the magnetic field present in the region of the measurement in a non-trivial way.

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Table 1: Relevant beam parameters in the PS during the flat top RF gymnastics for the two bunch spacings of 50 and 25ns.

	50ns	25ns
Beam energy (GeV/c)	26	
Bunch intensity ($\times 10^{11}$ ppb)	0.82-1.95	0.83-1.33
Bunch length (ns)	15 $\rightarrow$ 12 $\rightarrow$ 4	
Number of bunches	36	72
Transv. norm. emittances (μm)	1-2	2-3

In 2011, new systematic measurements of electron cloud have been performed at the CERN-PS with the goal of extracting the following information:

- Dependence of the electron cloud build up evolution on some controllable beam parameters (bunch spacing, bunch intensity, bunch length).
- A new collection of time resolved experimental data of electron cloud build up in some desired sets of beam conditions.

These sets of data can serve two purposes. First, comparing them with build up simulations will allow us to validate (or improve) the simulation model on which our tools are based. Second, by matching the simulations to the experimental data in all the different beam conditions, we can pin down the surface properties of the PS vacuum chamber (secondary electron yield, δ_{max}, and reflectivity of the electrons at zero energy, R_0) and extrapolate then how much electron cloud we can expect in the PS with the higher intensity beams foreseen in the frame of the LHC Injector Upgrade (LIU) project, and whether that can be detrimental to the beam.

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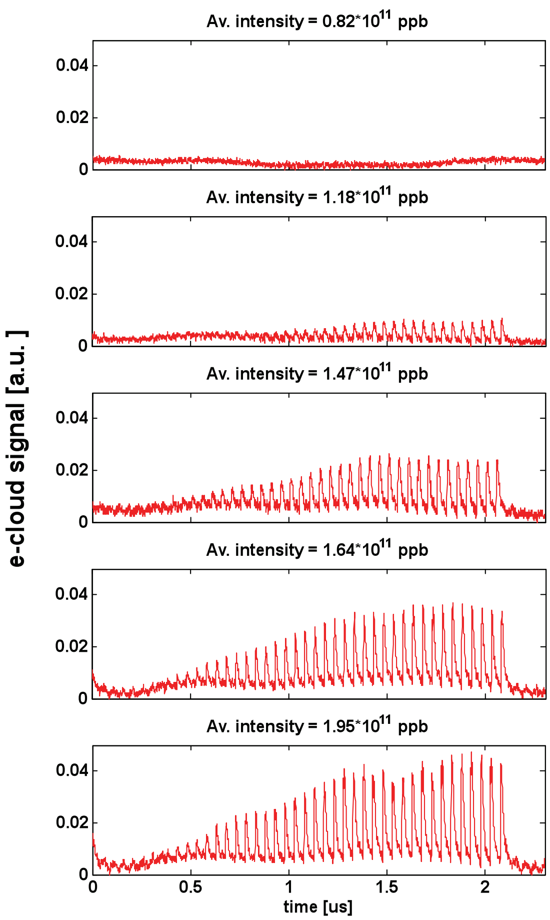

Figure 1: E-cloud build up during passage of a 50ns bunch train with 4ns bunch length.

2011 MEASUREMENTS

In 2011, the Machine Develpment (MD) program in the PS for electron cloud studies took place in November and extended over several sessions to cover different sets of beam parameters. In particular, electron cloud build up data were recorded for 25ns and 50ns beams. The bunch intensities were scanned in the ranges indicated in Table 1. The trigger for the data acquisition was set at extraction, when in normal conditions each bunch of the beam has been already fully rotated (4ns bunch length). However, specifically for these measurements, the bunch length at this time for a fixed bunch intensity was also set to 6.5ns or 15ns by simply adjusting or fully removing, respectively, the final step of the fast bunch rotation. This allowed studying the dependence of the electron cloud build up not only on the bunch intensity but also on the bunch length.

