PERFORMANCE LIMITATIONS FROM ELECTRON CLOUD IN 2015

G. Iadarola* H. Bartosik, K. Li, L. Mether, A. Romano, G. Rumolo, M. Schenk (CERN, Geneva)

Abstract

The brief experience with 25 ns beams in the LHC at the end of Run 1 suggested that the electron cloud effects were set to pose important challenges to the machine operation during Run 2. In spite of four weeks of dedicated scrubbing run, the 2015 proton run of the LHC fully confirmed this expectation, with the electron cloud severely degrading the beam quality at the beginning of the scrubbing run and then limiting the number of bunches at 6.5 TeV, due to strong heat load in the cold regions. This contribution describes the main e-cloud observations and limitations encountered during the 2015 run. The dedicated scrubbing periods at 450 GeV, the intensity ramp-up with 25 ns beams at 6.5 TeV and tests with special beam variants (doublets, 8b+4e) are covered. Finally, based on the acquired experience and the lesson learned in 2015, a proposal for the scrubbing strategy and 25 ns intensity ramp-up in 2016 is presented.

INTRODUCTION

While most of the luminosity production for the LHC Run 1 was performed with 50 ns bunch spacing, for Run 2 it was decided to move to the design value of 25 ns. Tests performed before the shutdown as well as simulation studies showed that e-cloud effects could pose important challenges to the operation of the machine [1, 2, 3, 4].

For this reason it was decided to start the operation with roughly nominal beam parameters (typically 1.1×10^{11} p/bunch within transverse emittances of about 2.5 μm), postponing to a later stage the exploitation of high brightness beam variants available from the injectors. Moreover, a significant time of the machine schedule was devoted to scrubbing runs for the mitigation of the e-cloud.

After a first period of commissioning with low intensity beams, a first scrubbing run took place in the period 24 June – 5 July 2015, with the aim of preparing the machine for a first intensity ramp-up in physics with 50 ns beams. With this bunch spacing only about 450 bunches per beam could be accelerated to 6.5 TeV, due to radiation to electronics faults in the Quench Protection System (fixed during the following Technical Stop) [5].

A longer scrubbing period took place in the period 25 July – 10 August, aiming at enabling physics production with 25 ns beams. After that, the LHC was operated mostly with 25 ns bunch spacing for the rest of the proton run, with a gradual increase of the beam intensity during this period.

SCRUBBING AT 450 GeV

After the Long Shutdown 1 (LS1), the Secondary Electron Yield (SEY) of the LHC beam screens was found to be reset to the values observed at the beginning of Run 1. This is not surprising, since most of the machine was exposed to air. In fact, e-cloud induced instabilities were observed even with 50 ns beams, which were used routinely for physics production before the shutdown, without major problems from the e-cloud.

Figure 1 (top) shows the beam intensity evolution during the scrubbing periods. Apart from an initial short period with 50 ns bunch spacing ($\sim$2 days), the scrubbing was mainly performed with 25 ns beams [6]. The main limitations encountered during these periods can be summarized as follows:

- At the beginning, the main limitation to the total injected intensity came from strong e-cloud instabilities, which often triggered the beam dump due to fast beam losses or large beam excursion at the interlocked Beam Position Monitors (BPMs). These instabilities became less violent with time, due to the scrubbing occurring on the beam screen surfaces and to the optimization of the machine settings (ADT configuration, octupoles, chromaticities).
- The vacuum in the injection kicker (MKI) regions required close follow-up, since the pressure interlock levels had to be increased in steps under expert monitoring to avoid strong limitations to the scrubbing efficiency.
- Strong vacuum spikes, in many occasions exceeding the beam dump interlock level, were observed on the injection absorber (TDI) in Point 8 (see also [7]). This effect limited the total number of bunches in beam 2 throughout the scrubbing, as is visible comparing the intensity of the two beams in Fig. 1.
- All along the scrubbing runs it was not possible to inject at the maximum speed allowed by the SPS repetition rate, since the increase of the heat load on the beam screens due to the injected beam caused strong transients on the beam screen temperature, which could easily lead to the loss of the cryogenic conditions.

Despite these limitations the intensity in the machine could be steadily increased up to about 2500 bunches per beam. The scrubbing efficiency was optimized based on

