

ELECTRON CLOUD MEASUREMENTS IN THE SPS IN 2004

D. Schulte, G. Arduini, V. Baglin, J. M. Jimenez, F. Ruggiero, F. Zimmermann
 CERN, Geneva, Switzerland

Abstract

Novel measurements of the electron cloud have been performed in the SPS in 2004. The LHC beam in the SPS consists of a number of short bunch trains. By varying the distance between these trains it is possible to test the survival of the electrons after the bunch passage. In this paper, results from simulations and experiments are compared.

INTRODUCTION

The electron cloud is observed in the SPS with LHC beam and several properties can be measured by a variety of detectors [3]. One purpose of these measurements is to benchmark the simulations. However, the experiment suffers from a number of uncertainties. Mainly the surface properties are changing during the machine operation and the vacuum level has a significant uncertainty.

The bombardment of the vacuum chamber surface with electrons reduces the secondary emission yield. This is very welcome for machine operation since the electron cloud density is strongly reduced with time. However, it complicates the benchmarking of the simulation code with the experiment. An in situ measurement of the secondary electron emission yield at the position of the considered electron flux detectors is not possible in the SPS. Since the surface conditions depend strongly on the local electron flux, measurements at different locations cannot be easily used to determine the state at the detector position.

Another property of the beam pipe surface is that it can elastically reflect low-energy electrons [1, 2]. The probability of this reflection is debated and it is expected to depend strongly on the material and the surface properties. It is also not clear how the reflectivity evolves during beam scrubbing. This adds to the experimental uncertainties and it is thus not sufficient to determine the secondary emission yield but one also needs to know the electron reflectivity for a given measurement.

A further difficulty arises from the fact that the electron flux on the chamber surface consists to a large part of very low momentum electrons. A serious concern is thus the precise knowledge of the detector response to different energy electrons. The measurements reported in the following were performed with a strip detector with no bias voltage. The sensitivity to the different electron energies is somewhat uncertain.

Hence, a simple comparison of the measured and simulated electron flux will not be very satisfying to verify the code. Since one does not know the secondary emission yield from an independent measurement, it enters the simulation as a free parameter.

The beam parameters also have some uncertainty, but the

Table 1: Parameters assumed in the simulation.

protons per bunch	11.5×10^{10}
σ_x	3 mm
σ_y	1.5 mm
RMS bunch length	20 cm
Ionisation rate	$0.25 \times 10^{-6} \text{ m}^{-1} p^{-1}$
chamber half width	76 mm
chamber half height	17.5 mm

main remaining difficulty is to determine the vacuum level in the detector during the measurement. We will assume an ionisation rate of 0.25×10^{-6} per meter and per proton, corresponding to about 30 ntorr of CO, but the uncertainty is large. The values assumed for the different variables are listed in Table 1.

MEASUREMENT STRATEGY

An effective comparison of simulations and measurements requires to remove some of the uncertainties described above. This can be achieved by further constraining the parameters by performing several measurements. Our strategy is described below.

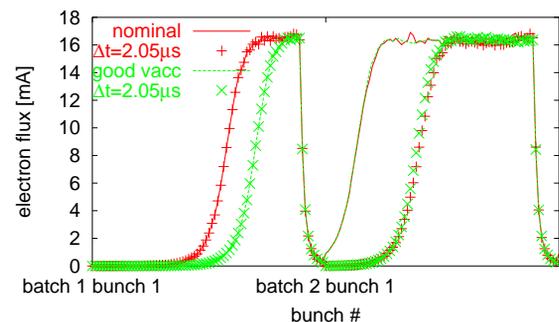


Figure 1: The simulated electron cloud build-up in two consecutive batches. In the case with lines the distance between the bunch trains was 225ns, for the points 2050 ns. The two lines correspond to the nominal vacuum level and one that is ten times better.