Several measurements of electron cloud build up were taken with 50ns beams and the results of the bunch intensity scan are displayed in Fig. 1. Each plot shows the electron cloud signal over a time window slightly longer than one PS revolution time (2.1μs with 1.8μs length of the 36-bunch train plus 300ns gap). The bunch intensity was varied over a broad range. The threshold for electron cloud formation with 50ns beams lies at about 10^{11} ppb and the measured signal increases monotonically with the bunch intensity. This is not entirely surprising, since the measurements were taken with zero magnetic field while the non-monotonic behaviour of the electron cloud build up with the bunch intensity is more frequent in dipole regions. The shielded pick up is installed inside a C-magnet, which was kept off during the MD sessions because the orbit perturbation it introduces would have required a specific correction.

The scan in bunch length for a fixed bunch intensity of 1.5×10^{11} ppb of Fig. 2 shows that, while the difference between the build up with bunches of 4 and 6.5ns is small, there is no sign of electron cloud with 15ns long bunches. This suggests that 50ns beams might see the electron cloud only in the very last phase of the beam production, i.e. during and after the fast bunch rotation.

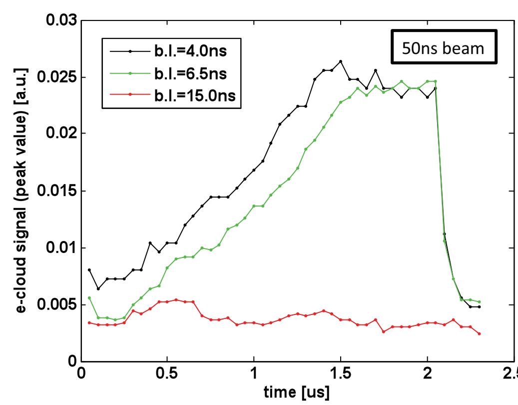

Figure 2: Envelope of the build up during passage of a 50ns bunch train with 1.5×10^{11} ppb.

Scans with 25ns beams were also made, covering a smaller intensity range, as shown in Fig. 3. Here we can see that the threshold for electron cloud formation is below 8×10^{10} ppb for 25ns spaced beams and then again the electron cloud signal increases with the bunch intensity. The scan in bunch length for a fixed bunch intensity of 1.15×10^{11} ppb of Fig. 4 shows that, while the difference between the electron cloud build up with bunches of 4 and 6.5ns is negligible, there is a lower yet still significant electron cloud with 15ns long bunches.

COMPARISON WITH SIMULATIONS

We have tried to fit the PS data with those from electron cloud build up simulations [4]. First of all, the output of the code that should be compared with the measured signal is the electron flux to the wall. In a first approximation, we do not consider the holes in the vacuum chamber, which are expected to cause only a minor perturbation in a field-free region. In general, the simulated electron flux to the wall vanishes during the bunch passage, because initially all the electrons are drawn to the center of the vacuum chamber by the passing bunch (e.g. during the first $\sim$2ns of a 4ns long bunch) and they are gradually released only during the falling edge of the bunch, when they may reach