* Giovanni.Iadarola@cern.ch

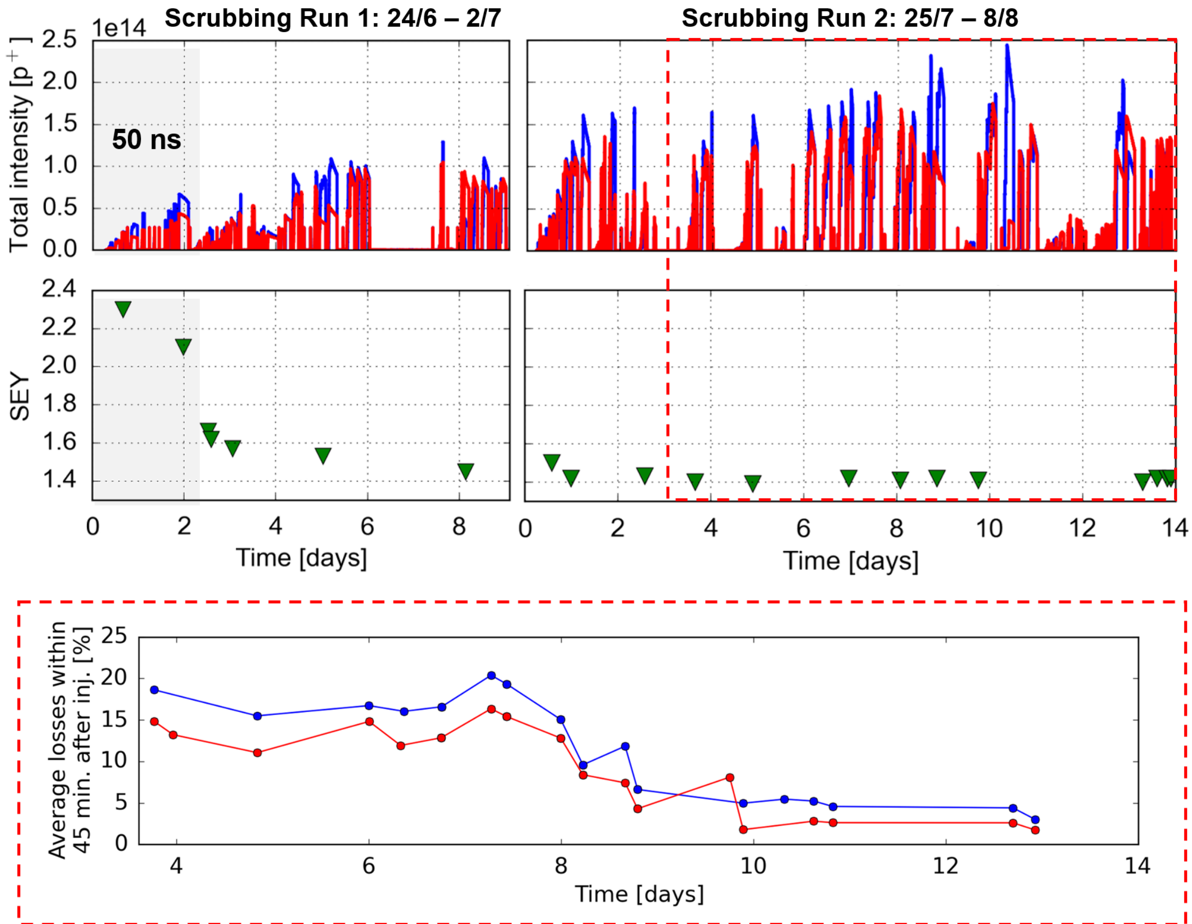


Figure 1: Evolution of the beam intensity during the scrubbing periods (top) and corresponding evolution of the SEY in the dipoles as estimated from simulations (middle). The bottom plot shows the evolution of the beam losses during the last period of the scrubbing run.

heat loads and bunch-by-bunch energy loss [8] measurements, which were made available online in the control room for the scrubbing run.

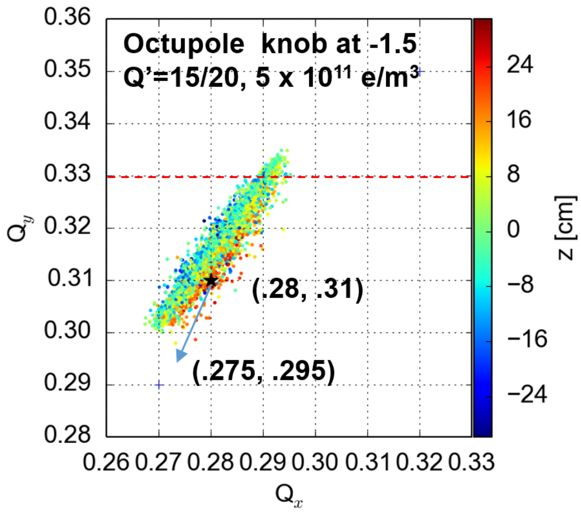
The evolution of the SEY of the beam screens in the main dipoles could be reconstructed by comparing heat load measurements with PyECLOUD buildup simulations (as described in [2]) and is shown in the middle part of Fig. 1. The SEY reduction is much faster at the early stages of the scrubbing process when the SEY is larger, which is a known feature of the surface behavior [9]. Nevertheless, an evident improvement of the beam quality was observed even in the later stages, as shown by the bottom plot in Fig. 1. In this figure, the average beam losses in the first 45 minutes after injection are plotted as a function of time. The behavior of these curves is explained by the fact that the effect of scrubbing is combined with both the gradual decrease of the spacing between batches at the LHC injection (up to day ∼8) and the constant adjustment of machine settings to optimize the beam lifetime. In particular octupoles and vertical chromaticity settings could be reduced (from $Q'_v \simeq 15$ and $I_{oct} \simeq 26$ A to $Q'_v \simeq 10$ and $I_{oct} \simeq 20$ A) since instabilities were much less violent.

INTENSITY RAMP-UP WITH 25 ns BEAMS AT 6.5 TeV

The Scrubbing Runs provided sufficient mitigation to control the beam degradation at 450 GeV and start the intensity ramp-up with 25 ns beams at 6.5 TeV, in spite of the fact that full suppression of the e-cloud was not achieved.

One of the first consequences of the presence of a strong e-cloud in the machine, was the difficulty to ensure the beam stability at 450 GeV. For this purpose, high chromaticity and octupoles settings ($Q' \simeq 15$ in both planes, $I_{oct} \simeq 20$ A) were needed together with the full performance of the transverse damper [10, 11, 12].