To be able to constrain the surface conditions during the measurements better than for previous studies, we took advantage of a particularity of the LHC beam in the SPS. This beam consists of up to four bunch trains (so-called batches) that are usually separated by $0.225 \mu\text{s}$. This distance between the batches can be increased. In simulations and measurements this alters the electron flux measured on the surface. Figure 1, shows the evolution of the electron cloud during the passage of two bunch trains. During the first part of the passage of batch number one, the electron flux density is increasing exponentially. It then saturates

when the forces of the beam current and the space charge introduced by the electron cloud itself approximately cancel. After the first batch, the cloud decays until the second batch arrives. Within the second batch, the cloud shows the same behaviour as in the first batch, except that it reaches the saturation limit earlier. This is due to the fact that a number of electrons survived the gap between the first and the second batch and can now seed the electron cloud build up; the number of surviving electrons depends on the reflectivity. Modifying the batch distance should affect the number of surviving electrons and consequently help to understand their survival time. This allows one to constrain the reflectivity for low energy electrons.

The first attempt to take advantage of the differences in the time to reach saturation was to use a monitor that can resolve the bunch-to-bunch change in electron flux. Since this monitor had too high a noise level, a different strategy has been used. The total flux Φ_n induced by a beam consisting of n batches is mainly determined by the speed with which the electron flux reaches saturation. Hence, the first measurement is the ratio $R_1 = \Phi_2/\Phi_1$. For different distances between batches the rise in the second to fourth batch will occur later; a second result thus is the ratio R_2 of the flux with four batches with inter batch distances from $0.225 \mu\text{s}$ ($\Phi_{0.225}$) to $2.05 \mu\text{s}$ ($\Phi_{2.05}$). Finally the absolute level of the flux Φ_2 can be compared to the simulated value, but one has to be aware of the uncertainty of the measured value.

SIMULATION RESULTS

We will first compare the measurement at one moment in time (after an integral proton current of about 4Ah had been accumulated) and the simulations assuming the best guesses for the beam and vacuum parameters. Later we will analyse the changes which would result from the use of different parameters in the simulation. All the simulations in the following have been performed using the code E-CLOUD [4]. The vacuum chamber has been approximated with an ellipse of the same dimensions as the actual rectangular beam pipe, since this is a well tested method, which is also used for the LHC simulations.

Three different measured quantities R_1 , R_2 and Φ_2 have been simulated using the nominal beam parameters and vacuum level. The results are displayed as a function of secondary emission yield δ_{max} and the reflectivity r in Fig. 2.

We will compare these simulations to the measurements that were performed by varying the batch spacings. They yielded $R_1 = 4$, $R_2 = 0.6$ and $\Phi_2 = 0.9\text{mA/m}$. In Fig. 3 for each of the measured quantities the combinations of secondary emission yield and reflectivity are shown for which the simulation best reproduces the measurement. As can be seen the combination of $\delta_{max} = 1.35$ and $r = 0.3$ can satisfy both R_1 and R_2 . The absolute flux level is also very well reproduced for these parameters.