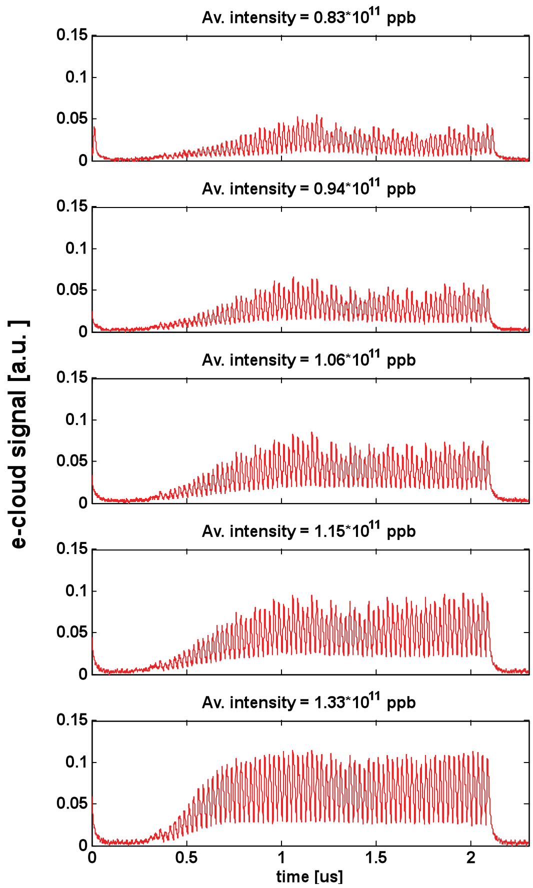

Figure 3: E-cloud build up during passage of a 25ns bunch train with 4ns bunch length. The sometimes visible saw-tooth behaviour follows a bunch-by-bunch intensity modulation present during the measurements.

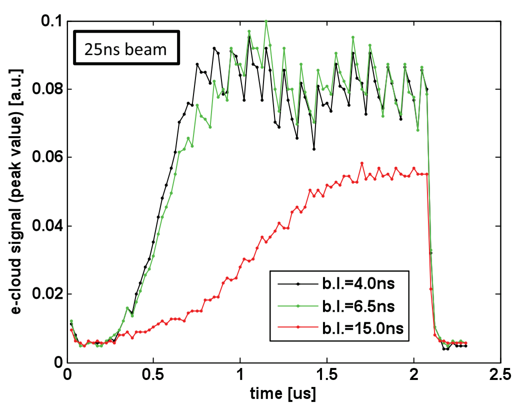

Figure 4: Envelope of the build up during passage of a 25ns bunch train with 1.15×10^{11} ppb.

the walls again. The fact that the measured signal does not exhibit this feature makes plausible a low pass filtering of the signal (inherent to the measurement technique or due to electronics and/or cables) with a corner frequency in the range of some hundreds of MHz. Figure 5 shows measured and simulated signal, where the simulated signal, obtained with $\delta_{\max} = 1.6$ and $R_0 = 0.5$, was low pass filtered with a corner frequency of 200 MHz. The impressive resemblance between the two suggests that our electron cloud model correctly describes the phenomenon and the rationale applied for the data analysis is promising.

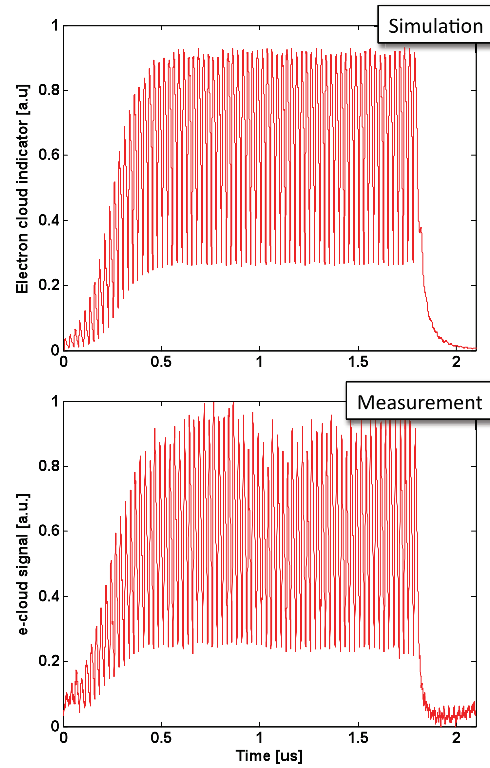

Figure 5: E-cloud build up simulation (top) and measurement (bottom) for a 25ns beam with 1.33×10^{11} ppb and 4ns long.

CONCLUSIONS AND OUTLOOK

New electron cloud measurements at the CERN PS reveal that the electron cloud builds up for bunch intensities above 10^{11} ppb for 50ns beams, while the threshold for 25ns beams lies below 8.0×10^{10} ppb. The dependence on bunch length has also been measured for both 25 and 50ns beams, recording the cloud signal for trains of 4.0, 6.5 and 15ns long bunches.

A preliminary exercise of matching measured to simulated signals using a specific set of 25ns data is very promising and points to $\delta_{\max}$ around 1.6. However, a more complete and accurate analysis is presently underway to fit all existing data and build a consistent picture.

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