Already in August, at the early stages of the intesity ramp-up with 25 ns, it was noticed that a better beam lifetime at injection could be achieved with a vertical tune slightly lower than nominal. The reason of this was found to be that high octupoles and chromaticity settings, together with the detuning induced by the e-cloud, lead to quite a large tune footprint at 450 GeV, which could reach the third order resonance Q_y=59.33 as shown in Fig. 2 (left). The contribution of the different mechanisms (Q', octupoles, e-cloud) to the tune footprint of the beams has been studied in



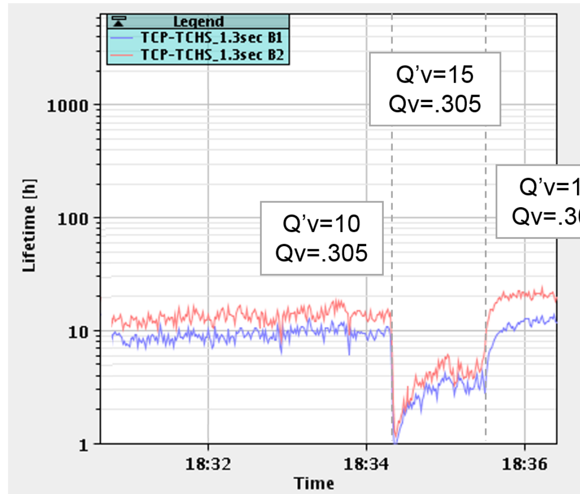


Figure 2: Left: tune footprint at 450 GeV as obtained from PyECLOUD-PyHEADTAIL simulations. Right: beam lifetime measured with 25 ns beams in the LHC for different settings of vertical tune and chromaticity.

detail with PyECLOUD-PyHEADTAIL simulations as described in [13]. Due to these mechanisms it was found that operating with vertical tunes slightly lower than nominal (Q_y=58.295 instead of Q_y=58.31) significantly improves the beam lifetime at 450 GeV. The effect of different tune and chromaticity settings on the beam lifetime is shown in Fig. 2 (right). Here the beam lifetime as a function time is displayed, while the vertical working point was moved to different values. First, a drop is observed when the vertical chromaticity is increased by five units, then the lifetime is recovered when the vertical tune is lowered by 0.005 units while keeping the chromaticity at 20 units. The fact that the e-cloud has an important impact on the beam lifetime is confirmed by the observed strong dependence of the losses on the bunch position along the bunch-train [13].

While instabilities and beam degradation could be kept reasonably under control, the e-cloud was still posing important challenges to the beam intensity ramp-up at 6.5 TeV due to the unprecedented heat loads on the beam screens of the cryogenic magnets. Already in the first stages of the intensity ramp-up, even with a relatively low number of bunches, strong transients of the beam screen temperatures were observed, leading to loss of cryo-conditions. In order to allow for fine tuning on the regulations of the cryogenic systems, the intensity ramp-up had to be performed in small steps, of the order of 150 bunches per step. Moreover, the injection speed often had to be decreased in order to better control beam screen temperatures. Eventually the limitations from transients on the heat loads could be strongly mitigated by modifications introduced on the Cryo Maintain rules, allowing for larger temperature excursion, as well as by the continuous effort in improving of cryogenic feed-forward control [14].

By the beginning of October, the LHC could be operated with around 1450 bunches per ring with a total beam intensity of 1.5×10^{14} p^+ per ring. At that point, the limit of the available cooling capacity on the arc beam screens became closer. To continue the increase of the beam current, on one hand, we had to rely on further conditioning of the beam screens, on the other hand the beam parameters had to be tuned in order to maximize the beam intensity within the constraints posed by the available cooling capacity. This consisted mainly in two actions, as shown in the top part of Fig. 3:

1. The target bunch length for the controlled longitudinal blowup in the ramp was increased from 1.25 ns to 1.35 ns;

2. The filling scheme was optimized in order to minimize the number of bunches at e-cloud saturation, based on the e-cloud risetime observed on the bunch-by-bunch energy loss from the RF stable phase shift [15]. In particular the heat load could be controlled by increasing the spacing between the bunch trains and by reducing the length of the trains themselves.

By the end of the proton run it was possible to operate with 2244 bunches per ring in short trains of 36 bunches, with bunch intensities of about 1.2×10^{11} p/bunch.

The bottom plot in Fig. 3 shows the average heat load measured on the arc beam screens during the intensity ramp-up with 25 ns beams. A global reduction of about a factor of two can be observed on the heat load per proton, as a combined effect of the accumulated scrubbing dose and of the tuning of the beam parameters.

In order to disentangle these two effects a reference fill was performed at the end of the p-p run with beam conditions (filling pattern, bunch intensity, bunch length) very similar to an early fill of the intensity ramp-up. The two comparable fills are marked by green arrows in Fig. 3. A

Figure 3: Evolution of the beam intensity (top), average heat load in the arc magnets (middle) and heat load normalized to the beam intensity (bottom) during the intensity ramp-up with 25 ns beams.