In order to demonstrate the robustness of the relative

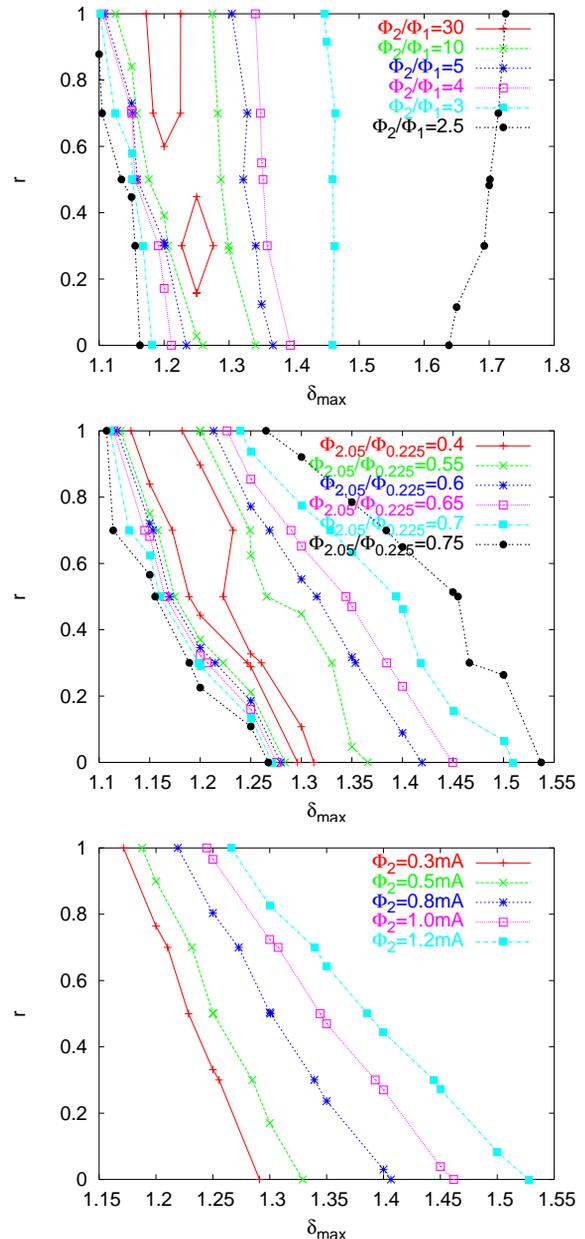


Figure 2: Upper plot: The ratio R_1 of current for two batches with nominal spacing versus a single batch; the measurement yielded $R_1 = 4$. Middle plot: The ratio R_2 of the current for four batches with $2.05\mu\text{s}$ spacing versus 225ns spacing; the measurement yielded $R_2 = 0.6$. Lower plot: The total current Φ_2 for two batches; the measurement yielded $\Phi_2 = 0.9\text{mA/m}$.

measurements, the same simulations are evaluated assuming that all the electrons with a vertical momentum of less than $10\text{ eV}/c$ are not detected when they hit the experiment, see Fig. 4. The same secondary emission yield and reflectivity are found as in the case before, if the two flux ratios are used. The absolute flux measurement does not agree with the simulation. This demonstrates that the relative measurements can be quite useful to deal with an unknown detector response to the electrons.

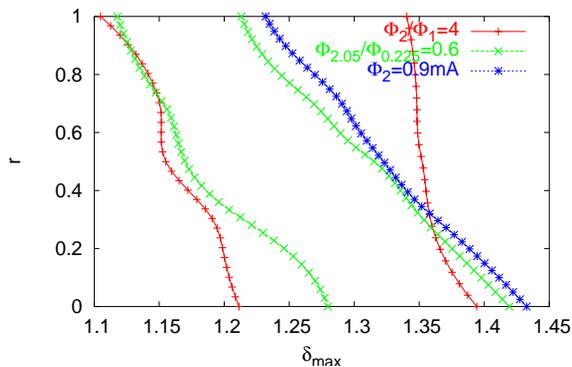


Figure 3: Combined representation of the different simulations. The best agreement with the measurement can be reached at $\delta_{max} \approx 1.35$ and $r \approx 0.3$.

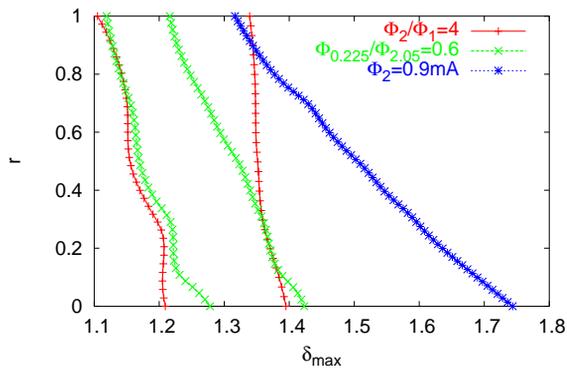


Figure 4: Combined representation of the different simulations assuming that the detector only detects electrons with a momentum of more than $10eV/c$. Clearly, it would not be possible to find a good point in the surface parameter space in this case.