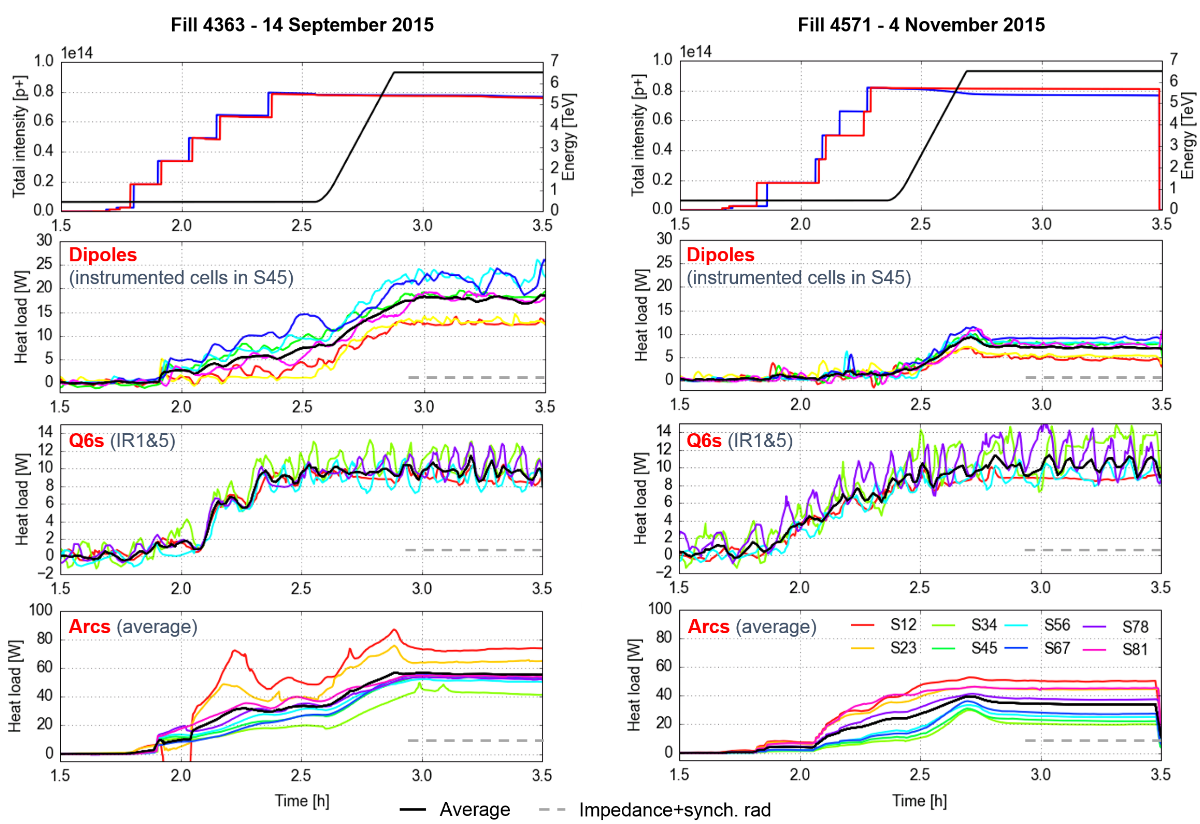


Figure 4: Heat loads measured in two similar fills, at the beginning and at the end of the 25 ns intensity ramp-up. The values for the arcs are in Watts per half-cell. The two fills are indicated by green arrows in Fig. 3.

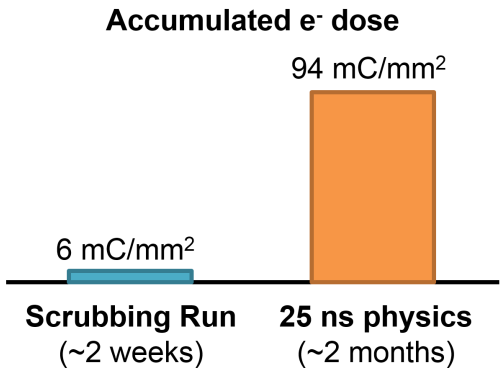


Figure 5: Electron dose accumulated in the arc dipoles during the second scrubbing period and during the physics intensity ramp-up. Only electrons with energies above 50 eV are considered, since they give a stronger contribution to the scrubbing process [9].

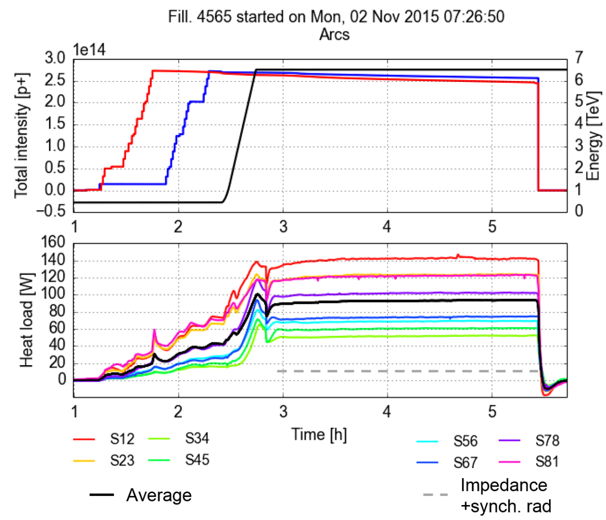


Figure 6: Average heat load (in Watts per half-cell) measured in the LHC arcs during one of the last fills of the proton run, peformed with 2244 bunches per beam in trains of 36 bunches.

detailed comparison is presented in Fig. 4, which shows the heat loads measured in the dipoles of the instrumented cells in sector 45, in the Q6 quadrupoles in IR1 and IR5 (equipped with beam screens very similar to those installed in the arcs) and the average heat load measured in the eight arcs. A heat load reduction is observed mainly in the dipole magnets, while the situation in the quadrupoles looks practically unchanged. This is an effect of their much lower multipacting threshold (see PyECLOUD simulation results presented in [4]). One can also notice how, in the later fill, there is hardly any measured heat load in the instrumented dipoles at injection energy. This means that the SEY in these chambers has reached values lower than 1.4, which is the multipacting threshold at 450 GeV. The overall effect observed in the LHC arcs is a heat load reduction in the range between 30% to 60%, which was achieved in a period of about two months running with 25 ns beams with increasing number of bunches.

The electron dose deposited on the beam screens over this period could be inferred combining heat load measurements and PyECLOUD simulations (providing information on the geometric distribution and energy spectrum of the electrons impacting on the beam screens). The result is shown in Fig. 5, which reports for comparison also the dose accumulated during the scrubbing run at the beginning of August. It appears evident that it would have been impossible to accumulate the same dose during a dedicated scrubbing run with a reasonable duration. Assuming that the behavior of the beam screen surfaces will be the same after future Long Shutdowns, the most efficient strategy will be to allocate a shorter scrubbing period, sufficient to achieve acceptable beam quality, and then accumulate further dose in parallel with physics (with the e-cloud defining the pace of the intensity ramp-up).

Figure 6 shows the heat loads measured in the LHC arcs during one of the last physics fills of the 2015 run, performed with 2244 bunches per beam, in trains of 36 bunches. The plot shows a strong difference in the behavior of the different sectors (up to a factor of three), with the sectors 81, 12 and 23 being still close to the limit of the available cooling capacity (see [14]) while the sectors 34, 45, 56, 67 having already enough margin to accommodate a significant increase of the beam intensity.

The origin of such a difference is still unclear and was the subject of different investigations [16, 17, 18, 19]. The main findings can be summarized as follows:

- The cryogenics team performed a calibration with external heaters, which excluded the possibility of a measurement artifact.
- A difference in heat load among the different LHC sectors was noticed also in the pilot run with 25 ns beams performed in 2012, but in that case sectors 45 and 56 were showing the highest heat load.
- The difference was observed also with 50 ns beams at the beginning of 2015 and then disappeared with scrubbing.
- Heat load measured with "doublet" beams showed the same feature (discussed below).
- A fill performed with beam 1 only showed the same behavior of the heat load.
- The heat load seems to correlate quite well with the integrated losses in the different arcs (compatible with a stronger beam-gas interaction in the sectors with stronger e-cloud).
- The heat loads are independent of the radial position of the beam for radial trims up to +/-0.2 mm.

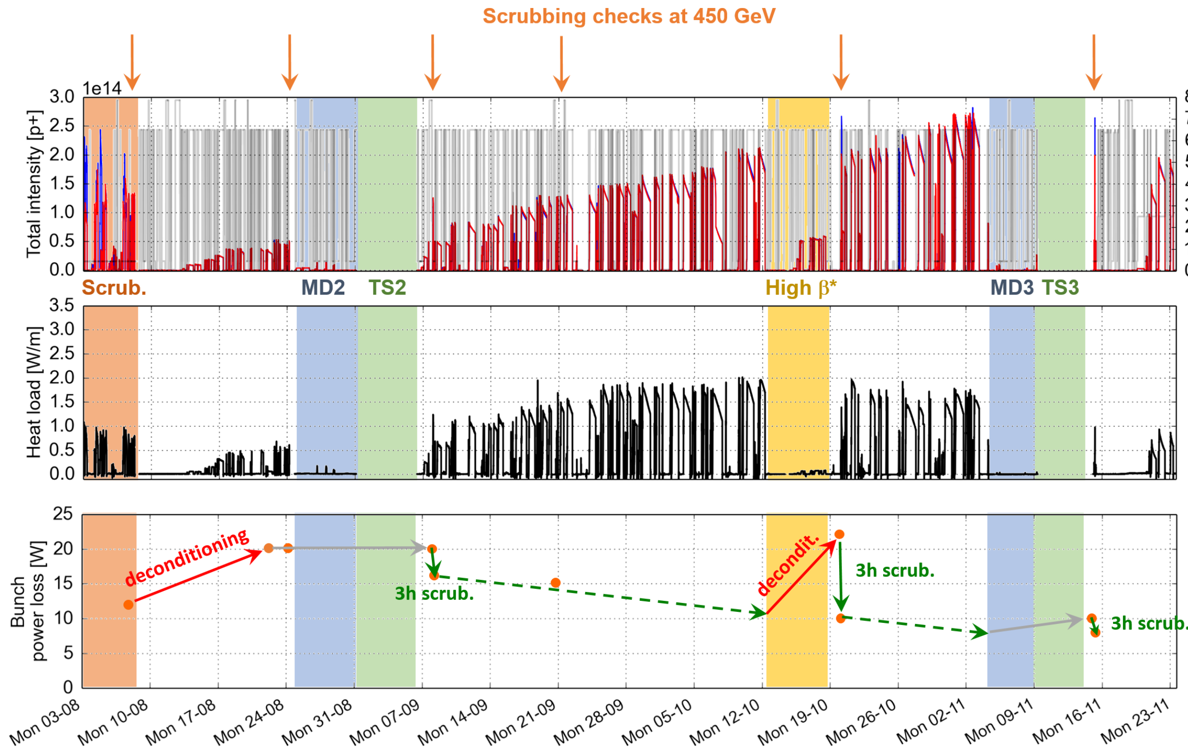


Figure 7: Beam intensity (top), heat load (middle) and energy loss measured on the bunches at the tail of the trains in dedicated fills at 450 GeV (bottom) along the physics operation with 25 ns beams.

- A thermal cycle on selected beam screens did not have an effect on the heat load behavior.
- As visible in Fig. 4, sectors with lower heat load exhibited a stronger reduction due to beam scrubbing during the intensity ramp-up with 25 ns beams.

DE-CONDITIONING AND RE-CONDITIONING CYCLES

By the end of the scrubbing run it was possible to store 1177 bunches per beam in the LHC in injections of 144 bunches without significant beam degradation from the electron cloud. Quite surprisingly, two weeks later, a strong emittance blow-up was observed with only 459 bunches in the machine, injected in trains of 72 bunches. The question emerged whether this effect could be caused by deconditioning of the beam chambers, as was already observed in Run 1 [2]. Therefore it was decided to perform a series of test fills during the year, with beam conditions that could be directly compared with the validation fills performed at the end of the Scrubbing Run.

Figure 7 shows the evolution found on the energy loss of the trailing bunches of the trains, which is presently dominated by the effect of the e-cloud in the arcs. The picture is very consistent with what was observed in terms of beam quality preservation and heat loads in the arcs.

In particular, the measurements clearly show that a significant de-conditioning occurred during the first period of intensity ramp-up (first weeks of August) when the LHC was operated with beam configurations which were not generating a strong e-cloud buildup (short trains and low number of bunches). This period was followed by a machine development period (MD2) and a technical stop (TS2), after which the e-cloud behavior was found to be basically unchanged. At that point a short scrubbing fill ($\sim$3 h, at 450 GeV) was performed, which evidently had a beneficial effect on the e-cloud, as witnessed by the improved beam quality and by the measured power loss.