We also investigated the impact of the vacuum level on the simulations. Figure 5 shows the simulation results for a vacuum ten times better than the level that we assumed and for a vacuum which is ten times worse. In the case of the better vacuum no single combination of secondary emission yield and reflectivity can explain the measured values of R_1 and R_2 , for a somewhat worse vacuum one can expect to find the combination $\delta_{max} = 1.4$ and $r = 0$ a valid choice. In the case of a ten times worse vacuum, the measured relative values can be reproduced by three different combinations of secondary emission yield and reflectivity. One finds $\delta_{max} = 1.3$ and the maximum reflectivity in any of the combinations is $r = 0.7$. One can thus constrain the reflectivity to be in the range of $0 \leq r \leq 0.7$, even if one allows for quite some uncertainty in the vacuum level.

Cross checks have been performed with a code module that simulates the rectangular chamber as a real rectangle. The two relative measurements yielded in this case a secondary emission yield $\delta_{max} = 1.3$ and a reflectivity $r = 0.15$. However, the absolute flux is about twice as high as in the simulations with the elliptical chamber. Further investigation is required to understand the origin of this difference.

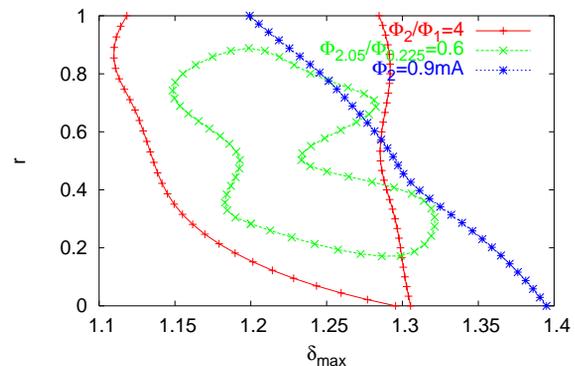
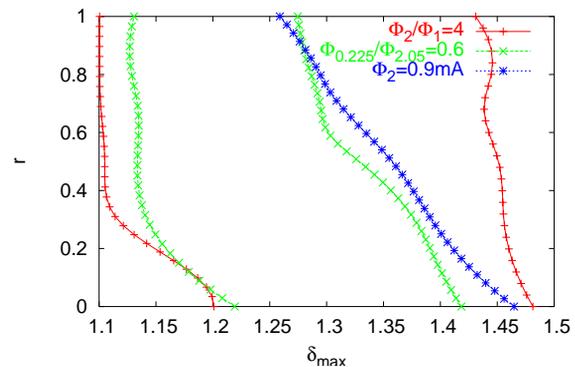


Figure 5: The reconstruction of the secondary emission yield and reflectivity for different vacuum levels. In the upper plot the vacuum was a factor 10 better than in Table 2 in the lower plot a factor 10 worse.

CONCLUSION

We have performed new measurements of the electron cloud build-up at the SPS in 2004. By using a novel measurement procedure we were able to constrain the reflectivity and secondary emission yield during the measurement. When we use the best guesses for the beam and vacuum parameters, we find that the simulation code produces results that are very consistent with the measurements for a secondary emission yield of $\delta_{max} = 1.35$ and a reflectivity of $r = 0.3$. Assuming an uncertainty of the vacuum level of a factor ten one can still constrain the values to $1.3 \leq \delta_{max} \leq 1.4$ and $0.7 \geq r \geq 0$.

ACKNOWLEDGMENT

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).

REFERENCES

- [1] B. Henrist et al., ECLLOUD’02, CERN-2002-001 (2002).
- [2] R. Cimino et al., Phys. Rev. Let. 93, 014801 (2004).
- [3] J.M. Jimenez et al., LHC Project Report 632 (2003).
- [4] ECLLOUD home page <http://wwwslap.cern.ch/collective/electron-cloud/Programs/Ecloud/ecloud.html>.