During the month of September, the intensity could be steadily increased up to $\sim$1800 bunches per beam, which allowed to accumulate a significant dose on the beam chambers, with a further mitigation of the e-cloud.

The second week of October was dedicated to a special run with high β^* at the main IPs. During this period the LHC was operated with 100 ns bunch spacing, a configuration for which e-cloud formation was neither expected nor observed. After this period the e-cloud was found much stronger than before, as shown by the energy loss in Fig. 7, with strong transverse emittance blowup observed on the beams. Again a short scrubbing fill ($\sim$3 h, at 450 GeV) was sufficient to recover the previous situation and continue with the intensity ramp-up in physics.

These observations seem to indicate that the scrubbing is reasonably well preserved during short Technical Stops and periods with very low intensities (like in MDs). On the other hand de-conditioning is observed when running with relatively high intensities (hundreds of bunches) with filling schemes with little or no formation of e-cloud. A possible mechanism explaining this behavior could be the gas desorption from all the inner walls of the beam screens, due to synchrotron radiation, that contaminates the parts of the beam pipes that are conditioned by the electron flux when operating with 25 ns bunch spacing.

An important lesson to retain is that de-conditioning can create problems with beam quality during the early stages of the intensity ramp-up. Therefore in 2016 it could be more efficient to have the first intensity steps at 6.5 TeV interleaved with the dedicated scrubbing fills.

EXPERIENCE WITH EXOTIC BUNCH SPACINGS

Doublets

During the 2015 scrubbing run, the "doublet" bunch pattern (5+20 ns) was tested for the first time in the LHC. Previously, simulation studies and tests at the SPS had shown its potential for enhancing the e-cloud in dipole magnets in order to boost the scrubbing efficiency (for more details see [2, 4]).

After careful setup carried out in the injectors, trains of 72 doublets were made available for injection into the LHC with intensities up to $1.6{\times}10^{11}$ p/doublet. First tests were performed with "single doublets" in order to gain experience on the behavior of the different LHC systems (instrumentation, RF, damper, machine protection) with this bunch pattern. As expected, the BPMs in IR6, were found to give false readings with this bunch pattern and therefore had to be characterized in order to adapt the interlock window to allow for reliable operation.

Later on, the injection of longer trains of doublets could be tested. Immediately, fast e-cloud induced instabilities were observed (see Fig. 8), difficult to control even with high chromaticity and octupole settings. This led to strong emittance blow-up and particle losses making the operation with this kind of beam extremely difficult.

Trains with up to 48 doublets could be injected in the LHC, but due to the instabilities it was only possible to accumulate trains of 24 doublets up to a total of about 250 doublets.

Even with this relatively small number of bunches and despite the strong beam degradation coming from the instabilities, the e-cloud enhancement could be observed on the arc heat load, as shown in Fig 9. On the other hand it was impossible to inject enough beam and keep sufficient beam quality to allow for efficient scrubbing fills with doublet beams.

In the future, to obtain a better scrubbing efficiency with doublets, we aim at achieving a better control on e-cloud instabilities and an acceptable beam lifetime, in order to be able to accumulate significantly more bunches in longer trains.

For this reason, doublets should be used only after having accumulated enough scrubbing dose with standard 25 ns beams (i.e. not at the beginning of the 2016 run). However as long as we are running at the cryogenics limit in physics (with strong heat load in the dipoles), as was the case at the end of the 2015 proton run, evidently there is little room to increase the scrubbing efficiency.

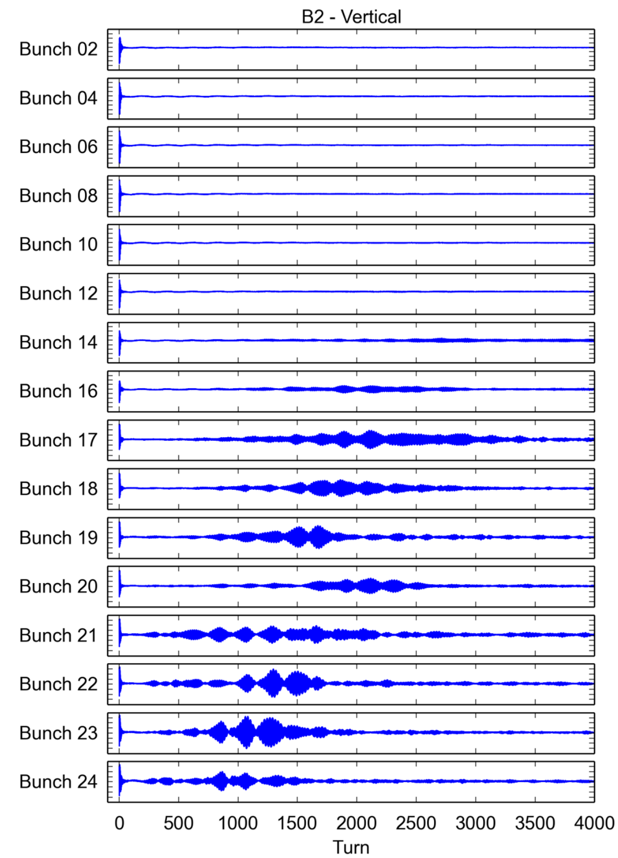


Figure 8: Vertical position of selected bunches in a train of doublets over the first 4000 turns after injection. A transverse instability developing on the trailing bunches is clearly visible.

Higher chromaticity settings (combined with lower vertical tunes to preserve the beam lifetime) and the optimization of the transverse damper configuration for the doublet intensity and working point, should also provide extra margin against beam instabilities.

8b+4e scheme

A short test in October was dedicated to the validation of the so called "8b+4e" bunch pattern. This filling scheme is made by short trains of eight bunches with 25 ns spacing, separated by four empty slots (with $\sim$30% less bunches compared to the nominal scheme). Buildup simulations and tests conducted in the SPS had shown that this beam has a larger multipacting threshold compared to the nominal 25 ns beam, and is therefore an interesting alternative to serve as a fallback scenario in case of strong limitations from the e-cloud.

The LHC test confirmed the suppression of the e-cloud, which was visible both on heat load measurements and on the beam energy loss from the RF stable phase. Figure 10

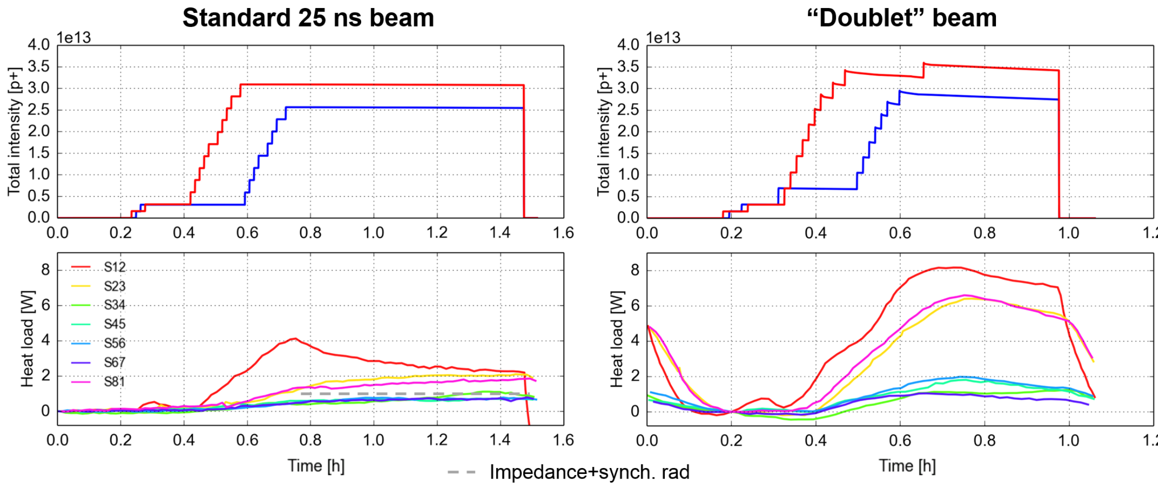


Figure 9: Average heat load (in Watts per half-cell) measured in the LHC arcs in two fills with similar intensities, performed with the standard 25 ns scheme (left) and with the “doublet” beam (right).

shows the comparison for the bunch-by-bunch energy loss between two fills performed with the nominal 25 ns and the 8b+4e schemes with similar total intensity (more details can be found in [20]).

LESSONS TO RETAIN AND POSSIBLE STRATEGY FOR 2016

The 2015 experience has shown that scrubbing at 450 GeV allows to achieve sufficient mitigation for e-cloud instabilities and beam degradation occurring at low energy with 25 ns bunch spacing.

After this stage, relying on the transverse damper and on high chromaticity and octupoles settings, it was possible to preserve good beam quality from injection to collision, in spite of the e-cloud still present in the machine (as witnessed by the heat load in the arcs).

This allowed the use of 25 ns beams for a large fraction of the luminosity production in 2015, with the positive side effect of accumulating a significant electron dose during the physics fills. This resulted in a reduction of the e-cloud induced heat load in the arc dipoles by roughly a factor of two in two months of operation.

Unfortunately, this also showed that the doses needed to observe an evolution of the heat loads at this stage are very large and are practically incompatible with a dedicated scrubbing run. This suggests that in the future the most efficient strategy might be to have relatively short scrubbing runs at injection, with the aim of achieving sufficient beam quality and then to accumulate further dose in parallel with physics to further reduce the heat load in the arcs (in this case a “slow” intensity ramp-up might be expected).

During the 2015-16 Year End Technical Stop (YETS) the arcs will be kept under vacuum. Therefore, even if some de-conditioning will most likely take place, recovery of the SEY should be rather quick. Hence, a short scrubbing period ($\sim$4 days) should be sufficient to recover the performance with high intensity beams at 450 GeV.

In order to avoid problems with de-conditioning (as observed in August 2015), a few “refresh” scrubbing fills should be performed during the first few weeks of intensity ramp-up in physics.

After that, further dose on the LHC beam screens will have to be accumulated exploiting the physics fills. For this purpose long bunch trains should be preferred for the intensity ramp-up in order to maximize the scrubbing dose, at least until limitations from e-cloud are encountered. At that point, as was done in 2015, the filling pattern could be optimized in order to maximize the number of bunches within the cryogenics cooling capacity.

As described in the previous section, when the SEY will have reached a sufficiently low value (i.e. at least after the end-2015 situation will be recovered), the doublet beam could be tested again in the LHC, to assess if good beam quality can be preserved. In case of a positive outcome of these tests, first scrubbing fills with doublets could be performed to attempt a further reduction of the SEY in the machine dipoles.

ACKNOWLEDGEMENTS

The authors would like to thank many colleagues from BE/ABP, BE/BI, BE/OP, BE/RF, EN/STI, TE/ABT, TE/CRG, TE/VSC for the fundamental support they provided throughout the presented studies, and G. Arduini and E. Metral for providing important input to this contribution.

REFERENCES

[1] F. Ruggiero, G. Rumolo, F. Zimmermann, “Simulation of the electron cloud buildup and its consequences on heat load, beam stability and diagnostics”, Phys.Rev.ST Accel.Beams 4 (2001) 012801.

[2] G. Iadarola, “Electron Cloud studies for CERN particle accelerators and simulation code development”, CERN-THESIS-2014-047 and references therein.

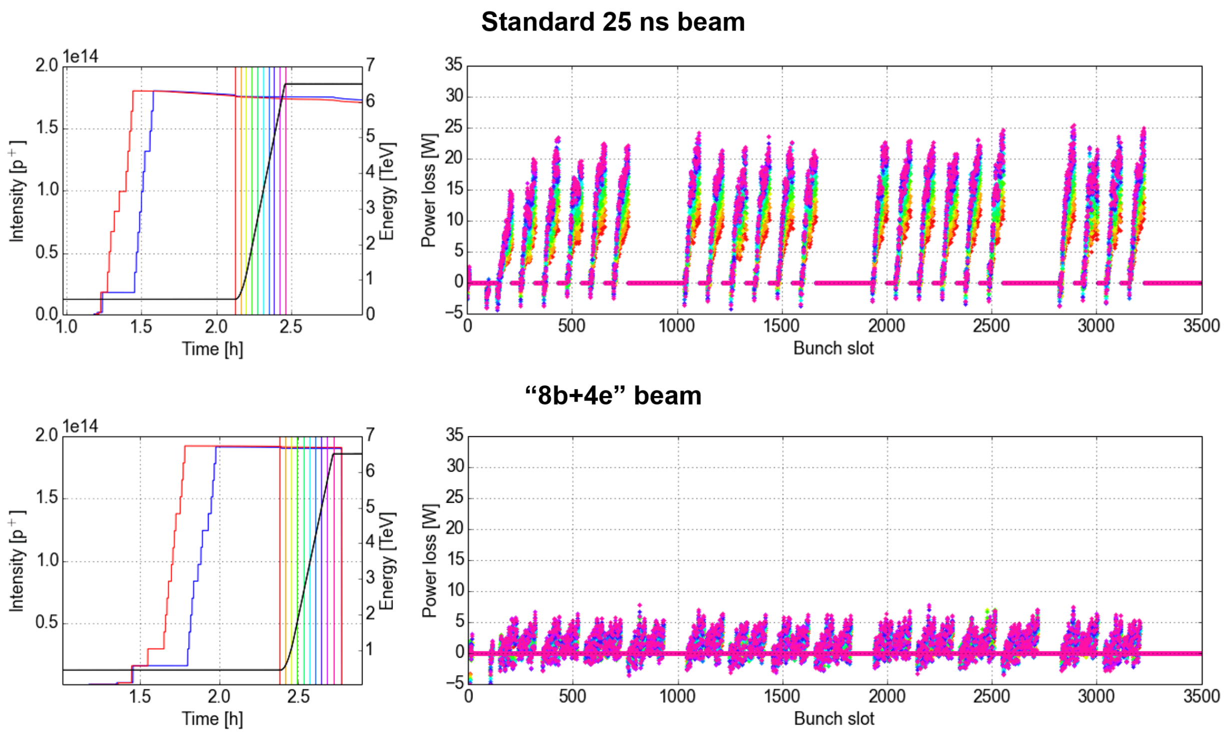


Figure 10: Comparison between two fills with similar number of bunches performed with the standard 25 ns beam (top) and with the 8b+4e scheme (bottom). The plots on the left show the beam energy and intensity, the plots on the right the bunch-by-bunch energy loss from the RF stable phase measurement.

[3] G. Iadarola, G. Arduini, H. Bartosik and G. Rumolo, "Electron cloud and scrubbing in 2012 in the LHC" in Proceedings of LHC Operation Workshop Evian 2012 (18-20 December, 2012, Evian, France).

[4] G. Iadarola and G. Rumolo, "Scrubbing: Expectations and Strategy, Long Range Perspective", proceedings of the Chamonix 2014: LHC Performance Workshop, Chamonix, France, 22 - 25 Sep 2014.

[5] S. Danzeca, "R2E - Is it still an issue", elsewhere in these proceedings.

[6] G. Rumolo, "Outcome of the scrubbing run", presented at LMC 19/08/2015.

[7] A. Lechner, "TDI", elsewhere in these proceedings.

[8] J. Esteban Müller and E. Shaposhnikova, "Synchronous phase measurements in the LHC for electron cloud observations", CERN-ACC-NOTE-2013-0007.

[9] R. Cimino et al., "Nature of the Decrease of the Secondary-Electron Yield by Electron Bombardment and its Energy Dependence", PRL 109, 064801 (2012).

[10] L. Carver, "Instabilities and Beam Induced Heating in 2015", elsewhere in these proceedings.

[11] D. Jacquet, "Injection", elsewhere in these proceedings.

[12] G. Kotzian, "ADT Post-LS1", elsewhere in these proceedings.

[13] A. Romano, "Effect of the e-cloud on the tune footprint at 450 GeV", presented at LBOC Meeting 27/10/2015.

[14] K. Brodzinski, "Cryogenics", elsewhere in these proceedings.

[15] G. Iadarola, "Heat load evolution, tests with different batch spacing and possible filling schemes for the next intensity steps", presented at LMC 07/10/2015.

[16] G. Iadarola, L.Mether, "Follow up from e-cloud team", Electron cloud meeting 13/10/2015.

[17] D. Mirarchi, S. Redaelli, "Integrated losses in the arcs", Electron cloud meeting 13/10/2015.

[18] G. Ferlin, "Follow up from cryogenics", Electron cloud meeting 13/10/2015.

[19] G. Bregliozzi, P. Chiggiato, C. Yin Vallgren, "Follow up from vacuum", Electron cloud meeting 13/10/2015.

[20] G. Iadarola, "Results of the scrubbing run and implications for HL-LHC", presented at the 5th Joint HiLumi LHC-LARP Annual Meeting, 2015.